MONTEZUMA NORCAL CARBON SEQUESTRATION HUB

Facility Information

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Partial List of Abbreviations and Acronyms

°C = Celsius	MIT = mechanical integrity test
3D = three-dimensional	mg = milligrams
Al = Aluminum	Mg = Magnesium
AoR = area of review	mg/L = milligrams per liter
As = Arsenic	mm = millimeters
Ba = Barium	mmol = millimole
Br = Bromide	MMV = monitoring, measurement and verification
BuriedArray = BuriedArray® system	Mn = Manganese
Ca = Calcium	MPa = megapascal
$CaCO_3$ = Calcium carbonate	mS/cm = milli Siemens per centimeter
CARB = California Air Resources Board	MS/MSD = matrix spikes/matrix spike duplicates
Cd = Cadmium	Mw = Magnitude
CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act	N_2 = Nitrogen

CH_4 = Methane	Na = Sodium
Cl = Chloride	NO_3 = Nitrate
Cr = Chromium	NTU = nephelometric turbidity units
CRs = corner reflectors	O_2 = Oxygen
CO_2 = carbon dioxide	P = Pressure
Cu = Copper	Pb = Lead
D = Density	ppm = parts per million
DAS = distributed acoustic sensors	PSET = Passive Seismic Emission Tomography
DTS = distributed temperature sensors	QA = Quality Assurance
°F = Fahrenheit	QASP = Quality Assurance and Surveillance Plan
F= Fluoride	QC = Quality Control
Fe = Iron	RCRA = Resource Conservation and Recovery Act
Fl = Flow	RDP = relative percent difference
ft = feet	RL = reporting limit
ft bgs = feet below ground surface	Sb = Antimony
G = gas composition	Se = Selenium
GHG = greenhouse gas	Si = Silicon
GNSS = Global Navigation Satellite System	SM = Standard Method
GS = geologic sequestration	SO_4 = Sulfate
H_2S = Hydrogen sulfate	SOP = standard operating procedure
ICP-MS = Inductively coupled plasma mass spectrometry	Sr = Strontium
InSAR = Interferometric Synthetic Aperture Radar	T = Temperature
K = Potassium	TDS = total dissolved solids
kPa = kilopascal	Tl = Thallium
km = kilometers	TOC = total organic carbons
LBNL = Lawrence Berkeley National Laboratory	UC Berkeley = University of California Berkeley
LCS/LCSDs = laboratory control samples/laboratory control sample duplicates	ug/L = micrograms per liter
m = meter	UIC = Underground Injection Control
mA = milliamps	USDW = Underground Source of Drinking Water
meq/L = milliequivalent per liter	US EPA = United States Environmental Protection Agency
Mc = magnitude of completeness	

MC = Montezuma Carbon	VSP = vertical seismic profiling
MDL = Method Detection Limit	X = Passive Seismic
	Zn = Zinc

Title and Approval Sheet

This Quality Assurance and Surveillance Plan (QASP) is approved for use and implementation at Montezuma NorCal Carbon Sequestration Hub. The signatures below denote the approval of this document and intent to abide by the procedures outlined within it.

Signature Jim Levine Managing Partner	Date

Distribution List

The following project participants will receive the completed QASP and all future updates for the duration of the project.

Plant Manager
Operations Manager
Maintenance Manager
Environmental Health and Safety Coordinator
Communications Coordinator
Chief Technology Officer

E.I.1 PROJECT MANAGEMENT

E.I.1.1 PROJECT/TASK ORGANIZATION

E.I.1.1.1.A/B KEY INDIVIDUALS AND RESPONSIBILITIES

Plant Manager

Operations Manager

Maintenance Manager

Environmental Health and Safety Coordinator

Communications Coordinator

Chief Technology Officer

Montezuma Carbon, LLC (MC) considers the names and contact information for these professionals confidential, and will provide a current site-specific emergency contact list to the United States Environmental Protection Agency (US EPA) Underground Injection Control (UIC) Program Director and California Air Recourses Board (CARB) Executive Officer, upon request.

E.I.1.1.2.C INDEPENDENCE FROM PROJECT QA MANAGER AND DATA GATHERING

The majority if not all of the physical samples collected and data gathered as part of the program are analyzed, processed, or witnessed by third parties independent and outside of the project management structure.

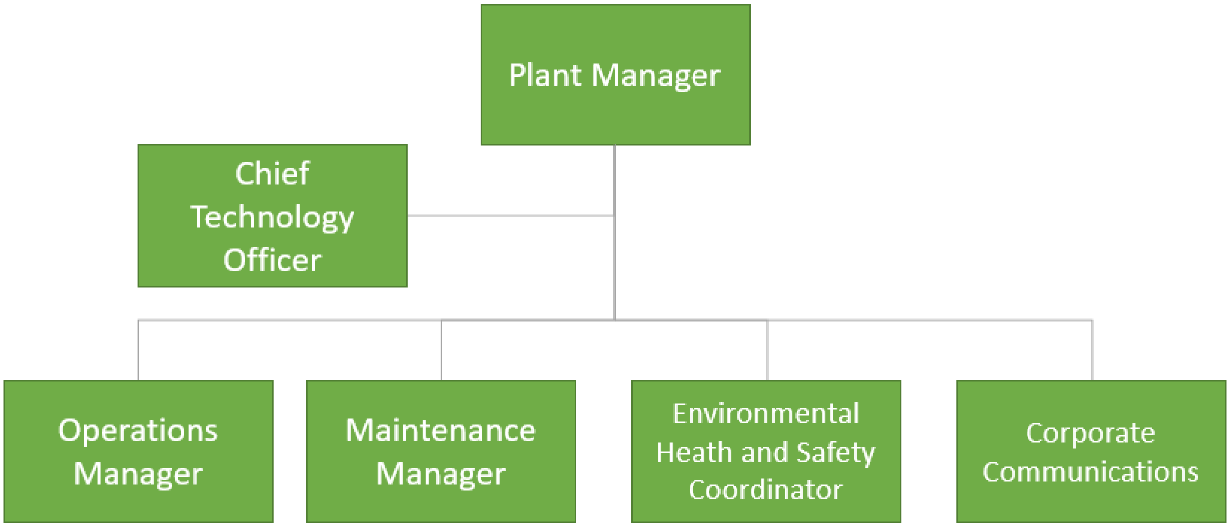
E.I.1.1.3.D QA PROJECT PLAN RESPONSIBILITY

MC will be responsible for maintaining and distributing the official, approved QASP. This QASP will be periodically reviewed, and the US EPA will be consulted if and when changes to the plan are warranted.

E.I.1.1.4.E ORGANIZATIONAL CHART FOR KEY PROJECT PERSONNEL

Figure E.I-1 shows the organizational structure of the project. The Personnel Contact List attachment provides names and contact information for the individuals currently fulfilling these roles.

FIGURE E.I-1. ORGANIZATIONAL STRUCTURE OF THE PROJECT



E.I.1.2 PROBLEM DEFINITION/BACKGROUND

E.I.1.2.1.A REASONING

The project site is being developed as a potential carbon sequestration hub with the future potential to capture and sequester multiple millions of tons of carbon dioxide (CO_2) per year. For the purpose of this Class VI application and the first Class VI injection well permit application for the project site, the initial CO_2 source is anticipated to be Pacific Gas and Electric's Gateway Generating Station that is capable of providing at least 1 million tons per year to the project site. This injection volume would continue for at least 12 years, and potentially continue for as long as 40 years. The targeted injection interval for this initial Class VI UIC well is the Anderson Sandstone for geologic sequestration (GS). Operational monitoring, verification, and accounting are required to confirm that the CO_2 is indeed fully sequestered in the target subsurface interval. Operational monitoring is used to ensure safety with the procedures associated with fluid injection, monitor the response of the geological storage unit, and the development of the CO_2 plume. Verification will provide information to confirm that leakage of CO_2 through the caprock is not occurring. Environmental monitoring will confirm that CO_2 is not being released into the shallow subsurface or biosphere.

E.I.1.2.2.B REASONS FOR INITIATING THE PROJECT

The MC project was initiated because of strong performance projections on the three foundational pillars of sustainability:

- **Economic**: The project creates financial benefits for MC, as it provides a second economic use for the 3,200-acre site that was purchased to restore wetland habitats. Also, by helping to de-carbonize the major industrial corridor in the San Francisco Bay Area, we are providing long-term sustainability for those industries, benefitting not only their employees but the California economy as a whole.

- **Environmental**: The project creates environmental benefits by reducing greenhouse gas (GHG) emissions associated with multiple power plants and industrial sources estimated to emit over 17 million tons of CO_2 per year that are located within 45 miles of the site. The devastating impacts of global warming on ecosystems can be seen everywhere, and this project could serve as an example for what other regions around the country (and potentially the world) can do to accelerate the reductions in GHG emissions that are so long overdue.
- **Social**: The project creates social benefits in several ways. De-carbonizing and retaining the major industries that currently emit CO_2 retains those jobs, but also creates jobs in the carbon capture and sequestration construction effort. Installation of carbon capture technologies is estimated to cost $200 - $400 million per site, and that work requires significant labor, equipment, and materials. This translates into environmentally friendly economic growth and coupled with job training and access programs in disadvantaged local communities, this project can yield tremendous social benefits in Northern California.

E.I.1.2.3.C REGULATORY INFORMATION, APPLICABLE CRITERIA, ACTION LIMITS

Federal requirements for the US EPA UIC Program for CO_2 GS wells are located in 40 CFR Parts 124, 144, 145, 146, and 147. The final rule establishing the Class VI well program was published by the US EPA in the Federal Register on December 10, 2010. The rule established minimum federal requirements under the Safe Drinking Water Act for underground injection of CO_2 for the purpose of GS. The rule applies to owners or operators of wells that will be used to inject CO_2 into the subsurface for the purpose of long-term storage. It established a new class of well, Class VI, and sets minimum technical criteria for the permitting, geologic site characterization, area of review (AoR) and corrective action, financial responsibility, well construction, operation, mechanical integrity testing (MIT), monitoring, well plugging, post-injection site case, and site closure of Class VI wells for the purposes of protecting Underground Sources of Drinking Water (USDWs). The elements of the rulemaking are based on the existing UIC regulatory framework with modifications to address the unique nature of CO_2 injection for geologic sequestration. This QASP details the measurements which will be taken and the implementation of steps to ensure the quality of the data collected during the project is such that the data can be used confidently for decision making throughout the project duration.

E.I.1.3 PROJECT/TASK DESCRIPTION

E.I.1.3.1.A/B SUMMARY OF WORK TO BE PERFORMED

Table E.I-1 describes the Testing and Monitoring tasks. Table E.I-2 summarizes the instrumentation.

TABLE E.I-1. SUMMARY OF TESTING AND MONITORING

Category	Parameter	Location	Primary Test Method					Complementary Test Methods
			Testing Frequency by Project Phase				Method	
			Pre-Injection	Injection	Initial PISC	Maintenance PISC		
Operational Testing and Monitoring During Injection	Analysis of CO_2 Stream	IW-A1	Not Applicable	Quarterly	Not Applicable	Not Applicable	Laboratory chemical analysis of spot samples	1) Continuous monitoring of operational parameters - CO_2 conc. 2) Laboratory isotope analysis every 5-years
	Monitoring of Operational Parameters	IW-A1	Not Applicable	Continuous	Not Applicable	Not Applicable	Measurements of CO_2 pressures, temperatures, mass flow, density, composition	Automatic alarms and shut-down systems
	Corrosion Monitoring	IW-A1	Not Applicable	Quarterly/ Annual	Not Applicable	Not Applicable	Corrosion coupon testing	1) Internal Mechanical integrity testing 2) External Mechanical Integrity testing
	Pressure Fall-Off Testing	IW-A1	Not Applicable	Every 5 Years	Not Applicable	Not Applicable	Standard pressure fall-off test protocol	Continuous monitoring of operational parameters

Category	Parameter	Location	Primary Test Method					Complementary Test Methods
			Testing Frequency by Project Phase				Method	
			Pre-Injection	Injection	Initial PISC	Maintenance PISC		
Internal Mechanical Integrity Testing	Annulus Pressure Testing	IW-A1	Once for Baseline	Every 5 Years or after potentially compromising well workovers	Not Applicable	Not Applicable	Separate annulus pressure test at baseline. Measurements of annulus pressure during pressure fall-off test during injection.	1) Corrosion monitoring 2) Measurements of annulus-side pressure during injection
	Operational Monitoring of Annulus	IW-A1	Not Applicable	Continuous	Not Applicable	Not Applicable	Measurements of annulus-side pressure during injection	1) Corrosion monitoring 2) Annulus pressure testing
External Mechanical Integrity Testing	Near-well formation monitoring	IW-A1	Baseline for Temperature Log	Annual	Annual	Every 5 Years	Oxygen activation log, temperature log, or noise log	1) Monitoring of operational parameters - annulus-side pressure 2) Corrosion monitoring 3) DAS/DTS continuous monitoring
		IZMW-A1	Baseline for Temperature Log	Annual	Annual	Every 5 Years	Oxygen activation log, temperature log, or noise log	1) Corrosion monitoring 2) DAS/DTS continuous monitoring

Category	Parameter	Location	Primary Test Method					Complementary Test Methods
			Testing Frequency by Project Phase				Method	
			Pre-Injection	Injection	Initial PISC	Maintenance PISC		
Groundwater Quality and Geochemical Monitoring	Groundwater Quality	MS-1 through MS-7	Continuous	Continuous	Continuous	Continuous	Monitoring (P, T, conductivity) dedicated network of groundwater wells penetrating the water table and lowermost USDW	Laboratory geochemical & isotope analyses of bottom-hole grab samples
	Geochemical Monitoring	MS-1 through MS-7	Quarterly,to establish baseline	Quarterly/Semi-annual/Annual	Annual	Every 5 Years	Laboratory geochemical & isotope analyses of bottom-hole grab samples	Monitoring (P, T, conductivity) of dedicated network of groundwater wells penetrating the water table and lowermost USDW

Category	Parameter	Location	Primary Test Method					Complementary Test Methods
			Testing Frequency by Project Phase				Method	
			Pre-Injection	Injection	Initial PISC	Maintenance PISC		
Plume and Pressure Front Tracking	Plume Tracking (Direct)	IZMW-A1	Establish baseline	See Testing & Monitoring Plan text	See Testing & Monitoring Plan text	See Testing & Monitoring Plan text	Field testing of headspace gas, plus laboratory geochemical & isotope analyses of formation fluid grab samples	Computational modeling
	Plume and Pressure Front Tracking (Indirect)	AoR	Establish baseline	Variable from minutes to years	-	Variable from minutes to years	Seismic data InSAR	Computational modeling
	Pressure Front Tracking (Direct)	IW-1	Establish baseline	Continuous	Continuous	Continuous	Bottom-hole pressure instrument, supplemented with liquid level measurements during PISC	Computational modeling
		MW-1	Establish baseline	Continuous	Continuous	Continuous	Bottom-hole pressure instrument, supplemented with liquid level measurements	Computational modeling

Category	Parameter	Location	Primary Test Method					Complementary Test Methods
			Testing Frequency by Project Phase				Method	
			Pre-Injection	Injection	Initial PISC	Maintenance PISC		
Additional Testing & Monitoring	Surface Air Monitoring	IW-1	Establish baseline	Continuous	Continuous	Continuous	CO_2 infrared sensor	Soil gas monitoring program
	Soil Gas Monitoring	AoR	Continuous	Continuous	Continuous	Continuous	Monitoring soil gas CO_2 with infrared sensor concentration across a network of dedicated stations	1) Lab analysis of samples from network of stations 2) CO_2 efflux measurements at each station
		AoR	Quarterly, to establish baseline	Quarterly/ Semi-annual/ Annual	Annual	Every 5 Years	1) Lab analysis of samples from network of stations 2) CO_2 efflux measurements at each station	Monitoring soil gas CO_2 concentration across a network of dedicated stations

DAS = distributed acoustic sensing

DTS = distributed temperature sensing

P = Pressure

T = Temperature

TABLE E.I-2. INSTRUMENTATION SUMMARY

Monitoring Location	Instrument Types(1)	Monitoring Target (Formation or Other)	Data Collection Location	Explanation
Injectate Monitoring Station	P, T, F, D, G	Injectate Stream	Pipeline, Proximate to IW-1	Monitoring of operational and equipment parameters
IW-1	P, T	Injection Tubing	Downhole, Surface	Monitoring of operational parameters and well integrity
	P, T	Annulus System	Downhole, Surface	Monitoring well integrity
	G	Surface Air	Wellhead	Verify containment
MW-1	P, T	Injection Zone	Downhole, Surface	Verify containment
Above Confining Zone Monitoring Stations	X	All Subsurface Formations	Seismometer Wells	Verify containment
	P, T, G	Water Table and Lowermost USDW	Groundwater Monitoring Wells	Verify containment
	G	Upper and Lower Vadose Zones	Soil Gas Monitoring Wells	Verify containment
	G	Surface Air	Infrared Sensors	Verify containment
	F	Ground Surface CO_2 Efflux	Closed Chamber Soil Collars	Verify containment

F = Flow, D = Density, G = Gas Composition, X = Passive Seismic

E.I.1.3.2.C GEOGRAPHIC LOCATIONS

Figure E.I-2 is a map illustrating geographic locations for the overall project including the surface equipment, transport pipeline, and the site. Figure E.I-3 is a map illustrating geographic locations for the various components of the overall site.

FIGURE E.I-2. SITE LOCATION

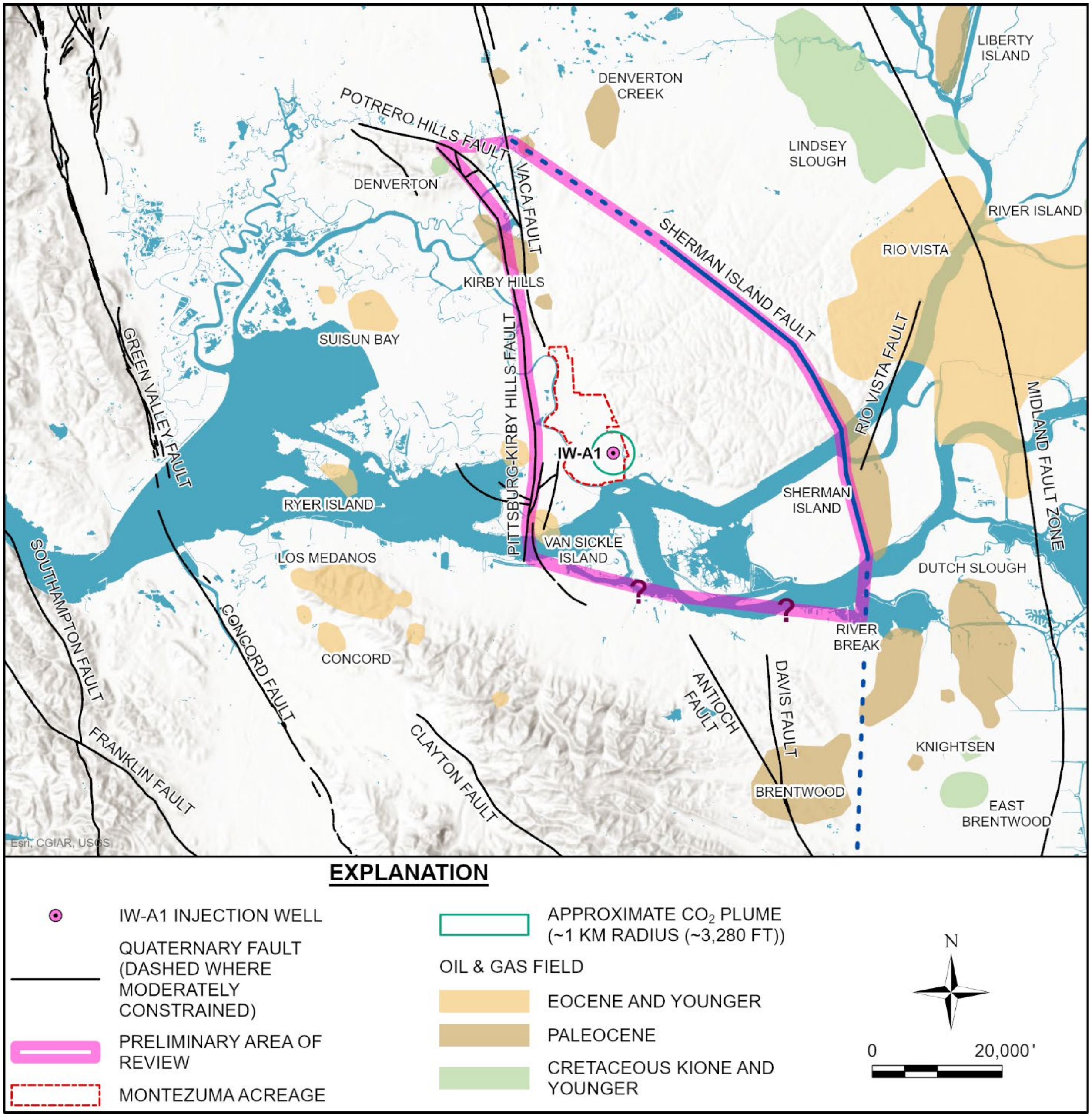
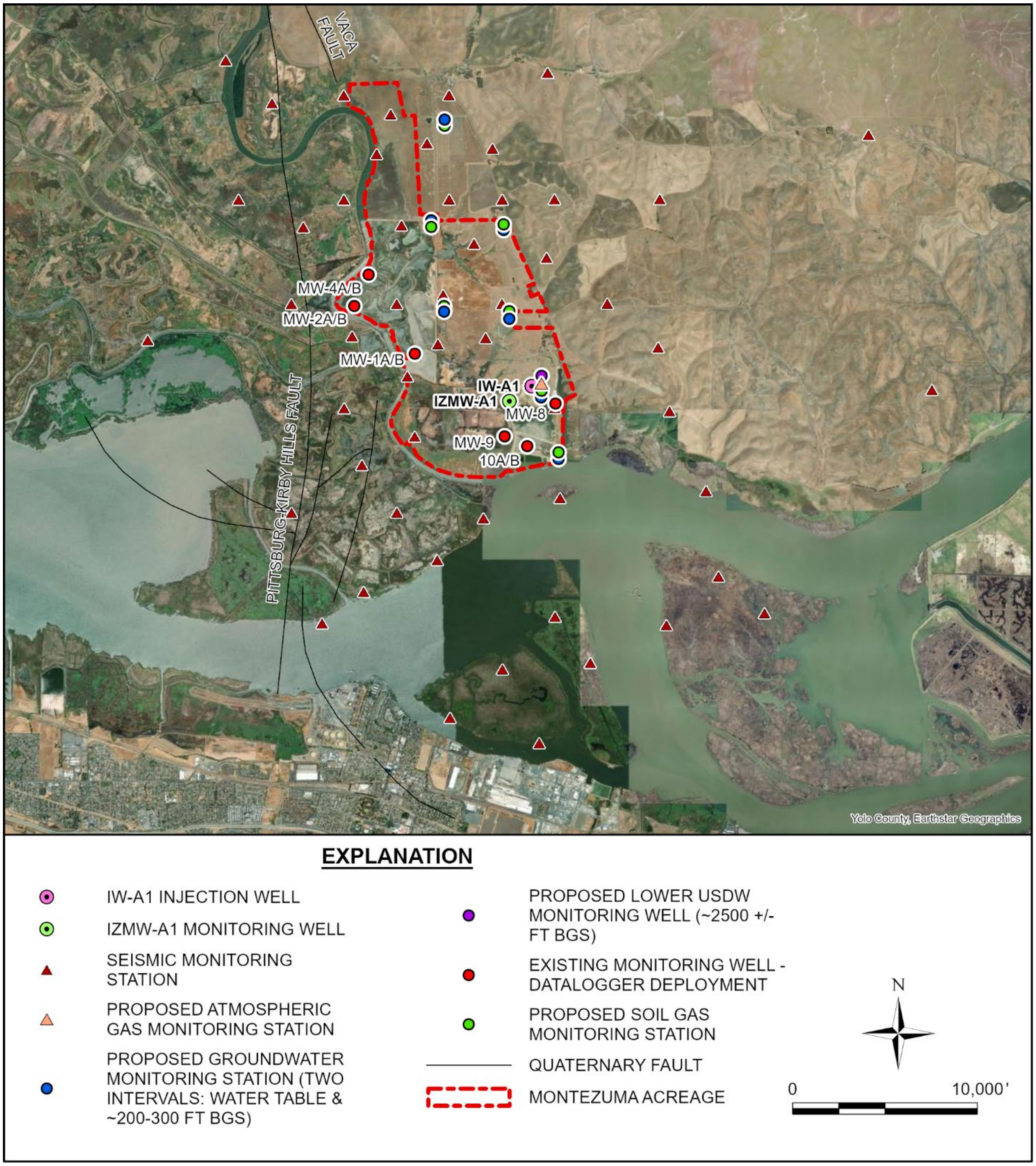


FIGURE E.I-3. SITE LAYOUT



E.I.1.3.3.D RESOURCE AND TIME CONSTRAINTS

There are no access constraints for the injection and monitoring infrastructure over the planned timeframe of the project. In addition, the monitoring infrastructure will be installed so as to be accessible in expected weather conditions (e.g., wind, precipitation, etc.). The one exception is CO_2 efflux measurements. These are conducted at ground surface with soil collars that have stickup heights of only a few inches. CO_2 efflux measurements are most viable in dry weather conditions. If the surface soils are very moist or saturated, CO_2 transport is limited and the efflux signal can be dampened. For these reasons, there may be sample events during which CO_2 efflux measurements are not possible. This is addressed in the sampling design by having multiple stations for monitoring, including a background location. It will be possible to compare results across stations, rather than only focusing on results over time at a given station. Using this approach, if a sample event is missed due to weather conditions, this will not significantly impact the ability to evaluate the results.

E.I.1.4 QUALITY OBJECTIVES AND CRITERIA

E.I.1.4.1.A PERFORMANCE/MEASUREMENT CRITERIA

The overall quality objective is to develop and implement procedures for subsurface monitoring, field sampling, laboratory analysis, and reporting, which will provide results that will meet the characterization and non-endangerment goals of this project. Tables E.I-3 through E.I-8 list analytes and parameters to be monitored. The list of analytes and parameters may be reassessed periodically and adjusted to include or exclude components based on their effectiveness to the overall monitoring program goals.

TABLE E.I-3 ANALYTICAL PARAMETERS FOR CO_2 STREAM

PARAMETERS	ANALYTICAL METHODS Note 1	DETECTION LIMITS/RANGE	TYPICAL PRECISIONS	TYPICAL QC PROTOCOLS
Oxygen	ISBT 4.0 (GC/DID)	1 uL/L to 5,000 uL/L (ppm by volume)	± 10 % of reading	daily standard within 10 % of calibration, secondary standard after calibration
	GC/TCD	0.1 % to 100 %	5 - 10 % relative across the range, RT ± 0.1 min	daily standard, duplicate analysis within 10 % of each other
Nitrogen	ISBT 4.0 GC/DID	1 uL/L to 5,000 uL/L (ppm by volume)	± 10 % of reading	daily standard within 10 % of calibration, secondary standard after calibration
	GC/TCD	0.1 % to 100 %	5 - 10 % relative across the range, RT ± 0.1 min	daily standard, duplicate analysis within 10 % of each other
Carbon Monoxide	ISBT 5.0 Colorimetric	5 uL/L to 100 uL/L (ppm by volume)	± 20 % of reading	duplicate analysis
	ISBT 4.0 GC/DID	1 uL/L to 5,000 uL/L (ppm by volume)	± 10 % of reading	daily standard within 10 % of calibration, secondary standard after calibration
Oxides of Nitrogen	ISBT 7.0 Colorimetric	0.2 uL/L to 5 uL/L (ppm by volume)	± 20 % of reading	duplicate analysis
Total Hydrocarbons	ISBT 10.0 THA (FID)	1 uL/L to 10,000 uL/L (ppm by volume)	5- 10 % of reading, relative across range	daily standard within 10 % of calibration, secondary standard after calibration
Methane	ISBT 10.1 (GC/FID)	0.1 uL/L to 1,000 uL/L (ppm by volume) - dilution dependent	5- 10 % of reading, relative across range	daily standard within 10 % of calibration, secondary standard after calibration
Acetaldehyde	ISBT 11.0 (GC/FID)	0.1 uL/L to 100 uL/L (ppm by volume) - dilution dependent	5- 10 % of reading, relative across range	daily standard within 10 % of calibration, secondary standard after calibration
Sulfur Dioxide	ISBT 14.0 (GC/SCD)	0.01 uL/L to 50 uL/L (ppm by volume) - dilution dependent	5- 10 % of reading, relative across range	daily standard within 10 % of calibration, secondary standard after calibration
Hydrogen Sulfide	ISBT 14.0 (GC/SCD)	0.01 uL/L to 50 uL/L (ppm by volume) - dilution dependent	5- 10 % of reading, relative across range	daily standard within 10 % of calibration, secondary standard after calibration
Ethanol	ISBT 11.0 (GC/FID)	0.1 uL/L to 100 uL/L (ppm by volume) - dilution dependent	5- 10 % of reading, relative across range	daily standard within 10 % of calibration, secondary standard after calibration

PARAMETERS	ANALYTICAL METHODS Note 1	DETECTION LIMITS/RANGE	TYPICAL PRECISIONS	TYPICAL QC PROTOCOLS
CO_2 Purity	ISBT 2.0 Caustic absorption Zahm-Nagel	99.00% to 99.99%	± 10 % of reading	User calibration per manufacturer recommendation
	ALI method SAM 4.1 subtraction method (GC/DID)	1 ppm for each target analyte (analyte dependent) - refer to Oxygen and Nitrogen analysis	5- 10 % of reading, relative across range	duplicate analysis within 10% of each other
	GC/TCD	0.1% to 100%	5- 10 % of reading, relative across range, RT ±0.1 mm	standard with every samples, duplicate analysis within 10% of each other

Notes:

Note 1 - An equivalent method may be employed with the prior approval of the UIC Program Director

ppm = parts per million

Source: Client (2023) and Trihydro (2023)

TABLE E.I-4. ANALYTICAL PARAMETERS FOR CORROSION COUPONS

PARAMETERS	ANALYTICAL METHODS	DETECTION LIMITS/RANGE	TYPICAL PRECISIONS	TYPICAL QC PROTOCOLS
Mass	NACE RPO775-2005	0.005 mg	± 2 %	Annual Calibration of Scale (3rd Party certification)
Thickness	NACE RPO775-2005	0.001 mm	± 0.0005 mm	Factory calibration

mg = miligrams

mm = milimeters

Source: Client (2023) and Trihydro (2023)

TABLE E.I-5A. SUMMARY OF MEASUREMENT PARAMETERS FOR FIELD TEMPERATURE/PRESSURE GAUGES

PARAMETERS	ANALYTICAL METHODS	DETECTION LIMITS/RANGE	TYPICAL PRECISIONS	TYPICAL QC PROTOCOLS
Booster Pump - Discharge Pressure (PIT 012)	ANSI Z540-I-1994	± 0.001 psi (0-3000 psi range)	± 0.01 psi	Annual Calibration of Scale (3rd Party)
Injection Tubing Temperature (TIT 019)	ANSI Z540-I-1994	± 0.001 ^{o}F (0-500 ^{o}F range)	± 0.01 ^{o}F	Annual Calibration of Scale (3rd Party)
Injection Tubing Pressure (PIT 009)	ANSI Z540-I-1994	± 0.001 psi (0-3000 psi range)	± 0.01 psi	Annual Calibration of Scale (3rd Party)
Annulus Pressure (PIT 014)	ANSI Z540-I-1994	± 0.001 psi (0-3000 psi range)	± 0.01 psi	Annual Calibration of Scale (3rd Party)
Injection Flow Rate (FIT 006)	Unknown	± 0.1000 % of rate (50,522-303,133 lbs/hr)	± 0.01 lbs/hr	Annual Calibration of Scale (3rd Party)
Westbay Pressure (MOSDAX)	Unknown	± 0.01 psi (0-4000 psi range)	± 0.01 psi	Annual Calibration of Scale (3rd Party)

oF = Fahrenheit, lbs/hr = pounds per hour, psi = pounds per square inch

TABLE E.I-5B. FIELD PRESSURE GAUGE - PIT 012 - CO2 BOOSTER PUMP DISCHARGE

PARAMETERS	SPECIFICATIONS/SENSITIVITIES
Calibrated working pressure range	0 to 3,000 psi and 4-20 mA
initial pressure accuracy	< 0.03125%
Pressure resolution	0.001 psi and 0.00001 mA
Pressure drift stability	To be determined after first year of operation

mA = milliamps

TABLE E.I-5C. FIELD TEMPERATURE GAUGE - TIT 019 - INJECTION TUBING TEMPERATURE

PARAMETERS	SPECIFICATIONS/SENSITIVITIES
Calibrated working temperature range	0 to 500 ^oF and 4-20 mA
initial temperature accuracy	< 0.0055%
Temperature resolution	0.001 ^oF and 0.0001 mA
Temperature drift stability	To be determined after first year of operation

TABLE E.I-5D. FIELD PRESSURE GAUGE - PIT 009 - INJECTION TUBING PRESSURE

PARAMETERS	SPECIFICATIONS/SENSITIVITIES
Calibrated working pressure range	0 to 3,000 psi and 4-20 mA
initial pressure accuracy	< 0.04375%
Pressure resolution	0.001 psi and 0.00001 mA
Pressure drift stability	To be determined after first year of operation

TABLE E.I-5E. FIELD PRESSURE GAUGE - PIT 014 - ANNULUS PRESSURE

PARAMETERS	SPECIFICATIONS/SENSITIVITIES
Calibrated working pressure range	0 to 3,000 psi and 4-20 mA
initial pressure accuracy	< 0.02500%
Pressure resolution	0.001 psi and 0.00001 mA
Pressure drift stability	To be determined after first year of operation

TABLE E.I-5F. FIELD MASS FLOW RATE GAUGE - FIT 006 - CO2 MASS FLOW RATE

PARAMETERS	SPECIFICATIONS/SENSITIVITIES
Calibrated working flow range	50,522-303,133 lbs/hr and 4-20 mA
initial mass flow rate accuracy	< 0.18%
Mass Flow Rate resolution	0.01 lbs/hr
Mass Flow Rate drift stability	To be determined after first year of operation

TABLE E.I-5G. FIELD PRESSURE GAUGE - MOSDAX - WESTBAY PRESSURE GAUGE

PARAMETERS	SPECIFICATIONS/SENSITIVITIES
Calibrated working pressure range	0 to 4,000 psi
initial pressure accuracy	< 0.01%
Pressure resolution	0.001 psi
Pressure drift stability	To be determined after first year of operation

TABLE E.I-6. ANALYTICAL AND FIELD PARAMETERS FOR GROUNDWATER SAMPLES

PARAMETERS	ANALYTICAL METHODS(1,2)	DETECTION LIMIT/RANGE(3)	TYPICAL PRECISIONS(3)	QC REQUIREMENTS
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Fe (dissolved and total), Pb, Sb, Se, Sr, Tl, and Zn	ICP-MS EPA Method 6020	Al: 50 ug/L Ba: 1 ug/L Mn: 1 ug/L As: 1 ug/L Cd: 0.50 ug/L Cr: 1 ug/L Cu: 1 ug/L Fe: 1 ug/L Pb: 1 ug/L Sb: 1 ug/L Se: 1 ug/L Sr: 1 ug/L Tl: 1 ug/L Zn: 1 ug/L	Al: ±1 ug/L Ba: ±0.1 ug/L Mn: ±0.1 ug/L As: ±0.1 ug/L Cd: ±0.01 ug/L Cr: ±0.1 ug/L Cu: ±0.1 ug/L Fe: ±0.1 ug/L Pb: ±0.1 ug/L Sb: ±0.1 ug/L Se: ±0.1 ug/L Sr: ±0.1 ug/L Tl: ±0.1 ug/L Zn: ±0.1 ug/L	Per method
Cations: Ca, Fe, K, Mg, Na, Si	ICP EPA Method 6010B	Ca: 200 ug/L Fe: 50 ug/L K: 500 ug/L Mg: 50 ug/L Na: 500 ug/L Si: 500 ug/L	Ca: ±100 ug/L Fe: ±1 ug/L K: ±100 ug/L Mg: ±100 ug/L Na: ±50 ug/L Si: ±10 ug/L	Per method
Anions: Br, Cl, F, NO_3, and SO_4	Ion Chromatography EPA Method 300.0	Br: 1 mg/L Cl: 1 mg/L F: 0.2 mg/L NO3: 0.1 mg/L SO4: 1 mg/L	Br: ±0.1 mg/L Cl: ±0.1 mg/L F: ±0.01 mg/L NO3: ±0.01 mg/L SO4: ±0.1 mg/L	Per method
Mercury	Cold Vapor Atomic Absorption EPA 7470B	0.2 ug/L	±0.02 ug/L	Per method
H_2S	SM4500	1 mg/L	±0.1 mg/L	Per method
CH_4	RSK-175	To be determined	To be determined	Per method
Stable Isotopes: $^{13/12}C$ in DIC, $^{2/1}H$ in H_2O, $^{18/16}O$ in H_2O	Isotope ratio mass spectrometry	Not applicable	±0.1 o/oo	Per method

PARAMETERS	ANALYTICAL METHODS[1,2]	DETECTION LIMIT/RANGE[3]	TYPICAL PRECISIONS[3]	QC REQUIREMENTS
Radiocarbon Isotope: $^{14/12}C$ in DIC	Accelerated mass spectrometry	Not applicable	Varies for run and sample age, typically ±0.002 o/oo	Per method
Total Dissolved Solids (TDS)	SM 2540C	10 mg/L	±1 mg/L	Per method
Total organic carbon (TOC)	SM 5310C	1 mg/L	±0.1 mg/L	Per method
pH	SM 4500 H+B	0 to 14 pH units	±0.1 pH units	Per method
Alkalinity, Bicarbonate (as $CaCO_3$)	SM 2320B	20 mg/L	±1 mg/L	Per method
Alkalinity, Carbonate (as $CaCO_3$)	SM 2320B	20 mg/L	±1 mg/L	Per method
Dissolved CO_2	Calculated from bicarbonate alkalinity and pH	20 mg/L	±1 mg/L	Per method
pH (field)	Field Meter	0 to 14 pH units	±0.2 pH units	Per Equipment Manufacturer
Dissolved CO_2 (field)	Field Meter	0 to 1,000 ppm	±0.5%	Per Equipment Manufacturer
Dissolved Oxygen (field)	Field Meter	0 to 500% air saturation or 0 to 50 mg/L	For 0 to 200% air saturation: ±2% of the reading or ±2% air saturation, whichever is greater. For 200 to 500% air saturation, ±6% of the reading.	Per Equipment Manufacturer

PARAMETERS	ANALYTICAL METHODS[1,2]	DETECTION LIMIT/RANGE[3]	TYPICAL PRECISIONS[3]	QC REQUIREMENTS
Turbidity (field)	Field Meter	0 to 1,000 NTU	For 0 to 49.99 NTU: ±5% of the reading or 0.5 NTU, whichever is greater. For 50 to 1,000 NTU: ±5% of the reading or 5 NTU, whichever is greater.	Per Equipment Manufacturer
Specific conductance (field)	Field Meter	0 to 200 mS/cm	±0.5% of the reading or +0.001 mS/cm, whichever is greater	Per Equipment Manufacturer
Temperature (field)	Field Meter	-5 to 45 oC	±0.15 oC	Per Equipment Manufacturer
Depth to water (field)	Field Meter	0 to 300 m	±0.01 ft	Per Equipment Manufacturer

PARAMETERS	ANALYTICAL METHODS[1,2]	DETECTION LIMIT/RANGE[3]	TYPICAL PRECISIONS[3]	QC REQUIREMENTS
Water pressure/depth, temperature, and conductivity/salinity (field)	Field Meter (continuous measurements)	Water pressure: 0 to 50 m water (DI282 model for shallower wells) and 0 to 100 m water (DI283 model for deeper wells) Temperature: -20 to 80 oC Conductivity: 0 to 300 mS/cm	Water pressure: ±2.5 m- on DI282 and ±5 m on DI283 Temperature: ±0.2 oC Conductivity: ±2% of reading	Per Equipment Manufacturer

Note 1: An equivalent method may be employed with the prior approval of the US EPA UIC Program Director

Note 2: All chemical analyses will be performed by a certified laboratory under the Environmental Laboratory Approval Program protocols; field measurements will be recorded by a qualified professional

Note 3: Detection limits and precisions are based on no dilutions by lab. Dilutions may be required to obtain representative measurements, which will increase these values.

°C = Celsius
Al = Aluminum
As = Arsenic
Ba = Barium
Br = Bromide
Ca = Calcium
$CaCO_3$ = Calcium carbonate
Cd = Cadmium
CH4 = Methane
Cl = Chloride
Cr = Chromium
Cu = Copper
F = Fluoride
Fe = Iron
ft = feet
H2S = Hydrogen Sulfate
ICP-MS = Inductively coupled plasma mass spectrometry
K = Potassium
m = meter
Mg = Magnesium
mg/L = milligrams per liter
Mn = Manganese
mS/cm = milli Siemens per centimeter
Na = Sodium
NO_3 = Nitrate
NTU = nephelometric turbidity units
Pb = Lead
QC = Quality Control
Sb = Antimony
Se = Selenium
Si = Silicon
SM = Standard Method
SO_4 = Sulfate
Sr = Strontium
Tl = Thallium
ug/L = micrograms per liter
Zn = Zinc

TABLE E.I-7. ANALYTICAL AND FIELD PARAMETERS FOR SOIL GAS SAMPLES

SAMPLE TYPE	PARAMETERS	ANALYTICAL METHODS[(1)]	DETECTION LIMIT/RANGE	TYPICAL PRECISIONS	QC REQUIREMENTS
Soil Gas/Vapor	CO_2, O_2, CH_4, and N_2 in shallow soil gas	ASTM D1945 modified or similar/equivalent	CO_2: 0.005 to 100% O_2: 0.01 to 20.9% CH_4: 0.0002 to 100% N_2: 0.01 to 100%	CO_2: 0.005 to 100% O_2: 0.01 to 20.9% CH_4: 0.0002 to 100% N_2: 0.01 to 100%	Per method
	Stable Isotopes: $^{13/12}C$ in CO_2 $^{13/12}C$ and $^{2/1}H$ in CH_4 (if present)	SRI 8610C	Reportable at CO_2 and CH_4 concentrations greater than 2,300 ppm	+/-0.10 o/oo	Per method
	Radiocarbon Isotope: $^{14/12}C$ in CO_2 $^{14/12}C$ in CH_4 (if present)	Accelerated mass spectrometry	Not applicable	Varies for run and sample age, typically ±0.002 o/oo	Per method
	CO_2, O_2, and CH_4 in shallow soil gas	Field meter (to confirm stabilization of sample prior to collection)	CO_2: 0 to 100% O_2: 0 to 25% CH_4: 0 to 100%	<u>CO_2</u> For 0 to 5%: ±0.3% For 5 to 60%: ±0.5% For 60 to 100%: ±1.5% of the reading <u>O_2:</u> ±1.0% of the reading <u>CH_4</u> For 0 to 5%: ±0.3% For 5 to 70%: ±0.5% For 70 to 100%: ±1.5% of the reading	Per method

SAMPLE TYPE	PARAMETERS	ANALYTICAL METHODS[1]	DETECTION LIMIT/RANGE	TYPICAL PRECISIONS	QC REQUIREMENTS
Soil Gas/Vapor	CO_2 in shallow soil gas	Field sensor (continuous measurements)	0 to 10,000 ppm	For 0 to 3,000 ppm: ±40 ppm. For 3,000 to 10,000 ppm: ±2% of the reading. For 10,000 to 30,000 ppm: ±3.5% of the reading.	Per method
CO_2 Efflux	CO_2 accumulation in dynamic closed chamber at ground surface, corrected for gas water content, converted to CO_2 efflux	Field instrument	CO_2 concentration: 0 to 20,000 ppm H_2O concentration: 0 to 60 mmol	CO_2 concentration: ±1.5% of the reading H_2O concentration: ±1.5% of the reading	Per method

Note 1: An equivalent method may be employed with the prior approval of the UIC Program Director.

mmol = millimole

N_2 = Nitrogen

O_2 = Oxygen

TABLE E.I-8. ANALYTICAL AND FIELD PARAMETERS FOR SURFACE AIR MONITORING

PARAMETERS	ANALYTICAL METHODS[1]	DETECTION LIMIT/RANGE	TYPICAL PRECISIONS	QC REQUIREMENTS
CO_2, O_2, CH_4, and N_2 in surface air	ASTM D1945 modified or similar/equivalent	CO_2: 0.005 to 100% O_2: 0.01 to 20.9% CH_4: 0.0002 to 100% N_2: 0.01 to 100%	CO_2: 0.005 to 100% O_2: 0.01 to 20.9% CH_4: 0.0002 to 100% N_2: 0.01 to 100%	Per method
CO_2, O_2, and CH_4 in shallow soil gas	Field meter (to confirm stabilization of sample prior to collection)	CO_2: 0 to 100% O_2: 0 to 25% CH_4: 0 to 100%	<u>CO_2</u> For 0 to 5%: ±0.3% For 5 to 60%: ±0.5% For 60 to 100%: ±1.5% of the reading <u>O_2:</u> ±1.0% of the reading <u>CH_4</u> For 0 to 5%: ±0.3% For 5 to 70%: ±0.5% For 70 to 100%: ±1.5% of the reading	Per method
CO_2 in surface air	Field sensor (continuous measurements)	0 to 10,000 ppm	For 0 to 3,000 ppm: ±40 ppm. For 3,000 to 10,000 ppm: ±2% of the reading. For 10,000 to 30,000 ppm: ±3.5% of the reading.	Per method

E.I.1.4.2.B PRECISION

Precision is the measure of agreement, or reproducibility, between duplicate or replicate measurements taken under a given set of conditions. The level of agreement is measured as relative percent difference (RPD), which is a quantitative measure of group variability compared to group average.

Field duplicates will be collected to evaluate field precision. Field duplicate samples will be analyzed for each constituent analyzed in field samples, providing precision data for each analyte, and indicating the presence of possible contaminants. The goal for precision with respect to acceptable levels of variability in field samples and their duplicates is less than 30% RPD for groundwater samples, and less than 25% RPD for gas samples. Field duplicates will be collected at a rate of one field duplicate sample per 20 field samples (equivalent to 5%).

Laboratory precision will be evaluated using RPDs calculated from the analyses of laboratory control samples/laboratory control sample duplicates (LCS/LCSD), matrix spikes/matrix spike duplicates (MS/MSD), and laboratory duplicates. These QC samples will be collected at a rate of at least 1 per 20 field samples (5%). These QC samples are analytical method-specific, and their performance criteria are specified in the methods, the laboratory standard operating procedures, and/or the US EPA data review and data validation guidance documents.

E.I.1.4.3.C BIAS

Bias, measured by accuracy, is the measure of agreement between a laboratory measurement and a known/standard value. It is measured through a variety of QC samples that undergo analyses at the laboratory. Key accuracy indicators include LCS/LCSDs, MS/MSDs, internal standards, laboratory blanks, field blanks, equipment blanks, trip blanks, and surrogates. These QC samples are analytical method-specific, and their performance criteria are specified in the methods, the laboratory standard operating procedures, and/or the US EPA data review and data validation guidance documents.

The performance of accuracy, with respect to laboratory analyses, will be detailed in the individual data validation reports. A summation of project accuracy will be provided in the investigation report.

Each laboratory will be responsible for the assessment of analytical accuracy as required by their standard operating procedures and analytical methodologies. Direct pressure and logging measurements do not include assessments of accuracy.

E.I.1.4.4.D REPRESENTATIVENESS

Representativeness is defined as the degree to which sample data represent the population being examined. Representativeness is a qualitative parameter and is dependent on the design of the investigation and proper laboratory protocol. The sampling design as described in the work plan is proposed to address collection of samples that are representative of the facility.

E.I.1.4.5.E COMPLETENESS

Completeness is defined as the number of valid sample results obtained compared to the total number of results expected. Samples scheduled within the Testing and Monitoring Plan that are not completed, either due to safety reasons, samples damaged or lost in transit, etc., will lower the project's completeness. Sample results that are rejected as unusable due to quality control non-conformances and failures will also lower the project's completeness. The completeness goal for each sampling matrix is 90%. For direct pressure and temperature measurements, data will be recorded no less than 90% of the time.

E.I.1.4.6.F COMPARABILITY

Comparability is the measurement of confidence that can be assigned when two data sets are compared to each other or combined. To evaluate comparability, the sampling techniques, laboratory methods, data distributions, and data quality must be considered for each data set before direct comparisons can be performed. Comparability of data gathered during the investigation will be achieved by consistently following standard field and laboratory procedures and by using standards. Historical data from prior sampling efforts will be considered, to the extent possible, when the data are of known and verifiable quality and the sampling methods are comparable with the proposed techniques used for the effort.

E.I.1.4.7.G METHOD SENSITIVITY

Field data sensitivity is dependent on the equipment maintenance, calibration, performance, and operator, as well as collection methods and sample handling. For the parameters being measured in the field, standard equipment is readily available to ensure the data collected meet the project goals and are of adequate quality to be used in making decisions. The field team will follow procedures detailed in this QASP and standard operating procedures (SOPs) to ensure usability of the data. Field meter operator manuals are provided in Appendix E.I-1 (groundwater), and Appendix E.I-2 (soil gas/surface air).

Like field data, laboratory data sensitivity is dependent on equipment maintenance, calibration, performance, and operator, as well as collection or extraction methods and sample handling. However, laboratories usually can provide lower detection limits with a higher degree of confidence given the controlled environment for the equipment and technician. Laboratories report their method detection limits and provide qualifiers if those values are uncertain. The laboratory should report all results down to the Method Detection Limits (MDLs).

E.I.1.5 SPECIAL TRAINING/CERTIFICATIONS

E.I.1.5.1.A SPECIALIZED TRAINING AND CERTIFICATIONS

The geophysical survey equipment and wireline logging tools will be operated by trained and qualified personnel, according to the service company which provides the equipment. Field gauges will be operated by personnel that have reviewed and/or been trained on field manuals. Environmental (e.g., groundwater, soil gas) sampling will be conducted by personnel trained to understand and follow the project specific sampling procedures.

E.I.1.5.2.B/C TRAINING PROVIDER AND RESPONSIBILITY

Training for personnel will be provided by the operator or subcontractor responsible for the data collection activities.

E.I.1.6 DOCUMENTATION AND RECORDS

E.I.1.6.1.A REPORT FORMAT AND PACKAGE INFORMATION

A monitoring report will be provided to the US EPA which will contain all required project data, including testing and monitoring information as specified by the UIC Class VI permit. Data will be provided in an electronic format unless otherwise specified by the UIC Program Director.

E.I.1.6.2.B OTHER PROJECT DOCUMENTS, RECORDS, AND ELECTRONIC FILES

Other documents, records, and electronic files (i.e., well logs, test results, or other data) will be provided as required by the UIC Program Director.

E.I.1.6.3.C/D DATA STORAGE AND DURATION

MC or a designated contractor will store and maintain the required project data as outlined in the permit.

E.I.1.6.4.E QASP DISTRIBUTION RESPONSIBILITY

MC will be responsible for distributing the most current copy of the approved QASP to all those listed in the distribution list.

E.I.2 DATA GENERATION AND ACQUISITION

E.I.2.1 SAMPLING PROCESS DESIGN

E.I.2.1.1.A DESIGN STRATEGY

E.I.2.1.1.A.1 CO_2 STREAM MONITORING STRATEGY

The primary objective of analyzing the carbon dioxide stream is to evaluate the potential interactions of carbon dioxide and/or other constituents associated with the injectate with native formation solids and fluids. This analysis can also identify (or rule out) potential interactions with well materials. Establishing the chemical composition of the injectate also supports a determination that the injectate does not meet the qualifications of a hazardous waste under the Resource Conservation and Recovery Act (RCRA), 42 U.S.C. 6901 et seq. (1976), and/or the Comprehensive Environmental Response, Compensation, and Liability Act, (CERCLA) 42 U.S.C. 9601 et seq. (1980). Additionally, monitoring the chemical and physical characteristics of the carbon dioxide (e.g., isotopic signature) may help distinguish the injectate from the native fluids and gases in case of a leak. Injectate monitoring is required at a sufficient frequency to detect changes to any physical and chemical properties that may result in a deviation from the permitted specifications.

E.I.2.1.1.A.2 CORROSION MONITORING STRATEGY

Corrosion coupon analyses will be conducted quarterly to aid in ensuring the mechanical integrity of the equipment in contact with carbon dioxide. Coupons shall be sent quarterly for analysis in accordance with NACE Standard RP-0775 (or similar) to determine and document corrosion wear rates based on mass loss.

E.I.2.1.1.A.3 ABOVE CONFINING ZONE GROUNDWATER MONITORING STRATEGY

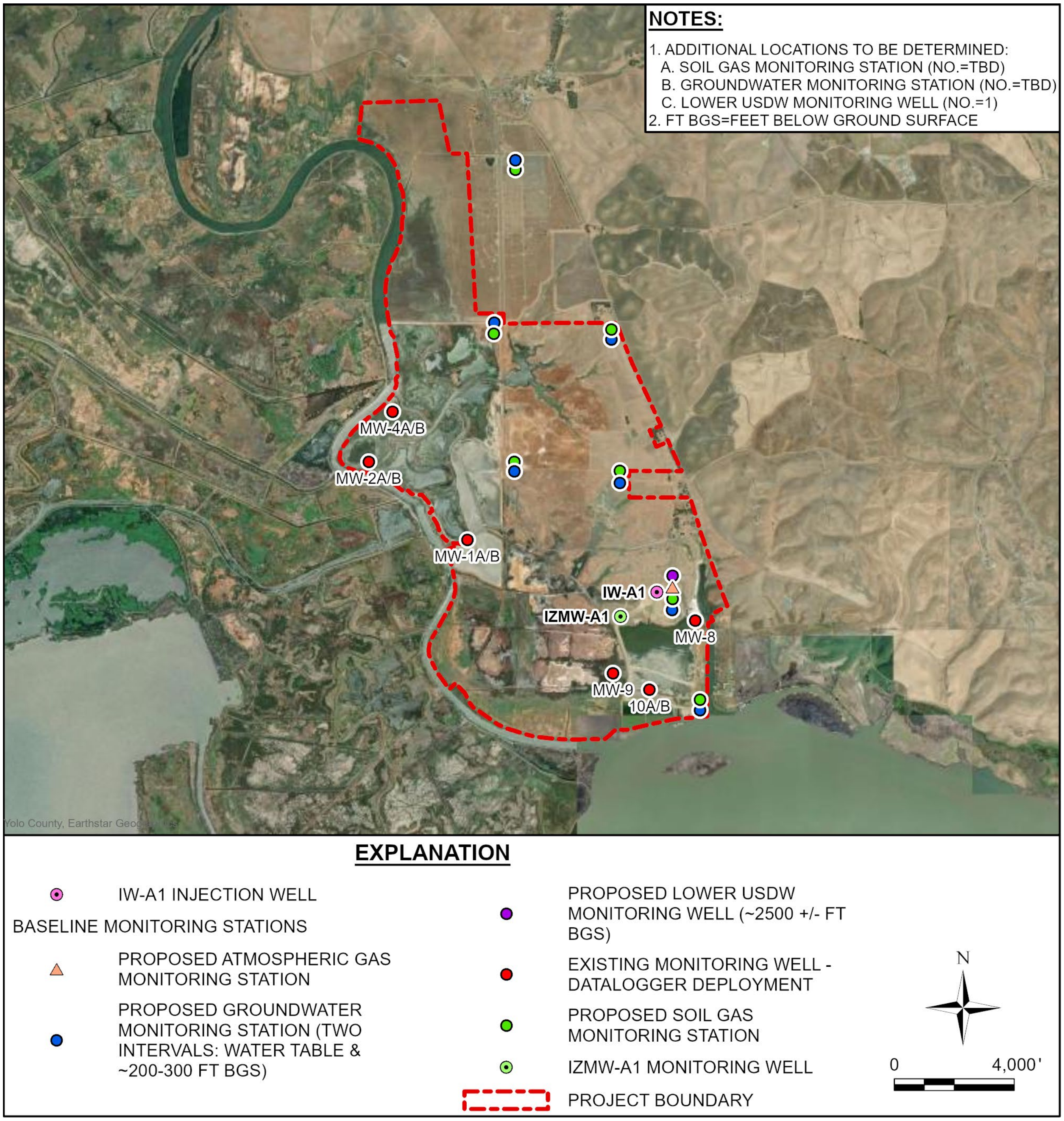
The above confining zone groundwater monitoring strategy includes use of six existing shallow alluvial groundwater monitoring wells associated with the Montezuma Wetland operations and seven additional proposed monitoring stations that will have two monitoring wells screened at discrete depth intervals (water table and roughly 250 to 300 feet below ground surface [ft bgs]). The proposed groundwater wells at each station will have 10 to 20-ft long screen intervals, with total depths of the shallower wells anticipated to range from 25 to 30 ft bgs. The surficial groundwater zone is comprised of extensive alluvial plains, which are formed by the deposition of sediment over time by the Sacramento and San Joaquin Rivers. The sediments are largely of Holocene age, meaning they have been deposited over the last 10,000 years. Due to the ongoing sediment deposition by rivers, the region's geology is relatively shallow, and the underlying bedrock is generally not exposed at the surface. The deep alluvial wells at each new monitoring station are proposed to have 20-ft long screens with total depths anticipated to range between 250 to 300 ft bgs. The deep alluvial groundwater zone is primarily composed of layers of alluvial deposits that have accumulated over thousands of years. These alluvial deposits create lithologic layers of sand, gravel, silt, and clay, which create a porous and permeable layer that can hold and transmit water. They have been deposited in various environments, including river channels, floodplains, and deltaic environments. The stations will be installed to give a spatial distribution around the injection location that allows for effective monitoring within the AoR (Figure E.I-4).

In additional to the nested shallow alluvial monitoring wells, MC is proposing to install and complete at least one (1) deep monitoring well to monitor the base of the USDW, which is anticipated to be within or near the bottom of the Tehama Formation at a depth of approximately 2,000 ft bgs; its final construction details will be determined after completion of the proposed stratigraphic test well at the project site. The Tehama Formation is comprised primarily of a sedimentary rock unit that is composed of sandstone, siltstone, shale, and conglomerate. It is part of the larger Cenozoic sedimentary sequence within the Sacramento Basin. The Tehama Formation consists of layers of marine and non-marine sediments that were deposited in various environments, including coastal plains, estuaries, and shallow marine environments. The deposition of sediments was influenced by factors such as sea-level changes, tectonic activity, and sediment supply from nearby mountain ranges. The sandstone and conglomerate layers within the Tehama Formation indicate the presence of ancient river systems that transported and deposited coarse sediments. The siltstone and shale layers, on the other hand, represent finer-grained deposits that settled in calm marine or estuarine environments.

The station locations will be installed to give an appropriate spatial distribution around the injection location to facilitate a comprehensive monitoring network to effectively assess any leakage of CO_2 from the sequestration reservoir. (Figure E.I-4).

Furthermore, the University of California Berkeley (UC Berkeley) and Lawrence Berkeley National Laboratory (LBNL) teaming partners are planning to perform a detailed geophysical and seismic evaluation of the subsurface conditions at the project site. As part of their analysis, they also plan to perform a stochastic modeling evaluation to assist the project team to identify potential project risks associated with the variability and uncertainty of the subsurface, especially in proximity to several of the nearby known faults. Thus, upon completion of this uncertainty evaluation, additional monitoring stations for the shallow/deep alluvial and lowermost USDW monitoring wells are anticipated to be added to the overall project monitoring program to address these identified data gaps. As this evaluation is not yet complete and the precise number and locations of these stations are as of yet unknown, they are not currently identified on a map.

FIGURE E.I-4. ABOVE CONFINING ZONE MONITORING WELL LOCATIONS



E.I.2.1.1.A.4 INJECTION ZONE GROUNDWATER MONITORING STRATEGY

Monitoring of the Anderson Sandstones will be used for early leakage detection. Fluid sampling at well IZMW-A1 in combination with pressure monitoring, temperature monitoring, and pulse neutron logging at IW-A1 will be used to determine if leakage is occurring above the confining unit (Meganos and Martinez shale units). MIT testing and DTS monitoring at the injection well will also provide data to ensure that mechanical integrity of the well is maintained. With the planned sampling and monitoring frequencies, it is expected that baseline conditions can be documented, natural variability in conditions can be characterized, unintended brine or CO_2 leakage could be detected if it occurred, and sufficient data will be collected to demonstrate that the effects of CO_2 injection are limited to the intended storage reservoir. Groundwater fluid sampling, including geochemical and isotope analyses, is planned for the Anderson until the plume reaches the location, at which time the groundwater sampling will cease.

E.I.2.1.1.A.5 SOIL GAS MONITORING STRATEGY

At each of the monitoring stations (Figure E.I-4), soil gas will be monitored by three methods. The first method will be sampling for laboratory analysis from soil gas probes planned to be installed at depths of approximately 5 to 7 ft bgs. The second method will be continuous field measurement of CO_2 concentrations with sensors placed in wells screened at roughly that same depth interval (between 5 to 7 ft bgs). The third method will be CO_2 efflux measurements taken at ground surface with a dynamic closed chamber. At each station, approximately 16 soil collars (4 x 4 grid pattern - receivers for the dynamic closed chamber) will be permanently installed for these measurements.

As described above, the UC Berkeley and LBNL team plans to perform a stochastic modeling evaluation to identify potential project risks associated with the variability and uncertainty of the subsurface conditions, especially in proximity to several of the nearby know faults. Upon completion of this uncertainty evaluation, additional soil gas monitoring stations as described above are anticipated to be added to the overall project monitoring program to address these identified data gaps. As this evaluation is not yet complete and the precise number and locations of these stations are as of yet unknown, they are not currently identified on a map.

E.I.2.1.1.A.6 SURFACE/ATMOSPHERIC AIR MONITORING STRATEGY

At the monitoring station co-located in close proximity to IW-A1 (Figure E.I-4), a surface/atmospheric air sampling station will be constructed and monitored by two methods which are similar to those used for the soil gas program. The first method will be sampling for laboratory analysis from a designated sample station located at or near the lowest topographic setting in close proximity to IW-A1 with its sample point located between 0.5 to 1 ft above the ground surface. The second method will be continuous field measurement of CO_2 concentrations with a sensor mounted onto the sampling station, also located between 0.5 to 1 ft above the ground surface

E.I.2.1.2.B TYPE AND NUMBER OF SAMPLES/TEST RUNS

CO_2 gas stream, monitoring of operational parameters, corrosion coupons, and groundwater sampling activities and frequencies are shown in Table E.2-1 of the Testing and Monitoring Plan.

E.I.2.1.3.C SITE/SAMPLING LOCATIONS

Grab samples for laboratory analysis will be taken from a station located either immediately upstream or downstream of the flow meter used to measure the injection flow, in conformance with the requirements of 40 CFR 98.444(b)(3).

The locations of the instruments for continuous monitoring of operational parameters are discussed in the Testing and Monitoring Plan.

Corrosion coupons will be mounted in holders located downstream of the surface equipment and upstream of the injection wellhead.

Near-surface soil gas sampling and above confining zone groundwater monitoring will be conducted at the seven stations shown on Figure E.I-4.

Also, at the monitoring station proposed to be placed near/adjacent to IW-A1 (Figure E.I-4), a lowermost USDW (Tehama Formation) monitoring well and a surface/atmospheric air sampling station will also be installed.

Injection zone groundwater monitoring will be conducted at IZMW-A1. The proposed location of IZMW-A1 is shown on Figure E.I-2.

E.I.2.1.4.D SAMPLING SITE CONTINGENCY

No problems of site inaccessibility are anticipated for CO_2 gas stream or corrosion coupon sampling.

The above confining zone and injection zone groundwater monitoring wells are located on property of the project participants or cooperative adjacent property owners and access permissions have already been granted or anticipated to be acquired. No problems of site inaccessibility are anticipated.

If inclement weather makes site access difficult, sampling schedules will be reviewed and alternative dates may be selected to align with the frequencies are shown in the Testing and Monitoring Plan to the extent practicable.

E.I.2.1.5.E ACTIVITY SCHEDULE

See the Testing and Monitoring Plan for frequencies of data collection.

E.I.2.1.6.F CRITICAL/INFORMATIONAL DATA

Detailed documentary information will be collected on field forms for each of the sampling activities. Critical information will include time and date of activity, people performing the activity, the location of the activity (e.g., well name), field instruments used, calibration information, and field parameter outputs from the instruments. The laboratories performing the analyses will also provide detailed documentary information including but not limited to custody transfer of the samples, time and date of analysis, analytical methods utilized, and test method results. Much of the critical data from the laboratories is generated during analysis and provided to end users in digital and printed formats.

E.I.2.1.7.G SOURCES OF VARIABILITY

Potential sources of variability related to monitoring activities include (1) natural variation in fluid quality, formation pressure and temperature and seismic activity; (2) variation in fluid quality, formation pressure and temperature, and seismic activity due to project operations; (3) changes in recharge due to rainfall, drought, and snowfall; (4) changes in instrument calibration during sampling or analytical activity; 5) different staff collecting or analyzing samples; (6) differences in environmental conditions during field sampling activities; (7) changes in analytical data quality during life of project; and (8) data entry errors related to maintaining project database.

Activities to eliminate, reduce, or reconcile variability related to monitoring activities include (1) collecting long-term baseline data to observe and document natural variation in monitoring parameters, (2) evaluating data in a timely manner after collection to observe anomalies in data that can be resampled or reanalyzed, (3) conducting statistical analysis of monitoring data to determine whether variability in a data set is the result of project activities or natural variation, (4) maintaining weather-related data using on-site weather monitoring data or data collected near the project site (such as from local airports), (5) checking instrument calibration before, during and after sampling or sample analysis, (6) thoroughly training staff, (7) conducting laboratory quality assurance checks using third party reference materials, and/or blind and/or replicate sample checks, and (8) developing a systematic review process of data that can include sample-specific data quality checks (e.g., cation/anion balance for aqueous samples).

E.I.2.2 SAMPLING METHODS

Logging, geophysical monitoring, and pressure/temperature monitoring does not apply to this section and are omitted.

E.I.2.2.1.A/B SAMPLING SOPS

See Tables E.I-9 and E.I-10 below for sampling stabilization criteria. Groundwater sampling will be collected primarily following low-flow sampling methods consistent with the 2017 US EPA Region 4 Groundwater Sampling Operating Procedure.

TABLE E.I-9. STABILIZATION CRITERIA OF WATER QUALITY PARAMETERS DURING SHALLOW WELL PURGING

FIELD PARAMETER	STABILIZATION CRITERIA
pH	±0.1 pH units
Temperature	Considered stabilized when other parameters are stable
Specific conductance	±5%
Dissolved oxygen	±0.2 mg/L or ±10% change in saturation, whichever is greater
Turbidity	Stabilized (EPA Region 4 does not prescribe a specific value) or < 10 NTUs
Dissolved CO_2 (Above Confining Zone Only)	Considered stabilized when above parameters are stable

Gas sampling in soil gas and surface/atmospheric air will follow procedures informed by the US EPA Region 4 Operating Procedure for Soil Gas Sampling.

TABLE E.I-10. STABILIZATION CRITERIA FOR SAMPLING OF SOIL GAS AND SURFACE/ATMOSPHERIC AIR

FIELD PARAMETER	STABILIZATION CRITERIA
O_2, CO_2, and CH_4 concentration	±10%

E.I.2.2.2.C IN-SITU MONITORING

In situ monitoring will be conducted by data loggers that are described in the Continuous Monitoring section below.

E.I.2.2.3.D CONTINUOUS MONITORING

Data loggers will be used to collect continuous measurements of above confining zone groundwater elevations (by water pressure), temperature, and conductivity. Both the shallow and deep alluvial monitoring wells at each of the seven stations on Figure E.I-4 will have continuous data logging. The measurements will be taken approximately once every 12 hours. The sensors will report each measurement to a data logger that will store the information for upload as appropriate. In addition, the data logger will load the measurements to a modem that will transmit the data by antennae via a 4G LTE cellular signal for retrieval by the project team.

A sensor will be used to collect continuous measurements of near surface CO2 concentrations in soil gas. The measurements will be taken from PVC wells screened between 5 to 7 ft bgs at each of the stations on Figure E.I-4. The sensors will measure the CO2 concentration approximately once every 30 minutes and report an average over that timeframe, for an aggregate of approximately 12 hours. The sensors will report each measurement to a data logger that will store the information for upload as appropriate. In addition, the data logger will load the measurements to a modem that will transmit the data by antennae via a 4G LTE cellular signal for retrieval by the project team.

E.I.2.2.4.E SAMPLE HOMOGENIZATION, COMPOSITION, FILTRATION

Sample homogenization, composition, and filtration will be conducted by the laboratories according to the methods for a given analysis.

E.I.2.2.5.F SAMPLE CONTAINERS AND VOLUMES

CO_2 grab samples will be collected following a written standard operating procedure, using clean sample containers (e.g., gas cylinders, sample bags) provided by the laboratory conducting the analytical tests, and are detailed in Table E.I-11.

TABLE E.I-11. SUMMARY OF SAMPLE CONTAINERS, PRESERVATION TREATMENTS, AND HOLDING TIMES FOR CO2 GAS STREAM ANALYSIS

TARGET PARAMETERS	VOLUME/CONTAINER MATERIAL	PRESERVATION TECHNIQUE	SAMPLE HOLDING TIME (MAX)
CO_2 Gas Stream	Two - 2L MLB Polybags	Sample Storage Cabinets/Shipping Containers	5 business days
	One - 75 cc mini-cylinder	Sample Storage Cabinets/Shipping Containers	5 business days

Groundwater sample containers and volumes are detailed in Table E.I-12.

TABLE E.I-12. SUMMARY OF ANTICIPATED SAMPLE CONTAINERS, PRESERVATION TREATMENTS, AND HOLDING TIMES FOR GROUNDWATER SAMPLES

TARGET PARAMETERS	VOLUME/CONTAINER MATERIAL	PRESERVATION TECHNIQUE	SAMPLE HOLDING TIME
Cations: Al, Ba, Mn, As, Cd, Cr, Cu, Fe (dissolved and total), Pb, Sb, Se, Sr, Tl, and Zn	250 mL polyethylene bottle	HNO_3 to a pH less than 2; cool to 4°C	6 months
Cations: Ca, Fe, K, Mg, Na, and Si	250 mL polyethylene bottle	HNO_3 to a pH less than 2; cool to 4°C	6 months
Anions: Br, Cl, F, NO_3, and SO_4 pH	250 mL polyethylene bottle	Cool to 4°C	28 days, except nitrate, which is 48 hours
Mercury	500 mL polyethylene bottle	HNO_3 to a pH less than 2	28 days
H_2S	250 mL plastic bottle	NaOH and zinc acetate; cool to 6°C	7 days
CH_4	To be determined	To be determined	To be determined
Stable Isotopes: $^{13/12}C$ in DIC, $^{2/1}H$ in H_2O, $^{18/16}O$ in H_2O	250 mL polyethylene bottle	Cool to 4°C	--
Radiocarbon Isotope: $^{14/12}C$ in DIC	To be determined	To be determined	To be determined
Alkalinity, Bicarbonate (as $CaCO_3$) Alkalinity, Carbonate (as $CaCO_3$) Total dissolved solids (TDS)	500 mL polyethylene bottle	Cool to 4°C	14 days
Total organic carbon (TOC)	250 mL amber glass bottle	H2SO4 to pH < 2; cool to 6oC	28 days

Soil gas sample containers and volumes are detailed in Table E.I-13.

TABLE E.I-13. SAMPLE CONTAINERS, PRESERVATION TREATMENTS, AND HOLDING TIMES FOR SAMPLING SOIL GAS

TARGET PARAMETERS	VOLUME/CONTAINER MATERIAL	PRESERVATION TECHNIQUE	SAMPLE HOLDING TIME
O_2, N_2, CO_2, and CH_4 Stable Isotopes: $^{13/12}C$ in CO_2 $^{13/12}C$ and $^{2/1}H$ in CH_4 (if present) Radiocarbon Isotope: $^{14/12}C$ in CO_2 $^{14/12}C$ in CH_4 (if present)	0.3 L Isobag	Storage Temperature range:-4°F (-20°C) TO +122°F (+50°C)	--

Surface/Atmospheric air sample containers and volumes are detailed in Table E.I-14.

TABLE E.I-14. SAMPLE CONTAINERS, PRESERVATION TREATMENTS, AND HOLDING TIMES FOR SAMPLING SURFACE/ATMOSPHERIC AIR

TARGET PARAMETERS	VOLUME/CONTAINER MATERIAL	PRESERVATION TECHNIQUE	SAMPLE HOLDING TIME
O_2, N_2, CO_2, and CH_4	0.3 L Isobag	Storage Temperature range:-4°F (-20°C) TO +122°F (+50°C)	--

E.I.2.2.6.G SAMPLE PRESERVATION

No preservation is required or used for the CO_2 stream samples.

Groundwater preservation is detailed in Table E.I-12, soil gas sample preservation is detailed in Table E.I-13, and surface/atmospheric air sample preservation is detailed in Table E.I-14.

E.I.2.2.7.H CLEANING/DECONTAMINATION OF SAMPLING EQUIPMENT

For CO2 grab sampling, the sample containers will be provided by the analytical laboratory in a pre-cleaned and ready-to-use state. The sampling containers will be either disposed or decontaminated by the analytical laboratory after use.

The soil gas sampling train is not prone to cross-contamination. The vacuum to drive the sample into the bag is achieved by a lung box, which isolates the bag from the atmosphere.

For above confining zone groundwater sampling, dedicated bladder pumps will be installed in each groundwater monitoring well to minimize potential cross contamination between wells. These pumps will remain in each well throughout the project period except for maintenance.

The equipment required for IZMW-A1 is currently under engineering design and will be provided once the design is finalized.

E.I.2.2.8.I SUPPORT FACILITIES

For CO_2 grab sampling, tubing, connectors, and valves required to sample the CO_2 gas stream will be supplied by MC (or its subcontractor) or the analytical laboratory providing the sample containers.

For soil gas sampling, the following are required: lung box for sample collection and field instrument for soil gas parameters. Field activities are completed from field vehicles.

For sampling of above confining zone groundwater, the following are required: bladder pump, compressor and power source, air-water interface probe, and field instrument for water quality parameters (e.g., pH, specific conductance). Field activities are completed from field vehicles.

The equipment required for sampling injection zone groundwater at IZMW-A1 is currently under engineering design and will be provided once the design is finalized.

E.I.2.2.9.J CORRECTIVE ACTION, PERSONNEL, AND DOCUMENTATION

Field staff will be responsible for properly testing equipment and performing corrective actions on broken or malfunctioning field equipment. If corrective action cannot be taken in the field, then equipment will be returned to the manufacturer for repair or replaced. Significant corrective actions affecting analytical results will be documented in field notes.

E.I.2.3 SAMPLE HANDLING AND CUSTODY

Logging, geophysical monitoring, and pressure/temperature monitoring does not apply to this section and is omitted.

E.I.2.3.1.A MAXIMUM HOLD TIME/TIME BEFORE RETRIEVAL

Holding times are denoted in Tables E.I-12 through E.I-14.

E.I.2.3.2.B SAMPLE TRANSPORTATION

Samples will be transported such that they minimize container breakage and arrive for analysis within the hold times detailed in Table E.I-12 through E.I-14.

E.I.2.3.3.C SAMPLING DOCUMENTATION

Field notes will be recorded for all samples collected during a sampling event. The laboratory performing the analytical tests will provide test results along with chain-of-custody documentation. The forms and reports will be retained and archived by MC for future reference.

E.I.2.3.4.D SAMPLE IDENTIFICATION

All samples will be properly labeled with labels provided by the laboratory denoting project, sample location/identification number, sample date and time, sampling personnel's initials, and volume collected.

E.I.2.3.5.E SAMPLE CHAIN-OF-CUSTODY

The chain-of-custody will be documented using a standardized form provided by the laboratory. Copies of the chain-of-custody will be provided with the samples to the laboratory and recorded with the field forms where the documents will be retained.

E.I.2.4 ANALYTICAL METHODS

E.I.2.4.1.A ANALYTICAL SOPS

Groundwater and soil gas/surface air laboratory standard operating procedures are provided in Appendix E.I-3 and Appendix E.I-4, respectively.

E.I.2.4.2.B EQUIPMENT/INSTRUMENTATION NEEDED

The groundwater and soil gas/surface air laboratory standard operating procedures provided in Appendix E.I-3 and Appendix E.I-4, respectively, describe equipment and instruments specific to the given analysis.

E.I.2.4.3.C METHOD PERFORMANCE CRITERIA

Each laboratory conducting analysis will be responsible for appropriately addressing analytical failure according to their individual SOPs.

E.I.2.4.4.D ANALYTICAL FAILURE

Each laboratory conducting the analyses will be responsible for appropriately addressing analytical failure according to their individual SOPs and laboratory quality assurance manuals.

E.I.2.4.5.E SAMPLE DISPOSAL

Each laboratory conducting the analyses will be responsible for appropriate sample disposal according to their individual SOPs.

E.I.2.4.6.F LABORATORY TURNAROUND

Laboratory turnaround will vary by laboratory; however, generally turnaround of verified analytical results within one month will be suitable for project needs.

E.I.2.4.7.G METHOD VALIDATION FOR NONSTANDARD METHODS

Nonstandard methods are not anticipated for this project. If nonstandard methods are determined to be needed or proposed in the future, the USEPA will be consulted prior to use of the nonstandard method, and additional appropriate action will be taken.

E.I.2.5 QUALITY CONTROL

Field QC for groundwater and soil gas sampling is described below.

E.I.2.5.1.A FIELD QC ACTIVITIES

E.I.2.5.1.A.1. BLANKS

For groundwater sampling, a field blank will be collected and analyzed for the applicable analytes at a frequency of 10% or greater. Field blanks will be exposed to the same field and transport conditions as the groundwater samples. Field blanks will be used to detect contamination resulting from the collection and transportation process.

E.I.2.5.1.A.2 DUPLICATES

For each groundwater sampling round, a field duplicate groundwater sample will be collected and analyzed for the applicable analytes at a frequency of 10% or greater from wells on a rotating schedule. Field duplicate samples are collected from the same source immediately after the original sample in different sample containers and processed as all other samples. Field duplicate samples are used to assess sample heterogeneity and analytical precision. (US EPA 2020a)

E.I.2.5.2.B EXCEEDING CONTROL LIMITS

If the sample analytical results exceed control limits (i.e., ion balances > ±10%), further examination of the analytical results will be done by evaluating the ratio of the measured TDS to the calculated TDS (i.e., mass balance) based on individual dissolved solids in the sample. The method indicates which ion analyses should be considered suspect. Suspect ion analyses are then reviewed in the context of historical data and interlaboratory results, if available. Suspect ion analyses are then brought to the attention of the analytical laboratory for confirmation and/or reanalysis. The ion balance is recalculated, and if the error is still not resolved, suspect data are identified and may be given less importance in data interpretations.

E.I.2.5.3.C CALCULATING APPLICABLE QC STATISTICS

E.I.2.5.3.C.1. CHARGE BALANCE

The analytical results are evaluated to determine correctness of analyses based on anion-cation charge balance calculations. Because all potable waters are electrically neutral, the chemical analyses should yield equally negative and positive ionic activity. The anion-cation charge balance will be calculated using the formula:

$$\%\ Difference = 100\ \frac{\sum cations - \sum anions}{\sum cations + \sum anions},$$ (Equation 1)

where the sums of the ions are represented in milliequivalents per liter (meq/L). The cations considered on a routine basis will be Ca^{2+}, Fe^{2+}, Mg^{2+}, Mn^{2+}, and Na^{+} and the anions will be HCO_3^-, CO_3^{2-}, Cl^-, and SO_4^{2-}. It the charge balance with this set for a given sample is ±10%, this will be considered acceptable. If the charge balance outside of this range, additional ions reported for the water sample will be considered.

E.I.2.5.3.C.2 MASS BALANCE

The ratio of the measured TDS to the calculated TDS will be calculated in instances where the charge balance acceptance criteria are exceeded using the formula:

$$1.0 < measured/calculated < 1.2,$$ (Equation 2)

where the anticipated values are between 1.0 and 1.2.

E.I.2.5.3.C.3 OUTLIERS

A determination of one or more statistical outliers will be conducted prior to the statistical evaluation of groundwater. This project will use the US EPA's March 2009 Unified Guidance as a basis for selection of recommended statistical methods to identify outliers in groundwater chemistry data sets as appropriate. These techniques include probability plots, boxplots, Dixon's test, Gibbon's test, and Rosner's test. The US EPA 1989 outlier test may also be used as another screening tool to identify potential outliers.

E.I.2.6 INSTRUMENT/EQUIPMENT TESTING, INSPECTION, AND MAINTENANCE

For groundwater and soil gas sampling, field equipment will be maintained, factory serviced, and calibrated per manufacturer's recommendations. Spare parts that may be needed during sampling will be included in supplies on hand during field sampling or obtained when the need is identified in the field.

All laboratory equipment, testing, inspection and maintenance will be conducted by the analytical laboratory per standard practice, method-specific protocols.

E.I.2.7 INSTRUMENT/EQUIPMENT CALIBRATION AND FREQUENCY

E.I.2.7.1.A CALIBRATION AND FREQUENCY OF CALIBRATION

For continuous monitoring of operational parameters, each instrument will be calibrated at the frequency specified by the instrument manufacturer.

For CO_2 grab analysis and corrosion coupon analysis, the calibration and frequency of calibration for instruments are the responsibility of the laboratory conducting the analysis and will be performed in accordance with their standard operating procedures, which are based upon the requirements of the specific analytical test methods being implemented and equipment manufacturer recommendations.

For groundwater and near surface soil gas, field meters will be calibrated according to manufacturer recommendations and equipment manuals. For meters calibrated in the field, calibrations will be conducted each day before sample collection begins. Recalibration will be performed if any components yield atypical values or fail to stabilize during sampling.

E.I.2.7.2.B CALIBRATION METHODOLOGY

For continuous monitoring of operational and field parameters, each instrument will be calibrated by the methods specified by the instrument manufacturer.

For CO_2 grab analysis and corrosion coupon analysis, the calibration methodology is the responsibility of the laboratory conducting the analysis and will be performed in accordance with their standard operating procedures, which are based upon the requirements of the specific analytical test methods being implemented and equipment manufacturer recommendations.

E.I.2.7.3.C CALIBRATION RESOLUTION AND DOCUMENTATION

For continuous monitoring of operational and field parameters, the calibration resolution for each instrument will follow the resolution specified by the instrument manufacturer.

For CO_2 grab analysis and corrosion coupon analysis, the calibration resolution and documentation are the responsibility of the laboratory conducting the analysis and will be performed in accordance with their standard operating procedures, which are based upon the requirements of the specific analytical test methods being implemented and equipment manufacturer recommendations.

E.I.2.8 INSPECTION/ACCEPTANCE FOR SUPPLIES AND CONSUMABLES

E.I.2.8.1.A/B SUPPLIES, CONSUMABLES, AND RESPONSIBILITIES

Supplies and consumables for field and laboratory operations will be procured, inspected, and accepted as required from vendors approved by MC or the respective subcontractor responsible for the data collection activity. Acquisition of supplies and consumables related to groundwater analyses will be the responsibility of the laboratory per established standard methodology or operating procedures.

E.I.2.9 NONDIRECT METHODS

E.I.2.9.1.A DATA SOURCES – SEISMIC MONITORING

A more detailed description of the seismic monitoring program is provided in Section E.10 of the Testing and Monitoring Plan. However, the following section provides a short description of the planned monitoring equipment and sensors.

Seismicity (baseline and injection induced), CO_2 plume characteristics (pressure, saturation, etc.), and above-USDW changes will be monitored using an extensive toolbox of conventional seismic methods including baseline conventional three-dimensional (3D), continuous passive seismic event monitoring, time lapse 3D vertical seismic profiling (VSP), and time lapse baseline conventional 3D.

E.I.2.9.1.A.1 CONTINUOUS EVENT MONITORING – ACQUISITION

Figure E.I-5 illustrates the system that will be used to detect natural and induced seismicity near the site, and geodetic measurements using a Global Navigation Satellite System (GNSS) sensor. Boreholes (approximately 300 ft total depth) will be drilled in and around the site in which multi-level geophones (3-component 4.5 Hz geophones) and hydrophones will be deployed. The geophones and hydrophones for each station will be permanently cemented in place, and the borehole space above the cement column will be filled with bentonite, and cuttings for the last 20 to 30 ft (this prevents noise from the surface contaminating the sensors).

FIGURE E.I-5. BOREHOLE GEOPHONE AND GNSS SYSTEMS

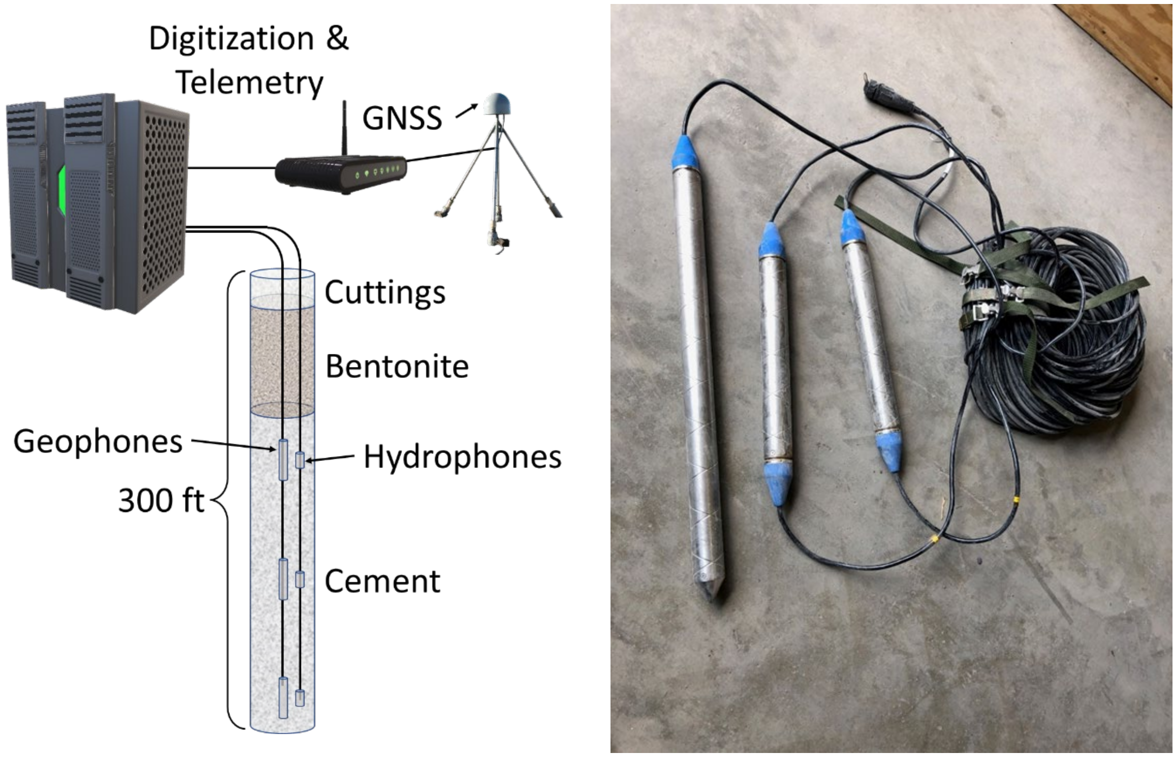
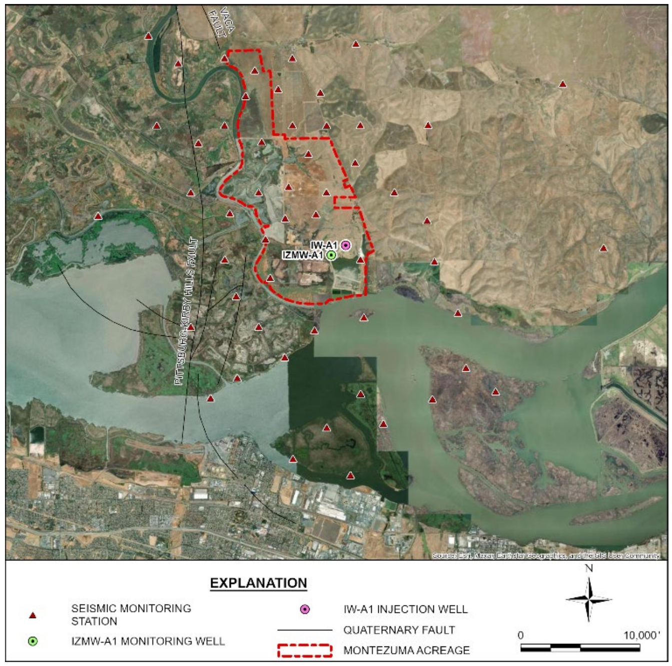


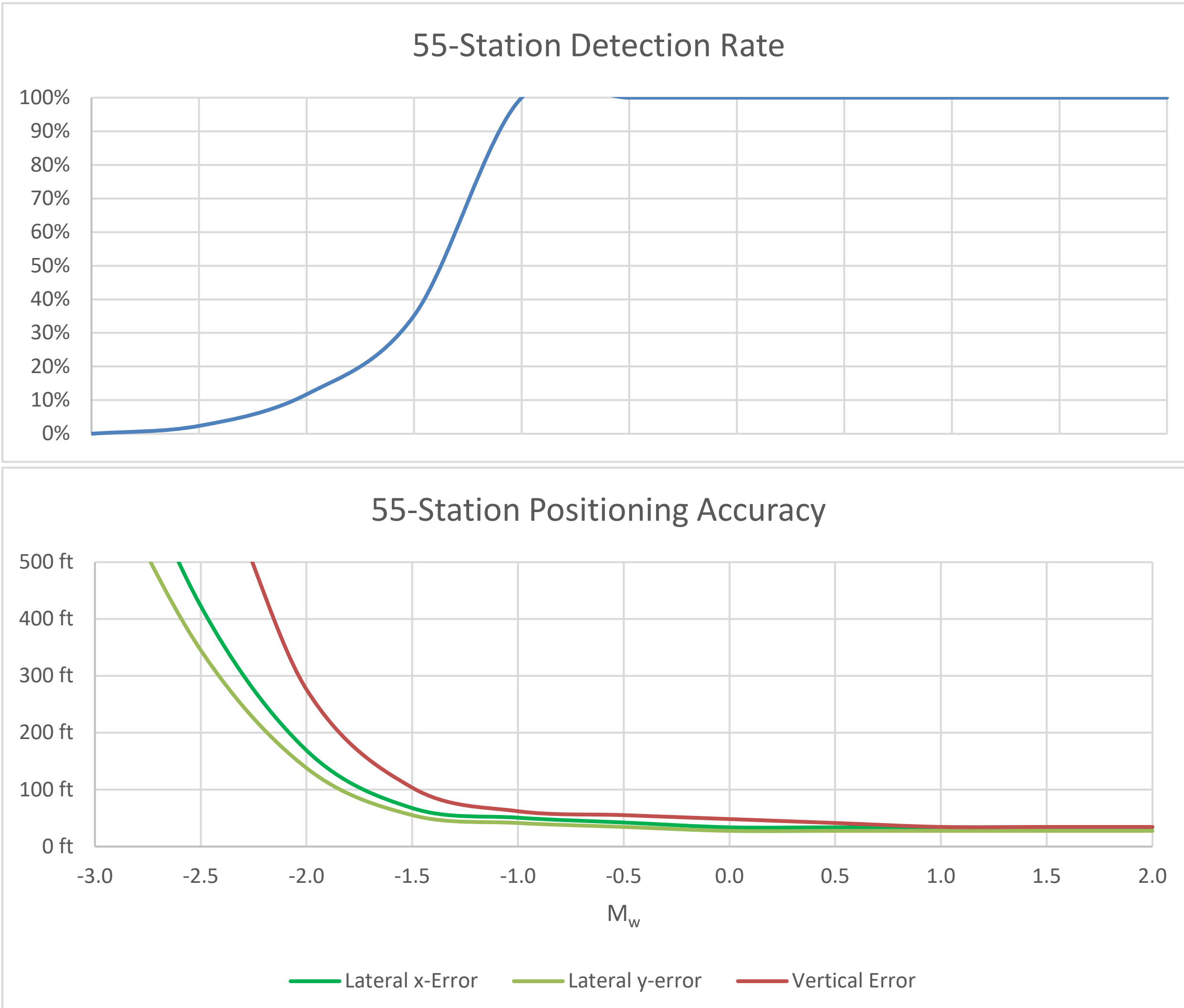
Figure E.I-6 (below) shows boreholes (in yellow) that will be drilled close to the injection well and in a zone around the Kirby Hills fault to detect deep natural seismicity from the fault at depths of approx. 20 kilometers (km), and injection induced seismicity, which should be confined to the reservoir interval at about 3.6 km. Sensors in these wells will be also used to augment other seismic surveys collected before and during injection.

FIGURE E.I.6. SEISMIC MONITORING BOREHOLE LOCATIONS



A Passive Seismic Emission Tomography (PSET) algorithm is used to detect and locate events within the model volume and compare those against the known synthetic event locations. Differences between event magnitude (M_W) and event locations determines probable event detection thresholds and location errors (Figure E.I-7).

FIGURE E.I-7. 55-STATION ARRAY RESPONSE



Preliminary PSET modeling shows the array has a Magnitude of Completeness (Mc) of approximately Mc = -1.5 (i.e., 90% or more of seismic events). Mw = -1.5 or higher will be detected and catalogued with a location accuracy of 50 to 75 ft.

E.I.2.9.1.A.2 CONTINUOUS EVENT MONITORING – PROCESSING AND INTERPRETATION

The monitoring stations will relay near real-time continuous seismic data to a cloud-based server. A daily report on the health of the array is maintained such that remedial action can be taken if the array should experience any station failures.

Real-time processing of the MSI's proprietary BuriedArray® system (BurriedArray) data involves the detection, location, and characterization of microseismic events accomplished with MSI's patented beamforming application PSET. Passive seismic event location via beamforming is a variation of Kirchhoff pre-stack depth migration, where the recorded seismic data are digitally backpropagated into a model of the earth. Points in time and space where energy focusing is observed are identified as potential event hypocenters and are refined and qualified as events using an analysis of the wavefield kinematics.

Once an event has been located and qualified, several attributes can be computed from the recorded wavefield to characterize the quality of the detection, the magnitude, and focal mechanism of the underlying microseismic event.

The PSET algorithm is used to detect and locate events within the recorded volume. During and after injection, the system continuously monitors seismicity so that a "Traffic Light System" can be implemented. If the system automatically detects any events *or event trends* that trigger the traffic light protocols, the operator is notified immediately to determine what (if any) steps are required to mitigate the induced seismic risk. These protocols are summarized as three distinct induced seismicity levels or trends.2

1. **Green**: 24/7 real time monitoring and event detection in effect, no seismic events of significance detected (i.e., no events or event trends larger than the background level established in the pre-injection baseline monitoring phase) – normal operations.
2. **Yellow**: Seismic events or event trends of possible significance detected. This may mean events of magnitude $M_w = 1$ or higher, or trends of events of Magnitude $M_w = 0$ or larger, clustered in a particular region, which trigger enhanced analysis of data from the anomalous event location(s). These events are ruled as "real/verified" or "artifact/disqualified", with a recommendation for further investigation or a decision is taken to return to Green.
3. **Red**: Verified significant seismic activity ($M_w > 2$). The site operator takes over the decision-making process to determine any further actions, including suspension of injection operations.

E.I.2.9.1.A.3 DISTRIBUTED ACOUSTIC SENSORS – DAS FIBER

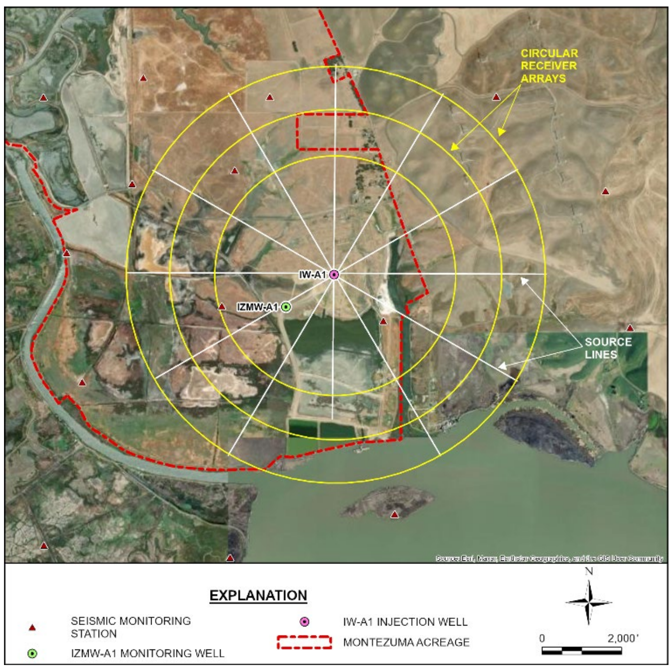
In addition to the BuriedArray, DAS fiber in the monitor and injection wells will be utilized as a seismic receiver to enhance the quality of induced seismicity event detection and to improve the image quality of the VSP and 3D seismic surveys. Modeling suggests the DAS array could improve the vertical accuracy of catalogued events in proximity to the monitoring well by as much as 30%.

E.I.2.9.1.B ACTIVE SOURCE 3D AND VSP SURVEYS

A baseline 3D survey, which will encompass the entire AoR, will be acquired prior to drilling the monitor hole to aid in site characterization and well locations. After the monitor well is completed, a 3D VSP will be acquired to provide parameters (velocity/attenuation, etc.) to aid in processing and interpretation of the baseline 3D survey.

During the early stages of injection when the plume and pressure are confined to a region near the injection well, extensive seismic monitoring using repeat surveys will be performed. For the first few months we plan to collect repeat surveys from time scales of minutes (passive seismic) to hours (VSP) to days (3D), to aid in understanding pressure front and early plume evolution. Most seismic monitoring studies in the past have been focused on very coarse snapshots (years). Our approach will provide much more granular information which will improve resolution, accuracy and allow other properties such as pressure diffusion to be characterized near the injection well. This will require the DAS system as well as a dedicated array of receivers deployed in a ring around the injection well, and multiple sources moving around the monitor well location (Figure E.I-8)

FIGURE E.I-8. MONITOR 3D SURVEY LAYOUT



E.I.2.9.1.C DATA SOURCES – GNSS

GNSS can be used to monitor surface deformation during carbon sequestration activities by detecting changes in surface elevation and horizontal position above and near the CO_2 reservoir, which can occur during injection operations. GNSS time series of 3D positions can be established in an external (global) reference frame and with respect to stations within the network at mm accuracy.

E.I.2.9.1.C.1 STRAIN MEASUREMENT

GNSS can measure ground strain, or deformation, by comparing the positions of multiple GNSS receivers over time. This movement may be an indication the ground is stretching or compressing due to the injection of CO_2.

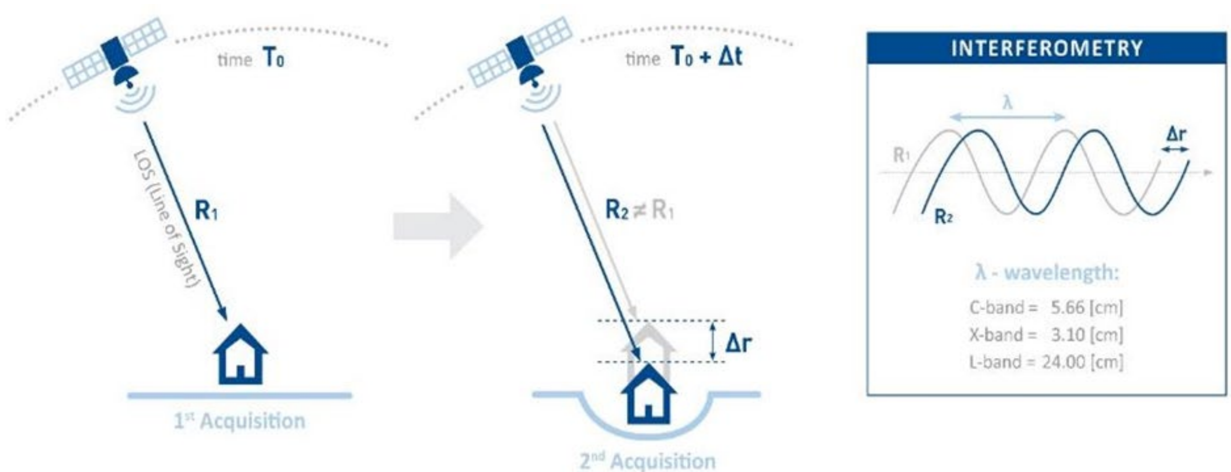
E.I.2.9.1.C.2 INJECTION WELL MONITORING

GNSS can be used to monitor the position and movement of injection wells used in carbon sequestration activities. By measuring the position of the well over time, any movement or deformation of the well due to the injection of CO_2 can be quantified.

E.I.2.9.1.D DATA SOURCES – INSAR

InSAR (Interferometric Synthetic Aperture Radar) has been in commercial use since the 1990s, leveraged globally to obtain millimeter-scale ground deformation data (Figure E.I-9). In California and around the world, InSAR has been used to quantify ground deformation associated with hydrocarbon production, enhanced oil recovery operations, ground water pumping, and geohazard/tectonic activity. As subsurface pressures increase as a result of CO_2 injection, millimeter-scale surface deformation may be observed that will reflect the morphology and evolution of the pressure front. InSAR has been included in several CO_2 injection monitoring, measurement and verification (MMV) programs, including at In Salah, Algeria; Decatur, Illinois; and Gorgon, Australia, among others.

FIGURE E.I-9. SCHEMATIC SHOWING THE RELATIONSHIP BETWEEN GROUND DISPLACEMENT AND SIGNAL PHASE SHIFT



InSAR has been used in North America and elsewhere for monitoring the migration and evolution of a pressure plume associated with injected fluids. In the western United States, several examples of the utility of InSAR to monitor and characterize disposal activity are available.

In Wyoming, InSAR is used to monitor and delineate the effectiveness of CO_2 sweep and conformance in an enhanced oil recovery operation. The map below (Figure E.I-10) shows the spatial distribution of the CO_2 pressure plume (blue), while the cross section (Figure E.I-11) shows the temporal evolution of the uplift associated with injection.

FIGURE E.I-10. SPATIAL DISTRIBUTION OF CO_2 PRESSURE PLUME

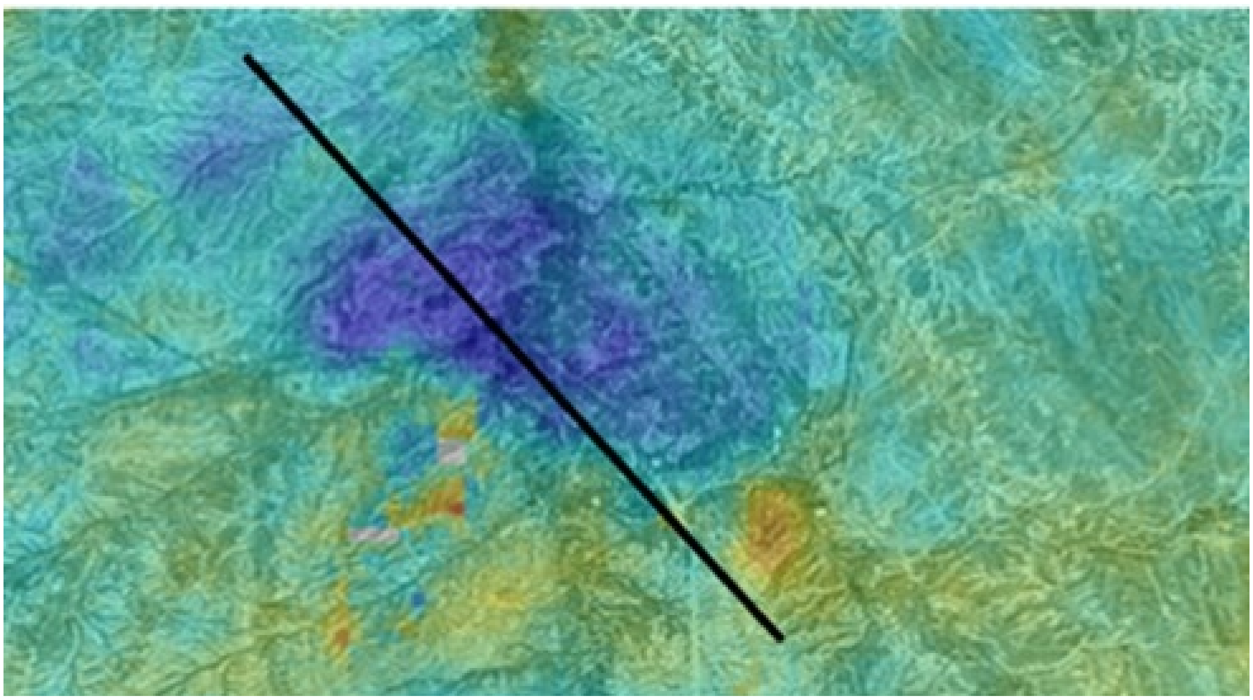
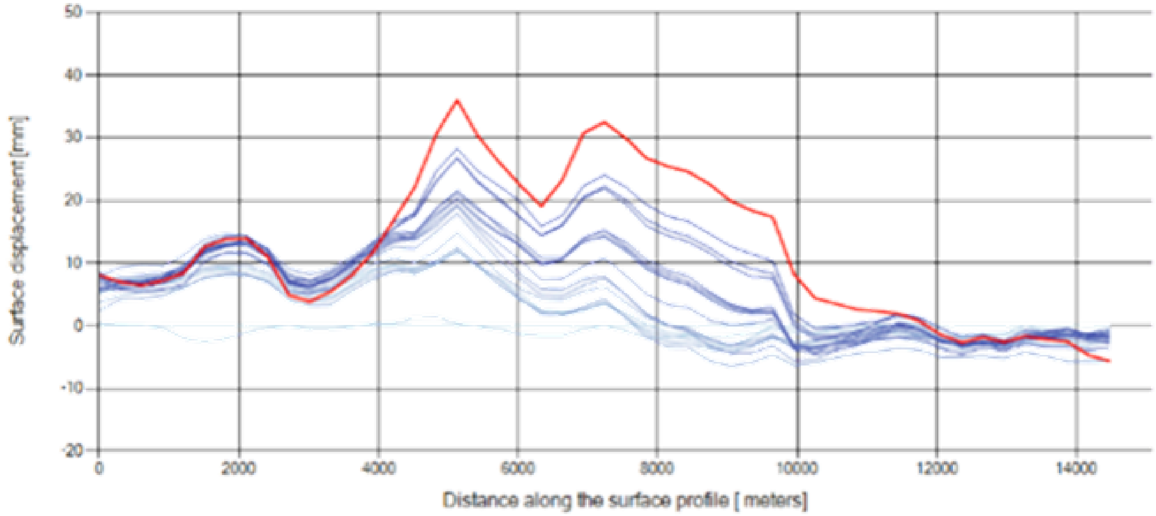


FIGURE E.I-11. TEMPORAL DISTRIBUTION OF CO_2 PRESSURE PLUME



E.I.2.9.1.D.1 MONTEZUMA CARBON MODELLING

TREA has performed an approximation of expected surface displacement (order of magnitude); incorporating geomechanical and operational parameters provided by MC. Given the following inputs:

- Reservoir height: 100 – 400 m
- Reservoir depth: 3,000 m
- Pressure change: 6,800 kPa
- Bulk Modulus of reservoir: 27 MPa (2.7x107 kPa)

Using an analytical solution to approximate surface displacement from an idealized cylindrical reservoir, TREA estimates displacement could be on the order of 10s to 100s of mm.

E.I.2.9.2. RELEVANCE TO PROJECT

E.I.2.9.2.1 SEISMIC MONITORING

During and after injection, the system continuously monitors seismicity so that a “Traffic Light System” can be implemented. If the system automatically detects any events *or event trends* that trigger the traffic light protocols (i.e., Green-to-Yellow, or Yellow-to-Red), the operator is notified immediately to determine what (if any) steps are required to mitigate the induced seismic risk. Furthermore, the seismic monitoring program will also be used as part of the Section H Emergency and Remedial Response Plan.

E.I.2.9.2.2 GNSS

GNSS can provide valuable data for monitoring 3D surface deformation with daily (or sub-daily) sampling during carbon sequestration activities, which can help ensure that carbon is being stored safely and effectively in geological formations. By detecting any potential issues with subsidence or deformation, corrective action can be taken to prevent environmental impacts and ensure the long-term success of the MC sequestration project.

E.I.2.9.2.3 INSAR

InSAR will provide several distinct advantages, including an historical baseline of ground deformation prior to injection operations. InSAR also affords the ability to capture spatially dense measurements, without the installation of a dense network of instrumentation. InSAR point clouds will provide measurement points that are collocated with other MRV data such as GNSS, surface and wellbore seismic, and pressure/temperature data obtained from wellbores. InSAR will provide data in between the discrete measurement points obtained via these methods.

E.I.2.9.3. ACCEPTANCE CRITERIA

E.I.2.9.3.1 PASSIVE AND ACTIVE SEISMIC MONITORING

Prior to installation of the BuriedArray, a comprehensive noise test will be performed to determine optimal configurations for geophones and hydrophones. The noise tests will be both passive and active, i.e., recording and analysis with and without an active surface source (e.g., Vibroseis).

The BuriedArray will be certified as operational with a comprehensive series of tests after the array is installed and transmitting data, which include test shots to determine the orientation of the 3-component geophones.

E.I.2.9.3.2 INSAR

The baseline analysis will utilize data that has been acquired by the Sentinel-1 satellite constellation, without installed corner reflectors. This satellite constellation has a pixel size (spatial resolution) of 65 ft x 15 ft, a wavelength of 2.2 inches and a nominal revisit frequency of 12 days, which is reduced to 6 days where multiple satellites are acquiring in the same configuration. This is the case over the AOI in the descending orbit from mid-2019 through to the beginning of 2022. Imagery collection for both tracks is ongoing; data will be used from two historical image stacks from both an ascending and descending orbit, to enable 1D or 2D processing for historical analysis.

As part of the standard SAR data acquisition procedures, all images are verified before being inserted into the SqueeSAR processing chain. Areal coverage, orbital parameters and acquisition interference patterns are all verified, to be certain they fall within acceptable ranges for interferometric analysis. Images that are unacceptable are discarded and the reason is noted and included in the InSAR processing report.

Corner reflectors are verified after installation to ensure they will provide reliable measurements throughout the period of analysis. The pile constructions are assessed to ensure they are within 5 degrees from vertical, and reflector orientations are assessed to ensure they are within 5 degrees of the acquisition angle of the satellites used in the analysis. Once reflector orientation has been confirmed, a visibility check is performed during which an analysis of reflectivity is undertaken, using actual imagery to confirm reflectors are oriented correctly, and that the signal reflections are strong enough to ensure feasibility.

E.I.2.9.3.3 GNSS

Prior to installation, each site will be assessed for sky view and potential multipath signal issues to ensure proper collection of data from the constellation of GNSS satellites. The sites will be selected to minimize signal blockage or scattering from vegetation and built structures. The local surface geology comprises largely unconsolidated sediments (farmland), consequently a deep-drilled braced monument will be used.
The GNSS array will be certified as operational following a test of data collection, transmission and processing, after the array is installed and transmitting data. This will include assessment of GNSS phase and code data streams, and processed 3D-position time series products.

E.I.2.9.4 RESOURCES/FACILITIES NEEDED

E.I.2.9.4.1 PASSIVE AND ACTIVE SEISMIC MONITORING

As shown in Figure E.I-12, the digitization hardware for the BuriedArray geophones and hydrophones includes Sigma3 24-bit delta-sigma digitizers, and a 5G Cradlepoint antenna with a Cradlepoint 5 GB MBA-3 router, powered by a 200 W solar panel with a charge controller for a 24-volt power supply (with battery backup). The power supply and router would also serve as power and telemetry for the GNSS system. Figure E.I-13 illustrates the surface expression of a BuriedArray station, with an enclosure that will provide protection for the power supply, digitization and telemetry hardware, GNSS sensor, and InSAR corner reflectors.

FIGURE E.I-12. SOLAR PANEL WITH DIGITIZATION AND TELEMETRY HARDWARE

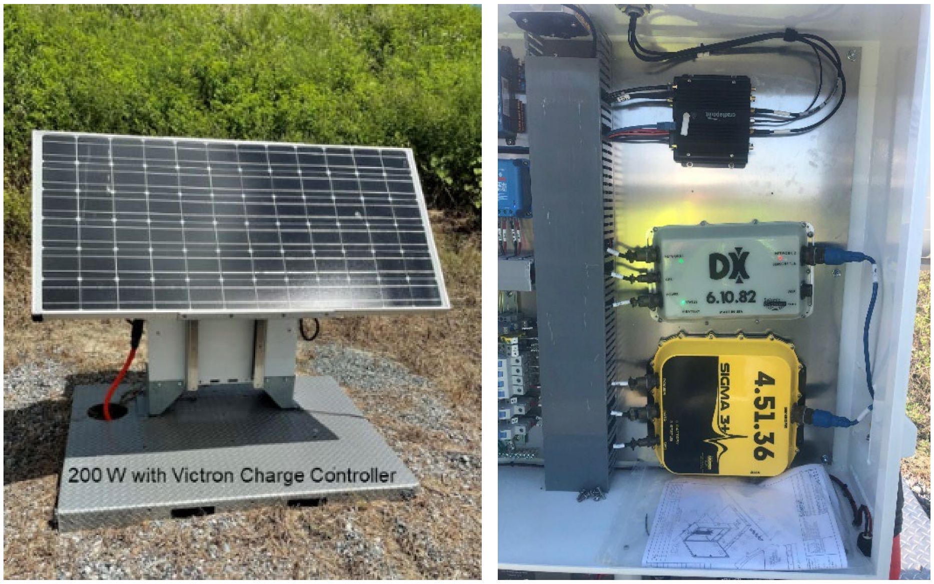


FIGURE E.I-13. SURFACE EQUIPMENT WITH ENCLOSURE

E.I.2.9.4.2 GNSS

Each GNSS station will use the same power supply and telemetry systems deployed for the BuriedArray stations at which they are co-located and will have similar enclosures illustrated in Figure E.I-12 and E.I-13 above.

E.I.2.9.4.3 INSAR

Certain conditions, such as heavy vegetation, may reduce the density of measurement points obtained through InSAR analysis. To ensure point coverage throughout a desired area of interest, corner reflectors (CRs) can be installed and co-location of CRs with other monitoring data, such as GNSS, wellbore or seismic monitoring stations, can provide calibration points between different datasets. CRs will be installed for two purposes as part of the monitoring program at the Montezuma site.

1. Following the acquisition of the baseline, MC or specialty contractor will assess the natural reflector point coverage and determine whether any CRs are required for optimal spatial coverage of the AoR. Recommendations on the number and location of CRs installed for spatial density will be provided following the baseline analysis.
2. TREA will collocate an array of CRs with monitoring instrumentation collected in other components of the Montezuma MMV program. 55 CRs will be installed in close proximity to boreholes planned as part of the comprehensive monitoring program. 4.5-inch helical piles will be installed, on top of which the corner reflector will be mounted and oriented to the satellite orbits. A subset of these CRs will also be co-located with GNSS stations. Together, these datasets will provide robust spatial and temporal correlation of the various acquisition techniques.

E.I.2.9.5 VALIDITY LIMITS AND OPERATING CONDITIONS

E.I.2.9.5.1 PASSIVE AND ACTIVE SEISMIC MONITORING

The BuriedArray seismic monitoring system is designed to work 24/7, irrespective of environmental conditions (i.e., rain-or-shine, day or night). The solar panel power supply has full battery back-up, with sufficient power for both the BuriedArray digitization and telemetry, and the GNSS array stations (the InSAR system does not require power). In the event of a failure at any station, a site visit will be undertaken to determine the source of the failure, and to effect repairs as needed. The BuriedArray is designed with sufficient redundancy to continue effective monitoring operations with as many as 10% of the stations being offline.

Biannual preventative maintenance site visits will take place to minimize instances of equipment failure. These visits would take approx. seven days in total, including travel days for two people. Field personnel would be qualified to inspect and service all elements of the monitoring system, including BuriedArray, InSAR and GNSS systems.

E.I.2.9.5.2 GNSS

The GNSS monitoring system is also designed to work 24/7, irrespective of environmental conditions, and shares its power supply and telemetry backbone with the BuriedArray seismic monitoring system. Station health is monitored continuously, and any outages or anomalous reports will trigger a site visit to determine the source of the failure, and to effect repairs as needed. The biannual preventative maintenance site visits described above would include inspections of all equipment at each station, including GNSS receivers.

E.I.2.9.5.3 INSAR

The InSAR monitoring system works 24/7, irrespective of environmental conditions and requires no power, consequently it is the most operationally robust system. The biannual preventative maintenance site visits described above would include inspections of all equipment at each station, including corner reflector towers.

E.I.2.10 DATA MANAGEMENT

E.I.2.10.1.A DATA MANAGEMENT SCHEME

MC or a designated contractor will maintain the required project data as provided elsewhere in the permit. Data will be backed up on secure servers. Montezuma Carbon or a designated contractor will ensure all raw data from the monitoring systems recorded on-site (i.e., BuriedArray and GNSS) are sent via the common telemetry backbone to a Cloud-based storage server, where they can be accessed by the appropriate, authorized entity for processing and analysis. InSAR data will be loaded to the same Cloud-based server separately, and all data will be available to any other entity authorized by MC (e.g., LBNL, UC Berkeley) for independent analysis and processing.

E.I.2.10.2.B RECORDKEEPING AND TRACKING PRACTICES

All records of gathered data will be securely held and properly labeled for auditing purposes. System health reports will be produced on a daily, weekly, and monthly basis with increasing levels of detail, and will also be available via the Cloud-based server.

E.I.2.10.3.C DATA HANDLING EQUIPMENT/PROCEDURES

All equipment used to store data will be properly maintained and operated according to data management industry best-practice protocols. MC IT system and vendor data acquisition systems will interface with one another, and all data will be stored on a secure Cloud-based server.

E.I.2.10.4.D RESPONSIBILITY

The primary MC project managers will be responsible for ensuring proper data management is maintained. Subcontractors will comply with MC data management protocols to ensure data integrity.

E.I.2.10.5.E DATA ARCHIVAL AND RETRIEVAL

All data will be held by MC, maintained, and stored for auditing purposes as described in Section E.I.2.10.1.A.

E.I.2.10.6.F HARDWARE AND SOFTWARE CONFIGURATIONS

All hardware and software configurations will be appropriately interfaced, and system health reports will be generated as described in Section E.I.2.10.2.B.

E.I.2.10.7.G CHECKLISTS AND FORMS

Processed images and project reports (separate from the system health reports) will be produced on a weekly, monthly, and yearly basis, and will be available to anyone with authorized access to the project Sharepoint site. These reports will be separate from the "Traffic Light" reports communicated directly to the injection operations team, for real-time decision-making to determine any further actions, including suspension of injection operations, however the "Traffic Light" reports will be included in the project reports.

E.I.3 ASSESSMENT AND OVERSIGHT

E.I.3.1 ASSESSMENTS AND RESPONSE ACTIONS

E.I.3.1.1.A ACTIVITIES TO BE CONDUCTED

After completion of sample analysis, results will be reviewed for QC criteria as noted in section E.I.2.5. If the data quality fails to meet criteria set in section E.I.2.5., samples will be reanalyzed, if still within holding time criteria. If outside of holding time criteria, additional samples may be collected, or sample results may be excluded from data evaluations and interpretations. Evaluation for data consistency will be performed according to procedures described in the US EPA 2009 Unified Guidance (US EPA 2009).

E.I.3.1.2.B RESPONSIBILITY FOR CONDUCTING ASSESSMENTS

Each organization gathering data will be responsible for conducting any internal assessments.

E.I.3.1.3.C ASSESSMENT REPORTING

All assessment information will be handled by each individual organizations project manager outlined in Section E.I.1.1.a/b.

E.I.3.1.3.D CORRECTIVE ACTION

All corrective action affecting only an individual organization's data collection responsibility will be addressed, verified, and documented by the individual project managers and communicated to the other project managers as necessary. Corrective actions affecting multiple organizations will be addressed by all members of the project leadership and communicated to other members on the distribution list for the QASP. Assessments may require integration of information from multiple monitoring sources across organizations (operational, in-zone monitoring, above-zone monitoring) to determine whether correction actions are required and/or the most cost-efficient and effective action to implement. MC will coordinate multiorganization assessments and corrective actions as warranted.

E.I.3.2 REPORTS TO MANAGEMENT

E.I.3.2.1.A/B QA STATUS REPORTS

QA status reports are not expected to be needed for this project. Any changes to testing and monitoring techniques will require a review and update according to the QASP in consultation with the US EPA. Revised QASPs will be distributed by MC to the full distribution list provided.

E.I.4 DATA VALIDATION AND USABILITY

E.I.4.1 DATA REVIEW, VERIFICATION, AND VALIDATION

E.I.4.1.1.A CRITERIA FOR ACCEPTING, REJECTING, OR QUALIFYING DATA

Data review, verification, and validation of field and laboratory data for the above confining zone groundwater, injection zone groundwater, and soil vapor/gas samples will be performed by Trihydro or its qualified designee through review of documentation of field procedures and comparison of the field measurements to the entire sample set. Data validation will be completed to determine if any data outliers are present and if there are explanations for the outliers. Knowing the limitations of the data is critical when interpreting site data. Qualified data may be usable so long as the data limitations are considered. Professional judgment may be required during the data validation process. An US EPA Level 2 data validation will be performed on the laboratory data according to US EPA guidelines. The objective of data validation is to identify any unreliable or invalid laboratory measurements and qualify those data for interpretive use. Laboratory data validation is reported by using data qualifiers and adjusting reporting limits as necessary (US EPA 2020b, US EPA 2020c, and Trihydro Data Validation Variance Documentation, March 2023).

E.I.4.2 VERIFICATION AND VALIDATION METHODS

E.I.4.2.1.A DATA VERIFICATION AND VALIDATION PROCESSES

Precision

Precision is the amount of scatter or variance that occurs in repeated measurements. Precision acceptance and rejection for the project will be based on the RPDs of the field and laboratory duplicates. When both values of the field/duplicate pair are greater than five times the reporting limit (RL) for a given analyte, analytical results for the duplicate samples will be evaluated using RPD. RPD is obtained by dividing the absolute value difference between the field and duplicate samples by the average of the two measurements and multiplying by 100 to convert the value to percent. RPD will be calculated as follows:

$$RPD(\%) = \frac{100(A - B)}{C}$$

Where:

A	=	analyte concentration determined analytically from the primary sample
B	=	the analyte concentration determined analytically from the duplicate sample
C	=	the average analyte concentration determined analytically from the primary and duplicate samples

When field duplicate analysis results for a given analyte exceed 30% RPD for aqueous samples and 25% RPD for gas samples, and the field sample and duplicate sample results are greater than five times their respective RLs, the results will be considered estimated (unless site-specific conditions indicate a high degree of heterogeneity is expected in the measured parameter).

Accuracy

Accuracy is the degree of agreement of a measurement or an average of measurements with an accepted reference or true value and is a measure of bias in the system. The accuracy of a measurement system is affected by errors introduced through the sampling process, field contamination, preservation, handling, sample matrix, sample preparation, and analytical techniques.

Accuracy acceptance or rejection will be based on the percent recovery (%R) of the laboratory MS and the LCS. To determine accuracy, the %R for each MS and LCS will be compared to the acceptable range as specified in the applicable laboratory method and/or US EPA data validation guidelines. Accuracy will be evaluated using the %R calculated using the following equation:

$$\%R = \frac{100(A - B)}{C}$$

Where:

A	=	the target analyte concentration determined analytically from the spiked sample
B	=	the background level determined by a separate analysis of the non-spiked sample
C	=	the concentration of spike added

Field sample results associated with MS %Rs and/or LCS %Rs outside of control limits will be considered as estimated or will be rejected, as appropriate, in accordance with US EPA criteria.

Although accuracy of the field program cannot be assessed quantitatively, sample handling, shipping, preservation, and holding time will be used for a qualitative accuracy assessment for this project. Laboratory accuracy will be assessed quantitatively through the analyses of MS/MSD samples, LCS/LCSD samples, standard reference materials, and surrogate spikes (organic analyses only).

Representativeness

The objective in addressing representativeness is to assess whether measurements obtained during the investigation reflect site conditions in the sampling unit or target area. Representativeness is evaluated by review of sampling design to confirm that areas reasonably suspected to have different characteristics were sampled separately. Representativeness will be examined after sample data have undergone data validation.

The systematic sampling design will help to ensure a data set that fully represents the conditions at the site. If data gaps are identified following the completion of the initial sampling, such that additional data are needed to acquire a fully representative data set, additional sampling and analysis will be planned for and completed.

Completeness

The objective in addressing completeness is to assess whether enough data have been collected and are valid to meet the project's requirements and goals. Completeness is evaluated by comparing the number of valid sample results to the number of samples collected and will be calculated as follows:

$$Percent\ Complete(\%) = \frac{100n_A}{n_I}$$

Where:

n_A	=	the actual number of valid analytical results obtained
n_I	=	the theoretical number of results obtainable under ideal conditions

The completeness target goal for this project is 90% or higher.

E.I.4.2.2.B DATA VERIFICATION AND VALIDATION RESPONSIBILITY

Trihydro or its designated subcontractor will verify and validate groundwater and soil gas sampling data.

E.I.4.2.3.C ISSUE RESOLUTION PROCESS AND RESPONSIBILITY

MC or its designated coordinator will overview the groundwater data handling, management, and assessment process. Staff involved in these processes will consult with the coordinator to determine actions required to resolve issues.

E.I.4.2.4.D CHECKLIST, FORMS, AND CALCULATIONS

Checklists and forms will be developed specifically to meet permit requirements.

E.I.4.3 RECONCILIATION WITH USER REQUIREMENTS

E.I.4.3.1.A EVALUATION OF DATA UNCERTAINTY

Data uncertainty will be considered by methods based on the US EPA 2009 Unified Guidance (US EPA 2009).

E.I.4.3.2.B DATA LIMITATIONS REPORTING

The organization-level project managers will be responsible for ensuring that data developed by their respective organizations is presented with the appropriate data-use limitations.

E.I.5 REFERENCES

API 2017, Manual of Petroleum Measurement Standards Chapter 14-Natural Gas Fluids Measurement, Section 1-Collecting and Handling of Natural Gas Samples for Custody Transfer, American Petroleum Institute, Washington, DC, Seventh Edition May 2016, Addendum August 2017, Errata August 2017

ASTM 2017, Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens, ASTM G1-03(2017)e1, ASTM International, West Conshohocken, PA, 2017

Atekwana, E. A. and R.V. Krishnamurthy, 1998. Seasonal variations of dissolved inorganic carbon and $\delta^{13}C$ of surface waters: application of a modified gas evolution technique. Journal of Hydrology, - Mar 1998 Vol. 205, No. 3, pgs. 265-278; https://ui.adsabs.harvard.edu/abs/1998JHyd..205..265A

EPA. 2009. Statistical analysis of groundwater monitoring data at RCRA facilities, Unified Guidance. EPA 530/R-09-007. March 2009.

EPA. 2020a. Review of field duplicates were conducted according to the US EPA Region 1 – New England Environmental Data Review Supplement for Region 1 Data Review Elements and Superfund Specific Guidance/Procedures, EQADR-Supllmenet2, September 2020.

EPA. 2020b. Data for organic analyses were evaluated according to validation criteria set forth in the USEPA CLP National Functional Guidelines for Organic Superfund Methods Data Review. EPA-540-R-20-005. November.

EPA. 2020c. Data for inorganic analyses were evaluated according to validation criteria set forth in the USEPA CLP National Functional Guidelines for Inorganic Superfund Methods Data Review EPA-542-R-20-006. November.

GPA 2017, Obtaining Natural Gas Sample for Analysis by Gas Chromatography, GPA Midstream Standard 2166-17, GPA Midstream Association, Tulsa, OK, 2017

NACE. 2018. Preparation, Installation, Analysis, and Interpretation of Corrosion Coupons in Oilfield Operations, NACE Standard SP0775-2018-SG, Association for Materials Protection and Performance (formerly NACE International), Houston, TX, 2018

Trihydro Data Validation Variance Documentation, March 2023

APPENDIX E.1-1

ABOVE CONFINING ZONE GROUNDWATER SAMPLING FIELD METER MANUALS

YSI Environmental

YSI®

YSI 556 MPS
Multi Probe System

Operations Manual

Contents

1. Safety

1.1 General Information

Read all safety information in this manual carefully before using the YSI 556 Multi-Probe System (MPS). Reagents that are used to calibrate and check this instrument may be hazardous to your health. Take a moment to review Appendix D Health and Safety.

⚠ **WARNING**

Warnings are used in this manual when misuse of the instrument could result in death or serious injury to a person.

⚠ **CAUTION**

Cautions are used in this manual when misuse of the instrument could result in mild or serious injury to a person and/or damage to equipment.

⚠ **IMPORTANT SAFETY INSTRUCTIONS!**

⚠ **SAVE THESE INSTRUCTIONS!**

⚠ In essence, the most important safety rule for use of the YSI 556 MPS is to utilize the instrument ONLY for purposes documented in this manual. This is particularly true of the YSI 6117 rechargeable battery pack that contains nickel metal hydride (NiMH) batteries. The user should be certain to read all of the safety precautions outlined below before using the instrument.

⚠ Batteries

⚠This instrument is powered by alkaline or optional nickel-metal hydride batteries, which the user must remove and dispose of when the batteries no longer power the instrument. Disposal requirements vary by country and region, and users are expected to understand and follow the battery disposal requirements for their specific locale.

The circuit board in this instrument contains a manganese dioxide lithium "coin cell" battery that must be in place for continuity of power to memory devices on the board. This battery is not user serviceable or replaceable.

When appropriate, an authorized YSI service center will remove this battery and properly dispose of it, per service and repair policies.

⚠YSI Rechargeable Battery Pack Safety Information

⚠Restrictions on Usage

1. Never dispose of the battery pack in a fire.
2. Do not attempt to disassemble the YSI 6117 battery pack
3. Do not tamper with any of the electronic components or the batteries within the battery pack. Tampering with either the electronic circuitry or the batteries will result in the voiding of the warranty and the compromising of the system performance, but, more importantly, can cause safety hazards which result from overcharging such as overheating, venting of gas, and loss of corrosive electrolyte.
4. Do not charge the battery pack outside the 0–40°C temperature range.
5. Do not use or store the battery at high temperature, such as in strong direct sunlight, in cars during hot weather, or directly in front of heaters.
6. Do not expose the battery pack to water or allow the terminals to become damp.
7. Avoid striking or dropping the battery pack. If the pack appears to have sustained damage from these actions or malfunctions after an impact or drop, the user should not attempt to repair the unit. Instead, contact YSI Customer Service. Refer to *Appendix E Customer Service.*
8. If the battery pack is removed from the YSI 556 MPS, do not store it in pockets or packaging where metallic objects such as keys can short between the positive and negative terminals.

⚠Precautions for Users with Small Children.

Keep the battery pack out of reach of babies and small children.

⚠Danger Notifications – Misuse creates a STRONG possibility of death or serious injury.

FAILURE TO CAREFULLY OBSERVE THE FOLLOWING PROCEDURES AND PRECAUTIONS CAN RESULT IN LEAKAGE OF BATTERY FLUID, HEAT GENERATION, BURSTING, AND SERIOUS PERSONAL INJURY.

1. Never dispose of the battery pack in a fire or in heat.
2. Never allow the positive and negative terminals of the battery pack to become shorted or connected with electrically conductive materials. When the battery pack has been removed from the YSI 556 MPS, store it in a heavy plastic bag to prevent accidental shorting of the terminals.
3. Never disassemble the battery pack and do not tamper with any of the electronic components or the batteries within the battery pack. The battery pack is equipped with a variety of safety features. Accidental deactivation of any of these safety features can cause a serious hazard to the user.
4. The NiMH batteries in the battery pack contain a strong alkaline solution (electrolyte). The alkaline solution is extremely corrosive and will cause damage to skin or other tissues. If any fluid from the battery pack comes in contact with a user’s eyes, immediately flush with clean water and consult a physician immediately. The alkaline solution can damage eyes and lead to permanent loss of eyesight.

⚠ Warning Notifications – Misuse creates a possibility of death or serious injury

1. Do not allow the battery pack to contact freshwater, seawater, or other oxidizing reagents that might cause rust and result in heat generation. If a battery becomes rusted, the gas release vent may no longer operate and this failure can result in bursting.
2. If electrolyte from the battery pack contacts the skin or clothing, thoroughly wash the area immediately with clean water. The battery fluid can irritate the skin.

⚠ Caution Notifications – Misuse creates a possibility of mild or serious injury or damage to the equipment.

1. Do not strike or drop the battery pack. If any impact damage to the battery pack is suspected, contact YSI Customer Service. Refer to *Appendix E Customer Service*.

2. Store the battery pack out of reach of babies and small children.
3. Store the battery pack between the temperatures of -20 and 30°C.
4. Before using the battery pack, be sure to read the operation manual and all precautions carefully. Then store this information carefully to use as a reference when the need arises.

⚠ YSI 616 Cigarette Lighter Charger Safety Information

1. This section contains important safety and operating instructions for the YSI 556 MPS cigarette lighter battery charger (YSI 616; RadioShack Number 270-1533E). BE SURE TO SAVE THESE INSTRUCTIONS.
2. Before using the YSI 616 cigarette lighter charger, read all instructions and cautionary markings on battery charger, battery pack, and YSI 556 MPS.
3. Charge the YSI 6117 battery pack with the YSI 616 cigarette lighter charger ONLY when the YSI 6117 is installed in the YSI 556 MPS.
4. Do not expose charger to rain, moisture, or snow.
5. Use of an attachment not recommended or sold by the battery charger manufacturer may result in a risk of fire, electric shock, or injury to persons.
6. To reduce risk of damage to cigarette lighter and cord, pull by cigarette lighter rather than cord when disconnecting charger.
7. Make sure that the cord is located so that it will not be stepped on, tripped over, or otherwise subjected to damage or stress.
8. Do not operate charger with damaged cord or cigarette lighter connector – replace it immediately.
9. Do not operate charger if it has received a sharp blow, been dropped, or otherwise damaged in any way; contact YSI Customer Service. Refer to *Appendix E Customer Service*.
10. Do not disassemble charger other than to change the fuse as instructed. Replace the part or send it to YSI Product Service if repair is required (refer to *Appendix E Customer Service*). Incorrect reassembly may result in a risk of electric shock or fire.

11. To reduce risk of electric shock, unplug charger before attempting any maintenance or cleaning. Turning off controls will not reduce this risk.

⚠ YSI 556 MPS Water Leakage Safety Information

The YSI 556 MPS has been tested and shown to comply with IP67 criterion, i.e. submersion in 1 meter of water for 30 minutes with no leakage into either the battery compartment or the main case. However, if the instrument is submersed for periods of time in excess of 30 minutes, leakage may occur with subsequent damage to the batteries, the rechargeable battery pack circuitry, and/or the electronics in the main case.

If leakage into the battery compartment is observed when using alkaline C cells, remove batteries, dispose of batteries properly, and dry the battery compartment completely, ideally using compressed air. If corrosion is present on the battery terminals, contact YSI Customer Service for instructions. Refer to *Appendix E Customer Service*.

If leakage into the battery compartment is observed when using the YSI rechargeable battery pack, remove the battery assembly and set aside to dry. Return the battery pack to YSI Product Service for evaluation of possible damage. Finally dry the battery compartment completely, ideally using compressed air. If corrosion is present on the battery terminals, contact YSI Customer Service for instructions. Refer to *Appendix E Customer Service*.

⚠ **CAUTION:** If water has contacted the rechargeable battery pack, do not attempt to reuse it until it has been evaluated by YSI Product Service (refer to Appendix E Customer Service). Failure to follow this precaution can result in serious injury to the user.

If it is suspected that leakage into the main cavity of the case has occurred, remove the batteries immediately and return the instrument to YSI Product Service for damage assessment. Refer to *Appendix E Customer Service*.

⚠ **CAUTION:** Under no circumstances should the user attempt to open the main case.

2. General Information

2.1 Description

The rugged and reliable YSI 556 MPS (Multi-Probe System) combines the versatility of an easy-to-use, easy-to-read handheld unit with all the functionality of a multi-parameter system. Featuring a waterproof, impact-resistant case, the YSI 556 MPS simultaneously measures dissolved oxygen, conductivity, temperature, and optional pH and ORP. A simple cellular phone style keypad and large display make the instrument easy to use. The YSI 556 MPS is compatible with YSI EcoWatch™ for Windows™ software.

The YSI 556 MPS assists the user in conforming to Good Laboratory Practice (GLP) standards which help ensure that quality control/quality assurance methods are followed. Battery life is displayed with a fuel gauge, and the user can choose standard alkaline batteries or an optional rechargeable battery pack.

The 1.5 MB memory can store more than 49,000 data sets. Other options include a flow cell and barometer. The internal barometer can be user-calibrated and displayed along with other data, used in dissolved oxygen calibrations, and logged to memory for tracking changes in barometric pressure.

Features

- Waterproof -meets IP67 specifications
- Field-replaceable DO electrode module; pH and pH/ORP sensors
- Compatible with EcoWatch™ for Windows™ data analysis software
- Assists with Good Laboratory Practice Standards (GLP)
- Choice of DO membrane material for different applications
- Easy-to-use, screw-on cap DO membranes
- User-upgradeable software from YSI website
- Three-year warranty on the instrument; one-year on the probe modules
- Available with 4,10, and 20 m cable lengths
- Stores over 49,000 data sets, time and date stamped

- Auto temperature compensating display contrast
- Optional barometer
- Optional rechargeable battery pack or standard alkaline batteries

2.2 Unpacking the Instrument

1. Remove the instrument from the shipping box. Note that the probe module and sensors are shipped in a separate box and will be unpacked later in Section *3.2 Unpacking the Probe Module*

   NOTE: Do not discard any parts of supplies.

2. Use the packing list to ensure all items are present.

3. Visually inspect all components for damage.

   NOTE: If any parts are missing or damaged, contact your YSI Service Center immediately. Refer to Appendix E Customer Service or www.ysi.com.

2.3 Features of the YSI 556 Multi-Probe System

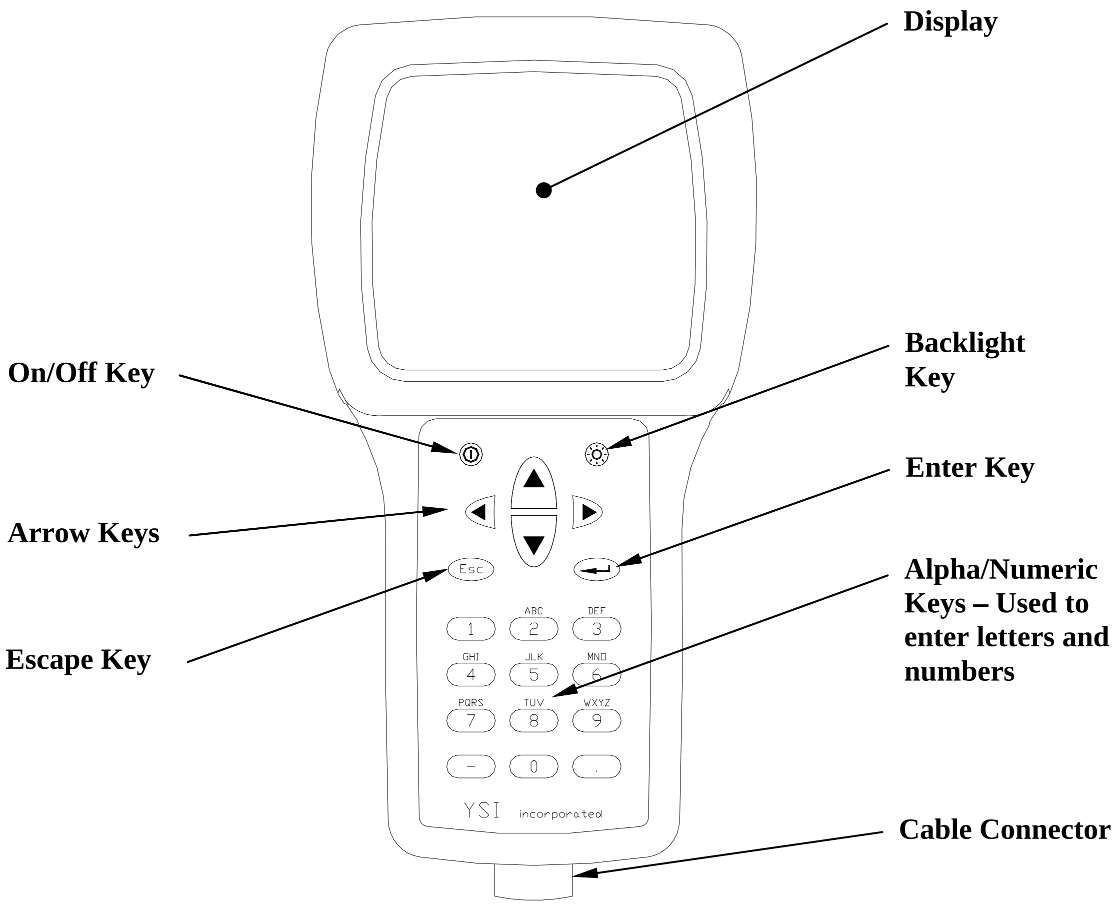


Figure 2.1 Front View of YSI 556 MPS

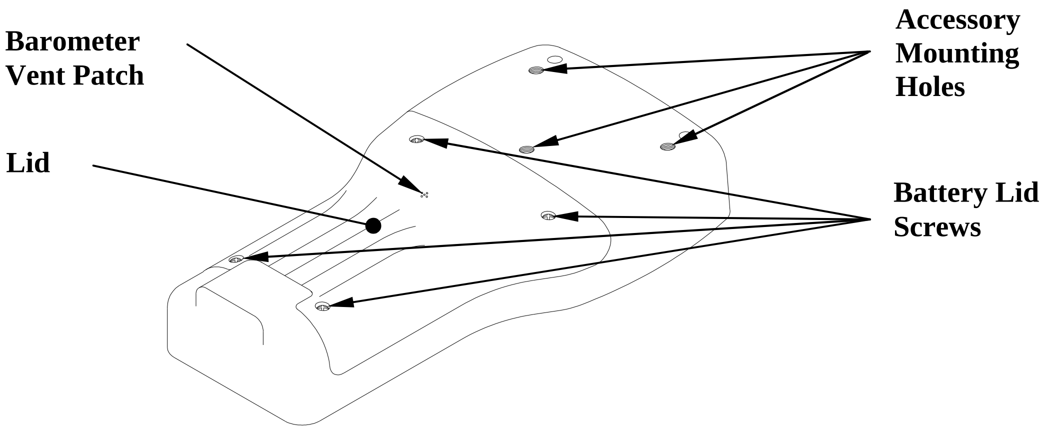


Figure 2.2 Back View of YSI 556 MPS

2.4 Batteries

2.4.1 Battery Life

Standard Alkaline Batteries

With the standard battery configuration of 4 alkaline C cells, the YSI 556 MPS will operate continuously for approximately 180 hours. Assuming a standard usage pattern when sampling of 3 hours of "on time" in a typical day, the alkaline cells will last approximately 60 days.

Optional Rechargeable Battery Pack

When fully charged, the optional rechargeable battery pack will provide approximately 50 hours of battery life.

2.4.2 Inserting 4 C Batteries

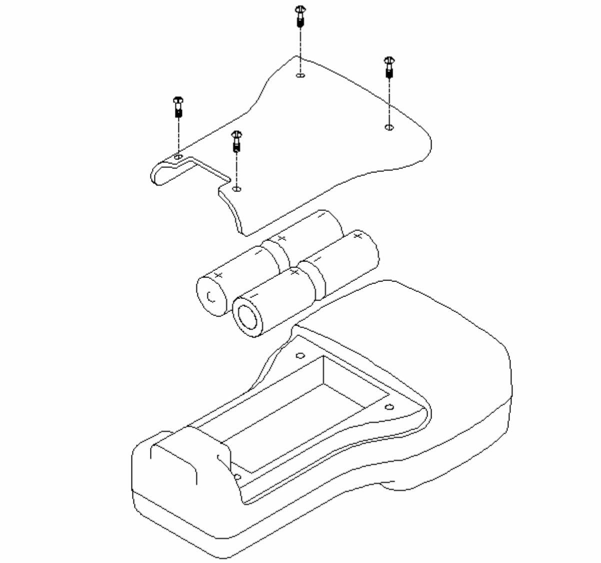


Figure 2.1 Inserting C Cells

⚠ **CAUTION: Install batteries properly to avoid damage to the instrument**.

1. Loosen the four screws in the battery lid on the back of the instrument using any screwdriver.
2. Remove the battery lid.
3. Insert four C batteries between the clips following the polarity (+ and -) labels on the bottom of the battery compartment.
4. Check gasket for proper placement on the battery lid.
5. Replace the battery lid and tighten the 4 screws securely and evenly.

NOTE: Do not over-tighten the screws.

2.4.3 Inserting Optional Rechargeable Battery Pack

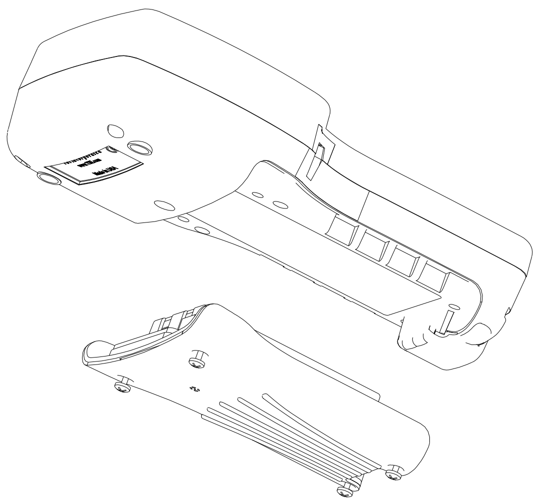


Figure 2.2 Inserting Battery Pack

⚠ **CAUTION: Read all cautions and warning that come with the battery pack before using the battery pack.**

1. Loosen the four screws in the battery lid on the back of the instrument using any screwdriver.

2. Remove the C battery lid and store for future use. Remove C batteries, if installed.

3. Install the rechargeable battery pack and lid and tighten the 4 screws securely and evenly.

NOTE: Do not over tighten the screws.

2.4.4 Charging the Optional Rechargeable Battery Pack

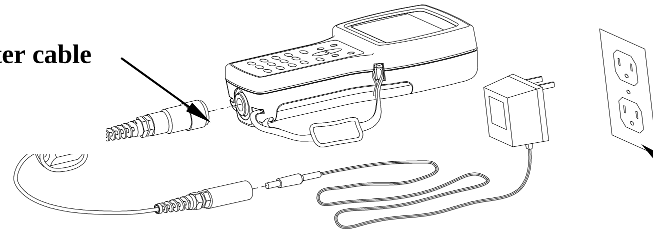


Figure 2.3 Charging the Battery Pack

⚠ **CAUTION: Do not use or store the battery pack at extreme temperatures such as in strong direct sunlight, in cars during hot weather or close to heaters.**

1. Install the rechargeable battery pack into the instrument as described in Section *2.4.3 Inserting Optional Rechargeable Battery Pack.*

2. Attach the charger adapter cable (YSI 6119) to the instrument.

NOTE: Wall power supplies for use in countries outside the US and Canada can be found in *Appendix B Instrument Accessories.*

3. Insert the barrel connector of the wall power supply into the barrel of the adapter cable.

⚠ **CAUTION: Do not charge the battery pack continuously for more than 48 hours.**

⚠ **CAUTION: Do not drop or expose to water.**

⚠ **CAUTION: Do no charge the battery pack at temperatures below 0°C or above 40°C.**

4. Plug the wall power supply into an AC power outlet for approximately 2 hours to obtain an 80% to 90% charge for 6 hours to get a full charge.

NOTE: The battery pack can be recharged whether the instrument is on or off.

2.4.5 Storing the Battery Pack

Remove the battery pack from the instrument when the instrument will not be used for extended periods of time to prevent over discharge of the battery pack.

Store the battery pack in a heavy plastic bag to prevent accidental shorting of the terminals. Store between –20 and 30°C.

2.4.6 Optional Cigarette Lighter Charger

⚠ **CAUTION: Read all warnings and cautions that come with the charger before using the charger.**

⚠ **CAUTION: Only use cigarette lighter charger when rechargeable battery pack is inserted into instrument.**

⚠ **CAUTION: Do not mishandle cigarette lighter charger. Do not expose to moisture.**

1. Plug the barrel connector of the cigarette lighter charger into the mating end of the YSI 6119 Charger Adapter Cable.
2. Attach the MS-19 end of the YSI 6119 Charger Adapter Cable to the instrument.
3. Make one of the following modifications to the other end of the charger:

Slide the adapter ring off the plug to use the device with an American or Japanese vehicle.

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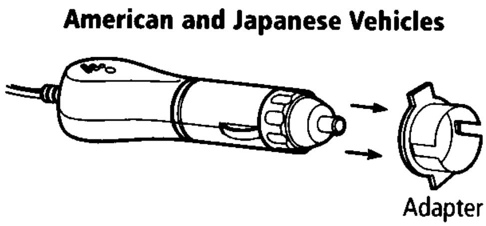


Figure 2.1 Charger Plug Adapter Use

Leave the adapter ring on the plug and position it so that the slots on the adapter ring line up with the plug's spring clips to use the device on a European vehicle.

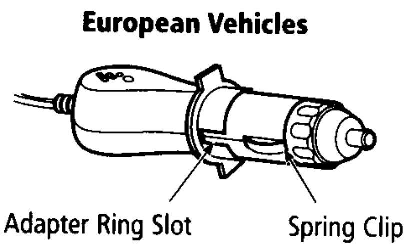


Figure 2.2 European Charger Plug Adapter Use

NOTE: If the charger stops working properly, refer to Section 13 *Troubleshooting.*

2.5 Power On

Press and release the on/off button in the upper left corner of the instrument keypad to turn the instrument on or off. See Figure2.1 Front View of YSI 556 MPS.

2.6 Setting Display Contrast

The display contrast automatically compensates for temperature changes. However, under extreme temperature conditions you may wish to optimize the display by manual adjustment as follows:

1. Press and *hold down* the backlight key in the upper right corner of the keypad and press the "up" arrow to increase (darken) the contrast.

2. Press and *hold down* the backlight key in the upper right corner of the keypad and press the "down" arrow to decrease (lighten) the contrast.

2.7 Backlight

Press and *release* the backlight key in the upper right corner of the keypad to turn the backlight on or off. See Figure 2.1 Front View of YSI 556 MPS.

NOTE: The backlight turns off automatically after two minutes of non-use.

2.8 General Screen Features

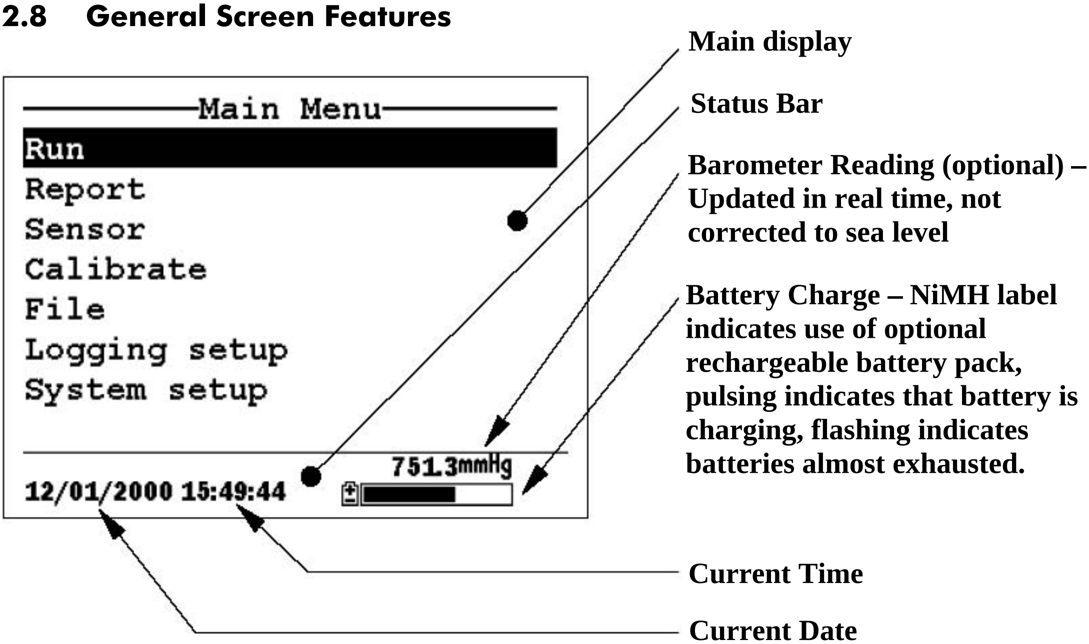


Figure 2.4 Main Screen Menu

2.9 Keypad Use

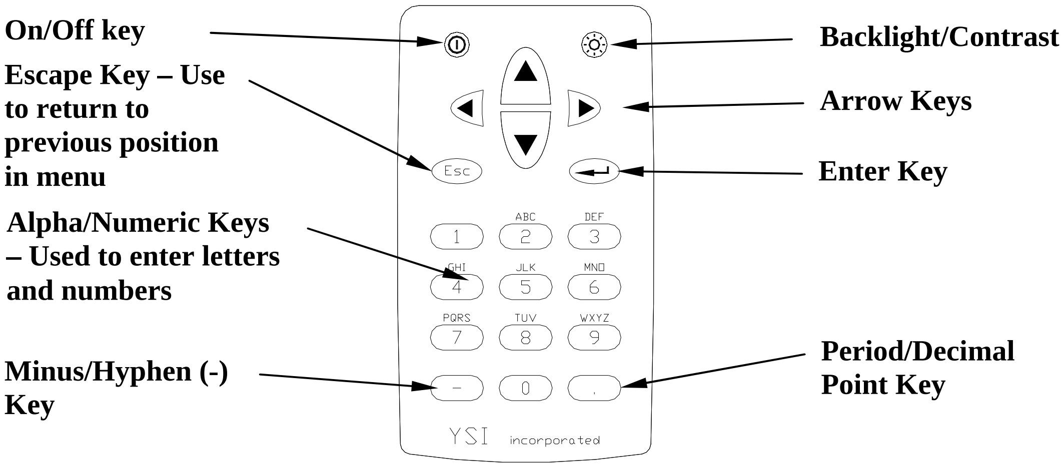


Figure 2.5 Keypad Features

KEY	LETTER/NUMBER
1	1
2	ABC2abc3
3	DEF3def3
4	GHI4ghi4
5	JKL5jkl5
6	MNO6mno6
7	PQRS7pqrs7
8	TUV8tuv8
9	WXYZ9wxyz9
0	0

Figure 2.6 Keypad Features

1. See Figure 2.10 Keypad Letters & Numbers and press the appropriate key repeatedly until letter or number desired appears in display.

NOTE: Press the key repeatedly in rapid succession to get to the desired letter or number. If you pause for more than a second, the cursor automatically scrolls to the right to prepare for the next input.

EXAMPLE 1: Press the **6** key *once* and *release* to display an uppercase "M".

EXAMPLE 2: Press the **6** key *four times* and *release* to display the number "6".

EXAMPLE 3: Press the **6** key *five times* and *stop* to display a lowercase "m".

2. Press the left arrow key to go back and reenter a number or setter that needs to be changed.

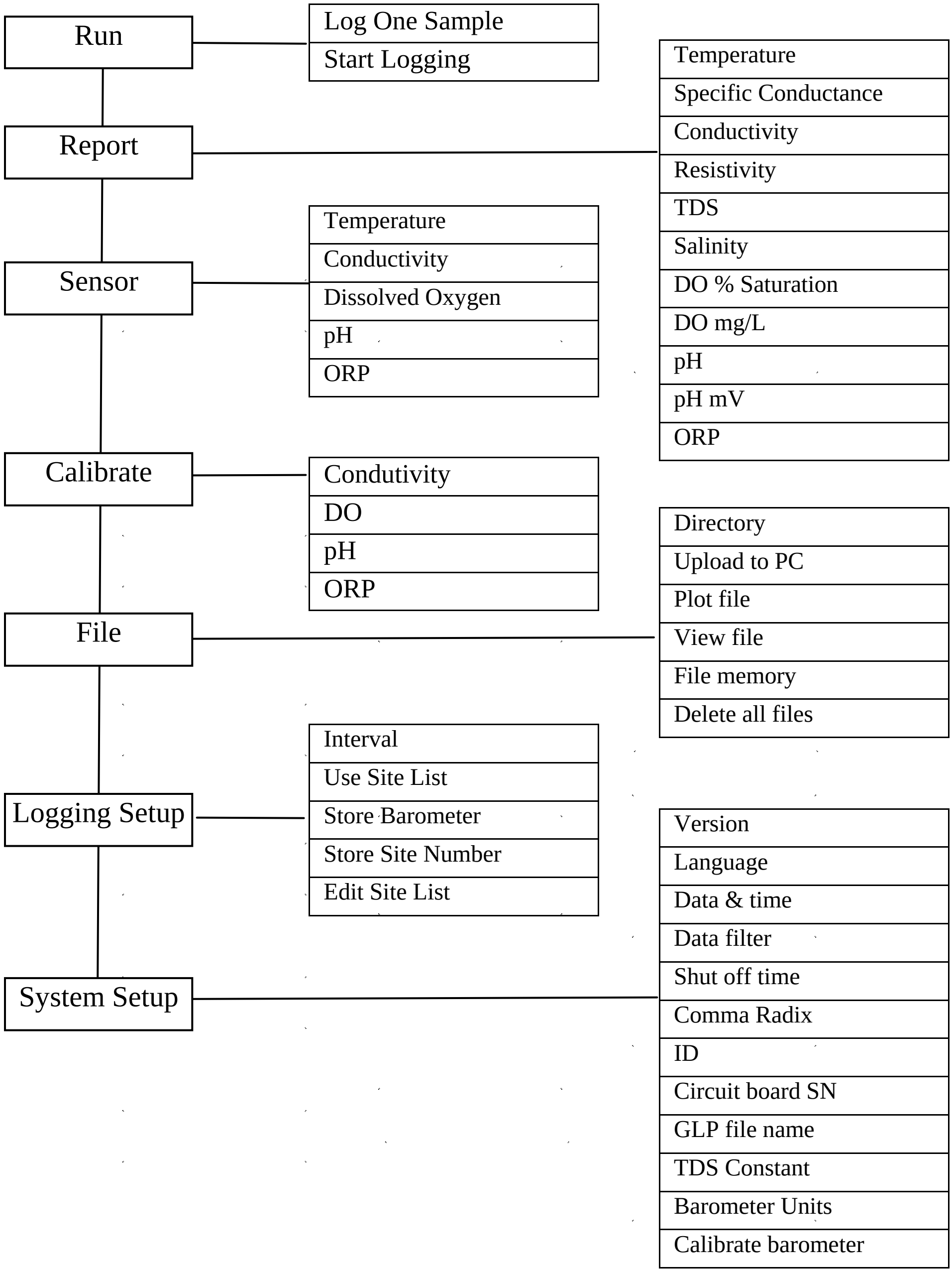
   Press the **Enter** key when your entry is complete.

   NOTE: The instrument software permits only numeric entries in many instances, such as when setting the clock or entering calibration parameters.

2.10 Instrument Reset

The YSI 556 MPS is characterized by sophisticated software that should provide trouble-free operation. However, as with all high-capability software packages, it is always possible that the user will encounter circumstances in which the instrument does not respond to keypad entry. If this occurs, the instrument function can easily be restored by removing and then reapplying battery power. Simply remove either your C-cells or rechargeable battery pack from the battery compartment, wait 30 seconds and then replace the batteries. See Section *2.4 Batteries* for battery removal/reinstallation instructions.

2.11 Menu Flowchart



3. Probe Module

3.1 Introduction

The YSI 5563 Probe module is used for measuring dissolved oxygen, temperature, conductivity, and optional pH and ORP. The probe module is rugged, with the sensors enclosed in a heavy duty probe sensor guard with attached sinking weight. A 4, 10 or 20 meter cable is directly connected to the probe module body making it waterproof. An MS-19 connector at the end of the cable makes the YSI 5563 fully compatible with the YSI 556 Multi-Probe System.

3.2 Unpacking the Probe Module

1. Remove the YSI 5563 Probe Module from the shipping boxes.

   NOTE: Do not discard any parts or supplies.

2. Use the packing list to ensure all items are present.

3. Visually inspect all components for damage.

NOTE: If any parts are missing or damaged, contact a YSI representative immediately. Refer to: *Appendix E Customer Service* o visit www.ysi.com.

3.3 Features of the YSI 5563 Probe Module

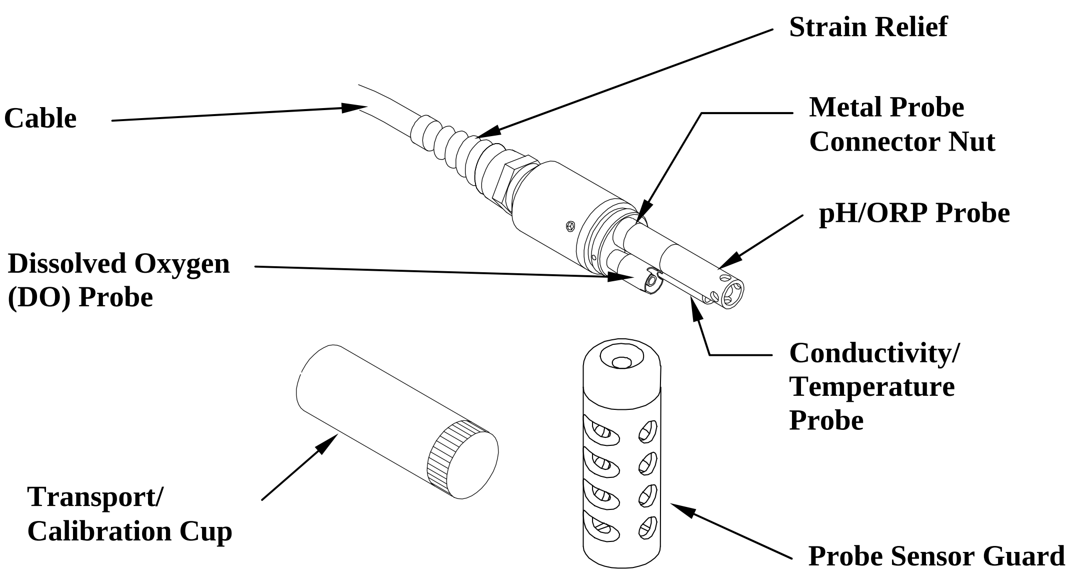


Figure 3.1 Probe Module

3.4 Preparing the Probe Module

To prepare the probe module for calibration and operation, you need to install the sensors into the connectors on the probe module bulkhead. In addition to sensor installation, you need to install a new DO membrane cap.

3.4.1 Sensor Installation

Whenever you install, remove or replace a sensor, it is extremely important that the entire probe module and all sensors be thoroughly dried prior to the removal of a sensor or a sensor port plug. This will prevent water from entering the port. Once you remove a sensor or plug, examine the connector inside the probe module sensor port. If any moisture is present, use compressed air to completely dry the connector. If the connector is corroded, return the probe module to your YSI Distributor or directly to YSI Customer Service. Refer to *Appendix E Customer Service*.

Conductivity/Temperature and pH, pH/ORP Sensor Installation

1. Unscrew and remove the probe sensor guard.

2. Using the sensor installation tool supplied in the YSI 5511 maintenance kit, unscrew and remove the sensor port plugs.

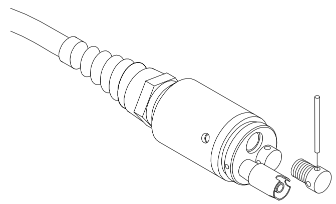


Figure 3.2 Port Plug Removal

3. Locate the port with the connector that corresponds to the sensor that is to be installed.

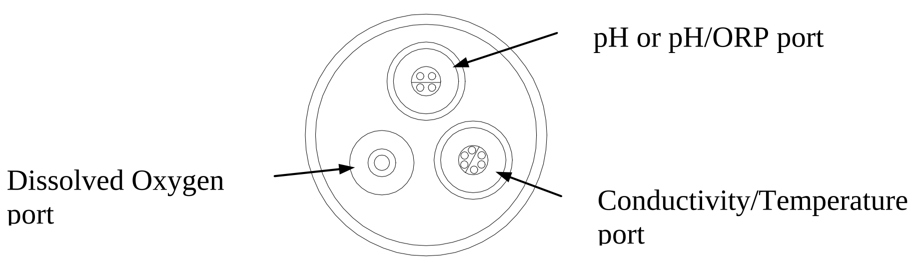


Figure 3.3 Sensor Port Identification

4. Apply a thin coat of o-ring lubricant (supplied in the YSI 5511 maintenance kit) to the o-rings on the connector side of the sensor (see Figure 3.4 O-ring Lubrication).

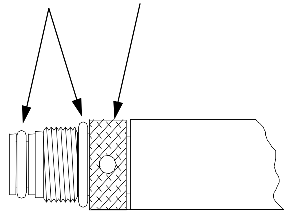


Figure 3.4 O-ring Lubrication

⚠ **CAUTION:** Make sure that there are NO contaminants between the o-ring and the sensor. Contaminants that are present under the o-ring may cause the o-ring to leak.

5. Be sure the probe module sensor port is free of moisture and then insert the sensor into the correct port. Gently rotate the sensor until the two connectors align.

6. With the connectors aligned, screw down the sensor nut using the sensor installation tool.

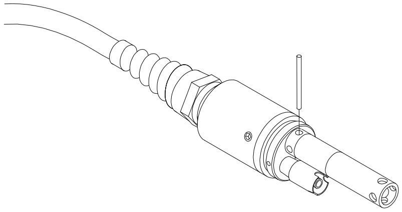


Figure 3.5 Sensor Installation

⚠ **CAUTION:** Do not cross thread the sensor nut. Tighten the nut until it is flush with the face of the probe module bulkhead. Do not over tighten.

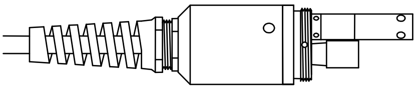


Figure 3.6 Bulkhead Seating

7. Repeat steps 3-6 for any other sensors.

8. Replace the probe sensor guard.

Dissolved Oxygen Sensor Installation

The YSI 5563 comes with the DO sensor already installed. Refer to Section *11.1.2 DO Sensor Replacement* for instructions on installing the YSI 559 Replaceable DO Module Kit.

3.4.2 Membrane Cap Selection

The YSI 5563 is shipped with a YSI 5909 kit that contains membrane caps made with 2 mil polyethylene (PE), a material which should be ideal for most field applications of the 556. However, YSI also offers membrane caps made with two other materials (1 mil polyethylene and 1 mil Teflon) which some users may also prefer. All membranes available for the 556/5563 system provide comparable accuracy if used properly. The difference between the two thicknesses of PE is found in the trade-off of flow dependence and response time as described below. Teflon is offered because some users may prefer to continue using the traditional membrane material used by YSI. To avoid confusion, the membrane caps are color coded as described below and can be ordered in kits as noted:

1 mil Teflon – Black Caps (Kit = YSI 5906)
1 mil Polyethylene (PE) – Yellow Caps (Kit = YSI 5908)
2 mil Polyethylene (PE) – Blue Caps (Kit = YSI 5909)

The 1 mil Teflon caps will offer traditional, reliable performance for most dissolved oxygen applications. The 1 mil PE caps will provide a significantly faster dissolved oxygen response (as long as your 556 Data Filter is set correctly as described below in Sections 10.2 and 10.3.1) while also giving readings which are significantly less flow dependent than the 1 mil Teflon caps. Finally, 2 mil PE caps will show a large reduction in flow dependence over 1 mil Teflon while not significantly increasing the response time. Generally, one of the PE caps is likely to provide better performance for your application.

IMPORTANT: No matter which type of membrane cap you select, you will have to confirm your selection in the 556 software from the Sensor menu as described in Section *4 Sensors*.

3.4.3 Membrane Cap Installation

NOTE: The YSI 5563 DO sensor (already installed in the probe module) was shipped dry. A shipping membrane was installed to protect the electrode. **A new membrane cap must be installed before the first use.**

1. Unscrew and remove the probe sensor guard.
2. Unscrew, remove, and discard the old membrane cap.
3. Thoroughly rinse the sensor tip with distilled water.
4. Prepare the electrolyte according to the directions on the electrolyte solution bottle.
5. Hold the new membrane cap and fill it at least ½ full with the electrolyte solution.
6. Screw the membrane cap onto the sensor moderately tight. A small amount of electrolyte should overflow.

⚠ **Caution:** Do not touch the membrane surface.

7. Screw the probe sensor guard on moderately tight.

3.5 Transport/Calibration Cup

The YSI 5563 Probe module has been supplied with a convenient transport/calibration cup. This cup is an ideal container for calibration of the different sensors, minimizing the amount of solution needed. Refer to Section *6 Calibrate*.

3.5.1 Transport/Calibration Cup Installation

1. Remove probe sensor guard, if already installed.

2. Ensure that an o-ring is installed in the o-ring groove on the threaded end of the probe module body.

3. Screw the transport/calibration cup on the threaded end of the probe module and securely tighten.

   NOTE: Do not over tighten as this could cause damage to the threaded portions.

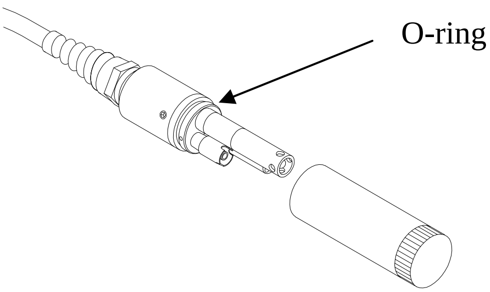


Figure 3.7 Transport/Calibration Cup Installation

3.6 Instrument/Cable Connection

Attach the cable to the instrument as follows:

1. Line up the pins and guides on the cable with the holes and indentations on the cable connector at the bottom of the YSI 556 instrument. See Figure 2.1 Front View of YSI 556 MPS.

2. Holding the cable firmly against the cable connector, turn the locking mechanism clockwise until it snaps into place.

Remove the cable from the instrument by turning the cable connector counterclockwise until the cable disengages from the instrument.

4. Sensors

The Sensors screen allows the user to enable or disable each of the sensors and select which membrane material will be used for the dissolved oxygen sensor. Disabled sensors will not be displayed on the screen in real time or logged to files.

1. Press the **On/off** key to display the run screen.

2. Press the **Escape** key to display the main menu screen.

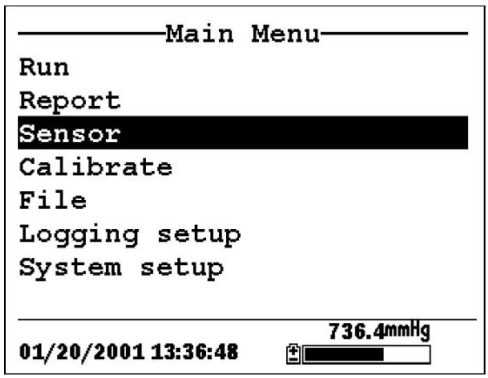


Figure 4.1 Main Menu Screen

3. Use the arrow keys to highlight the **Sensor** selection.

4. Press the **Enter** key to display the sensors enabled screen.

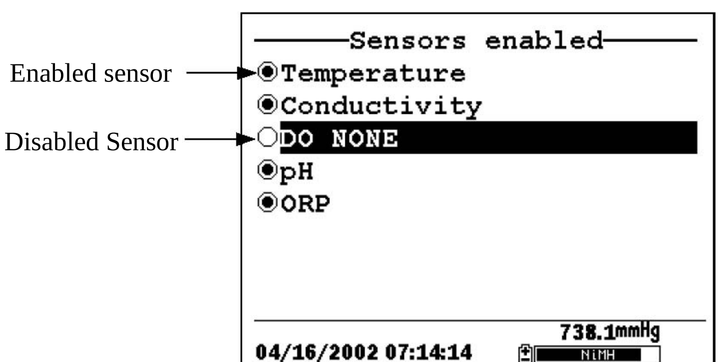


Figure 4.2 Sensors Enabled Screen Before DO Membrane Selection

A black dot to the left of a sensor indicates that sensor is enabled. Sensors with an empty circle are disabled.

Highlight the "DO None" entry as shown above and press **Enter** to display the membrane choice screen. Consult Section *3.4.2 Membrane Cap Selection* for information on the advantages of each type of membrane material. Blue membrane caps using 2 mil polyethylene (PE) were shipped with your YSI 5563 and are likely to be the best choice for most 556 field applications.

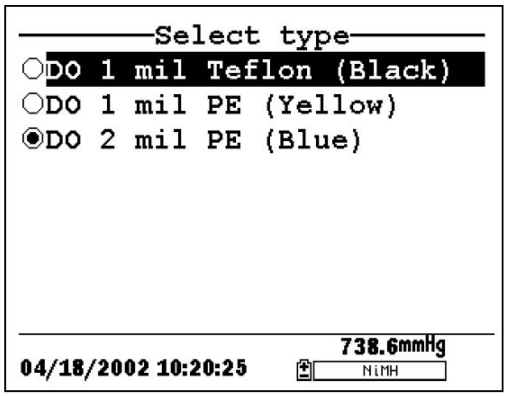


Figure 4.3 Membrane Selection Screen

Highlight the desired membrane choice – in this case, 2 mil PE - and press Enter to activate your selection with a dot to the left of the screen. Then press **Escape** to return to the Sensor menu that now shows your DO membrane selection.

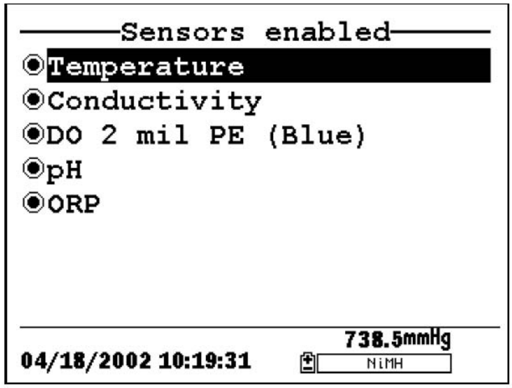


Figure 4.4 Sensors Enabled Screen After DO Membrane Selection

NOTE: The Temperature sensor cannot be disabled. Most other sensors require temperature compensation for accurate readings. In addition, the conductivity sensor must be activated in order to obtain accurate dissolved oxygen mg/L readings.

5. Use the arrow keys to highlight the sensor you want to change, then press the Enter key to enable or disable it.

6. Repeat step 5 for each sensor you want to change.

7. Press the Escape key to return to the main menu screen.

5. Report

The Report Setup screen allows the user to select which sample parameters and units the YSI 556 MPS will display on the screen. It does NOT determine which parameters are logged to memory. Refer to Section *4 Sensors.*

1. Press the **On/off** key to display the run screen.

2. Press the **Escape** key to display the main menu screen.

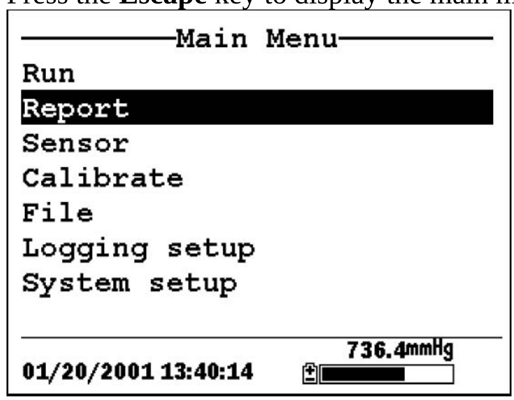


Figure 5.1 Main Menu

3. Use the arrow keys to highlight the **Report** selection.

4. Press the **Enter** key to display the report setup screen.

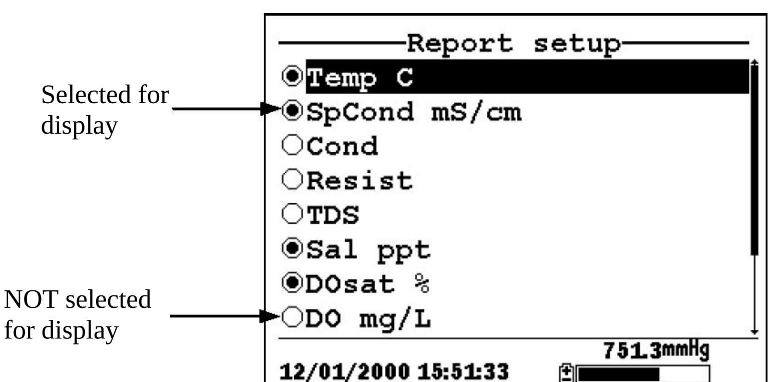


Figure 5.2 Report Setup Screen

NOTE: A black dot to the left of a parameter indicates that parameter is selected for display. Parameters with an empty circle will not be displayed.

NOTE: You may have to scroll down past the bottom of the screen to see all the parameters.

5. Use the arrow keys to highlight the parameter you want to change, then press the **Enter** key. If you can't find the parameter you want, even after scrolling down past the bottom of the screen, the sensor used for that parameter is disabled. Refer to Section *4 Sensors*.

6. If you selected Temperature, Specific Conductivity, Conductivity, Resistance or Total Dissolved Solids, the Units screen will appear.

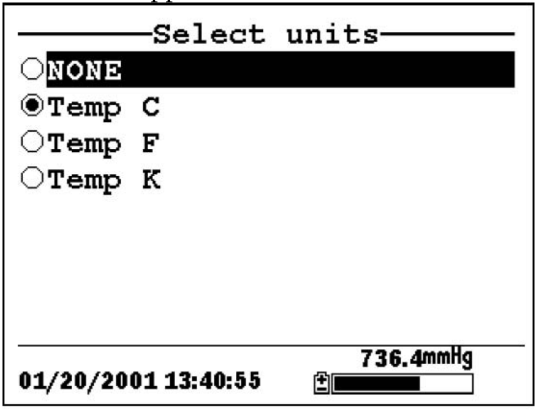


Figure 5.3 Units Screen

7. Use the arrow keys to select the units desired, then press the **Enter** key to return to the report setup screen.

8. Repeat steps 5 and 6 for each parameter you want to change.

NOTE: Specific Conductance (temperature compensated conductivity) is notated on the Run screen with a small 'c' after the units of measure.

All parameters may be enabled at the same time.

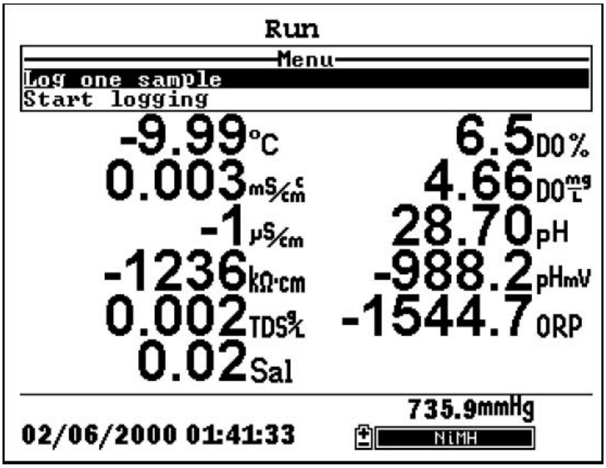


Figure 5.4 All Parameters Displayed

9. Press the **Escape** key to return to the Main menu screen.

6. Calibrate

All of the sensors, except temperature, require periodic calibration to assure high performance. You will find specific calibration procedures for all sensors that require calibration in the following sections. If a sensor listed is not installed in your probe module, skip that section and proceed to the next sensor until the calibration is complete.

⚠ **CAUTION:** Reagents that are used to calibrate and check this instrument may be hazardous to your health. Take a moment to review *Appendix D Health and Safety*. Some calibration standard solutions may require special handling.

6.1 Getting Ready to Calibrate

6.1.1 Containers Needed to Calibrate the Probe Module

The transport/calibration cup that comes with your probe module serves as a calibration chamber for all calibrations and minimizes the volume of calibration reagents required.

Instead of the transport/calibration cup, you may use laboratory glassware to perform calibrations. If you do not use the transport/calibration cup that is designed for the probe module, you are cautioned to do the following:

- ✓ Perform all calibrations with the Probe Sensor Guard installed. This protects the sensors from possible physical damage.
- ✓ Use a ring stand and clamp to secure the probe module body to prevent the module from falling over. Most laboratory glassware has convex bottoms.
- ✓ Ensure that all sensors are immersed in calibration solutions. Many of the calibrations factor in readings from other sensors (e.g., temperature sensor). The top vent hole of the conductivity sensor must also be immersed during some calibrations.

6.1.2 Calibration Tips

1. If you use the Transport/Calibration Cup for dissolved oxygen (DO) calibration, make certain to loosen the seal to allow pressure equilibration before calibration. The DO calibration is a water-saturated air calibration.

2. When calibrating pH, always calibrate with buffer 7 first, regardless if performing a 1, 2, or 3 point calibration

3. The key to successful calibration is to ensure that the sensors are completely submersed when calibration values are entered. Use recommended volumes when performing calibrations.

4. For maximum accuracy, use a small amount of previously used calibration solution to pre-rinse the probe module. You may wish to save old calibration standards for this purpose.

5. Fill a bucket with ambient temperature water to rinse the probe module between calibration solutions.

6. Have several clean, absorbent paper towels or cotton cloths available to dry the probe module between rinses and calibration solutions. Shake the excess rinse water off of the probe module, especially when the probe sensor guard is installed. Dry off the outside of the probe module and probe sensor guard. Making sure that the probe module is dry reduces carry-over contamination of calibrator solutions and increases the accuracy of the calibration.

7. If you are using laboratory glassware for calibration, you do not need to remove the probe sensor guard to rinse and dry the sensors between calibration solutions. The inaccuracy resulting from simply rinsing the sensor compartment and drying the outside of the guard is minimal.

8. If you are using laboratory glassware, remove the stainless steel weight from the bottom of the probe sensor guard by turning the weight counterclockwise. When the weight is removed, the calibration solutions have access to the sensors

without displacing a lot of fluid. This also reduces the amount of liquid that is carried between calibrations.

9. Make certain that port plugs are installed in all ports where sensors are not installed. It is extremely important to keep these electrical connectors dry.

6.1.3 Recommended Volumes

Follow these instructions to use the transport/calibration cup for calibration procedures.

- ✓ Ensure that an o-ring is installed in the o-ring groove of the transport/calibration cup bottom cap, and that the bottom cap is securely tightened.

  NOTE: Do not over-tighten as this could cause damage to the threaded portions.

- ✓ Remove the probe sensor guard, if it is installed.
- ✓ Remove the o-ring, if installed, from the probe module and inspect the installed o-ring on the probe module for obvious defects and, if necessary, replace it with the extra o-ring supplied.
- ✓ Some calibrations can be accomplished with the probe module upright or upside down. A separate clamp and stand, such as a ring stand, is required to support the probe module in the upside down position.
- ✓ To calibrate, follow the procedures in the next section, Calibration Procedures. The approximate volumes of the reagents are specified below for both the upright and upside down orientations.
- ✓ When using the Transport/Calibration Cup for dissolved oxygen % saturation calibration, make certain that the vessel is vented to the atmosphere by loosening the bottom cap or cup assembly and that approximately 1/8 inch (3 cm) of water is present in the cup.

Sensor to Calibrate	Upright	Upside Down
Conductivity	55ml	55ml
pH/ORP	30ml	60ml

Table 6.1 Calibration Volumes

6.2 Calibration Procedures

6.2.1 Accessing the Calibrate Screen

1. Press the **On/off** key to display the run screen.

2. Press the **Escape** key to display the main menu screen.

3. Use the arrow keys to highlight the **Calibrate** selection.

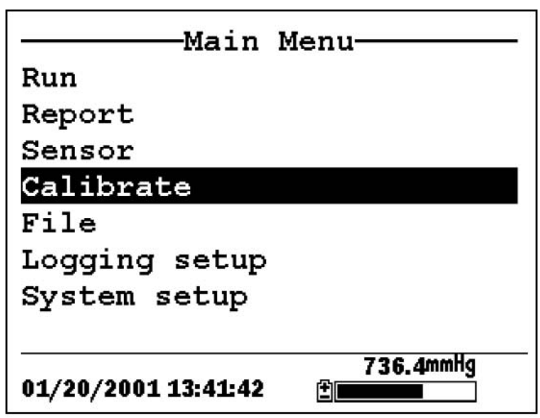


Figure 6.1 Main Menu

4. Press the **Enter** key. The Calibrate screen will be displayed.

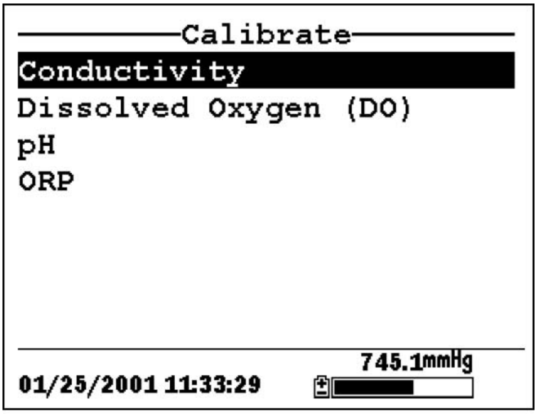


Figure 6.2 Calibrate Screen

6.2.2 Conductivity Calibration

This procedure calibrates specific conductance (recommended), conductivity and salinity. Calibrating any one option automatically calibrates the other two.

1. Go to the calibrate screen as described in Section *6.2.1Accessing the Calibrate Screen.*.

2. Use the arrow keys to highlight the **Conductivity** selection. See Figure 6.2 Calibrate Screen.

3. Press **Enter**. The Conductivity Calibration Screen is displayed.

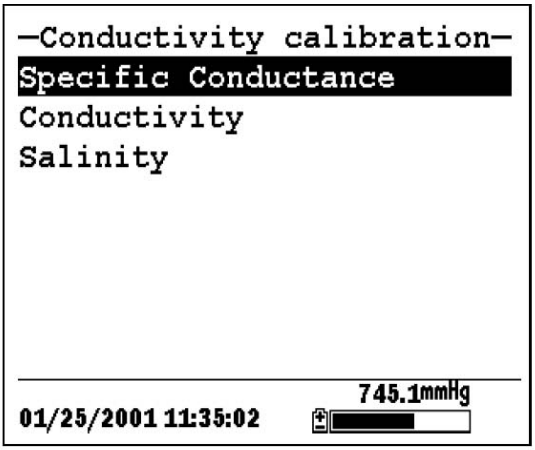


Figure 6.3 Conductivity Calibration Selection Screen

4. Use the arrow keys to highlight the Specific Conductance selection.

5. Press **Enter**. The Conductivity Calibration Entry Screen is displayed.

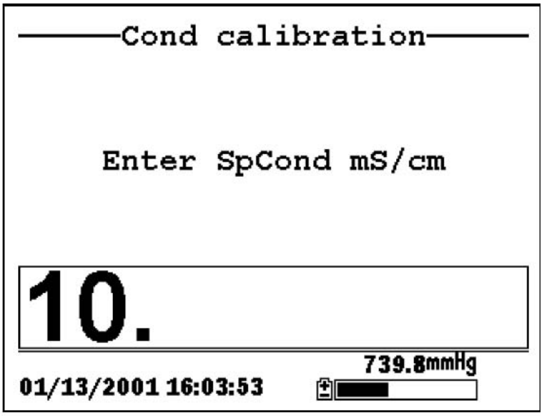


Figure 6.4 Conductivity Calibration Selection Screen

6. Place the correct amount of conductivity standard (see Table 6.1 Calibration Volumes) into a clean, dry or pre-rinsed transport/calibration cup.

⚠ **WARNING**: Calibration reagents may be hazardous to your health. See *Appendix D Health and Safety* for more information.

NOTE: For maximum accuracy, the conductivity standard you choose should be within the same conductivity range as the samples you are preparing to measure. However, we do not recommend using standards less than 1 mS/cm. For example:

- ✓ For fresh water use a 1 mS/cm conductivity standard.
- ✓ For brackish water use a 10 mS/cm conductivity standard.
- ✓ For seawater use a 50 mS/cm conductivity standard.

NOTE: Before proceeding, ensure that the sensor is as dry as possible. Ideally, rinse the conductivity sensor with a small amount of standard that can be discarded. Be certain that you avoid cross-contamination of solutions. Make certain that there are no salt deposits around the oxygen and pH/ORP sensors, particularly if you are employing standards of low conductivity.

7. Carefully immerse the sensor end of the probe module into the solution.

8. Gently rotate and/or move the probe module up and down to remove any bubbles from the conductivity cell.

NOTE: The sensor must be completely immersed past its vent hole. Using the recommended volumes from Table 6.1 Calibration Volumes, should ensure that the vent hole is covered.

9. Screw the transport/calibration cup on the threaded end of the probe module and securely tighten.

NOTE: Do not over tighten as this could cause damage to the threaded portions.

10. Use the keypad to enter the calibration value of the standard you are using.

NOTE: Be sure to enter the value in **mS/cm at 25°C**.

11. Press **Enter**. The Conductivity Calibration Screen is displayed.

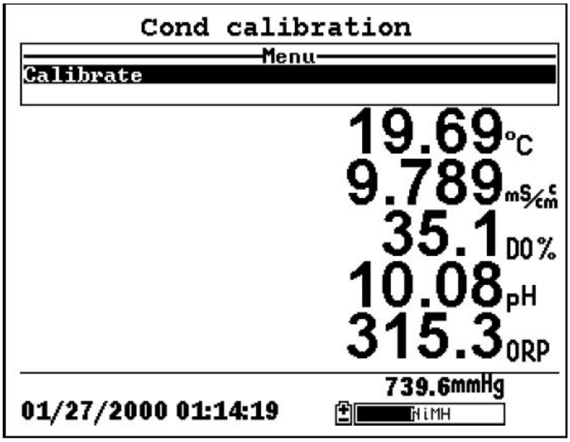


Figure 6.5 Conductivity Calibration Screen

12. Allow at least one minute for temperature equilibration before proceeding. The current values of all enabled sensors will appear on the screen and will change with time as they stabilize.

13. Observe the reading under Specific Conductance. When the reading shows no significant change for approximately 30 seconds, press **Enter**. The screen will indicate that the calibration has been accepted and prompt you to press **Enter** again to Continue.

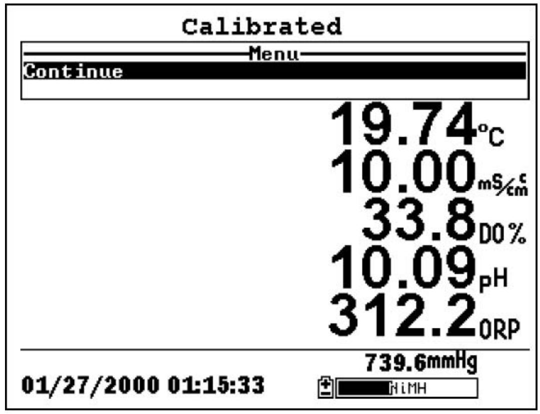


Figure 6.6 Calibrated

14. Press **Enter**. This returns you to the Conductivity Calibrate Selection Screen, See Figure 6.3 Conductivity Calibration Selection Screen..

15. Press **Escape** to return to the calibrate menu. See Figure 6.2 Calibrate Screen .

16. Rinse the probe module and sensors in tap or purified water and dry.

6.2.3 Dissolved Oxygen Calibration

This procedure calibrates dissolved oxygen. Calibrating any one option (% or mg/L) automatically calibrates the other.

1. Go to the calibrate screen as described in Section *6.2.1 Accessing the Calibrate Screen*.

   NOTE: The instrument must be on for at least 10 - 15 minutes to polarize the DO sensor before calibrating.

2. Use the arrow keys to highlight the **Dissolved Oxygen** selection. See Figure 6.2 Calibrate Screen.

3. Press **Enter**. The dissolved oxygen calibration screen is displayed.

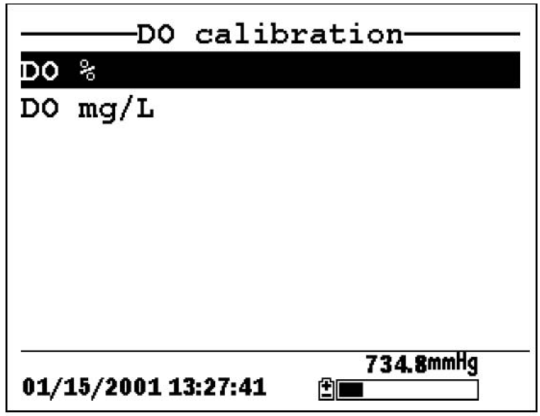


Figure 6.7 DO Calibration Screen

DO Calibration in % Saturation

1. Use the arrow keys to highlight the DO% selection.

2. Press **Enter**. The DO Barometric Pressure Entry Screen is displayed.

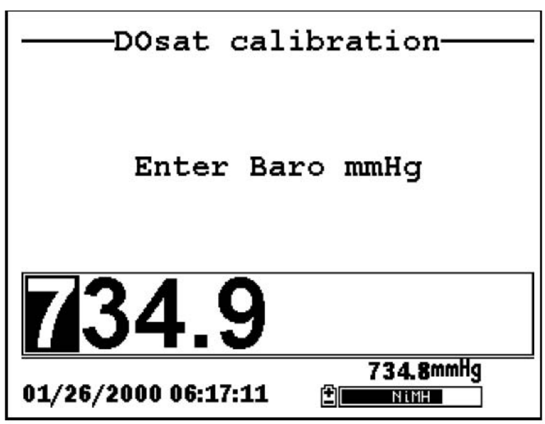


Figure 6.8 DO Barometric Pressure Entry Screen

3. Place approximately 3 mm (1/8 inch) of water in the bottom of the transport/calibration cup.

4. Place the probe module into the transport/calibration cup.

NOTE: Make sure that the DO and temperature sensors are **not** immersed in the water.

5. Engage only 1 or 2 threads of the transport/calibration cup to ensure the DO sensor is vented to the atmosphere.

6. Use the keypad to enter the current local barometric pressure.

NOTE: If the unit has the optional barometer, no entry is required.

NOTE: Barometer readings that appear in meteorological reports are generally corrected to sea level and must be uncorrected before use (refer to Section *10.10 Calibrate Barometer, Step 2*).

7. Press **Enter**. The DO% saturation calibration screen is displayed.

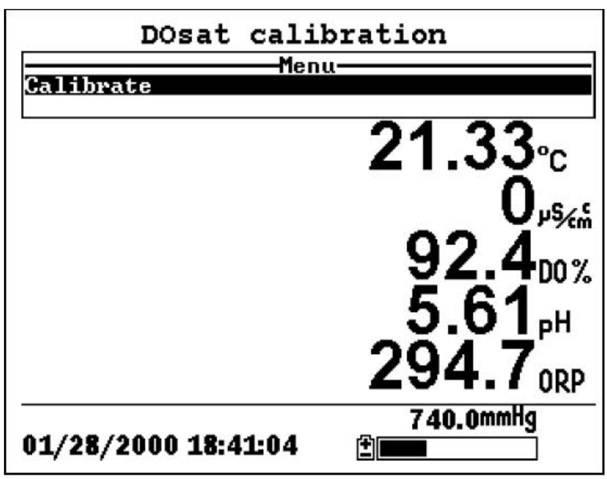


Figure 6.9 DO Sat Calibration Screen

8. Allow approximately ten minutes for the air in the transport/calibration cup to become water saturated and for the temperature to equilibrate before proceeding.

9. Observe the reading under DO %. When the reading shows no significant change for approximately 30 seconds, press **Enter**. The screen will indicate that the calibration has been accepted and prompt you to press **Enter** again to Continue. See Figure 6.6 Calibrated.

10. Press **Enter**. This returns you to the DO calibration screen, See Figure 6.7 DO Calibration Screen.

11. Press **Escape** to return to the calibrate menu. See Figure 6.2 Calibrate Screen.

12. Rinse the probe module and sensors in tap or purified water and dry.

DO Calibration in mg/L

DO calibration in mg/L is carried out in a water sample which has a known concentration of dissolved oxygen (usually determined by a Winkler titration).

1. Go to the DO calibrate screen as described in Section *6.2.3 Dissolved Oxygen Calibration*, steps 1 through 3.

2. Use the arrow keys to highlight the **DO mg/L** selection.

3. Press **Enter**. The DO mg/L Entry Screen is displayed.

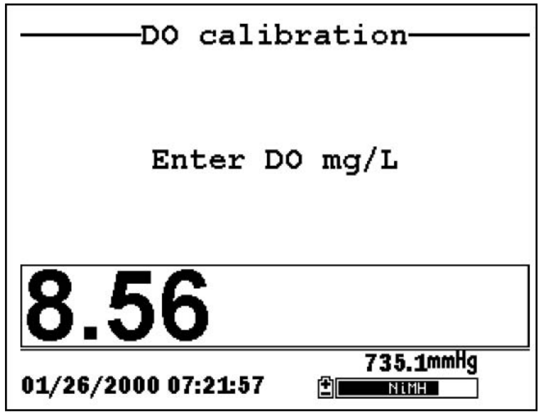


Figure 6.10 DO mg/L Entry Screen

4. Place the probe module in water with a known DO concentration.

NOTE: Be sure to completely immerse all the sensors.

5. Use the keypad to enter the known DO concentration of the water.

6. Press **Enter**. The Dissolved Oxygen mg/L Calibration Screen is displayed.

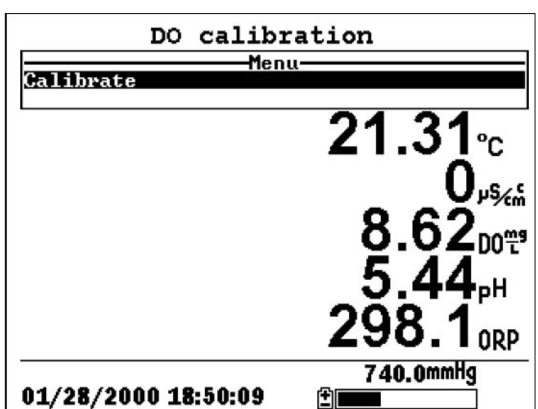


Figure 6.11 DO mg/L Calibration Screen

7. Stir the water with a stir bar, or by rapidly moving the probe module, to provide fresh sample to the DO sensor.

8. Allow at least one minute for temperature equilibration before proceeding. The current values of all enabled sensors will appear on the screen and will change with time as they stabilize.

9. Observe the DO mg/L reading, when the reading is stable (shows no significant change for approximately 30 seconds), press **Enter**. The screen will indicate that the calibration has been accepted and prompt you to press **Enter** again to Continue.

10. Press **Enter**. This returns you to the DO calibration screen. See Figure 6.7 DO Calibration Screen.

11. Press **Escape** to return to the calibrate menu. See Figure 6.2 Calibrate Screen.

12. Rinse the probe module and sensors in tap or purified water and dry.

6.2.4 pH Calibration

1. Go to the calibrate screen as described in *Section 6.2.1 Accessing the Calibrate Screen*.

2. Use the arrow keys to highlight the **pH** selection. See Figure 6.2 Calibrate Screen.

3. Press **Enter**. The pH calibration screen is displayed.

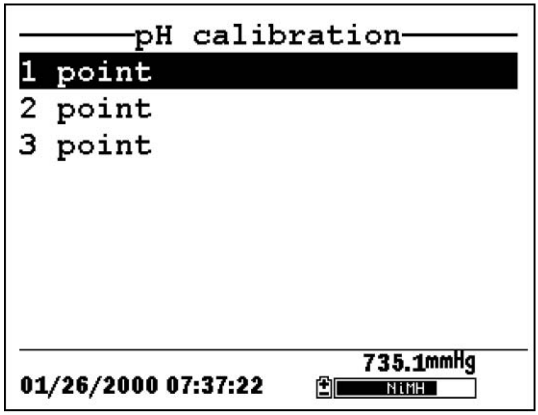


Figure 6.12 pH Calibration Screen

- Select the **1-point** option only if you are adjusting a previous calibration. If a 2-point or 3-point calibration has been performed previously, you can adjust the calibration by carrying out a one point calibration. The procedure for this calibration is the same as for a 2-point calibration, but the software will prompt you to select only one pH buffer.
- Select the **2-point** option to calibrate the pH sensor using only two calibration standards. Use this option if the media being monitored is known to be either basic or acidic. For example, if the pH of a pond is known to vary between 5.5 and 7, a two-point calibration with pH 7 and pH 4 buffers is sufficient. A three point calibration with an additional pH 10 buffer will not increase the accuracy of this measurement since the pH is not within this higher range.
- Select the **3-point** option to calibrate the pH sensor using three calibration solutions. In this procedure, the pH sensor is calibrated with a pH 7 buffer and two additional buffers. The 3-point calibration method assures maximum accuracy when the pH of the media to be monitored cannot be anticipated. The procedure for this calibration is the same as for a 2-point calibration, but the software will prompt you to select a third pH buffer.

4. Use the arrow keys to highlight the **2-point** selection.

5. Press **Enter**. The pH Entry Screen is displayed.

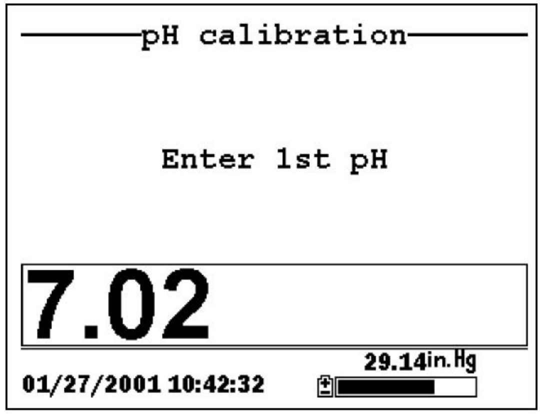


Figure 6.13 pH Entry Screen

6. Place the correct amount (see Table 6.1 Calibration Volumes) of pH buffer into a clean, dry or pre-rinsed transport/calibration cup.

NOTE: Always calibrate with buffer 7 first, regardless if performing a 1, 2, or 3 point calibration.

⚠ **WARNING**: Calibration reagents may be hazardous to your health. See *Appendix D Health and Safety* for more information.

NOTE: For maximum accuracy, the pH buffers you choose should be within the same pH range as the water you are preparing to sample.

NOTE: Before proceeding, ensure that the sensor is as dry as possible. Ideally, rinse the pH sensor with a small amount of buffer that can be discarded. Be certain that you avoid cross-contamination of buffers with other solutions.

7. Carefully immerse the sensor end of the probe module into the solution.

8. Gently rotate and/or move the probe module up and down to remove any bubbles from the pH sensor.

NOTE: The sensor must be completely immersed. Using the recommended volumes from Table 6.1 Calibration Volumes, should ensure that the sensor is covered.

9. Screw the transport/calibration cup on the threaded end of the probe module and securely tighten

NOTE: Do not over tighten as this could cause damage to the threaded portions.

10. Use the keypad to enter the calibration value of the buffer you are using **at the current temperature**.

NOTE: pH vs. temperature values are printed on the labels of all YSI pH buffers.

11. Press **Enter**. The pH calibration screen is displayed.

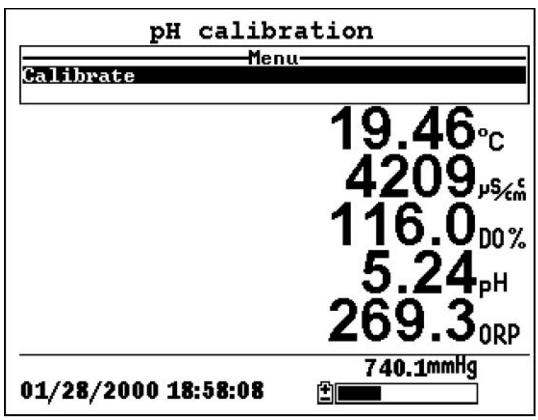


Figure 6.14 pH Calibration Screen

12. Allow at least one minute for temperature equilibration before proceeding. The current values of all enabled sensors will appear on the screen and will change with time as they stabilize.

13. Observe the reading under pH, when the reading shows no significant change for approximately 30 seconds, press **Enter**.

The screen will indicate that the calibration has been accepted and prompt you to press **Enter** again to Continue.

14. Press **Enter**. This returns you to the specified pH Calibration Screen, See Figure 6.13 pH Entry Screen.

15. Rinse the probe module, transport/calibration cup and sensors in tap or purified water and dry.

16. Repeat steps 6 through 13 above using a second pH buffer.

17. Press **Enter**. This returns you to the pH Calibration Screen, See Figure 6.12 pH Calibration Screen.

18. Press **Escape** to return to the calibrate menu. See Figure 6.2 Calibrate Screen.

19. Rinse the probe module and sensors in tap or purified water and dry.

6.2.5 ORP Calibration

1. Go to the calibrate screen as described in Section *6.2.1 Accessing the Calibrate Screen*.

2. Use the arrow keys to highlight the **ORP** selection. See Figure 6.2 Calibrate Screen..

3. Press **Enter**. The ORP calibration screen is displayed.

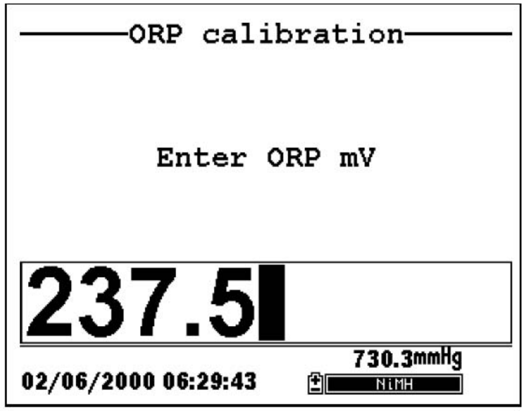


Figure 6.15 Specified ORP Calibration Screen

4. Place the correct amount (see Table 6.1 Calibration Volumes) of a known ORP solution (we recommend Zobell solution) into a clean, dry or pre-rinsed transport/calibration cup.

⚠ **WARNING**: Calibration reagents may be hazardous to your health. See *Appendix D Health and Safety* for more information.

NOTE: Before proceeding, ensure that the sensor is as dry as possible. Ideally, rinse the ORP sensor with a small amount of solution that can be discarded. Be certain that you avoid cross-contamination with other solutions.

5. Carefully immerse the sensor end of the probe module into the solution.

6. Gently rotate and/or move the probe module up and down to remove any bubbles from the ORP sensor.

NOTE: The sensor must be completely immersed. Using the recommended volumes from Table 6.1 Calibration Volumes should ensure that the sensor is covered.

7. Screw the transport/calibration cup on the threaded end of the probe module and securely tighten.

NOTE: Do not over tighten as this could cause damage to the threaded portions.

8. Use the keypad to enter the correct value of the calibration solution you are using at the current temperature. Refer to Table 6.2 Zobell Solution Values.

Temperature °C	Zobell Solution Value, mV
-5	270.0
0	263.5
5	257.0
10	250.5
15	244.0
20	237.5
25	231.0
30	224.5
35	218.0
40	211.5
45	205.0
50	198.5

Table 6.2 Zobell Solution Values

9. Press **Enter**. The ORP calibration screen is displayed.

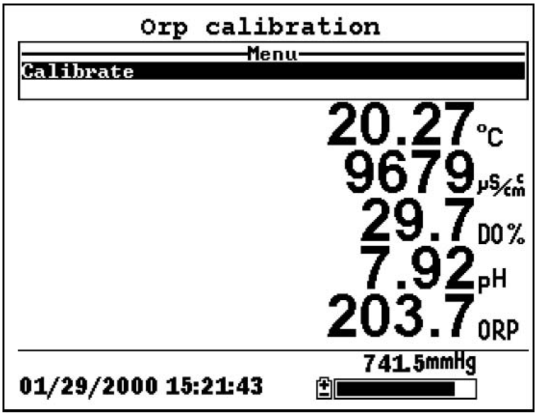


Figure 6.16 DO Cal Screen

10. Allow at least one minute for temperature equilibration before proceeding. The current values of all enabled sensors will appear on the screen and will change with time as they stabilize.

NOTE: Verify that the temperature reading matches the value you used in Table 6.2 Zobell Solution Values.

11. Observe the reading under ORP, when the reading shows no significant change for approximately 30 seconds, press **Enter**. The screen will indicate that the calibration has been accepted and prompt you to press **Enter** again to Continue.

12. Press **Enter**. This returns you to the Calibrate Screen. See Figure 6.2 Calibrate Screen.

13. Rinse the probe module and sensors in tap or purified water and dry.

6.3 Return to Factory Settings.

1. Go to the calibrate screen as described in Section *6.2.1 Accessing the Calibrate Screen*.

2. Use the arrow keys to highlight the **Conductivity** selection. See Figure 6.2 Calibrate Screen.

   NOTE: We will use the Conductivity sensor as an example; however, this process will work for any sensor.

3. Press **Enter.** The Conductivity Calibration Selection Screen is displayed. See Figure 6.3 Conductivity Calibration Selection Screen.

4. Use the arrow keys to highlight the **Specific Conductance** selection.

5. Press **Enter.** The Conductivity Calibration Entry Screen is displayed. See Figure 6.4 Conductivity Calibration Entry Screen.

6. Press and hold the **Enter** key down and press the **Escape** key.

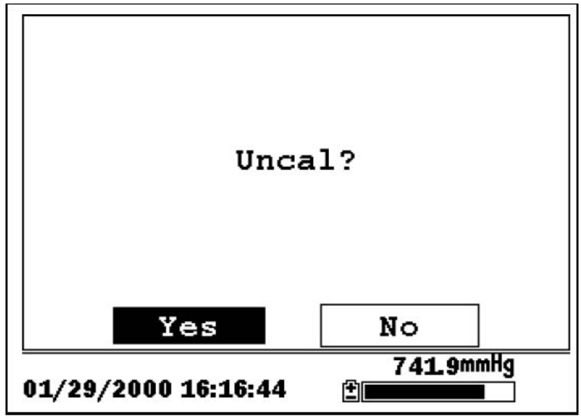


Figure 6.17 ORP Calibration Screen

7. Use the arrow keys to highlight the **YES** selection.

CAUTION: This returns a sensor to the factory settings. For example, in selecting to return specific conductance to the factory setting, salinity and conductivity will automatically return to their factory settings.

8. Press **Enter**. This returns you to the Conductivity Calibrate Selection Screen, See Figure 6.3 Conductivity Calibration Selection Screen. .

9. Press **Escape** to return to the calibrate menu. See Figure 6.2 Calibrate Screen.

7. Run

The Run screen displays data from the sensors in real-time and allows the user to log sample data to memory for later analysis. Refer to Section *9 Logging* for details on logging sample data.

7.1 Real-Time Data

NOTE: Before measuring samples you must prepare the probe module (refer to Section *3.4 Preparing the Probe Module*), attach the probe module to the instrument (refer to Section *3.6 Instrument/Cable Connection*) and calibrate the sensors (refer to Section *6 Calibrate*).

1. Press the On/off key.

OR select Run from the main menu to display the run screen.

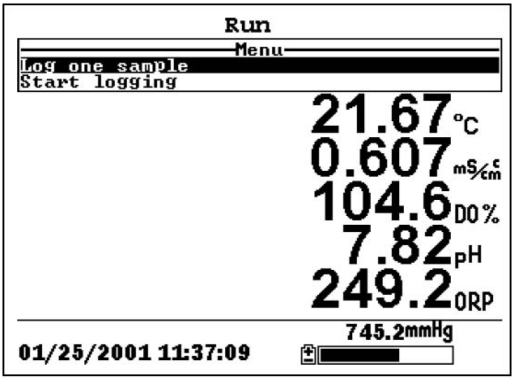


Figure 7.1 Run Screen

2. Make sure the probe sensor guard is installed.

3. Place the probe module in the sample. Be sure to completely immerse all the sensors.

4. Rapidly move the probe module through the sample to provide fresh sample to the DO sensor.

5. Watch the readings on the display until they are stable.

6. Refer to Section *9 Logging* for instructions on logging sample data.

8. File

The File menu allows the user to view, upload or delete sample data and calibration record files stored in the YSI 556 MPS.

8.1 Accessing the File Screen

1. Press the **On/off** key to display the run screen.

2. Press the **Escape** key to display the main menu screen.

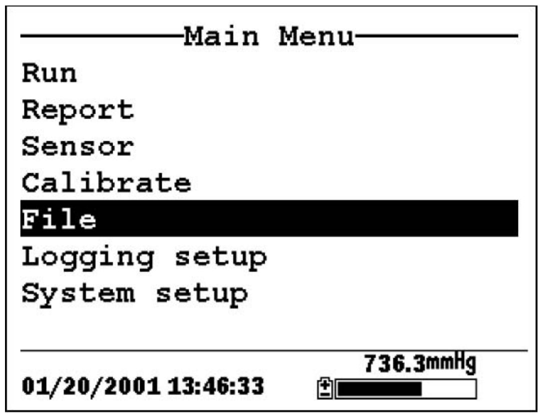


Figure 8.1 Main Menu Screen

3. Use the arrow keys to highlight the **File** selection.

4. Press the **Enter** key. The file screen is displayed.

Figure 8.2 File Screen

8.2 Directory

1. Go to the file screen as described in Section *8.1 Accessing the File Screen*.

2. Use the arrow keys to highlight the **Directory** selection. See Figure 8.2 File Screen.

3. Press the **Enter** key. The file list screen is displayed.

NOTE: Files are listed in the order in which they are logged to memory. Sample Data files have the file extension **.dat**, while Calibration Record files have the file extension **.glp**.

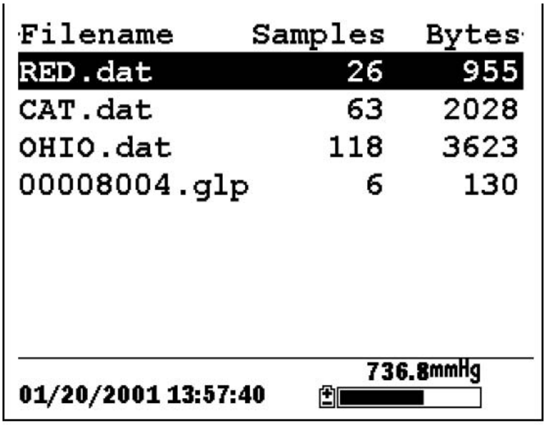


Figure 8.3 File List Screen

4. Use the arrow keys to highlight a file.

5. Press the **Enter** key. The file details screen is displayed.

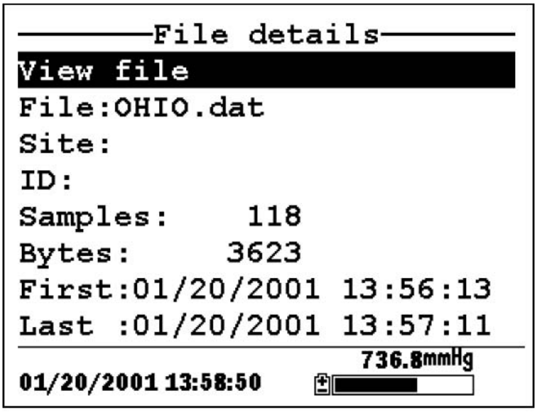


Figure 8.4 File Details Screen

6. Press the **Enter** key to view the file data. Refer to Section *8.3 View File* for details.

7. Press the **Escape** key repeatedly to return to the main menu screen.

8.3 View File

1. Go to the file screen as described in Section *8.1 Accessing the File Screen*. See Figure 8.2 File Screen.

2. Use the arrow keys to highlight the **View file** selection.

3. Press the **Enter** key. A list of files is displayed. See Figure 8.3 File List Screen.

4. Use the arrow keys to highlight an individual file.

   NOTE: You may have to scroll down to see all the files.

5. Press the **Enter** key. The file data is displayed with the file name at t8e top of the display.

   NOTE: If no file name was specified, the data is stored under the default name NONAME1.dat.

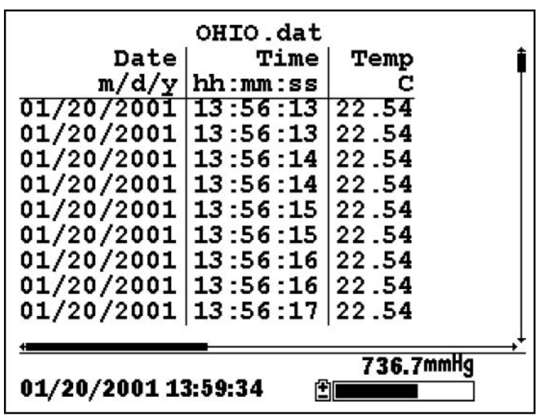


Figure 8.5 File Data Screen

6. Use the arrow keys to scroll horizontally and/or vertically to view all the data.

7. Press the **Escape** key repeatedly to return to the main menu screen.

8.4 Upload to PC

EcoWatch™ for Windows™ must be used as the PC software interface to the YSI 556 MPS. Refer to *Appendix G EcoWatch* for more information. EcoWatch for Windows® is available at no cost via a download from the YSI Web Site (www.ysi.com) or by contacting YSI Customer Support. Refer to *Appendix E Customer Service*.

8.4.1 Upload Setup

1. Disconnect the YSI 5563 Probe Module from the YSI 556 MPS instrument.

2. Connect the YSI 556 MPS to a serial (Comm) port of your computer via the 655173 PC Interface cable as shown in the following diagram:

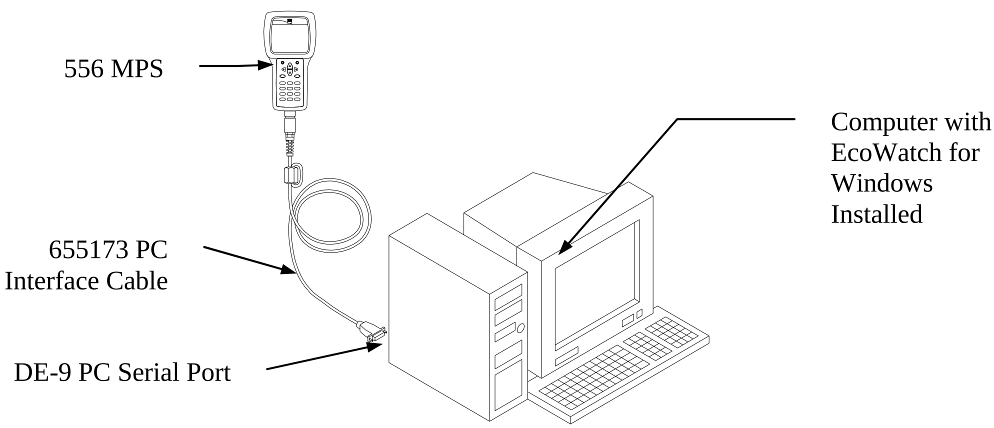


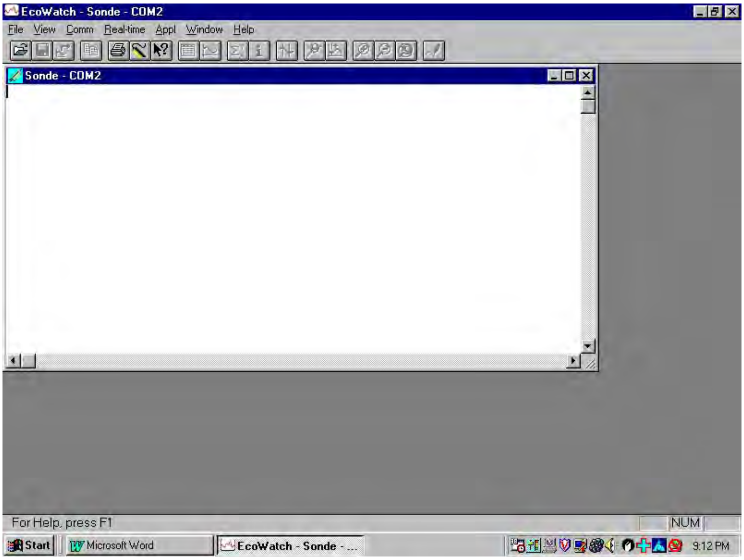
Figure 8.2 Computer/Instrument Interface

3. Open EcoWatch for Windows on your computer.

   NOTE: See *Appendix G EcoWatch* for installation instructions.

4. Click on the sonde/probe icon  in the upper toolbar.

5. Set the Comm port number to match the port the YSI 556 MPS is connected to. After this setup procedure, the following screen will be present on your PC monitor:



8.4.2 Uploading a .DAT File

1. Setup the instrument as described in Section *8.4.1 Upload Setup*.

2. Go to the YSI 556 MPS file screen as described in Section *8.1 Accessing the File Screen.*

3. Use the arrow keys to highlight the **Upload to PC** selection. See Figure 8.2 File Screen.

4. Press the **Enter** key. The file list screen is displayed. See Figure 8.3 File List Screen.

5. Use the arrow keys to highlight the DAT file that you wish to transfer and press **Enter**, both the YSI 556 MPS and PC displays show the progress of the file transfer.

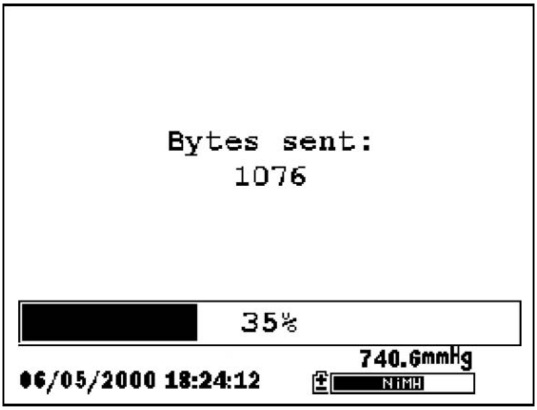
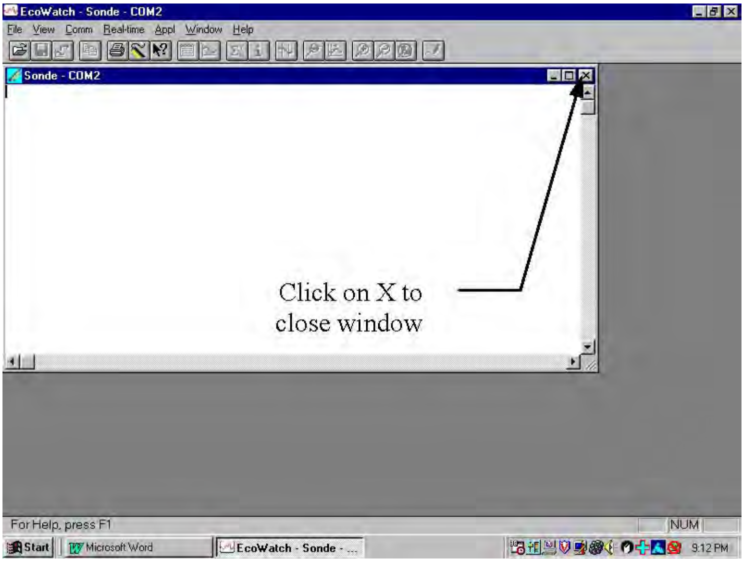


Figure 8.3 File Transfer Progress Screen

NOTE: After transfer, the file will be located in the C:\ECOWWIN\DATA folder of your PC, designated with a .DAT extension.

6. After the file transfer is complete, close the terminal window (small window on the PC) by clicking on the “X” at its upper right corner.



7. Press the **Escape** key on the YSI 556 MPS repeatedly to return

to the main menu screen.

8.4.3 Uploading a Calibration Record (.glp) File

For more information on the calibration record, refer to *Appendix H Calibration Record Information*.

1. Setup up the instrument as described in Section *8.4.1 Upload Setup*.

2. Go to the YSI 556 MPS file screen as described in Section

3. Use the arrow keys to highlight the Upload to PC selection. See Figure 8.2 File Screen.

4. Press the **Enter** key. The file list screen is displayed. See Figure 8.3 File List Screen.

5. Use the arrow keys to highlight the calibration record file that you wish to transfer and press **Enter.**

6. You will then be given a choice of uploading the file in three formats; **Binary, Comma & "" Delimited, and ASCII Text**.

   NOTE: The binary format is reserved for future YSI software packages.

7. Choose an option and press Enter, both the YSI 556 and PC displays show the progress of the file transfer.

   NOTE: After transfer, the file will be located in the C:\ECOWWIN\DATA folder of your PC, designated with the appropriate file extension.

   NOTE: To view the Calibration Record data after upload, simply open the .txt file in a general text editor such as Wordpad or Notepad.

8. After the file transfer is complete, close the terminal window (small window on the PC) by clicking on the "X" at its upper right corner.

9. Press the **Escape** key repeatedly to return to the main menu screen.

8.5 File Memory

1. Go to the file screen as described in Section *8.1 Accessing the File Screen*.

2. Use the arrow keys to highlight the **File memory** selection. See Figure 8.2 File Screen.

3. Press the **Enter** key. The file bytes used screen is displayed.

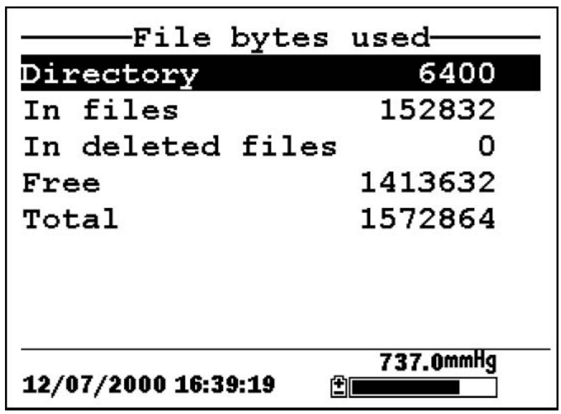


Figure 8.4 File Bytes Used Screen

4. The amount of free memory is listed in line 4 of the file bytes used screen.

   NOTE: If the amount of free memory is low, it may be time to delete all files (after first uploading all data to a PC). Refer to Section *8.6 Delete All Files*.

5. Press the **Escape** key repeatedly to return to the main menu screen.

8.6 Delete All Files

NOTE: It is not possible to delete individual files in order to free up memory. The only way to free up memory is to delete ALL files present. Take care to transfer all files to your computer (refer to Section 8.4 Upload to PC) before deleting them.

1. Go to the file screen as described in Section *8.1 Accessing the File Screen*.

2. Use the arrow keys to highlight the **Delete all files** selection. See Figure 8.2 File Screen.

3. Press the **Enter** key. The Delete all Files screen is displayed.

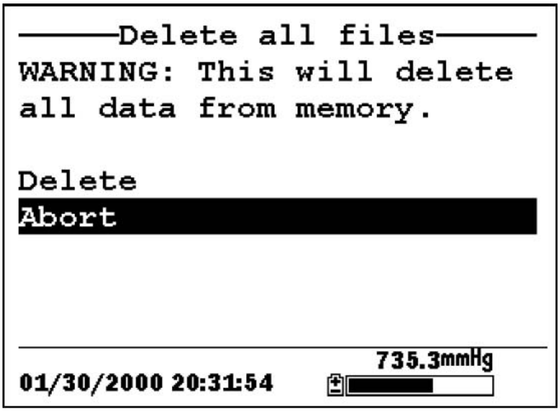


Figure 8.5 Delete All Files Screen

4. Use the arrow keys to highlight the **Delete** selection.

5. Press the **Enter** key.

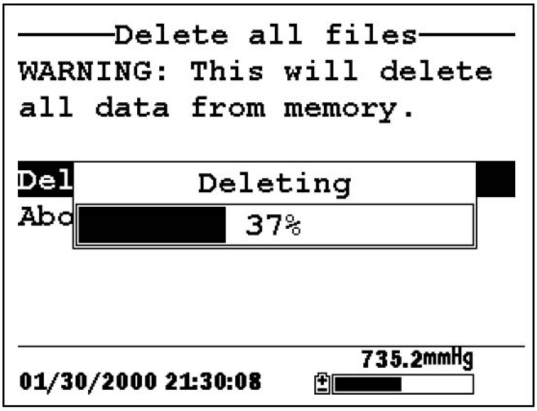


Figure 8.10 Deleting

The progress of file deletion is displayed in bar graph format.

NOTE: Deleting all files in the directory will not change any information in the site list.

6. Press the Escape key repeatedly to return to the main menu screen.

9. Logging

9.1 Accessing the Logging Setup Screen

1. Press the **On/off** key to display the run screen.

2. Press the **Escape** key to display the main menu screen.

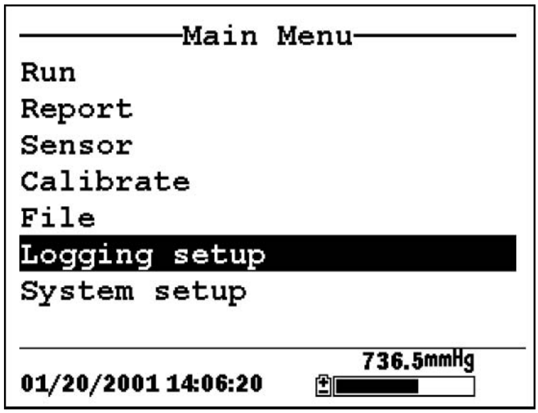


Figure 9.1 Main Menu

3. Use the arrow keys to highlight the **Logging setup** selection.

4. Press the **Enter** key. The logging setup screen is displayed.

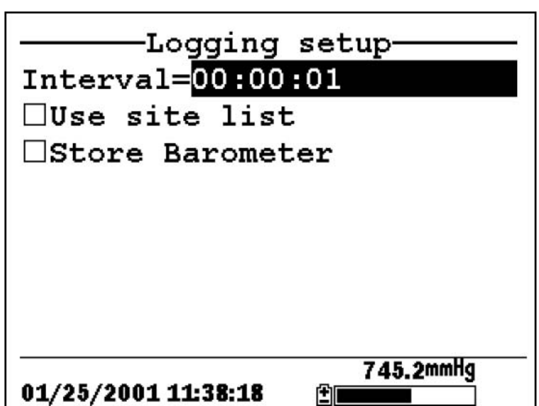


Figure 9.2 Setup Screen

9.2 Setting Logging Interval

Follow steps below to set the interval for logging a data stream.

NOTE: If you do not specify an interval, the instrument will use a default interval setting of 1 second.

NOTE: It is not necessary to set a logging interval when logging a single sample.

1. Go to the logging setup screen as described in Section *9.1 Accessing the Logging Setup Screen*.

2. Use the keypad to enter an interval between 1 second and 15 minutes. Refer to Section *2.9 Keypad Use*.

   NOTE: The interval field has hour, minute and second entry fields. Any entry over 1 hour will change automatically to a 15-minute setting.

3. Press the **Enter** key. The data stream interval is set.

4. Press the **Escape** key repeatedly to return to the main menu screen.

9.3 Storing Barometer Readings

NOTE: The **Store barometer** option is only available on instruments that are equipped with the optional barometer.

1. Go to the logging setup screen as described in Section *9.1 Accessing the Logging Setup Screen*.

2. Use the arrow keys to highlight the **Store barometer** selection. See Figure 9.2 Logging Setup Screen.

3. Press the **Enter** key until a check mark is entered in the box next to the store barometer selection if you want to log barometric readings.

OR press the **Enter** key until the box next to the barometer selection is empty if you do not want to log barometric readings.

Figure 9.3 Store Barometer

4. Press the **Escape** key repeatedly to return to the main menu screen.

9.4 Creating a Site List

The site list option allows you to define file and site descriptions in the office or laboratory before moving to field logging studies. This is usually more convenient than entering the information at the site and is particularly valuable if you are visiting certain sites on a regular basis. The following section describes how to set up site lists which contain entries designated “Site Descriptions” that will be instantly available to the user in the field to facilitate the logging of data with pre-established naming of files and sites. There are two kinds of **Site Descriptions** available for use in Site lists:

• **Site Descriptions** associated with applications where data from a single site is always logged to a single file. This type is referred to as a “Single-Site Description” and is characterized by two parameters – a file name and a site name. Files logged to YSI 556 MPS memory under a **Single-Site Description** will be characterized primarily by the file name, but will also have the Site name attached, so that it is viewable in either the YSI 556 MPS **File directory** or in EcoWatch for Windows after upload to a PC

• **Site Descriptions** associated with applications where data from multiple sites are logged to a single file. This type is referred to as a “Multi-site Description” and is characterized by three parameters – a file name, a site name, and a site number. Files logged to YSI 556 MPS memory under a

Multi-site Description are characterized by a file name, but not a site name, since multiple sites are involved. However, each data point has a Site Number attached to it so that the user can easily determine the sampling site when viewing the data from the YSI 556 MPS **File** menu or processing the data in EcoWatch for Windows after upload to a PC.

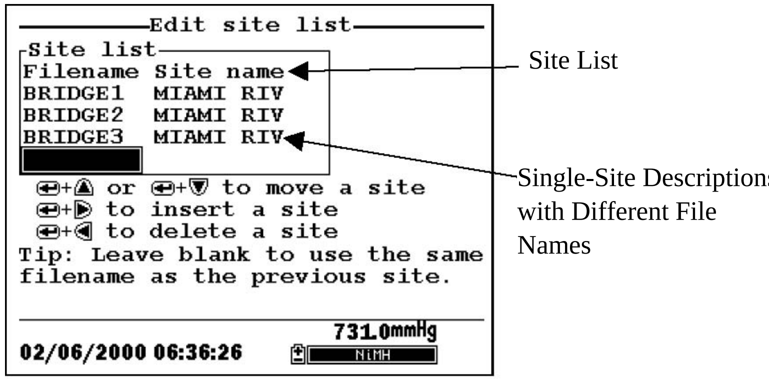


Figure 9.4 Single-Site Descriptions

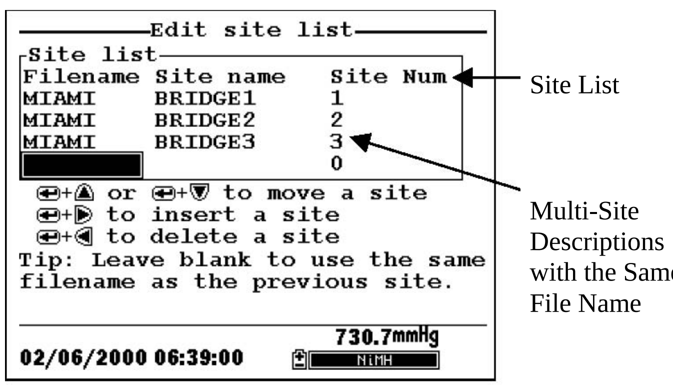


Figure 9.5 Multiple-Site Descriptions

NOTE: Site lists containing Single Site Descriptions are usually input with the designation **Store Site Number** INACTIVE in the YSI 556 MPS **Logging setup** menu. Thus, no site numbers appear in the first **Site list** example. Conversely, **Site lists** containing **Multi-Site Descriptions** MUST be input with the **Store Site Number** selection ACTIVE as shown in the second example.

To create a site list:

1. Go to the logging setup screen as described in Section *9.1 Accessing the Logging Setup Screen*.

2. Use the arrow keys to highlight the **Use site list** selection.

3. Press the **Enter** key. A check mark is entered in the box next to the use site list selection *and* two new entries appear on the logging setup screen. See Figure 9.6 Logging Setup Screen.

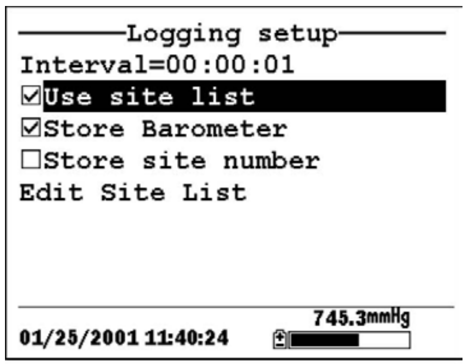


Figure 9.6 Logging Setup Screen

4. Use the arrow keys to highlight the **Store site number** selection.

5. If you are creating Multi-Site Descriptions (which require that the site **number** be stored in your data files), press the **Enter** key until a check mark appears in the box next to the store site number selection.

OR Press the **Enter** key until the box next to the store site number selection is empty, to create Single-Site Descriptions. The site **name** will be stored in the header of your data files.

6. Use the arrow keys to highlight the **Edit site list** selection.

7. Press the **Enter** key. The edit site list screen is displayed. See Figure 9.7 Edit Site List Screen. The **Filename** field is ready for input.

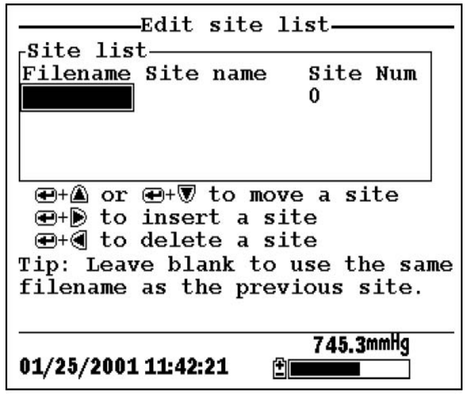


Figure 9.7 Edit Site List Screen

8. Use the keypad to enter a filename up to 8 characters in length. Refer to Section *2.9 Keypad Use*.

9. Press the **Enter** key. The cursor moves to the right for the entry of a **Site name**.

10. Use the keypad to enter a site name up to 11 characters in length. Refer to Section *2.9 Keypad Use*.

NOTE: If the store site number selection is *not* checked, skip to Step 13.

11. Press the **Enter** key. The cursor moves to the site number entry position.

12. Use the keypad to enter a site number up to 7 characters in length. Refer to Section *2.9 Keypad Use*.

13. Press **Enter**. The cursor moves to the next filename entry position.

14. Repeat Steps 8 to 13 until all filenames and sites have been entered.

15. Press **Escape** repeatedly to return to the main menu screen.

9.5 Editing a Site List

1. Go to the logging setup screen as described in Section *9.1 Accessing the Logging Setup Screen*.

2. Use the arrow keys to highlight the **Edit Site List** selection. See Figure 9.6 Logging Setup Screen.

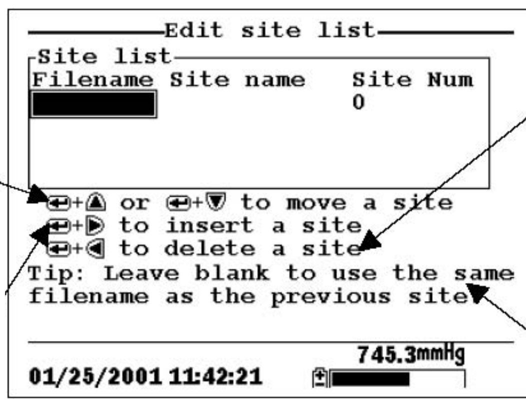
3. Press the **Enter** key. The edit site list screen is displayed.

4. Edit the site list using the keystrokes described below.

NOTE: Editing the site list will not have any effect on files stored in the instrument memory.

To MOVE a site:
Use the arrow keys to highlight a site. Press the Up or Down arrow key while holding down the Enter key.

To INSERT a site above another site:
Use the arrow keys to highlight the site. Press the Right arrow key while holding down the Enter key. Use keypad to input letters. Refer to Section 2.9 *Keypad Use.*



To DELETE a site:
Use the arrow keys to highlight a site. Press the Left arrow key while holding down the Enter key.

To use the same file name as the previous site: **Leave the filename blank**

Figure 9.1 Keystrokes for Editing Site List

9.6 Logging Data Without a Site List

1. Follow Steps 1 through 5 in Section 7.1 Real-Time Data.

2. Use the arrow keys to highlight the **Log one sample** selection on the run screen if only a single sample is being logged.

OR Use the arrow keys to highlight the **Start logging** selection on the run screen if a data stream is being logged.

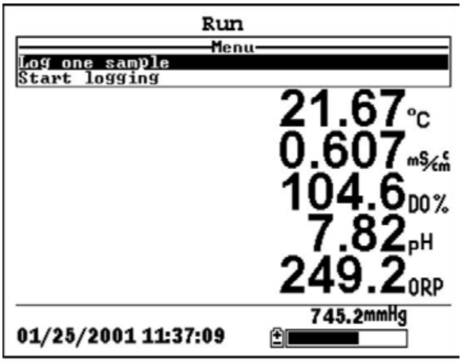


Figure 9.9 Run Screen

3. Press the **Enter** key. The Enter information screen is displayed.

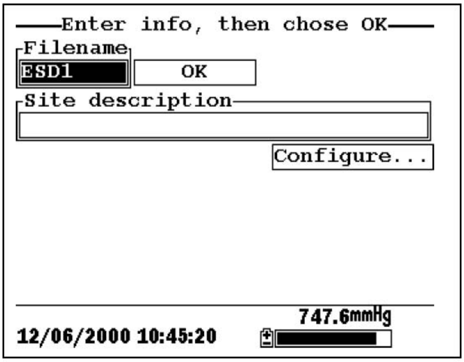


Figure 9.10 Enter Information Screen

NOTE: The last filename used will be displayed.

4. Use the keypad to enter a file name. Refer to Section *2.9 Keypad Use*.

   NOTE: The instrument will assign a default file name of NONAME if no file name is specified.

5. Press the **Enter** key to input the file name.

6. Use the arrow keys to highlight the **Site description** field in the enter information screen.

NOTE: Entering a Site Description is optional. You may leave the Site Description blank and skip to Step 9.

7. Use the keypad to enter a site description name. Refer to Section *2.9 Keypad Use*.

8. Press the **Enter** key to input the site description.

NOTE: If you want to change the logging setup, such as sampling interval or storing the barometer reading, use the arrow keys to highlight the **Configure** field, press the **Enter** key, then refer to Section *9.2 Setting Logging Interval* or *9.3 Storing Barometer Readings* for details.

9. Use the arrow keys to highlight the **OK** field in the center of the information screen.

10. Press the **Enter** key to start logging.

NOTE: If the parameter mismatch screen is displayed, refer to Section *9.8 Adding Data to Existing Files*.

11. If a single point is being logged, the header on the run screen changes momentarily from **Menu** to **Sample logged** to confirm that the point was successfully logged. Skip to Step

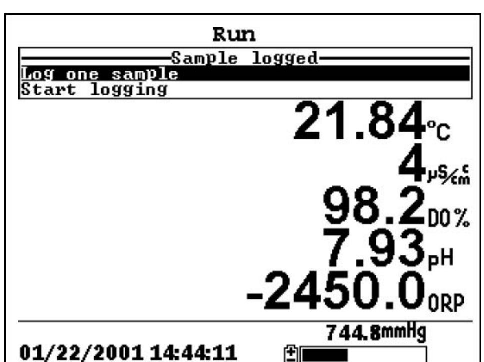


Figure 9.11 Sample Logged Screen

If a continuous stream of points is being logged, the start logging entry in the run screen changes from **Start logging** to **Stop logging**.

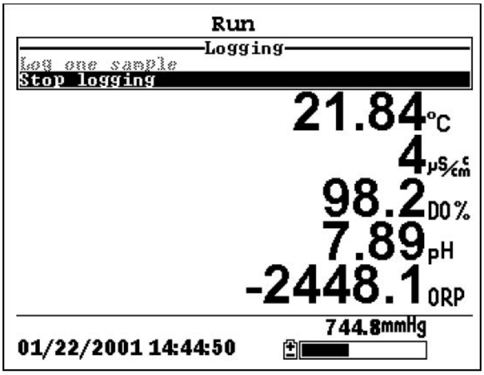


Figure 9.12 Logging Screen

12. At the end of the logging interval, press **Enter** to stop logging.

13. Refer to Section *8.3 View File* to view the data on the instrument display.

9.7 Logging Data with a Site List

1. If you have not already created a site list, refer to Section *9.4 Creating a Site List*.

2. Follow Steps 1 through 5 in Section 7.1 Real-Time Data.

3. Use the arrow keys to highlight the **Log one sample** selection on the run screen if only a single sample is being logged.

OR Use the arrow keys to highlight the **Start logging** selection on the run screen if a data stream is being logged. See Figure 9.9 Run Screen.

4. Press the **Enter** key. The Pick a site screen is displayed.

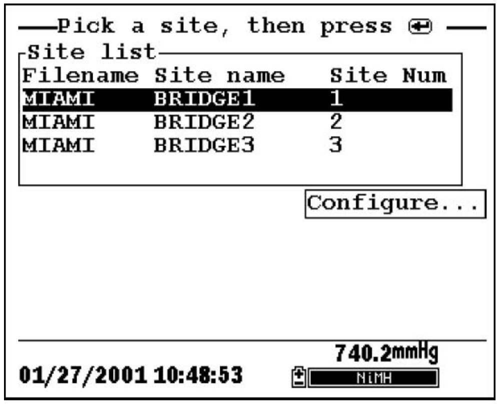


Figure 9.13 Pick a Site Screen

5. Use the arrow keys to highlight the **site** of your choice.

   NOTE: If the site of your choice is grayed out in the site list, refer to Section *9.8 Adding Data to Existing Files*.

   NOTE: Refer to Section *9.5 Editing a Site List* if you want to edit the site list.

6. Press the **Enter** key to start logging.

   NOTE: If the parameter mismatch screen is displayed, refer to Section 9.8 Adding Data to Existing Files.

7. If a single point is being logged, the header on the run screen changes momentarily from **Menu** to **Sample logged** to confirm that the point was successfully logged. See Figure 9.11 Sample Logged Screen. Skip to Step 9.

   If a continuous stream of points is being logged, the start logging entry in the run screen changes from **Start logging** to **Stop logging**. See Figure 9.12 Logging Screen.

8. At the end of the logging interval, press **Enter** to stop logging.

9. Refer to Section *8.3 View File* to view the data on the instrument display.

9.8 Adding Data to Existing Files

In order to add new data to an existing file, the current logging and sensor setup must be *exactly* the same as when the file was created. The following settings must be the same:

- **Sensors enabled** (refer to Section *4 Sensors*)
- **Store Barometer** (refer to Section *9.3 Storing Barometer Readings*)
- **Store Site Number** (refer to Section *9.4 Creating a Site List*)

If the current logging setup is not exactly the same as when the file was created, a parameter mismatch screen is displayed.

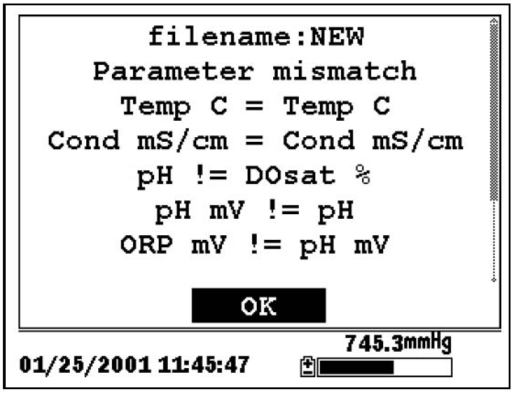


Figure 9.14 Parameter Mismatch Screen

NOTE: The right column shows parameters used when the file was created. The left column shows current parameters.

1. Press the **Down Arrow** key to scroll down and find the mismatch(es).

2. Use the following chart to resolve the mismatch(es).

Mismatch	**Action**	**Reference**
Sensor(s) missing from left column	Enable the missing sensor(s)	Section *4 Sensors*
Extra sensor(s) listed in left column	Disable the extra sensor(s)	Section *4 Sensors*
Barometer missing from left column, but present in right column	Enable the Store Barometer setting	Section *9.3 Storing Barometer Readings*
Barometer present in left column, but missing from right column	Disable the Store Barometer setting	Section *9.3 Storing Barometer Readings*
Store Site Number missing from left column, but present in right column	Enable the Store Site Number setting	Section *9.4 Creating a Site List*
Store Site Number present in left column, but missing from right column	Disable the Store Site Number setting	Section *9.4 Creating a Site List*

3. Return to Section *9.6 Logging Data without a Site List* or *9.7 Logging Data with a Site List*.

10. System Setup

The YSI 556 MPS has a number of features that are user-selectable or can be configured to meet the user's preferences. Most of these choices are found in the **System setup** menu.

10.1 Accessing the System Setup Screen

1. Press the **On/off** key to display the run screen. See Figure Front View of YSI 556 MPS.

2. Press the **Escape** key to display the main menu screen.

3. Use the arrow keys to highlight the **System setup** selection.

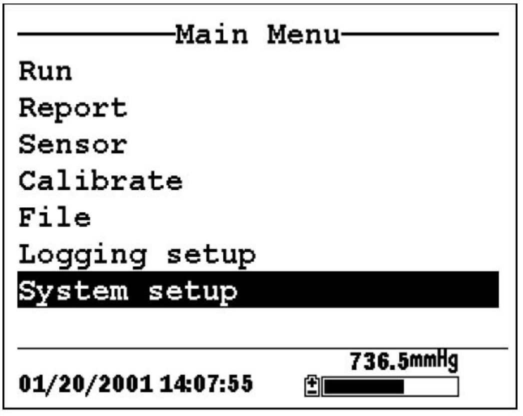


Figure 10.1 Main Menu

4. Press the **Enter** key. The system setup screen is displayed.

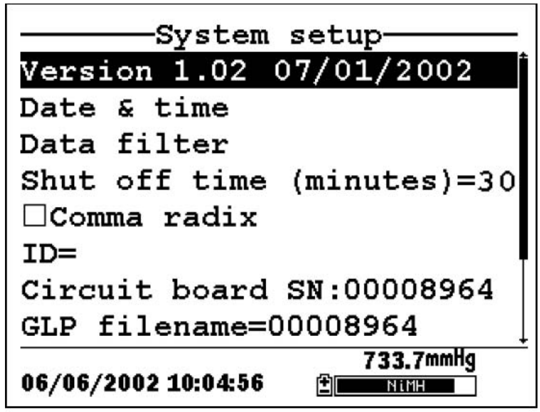


Figure 10.2 System Setup Screen

NOTE: The first line of the **System setup** menu shows the current software version of your YSI 556 MPS. As software enhancements are introduced, you will be able to upgrade your YSI 556 MPS from the YSI Web site. Refer to Section *11.2 Upgrading YSI 556 MPS* Software for details.

10.2 Language Setting

1. Go to the System Setup screen as described in Section *10.1 Accessing the System Setup Screen*.
2. Use the arrow keys to highlight **Language** on the System Setup screen. Press **Enter** to open the Language screen. .
3. Use the arrow keys to highlight your desired **Language**. Press **Enter**.
4. Press the Escape key repeatedly to return to the Main men

10.3 Date and Time Setup

1. Go to the system setup screen as described in Section *10.1 Accessing the System Setup Screen*.

2. Use the arrow keys to highlight the **Date & time** selection on the system setup screen. See Figure 10.2 System Setup Screen.

3. Press **Enter**. The date and time setup screen is displayed.

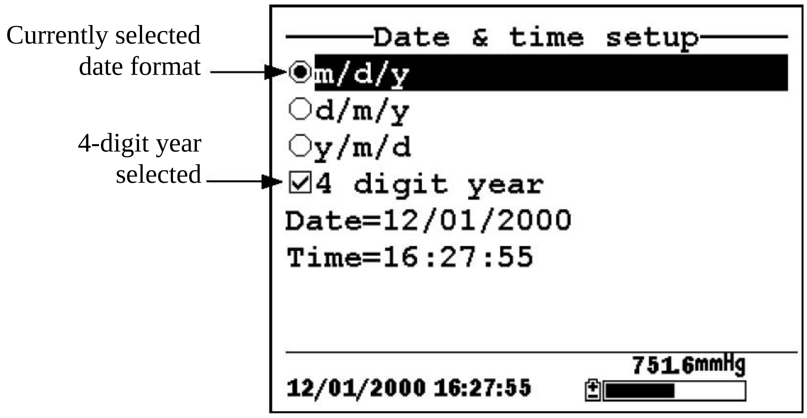


Figure 10.3 Date Setup Screen

NOTE: A black dot to the left of a date format indicates that format is selected.

4. Use the arrow keys to highlight your desired date format.

5. Press **Enter**.

6. Use the arrow keys to highlight the 4-digit year selection.

7. Press **Enter**. A check mark appears in the check box next to the 4-digit year selection.

NOTE: If unchecked, a 2-digit year is used.

8. Use the arrow keys to highlight the **Date** selection.

9. Press **Enter**. A cursor appears over the first number in the date.

10. Enter the proper number from the keypad for the highlighted date digit. The cursor moves automatically to the next date digit. Refer to Section *2.9 Keypad Use* for more keypad information.

11. Repeat Step 10 until all date digits are correct.

12. Press **Enter** to input the specified date.

13. Use the arrow keys to highlight the **Time** selection.

14. Press **Enter**. A cursor appears over the first number in the time selection.

15. Enter the proper number from the keypad for the highlighted time digit. The cursor moves automatically to the next time digit.

    NOTE: Use military format when entering time. For example, 2:00 PM is entered as 14:00.

16. Repeat Step 15 until all time digits are correct.

17. Press **Enter** to input the correct time.

18. Press the **Escape** key repeatedly to return to the Main menu screen.

10.4 Data Filter

The Data Filter is a software filter that eliminates sensor noise and provides more stable readings.

NOTE: YSI recommends using the default values for the data filter for most field applications.

However, users who are primarily interested in a fast response from their dissolved oxygen sensor should consider a change of the default time constant setting of 8 seconds to one of 2 seconds. This change can be made according to the instructions in Section *10.3.1 Changing the Data Filter Settings* below. The disadvantage of lowering the time constant is that field pH readings may appear somewhat noisy if the cable is in motion.

10.4.1 Changing the Data Filter Settings

1. Go to the system setup screen as described in Section *10.1 Accessing the System Setup Screen*.

2. Use the arrow keys to highlight the **Data filter** selection. See Figure 10.1 Main Menu.

3. Press the **Enter** key. The Data filter setup screen is displayed.

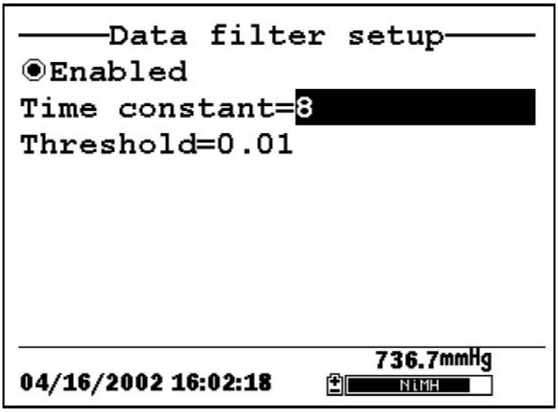


Figure 10.4 Data Filter Screen

4. With Enabled highlighted, press the **Enter** key to Enable or Disable the data filter. A black dot to the left of the selection indicates the data filter is enabled.

5. Use the arrow keys to highlight the **Time constant** field.

   NOTE: This value is the time constant in seconds for the software data filter. Increasing the time constant will result in greater filtering of the data, but will also slow down the apparent response of the sensors.

6. Use the keypad to enter a value. The default value is 8 and this value is ideal for most 556 field applications. As described in Section *10.3 Data Filter* above, users who wish to decrease the response time of the DO readings at the expense of some noise for the pH readings determined

concurrently, should change the Time Constant to a value of 2.

7. Press the **Enter** key to enter the time constant.

8. Use the arrow keys to highlight the **Threshold** field.

   NOTE: This value determines when the software data filter will engage/disengage, speeding the response to large changes in a reading. When the difference between two consecutive readings is larger than the threshold, then the reading is displayed unfiltered. When the difference between two consecutive readings drops below the threshold, readings will be filtered again.

9. Use the keypad to enter a value. The default value is 0.01.

10. Press the **Enter** key to enter the threshold.

11. Press the **Escape** key repeatedly to return to the Main menu screen.

10.5 Shutoff Time

The YSI 556 MPS shuts off automatically after 30 minutes of inactivity. The shut off time may be changed as described below.

1. Go to the system setup screen as described in Section *10.1 Accessing the System Setup Screen*.

2. Use the arrow keys to highlight the **Shutoff time** selection on the system setup screen. See Figure 10.2 System Setup Screen.

3. Use the keypad to enter a value from 0 to 60 minutes. The default value is 30.

   NOTE: To disable the automatic shutoff feature, enter a zero (0).

4. Press the **Enter** key to enter the correct shutoff time.

5. Press the **Escape** key repeatedly to return to the main menu screen.

10.6 Comma Radix

The user can toggle between a period (default) and comma for the radix mark by selecting this item and pressing the **Enter** key as follows:

1. Go to the system setup screen as described in Section *10.1 Accessing the System Setup Screen*.

2. Use the arrow keys to highlight the **Comma radix** selection on the system setup screen. See Figure 10.2 System Setup Screen.

3. Press the **Enter** key. A check mark appears in the check box next to the comma radix selection indicating that the radix mark is a comma.

10.7 ID

This selection allows you to enter an identification name/number for your YSI 556 MPS. This ID name/number is logged in the header of each file.

1. Go to the system setup screen as described in Section *10.1 Accessing the System Setup Screen*.

2. Use the arrow keys to highlight the **ID** selection. See Figure 10.1 Main Menu.

3. Use the keypad to enter an alphanumeric ID up to 15 characters in length. Refer to Section *2.9 Keypad Use*.

4. Press the **Enter** key to enter the ID.

5. Press the **Escape** key repeatedly to return to the main menu screen.

10.8 GLP Filename

This selection allows you to enter a different filename for the YSI 556 MPS Calibration Record file.

NOTE: The default filename is the "556 PC board Serial Number.glp."

1. Go to the system setup screen as described in Section *10.1 Accessing the System Setup Screen*.

2. Use the arrow keys to highlight the **GLP Filename** selection. See Figure 10.1 Main Menu.

3. Use the keypad to enter a filename up to 8 characters in length. Refer to Section *2.9 Keypad Use*.

4. Press the **Enter** key to enter the new filename.

5. Press the **Escape** key repeatedly to return to the main menu screen.

10.9 TDS Constant

This selection allows you to set the constant used to calculate Total Dissolved Solids (TDS). TDS in g/L is calculated by multiplying this constant times the specific conductance in mS/cm.

10.9.1 Changing the TDS Constant

1. Go to the system setup screen as described in Section *10.1 Accessing the System Setup Screen*.

2. Use the arrow keys to highlight the **TDS Constant** selection. See Figure 10.1 Main Menu.

3. Use the keypad to enter a value. Refer to Section *2.9 Keypad Use*. The default value is 0.65.

4. Press the **Enter** key to enter the correct TDS constant.

5. Press the **Escape** key repeatedly to return to the main menu screen.

10.10 Barometer Units

The following information is only for instruments with the barometer option.

1. Go to the system setup screen as described in Section *10.1 Accessing the System Setup Screen*.

2. Use the arrow keys to highlight the **Barometer units** selection on the system setup screen. See Figure 10.2 System Setup Screen.

3. Press the **Enter** key. The Barometer units screen will appear.

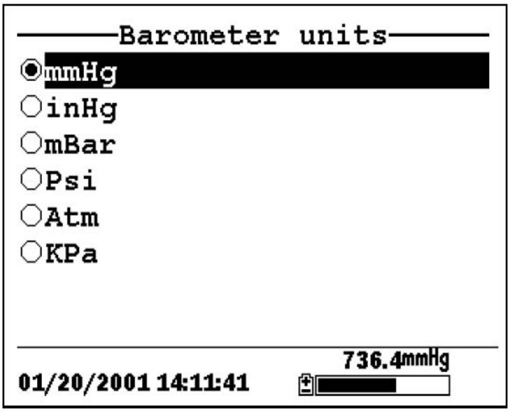


Figure 10.5 Data Filter Screen

A black dot indicates the currently selected units.

4. Use the arrow keys to highlight your desired barometric unit.

5. Press the **Enter** key to select your choice. A black dot will appear in the circle next to your selected units.

6. Press the **Escape** key repeatedly to return to the main menu screen.

10.11 Calibrate Barometer

The optional barometer has been factory calibrated to provide accurate readings. However, some sensor drift may occur over time, requiring occasional calibration by the user, as follows:

1. Determine your local barometric pressure from an independent laboratory barometer or from your local weather service.

2. If the barometric pressure (BP) reading is from your local weather station, reverse the equation that corrects it to sea level.

   NOTE: For this equation to be accurate, the barometric pressure units must be in mmHg.

   True BP = (Corrected BP) – [2.5 * (Local Altitude/100)]

3. Go to the system setup screen as described in Section *10.1 Accessing the System Setup Screen*.

4. Use the arrow keys to highlight the **Calibrate barometer** selection on the system setup screen. See Figure 10.2 System Setup Screen.

5. Press the **Enter** key. The Calibrate Barometer screen is displayed.

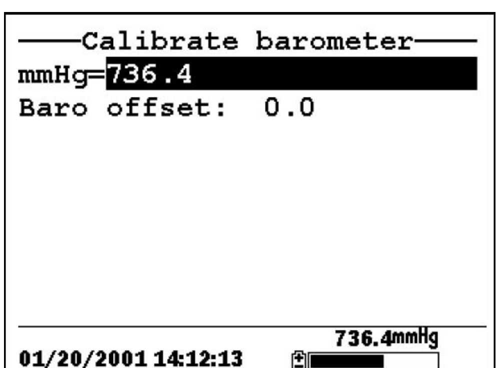


Figure 10.6 Barometer Calibration Screen

6. Use the keypad to input the known barometric pressure value as determined in Step 2.

7. Press the **Enter** key. The new barometer reading is displayed as well as the approximate offset from the factory reading.

   NOTE: To return the sensor to the factory setting, subtract the offset amount from the current setting and repeat Steps 5 to 7.

8. Press the **Escape** key repeatedly to return to the main menu screen.

11. Maintenance

11.1 Sensor Care and Maintenance

Once the sensors have been properly installed, remember that periodic cleaning and DO membrane changes are required.

11.1.1 DO Sensor

For best results, we recommend that the KCl solution and the membrane cap be changed at least once every 30 days.

1. It is important to recognize that oxygen dissolved in the sample is consumed during sensor operation. It is therefore essential that the sample be continuously stirred at the sensor tip. If stagnation occurs, your readings will be artificially low. Stirring may be accomplished by mechanically moving the sample around the sensor tip, or by rapidly moving the sensor through the sample. The rate of stirring should be at least 1 foot per second.

2. Membrane life depends on usage. Membranes will last a long time if installed properly and treated with care. Erratic readings are a result of loose, wrinkled, damaged, or fouled membranes, or from large (more than 1/8" diameter) bubbles in the electrolyte reservoir. If erratic readings or evidence of membrane damage occurs, you should replace the membrane and the electrolyte solution. The average replacement interval is two to four weeks.

3. If the membrane is coated with oxygen consuming (e.g. bacteria) or oxygen producing organisms (e.g. algae), erroneous readings may occur.

4. Chlorine, sulfur dioxide, nitric oxide, and nitrous oxide can affect readings by behaving like oxygen at the sensor. If you suspect erroneous readings, it may be necessary to determine if these gases are the cause.

5. Avoid any environment that contains substances that may attack the probe module and sensor materials. Some of these substances are concentrated acids, caustics, and strong solvents. The sensor materials that come in contact

with the sample include FEP Teflon, acrylic plastic, EPR rubber, stainless steel, epoxy, polyetherimide and the PVC cable covering.

6. It is possible for the silver anode, which is the entire silver body of the sensor, to become contaminated. This will prevent successful calibration. To restore the anode, refer to Section *11.1.1 DO Sensor, Silver Anode Cleaning*.

7. For correct sensor operation, the gold cathode must always be bright. If it is tarnished (which can result from contact with certain gases), or plated with silver (which can result from extended use with a loose or wrinkled membrane), the gold surface must be restored. To restore the cathode, refer to Section *11.1.1 DO Sensor, Gold Cathode Cleaning.*

8. To keep the electrolyte from drying out, store the sensor in the transport/calibration cup with at least 1/8″ of water.

Silver Anode Cleaning

After extended use, a thick layer of AgCl builds up on the silver anode reducing the sensitivity of the sensor. The anode must be cleaned to remove this layer and restore proper performance. The cleaning can be chemical or mechanical:

Chemical Cleaning: Remove the membrane cap and soak the entire anode section in a 14% ammonium hydroxide solution for 2 to 3 minutes, followed by a thorough rinsing with distilled or deionized water. The anode should then be thoroughly wiped with a wet paper towel to remove the residual layer from the anode.

Mechanical Cleaning: Sand off the dark layer from the silver anode with 400 grit wet/dry sandpaper. Wrap the sandpaper around the anode and twist the sensor. Rinse the anode with clean water after sanding, followed by wiping thoroughly with a wet paper towel.

NOTE: After cleaning, a new membrane cap must be installed. Refer to Section *3.4.3 Membrane Cap Installation*.

Turn the instrument on and allow the system to stabilize for at least 30 minutes. If, after several hours, you are still unable to calibrate, contact your dealer or YSI Customer Service. Refer to *Appendix E Customer Service*.

Gold Cathode Cleaning

For correct sensor operation, the gold cathode must be textured properly. It can become tarnished or plated with silver after extended use. The gold cathode can be cleaned by using the adhesive backed sanding disc and tool provided in the YSI 5238 Probe Reconditioning Kit.

Using the sanding paper provided in the YSI 5238 Probe Reconditioning Kit, wet sand the gold with a twisting motion about 3 times or until all silver deposits are removed and the gold appears to have a matte finish. Rinse the cathode with clean water after sanding, followed by wiping thoroughly with a wet paper towel. If the cathode remains tarnished, contact your dealer or YSI Customer Service. Refer to *Appendix E Customer Service*.

NOTE: After cleaning, a new membrane cap must be installed. Refer to Section *3.4.3 Membrane Cap Installation***.**

11.1.2 DO Sensor Replacement

1. Remove the probe sensor guard.

⚠ **CAUTION:** Thoroughly dry the sensor so that no water enters the probe module sensor port when the sensor is removed.

2. Insert the long end of the hex key wrench into the small hole in the side of the probe module bulkhead. Turn the wrench counterclockwise and remove the screw. (You do not have to remove the screw all the way to release the sensor.)

3. Pull the old DO sensor module straight out of the probe module body.

   NOTE: The DO sensor is not threaded, it is keyed, so it cannot be removed by twisting.

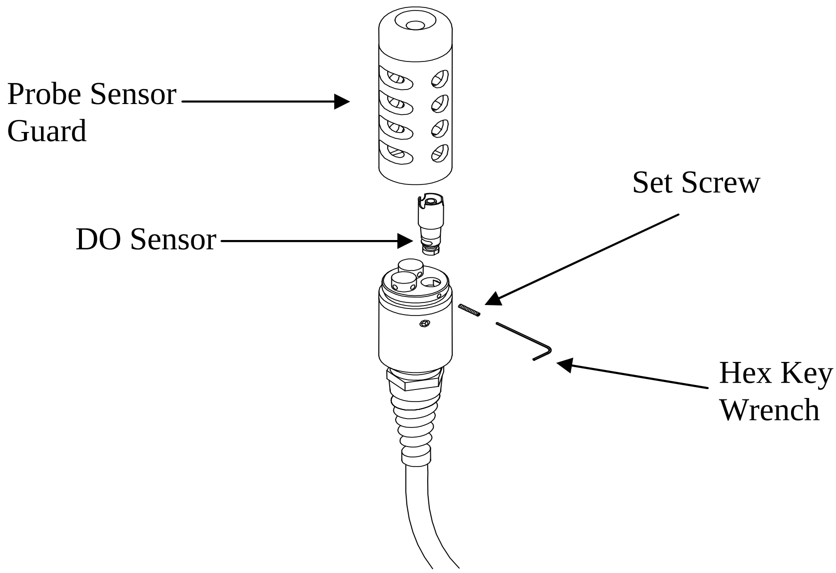


Figure 11.1 DO Sensor Replacement

4. Insert the new DO sensor module. Make sure that the inside of the probe module sensor port and the o-ring on the sensor are clean, with no contaminants, such as grease, dirt, or hair. The DO sensor is keyed, or has a flat side, so that it cannot be aligned improperly.

NOTE: Make sure the DO sensor bottoms out before the set screw is inserted.

5. Insert the set screw into the small hole in the side of the probe module bulkhead, and turn clockwise to rethread.

⚠ **CAUTION**: Make sure that you do not cross-thread the set screw. Use the hex key wrench to tighten the screw in properly, making sure that the screw does not stick out of the side of the probe module bulkhead. The probe sensor guard will not thread on properly and damage may result if the screw is allowed to stick out.

NOTE: The YSI 5563 DO sensor is shipped dry. A shipping membrane was installed to protect the electrode. A new membrane cap must be installed before the first use. Refer to Section 3.4.1 Sensor Installation.

11.1.3 YSI 5564 pH and 5565 Combination pH/ORP Sensor Cleaning

Cleaning is required whenever deposits or contaminants appear on the glass and/or platinum surfaces of these sensors or when the response of the sensor becomes slow.

1. Remove the sensor from the probe module.

2. Initially, simply use clean water and a soft clean cloth, lens cleaning tissue, or cotton swab to remove all foreign material from the glass bulb (YSI 5564 and YSI 5565) and platinum button (YSI 5565). Then use a moistened cotton swab to carefully remove any material that may be blocking the reference electrode junction of the sensor.

⚠ **CAUTION:** When using a cotton swab with the YSI 5564 or YSI 5565, be careful NOT to wedge the swab tip between the guard and the glass sensor. If necessary, remove cotton from the swab tip, so that the cotton can reach all parts of the sensor tip without stress.

NOTE: If good pH and/or ORP response is not restored by the above procedure, perform the following additional procedure:

1. Soak the sensor for 10-15 minutes in clean water containing a few drops of commercial dishwashing liquid.

2. GENTLY clean the glass bulb and platinum button by rubbing with a cotton swab soaked in the cleaning solution.

3. Rinse the sensor in clean water, wipe with a cotton swab saturated with clean water, and then re-rinse with clean water.

   NOTE: If good pH and/or ORP response is still not restored by the above procedure, perform the following additional procedure:

1. Soak the sensor for 30-60 minutes in one molar (1 M) hydrochloric acid (HCl). This reagent can be purchased from most distributors. Be sure to follow the safety instructions included with the acid.

2. GENTLY clean the glass bulb and platinum button by rubbing with a cotton swab soaked in the acid.

3. Rinse the sensor in clean water, wipe with a cotton swab saturated with clean water, and then re-rinse with clean water. To be certain that all traces of the acid are removed from the sensor crevices, soak the sensor in clean water for about an hour with occasional stirring.

   NOTE: If biological contamination of the reference junction is suspected or if good response is not restored by the above procedures, perform the following additional cleaning step:

1. Soak the sensor for approximately 1 hour in a 1 to 1 dilution of commercially available chlorine bleach.

2. Rinse the sensor with clean water and then soak for at least 1 hour in clean water with occasional stirring to remove residual bleach from the junction. (If possible, soak the sensor for period of time longer than 1 hour in order to be certain that all traces of chlorine bleach are removed.) Then re-rinse the sensor with clean water and retest.`

11.1.4 Temperature/Conductivity Sensor Cleaning

The single most important requirement for accurate and reproducible results in conductivity measurement is a clean cell. A dirty cell will change the conductivity of a solution by contaminating it. The small cleaning brush included in the YSI 5511 Maintenance Kit is ideal for this purpose.

To clean the conductivity cell:

1. Dip the brush in clean water and insert it into each hole 1520 times.

2. Rinse the cell thoroughly in deionized or clean tap water.

NOTE: In the event that deposits have formed on the electrodes, perform the following additional procedure:

1. Use a mild detergent solution in combination with the brush. Dip the brush in the solution and insert it into each hole 1520 times.

2. Rinse the cell thoroughly in deionized or clean tap water.

   NOTE: After cleaning, check the response and accuracy of the conductivity cell with a calibration standard.

   NOTE: If this procedure is unsuccessful, or if sensor performance is impaired, it may be necessary to return the sensor to a YSI authorized service center for service, Refer to *Appendix E Customer Service*.

   The temperature portion of the sensor requires no maintenance.

11.2 Upgrading YSI 556 MPS Software

1. Access the YSI Environmental Software Downloads page as described in *Appendix G EcoWatch* Step 1 through 3.

2. Click on the **YSI Instruments Software Updates** link (or scroll down until you see YSI 556 MPS).

3. Click on the file icon to the right of the **YSI 556 MPS** listing and save the file to a temporary directory on your computer.

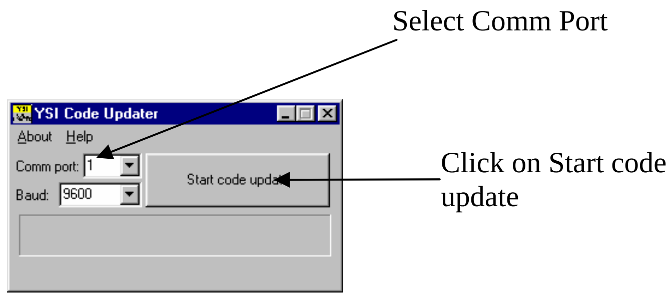
4. After the download is complete, run the file (that you just downloaded) and follow the on screen instructions to install the YSI Code Updater on your computer. If you encounter difficulties, contact YSI customer service for advice. Refer to *Appendix E Customer Service*.

5. If necessary, disconnect the YSI 5563 Probe Module from the YSI 556 MPS instrument.

6. Connect the YSI 556 MPS to a serial port of your computer via the 655173 PC interface cable. See Figure 8.6 Computer/Instrument Interface.

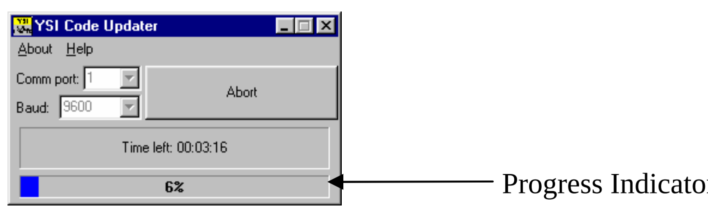
7. Press the **On/off** key on the YSI 556 MPS to display the run screen.

8. Run the YSI Code Updater software that you just installed on your computer. The following window will be displayed:



9. Set the Comm port number to match the port that you connected the 655173 PC Interface Cable to, then click on the Start Code Update button.

The YSI 556 MPS screen will blank out and a progress indicator will be displayed on the PC.



When the update is finished (indicated on the PC screen), the YSI 556 MPS will return to the Run screen. See Figure 7.1 Run Screen.

10. Close the YSI Code Updater window (on the PC) by clicking on the "X" in the upper right corner of the window.

11. Disconnect the YSI 556 MPS from the 655173 PC interface cable and reconnect it to the YSI 5563 Probe Module. Refer to Section *3.6 Instrument/Cable Connection*.

12. Storage

Proper storage between periods of usage will not only extend the life of the sensors, but will also ensure that the unit will be ready to use as quickly as possible in your next application.

12.1 General Recommendations for Short Term Storage

No matter what sensors are installed in the instrument, it is important to keep them moist without actually immersing them in liquid. Immersing them could cause some of them to drift or result in a shorter lifetime.

YSI recommends that short term storage of all multi-parameter instruments be done by placing approximately 1/2 inch of tap water in the transport/calibration cup that was supplied with the instrument, and by placing the probe module with all of the sensors installed into the cup. The use of a moist sponge instead of a 1/2 inch of tap water is also acceptable, as long as its presence does not compromise the attachment of the cup to the probe module. The transport/calibration cup should be sealed to prevent evaporation.

NOTE: Ensure that an o-ring is installed in the o-ring groove on the threaded end of the probe module body. See Figure 3.7 Transport/Calibration Cup Installation.

⚠ **CAUTION**: The water level has to be low enough so that none of the sensors are actually under water. Check the transport/calibration cup periodically to make certain that the water is still present or the sponge is still moist.

NOTE: If the storage water (tap water) is accidentally lost during field use, environmental water can be used.

12.2 General Recommendations for Long Term Storage

12.2.1 Probe Module Storage

1. Remove the pH or pH/ORP sensor from the probe module and store according to the individual sensor storage instructions found in Section *12.2.2 Sensor Storage*.

2. Seal the empty port with the provided port plug.

   NOTE: Leave the conductivity/temperature sensor and dissolved oxygen sensor, with membrane cap still on, in the probe module.

3. Place 1/2″ of water, deionized, distilled or tap, in the transport/calibration cup.

⚠ **CAUTION:** The water level has to be low enough so that none of the sensors are actually under water. Check the transport/calibration cup periodically to make certain that the water is still present or the sponge is still moist.

4. Insert the probe module into the cup.

   NOTE: Ensure that an o-ring is installed in the o-ring groove on the threaded end of the probe module body. See Figure 3.7 Transport/Calibration Cup Installation.

12.2.2 Sensor Storage

Temperature/Conductivity Sensor

No special precautions are required. Sensor can be stored dry or wet, as long as solutions in contact with the thermistor and conductivity electrodes are not corrosive (for example, chlorine bleach). However, it is recommended that the sensor be cleaned with the provided brush prior to long term storage. Refer to Section *11.1.4 Temperature/Conductivity Sensor Cleaning*.

pH and Combination pH/ORP Sensor

The key to sensor storage is to make certain that the reference electrode junction does not dry out. Junctions which have been allowed to dry out due to improper storage procedures can usually be rehydrated by soaking the sensor for several hours (overnight is recommended) in a solution which is 2 molar in potassium chloride. If potassium chloride solution is not available, soaking the sensor in tap water or commercial pH buffers may restore sensor function. However in some cases the sensor may have been irreparably damaged by the dehydration and will require replacement.

⚠ **CAUTION:** Do not store the sensor in distilled or deionized water as the glass sensor may be damaged by exposure to this medium.

1. Remove the pH or pH/ORP sensor from the probe module.

2. Seal the empty port with the provided port plug.

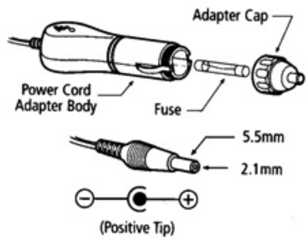
3. Place the sensor in the storage vessel (plastic boot or bottle) which was on the sensor at delivery. The vessel should contain a solution which is 2 molar in potassium chloride.

   NOTE: Make certain that the vessel is sealed to prevent evaporation of the storage solution.

13. Troubleshooting

The following sections describe problems you may encounter when using the YSI 556 MPS and provides suggestions to overcome the symptom.

PROBLEM	POSSIBLE SOLUTION
Display Problems	
No display is visible after pressing the on/off key.	If C cells are used, make certain that they are installed properly with regard to polarity and that good batteries are used. If a rechargeable battery pack is used, place the pack in the instrument and charge for 30 minutes.
Instrument software appears to be locked up as evidenced by no response to keypad entries or display not changing.	First, attempt to reset the instrument by simply turning off and then on again. If this fails, remove battery power from the instrument for 30 seconds and then reapply power. When using C cells, remove the battery lid and one of the batteries; when using the rechargeable battery pack, remove the pack completely from the instrument. After 30 seconds replace the battery or battery pack and check for instrument function.
The 556 display flashes and the instrument speaker makes a continuous clicking sound.	The battery voltage is low. Change to new C cells or recharge the 6117 battery pack.
Water Damage to Instrument	
Leakage detected in battery compartment when using C cells.	Dispose of batteries properly. Dry the battery compartment using compressed air if possible. If corrosion is present on battery terminals, contact YSI Customer Service.
Water has contacted rechargeable battery pack.	Remove battery pack immediately. Send battery pack to YSI Product Service for evaluation. **CAUTION**: DO NOT REUSE BATTERY PACK UNTIL YSI PRODUCT SERVICE HAS EVALUATED IT.
Leakage suspected into the main cavity of the instrument case.	Remove the batteries immediately. Return the instrument to YSI Product Service.

PROBLEM	POSSIBLE SOLUTIONS
Optional Cigarette Lighten Charger	
Power cord fuse blown.  	1. Unscrew adapter's cap, remove tip and pull out fuse. 2. Replace fuse with a new 2-amp fast-blow fuse from an electronics store such as Radio Shack. 3. Reassemble the adapter and securely screw the cap back onto the adapter body.
File Problems	
Upload of files from YSI 556 MPS to PC fails	1. Make sure that cable is connected properly to both 556 and PC. 2. Make certain that the proper Comm port is selected in EcoWatch for Windows.
Barometer data is not stored with sensor data file.	Make sure **Store barometer** is active in the 556 **Logging setup** menu.
Site Descriptions in the **Site List** are "grayed-out" and not available for appending files with additional data.	There is a parameter mismatch between the current 556 setup and that initially used. Change the current logging and sensor setup to match the setup that was initially used to create the file.
Sensor Problems	
Dissolved Oxygen reading is unstable or inaccurate. Out of Range message appears during calibration.	Sensor not properly calibrated. Follow DO cal procedures.
	Membrane not properly installed or may be punctured. Replace membrane cap.
	DO sensor electrodes require cleaning. Follow DO cleaning procedure. Use 5511 Maintenance kit.
	Water in sensor connector. Dry connector; reinstall sensor.
	Algae or other contaminant clinging to DO sensor. Rinse DO sensor with clean water.
	Barometric pressure entry is incorrect. Repeat DO cal procedure.
	Calibrated at extreme temperature. Recalibrate at (or near) sample temperature.
	DO sensor has been damaged. Replace sensor.
	Internal failure. Return probe module for service.

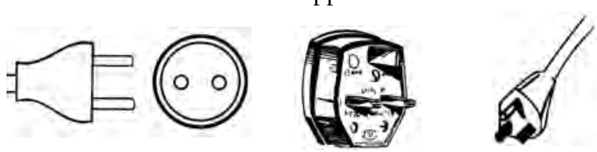
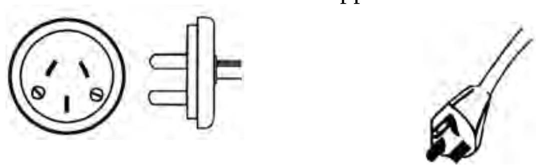
PROBLEM	POSSIBLE SOLUTIONS
Sensor Problems	
pH or ORP readings are unstable or inaccurate. Out of Range message appears during calibration.	Sensor requires cleaning. Follow sensor cleaning procedure.
	Sensor requires calibration. Follow cal procedures.
	pH sensor reference junction has dried out from improper storage. Soak sensor in tap water or buffer 4 until readings become stable.
	Water in sensor connector. Dry connector; reinstall sensor.
	Sensor has been damaged. Replace sensor.
	Calibration solutions out of spec or contaminated with other solution. Use new calibration solutions
	ORP fails Zobell check. Take into account temperature dependence of Zobell solution readings.
	Internal failure. Return probe module for service.
Conductivity unstable or inaccurate. Out of Range message appears during calibration	Conductivity improperly calibrated. Follow calibration procedure.
	Conductivity sensor requires cleaning. Follow cleaning procedure.
	Conductivity sensor damaged. Replace sensor.
	Calibration solution out of spec or contaminated. Use new calibration solution.
	Internal failure. Return probe module for service.
	Calibration solution or sample does not cover entire sensor. Immerse sensor fully.
Temperature, unstable or inaccurate	Water in connector. Dry connector; reinstall sensor.
	Sensor has been damaged. Replace the 5560 sensor.
Installed sensor has no reading	The sensor has been disabled. Enable sensor.
	Water in sensor connector. Dry connector; reinstall sensor.
	Sensor has been damaged. Replace sensor.
	Report output improperly set up. Set up report output.
	Internal failure. Return probe module for service.

If these guidelines and tips fail to correct your problem or if any other symptoms occur, contact YSI Customer Service for Advice. Refer to *Appendix E Customer Service*.

14. Appendix A YSI 556 MPS Specifications

For the most recent product specifications, please visit the YSI website: www.ysi.com

15. Appendix B Instrument Accessories

ITEM #	ACCESSORY
5563-4	4m Cable with DO/temp/conductivity
5563-10	10m Cable with DO/temp/conductivity
5563-20	20m Cable with DO/temp/conductivity
5564	pH Kit
5565	pH/ORP Kit
6118	Rechargeable Battery Pack Kit for use in US
5094	Rechargeable Battery Pack Kit with universal charger and three adapter cables for use in international applications 
5095	Rechargeable Battery Pack Kit with universal charger and two adapter cables for use in international applications 
5083	Flow Cell – probe module is secured in the flow cell and groundwater is pumped through it. Displaced volume approx. 475 ml
3059	Flow Cell, low volume. Displaced volume approx. 200 ml
116505	Battery Lid
616	Charger, Cigarette Lighter – used to power up the instrument from a car's cigarette lighter
4654	Tripod
614	Ultra Clamp, C Clamp –used to clamp the instrument to a table top or car dashboard
6081	Large Carrying Case, Hard-sided
5085	Hands-free Harness
5065	Carrying Case, Form-fitted, for use in the field – has a clear vinyl window, shoulder strap, belt loop strap and hand strap

16. Appendix C Required Federal Communications Notice

The Federal Communications Commission defines this product as a computing device and requires the following notice.

This equipment generates and uses radio frequency energy and if not installed and used properly, may cause interference to radio and television reception. It has been type tested and found to comply with the limits for a Class A or Class B computing device in accordance with the specification in Subpart J of Part 15 of FCC Rules, which are designed to provide reasonable protection against such interference in a residential installation. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient the receiving antenna
- Relocate the computer with respect to the receiver
- Move the computer away from the receiver
- Plug the computer into a different outlet so that the computer and receiver are on different branch circuits.

If necessary, the user should consult the dealer or an experienced radio/television technician for additional suggestions. The user may find the following booklet, prepared by the Federal Communications Commission, helpful: "How to Identify and Resolve Radio-TV Interference Problems". This booklet is available from the U.S. Government Printing Office, Washington, D.C. 20402, Stock No.0004-000-00345-4.

17. Appendix D Health Safety

YSI Conductivity Solutions: 3161, 3163, 3165, 3167, 3168, 3169

INGREDIENTS:

- Iodine
- Potassium Chloride
- Water

WARNING: INHALATION MAY BE FATAL

⚠ ***CAUTION*: AVOID INHALATION, SKIN CONTACT, EYE CONTACT OR INGESTION. MAY EVOLVE TOXIC FUMES IN FIRE.**

Harmful if ingested or inhaled. Skin or eye contact may cause irritation. Has a corrosive effect on the gastro-intestinal tract, causing abdominal pain, vomiting, and diarrhea. Hyper-sensitivity may cause conjunctivitis, bronchitis, skin rashes etc. Evidence of reproductive effects.

FIRST AID:
INHALATION: Remove victim from exposure area. Keep warm and rest. In severe cases seek medical attention.
SKIN CONTACT: Remove contaminated cloth immediately. Wash affected area thoroughly with large amounts of water. In severe cases seek medical attention.
EYE CONTACT: Wash eyes immediately with large amounts of water, (approx. 10 minutes). Seek medical attention immediately.
INGESTION: Wash out mouth thoroughly with large amounts of water. Seek medical attention immediately.

YSI pH 4.00, 7.00, y 10.00: 3821, 3822, 3823

pH 4 INGREDIENTS:

- Potassium Hydrogen Phthalate
- Formaldehyde
- Water

pH 7 INGREDIENTS:

- Sodium Phosphate, Dibasic
- Potassium Phosphate, Monobasic
- Water

pH 10 INGREDIENTS:

- Potassium Borate, Tetra
- Potassium Carbonate
- Potassium Hydroxide
- Sodium (di) Ethylenediamine Tetraacetate
- Water

⚠ **CAUTION -AVOID INHALATION, SKIN CONTACT, EYE CONTACT OR INGESTION. MAY AFFECT MUCOUS MEMBRANES.**

Inhalation may cause severe irritation and be harmful. Skin contact may cause irritation; prolonged or repeated exposure may cause Dermatitis. Eye contact may cause irritation or conjunctivitis. Ingestion may cause nausea, vomiting and diarrhea.

FIRST AID:
INHALATION – Remove victim from exposure area to fresh air immediately. If breathing has stopped, give artificial respiration. Keep victim warm and at rest. Seek medical attention immediately.
SKIN CONTACT – Remove contaminated clothing immediately. Wash affected area with soap or mild detergent and large amounts of water (approx. 15-20 minutes). Seek medical attention immediately.
EYE CONTACT - Wash eyes immediately with large amounts of water (approx. 15-20 minutes), occasionally lifting upper and lower lids. Seek medical attention immediately.

INGESTION – If victim is conscious, immediately give 2 to 4 glasses of water and induce vomiting by touching finger to back of throat. Seek medical attention immediately.

YSI Zobell Solution: 3682

INGREDIENTS:

- Potassium Chloride
- Potassium Ferrocyanide Trihydrate
- Potassium Ferricyanide

⚠ **CAUTION -AVOID INHALATION, SKIN CONTACT, EYE CONTACT OR INGESTION. MAY AFFECT MUCOUS MEMBRANES.**

May be harmful by inhalation, ingestion, or skin absorption. Causes eye and skin irritation. Material is irritating to mucous membranes and upper respiratory tract. The chemical, physical, and toxicological properties have not been thoroughly investigated.

Ingestion of large quantities can cause weakness, gastrointestinal irritation and circulatory disturbances.

FIRST AID:
INHALATION – Remove victim from exposure area to fresh air immediately. If breathing has stopped, give artificial respiration. Keep victim warm and at rest. Seek medical attention immediately.
SKIN CONTACT – Remove contaminated clothing immediately. Wash affected area with soap or mild detergent and large amounts of water (approx. 15-20 minutes). Seek medical attention immediately.
EYE CONTACT - Wash eyes immediately with large amounts of water (approx. 15-20 minutes), occasionally lifting upper and lower lids. Seek medical attention immediately.
INGESTION – If victim is conscious, immediately give 2 to 4 glasses of water and induce vomiting by touching finger to back of throat. Seek medical attention immediately.

18. Appendix E Customer Service

18.1 Ordering and Technical Support

Telephone:	800 897 4151 (US)
	+1 937 767 7241 (Globally)
	Monday through Friday, 8:00 AM to 5:00 ET
Fax:	+1 937 767 9353 (orders)
	+1 937 767 1058 (technical support)
Email:	environmental@ysi.com or proseries@ysi.com
Mail:	YSI Incorporated
	1725 Brannum Lane
	Yellow Springs, OH 45387 USA
Website:	www.ysi.com

18.2 YSI Authorized Service Centers

YSI has authorized service centers throughout the United States and Internationally. For the nearest service center information, please visit www.ysi.com and click ‘Support’ or contact YSI Technical Support directly at 800-897-4151.

When returning a product for service, include the Product Return form with cleaning certification. The form must be completely filled out for a YSI Service Center to accept the instrument for service. The form may be downloaded from www.ysi.com by clicking on the ‘Support” tab, then the Product Return Form button.

18.3 Cleaning Instructions

Equipment exposed to biological, radioactive, or toxic materials must be cleaned and disinfected before being serviced. Biological contamination is presumed for any instrument, probe, or other device that has been used with body fluids or tissues, or with wastewater. Radioactive contamination is presumed for any instrument, probe or other device that has been used near any radioactive source.

If an instrument, probe, or other part is returned or presented for service without a Cleaning Certificate, and if in our opinion it represents a potential biological or radioactive hazard, our service personnel reserve the right to withhold service until appropriate cleaning, decontamination, and certification has been completed. We will contact the sender for instructions as to the disposition of the equipment. Disposition costs will be the responsibility of the sender.

When service is required, either at the user's facility or at a YSI Service Center, the following steps must be taken to ensure the safety of service personnel.

- In a manner appropriate to each device, decontaminate all exposed surfaces, including any containers. 70% isopropyl alcohol or a solution of 1/4-cup bleach to 1-gallon tap water is suitable for most disinfecting. Instruments used with wastewater may be disinfected with .5% Lysol if this is more convenient to the user.
- The user shall take normal precautions to prevent radioactive contamination and must use appropriate decontamination procedures should exposure occur.
- If exposure has occurred, the customer must certify that decontamination has been accomplished and that no radioactivity is detectable by survey equipment.
- Any product being returned to the YSI Repair Center should be packed securely to prevent damage.
- Cleaning must be completed and certified on any product before returning it to YSI.

18.4 Packing Procedure

- Clean and decontaminate items to ensure the safety of the handler.
- Complete and include the Cleaning Certificate.
- Place the product in a plastic bag to keep out dirt and packing material.
- Use a large carton, preferably the original, and surround the product completely with packing material.
- Insure for the replacement value of the product.

18.5 Warranty

The instrument is warranted for three years against defects in workmanship and materials when used for its intended purposes and maintained according to instructions. The probe module and cables are warranted for one year. The dissolved oxygen, temperature/conductivity, pH, and pH/ORP combination sensors are warranted for one year. Damage due to accidents, misuse, tampering, or failure to perform prescribed maintenance is not covered. The warranty period for chemicals and reagents is determined by the expiration date printed on their labels. Within the warranty period, YSI will repair or replace, at its sole discretion, free of charge, any product that YSI determines to be covered by this warranty.

To exercise this warranty, write or call your local YSI representative, or contact YSI Customer Service in Yellow Springs, Ohio. Send the product and proof of purchase, transportation prepaid, to the Authorized Service Center selected by YSI. Repair or replacement will be made and the product returned transportation prepaid. Repaired or replaced products are warranted for the balance of the original warranty period, or at least 90 days from date of repair or replacement.

Limitation of Warranty

This Warranty does not apply to any YSI product damage or failure caused by (i) failure to install, operate or use the product in accordance with YSI's written instructions, (ii) abuse or misuse of the product, (iii) failure to maintain the product in accordance with YSI's written instructions or standard industry procedure, (iv) any improper repairs to the product, (v) use by you of defective or improper components or parts in servicing or repairing the product, or (vi) modification of the product in any way not expressly authorized by YSI.

THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED OR IMPLIED, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. YSI'S LIABILITY UNDER THIS WARRANTY IS LIMITED TO REPAIR OR REPLACEMENT OF THE PRODUCT, AND THIS SHALL BE YOUR SOLE AND EXCLUSIVE REMEDY FOR ANY DEFECTIVE PRODUCT COVERED BY THIS WARRANTY. IN NO EVENT SHALL YSI BE LIABLE FOR ANY SPECIAL, INDIRECT, INCIDENTAL OR CONSEQUENTIAL DAMAGES RESULTING FROM ANY DEFECTIVE PRODUCT COVERED BY THIS WARRANTY.

19. Appendix F Ferrite Bead Installation

⚠ **WARNING:** If you are using your YSI 556 in a European Community (CE) country or in Australia or New Zealand, you must attach a ferrite bead to the 655173 PC Interface Cable and the YSI 6117 Charger Adapter Cable in order to comply with the Residential, Commercial and Light Industrial Class B Limits for radio-frequency emissions specified in EN55011 (CISPR11) for Industrial, Scientific and Medical laboratory equipment. These ferrite assemblies are supplied as part of cable kits.

1. Make a small loop (approximately 5 cm in diameter) in the cable near the YSI 556 MS-19 connector.

2. Lay the open ferrite bead assembly under the loop with the cable cross-over position within the cylinder of the ferrite bead.

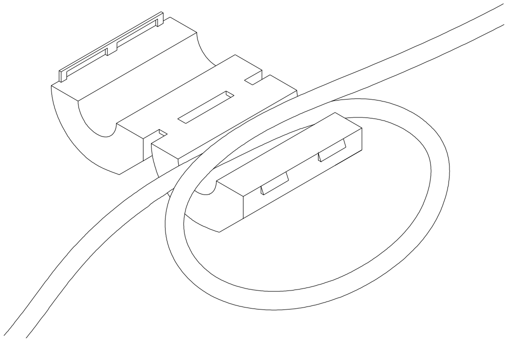


Figure 19.1 Ferrite Bead Installation

3. Snap the two pieces of the bead together making certain that the tabs lock securely.

4. When the installation is complete, the 655173 and 6117 cables should resemble the following drawings.

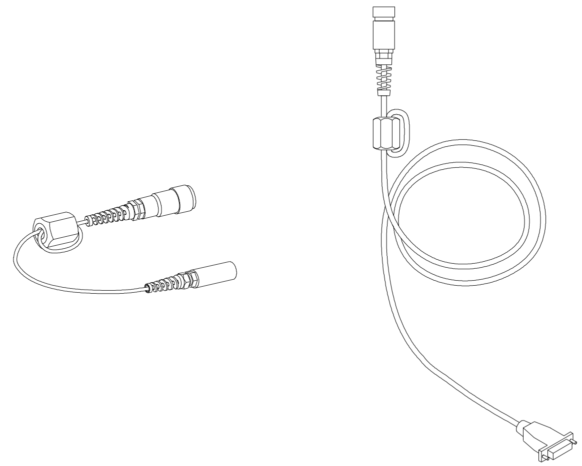


Figure 19.2 Cables with Ferrite Beads

20. Appendix G EcoWatch

EcoWatch™ for Windows™ must be used as the PC software interface to the YSI 556 MPS. EcoWatch is a powerful tool that can also be used with YSI 6-series sondes. Many features of the software will only be utilized by advanced users or are not relevant to the 556 MPS at all. This section is designed in tutorial format to familiarize you with the commonly used features of EcoWatch so that it will be possible to:

- Upload data from a 556 MPS to a PC
- Assemble plots and reports of your data
- Zoom in on certain segments of the plots of your data to facilitate analysis
- Show statistical data for your studies
- Export data in spreadsheet-compatible formats
- Print plots and reports

The advanced features of EcoWatch can be explored by downloading a 6-series manual from the YSI Web Site (www.ysi.com), purchasing a hard copy of the manual through YSI Customer Service (Item # 069300), or utilizing the on-line help feature of the software.

20.1 Installing EcoWatch for Windows

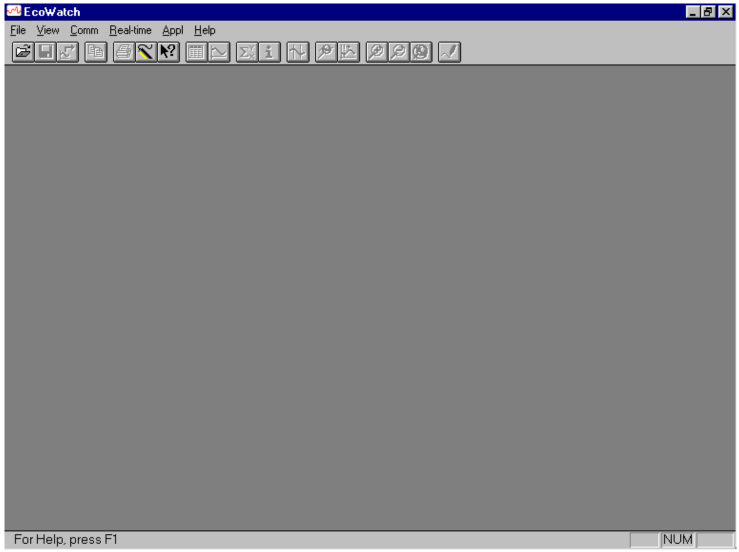
EcoWatch for Windows is available at no cost via a download from the YSI Web Site – www.ysi.com

20.2 EcoWatch Tutorial

This EcoWatch tutorial is designed to teach you the commonly used operations associated with the software when used with your 556 MPS.

After you have uploaded a file, Refer to Section 8.4 Upload to PC, you will see two files in the C:\ECOWWIN\DATA directory; the file you transferred and a file supplied by YSI designated SAMPLE.DAT. This SAMPLE.DAT file is referred to in the remainder of this tutorial section. After following the instructions below for the analysis of SAMPLE.DAT, you apply the same analysis to the data file which was uploaded from your 556 MPS to assure that you are familiar with the basic features and capabilities of EcoWatch for Windows.

To start the analysis of the SAMPLE.DAT file, note that a shortened menu bar is visible and many of the tools in the toolbar appear dimmed or "grayed out" before any file is opened (see below).

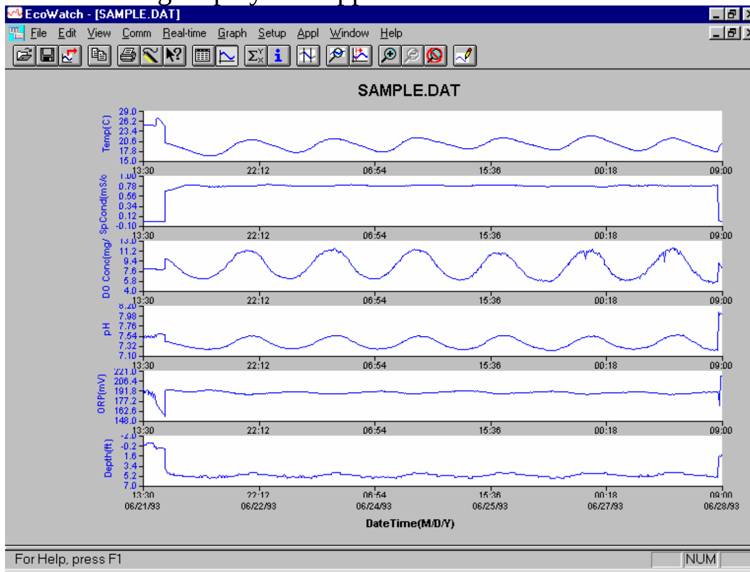


Full activation of EcoWatch features will be realized after a file is opened.

To open the sample data file:

1. Click the **File** menu  button in the toolbar.
2. Select the **SAMPLE.DAT** file.
3. Click **OK** to open the file.

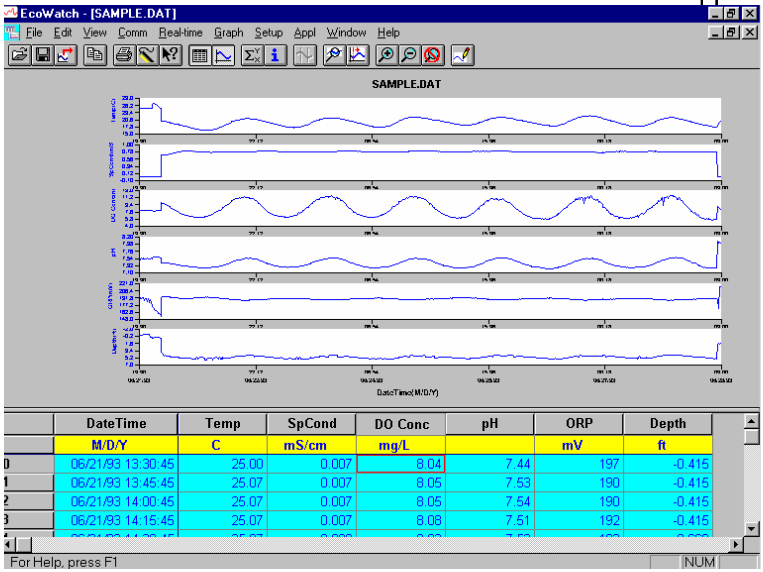
The following display will appear:



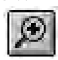
Note that the data in this file appears as a graph of temperature, specific conductance, dissolved oxygen, pH, ORP, and depth, all versus time. The graphs are scaled automatically so that all data fits comfortably on the computer screen. Note also that this data file was obtained with a 6-series sonde for which a depth sensor is available. Depth is NOT a current parameter for the 556 MPS.

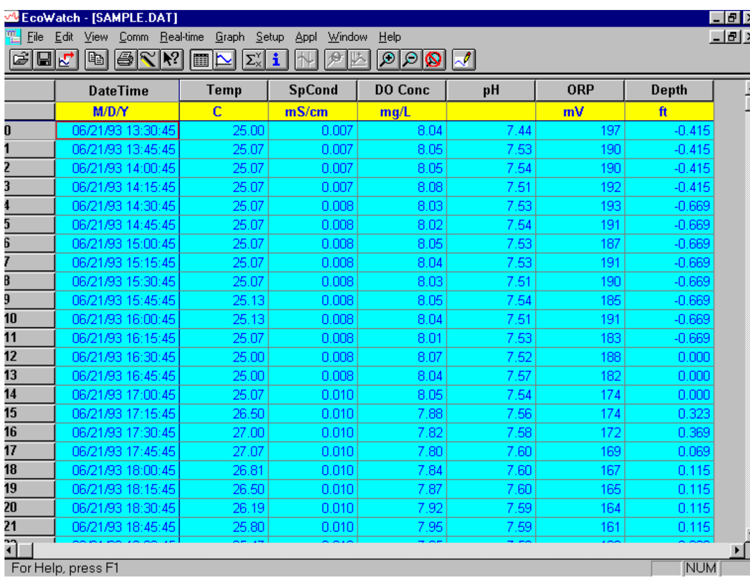
The **Table**  and **Graph**  buttons on the toolbar are on/off switches that are used to display or hide the graph and table pages respectively. When displaying a graph and a table at the same time, you can control the relative size of the two pages by placing the cursor over the small bar that separates them and

then dragging it to the desired location. Click the **Table**  button to generate the following dual display of data.

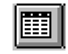
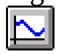


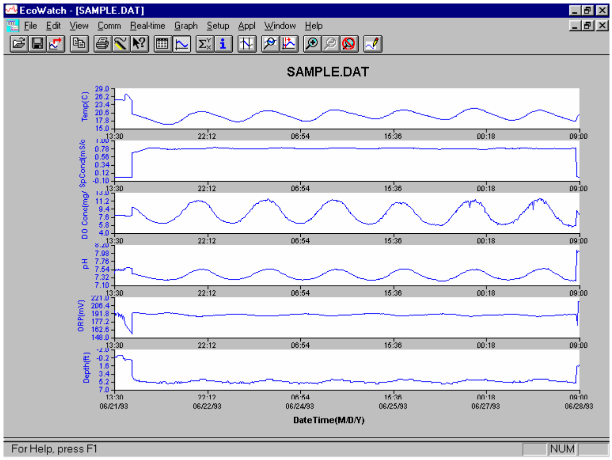
	DateTime	Temp	SpCond	DO Conc	pH	ORP	Depth
	M/D/Y	C	mS/cm	mg/L		mV	ft
0	06/21/93 13:30:45	25.00	0.007	8.04	7.44	197	-0.415
1	06/21/93 13:45:45	25.07	0.007	8.05	7.53	190	-0.415
2	06/21/93 14:00:45	25.07	0.007	8.05	7.54	190	-0.415
3	06/21/93 14:15:45	25.07	0.007	8.08	7.51	192	-0.415

Now click the **Graph**  button (turn it off) to display only a report of your data as shown below. Note that the size of the report can be varied by clicking on the  and  buttons in the Toolbar.

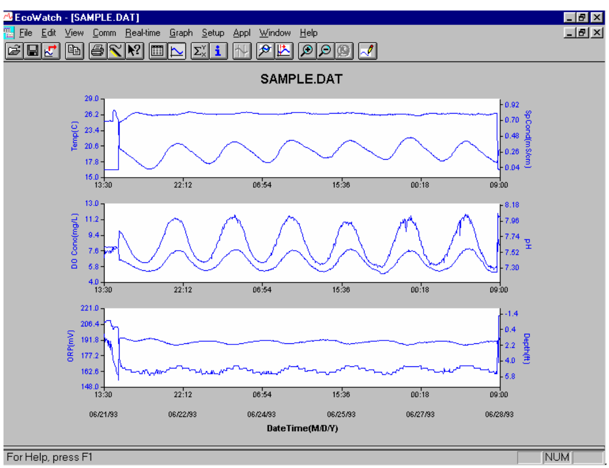


	DateTime	Temp	SpCond	DO Conc	pH	ORP	Depth
	M/D/Y	C	mS/cm	mg/L		mV	ft
0	06/21/93 13:30:45	25.00	0.007	8.04	7.44	197	-0.415
1	06/21/93 13:45:45	25.07	0.007	8.05	7.53	190	-0.415
2	06/21/93 14:00:45	25.07	0.007	8.05	7.54	190	-0.415
3	06/21/93 14:15:45	25.07	0.007	8.08	7.51	192	-0.415
4	06/21/93 14:30:45	25.07	0.008	8.03	7.53	193	-0.669
5	06/21/93 14:45:45	25.07	0.008	8.02	7.54	191	-0.669
6	06/21/93 15:00:45	25.07	0.008	8.05	7.53	187	-0.669
7	06/21/93 15:15:45	25.07	0.008	8.04	7.53	191	-0.669
8	06/21/93 15:30:45	25.07	0.008	8.03	7.51	190	-0.669
9	06/21/93 15:45:45	25.13	0.008	8.05	7.54	185	-0.669
10	06/21/93 16:00:45	25.13	0.008	8.04	7.51	191	-0.669
11	06/21/93 16:15:45	25.07	0.008	8.01	7.53	183	-0.669
12	06/21/93 16:30:45	25.00	0.008	8.07	7.52	188	0.000
13	06/21/93 16:45:45	25.00	0.008	8.04	7.57	182	0.000
14	06/21/93 17:00:45	25.07	0.010	8.05	7.54	174	0.000
15	06/21/93 17:15:45	26.50	0.010	7.88	7.56	174	0.323
16	06/21/93 17:30:45	27.00	0.010	7.82	7.58	172	0.369
17	06/21/93 17:45:45	27.07	0.010	7.80	7.60	169	0.069
18	06/21/93 18:00:45	26.81	0.010	7.84	7.60	167	0.115
19	06/21/93 18:15:45	26.50	0.010	7.87	7.60	165	0.115
20	06/21/93 18:30:45	26.19	0.010	7.92	7.59	164	0.115
21	06/21/93 18:45:45	25.80	0.010	7.95	7.59	161	0.115

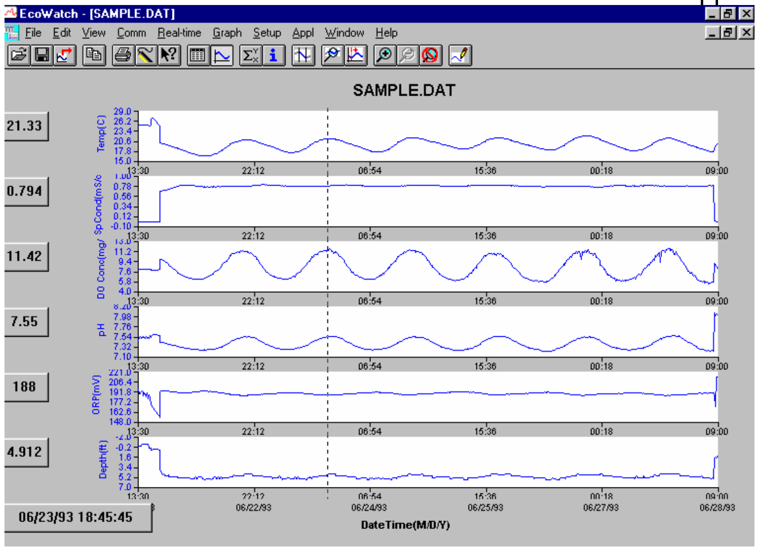
Now return to the original graphic display by toggling the **Table**  button “off” and **Graph**  button “on”.



From the **Setup** menu, click **Graph**. Click **2 Traces per Graph** and notice that the parameters are now graphed in pairs for easy comparison of parameters.

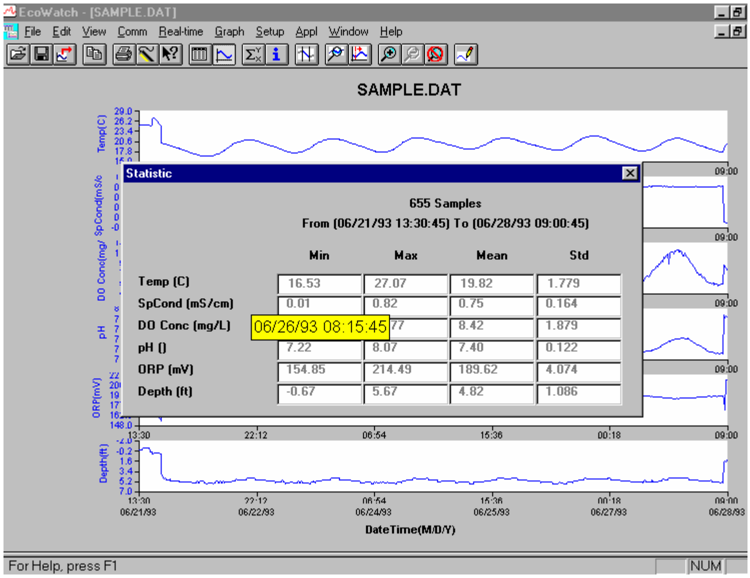


Click **1 Trace per Graph** to return the display to the original setting. Move the cursor to any position in the graph, then click and hold the right mouse button.

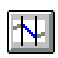


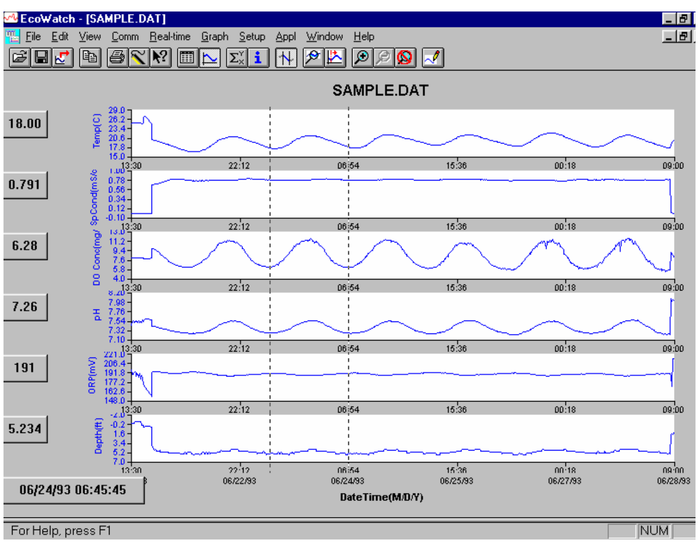
Note that the exact measurements for this point in time are displayed to the left of the graph. While holding down the right mouse button, move to another area on the graph. Notice how the measurements change as you move. When you release the mouse button, the display returns to normal.

To view statistical information for the study, click the **Statistics**  button on the toolbar. On the statistics window, click on any min or max value to display the time when it occurred.

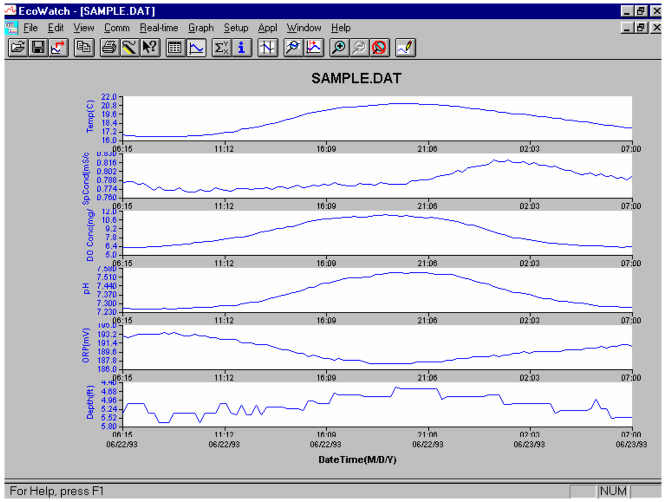


After viewing statistics, click the “x” at the upper right to close the window and return to the normal display.

Now click on the delimiter  icon in the toolbar and then move the displayed icon to the graph. Click at the two points shown by dotted lines in the display below, being sure that the first click is to the left of the second.

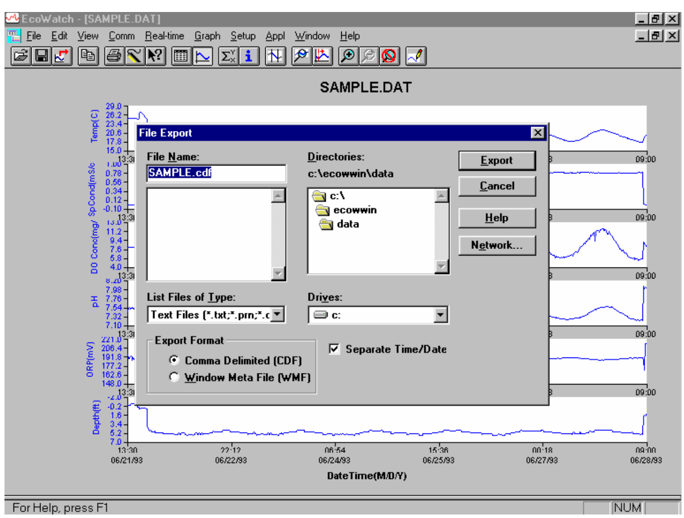


The data between the two selected points will then be graphed in higher resolution as shown below.

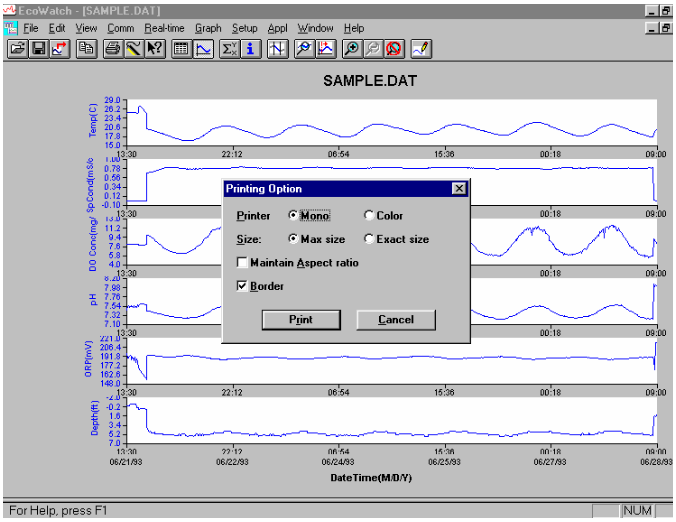


To return to the complete data set, select **Graph** from the toolbar and then click **Cancel Limits**.

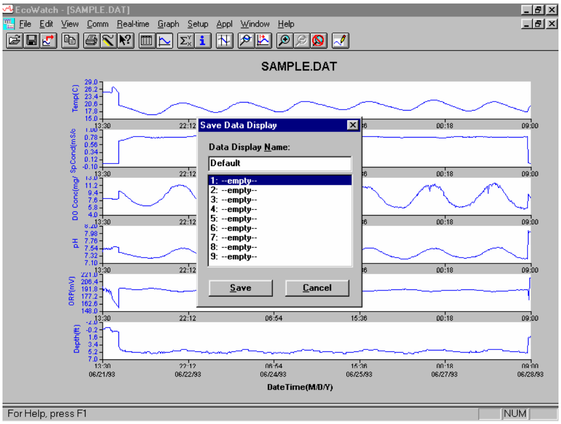
Now select the  icon from the Toolbar to create a new data file which will allow your data to be imported into spreadsheets. Select the default export settings for a Comma Delimited File (.CDF) and click OK. A new spreadsheet-importable file (SAMPLE.CDF) is now present in the same folder as the SAMPLE.DAT file.



Now select the  icon from the toolbar to print the plot. Accept the default settings and click OK to complete the printing operation.



Finally, end the tutorial by saving the **Data Display** in the format shown. From the File menu, click **Save Data Display**.

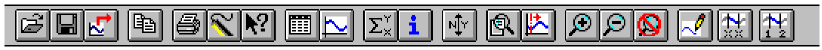


Then type "Default" for the file name and click **Save**. The parameters, colors, format, and x-axis time interval associated with the current display are now saved and can be accessed any time in the future. Nine different data displays may be saved for any data file. You can easily switch between various displays of the data. The data files can be accessed by clicking **Load Data Display** from the file menu and then selecting the desired presentation.

20.2.1 Summary of Toolbar Capability

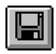
The EcoWatch toolbar includes buttons for some of the most common commands in EcoWatch, such as **File Open**. To display or hide the toolbar, open the **View** menu and click on the **Toolbar** command. A check mark appears next to the menu item when the toolbar is displayed.

The toolbar is displayed across the top of the application window, below the menu bar.

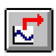


Click to:

Open an existing data file (.DAT). EcoWatch displays the **Open** dialog box, in which you can locate and open the desired file.



Save the working Data Display of the active data file. EcoWatch displays the **Save Data Display** dialog box in which you can overwrite existing Data Display or save to a new one.



Export data as a graph in Window Meta File (.WMF) format or as data in Comma Delimited (.CDF) format.

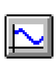
Copy the whole graph page or data from the selection on the table to the clipboard.

Print the active graph page or table page depending on which one is currently active.

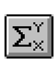
Open a new terminal window to communicate with the sonde.

Access context sensitive help (Shift+F1).

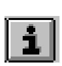
Toggle table window during file processing.



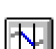
Toggle graph window during file processing.



Display study statistics.



Display study info.



Limit the data to be processed.

Enlarge a selective portion of graph.


Center the graph under the cursor.


Enlarge graph of table 20%.


Reduce graph of table 20%.


Return graph or table to its normal size (unzoom).


Redraw the graph.

20.2.2 Other capabilities

The above tutorial and function list for the toolbar provide basic information to allow you to view and analyze the field data which was stored in your 556 MPS. Some of the other commonly used capabilities of EcoWatch which the user may want to explore are listed below:

- Customize the units for each parameter, e.g., report uS/cm instead of mS/cm for conductivity.
- Customize the order of parameters in each plot or report.
- Customize the colors and fonts of each data display.
- Manually scale the y-axis sensitivity for each parameter.
- Merging of two or more data files with compatible parameter formats
- View information about the study such as number of points, instrument serial number, etc. which was stored in the 556 with the data.
- Print data reports in different statistical formats.
- Create plots of parameter vs. parameter rather than parameter vs. time.

These additional features of EcoWatch for Windows are explained in detail in the YSI 6-series manual (which can be downloaded at no cost from the YSI Web Site as described above) and the Help selection in the EcoWatch menu bar. To purchase a hard copy of the 6-series manual, contact YSI Customer Service using the contact information in *Appendix E Customer Service*.

21. Appendix H Calibration Record Information

When your YSI 556 MPS sensors are initially calibrated, relevant information about the sensors will be stored in a separate file in the YSI 556 MPS memory.

NOTE: This file, by default, will have the name "556 Circuit Board Serial Number.glp." The circuit board serial number is assigned at the factory and has a hexadecimal format such as 000080A4. Thus the default calibration record file would be designated 00080A4.glp. Refer to Section *10.7 GLP Filename* to change the filename.

The information in the calibration record will track the sensor performance of your instrument and should be particularly useful for programs operating under Good Laboratory Practices (GLP) protocols.

21.1 Viewing the Calibration Record (.glp) File

NOTE: Make certain that you have performed a calibration on at least one of the sensors associated with your YSI 556 MPS.

Follow the procedures outlined in Section *8.3 View File*.

21.2 Uploading the Calibration Record (.glp) File

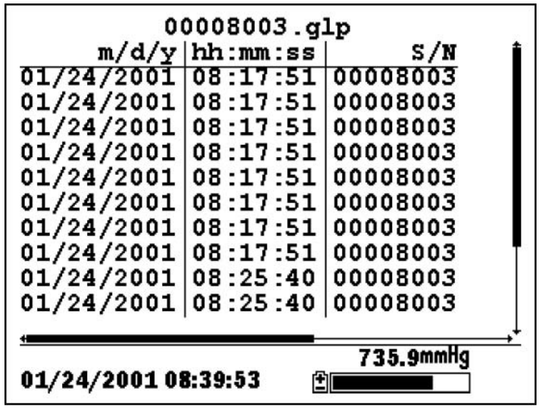
NOTE: Make certain that you have performed a calibration on at least one of the sensors associated with your YSI 556 MPS.

Follow the procedures outlined in Section *8.4 Upload to PC*.

21.3 Understanding the Calibration Record (.glp) File

1. Open a calibration record file. Refer to Section 8.3 View File.

2. Use the arrow keys to scroll horizontally and/or vertically to view all the data.

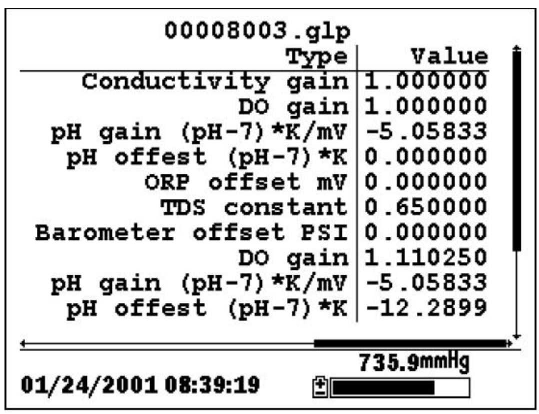


00008003.glp

m/d/y	hh:mm:ss	S/N
01/24/2001	08:17:51	00008003
01/24/2001	08:17:51	00008003
01/24/2001	08:17:51	00008003
01/24/2001	08:17:51	00008003
01/24/2001	08:17:51	00008003
01/24/2001	08:17:51	00008003
01/24/2001	08:17:51	00008003
01/24/2001	08:17:51	00008003
01/24/2001	08:25:40	00008003
01/24/2001	08:25:40	00008003

735.9mmHg
01/24/2001 08:39:53

Figure 21.1Calibration Record Screen 1



00008003.glp

Type	Value
Conductivity gain	1.000000
DO gain	1.000000
pH gain (pH-7)*K/mV	-5.05833
pH offest (pH-7)*K	0.000000
ORP offset mV	0.000000
TDS constant	0.650000
Barometer offset PSI	0.000000
DO gain	1.110250
pH gain (pH-7)*K/mV	-5.05833
pH offest (pH-7)*K	-12.2899

735.9mmHg
01/24/2001 08:39:19

Figure 21.2 Calibration Record Screen 2

NOTE: Each sensor (not parameter) is characterized by either 1 line (Conductivity, Dissolved Oxygen, ORP, TDS, or Barometer (Optional)) or 2 lines (pH) of calibration documentation.

The left hand portion of each calibration entry shows the date and time that a calibration of a particular sensor was performed. In addition, each calibration entry is characterized by the instrument serial number, as defined by YSI. See Figure 21.1 Calibration Record Screen 1. The right hand portion shows the YSI designation of the calibration constants and their values after their calibration has been performed. A more detailed description of the calibration constants is provided below:

- **Conductivity Gain** – A relative number which describes the sensitivity of the sensor. Basically, the value represents the calculated cell constant divided by the typical value of the cell constant (5 cm^{-1}).
- **DO Gain** – A relative number which describes the sensitivity of the sensor. Basically, the value represents the sensor current at the time of calibration divided by the typical value of the sensor current (15 uA).
- **pH Gain** – A number which basically represents the sensitivity of the pH sensor. To remove the effect of temperature on the slope of the relationship of probe output in mv versus pH, the value of pH/mv is multiplied by the temperature in degrees Kelvin (K).
- **pH Offset** – A number which basically represents the offset (or intercept) of the relationship of probe output in mv versus pH, the value of pH is multiplied by the temperature in degrees Kelvin (K).

Anytime you perform a calibration, information concerning the calibration constants will be logged to the Calibration Record file (.glp file). However, if the **Delete All Files** command is used, Refer to Section *8.6 Delete All Files*, the Calibration Record file will also be lost. It is critical that this file should be uploaded to your PC prior to issuing a **Delete All Files** command. Refer to Section *8.4 Upload to PC*.

YSI Environmental
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45387 USA
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937.767.9353 fax
environmental@YSI.com
www.YSI.com

Item # 655279
Rev D
Drawing # A655279
August 2009

Water Quality Meters

geotech

YSI 556 MPS Multi-Probe Field Meter

The YSI 556 MPS simultaneously measures dissolved oxygen, pH, conductivity, temperature, ORP, and more.

The YSI 556 combines the versatility of an easy-to-use, easy-to-read handheld unit with all the functionality of a multiparameter system.

YSI 556 MPS with Kit and optional YSI 5083 Flow Cell

FEATURES

- **Field replaceable Dissolved Oxygen (DO), Conductivity, and pH/ORP electrode modules.**
- **Easy-to-use screw-on cap DO membranes.**
- **4, 10 and 20 meter cable lengths available.**
- **Stores over 49,000 data sets, time and date stamped. Easy download to PC.**
- **Standard soft-sided carrying case with enough space for the YSI 556, 20-meter cable and calibrating supplies.**
- **Probe guard protects sensors for down-well or open channel readings.**

YSI 5083 Screw-On Flow Cell

YSI 3059 Screw-On Flow Cell

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Water Quality Meters

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YSI 556 MPS Multi-Probe Field Meter

SENSOR SPECIFICATIONS

	Sensor Type	Range	Accuracy	Resolution
Dissolved Oxygen (% Saturation)	Steady state polarographic	0 to 500% air saturation	0 to 200% air sat.; ±2% of the reading or ±2% air sat., whichever is greater; 200 to 500% air sat., ±6% of the	0.1% air saturation
Dissolved Oxygen (mg/L)	Steady state polarographic	0 to 50 mg/L	0 to 20mg/L; ±2% of the reading or ±0.2mg/L whichever is greater; 20 to 50 mg/L, ±6% of the reading	0.01 mg/L
Temperature	YSI Temp Precision thermistor	-5° to 45°C	±0.15°C	0.1°C
Conductivity	4-electrode cell with autoranging	0 to 200 mS/cm	±0.5% of reading or +0.001 mS/cm; whichever is greater (4-meter cable) ±1.0% of reading or ±0.001 mS/cm; whichever is greater (20-meter cable)	0.001 mS/cm to 0.1 mS/cm (range dependent)
Salinity	Calculated from conductivity and temperature	0 to 70 ppt	±1.0% of reading or ±0.1ppt, whichever is greater	0.01 ppt
pH Optional	Glass combination electrode	0 to 14 units	±0.2 units	0.01 units
Amplified pH Optional	Combination electrode with ribbon junction and glass	0 to 14 units	±0.2 units	0.01 units
ORP Optional	Platinum button	-1999 to +1999 mV	±20 mV	0.1 mV
Amplified pH/ORP Combo Optional (pH the same as above)	Combination electrode with ribbon junction and platinum button	-999 to 999 mV	±20 mV	0.1 mV
Barometer Optional		500 to 800 mm Hg	±3 mm Hg within ±10°C temperature range from calibration point	0.1 mm Hg
Total Dissolved Solids (TDS)	Calculated from conductivity (variable constant, default 0.65)	0 to 100 g/L		4 digits
Resistivity	Calculated from conductivity reading	Measured in KOhm cm, user dependent	±0.5% of reading	

INSTRUMENT SPECIFICATIONS

Size: 11.9 cm width x 22.9 cm length (4.7 in. x 9 in.)

Weight with Batteries: 2.1 lbs. (916 grams)

Power: 4 alkaline C-cells
Optional rechargeable pack

Cables: 4-m, 10-m, 20-m lengths (13.1 ft., 32.8 ft. and 65.6 ft.)

Communication Port: RS-232 Serial

Data Logger: 49,000 data sets, date and time stamp, manual or logging, with user-selectable intervals

Warranty: 3 year for the instrument, 1 year for probes and cables

Options: Flow Cell
Hard-sided carry case

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Turbidity Meter

860040

Instruction Manual

SPER
SCIENTIFIC

Environmental Measurement Instruments

TABLE OF CONTENTS

INTRODUCTION

This Sper Scientific Turbidity Meter (model 860040) displays the turbidity level of aqueous solutions on a large LCD screen. This meter can measure numerous different types of aqueous solutions and offers a two-point self-calibration feature that can be performed in under a minute. The meter conveniently displays turbidity in the internationally recognized Nephelometric Turbidity Unit of measure (NTU), used in many industries including the beer/wine, water quality, biological growth, and chemical manufacturing industries.

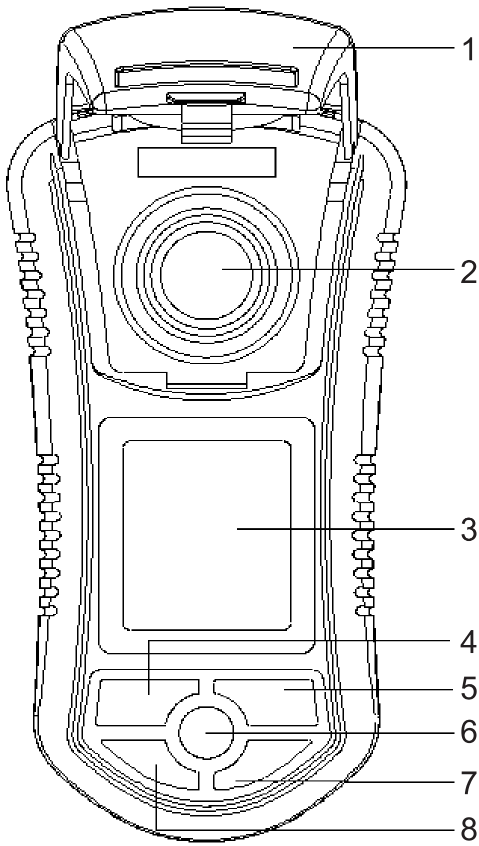
FEATURES

- Reads turbidity values of aqueous solutions
- Protective chamber with lid to prevent debris from entering
- Maximum and Minimum values
- Portable design for use in the field or laboratory
- Data Hold Function
- Optional DC adapter for field use
- Zero adjustment feature for low turbidity solutions

MATERIALS SUPPLIED

- Turbidity meter
- Calibration standards solutions of 0 NTU and 100 NTU
- 2 sampling bottles
- Instruction manual
- 6 AAA batteries
- Carrying case with custom foam interior
- Low Lint Cloth
- Distilled Water for cleaning

FRONT PANEL DESCRIPTION



1. Chamber Lid/protective cover
2. Testing chamber
3. LCD screen
4. Data Hold Button
5. Test / Calibration Button
6. Power Button
7. Zero Button
8. Min/Max Button

SET UP

Battery Installation

This meter uses six AAA batteries. To install the batteries before first use:

1. Unscrew the two screws on the back of the meter. These screws secure the battery cover.
2. Remove the battery cover.
3. Insert six new AAA batteries, ensuring correct polarity.
4. Replace the battery cover and reinstall the screws.

Replace the batteries when the low-battery icon blinks on the LCD.

Note…
Before replacing the batteries, turn the meter off.

Meter On and Off

1. Press **POWER** to turn the meter on/off
2. The meter will automatically turn off after ten minutes of inactivity.

CALIBRATION

Before beginning the calibration procedure, locate the two calibration solutions and keep them close to the meter. If the calibration is not performed quickly, the meter will return to test mode and the calibration will not hold. While this does not damage the meter, the calibration will have to be performed again.

1. Remove the 0NTU and 100NTU bottles from their protective cases. Tighten both caps and shake the bottles gently to ensure they are properly mixed.
2. Clean the outside of both bottles to ensure there are no fingerprints on the glass. Fingerprints or dirt on the glass will alter the readings, so it is critical to handle the bottles by the cap from this point on.
3. Turn the meter on.
4. Press and hold the **TEST/CAL** button until CAL appears on the screen.
5. Let go of the TEST/CAL button. The screen will display 0.0, prompting for the 0NTU standard solution. You will have 20 seconds to perform the next step or the meter will exit calibration mode and return to test mode.

6. Place the 0NTU bottle into the test chamber, lining the vertical white line of the bottle with the white dot on the meter. Close the lid and press the **TEST/CAL** button once. The meter will flash the word CAL on the screen for up to ten seconds.

Note…
If the word Test appears on the screen, you did not perform step 6 fast enough and will need to repeat the process.

7. If the zero point calibration was successful, the meter will stop blinking and display the number 100, prompting for the 100NTU standard solution. Again, you will have 20 seconds to perform this step or the meter will exit calibration mode.
8. Place the 100NTU bottle into the test chamber, lining the vertical white line of the bottle with the white dot on the meter. Close the lid and press the **TEST/CAL** button once. The meter will flash CAL on the screen for up to ten seconds.

Note…
If TEST appears on the screen, you did not perform the 100NTU point fast enough and will need to repeat the process.

9. If the calibration was successful, the screen will stop blinking and display 0.0, indicating that it is ready to test samples.

MEASUREMENT PROCEDURES

For Single Point Readings

1. Pour test sample into one of the two included sample vials.
2. Gently shake the bottle to ensure the sample is properly mixed. If there is sediment in the sample that sinks to the bottle of the vial, the meter will not detect it.
3. Tighten the cap and clean the outside of the sample bottle with a lint free cloth. Be careful not to touch the glass as fingerprints can affect the readings. Handle the sample vial by the cap.
4. Place the sample vial in the test chamber, lining up the white line on the bottle with the white dot on the meter.
5. Press the **TEST/CAL** button once.

For Multi Point Readings

Multi-point mode produces the minimum and maximum values of a set of samples. This is especially useful in the case where there are slight changes in the turbidity of many samples or there is heavy sediment in a single sample. In the case of sediment, you can use this function to get a minimum and maximum reading based on how well the sample is mixed.

Note…
This mode will only provide the minimum and maximum of the samples tested and will not internally store or recall the individual readings within that sample set.

1. Press the **MIN/MAX** button to enter multi-point mode. REC will appear in the upper right hand corner of the meter.
2. Prepare the test sample in the included sample vials and ensure they are clean, dry and free of fingerprints.
3. Place the test sample in the chamber and close the lid.
4. Press the **TEST/CAL** button once. The meter will display the turbidity value of the sample in NTU.

5. Repeat steps 3 and 4 for all samples. The meter can analyze up to 50 samples.
6. Press the **MIN/MAX** button when you are finished with all samples. After pressing the MIN/MAX button, no new values can be added to the set.
7. Press the **MIN/MAX** button as often as needed to display the minimum and maximum turbidity values of the data set in NTU.
8. Press and hold the Min/Max button to exit the Multi-Point mode.
9. After exiting, all values are cleared. Therefore, the next time you enter Multi-Point mode, the meter will only analyze the samples within the new set.

Zero Point Adjustment

This feature is used for low turbidity systems such as well water, tap water, or surface water from lakes and rivers. This method is effective for any solutions whose expected value is <2.0 NTU. The feature allows you to define a custom standard for the zero value. All successive measurements will be offset by this zero value.

Note…
The Zero Adjustment is NOT a calibration. Calibration is performed using the 0NTU and 100NTU solutions as described on page 6.

1. Obtain a sample of your zero standard. This standard should be the lowest turbidity seen in your sample sets. For example, if you were testing a filtration system for drinking water, you would want to obtain a sample from the most successful filtration produced.
2. Place your sample in one of the included test bottles, tighten the cap and ensure the outside of the bottle is free of fingerprints.

3. Place the sample in the test chamber lining up the two white lines and close the lid.
4. Press and hold the **ZERO** button until ZERO appears on the LCD and release the button.
5. The screen will display 0.0 NTU.
6. All readings will be offset by the zero value until the meter is recalibrated or zeroed with the 0NTU standard.

Data Hold

The Minimum/Maximum functions on the meter are disabled during data hold. Also, new readings cannot be taken.

1. Press **HOLD** to freeze the reading on the display. “Hold” appears at the top of the LCD and the reading remains on the display until hold is disabled.
2. Press **HOLD** to return to Normal Mode.

CARE AND MAINTENANCE

- Never wash sample bottles with tap water. The residue left behind can alter readings. Use the included distilled water to clean the sample vials.
- Store the meter with the lid closed to prevent debris from entering the test chamber.
- Periodically wipe the meter with a dry, lint-free antistatic cloth.
- Do not use abrasives, solvents or cleaning agents containing carbon, alcohol or benzenes on the meter.
- Repairs or services not covered in this manual should be performed by qualified personnel only. Please contact Sper Scientific to speak with a technician.
- Periodically wipe the test chamber with a lint free cloth to ensure the internal lens is clean.

SPECIFICATIONS

	Range	Resolution	Accuracy
Turbidity	0 – 49.99 NTU	0.01 NTU	±5% RDG or 0.5 NTU, whichever is greater
	50 – 1000 NTU	1 NTU	±5% RDG or 5 NTU, whichever is greater
Operating Temperature and Humidity	0 - 50°C And less than 85% Relative Humidity		
Power Supply	AAA, 1.5V battery x 6		
Battery Life	250 hours		

WARRANTY

Sper Scientific warrants this product against defects in materials and workmanship for a period of **one (1) year** from the date of purchase, and agrees to repair or replace any defective unit without charge. If your model has since been discontinued, an equivalent Sper Scientific product will be substituted if available. This warranty does not cover sample vials, batteries, battery leakage, or damage resulting from accident, tampering, misuse, or abuse of the product. Opening the meter to expose its electronics will break the waterproof seal and void the warranty. To obtain warranty service, ship the unit postage prepaid to:

SPER SCIENTIFIC LTD.
8281 E. Evans Rd., Suite #103
Scottsdale, AZ 85260
(480) 948-4448

The defective unit must be accompanied by a description of the problem and your return address. Register your product online at www.sperwarranty.com within 10 days of purchase.

rev. 3/15/2018

CO_2-Pro

User's Manual

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Revision 3.0.2

Table of Contents

1.0 Introduction

The CO_2-Pro is an accurate in situ submersible pCO_2 sensor designed for use by scientists for applications in aquatic sciences and the environment where long-term, stable measurements of pCO_2 near the surface are required. The sensor can be deployed in either fresh- or sea- water. The CO_2-Pro is designed for long-term deployments with minimal maintenance.

The CO_2-Pro operates through diffusion of dissolved gases from liquids through a patented supported semi-permeable tubular membrane to a non-dispersive infrared detector (NDIR). The NDIR sensor is factory calibrated using trace gases from the NOAA ESRL GMD Central Calibration Laboratory (http://www.esrl.noaa.gov/gmd/ccl/).

Long-term signal stability is achieved through an automatic zero compensation function that periodically removes CO_2 from the system and records a new zero CO_2 baseline value.

2.0 Instrument Setup

2.1 Instrument Checklist

Each CO_2-Pro purchase comes complete with:

A. CO_2-Pro Instrument

B. Water-Resistant Deck Box with

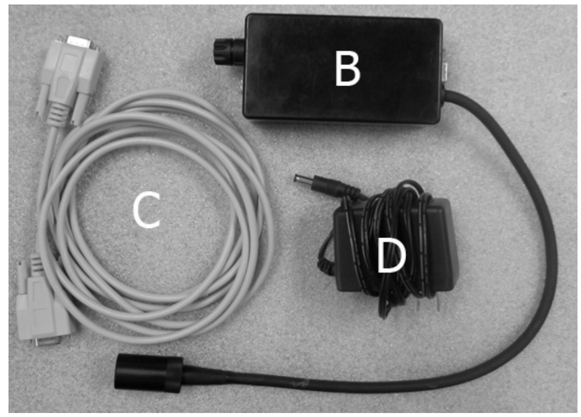
2 meter Underwater Cable and Connector Sleeve

C. 2 meter RS-232 cable

D. AC to DC 12 V Power Supply

E. Pelican Storm Carrying Case

F. User's Manual, QuickStart Guide



2.2 Optional Accessories

a) Internal Datalogger and Controller
b) Seabird 5P (Plastic) or 5T (Titanium) water pump with cable
c) External Battery Pack
    a. 76 Amp-hour capacity
    b. 134 Amp-hour capacity
    c. 268 Amp-hour capacity
d) Mooring frame with instrument brackets
e) Mooring cage with instrument brackets
f) Pigtail Cables with Locking Sleeve
    a. 5 meter Pigtail Cable with Locking Sleeve
    b. 10 m Pigtail Cable with Locking Sleeve
    c. 25 meter Pigtail Cable with Locking Sleeve
    d. 50 meter Pigtail Cable with Locking Sleeve

SBE 5T Water Pump

Instrument and Battery Housing Mooring Bracket

Underwater pigtailed cable with connector and locking sleeve

2.3 Gas Concentration Ranges Available

Standard Measurement Range	0 – 1000 ppm pCO_2
Optional Ranges:	0 – 600 ppm
	0 – 2000 ppm
	0 – up to 100,000 ppm

2.4 Customized Units

Pro-Oceanus can provide customers with uniquely designed and/or modified CO_2-Pro instruments. Customizations can take the form of larger battery pack capacity, variable concentration ranges, and modifications to the logging program, housing material, membrane thickness, and more. If you have a specific need, contact Pro-Oceanus to discuss possible solutions.

3.0 Instrument Setup and User Interface

3.1 Instrument Setup

The CO_2-Pro employs a patented supported semi-permeable tubular membrane interface for equilibration of headspace gas with surrounding water. Water must be pumped through the instrument head for equilibration. The water flow induces shear stress across the membrane surface to prevent fouling.

The instrument is designed for the flow rate provided by Seabird Electronics 5P/5T pumps operating at 12 VDC and either 2000 or 3000 rpm (available from Pro-Oceanus). For other water pumps, water flow rates should be less than three (3) liters per minute. A Seabird Electronics Water Pump can be powered through the 2-Pin underwater bulkhead connector on the CO_2-Pro instrument (labelled Seabird Pump in image below), see pinout diagram in Appendix B. Power and communication to the instrument is through an Impulse MCBH 4-pin underwater bulkhead connector (labelled Power/Comm in the image below). Alternative bulkhead connectors are available (i.e. Subcon).

Drift in the sensor signal over time is eliminated through use of the zero point compensation (ZPC) function. The ZPC automatically corrects the CO_2 measurement for changes in detector performance and environmental conditions and facilitates sensor stability. The ZPC operates through stripping CO_2 from the gas stream by routing instrument gas through a column filled with CO_2 absorbent. The frequency of zeroing is user-set with the user interface.

3.2 Sensor Communication and User Interface

The CO_2-Pro sensor is equipped with an internal Oceanus Logger/ Controller module. The hardware provides the user with an easy to use system for modifying data logging parameters. Units without the logger/controller will still be controlled through the user interface described below, however, many of the features will not be available to the user.

*NOTE: The "Legacy" non-logging CO2-Pro sensor can be ordered with the operational commands that are outlined in Appendix C. This is for customers who currently have non-logging CO2-Pro and CO2-Pro CV instruments and would like to have the same data format and functions as their current instrument.

Communication with the Oceanus Controller begins with a PC-based computer running Microsoft Windows. The computer must be equipped with a serial port, or a USB-serial cable with appropriate drivers installed. Any terminal program can be used to communicate with the Oceanus Logger. Tera Term is recommended by Pro-Oceanus and is freely available for download online. The setup of the communication port must be set as described below.

Serial Communications Parameter	**Value**
Baud rate	19200
Data bits	8
Parity	none
Stop bits	1

The logger completely controls the sensor to provide highly accurate data at the lowest possible power consumption. It handles all interface and timing functions and controls the water pump duty cycle, sensor power and wait times to provide accurate data that is stored in internal memory with a capacity of two gigabytes.

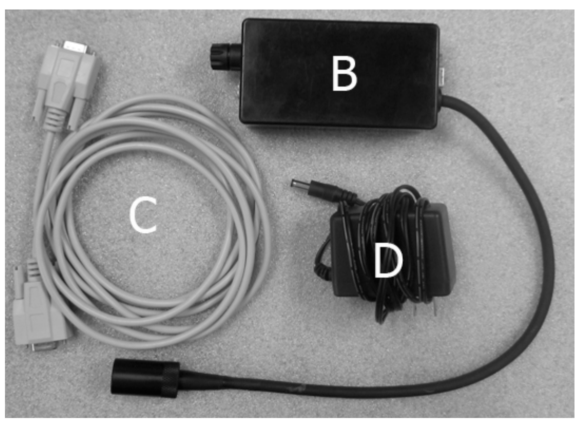
The logger has three operational modes with different options available for each. *Continuous mode* takes samples as fast as possible. *Timed mode* takes samples on a timed schedule. *Command mode* allows the user to trigger a single sampling sequence. Different options are provided for each mode to allow the user to fine tune the sampling process. Detailed settings for each mode are described in section 3.2.3

3.2.1 User Interface

The logger is controlled and configured through the user interface that consists of a dedicated serial port and a menu driven command and control system. The serial port is normally shut down for low power consumption, but will power up automatically on the reception of any byte on the port. Once the system is powered up, an "*escape*" (0x1b hex) command is required to activate the user interface.

To begin communication with the Oceanus Logger/ Controller:

1) Connect the instrument to the communication/power deck-box supplied with the instrument (item **B** in the image below).
2) Connect the instrument to a personal computer with the supplied RS-232 cable (item **C** in image below).
3) Open a terminal program on the computer and set the baud rate to 19,200 (see user interface for more details).
4) Select the correct communication port and open this port.
5) Using the supplied AC/DC wall outlet adapter (item **D** in image below), power the instrument through the deck box.
6) Follow the instructions in section 3.2.2, *Logger / Controller Menu*, to set up the instrument parameters including the time, sampling mode, sampling rate, and frequency of automatic zero CO_2 drift correction.



When power is applied to the instrument, or when a byte is received on the user interface while the system is in low power sleep, the following text will appear in the terminal program:

```
*********************************(CO2 Pro and CO2 Pro CV)*********************************
Oceanus Logger Main Menu
FW Version 1.0.18
Pro Oceanus Inc.

Date: 2015/01/01 Time: 12:00:37

System status:
Detector ORT = 63.06 hours, Zero Count = 0, Supply Voltage = 16.3 volts, Mode = Timed
*******************************************************************************************
```

Above is the system banner that contains the software version as well as the current time and a system status line. The Oceanus Controller is equipped with automatic sleep mode. If no user interaction is detected within 60 seconds of powering the instrument, it will return to low-power sleep. From the banner display press the "*escape"* key to enter the user interface. If the 60-second user-interface timeout has occurred, press any key first and then the "*escape"* key. The first key press will wake the unit from sleep mode and reprint the banner, and the "*escape*" key press will start the user interface.

The system status line has four entries:

1) Detector ORT: the amount of time that the CO_2 detector module connected to the logger has been on and operating,
2) Zero count: a count of the number of internal zero CO2 measurements completed, and,
3) Supply Voltage: measure of the main system power input.
4) Mode: This is the current mode of measurement the sensor has been configured for. This is changed in the main menu under *Setup Sampling*.

3.2.2 Logger / Controller Menu

Once activated, the user interface will display the main system menu as shown below.

```
************************************************************************************
1) START sampling                      6) Print status banner
2) STOP sampling                       7) Sensor status
3) Setup sampling

4) View logged data                    t) Set clock time
5) Erase logged data                   b) Set baud rate
                                       f) Restore factory defaults

z) Schedule a zero for next sample     s) Single sample acquisition in command mode

************************************************************************************
```

The menu is navigated by pressing the character immediately before the ")" in the menu listing above. No *enter* key is required for any menu selection and the *escape* key always exits sub-menus and returns the user to the **main** menu. All other entries other than menu selections must be followed by the *enter* key.

Each of the menu options is described below.

1) START sampling

This option is used to start the system logging data. It is used after the setup sampling system has been configured using the *Setup sampling* menu selection to start operation of the logging system.

2) STOP sampling

This option stops any sampling in progress. **NOTE:** In order to resume sampling after using this option the user must select *Start sampling* from the main menu. **CAUTION:** Once a program has been started, it MUST be STOPPED prior to setting new sampling parameters.

3) Setup sampling

This option displays the sampling setup menu. The *Setup sampling* menu and its options are detailed in section 3.2.3.

4) View logged data

This option is used to view the information saved onboard the Oceanus Logger. When viewing logged data, the first two lines do not contain sensor data. The first line contains the column headings for the data and the second line contains the formatting information used by the Pro-Oceanus Windows hosted user interface program (in development). Printing the data to a terminal program in this can be time consuming due to the limitation of baud rate. To reduce the time to download data in this manner, adjust the baud rate to the maximum allowable rate under the *Set baud rate* option. Ensure that the baud rate is then changed in the terminal program to allow communication. Pressing the *escape* key stops the printing and reprints the main menu returning control to the user. **CAUTION:** Viewing the data will *stop all logging* of data and the *START sampling* menu selection MUST be used to begin logging data again.

For faster data download, the micro-SD memory card may be removed from the internal logger electronics board (and read by a PC equipped with an SD card reader). The log file is named *MainLog.txt* and is in standard comma separated variable format that can be read by any spreadsheet program or text editor such as *notepad*. **NOTE:** For details on removing the micro-SD card, please contact Pro-Oceanus Systems.

5) Erase logged data
This option is used to clear the memory of ALL internally saved data. To prevent the accidental deletion of data, a second confirmation is required. After a second confirmation, any saved data on the Oceanus Logger is permanently erased. Erasing the data will stop all logging of data and the *START sampling* menu selection must be used to begin logging data again.

6) Print status banner
This selection displays the system banner.

7) Sensor status
This option displays the factory settings menu. The factory settings are password protected and are not detailed in this manual.

t) Set clock time
This option is used for changing the system clock that is used to sync all operations of the Oceanus Controller. After selecting this option, the user will be prompted to enter the year, month, day, as well as hour, minute and seconds. Time is entered in 24-hour format. **NOTE:** This must be completed before the start time of the first sample is set.

b) Set baud rate
The baud rate for communication with the sensor can be changed by selecting this option. The following options will be displayed:

The present setting is 19200

Please select one of the following baud rates:
1. 9600
2. 14400
3. 19200
4. 57600
5. 115200

f) Restore factory defaults
This restores all settings to their factory defaults.

z) Schedule a zero for next sample
This selection schedules a zero CO_2 measurement on the **next** sample. Making a measurement on a zero CO_2 gas sample allows for the infrared detector to maintain a steady baseline value over time to ensure the best accuracy of the data.

s) Single sample acquisition in command mode
This option commands the logger to acquire a single sample. It is only active if the system is configured to command mode using the sampling setup menu. During this sample, all system timing is followed so the logger will power up the sensor, wait for warm-up and equilibration then take and store the sample. Once the sample is complete the logger will enter polled mode for two minutes then re-enter low power sleep mode.

3.2.3 Sample Setup Menu

This menu allows setting the sampling mode of the instrument. There are three possible modes, 1) Continuous, 2) Timed, and 3) Command. Each mode is outlined below. After selecting "3" from the main menu, the following appears on screen:

```
*****************************************************************
1) Continuous
2) Timed
3) Command

Current mode is set to timed
*****************************************************************
Press ESC to exit
```

Selecting 1, 2, or 3 will bring up a sub-menu of options for each mode of operation.

1) Continuous Mode:

This mode is intended for use when the logger is connected to an external computer. The logger will wait for the sensor to warm up and then start acquiring data at the fastest rate possible, approximately 1 sample every 1.6 seconds. Each sample is sent to the user interface port for display in a terminal program running on an external computer. In addition, each sample is stored locally in the internal memory. The menu for continuous mode is shown below:

```
Continuous mode menu
***********************************************************************
 1) Number of continuous mode samples skipped between log entries (0)
 2) Clear the zero count
 3) Set re-zero interval in hours                                 (6.00)
***********************************************************************
Press ESC to exit
```

The current setting for any option is displayed in parentheses at the end of each line. The number at the start of each line is pressed to select that option from the setup menu.

1) Number of continuous mode samples skipped between log entries

This selection sets the number of samples to skip between logging in continuous mode. Samples are still displayed on the user interface, but skipped samples are not logged internally to save file space on the micro SD card. To save space in the memory, the logger can be configured to store every N'th reading, where N can range from zero to twenty.

2) Clear the zero count

This selection clears the count of the number of zero point corrections completed. The zero count is used as a guide as to when the CO_2 absorbent should be replaced. This option is used to clear the count when replacing the CO_2 absorbent. The number of recommended zeroes between replacements of CO_2 absorbent is dependent on a number of factors including time, CO_2 level, and temperature. For most ocean applications, 300 zeroes is a reasonable number between CO_2 replacements. **NOTE:** Pro-Oceanus does not guarantee the number of zeroes between CO_2 absorbent replacement because of the range of factors in CO_2 absorbent life.

3) Set re-zero interval in hours

This sets the number of hours between zero point corrections (ZPC). Fractional hours are allowed with a minimum setting of 1 hour and a maximum of 24 hours between zeroing. The re-zero function is used to maintain calibration and accuracy of the detector. To ensure accurate measurements, zero CO_2 readings should be taken periodically to adjust the sensor output for changes in environmental conditions and detector ageing effects. It is recommend to make at least two (2) zero CO_2 measurements per day.

2) Timed Mode

In this mode the logger is configured for autonomous operation. The system will take a sample on a timed schedule and the user may set the time of the first sample and the time interval between samples. Each sample is comprised of up to 20 readings and either the individual readings or their average may be logged to the internal memory, with all readings sent to the user interface. After all the readings for a given sample are complete, the logger will remain operational in a polled state for an additional two minutes allowing the user to request one more reading. Sending an upper case "*D*" or lower case *"d"* to the instrument through the user interface port causes the logger to take an additional reading and output it to the user interface port for use by an external computer. Any polled samples are not stored in the logger internal memory.

The timed mode menu is as follows:

```
Timed sampling setup menu
*********************************************************************************
 1) Set sample interval in minutes                    (35)
 2) Set number of readings per sample                 (1)
3) Start time for first sample                         (00:20:00)
4) Log average                                        (n)
5) Clear the zero count
 6) Set re-zero interval in hours                     (6.00)
*********************************************************************************
Press ESC to exit
```

Each of the menu options is described below.

1) Set sample interval in minutes

This selection is used to set the time interval between samples. The time interval is set in minutes with a minimum value of 30 minutes and a maximum of 10080 minutes. As a reference:

3 hours = 180 minutes
6 hours = 360 minutes
1 day = 1440 minutes
7 days = 10080 minutes

2) Set number of readings per sample

This selection allows the user to set the number of consecutive readings taken at each sample interval. If the *log average* (selection 4) is set to *y* (yes) then the average value of all the data samples is logged. If the *log average* selection is set to *n* (no) then each data sample is logged.

3) Start time for first sample
This sets the time of the first sample in timed mode. This allows for delays to deploy the sensor. Any time may be entered, up to 24 hours from the current time. The user will be prompted to enter the hour, the minute and the second of the start time. Setting a time before the present will result in a start time during the following day. The function basically acts as an alarm clock, waking the system and starting the first sample. **NOTE:** The start time must be set to at least 20 minutes beyond the current time in order to allow the sensor to turn on 20 minutes before the measurement. This time is required to provide sufficient time for the instrument to warm up and equilibrate.

4) Log average
This selection allows averaging multiple readings for each sample in timed mode. If set to "*y*" (yes), the instrument will average N readings per sample. N is set using the number two selection from the sampling setup menu. If set to *"n",* (no) all readings will be logged for each sample.

5) Clear the zero count
This selection clears the count of the number of zero point corrections completed. The zero count is used as a guide as to when the CO_2 absorbent should be replaced. This option is used to clear the count when replacing the CO_2 absorbent. The number of recommended zeroes between replacements of CO_2 absorbent is dependent on a number of factors including time, CO_2 level, and temperature. For most ocean applications, 300 zeroes is a reasonable number between CO_2 replacements. **NOTE:** Pro-Oceanus does not guarantee the number of zeroes between CO_2 absorbent replacement because of the range of factors in CO_2 absorbent life.

6) Set re-zero interval in hours
This sets the number of hours between zero point corrections (ZPC). Fractional hours are allowed with a minimum setting of 1 hour and a maximum of 24 hours between zeroing. The re-zero function is used to maintain calibration and accuracy of the detector. To ensure accurate measurements, zero CO_2 readings should be taken periodically to adjust the sensor output for changes in environmental conditions and detector ageing effects. It is recommend to make at least two (2) zero CO_2 measurements per day.

3) Command mode

This mode gives the user control over the timing of the sample. When configured in this mode the user may start a sample by typing an "*a*" in the user interface at the main menu. All other functions of this mode are the same as timed mode. This mode is useful for external controllers to initiate a sample when desired. **Note** that a sample takes 20 minutes to complete from warm-up through to final equilibration, and the "*a*" command should be sent to the instrument 20 minutes *before* the desired sample time. The menu is as follows:

```
Commanded mode sampling setup menu
*********************************************************************************
 1) Set number of readings per sample                (1)
 2) Log average                                      (n)
3) Clear the zero count
 4) Set re-zero interval in hours                    (6.00)
*********************************************************************************
Press ESC to exit
```

1) Set number of readings per sample

This selection allows the user to set the number of consecutive readings taken at each sample interval. If the *log average* (selection 8) is set to *y* (yes) then the average value of all the data samples is logged. If the *log average* selection is set to *n* (no) then each data sample is logged.

2) Log average

This selection allows averaging multiple readings for each sample in timed mode. If set to "*y*" (yes), the instrument will average N readings per sample. N is set using the number two selection from the sampling setup menu. If set to *"n",* (no) all readings will be logged for each sample.

3) Clear the zero count

This selection clears the count of the number of zero point corrections completed. The zero count is used as a guide as to when the CO_2 absorbent should be replaced. This option is used to clear the count when replacing the CO_2 absorbent. The number of recommended zeroes between replacements of CO_2 absorbent is dependent on a number of factors including time, CO_2 level, and temperature. For most ocean applications, 300 zeroes is a reasonable number between CO_2 replacements. **Note:** Pro-Oceanus does not guarantee the number of zeroes between CO_2 absorbent replacement because of the range of factors in CO_2 absorbent life.

4) Set re-zero interval in hours

This sets the number of hours between zero point corrections (ZPC). Fractional hours are allowed with a minimum setting of 1 hour and a maximum of 24 hours between zeroing. The re-zero function is used to maintain calibration and accuracy of the detector. To ensure accurate measurements, zero CO_2 readings should be taken periodically to adjust the sensor output for changes in environmental conditions and detector ageing effects. It is recommend to make at least two (2) zero CO_2 measurements per day.

3.2.4 Polling Data

A feature of the *sampled mode* of operation is its polling capability. Sending an upper case "*D"* or lower case *"d"* after the instrument has finished logging a sample will return another line of data directly to the user terminal. This polling window remains open for 2 minutes after each logging interval before the unit returns to low power sleep mode. This data is not recorded on the micro SD card.

3.3 Data Output

The data is output and stored in the following format:

W M,2015,01,15,12,03,05,38661,37901,103.66,44.5,1.625,17.023,1017,44.2,44.8,13.6,4095,2487,1875,0,1

The data is in coma separated variable (CSV) format where the fields (numbers between the comas) have the following meanings:

Field number	Description	Value in example
1	Start of data line (this is fixed and may be used to search for the beginning of the data on any line)	*W M*
2	Year	*2015*
3	Month	*01*
4	Day	*15*
5	Hour	*12*
6	Minute	*03*
7	Second	*05*
8	Zero A/D [counts] of most recent auto-zero sequence	*38661*
9	Current A/D [counts]	*37901*
10	Measured CO_2 [ppm]	*103.66*
11	Average IRGA temperature [°C]	*44.5*
12	Humidity [mbar]	*1.625*
13	Humidity sensor temperature [°C]	17.023
14	Gas stream pressure [mbar]	*1017*
15	IRGA detector temperature [°C]	*44.2*
16	IRGA source temperature [°C]	*44.8*
17	Supply voltage [volts]	*13.8*
18	Logger temperature [A/D counts] (0-4095)	*4095*
19	Analog input 1 [A/D counts] (0-4095)	*2487*
20	Analog input 2 [A/D counts] (0-4095)	*1875*
21	Digital input 1 [logic level] (0-1)	*0*
22	Digital input 2 [logic level] (0-1)	*1*

Each data line is terminated with a carrage return linefeed, *CRLF*, sequence. The resolution (number of digits after the decimal) is fixed for each field.

4.0 CO_2 Measurement

4.1 Equilibration dynamics and instrument response time

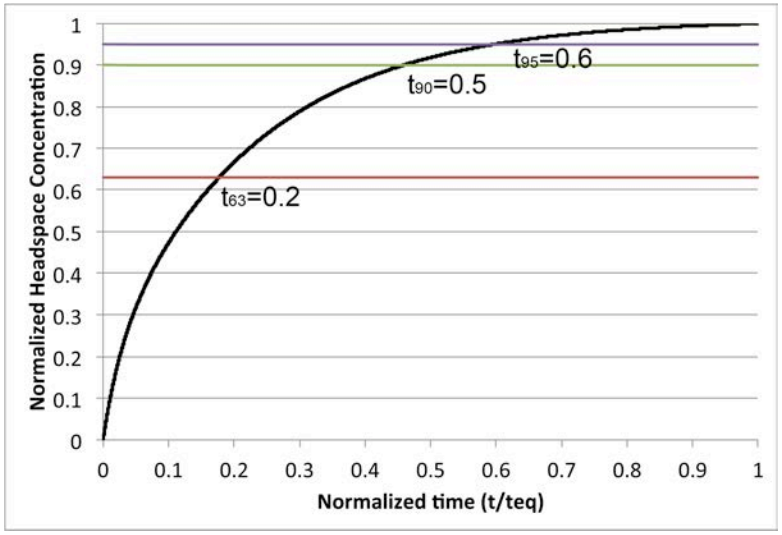
The equilibrium of dissolved gas sensors with surrounding water requires diffusion of molecules from a liquid across a semi-permeable membrane to a gaseous headspace. Once in the gas phase, detectors are used to measure a concentration in gaseous form. Several factors affect the time it takes to equilibrate a gas headspace with a surrounding water parcel through a semi-permeable membrane. The main factors are described below.

There is a finite time that is required for the shift between the dissolved and gas phases of a substance due to the kinetics of solubility. The rate is dependent on temperature and salinity, and to a much lesser degree, pressure.

The membrane effect can be described using the Laws of Diffusion, whereby the diffusion coefficient of the semi-permeable membrane is a function of the gas solubility coefficient in the membrane, and the permeability of that gas through the membrane. The thickness of the membrane also plays a crucial role in the time for equilibration. Temperature and salinity can dramatically affect the diffusion through a membrane.

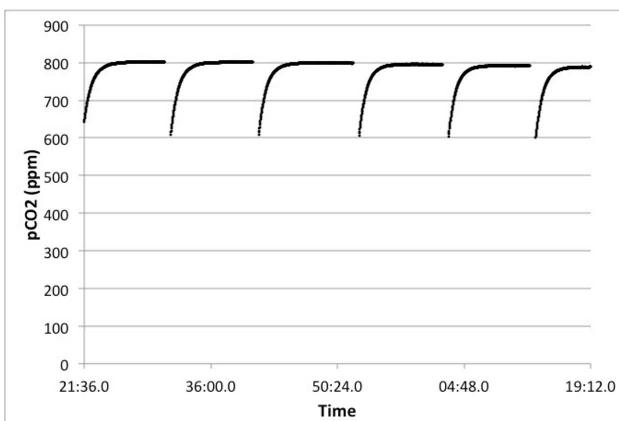
The equilibration rate of diffusion processes is often measured in terms of a time constant, t_{63}. This represents the time it takes reach 63% of equilibrium. The flux of gases across a membrane is a function of the gradient of difference between the concentrations on either side of the membrane. For example, the flux of a gas across a membrane will be rapid when the difference in concentration in surrounding water and the gas headspace is large. As a gas moves across the membrane either into or out of the gas headspace, the concentration gradient decreases, and as a result, the rate of gas flux across the membranes slows.

The concentration gradient across the membrane continually changes, and the resulting change in concentration of a particular gas in a headspace can be described mathematically as a logarithmic function. Below is a graph that illustrates the change in concentration in the headspace of an instrument using a semi-permeable membrane to equilibrate. The graph also shows commonly used time constants used in industry, t_{63}, t_{90}, t_{95}.



t_{63} is taken as one fifth of the total time to equilibrate,
t_{90} is approximately half the time to equilibrate, and
t_{95} is roughly 60% of the time to equilibrate.
t_{99} is taken as teq.

The time constant, t_{63} is commonly used and is the number referred to by Pro-Oceanus. Below is an example of the response of the CO_2-Pro CV after several internal zeroes.



There is also the effect of the water-side boundary layer. Advection transfers the dissolved gas to near the membrane surface is a rapid process, but diffusion of gas through the water boundary layer is the rate limiting factor in the transfer from the water to the outer surface of the semi-permeable membrane. Temperature once again has a major effect on the diffusion rate. In all cases, warmer temperatures improve the response time of the instruments, while cooler waters will slow the process.

The thickness of the boundary layer can vary (and as a result, so too does the time to diffuse through the boundary layer) and the thickness is determined by the hydrodynamics next to the membrane surface. Stagnant water will produce the thickest boundary layer, resulting in the slowest response time. Maximizing the water shear across the membrane surface will reduce the boundary layer thickness to a minimum and is recommended using a Pro-Oceanus pumped head assembly. The effect of high shear also reduces the potential for biofouling of the instrument.

4.2 Infrared detection method

The CO_2-Pro instrument employs a non-dispersive infrared detector (NDIR) to facilitate the measurement of the wet mole fraction of CO_2 in the gas phase that is in equilibrium with the surrounding water. Measurement of CO_2 using IR-based detectors is a standard method for accurate determination of CO_2 at both low and high concentrations.

IR detection measures a gaseous mole fraction of CO_2 within the measurement cell and the output must be corrected for any pressure variations within the cell. A pressure sensor within the detector cell outputs the pressure in millibars (see Data Output). This pressure is used to internally correct the CO_2 measurement and this value is output by the instrument.

Pressure Dependence of Signal:

The dependence of the gas pressure within an NDIR cell is an important, yet often understated issue in measuring gas concentration accurately. The underlying physical principles of NDIR sensor gas detection provide a measure of the number of molecules of a specific gas. In order to accurately calculate the concentration, the total gas pressure must be known in order to determine the ratio of molecules being measured versus the total number of molecules.

The CO_2-Pro detector is fully pressure compensated so that changes in gas pressure are corrected for without the need for post-processing. The pressure of gas inside the detector cell can also be used to estimate the partial pressure of CO_2, pCO_2.

Temperature Dependence:

Changes in temperature within the detector cell will affect the accuracy of the measurement if not appropriately corrected. As gas molecules are heated, their velocities increase, leading to the apparent increase in the number of gas molecules in a given volume by a NDIR detector.

The Pro-Oceanus CO_2-Pro has an internally stabilized gas detector cell temperature that is held at a temperature well above the surrounding water temperature to prevent condensation within the sensing cell.

4.3 Partial pressure of CO_2, pCO_2

CO_2 (g) is commonly measured in units of ppm (parts per million). This is the molar ratio of **x** number of **CO_2** molecules per million molecules of total gas. The ppm of CO_2 in air does not change with pressure. Ppm CO_2 is also referred to as the mixing ratio, xCO_2.

In natural waters, CO_2 (g) is often reported as a partial pressure, pCO_2, with units of microatmospheres (µatm). Unlike xCO_2, pCO_2 is dependent on the total gas pressure. The two terms are related through pressure by:

$$pCO_2 = xCO_2 \text{ X } P \qquad (4.1),$$

where P is pressure measured in microatmospheres and xCO_2 is in ppm.

A third unit of measure for CO_2 is the fugacity, fCO_2. The fugacity corrects for non-ideal gas behavior of gases and can be estimated from approximate expressions along with temperature and pCO_2. In most cases fCO_2 is within a few µatm of pCO_2.

The CO_2-Pro measures the "wet" (i.e. partial pressure of water vapour included) xCO_2 of a gas stream that has equilibrated with surrounding water. In addition, the sensor measures the total pressure, P, of the gas stream, in millibars (mbar). The measured ppm output from the sensor is corrected for pressure variation, as is needed for NDIR measurement. By converting the measured gas pressure to units of atmospheres:

$$P \text{ (mbar)} / 1013.25 / 1000000 = P \text{ (µatm)} \qquad (4.2),$$

pCO_2 (µatm) can then be calculated using Eq. 4.1.

Typically, headspace equilibrators remove water vapor prior to measurement of CO_2, and must be corrected for this. The CO_2-Pro sensor measures the "wet" CO_2 concentration and do not need to be corrected for water vapor.

4.4 CO_2 solubility and dissolved phase concentration

The measurement of CO_2 in water is facilitated by the CO_2-Pro through equilibration of a gas headspace with surrounding water. This results in a measurement that is in the "gas" phase as a partial pressure of the total gas pressure equilibrated with the water. The same equilibration dynamics occur at the surface of a body of water in contact with the atmosphere, such that the concentration of CO_2 in the water is in equilibrium with the partial pressure of CO_2 in the atmosphere.

$$CO_2(g) \leftrightarrow CO_2(aq) \qquad (4.3).$$

The equilibrated ratio of partial pressure to dissolved concentration is governed by:

$$pCO_2 = K_o[CO_2(aq)] \qquad (4.4),$$

where pCO_2 is the partial pressure of CO_2 in the gas phase, K_o is a solubility coefficient, and CO_2 (aq) is the concentration of CO_2 dissolved in the water.

The units of pCO_2 used in the equations that follows are µatm.

The solubility of CO_2 in water is a function of both the temperature and the salinity of the water, from Weiss (1974):

$$\ln(K_o) = -60.2409 + 93.4517\left(\frac{100}{T}\right) + 23.3585\ln\left(\frac{T}{100}\right) + \qquad (4.5),$$

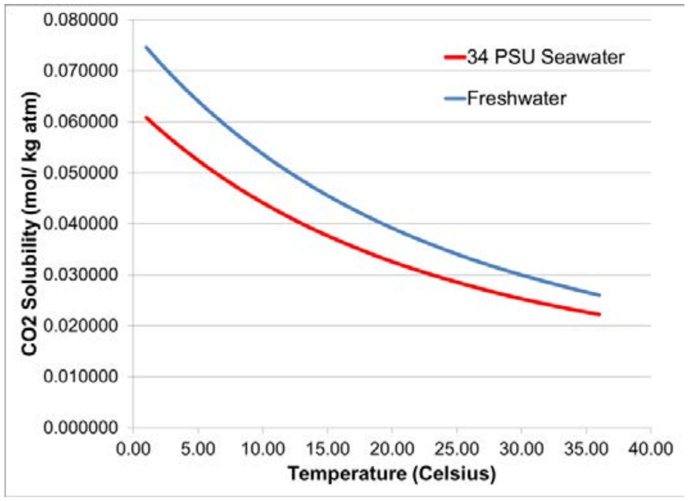
$$S(0.023517 - 0.023656\left(\frac{T}{100}\right) + 0.0047036\left(\frac{T}{100}\right)^2)$$

Where the solubility coefficient, K_o has the units of mol kg^{-1} atm^{-1}, temperature is Kelvin, and salinity is in parts per thousand (approximately equal to PSU).

For non-saline waters, the second term of the equation becomes zero, leading to:

$$\ln(K_o) = -60.2409 + 93.4517\left(\frac{100}{T}\right) + 23.3585\ln\left(\frac{T}{100}\right) \qquad (4.6).$$

The figure below depicts the solubility of CO_2 in both freshwater and seawater (S=34) as a function of temperature. CO_2 is more soluble in freshwater than seawater, and solubility decreases with increasing temperature, see figure below.



An excel spreadsheet for conversion calculations can be obtained by contacting Pro-Oceanus Systems.

Reference: Weiss, RF. 1974. Carbon dioxide in water and seawater: the solubility of a non-ideal gas. Marine Chemistry. 2:203-215. 10.1016/0304-4203(74)90015-2.

5.0 Instrument Deployment

5.1 Pre-deployment set-up

Prior to deployment of the CO_2-Pro, cleaning the instrument's semi-permeable membrane is highly recommended to ensure accurate CO_2 measurements and fastest equilibration times. The membrane is the most important part of the instrument and great care must be taken to not damage the instrument during cleaning. Section 6.3 describes the recommended cleaning process. If the membrane appears to be damaged, the user can replace it, as described in Section 6.4.

The current instrument zero count should be checked to ensure that the CO_2 absorbent is sufficient to provide accurate zero measurements for the duration of the scheduled deployment period. The replacement of the CO_2 absorbent is described in Section 6.2. When replacing the absorbent, it is also recommended to replace the internal clock battery (Section 6.3). This battery ensures the instrument maintains accurate time even when power is removed from the instrument.

Immediately prior to deployment, the user must program the instrument clock time and sampling routine, and first sample start time, as described in the previous section. Note that the sample start time must be set to at least 20 minutes after setting up the sampling parameters, to allow for the instrument to thermally stabilize and equilibrate before the scheduled measurement.

5.2 Recommended Deployment Practices

After ensuring the instrument is configured correctly for sampling mode and frequency, deployment of the instrument is simple. It is recommended that the sensor be mounted in a horizontal position if possible, however, a vertical mount with the instrument membrane head pointed downwards may be more practical on a mooring and this is an acceptable orientation. If mounting the sensor head pointed downwards, ensure that gas does not become trapped along the outside of the membrane. A simple solution to this is to briefly tilt the sensor to a vertical position once in placed into the water prior to deployment.

During deployment, the instrument membrane may not be fully compressed against its support and this will lead to elevated total dissolved gas pressure inside the gas stream where CO_2 is measured. While the detector compensates for changes in gas pressure, readings may not be within the specified accuracy while this excess pressure is released via diffusion through the membrane.

Biofouling is always a concern for instrumentation deployed for long periods of time. Any additional biofouling prevention that can be used to aide in providing an accurate CO_2 measurement is encouraged. The instrument will not be affected by most traditional biofouling methods, but if you are unsure about the method and its affect on the CO_2-Pro and its measurement, contact Pro-Oceanus.

5.3 Integration Options

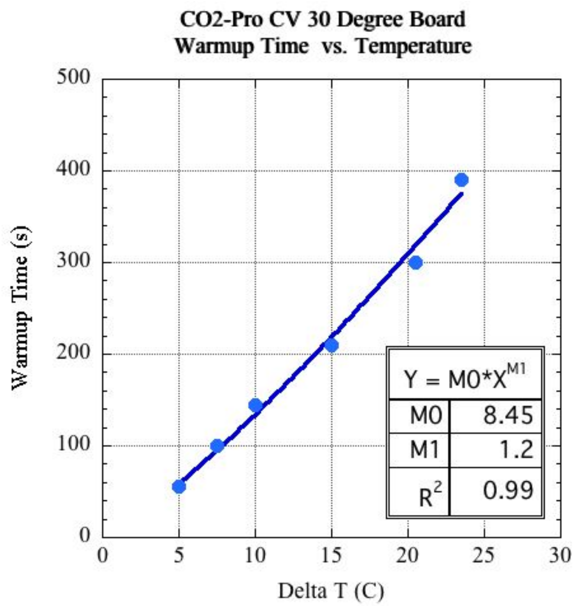
The CO_2-Pro can easily be integrated into a number of platforms. It provides real-time data that does not require any post-processing of data, allowing for direct input into a system with minimal effort.

If you have a specific requirement for integration and require assistance, Pro-Oceanus staff can assist in this process.

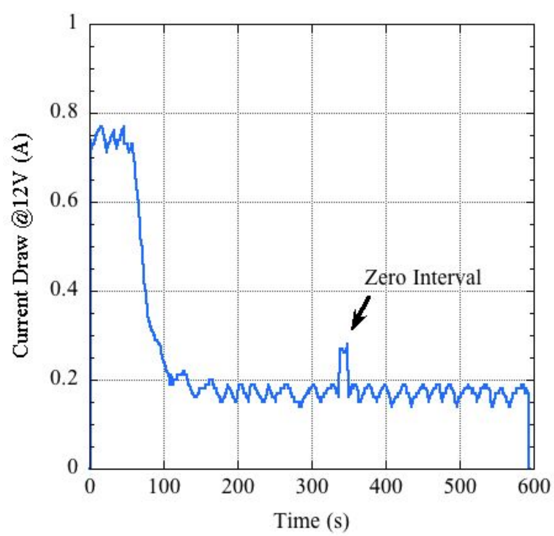
5.4 Power Budgets

The CO_2-Pro can be operated using direct cable power input or through an external battery pack. The power required by the instrument varies based on the difference in between the surrounding water temperature and the detector temperature. The detector temperature is factory-set prior to instrument calibration and this temperature is chosen to be, at a minimum, 10-15ºC above the maximum water temperature in which the instrument will be making measurements. This temperature difference is required to prevent condensation inside the detector cell.

The result of having a thermally stable detector is that accuracy is improved. The internal heater element requires additional power during the "warm-up" of the instrument. The average power consumption during warmup for the CO_2-Pro is 9 W (750 mA @ 12 VDC). The duration of warmup is dependent on the temperature differential and the graph below shows an approximate warmup time based on the difference in the detector temperature and the surrounding water.



After warmup, the sensor power consumption is reduced to ~3 W (250 mA @ 12 VDC). The internal controller requires ~30 µA of current during sleep. A typical power curve for a measurement period is shown below.



In order to estimate the battery endurance of a pre-set measurement frequency, two tables below outline an estimate of the duration a battery pack will provide power to the CO_2-Pro. Please note that these are estimates based on a standard water temperature range CO_2-Pro (2-30ºC) with an average water temperature of 20ºC.

CO_2-Pro battery pack endurance- not including water pump power.

Logger Mode	Samples per day	Battery Pack Endurance in Days (134 Amp-hours)	(268 Amp-hours)
Continuous		25	50
30 minute	48	23	45
1 hr	24	45	90
3 hr	8	135	271
6 hr	4	270	541
12 hr	2	540	1080
1 day	1	1077	2153

CO_2-Pro battery pack endurance- including SBE 5P/5T water pump power (3000 RPM).

Logger Mode	Samples per day	Battery Pack Endurance in Days (134 Amp-hours)	(268 Amp-hours)
Continuous		15	30
30 minute	48	17	35
1 hr	24	35	70
3 hr	8	104	209
6 hr	4	209	417
12 hr	2	417	833
1 day	1	831	1662

6.0 Care and Maintenance

6.1 Instrument Housing and Bulkhead Connectors

The standard CO_2-Pro instrument is made of acetal plastic and uses 316 stainless steel screws and electrical connectors. The optional titanium housing uses titanium screws and electrical bulkhead connectors.

Upon recovery, rinse the external surface of the housing with clean, fresh water. Mild detergents may be used to help remove biofilms. A soft cloth can be used on the housing to remove larger and more difficult to remove biological material. Next, flush the equilibration channel using fresh water and the water pump used during deployment. See "Cleaning the Interface" for instructions on proper maintenance of the interface.

Unplug all cables and dummy plugs from the rear of the housing and inspect the connectors for corrosion. Apply a light coat of non-conductive grease to each of the connector pins. Re-connect electrical cables and plugs and ensure the lock-down sleeves are secured. Do not over-tighten the locking sleeves, hand tighten only.

6.2 Replacing the CO_2 Absorbent

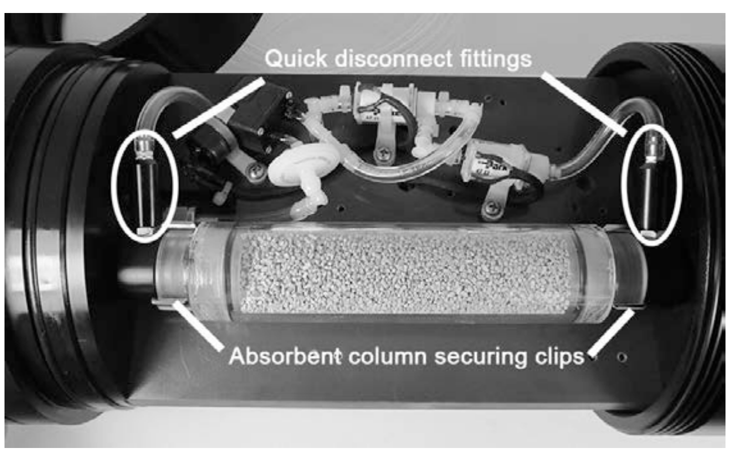
Under normal conditions of use, the absorbent should not need replacing more than once per year, but must be replaced if the CO_2 zero drops significantly below previous levels obtained under the same environmental conditions. It is recommended that the CO_2 absorbent be replaced if the instrument is to be deployed for an extended period. Note: Ascarite II is the preferred absorbent and is supplied in 8-20 mesh granule size and it must be used with Drierite to ensure best lifespan. Sodalime can also be used and should not be used with Drierite. MSDS sheets for Ascarite II, Sodalime, and Drierite are in Appendix D.

To replace the CO_2 absorbent, follow the steps below.

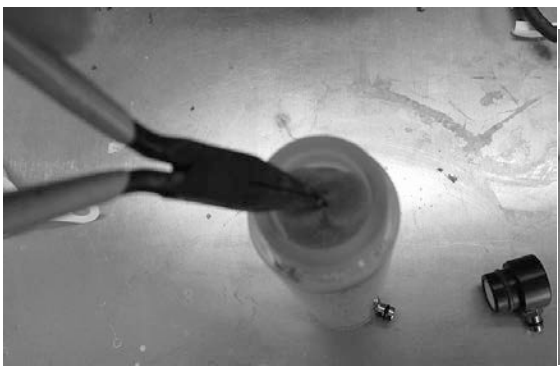
1) Remove the instrument locking ring by turning it counter-clockwise. After deployments, this locking ring may become stuck and require two persons to loosen it, with one person holding the instrument securely while the second person turns the locking ring.

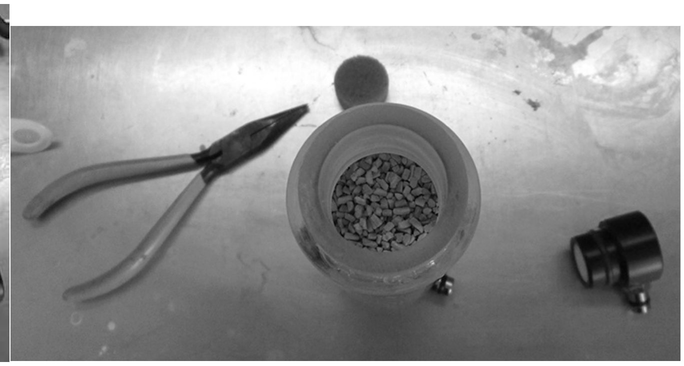
2) Loosen one of the electrical bulkheads on the back of the instrument (Water Pump connecter preferred). Only loosen enough to allow for gas pressure inside the housing to remain in equilibrium with surrounding air. Two turns is typically enough to facilitate this.
3) Carefully pull on the CO_2-Pro sensor heads handles to remove the internal electronics and detector from the housing. Carefully remove the electronics tray to avoid damage to the wiring.

4) Inspect the internal chamber for damage and signs of water.
5) Locate the CO_2 absorbent column and carefully remove the column from the securing clips. Remove the column from the zero CO_2 gas sample line by disconnecting at both Quick disconnect fittings.

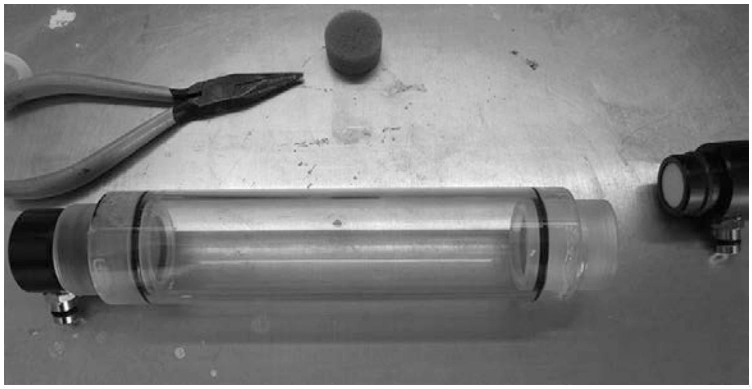


6) Remove one Foam Filter insert and carefully discard the exhausted CO_2 absorbent material.





7) Ensure that both Foam Filters are not worn or damaged. The foam prevents absorbent from spilling out of the column. Replacement pieces can be obtained from Pro-Oceanus or can be made using open cell type foam.
8) Check that the End Caps contain the white filter disks. These disks ensure that absorbent particles do not enter the sensor. They rarely need replacement.
9) Check the O-ring seals on the absorption column End Caps for integrity and ensure that they are lightly greased with silicone grease.
10) Check that the components of the absorption column are not cracked or otherwise damaged. Integrity of the column is essential for reliable AZPC.



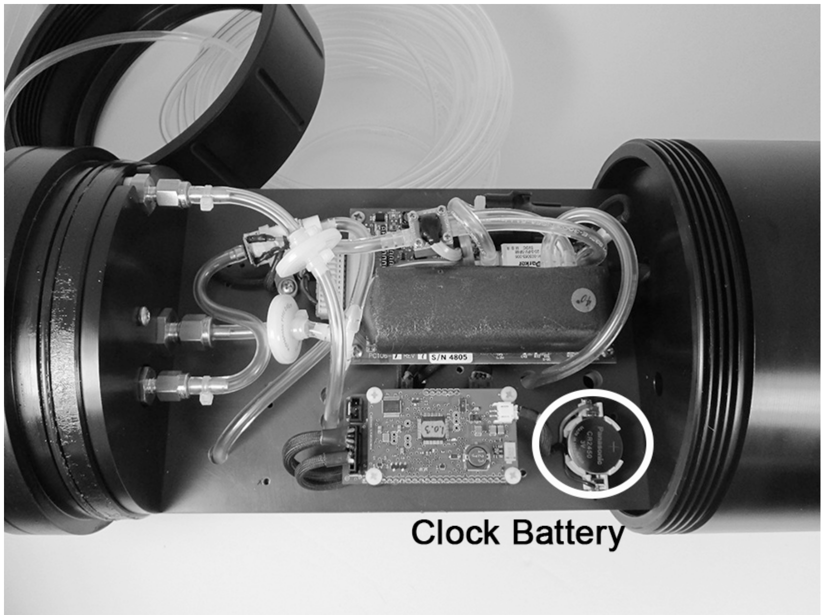
11)After placing one Foam Filter followed by one End Cap, carefully refill the column with new CO_2 absorbent. If Ascarite II is used, place a small amount of Drierite at each end of the absorption column for water removal from the zero line - approximately 1 cm on each side of the Ascarite is adequate. Ensure that enough space is left at the top of the column to accommodate the second Foam Filter and End Cap without compression of the foam. Gently tap the side of the column to remove any larger air voids that may occur during the process.

12)Re-insert the Foam Filter and End Cap.
13)Re-connect the column to the zeroing sample line using the Quick Connect connectors and secure the column in place using the metal clips.
14)Carefully remove the housing endcap O-ring (see image below) using a plastic object. Do not scratch the O-ring groove or O-ring, as this could compromise the pressure rating of the instrument.

15) Lightly grease a new O-ring (Size 256 - 6" OD x 1/8" Thick, BUNA 70 Durometer) and install into O-ring groove.
16) Carefully insert the instrument electronics tray back into the housing taking care to ensure all the internal components are not pinched against the instrument housing.
17) Secure the threaded locking ring back onto the CO_2-Pro instrument.
18) Re-tighten the electrical bulkhead connector once the instrument head has been sealed

6.3 Internal Clock Battery Replacement

The CO_2-Pro A uses an internal battery to power the logger/controller when not powered externally. This allows for the clock to remain active and accurate when not in use, or between measurements when external power is removed. It is recommended to replace the clock battery whenever the instrument CO_2 absorbent is replaced, as it requires the instrument to be opened. The clock battery is located next to the internal logger/controller board and uses a secure mount to keep the battery in place, see image below.



The battery model is a 3V Panasonic CR2450, and can continually power the instrument's clock and maintain the sensor in sleep mode for more than 3 years (at 20 degrees Celsius with new battery).

6.4 Cleaning the Interface

The gas transfer interface is a supported semi-permeable membrane located within a flow channel where water is pushed by the membrane by an external water pump. The flow-through water head is engineered to minimize biofouling, and is NOT to be disassembled by the user.

In the laboratory, immerse the instrument in a solution of dilute cleaning agent, oil-free detergent is recommended. Use a water pump attached to the water-pumped head to flow the soapy water solution through the sensor head, a flow rate of 1-3 liters per minute for several hours is recommended. A check of the outflow rate compared to the pump flow rate is recommended to check for any blockages in the instrument flow-through head.

If the sensor flow rate is low and cannot be revived by the recommended cleaning procedure above, please contact Pro-Oceanus for methods of cleaning safely.

6.5 Detector Re-Calibration

Calibration of the CO_2-Pro must be completed by Pro-Oceanus staff. The calibration procedure requires 5-9 NOAA ESRL GMD traceable gases and a proprietary three-segment polynomial curve fit. Multiple calibrations are made in sequence to ensure the best possible accuracy.

It is recommended that each CO_2-Pro to be returned to Pro-Oceanus once every 12-18 months for re-calibration and functional testing. Normal sensor drift over one year is typically less than 5 ppm.

To return an instrument for re-calibration, please contact Pro-Oceanus for an RMA number prior to shipping it freight pre-paid to Pro-Oceanus:

Pro-Oceanus Systems

80 Pleasant Street

Bridgewater, NS, CANADA

B4V 1N1

Carefully package in the instrument's original protective case, and clearly mark as "fragile goods" and "return for repair" on the outside of the case.

7.0 Troubleshooting

1) No power: check the power supply (should be 12-18 VDC); if no power is reaching the instrument, check the fuse in the deckbox and replace if necessary.

2) Erratic CO_2 measurement: re-zero; if still a problem, open instrument head and ensure that all tubing is in place and connected and replace the CO_2 absorbent.

3) Standard gas measurements are not accurate: typically this means that the instrument has experienced a significant temperature or other environmental change; re-zero the sensor.

4) Upon startup, very high CO_2 levels are experienced. This may mean that the interface was not prepared properly for storage, and the damp interface has a substantial bio-film layer. The best solution is to avoid this problem entirely by preparing the interface properly before storage. See section above "Cleaning the Interface"**.**

5) Length of time for gas – water equilibration after the instrument has warmed up is excessively long. The membrane interface has a biofilm that needs to be removed, see section above "Cleaning the Interface".

8.0 Warranty

Pro-Oceanus CO_2-Pro series instruments are covered by a 1-Year Limited Warranty

For a period of one year after the date of original shipment, products manufactured by Pro-Oceanus Systems Inc. are warranted to function properly and be free of defects in materials and workmanship. Should an instrument fail during the warranty period, please contact Pro-Oceanus for an RMA number prior to shipping it freight pre-paid to Pro-Oceanus:

Pro-Oceanus Systems

80 Pleasant Street

Bridgewater, NS, CANADA

B4V 1N1

Carefully package in the instrument's original protective case, and clearly mark as fragile goods and return for repair on the outside of the case.

Pro-Oceanus Systems Inc. will repair it (or at the company's discretion, replace it) at no charge, and pay the cost of shipping it back to the customer.

Modifications / Exceptions / Exclusions

1. Gas permeable membranes, rigid permeable membrane supports, support screens, absorbents, batteries, and other consumable/expendable items are not covered under this warranty.

2. Damage to the sensor or other internal electronics as a result of flooding from either a punctured membrane or an improperly customer installed O-ring seal is not covered under this warranty. Care must be taken to deploy instruments according to procedures described in this manual to minimize the possibility of instrument flooding.

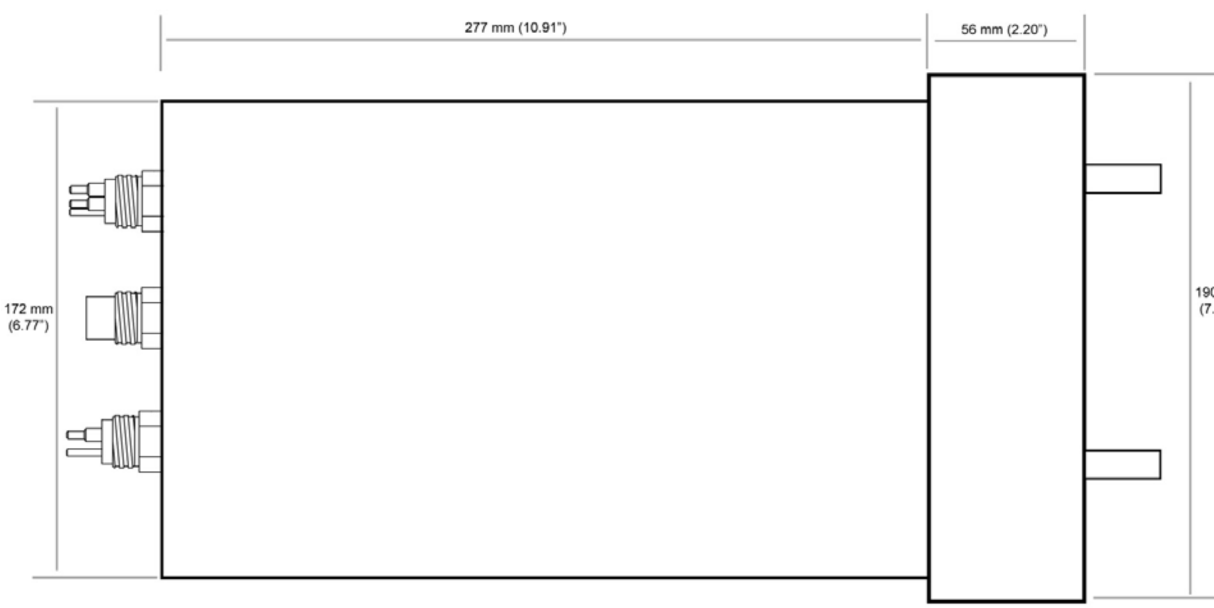
3. Corrosion damage is not covered under this warranty

4. Welded mounting tabs and other mechanisms used to mount Pro-Oceanus Systems Inc. instruments to ships, buoys, mooring lines etc., are not covered under this warranty. Pro-Oceanus Systems Inc. expects the best and safest engineering practices to be applied by knowledgeable and experienced persons during the deployment and recovery of instruments and cannot be held liable for any injuries or damages incurred during use of Pro-Oceanus instruments.

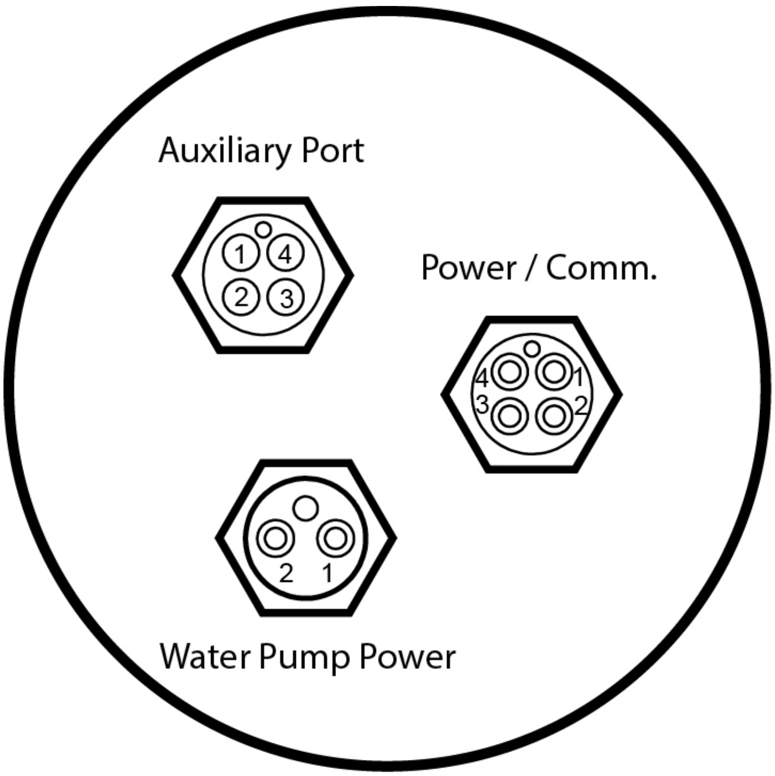
6. This warranty is void if the instrument has been damaged by accident, mishandled, altered, or repaired by the customer where such treatment has affected its performance or reliability. In the event of such abuse by the customer, repair costs plus two-way freight costs will be borne by the customer.

Appendix A: Sensor Specifications

Parameter	Specification
Accuracy	± 0.5% (0 – 1000 ppm range)
Power Consumption	250 mA @ 12 VDC 750 mA @ 12 VDC during warmup 30 µA Sleep Current
Input Voltage	12-18 VDC
Signal Output	RS-232, CSV ASCII String 0-5 VDC or 4-20 mA Analog output available
Water Temperature Range	2 to 30 ˚C (Standard Model) -2 to 20 ˚C (Arctic Version) 10 to 40 ˚C (Tropical Version)
Detector	Non-Dispersive Infrared (NDIR)
Warm up Time	3-8 minutes (dependent on water Temp.)
Housing Material	Acetal Plastic
Dimensions	Length: 35 cm; Diameter: 19 cm
Depth Rating	110 meters
Weight	5 kg in Air -0.1 kg in Water



Appendix B: Instrument Pin Out



Power / Comm.

1. Gnd
2. RX
3. TX
4. V+ (12 VDC)

MCBH(WB)-4-MP-SS

Water Pump Power

1. Gnd
2. V+ (12 VDC)

MCBH(WB)-2-MP-SS

Appendix C: Pass-through Mode commands

The CO_2-Pro instrument can be configured by Pro-Oceanus with a "legacy" data output format and CO2-detector control. This option is only available to current customers who have a CO_2-Pro product and would like to maintain the same format.

Commands can be sent from a terminal emulation application, such as HyperTerminal or Tera Term, running on a personal computer (PC) via a RS-232 or USB (using an RS-232 to USB converter) port to the CO_2 instrument. The instrument parses commands sent to it for valid format. If the command received by the CO_2 sensor is valid, then the command is returned to the PC as a response. If a command received by the CO_2 sensor is not valid, then an error message will be returned to the PC as a response. Commands that include a *value* or *range* must be terminated with a Carriage Return (CR) i.e. "Enter". Editing is not valid while typing a command. Blank spaces are ignored in command strings. Floating point numbers can be entered in decimal or exponential form i.e. 0.01 or 1.0E-02. Do not use more than six digits to the right of the decimal point for floating point numbers.

Command Summary:

A<value>CR	Time [minutes] between zero operations
D<value>CR	Determines whether an initial zero operation occurs at warmup
E<char>CR	Zero operation duration
L<value>CR	Low CO_2 In [ppm] alarm
M	Display a measurement
X	Saves the current configuration to non-volatile memory
Z	Perform a zero operation
?	Display the configuration header currently in use

Measurement Command Response:

Measurement format M aaaa bbbb ccc.ccc dd.d ee.eeee ff.ffff gggg hh.h ii.i j

aaaaa	Zero A/D [counts] from most recent autozero sequence
bbbbb	Current A/D [counts]
ccc.ccc	Measured CO_2 [ppm]
dd.d	Average IRGA temperature [°C]
ee.eeee	Humidity [mbar]
ff.ffff	Humidity sensor temperature [°C]
gggg	Cell gas pressure in IRGA [mbar]
hh.h	IRGA detector temperature [°C]
ii.i	IRGA source temperature [°C]
j	Status/Error code. Continuously displayed measurements do not display the j but instead display a text message. No errors aaaa less tam 25000 counts dd.d less than 5°C from user specified temperature dd.d greater than 5°C from user specified temperature ccc.ccc less than *range* from L command ee.eeee greater than 90 mbar Board voltage less than 4V

Measurement String Format Command:

F<value>CR	Enables or disables individual measurement fields in the output measurement string. Range 0255 (integer). For each field desired in the output string, sum values from the following list: aaaaa and bbbbb enable with value =128 dd.d enable with value=64 ee.eeee and ff.ffff enable with value=32 gggg enable with value=16 hh.h and ii.i enable with value=08

	j enable with bit value=4 ccc.ccc is always present in output string For example, when value is 212 (=128+64+16+4) the output string will be "M aaaaa bbbbb ccc.ccc dd.d gggg j"

Zero Valve Related Commands:

Z	Perform a zero operation
D<char>CR	Determines whether a zero operation is performed on completion of initial warmup or not. If not, then CO2 readings are computed with a previously stored zero reading that may produce inaccurate results. Recommended practice (and the default) is to perform a zero on power-up. Sending "D1" enables the power-up zero, and the string "Zpup=1" is shown in the configuration status (in response to a ? command). Sending "D0" disables the power-up zero, and the string "Zpup=0" is shown.
E<char>CR	Zero operation duration char: "S" = 13 cycles "M"= 25 cycles "L"=73 cycles Default is Short in which the autozero sequence is approximately 20 sec long. Longer duration zero cycles can be useful if the measured gas concentration is above 10,000 ppm to insure full purging of CO_2 gas from the cell prior to recording a zero reading.
A<value>CR	Time [minutes] between zero operations. *range*: 0-10000 (integer, but can be negative). Recommended maximum setting is 20 minutes. Longer time between zero cycles can reduce instrument accuracy. Sending the A command with any non-zero *value* will cause an immediate zero operation, followed by subsequent zero operations every *value* minutes. Normally, the detector performs a series of zero operations at power-up while the temperature is stabilizing. The time between these initial zero operations is a geometric progression starting at 2 minutes, then 4 minutes, then 8 minutes, etc. up to the maximum time between zeros as specified in the A command.

	It is possible to disable these progressive zero operations during startup by setting the value in the A command to a negative number. For example, "A-10" will disable the progressive zeros if the configuration is saved with the X command, so that on the next power-up, the first timed zero occurs after 10 minutes (there still can be a power-up zero immediately after warm-up is complete, depending on the setting of the D command and Zpup). A0 disables all timed zeros and all progressive zeros. See D command to also disable the power-up zero. This is not a recommended setting.

CO_2 Related Commands:

C<value>CR	Number of digits to the right of the decimal point for ccc.ccc. range: 0-3 (integer).
L<value>CR	Low CO_2 in [ppm] alarm. *range*: 0-100000 (floating point). In typical environmental applications, a CO_2 reading in measurement mode of less than 350 ppm indicates a problem with the autozero operation, such as the zero gas is not connected, the CO_2 absorber is exhausted, or the zero valve is not operating. The Low CO_2 Error helps identify those common problems before the abnormal readings can affect subsequent data. This value can be adjusted to suit a particular operating environment or can be eliminated completely by setting the *value* to 0.
B<value>CR	Averaging limit for CO_2 running average. Normally, an exponential running average algorithm is implemented with a rime response to a step change of 5.6 seconds to 66% of final value and 26.4 seconds to 99% of final value. If a new reading differs from the current running average by more than the Averaging Limit *value*, a new running average is begun. Thus when the CO_2 concentration is changing rapidly, the average is eliminated and the instrument can track changes at the basic instrument data rate of 1.6 seconds. When the Averaging Limit *value* is set to 0, no running average is performed. The default Averaging Limit *value* is 0.3% of full scale or 6 ppm for a 2000 ppm instrument. The running averaging is applied to both digital

	and analog output signals.

Other Commands:

?	Display the CO_2 Detector configuration currently in use (the volatile memory working area).
X	Saves the current configuration to non-volatile memory. Use this command to save configuration changes before powering off the CO_2 detector

At CO_2 detector power on, the non-volatile memory working area is copied to the volatile memory working area.

Command Files:

Any of the commands can be included in a text file created by a program such as Microsoft Notepad. This file can be downloaded to the CO_2 detector by using the HyperTerminal menu item Transfer>Send Text File… Command a zero operation before transferring the command file to ensure the maximum time until the next zero operation. Ensure that all lines including the last end with a carriage return and line feed (LF). Command files may include comments in the following format: ;commentCRLF.

The following additional serial communication setup parameters should be set in ASCII Setup>ASCII Sending when sending command files to the CO_2 detector:

- Do not send line ends with line feeds
- Do not echo typed characters locally
- Character delay: 10 milliseconds

Appendix D: Material Safety Data Sheets

Ascarite II

See https://www.thomassci.com/FetchFile.ashx?id=2a88ef77-b0a4-40bf-a3c1-0212cd29e82b or contact Pro-Oceanus for full MSDS.

Thomas Scientific
Material Safety Data Sheet

From Thomas Scientific
1654 High Hill Road
Swedesboro, NJ 08085
1-800-345-2100

24 HOUR EMERGENCY PHONE NUMBERS
US and Canada:
CHEMTREC 1-800-424-9300
Outside US and Canada:
CHEMTREC 1-703-527-3887

ASCARITE II®

1. Product Identification

Synonyms: **Sodium Hydroxide Coated Non-Fibrous Silicate**
CAS No.: **Not applicable to mixtures.**
Molecular Weight: **Not applicable to mixtures.**
Chemical Formula: **Not applicable to mixtures.**
Product Codes: **C049H40, C049H42, C049U90, C049U92**

2. Composition/Information on Ingredients

Ingredient	CAS No	Percent	Hazardous
Sodium Hydroxide	1310-73-2	90 - 95%	Yes
Vermiculite	1318-00-9	5 - 10%	Yes

3. Hazards Identification

Emergency Overview

POISON! DANGER! CORROSIVE. MAY BE FATAL IF SWALLOWED. HARMFUL IF INHALED. CAUSES BURNS TO ANY AREA OF CONTACT.

Potential Health Effects

The health effects from exposure to sodium hydroxide are described below.

Inhalation:
Severe irritant. Effects from inhalation of dust or mist vary from mild irritation to serious damage of the upper respiratory tract, depending on severity of exposure. Symptoms may include sneezing, sore throat or runny nose. Severe pneumonitis may occur.
Ingestion:
Corrosive! Swallowing may cause severe burns of mouth, throat, and stomach. Severe scarring of tissue and death may result. Symptoms may include bleeding, vomiting, diarrhea, fall in blood pressure. Damage may appears days after exposure.

Drierite

See https://secure.drierite.com/IndicatingDrieriteSDS.pdf or contact Pro-Oceanus for full MSDS.

W A HAMMOND DRIERITE CO., LTD.

SAFETY DATA SHEET

Section I Product Information

Products: Drierite, Regular Drierite, Non-Indicating Drierite, Commercial Drierite

Common Name: Calcium Sulfate

Chemical Name: Calcium Sulfate Anhydrous

Applicable Drierite Stock Numbers:

11001,11005,11025,11050,12001,12005,12025,12050,13001,13005,13025,13050,14001,
14005,14025,14050,15001,15005,15025,15050,19045,26910,26940,31050,32050,33050,
34020,34050,35050,39045,60011,60012,60013,60014,60016,60018,60061,61025,62020,
63025, 64010,66025,68005,68050

Distributor Name: W A Hammond Drierite Co, Ltd.
Address: P O Box 460, Xenia, OH 45385
Phone Number: 937-376-2927

Manufacturer Name: W A Hammond Drierite Co, Ltd.
Address: P O Box 460, Xenia, OH 45385
Phone Number: 937-376-2927

Emergency Phone: 937-376-2927

Recommended Use: Desiccant, Drying Agent

Section II Hazard Identification

Pictogram: 

Signal Word: Warning

Hazard Statement(s): This product can release nuisance dust in handling or during use. Eye, skin, nose, throat, and upper respiratory irritation may occur with prolonged dust exposures.

Effects of Overexposure:

Acute:
Eyes: Direct contact can cause mechanical irritation of eyes. If burning, redness, itching, pain or other symptoms persist or develop, consult physician. Eye irritation Category 2, Subcategory 2B.

Soda Lime

See https://www.avantormaterials.com/documents/MSDS/usa/sap/00034013.pdf or contact Pro-Oceanus for full MSDS.

AVANTOR PERFORMANCE MATERIALS

Version: 1.0
Revision Date: 12-30-2014

SAFETY DATA SHEET

1. Identification

Product identifier: SODA LIME

Other means of identification
Product No.: 3447, 3448

Recommended use and restriction on use
Recommended use: Not available.
Restrictions on use: Not known.

Manufacturer/Importer/Supplier/Distributor Information

Manufacturer

Company Name:	Avantor Performance Materials, Inc.
Address:	3477 Corporate Parkway, Suite 200 Center Valley, PA 18034
Telephone:	Customer Service: 855-282-6867
Fax:	
Contact Person:	Environmental Health & Safety
e-mail:	info@avantormaterials.com

Emergency telephone number:
24 Hour Emergency: 908-859-2151

Chemtrec: 800-424-9300

2. Hazard(s) identification

Hazard Classification

Health Hazards

Acute toxicity (Dermal)	Category 4
Skin Corrosion/Irritation	Category 2
Serious Eye Damage/Eye Irritation	Category 2A

Environmental Hazards

Acute hazards to the aquatic environment	Category 3

Label Elements
Hazard Symbol:

Signal Word: Warning

Hazard Statement: Harmful in contact with skin.
Causes skin irritation.
Causes serious eye irritation.
Harmful to aquatic life.

SDS_US - SDSMIX000240 1/11

PRODUCT MANUAL

CTD-Diver® – DI28x Series

Contact details:

Van Essen Instruments B.V.
Delftechpark 20, 2628 XH Delft

Netherlands

Tel: +31 (0)15 275 5000

Van Essen Instruments - Canada
219 Labrador Drive, Suite 201, Waterloo

ON, Canada N2K 4M8

Tel: +1 226-791-6499

Van Essen Instruments - USA
4561 Greer Circle, Suite 100, Tucker

GA, United States 30083

Tel: +1 520-203-3445 (US West)

Tel: +1 678-983-2818 (US East)

Internet: www.vanessen.com

Support: diver@vanessen.com

The presence of the Waste Electrical and Electronic Equipment (WEEE) marking on the product indicates that the device is not to be disposed via the municipal waste collection system of any member state of the European Union. For products under the requirement of WEEE directive (2012/19/EU), please contact your distributor or local Van Essen Instruments B.V. office for the proper decontamination information and take back program, which will facilitate the proper collection, treatment, recovery, recycling, and safe disposal of the device.

CE COMPLIANCE STATEMENT (EUROPE)

We hereby declare that the device(s) described below are in conformity with the directives listed. In the event of unauthorized modification of any devices listed below, this declaration becomes invalid.

Type: Datalogger
Product Model: CTD-Diver (DI281, DI282, DI283, DI284)

Relevant EC Directives and Harmonized Standards:

1999/5/EC R&TTE Directive for Radio and Telecommunications Terminal Equipment in accordance to annex III to which this directive conform to the following standards:

Low Voltage Directive per EN60950-1 (2006)+A11 (2011) for Product Safety testing standard for "Information Technology Equipment"

EMC Directive EN 301 489-1 V1.8.1 / EN 301 489-17 V1.3.2 Electromagnetic emission and immunity for "Information Technology Equipment"

2014/30/EU Electromagnetic Compatibility directive, as amended by EN61326-1:2013

The product(s) to which this declaration relates is in conformity with the essential protection requirements of 2014/30/EU Electromagnetic Compatibility directive. The products are in conformity with the following standards and/or other normative documents:

EMC: Harmonized Standards: EN 61326-1:2013 Lab Equipment, EMC

IEC61000-6-3:2007 Emission standard for residential, commercial and light-industrial environments
IEC61000-4-2:2009 Electrostatic discharge immunity test
IEC61000-4-3:2006 Radiated, radio-frequency, electromagnetic field immunity test
IEC61000-4-4:2012 Electrical fast transient/burst immunity test
IEC61000-4-5:2006 Surge immunity test
IEC61000-4-6: 2014 Immunity to conducted disturbances, induced by radio-frequency fields
IEC61000-4-11:2004 Voltage dips, short interruptions and voltage variations immunity tests

I hereby declare that the equipment named above has been designed to comply with the relevant sections of the above referenced specifications. The items comply with all applicable Essential Requirements of the Directives.

Contents

1 Introduction

The CTD-Diver® is a compact, groundwater monitoring instrument for continuously measuring level, temperature and electrical conductivity in groundwater, surface water, and industrial waters. The data collected can be used to manage water resources, estimate hydraulic conductivity and other aquifer conditions. Examples of applications are:

- monitor potable water recharge areas for water supply,
- monitor tailings ponds, dewatering activities and water supply levels of mines,
- general site investigations for construction, and
- contaminant plume monitoring on spill sites, remediation sites, chemical storage facilities, landfill sites and hazardous waste storage sites.

The CTD-Diver is an easy-to-use datalogger featuring state-of-the-art electronics , a robust high precision pressure sensor for long term accuracy and a platinum 4-electrode conductivity sensor. The absolute pressure sensor requires minimal maintenance and re-calibration.

The CTD-Diver is a datalogger housed in a cylindrical casing with a suspension eye at the top. The suspension eye can be unscrewed and is designed to install the CTD-Diver into the monitoring well. The suspension eye also protects the optical connector. The electronics, sensors and battery are installed maintenance-free into the casing. The CTD-Diver is not designed to be opened.

The name of the datalogger, the model number, the measurement range and the serial number are identified on the side of the CTD-Diver. This information is etched using a laser and is consequently chemically neutral and not erasable.

1.1 About this Manual

This manual contains information about Van Essen Instruments' CTD-Diver with part number DI28x, see section 2.5, an instrument designed to measure groundwater levels, temperature and electrical conductivity.

This chapter contains a brief introduction to the CTD-Diver's measurement principles. Chapter 2 contains the technical specifications for the CTD-Diver as well as guidelines for Diver maintenance. Chapter 3 covers the deployment of Divers. This includes programming the Diver with the Diver-Office software. Subsequently, installation of Divers in monitoring wells and in surface water is discussed. There are three appendices that describe the use of Divers at varying elevation, the Diver communication protocol and a list of CTD-Diver accessories.

1.2 Operating Principle

The CTD-Diver is a datalogger designed to measure water pressure, temperature and conductivity. Measurements are subsequently stored in the CTD-Diver's internal memory. The CTD-Diver consists of a pressure sensor designed to measure water pressure, a temperature sensor, a 4-electrode conductivity sensor and a battery that powers the electronics that takes and stores the measurements. The CTD-Diver is an autonomous datalogger that can be programmed by the user. The CTD-Diver has a completely sealed inert ceramic enclosure. The communication between CTD-Divers and Laptops/field devices is based on optical communication.

The CTD-Diver measures the absolute pressure. This means that the pressure sensor not only measures the water pressure, but also the air pressure pushing on the water surface. If the air pressure varies, the measured water pressure will thus also vary, without varying the water level. The air pressure can be measured by a Baro-Diver and subsequently be used in the Diver-Office software to convert the CTD-Diver pressure readings into water level data.

1.3 Measuring Water Level

The CTD-Diver establishes the height of a water column by measuring the water pressure using the built-in pressure sensor. As long as the CTD-Diver is not submerged in water it measures atmospheric pressure, just like a barometer. Once the Diver is submerged this is supplemented by the water's pressure: the higher the water column the higher the measured pressure. The height of the water column above the Diver's pressure sensor is determined based on the measured pressure.

To measure these variations in atmospheric pressure a Baro-Diver is installed for each site being measured. The barometric compensation for these variations in atmospheric pressure can be done using the Diver-Office software, see www.vanessen.com for a free download. It is also possible to use alternative barometric data such as data made available online.

The barometrically adjusted water values can be related to a reference point such as the top of the monitoring well or Mean Sea Level (MSL) or any other vertical reference datum.

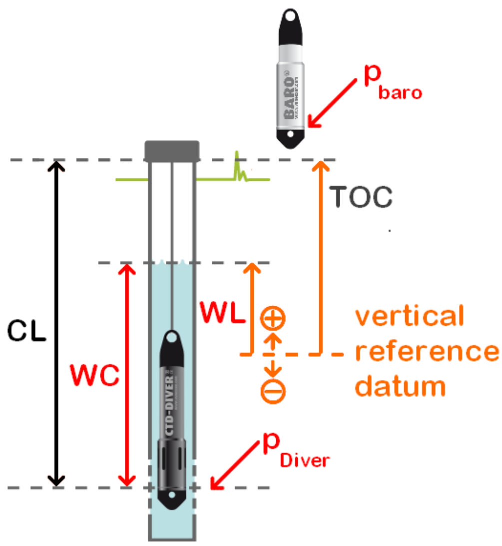
1.3.1 Converting Diver Data into Water Level

This section explains how to calculate the water level in relation to a vertical reference datum using the CTD-Diver and Baro-Diver's measurements.

The figure below represents an example of a monitoring well in which a CTD-Diver has been installed. In this case we are therefore interested in the height of the water level (WL) in relation to the vertical reference datum. If the water level is situated above the reference datum it has a positive value and a negative value if it is situated below the reference datum.

The top of casing (TOC) is measured in relation to the vertical reference datum and is denoted in the diagram below as TOC. The CTD-Diver is suspended with a cable with a length CL. If the cable length is not exactly known, it can be calculated from a manual measurement as described in section 1.3.2.

The Baro-Diver measures the atmospheric pressure (p_{baro}) and the CTD-Diver measures the pressure exerted by the water column (WC) above the CTD-Diver and the atmospheric pressure (p_{Diver}).



The water column (WC) above the CTD-Diver can be expressed as:

$$\mathrm{WC} = 9806.65 \frac{p_{\mathrm{Diver}} - p_{\mathrm{baro}}}{\rho \cdot g} \qquad (1)$$

where p is the pressure in cmH_2O, g is the acceleration due to gravity (9.80665 m/s^2) and ρ is the density of the water (1,000 kg/m^3).

The water level (WL) in relation to the vertical reference datum can be calculated as follows:

$$\mathrm{WL} = \mathrm{TOC} - \mathrm{CL} + \mathrm{WC} \qquad (2)$$

By substituting WC from equation (1) in equation (2) we obtain:

$$\mathrm{WL} = \mathrm{TOC} - \mathrm{CL} + 9806.65 \frac{p_{\mathrm{Diver}} - p_{\mathrm{baro}}}{\rho \cdot g} \qquad (3)$$

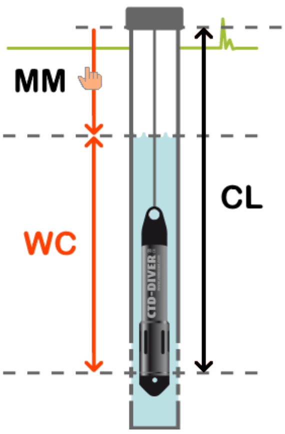
1.3.2 Calculating the Cable Length from a Manual Measurement

If the cable length is not exactly known, it can be determined using a manual measurement, see the figure below. The manual measurement (MM) is taken from the top of casing to the water level. The value of the water level is positive unless, in exceptional circumstances, the water level is situated above the top of casing.

The cable length can now be calculated as follows:

$$\mathrm{CL} = \mathrm{MM} + \mathrm{WC} \qquad (4)$$

where the water column (WC) is calculated based on the measurements taken by the CTD-Diver and the Baro-Diver.



Notes:

- If the pressure measured by the CTD-Diver and the Baro-Diver is measured at different points in time, it is necessary to interpolate. The Diver-Office software automatically performs this interpolation.
- It is possible to enter manual measurements into the Diver-Office software. The software subsequently automatically calculates the cable length.

Example

The top of casing is measured to be 150 cm above the Mean Seal Level (MSL): TOC = 150 cm. The cable length is not exactly known and therefore a manual measurement is taken. It turns out to be 120 cm: MM = 120 cm.

The CTD-Diver measures a pressure of 1,170 cmH_2O and the Baro-Diver measures a pressure of 1,030 cmH_2O. Substituting these values into equation (1), results in a water column of 140 cm above the Diver: WC = 140 cm.

Substituting the values of the manual measurement and the water column in equation (4) results in the following cable length: CL = 120 + 140 = 260 cm.

The water level in relation to MSL can now be easily calculated using equation (2): WL = 150 – 260 + 140 = 30 cm above MSL.

1.4 Measuring Temperature

All Divers measure the groundwater temperature. This can, for example, provide information about groundwater flows.

The temperature is measured using a semiconductor sensor. This sensor not only measures the temperature, but also uses the value of the temperature at the same time to compensate the pressure sensor and electronics for the effects of temperature to ensure the best possible performance.

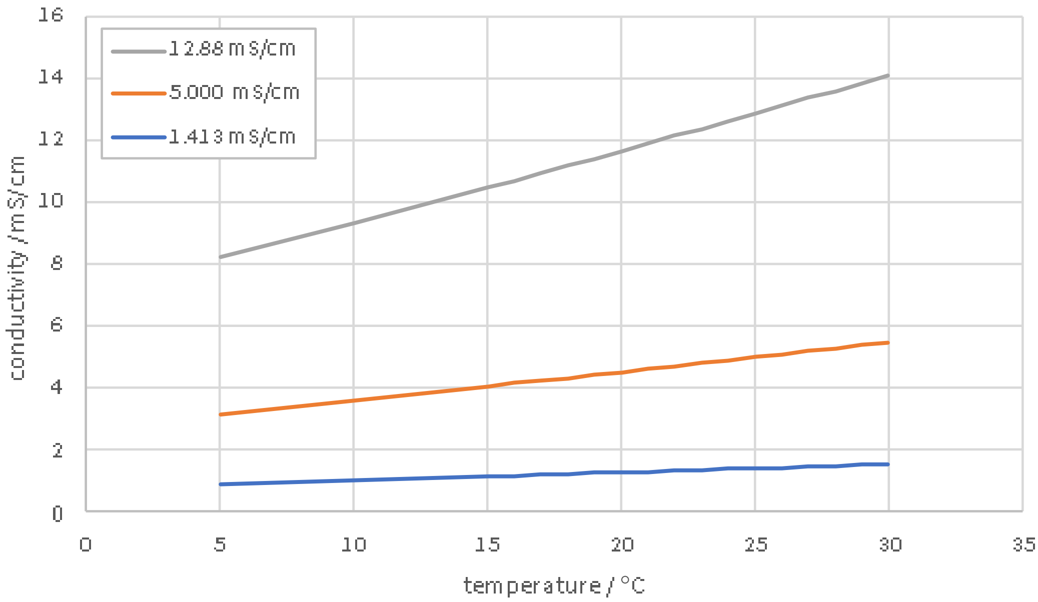
1.5 Measuring Conductivity

In addition to water levels and temperature, the CTD-Diver also measures the water’s electrical conductivity in milli Siemens per centimeter (mS/cm). A change in conductivity may be caused by for example changes in water flow or increasing/decreasing pollution or salinization.

The conductivity is measured using a 4-electrode measuring cell. This type of measuring cell is relatively insensitive to sensor fouling, thus keeping maintenance to a minimum. *The measuring cell combined with the selected measurement method results in an electrolysis-free measurement system.*

The CTD-Diver measures the conductivity of a solution. The CTD-Diver can be programmed to measure either the true conductivity or the specific conductivity. The specific conductivity is defined as the conductivity as if the temperature is 25 °C. This setting must be programmed prior to starting the CTD-Diver.

The conductivity of a liquid depends on the type of ions in the liquid and to a significant degree on the liquid’s temperature. This dependency is indicated on the packaging of the calibration solution. The diagram below displays the conductivity as a function of temperature for three different calibration liquids. The specified value of the calibration liquid is the conductivity of the liquid at 25 °C.



As a rule of thumb, it can be assumed that conductivity varies by 2% for each 1 °C change in temperature. This means that a calibration solution rated 5 mS/cm (at 25 °C) has a conductivity of approximately 4 mS/cm at 15 °C.

The table below lists several typical conductivity values for various types of water.

Type	Conductivity [mS/cm]
Tap water	0.2 – 0.7
Groundwater	2 - 20
Seawater	50 - 80

1.5.1 Specific Conductivity

The specific conductivity of an electrolyte solution is defined as the conductivity if the solution is at a certain – reference – temperature. The specific conductivity is an indirect measure of the presence of dissolved solids such as chloride, nitrate, phosphate, and iron, and can be used as an indicator of water pollution.

The following equation is used for calculating the specific conductivity K_{Tref} from the measured conductivity K.

$$K_{Tref} = \frac{100}{100+\theta(T-T_{ref})} \cdot K \qquad (5)$$

where:

K_{Tref} = Specific conductivity at T_{ref}

K = Conductivity at T

T_{ref} = Reference temperature (25 °C)

T = Sample temperature

θ = Temperature coefficient (1.91 %/°C)

The temperature coefficient used in the CTD-Diver is 1.91 %/°C and the reference temperature is 25°C. The setting to measure conductivity or specific conductivity can be programmed into the CTD-Diver by the user.

1.6 CTD-Diver Model

The Diver models described in this manual are from the DI28x Series: the CTD-Diver. The CTD-Diver measures absolute pressure, temperature and conductivity.

CTD-Diver

This Diver is manufactured using a zirconia (ZrO_2) casing with a 22 mm diameter. The CTD-Diver can store a maximum of 144,000 measurements (date/time, pressure, temperature and conductivity) in its working memory and 144,000 measurements in its backup memory.

The CTD-Diver samples pressure, temperature and conductivity and has the following measurement options:

- Fixed length intervals in fixed length or continuous memory.
- Average values.
- Pre-programmed or user-defined pump tests.
- Event-based. The CTD-Diver only stores measurements once the user-adjustable variation limit set for the conductivity measurement is exceeded.

The CTD-Diver is available in the following pressure ranges: 10 m, 50 m, 100 m and 200 m.

1.7 Factory Calibration Procedure

Each CTD-Diver is calibrated for pressure, temperature and conductivity:

1. First the CTD-Diver is individually calibrated and tested at several temperature and pressure values to ensure superior performance. The CTD-Diver is calibrated for the lifetime of the instrument, as long as it is used within its specified range.
2. Then the conductivity sensor is individually calibrated and tested at several conductivity values. The factory calibration is stored permanently in the CTD-Diver.

A calibration certificate is available upon request.

2 Technical Specification

2.1 General

There are four CTD-Diver models with different pressure ranges for pressure, temperature and conductivity measurements. The table below lists the general specifications of the CTD-Diver.

Diameter	Ø 22 mm
Length (incl. suspension eye)	~ 135 mm
Weight	~ 95 grams
Materials	
Casing	Ceramic (zirconia ZrO_2)
Pressure sensor	Piezoresistive ceramic (alumina Al_2O_3)
Conductivity sensor	4-electrode with platinum electrodes
Suspension eye	Nylon PA6 glass fiber reinforced (30%)
nose cone	ABS
O-rings	Viton®
Communication	
Interface	Optically separated
Protocol	Serial RS232, a limited set of commands is available as specified in Appendix II
Memory capacity	288,000 measurements
working	144,000 measurements
backup	144,000 measurements
Memory	Non-volatile memory. A measurement consists of date/time, pressure, temperature, and conductivity Continuous and fixed length memory
Battery life*	Up to 10 years, depending on use
Theoretical battery capacity	2 million measurements + 1000× full memory readouts + 2000× programming
Clock accuracy	Better than ± 1 minute per year at 25 °C
	Better than ± 5 minutes per year within the operating temperature range
CE marking	EMC in accordance with the 89/336/EEC directive Basic EN 61000-4-2 standard
Emissions	EN 55022 (1998) + A1 (2000) + A2 (2003), Class B
Immunity	EN 55024 (1998) + A1 (2000) + A2 (2003)

* The CTD-Diver is always in stand-by when not making a measurement. The power consumption of the integrated battery is dependent on the temperature and usage.
If the CTD-Diver is used, stored or transported for extended periods of time under high temperature, this will adversely affect the life of the battery. The battery's capacity at lower temperatures is reduced, but this is not permanent. This is normal behavior for batteries.
Excessive programming, high frequency sampling and data reading will reduce the battery capacity.

** The accuracy of the clock is highly dependent on temperature. The clock is actively compensated for temperature variations.

2.2 Environmental

Ingress protection	IP68, 10 years continuously submerged in water at 200 m

2.3 Transportation

Suitable for transportation by vehicles, ships and airplanes in the supplied packaging.

Resistance to vibration	In accordance with MIL-STD-810.
Mechanical shock test	In accordance with MIL-STD-810, for light-weight equipment
Temperature	-20 °C to 80 °C (affects battery life)

2.4 Temperature

Measurement range	-20 °C to 80 °C
Operating Temperature (OT)	0 °C to 50 °C
Accuracy (max)	± 0.2 °C
Accuracy (typical)	± 0.1 °C
Resolution	0.01 °C
Response time (90% of final value)	3 minutes (in water)

2.5 Pressure

The specifications for water pressure measurements vary by CTD-Diver model. The specifications below apply at operating temperature.

	DI281	DI282	DI283	DI284	Unit
Water column measurement range	10	50	100	200	mH_2O
Accuracy (max)	± 2.0	± 10.0	± 20.0	± 40.0	cmH_2O
Accuracy (typical)	± 0.5	± 2.5	± 5.0	± 10.0	cmH_2O
Long-term stability	± 2	± 10	± 20	± 40	cmH_2O
Resolution	0.2	1	2	4	cmH_2O
Display resolution	0.058	0.192	0.358	0.716	cmH_2O
Overload pressure	15	75	150	300	mH_2O

2.5.1 Water Column Measurement Range

The height of water above the CTD-Diver that can be measured.

2.5.2 Accuracy (maximum)

Accuracy is the proximity of measurement results to the true value. The algebraic sum of all the errors that influence the pressure measurement. These errors are due to linearity, hysteresis and repeatability. During the CTD-Diver calibration process a CTD-Diver is rejected if the difference between the measured pressure and the applied pressure is larger than the stated accuracy.

2.5.3 Accuracy (typical)

At least 68% of the measurements during the calibration check are within 0.05% FS of the measurement range.

2.5.4 Long-term Stability

The stability of the measurement over a period of time when a constant pressure is applied at a constant temperature.

2.5.5 Resolution

The smallest change in pressure that produces a response in the CTD-Diver measurement.

2.5.6 Display Resolution

The smallest increment in pressure that the CTD-Diver can measure.

2.5.7 Overload Pressure

The pressure at which the CTD-Diver pressure sensor will catastrophically fail.

2.6 Conductivity

Measurement range*	30 mS/cm	120 mS/cm	300 mS/cm
Accuracy**	±2% of reading with a minimum of 20 µS/cm		
Resolution	1 µS/cm	4 µS/cm	10 µS/cm

* User adjustable

** Undefined when reading > 120 mS/cm

2.7 Sample Interval and Methods

The minimum and maximum sample interval plus the various sample methods available for the CTD-Diver are listed below.

Sample interval: 1 sec to 99 hours

Sample methods:

- Fixed length intervals in fixed length or continuous (ring) memory.
- Average values over a specified period.
- Pre-programmed pump tests or user-defined pump tests (no backup memory).
- Event-based. In this case the CTD-Diver only stores measurements once the variation limit set for the conductivity measurement is exceeded. This variation limit is user adjustable (no backup memory).

2.7.1 Fixed

When this method is selected, the CTD-Diver will take and store samples in regular time intervals.

For example, with a 10-second fixed record interval, the CTD-Diver will take a measurement every 10 seconds on all channel settings and then store these values in internal memory, with the date and time.

For the CTD-Diver there are two methods for storing data:

- Fixed Length Memory – The CTD-Diver will take measurements at a sample interval set by the user, for example every hour. When the number of samples reaches 144,000, i.e. the memory is full, the CTD-Diver stops measuring.
- Continuous Memory – The CTD-Diver will take measurements at a preset sample interval data. When the memory fills up, new samples begin overwriting the oldest records.

2.7.2 Averaging

When programmed with the Averaging Sample method, the CTD-Diver samples data at a specified "fast" rate (Sample Interval) and then stores an average of these values at the specified averaging rate (Record Interval).

Example

Record Interval: 1 hour

Sample Interval: 1 Minute

When programmed and started with these settings, the CTD-Diver will read a sample every minute, and record an average of the samples every 1 hour.

For surface water applications it is recommended using the averaging sampling method. This way the effects of waves are 'averaged out'.

2.7.3 Event Based

When you select this method, the CTD-Diver compares each conductivity sample to the last stored conductivity sample and calculates a difference. A new sample is only stored when:

- The difference exceeds the specified difference (percentage) from the last stored sample on the conductivity measurement.
- If no samples were stored for the past 250 samples.

If you select this method, the Variation field will be displayed. In the Variation field, specify the appropriate difference threshold. Enter this difference as a percentage of the total conductivity range. The percentage must lie between 0.1% and 25%.

Example

The conductivity range is set to 120 mS/cm, the Variation field is set to 2% and the sample interval is set to 30 seconds. A new sample will be stored when it deviates more than 120 × 2% = 2.4 mS/cm from the previously stored sample.

The CTD-Diver is started at 12:00:00. It will immediately record a sample (pressure, temperature and conductivity). The recorded conductivity is 23 mS/cm. After 30 seconds, the CTD-Diver takes a new sample: the conductivity is 23.5 mS/cm. This sample will not be recorded, because the difference is 0.5 mS/cm, which is less than 2.4 mS/cm.

Also, for the next 249 samples the difference is less than 2.4 mS/cm, so no samples are recorded. However, when the 250th sample is taken, it is recorded (at 14:05:00) regardless the difference.

2.7.4 Pumping Tests

The CTD-Diver can be programmed with a pumping test logging scheme. Generally, the logging interval is short at the start and increases when the pumping tests progresses.

There are two pre-programmed pumping tests available for the CTD-Diver. These are as listed in the two tables below. In addition, user-defined pumping tests can be programmed in the CTD-Diver.

A pumping test is defined by a base sample interval (from 1 second to 99 hours) and up to 10 different logging steps. For each step the number of samples that must be taken must be set plus the Interval Multiplier (1 to 250). The interval between two successive samples is equal to the Base Sample Interval multiplied by the Interval Multiplier. For example, if the Base Sample Interval is 3 seconds and the Interval Multiplier is 5, then the sampling interval is 15 seconds. Note: The Base Sample Interval is equal for all steps.

Aquifer Log Scale Test - 3 Day

Base Sample Interval: 1 second

Step	Number of samples	Interval multiplier	Interval between samples	Duration
1	600	1	1 seconds	10 minutes
2	1080	5	5 seconds	90 minutes
3	5400	10	10 seconds	15 hours
4	136920	30	30 seconds	47 days

Aquifer Log Scale Test - 2 Month

Base Sample Interval: 5 seconds

Step	Number of samples	Interval multiplier	Interval between samples	Duration
1	120	1	5 seconds	10 minutes
2	270	4	20 seconds	90 minutes
3	900	12	60 seconds	15 hours
4	1800	60	5 minutes	150 hours
5	140910	240	20 minutes	1957 days

3 CTD-Diver Installation and Maintenance

3.1 Introduction

In practice the CTD-Diver is suspended in a monitoring well and the Baro-Diver is installed at the surface for recording barometric pressure. Atmospheric pressure data must be used to compensate the pressure measurements recorded by the CTD-Diver for variations in atmospheric pressure. In principle, a single Baro-Diver is sufficient for an area with a radius of 15 kilometers depending on terrain conditions. Also see *Appendix I – Use of CTD-Divers at Varying Elevations*. A 10-meter change in elevation is the equivalent of a barometric pressure change of approx. 1 cmH2O or 1 mbar.

The following sections describe how to install the CTD-Diver and Baro-Diver.

3.2 Configuring and Reading the CTD-Diver

A CTD-Diver must be programmed with the desired sample method, sample interval, and monitoring point name before it is deployed. The CTD-Diver can be programmed, started, stopped and its data read using the Diver-Office software. The latest version of Diver-Office can be downloaded for free from www.vanessen.com. Once the software is installed, a CTD-Diver can be connected to the computer through a USB Reading Unit (part no AS330), a Smart Interface Cable (part no. AS346) or the Diver-Gate(M) (part no. AS345).

3.2.1 Configuring a CTD-Diver

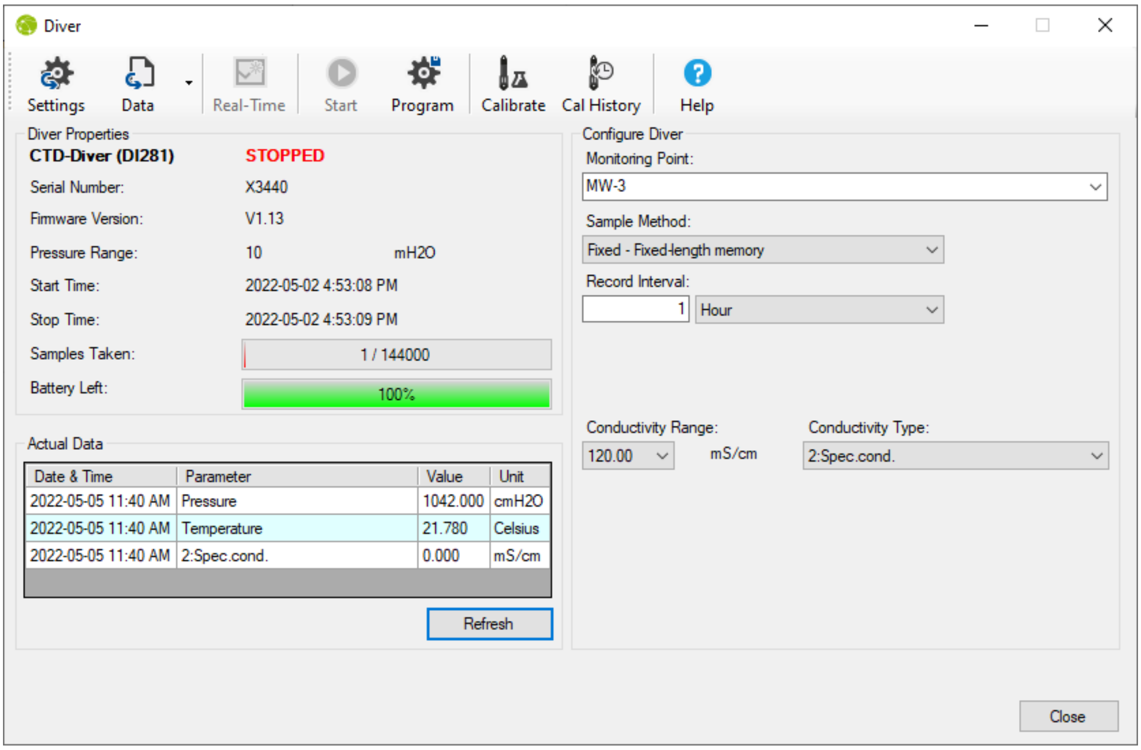
Open the Diver-Office software and click the Diver button to open the Diver window. See the image below for an example where the following settings were entered:

- monitoring point name: “MW-3”,
- sample method: “Fixed – Fixed-length memory”,
- record interval: 1 hour,
- conductivity range: 120 mS/cm,
- conductivity type: specific conductivity.

After entering the settings, the Diver must be programmed by clicking the Program button.

The conductivity range can be set to 30, 120 or 300 mS/cm. Select the range corresponding to the expected measurement values. A higher range reduces the resolution of the measurements. When the actual measurement value exceeds the conductivity range, then stored value is clipped to the maximum value.

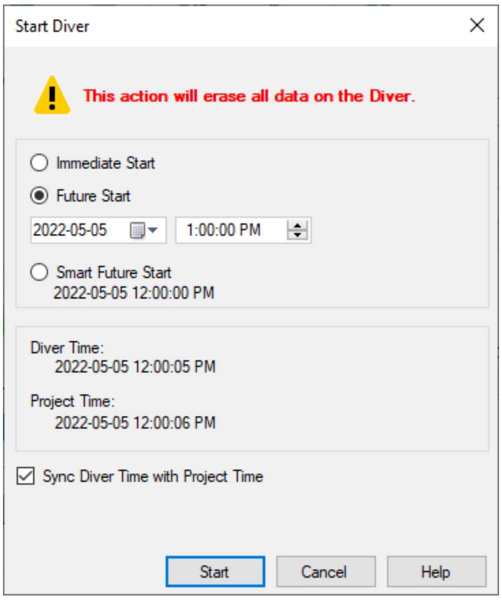
Set the conductivity type to the desired type. See section *1.5.1 Specific Conductivity* for more details.



Once the settings are successfully programmed into the CTD-Diver the Start button will be enabled. Clicking the Start button opens the Start Diver dialog as shown below. Here you can select from the following three start methods:

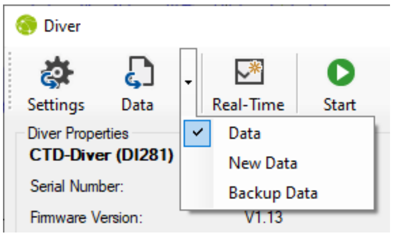
- Immediate Start - Select this option to start the CTD-Diver immediately. Upon clicking [Start], the Diver will begin to take and record samples, as defined in the CTD-Diver settings
- Future Start - Select this option to start the CTD-Diver at a specified time in the future. Use the date and time boxes to enter the desired future start time.
- Smart Future Start - This option is useful in situations where you want to stop the CTD-Diver, download its data and then continue collecting data at the specified sample interval.

After selecting the desired start method, click the [Start] button to save the start settings to the CTD-Diver.



3.2.2 Reading Data from a CTD-Diver

Click the Data button to download data from the CTD-Diver. Click the down arrow next to the Data button to change the mode/type of data download:



Depending on the sample interval the following 3 options are available:

- Data - download all the data recorded by the Diver.
- New Data - download only newly recorded data (since the last data download). This option is not available when the sample interval is 5 seconds or less.
- Backup Data - download data from the previous monitoring session.

During the data download the progress is indicated by a progress bar. Once the data has been downloaded it will be exported if this option is selected in the Project Settings. Subsequently, the program will jump to the tree view where the downloaded time series will be selected and a graph/table of the data will be shown.

3.3 Installation in a Monitoring Well

CTD-Divers are normally installed below the water level/table in a monitoring well. The depth at which a CTD-Diver can be suspended depends on the instrument's measurement range. Further information about the CTD-Diver's range is contained in the chapter 2 *Technical Specification*.

First determine the length of the non-stretch suspension cable (part no MO500) based on the lowest groundwater level. Provide for the required additional length for attaching the cable to the suspension eye of the Diver and at the upper end when you cut the wire to size.

Next use cable clips (part no MO310) to attach the ends of the cable to the monitoring well's end cover and the Diver's suspension eye, respectively.

To determine the distance of the pressure sensor in the monitoring well requires the precise length of the cable to be known, to which the distance to the location of the pressure sensor in the Diver must be added to obtain the overall effective cable length. This is depicted in the diagram below.

It is also possible to install the CTD-Diver with a communication cable (part no AS2xxx). This cable allows you to readout the CTD-Diver at the top of the monitoring well by using a Smart Interface Cable (part no AS346).

Note that in small diameter wells the installation and removal of the CTD-Diver may affect the water level.

3.4 Installation in Surface Water

If a CTD-Diver is used in surface water, it is important that there is sufficient circulation around the CTD-Diver's sensors.

Sedimentation, algae and plant growth should be minimized as much as possible to ensure the CTD-Diver measures the surrounding water level.

Position the CTD-Divers deep enough so that they remain below a possible ice layer.

A steel protective cover that can be locked should be used to prevent vandalism or theft of the CTD-Diver.

CTD-Divers can also be used to indirectly measure discharge. In such a case, the CTD-Diver can be installed in a monitoring tube/screen next to a weir.

3.5 Use of CTD-Divers at Varying Elevation

CTD-Divers can be used at any elevation ranging from 300 meters below sea level to 5,000 meters above sea level. Appendix I contains further information on the use of CTD-Divers at varying elevation.

3.6 Use in Seawater

The CTD-Diver is an excellent choice for use in semi-saline water/seawater. The CTD-Diver has a ceramic casing that does not corrode and is inert to most substances.

3.7 Biofouling

Biofouling is the undesirable accumulation of microorganisms, plants, algae, or animals on wetted structures. This is especially prominent in surface water monitoring in warm environments. Biofouling causes an algal growth on the electrodes of the CTD-Diver. This may affect the conductivity readings and increases the need for maintenance. Removing the biological materials from the electrodes can be damaging over a prolonged period and increase time spent in the field.

The Diver Copper Shield (part no AS350) protects the CTD-Diver from biofouling and reduces maintenance cost. There are many methods that can be used to prevent and remove the bioaccumulations. However, these methods can be expensive and detrimental to the environment. The Diver Copper Shield is a copper coil shield specifically designed to significantly reduce the growth of algae on the electrodes. Thus, reducing the need for maintenance and reducing the time spent on site.

3.8 CTD-Diver Maintenance

The CTD-Diver casing can be cleaned with a soft cloth. Calcium and other deposits can be removed by soaking the CTD-Diver in commercially available acidic cleaner (such as cleaning vinegar) and/or sodium bicarbonate (commonly known as baking soda or bicarbonate of soda).

Notes:

- Only use diluted acidic solutions if the CTD-Diver has severe build-up of, for example, lime scale and other cleansers are not effective.
- Never use any hard brushes, abrasives or sharp objects for cleaning the CTD-Diver and always rinse it properly with clean water after cleaning, particularly near the flow-through openings. Do not use any powerful jets. This could damage the pressure sensor.

3.9 User Conductivity Calibration

3.9.1 Introduction

The conductivity sensor is, in contrast to the pressure and temperature sensor, sensitive to pollution and fouling. Therefore, it is recommended to check the sensor regularly. A simple verification consists of two steps. First, take the CTD-Diver out of the well and shake it dry. Then take an actual reading, the reading should be 0 mS/cm. The reading may be slightly higher if the conductivity sensor is not completely dry. Second, immerse the CTD-Diver in a conductivity calibration solution. Ensure, that there are no air bubbles trapped inside the conductivity measurement cell. Take another actual reading and compare with the value of the calibration solution.

Note: If the CTD-Diver is set to read Conductivity (and not Specific Conductivity), ensure that the reading is corrected for temperature.

If the deviation is greater than the specified accuracy it is recommended to recalibrate the CTD-Diver. It is important to note that this calibration should be performed in an environment with a stable temperature. It is necessary to make use of good reference fluids and clean tools in order to perform a proper and reliable recalibration.

The conductivity accuracy specification of the CTD-Diver for the full 0-120 mS/cm measurement range can only be achieved if the CTD-Diver is calibrated at all four calibration points: 1.413; 5.000; 12.88 and 80.00 mS/cm.

If you choose to use the CTD-Diver in a specific application, you may decide to perform the calibration on 1 or 2 points. This means that the CTD-Diver meets the specifications in that measurement range. The CTD-Diver may deviate somewhat from the specifications outside the calibrated measurement range.

Example: If the CTD-Diver is used in a measurement range of 2-3 mS/cm, perform the user calibration at 1.413 and/or 5.000 mS/cm. The CTD-Diver will consequently be within the specifications for the 1.413 to 5 mS/cm measurement range.

If the user calibration is later carried out at the four calibration points, then the CTD-Diver will once again meet its specifications for the full measurement range.

Note: When the CTD-Diver has not been used for an extended period take the following steps prior to calibration. Program the CTD-Diver with a one-minute sample interval and start the CTD-Diver. Immerse the CTD-Diver in tap water for at least 24 hours.

Important: Prior to each reference measurement and/or calibration, the CTD-Diver must be thoroughly rinsed in demineralized water. After it has been rinsed it may not be touched by bare hands since the reference liquid can easily become contaminated by residual contaminants and/or residual salts left on hands. This invalidates a reference measurement/calibration since the reference has become distorted. This effect is highest at the low conductivity values.

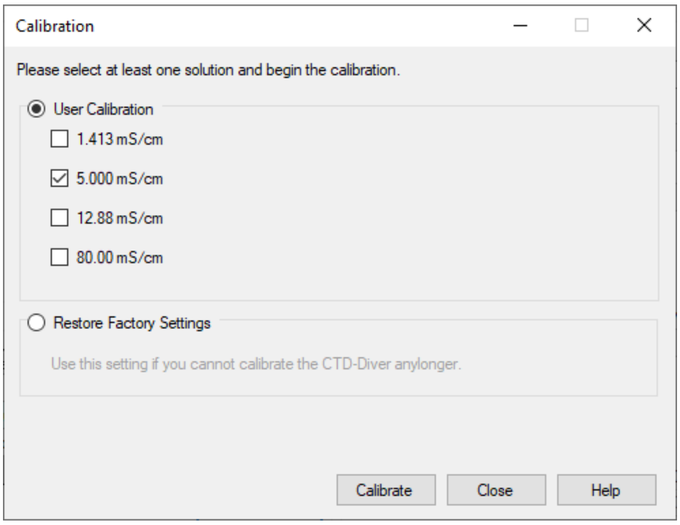
Erroneous or improper calibration can negatively affect the accuracy of the CTD-Diver.

Cleanliness during calibration is especially important. All salt residues adhering to the CTD-Diver will negatively affect the accuracy of the calibration liquid. Therefore, a calibration solution may never be used twice.

Temperature differences, between the conductivity solution and the CTD-Diver, may also cause errors (extended acclimatization is required).

3.9.2 Perform a User Calibration

To calibrate a CTD-Diver, open the Diver-Office software and click the Diver button to open the Diver window. Click the **Calibrate** button located in the **Diver** dialog toolbar. This button is only visible when a CTD-Diver is connected and only enabled when the logging status of the CTD-Diver is stopped. Upon clicking the **Calibrate** button, the following dialog will display.



Select the check boxes next to the calibration solutions that will be used to calibrate the CTD-Diver. Click the Calibrate button to begin calibrating the CTD-Diver.

Next, you will be prompted to immerse the CTD-Diver in the selected solution. Click OK to continue. If you are using multiple solutions, you will be prompted to calibrate from the lowest to the highest concentration.

Diver-Office will then calibrate the CTD-Diver according to the specified solutions. It is important to keep the CTD-Diver connected until the success message appears. If the calibration fails:

- check to make sure you are using the appropriate calibration solution,
- ensure that the CTD-Diver is connected securely to the Reading Unit,
- ensure that the CTD-Diver's sensors are submerged in the solution.

3.9.3 Restore Factory Settings

Select this option to reset the CTD-Diver calibration to its factory settings. This option can be useful if you are experiencing difficulties calibrating the CTD-Diver.

When this option is selected, click the Calibrate button to perform the reset.

4 Appendix I – Use of CTD-Divers at Varying Elevations

CTD-Divers can be used at any elevation ranging from 300 meters below sea level to 5,000 meters above sea level. It is however recommended that all Divers and the Baro-Diver forming part of the same network be used at the same elevation (whenever possible).

The relationship between atmospheric pressure variations and elevation is exponential, rather than linear:

$$P_H = P_0 \cdot \exp[-(M \cdot g \cdot H)/(R \cdot T)]$$

where

P_H = atmospheric pressure at elevation height H

P_0 = atmospheric pressure at reference height

$M = 28.8 \cdot 10^{-3}$ kg/mol (molecular mass of air)

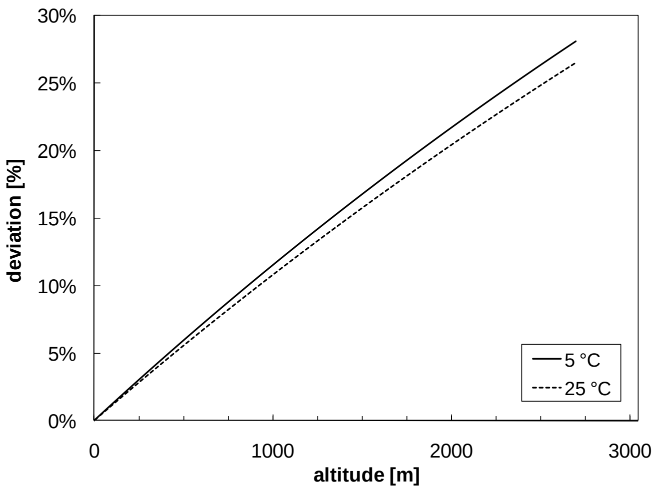
$g = 9.81$ m/s^2 (standard gravity)

H = height in meters

R = 8.314 J/mol/K (gas constant)

T = temperature in Kelvin

If the Baro-Diver is placed at a different elevation from the other Divers in a monitoring network, it is possible for a deviation to occur in the barometrically compensated data due to the relationships referred to above. The graph below illustrates the deviation in the barometric data as a function of the variation in elevation at 5 °C and 25 °C.



To determine the relative barometric pressure deviation relative to P_0 at 5 °C (T = 278.15°K) at a height differential of H, the above referenced formula can be used:

$$(P_H - P_0) / P_0 = 1 - \exp[-(M \cdot g \cdot H)/(R \cdot T)] \times 100\% \qquad (6)$$

By substituting the data, a relative deviation of 1.2 % at a height differential of 100 m is obtained. At a height differential of 1,000 m this increases to 11.5 %.

We therefore recommend that all Divers and the Baro-Divers in a network be placed such that the mutual height differentials are minimized.

If necessary, multiple Baro-Divers can be deployed to avoid the abovementioned issues.

5 Appendix II – CTD-Diver Communication Protocol

5.1 Introduction

The CTD-Diver supports a set of commands that allows the user to communicate with the Diver through other software than Diver-Office. The following commands are available:

- reading measured/stored data
- read date/time
- read serial number
- read monitoring point name
- real-time pressure, temperature and conductivity value including time stamp
- read sample mode (record method and interval)
- read product ID, name, and firmware version
- read remaining battery capacity
- read status: started, stopped, future start, free memory

5.2 Serial Port Settings

Bitrate: 9600
Parity: None
Databits: 8
Stopbits: 1

5.3 Frame Format

The frame format for a command/response is:

STX (1 byte)	Length (1 byte)	OC (2 bytes)	Payload (n bytes)	CC (1 byte)

field	size	description	remarks
STX	1 byte	Start of text, value is 0x02	Used to identify start of command
Length	1 byte	Length of frame	Number of bytes in frame including STX and Checksum
OC	2 bytes	OpCode	Identifies the OpCode type
Payload	n bytes	Data field (n bytes)	Data in command or response
CC	1 byte	Checksum	Ones' complement of the low byte of the sum of all bytes excluding CC

Time-out:

- All bytes must be sent with a maximum delay of 30 ms between the bytes.
- When the delay exceeds 30 ms, a communication error response will be sent.

Response:

- Response will only follow when STX is detected.
- Response will follow the command with a delay of 0 to 500 ms (depending on OpCode and/or other Diver operations).
- If the frame format is incorrect, the OpCode is not supported or the checksum is not correct, then a communication error will be sent when STX is detected.

5.4 List of Commands

5.4.1 Read Date/Time

Read the date/time of the Diver clock.

Command:

STX	5	CL	None	CC

Response:

STX	22	CL	YY/MM/DD HH:MM:SS	CC

Data field length is 17 characters per described format

YY/MM/DD HH:MM:SS = Date/time format 17 characters

5.4.2 Read Monitoring Point Name

Read the name of the monitoring point programmed by the user.

Command:

STX	5	MP	None	CC

Response:

STX	25	MP	XXXXXXXXXXXXXXXXXXXX	CC

Data field length must be 20 characters

XXXXXXXXXXXXXXXXXXXX = Monitoring point name 20 characters

Example	Description
MW-3␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣	20 characters (all ASCII)

5.4.3 Read Serial Number

Read the unique serial number of the Diver.

Command:

STX	5	SN	None	CC

Response:

STX	15	SN	XXXXXXXXXX	CC

Data field length is 10 characters

XXXXXXXXXX = Serial number 10 characters

Example	Description
`X3440␣␣␣␣␣`	10 characters (all ASCII)

5.4.4 Read Real Time Pressure, Temperature and Conductivity Value

Read a real-time pressure, temperature and conductivity value of the Diver including a time stamp. If this command is given the Diver will take a reading immediately whether the Diver is logging or not. This data will not be stored in the Diver memory.

Command:

STX	5	RT	none	CC

Response:

STX	52	RT	YY/MM/DD HH:MM:SS:XXXXX.XXXZZZZZZ.ZZZ:KKKKK.KKK	CC

Data field length is 47 characters per described format

YY/MM/DD HH:MM:SS = Date/time format 17 characters

XXXXX.XXX = value Level (in cmH_2O and with 3 decimal) 9 characters

ZZZZZZ.ZZZ = value Temperature (in degrees Celsius with 3 decimals) 9 characters

KKKKK.KKK = value Conductivity (in mS/cm with 3 decimals) 9 characters

Example	Description
`22/05/06␣15:38:47:␣1048.491:␣␣␣22.700:␣␣␣␣4.860`	47 characters (all ASCII)

5.4.5 Read Recorded Pressure, Temperature and Conductivity

Read the data recorded by the Diver. Each data record consisting of a time stamp, pressure, temperature and conductivity value must be read separately.

Command:

STX	15	SD	XXXXXXXXXX	CC

Data field length is 10 characters per described format

XXXXXXXXXX = Record number 10 characters (first record is record number 1; last record number is 144,000)

Example	Description
`10000␣␣␣␣␣`	10 characters (all ASCII)

Response:

STX	52	SD	YY/MM/DD␣HH:MM:SS:XXXXX.XXX:ZZZZZ.ZZZ:KKKKK.KKK	CC

Data field length is 47 characters per described format

YY/MM/DD HH:MM:SS = Date/time format 17 characters

XXXXX.XXX = value Level (in cmH_2O with 3 decimals) 9 characters

ZZZZZ.ZZZ = value temperature (in degrees Celsius with 3 decimals) 9 characters

KKKKK.KKK = value conductivity (in mS/cm with 3 decimals) 9 characters

Example	Description
`22/05/06␣16:00:21:␣1049.016:␣␣␣21.130:␣␣␣␣4.976`	47 characters (all ASCII)

5.4.6 Read Product ID, Name and Firmware Version

Command:

STX	5	PI	none	CC

Response:

STX	25	PI	PP:XXXXXXXXXX:VVVVVV	CC

Data field length is 20 characters per described format

PP = Diver type 2 characters; type is 24 for CTD-Diver

XXXXXXXXXX = Product name Diver 10 characters

VVVVVV = Firmware version number 6 characters

Example	Description
`24␣:CTD-Diver:␣V1.13`	20 characters (all ASCII)

5.4.7 Read Product Status and Free Memory

Read the logging status and the free memory of the Diver. The logging status is either STARTED, STOPPED, or FUTURE START. The free memory indicates how many records (time stamp, pressure and temperature value) can be read until the Diver memory is full.

Command:

STX	5	PS	None	CC

Response:

STX	25	PS	XXXXXXXXXXXXX:MMMMMM	CC

Data field length is 20 characters per described format

XXXXXXXXXXXXX = Logging status Diver (STARTED, STOPPED, FUTURE START) 13 characters

MMMMMM = Free memory 6 characters from 0 to 144,000

Example	Description
STARTED␣␣␣␣␣␣:143914	20 characters (all ASCII)

5.4.8 Read Sample Method and Interval

Read the Diver’s sample method and interval. The available sample methods are fixed time interval – continuous (FIXED␣RING) and fixed time interval – fixed length memory (FIXED␣␣␣␣␣), i.e. the Diver will stop logging when its memory is full.

Command:

STX	5	RS	None	CC

Response:

STX	35	RS	XXXXXXXXXX:YYYYYYYYY:ZZZZZZZZZ	CC

Data field length is 30 characters per described format

XXXXXXXXXX = Record method 10 characters

YYYYYYYYY = Record interval 9 characters

ZZZZZZZZZ = 9 spaces (not used)

XXXXXXXXXX	YYYYYYYYY	ZZZZZZZZZ
FIXED␣␣␣␣␣	xx␣SEC␣␣␣	␣␣␣␣␣␣␣␣␣
FIXED␣RING	xx␣MIN␣␣␣	␣␣␣␣␣␣␣␣␣

5.4.9 Read Remaining Battery Capacity

Read how much capacity of the battery is left from the initial capacity (%). Note that this is an estimated and calculated value and not a measured value.

Command:

STX	5	BC	None	CC

Response:

STX	15	BC	XXXXXXXXXX	CC

Data field length is 10 characters per described format

XXXXXXXXXX = Remaining battery capacity in percentage 10 characters

Example	Description
␣␣␣␣␣␣␣␣␣58	42 % battery capacity used and 58 % battery capacity remaining

5.4.10 Failure/Error Response

A Diver error response will be returned in the following format:

STX	15	FL	XXXXXXXXXX	CC

Data field length is 10 characters per described format

XXXXXXXXXX = Failure/error description 10 characters

Results	Description
TIME-OUT␣␣	Time-out occurred when still expecting characters
UNKNOWN␣OC	OpCode not recognized
ERROR␣CC␣␣	Checksum received incorrect
WRONG␣LEN␣	Length byte value incorrect
ERROR␣DATA	Data field incorrect (value incorrect)

6 Appendix III – CTD-Diver Accessories

6.1 Diver-Office software

Program Diver dataloggers and download measurements onto your PC. Export the data to a spreadsheet or modeling program. Diver-Office is a flexible "project-based" measurement software package designed for exchanging Diver data. Diver-Office is easy-to-use and has an intuitive user interface.

- Barometric compensation
- Units: Metric and U.S.
- 8 languages: Chinese, Dutch, English, French, German, Polish, Portuguese and Spanish

Free download from www.vanessen.com

6.2 USB Reading Unit

The Diver USB Reader can be used for programming or reading the Diver. Connect the USB Reader to the USB port of your PC or Laptop. Simply insert the Diver into the base of the USB Reading Unit and you are ready to communicate with your Diver.

The USB Reading Unit can be used in the field or the office.

Part no: AS330

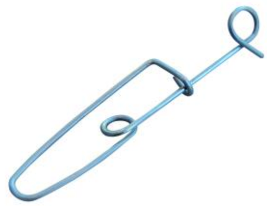
6.3 Stainless Steel Cable

Divers may be suspended on a stainless-steel wireline. This is an inexpensive method of deployment, and if in a well, allows the Diver to be easily locked out of sight and inaccessible.

Part no: MO500

6.4 Cable Clip

The cable clip provides an easy way to connect a Diver to a stainless-steel cable. The cable clip can also be used to attach the stainless-steel cable with the Diver to the top of casing.



Part no: MO310 (10 pcs)

6.5 Diver Copper Shield

The Diver Copper Shield protects the CTD-Diver from bio-fouling and reduces maintenance cost. The Diver Copper Shield is a copper coil shield specifically designed to significantly reduce the growth of algae on the electrodes. Thus reducing the need for maintenance and reducing the time spent on site.

Part no: AS350

6.6 Smart Interface Cable

The Diver Smart Interface Cable allows you to communicate with a Diver that has been deployed with the communication cable. The Smart Interface Cable has a mating connection for the communication cable on one end, and a standard USB port on the other, for connection to a laptop computer.

The Smart Interface Cable allows for data download, programming settings, or starting/stopping the Diver while in the field.

Part no: AS346

6.7 Communication Cable

Deploying a Diver on a Diver communication cable saves time on downloading and provides real time data from a Diver. Connect your laptop equipped with Diver-Office to the Diver Data Cable using the USB Interface Cable to program and read data from the Diver.

Available in lengths from 1 meter to 500 meter.

Part no: AS2xxx

xxx = length in meter, e.g 10 meter cable is AS2010

6.8 Diver-Mate

The Diver-Mate is designed for simple and fast download of data, increasing download efficiency while reducing data transfer errors.

The Diver-Mate can store Diver data from hundreds of Divers. Used in combination with a Diver communication cable, this downloading unit stores data in a non-volatile memory drive, meaning that even if the battery is empty the data will still be available. A full battery can support more than 10 days of operational use and a LED will indicate when the battery voltage is low.

Part no: DM421

6.9 Diver-Link

The Diver-NETZ remote monitoring system integrates field instrumentation with wireless communication and data management to effectively manage groundwater resources. A key part in this system is the Diver-Link, a compact 4G/LTE telemetry unit. The Diver-Link is suitable for the continuous long- and short-term monitoring projects.

Diver-Link is easy-to-install in a variety of borehole locations such as flush mount and stick-up wells. The Diver-Link transmits data from up to 3 Diver data loggers over a cellular network. Easily integrate Diver-Link into the Diver-HUB web portal for real-time management of site data, monitoring equipment and water levels.

Part no: DN4xx

Water Level Meter

Model 101

For measuring the depth to water in wells, boreholes, standpipes, and tanks, Model 101 Water Level Meters are the industry standard for portable hand operated meters. They are sturdy, easy to use and read accurately to 1/100 ft. or each millimeter.

There are two versions to choose from. The Model 101 P7 Water Level Meter features a pressure-proof probe and laser marked PVDF tape. The Model 101 P2 Water Level Meter features an easy-to-repair probe and heat embossed polyethylene tape.

Also available, are the less expensive Model 102 and 102M Coaxial Cable Water Level Meters for use in small diameter tubes, and the basic Model 101B Water Level Meter (see Model 102 and 101B Data Sheets). The Model 101D Water Level DrawDown Meter provides both depth to water and drawdown measurements using one probe (See Model 101D Data Sheet).

101 P7

Water Level Meter Reels

With a stand-alone design, convenient carrying handle, and sturdy probe holder, the standard reels are ergonomically designed for ease of use. They are robust and smooth running. The battery is housed in a convenient drawer in the front of the reel, allowing quick replacement. The reels are equipped with an on/off sensitivity switch, light, buzzer, battery test button, brake and a tape guide stored on the frame.

Get Quote

Water Level Meter Specifications

Operating temperature of reel:	-20°C to +50°C
Submerged operating temperature (tape/probe):	-20°C to +80°C
Wetted materials (tape/probe):	P7: PVDF, Santoprene, ®Delrin, ®Viton, 316 stainless steel
	P2: MDPE, neoprene, Delrin, 316 stainless steel
Probe pressure rating:	P7: Fully submersible to depth of all tape lengths
Reel IP Rating:	IP64 (dust and splash proof)
Tape lengths:	P7: 100 to 5000 ft, 30 - 1500 m
	P2: 100 to 1000 ft, 30 - 300 m

Model 101 P7 Water Level Meter Features

Accurate:
- Markings each 1/100 ft. or millimeter
- Traceable to national standards
- Sensitivity adjustable to conductivity
- Probes avoid false readings in cascading water

Reliable:
- Permanent laser markings
- Non-stretch PVDF tape with stainless steel conductors

Long Life:
- Rugged, corrosion proof components
- Strong, flexible tapes
- Easy to splice and repair

Flexible:
- PVDF replacement tapes are interchangeable with other meters

Water Level Meter Operating Principles

Model 101 Water Level Meters use corrosion proof stainless steel probes attached to permanently marked flat tape, fitted on a well-balanced reel. They are powered by a standard 9 volt battery.

The probes incorporate an insulating gap between electrodes. When contact is made with water, the circuit is completed, activating a loud buzzer and a light. The water level is then determined by taking a reading directly from the tape at the top of the well casing or borehole.

A sensitivity control allows the buzzer to be turned off while in cascading water, and ensures a clear signal in both high and low conductivity conditions.

P7 Probe

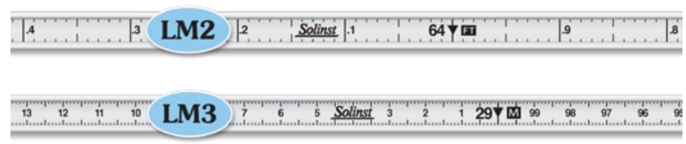
The P7 Probe is submersible the full length of the tape, therefore, you can measure total well depth in ideal conditions. The sensor at the tip of the probe provides consistent measurements with almost zero displacement. The tape seal plug design allows the probe to be quickly and easily replaced, if required.

Zero Measurement Point

Size: 5/8” dia., 5.38” long (16 mm x 137 mm)
Weight: ~4.5 ounces (128 g)

PVDF Laser Marked Tape

The Model 101 P7 Water Level Meter uses extremely durable, PVDF flat tape, traceable to NIST and EU measurement standards. Each tape conductor contains 13 strands of stainless steel, and 6 strands of copper-coated steel, making the tape non-stretch and high in tensile strength and electrical efficiency. The tape has a thick dog bone design that prevents adherence to wet surfaces, and allows it to hang straight in application. It is also easy to splice. The 3/8" (10 mm) tape comes with permanent laser markings every 1/100 ft. or each millimeter, in lengths up to 5000 ft. (1500 m).



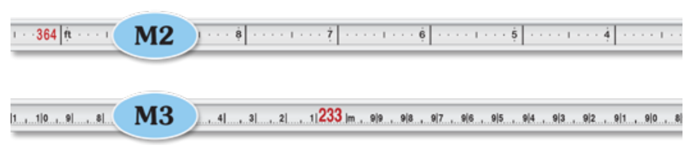
LM2: Feet and tenths: with markings every 1/100 ft.
LM3: Meters and centimeters: with markings every mm

101 P2

Polyethylene Tape

The Model 101 P2 Water Level Meter uses high quality polyethylene tape that reels smoothly, remains flexible and hangs straight in the well. Heat embossed marking each millimeter or 1/100 ft. allow accurate readings. The 3/8" (10 mm) wide tapes come in lengths up to 1000 ft. (300 m).

Seven stranded stainless steel conductors resist corrosion, provide strength and are non-stretch. They make the tape very easy to repair and splice. The dog-bone design reduces adherence to wet surfaces.



M2 Feet and tenths: with markings every 1/100 ft.
M3 Meters and centimeters: with markings every mm.

P2 Probe

The P2 Probe is shielded in design to reduce or eliminate false readings in cascading water. The probe consists of a stainless steel body with a neoprene heat shrink seal. It is not suitable for submergence to any significant depth. Its simple design makes it easy to repair.

Zero Measurement Point

Size: 0.55" dia., 7.5" long (14 mm x 190 mm)
Weight: ~7 ounces (200 g)

Model 101 Water Level Meter Reels

Length Options

Solinst Model 101 P7 and P2 Water Level Meters are available on reels as shown below, in the following standard lengths:

Reel	ft.	m
Small Reel	* 100 ft.	30 m
	* 200 ft.	60 m
	* 300 ft.	100 m
Medium Reel	* 500 ft.	150 m
	* 750 ft.	250 m
	* 1000 ft.	300 m
Large Reel	1250 ft.	400 m
X-Large Reel	1650 ft.	500 m
	2000 ft.	600 m

* Polyethylene tapes are only available in these lengths

Other Options

Carrying Case: Small and medium padded nylon carrying cases are available, as an optional extra. Their design has a convenient shoulder strap, zippered front pocket, zippered top, and a grommet in the base to prevent moisture build-up.

Power Reels: Power reels can be very useful to allow faster or less strenuous operation of longer lengths of tape. They are available as 12V or 110V.

Replacement Parts: Replacement probes, tapes and other spare parts are available.

Tape Guide/Datum

A tape guide is provided with each Meter. It protects the tape from damage on rough edges of well casing and ensures easy, consistent measurements, regardless of who takes the readings. It can also provide support on the casing, for small reels.

Power Winder

The Solinst Model 101 Power Winder allows ease of use when deploying longer lengths of tape. It is lightweight and easy to attach to the frame of small, medium and large Model 101 Water Level Meter reels (see Model 101 Power Winder Data Sheet).

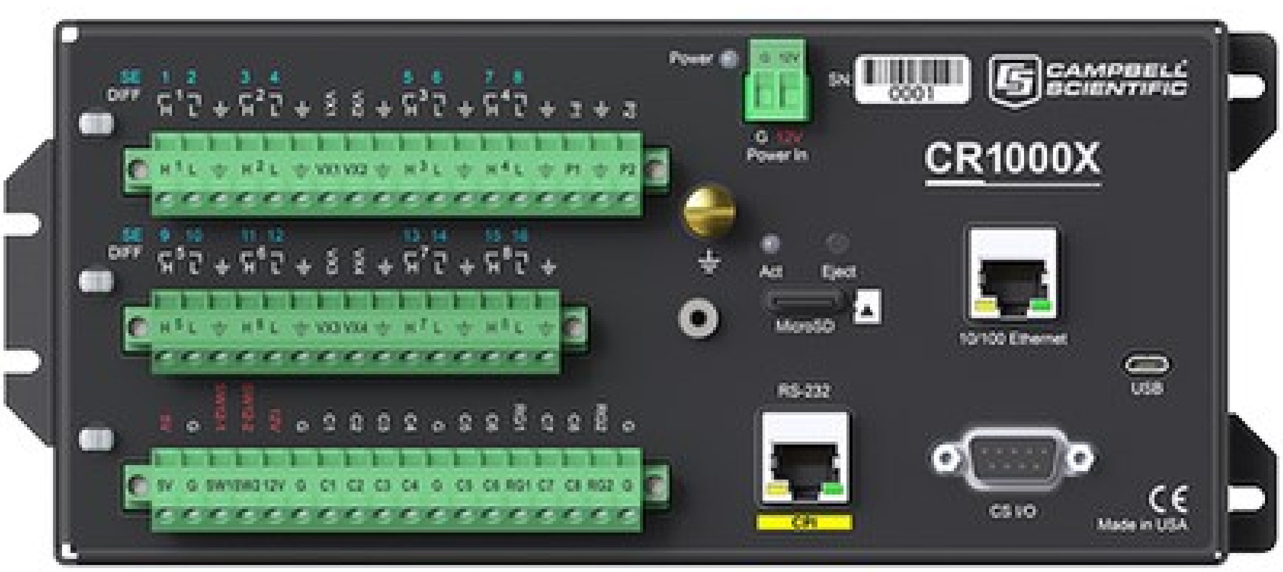
A standard drill provides power to the Power Winder, which turns the rollers that are in contact with the reel. The drill is used at various speeds, in forward and reverse, to turn the reel and unwind and rewind the tape.

Product Manual

Datalogger

CR1000X

Measurement and Control Datalogger



Revision: 04/22/2022

RELIABLE SINCE 1974 MONITORING

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Table of Contents

1. Introduction

The CR1000X is our flagship data logger that provides measurement and control for a wide variety of applications. Its reliability and ruggedness make it an excellent choice for remote environmental applications, including weather stations, mesonet systems, wind profiling, air quality monitoring, hydrological systems, water quality monitoring, and hydrometeorological stations.

The CR1000X is a low-powered device that measures sensors, drives direct communications and telecommunications, analyzes data, controls external devices, and stores data and programs in onboard, nonvolatile storage. The electronics are RF-shielded by a unique sealed, stainless-steel canister. A battery-backed clock assures accurate timekeeping. The onboard, BASIC-like programming language supports data processing and analysis routines.

The Getting Started Guide provides an introduction to data acquisition and walks you through a procedure to set up a simple system. You may not find it necessary to progress beyond this. However, should you want to dig deeper into the complexity of the data logger functions or quickly look for details, extensive information is available in this and other Campbell Scientific manuals.

Additional Campbell Scientific publications are available online at www.campbellsci.com. Video tutorials are available at www.campbellsci.com/videos. Generally, if a particular feature of the data logger requires a peripheral hardware device, more information is available in the help or manual written for that device.

2. Precautions

READ AND UNDERSTAND the Safety section at the back of this manual.

An authorized technician shall verify that the installation and use of this product is in accordance to the manufacturer's instructions, recommendations and intended use.

Although the CR1000X is rugged, it should be handled as a precision scientific instrument.

Maintain a level of calibration appropriate to the application. Campbell Scientific recommends factory recalibration every three years.

3. Initial inspection

Upon receiving the CR1000X, inspect the packaging and contents for damage. File damage claims with the shipping company.

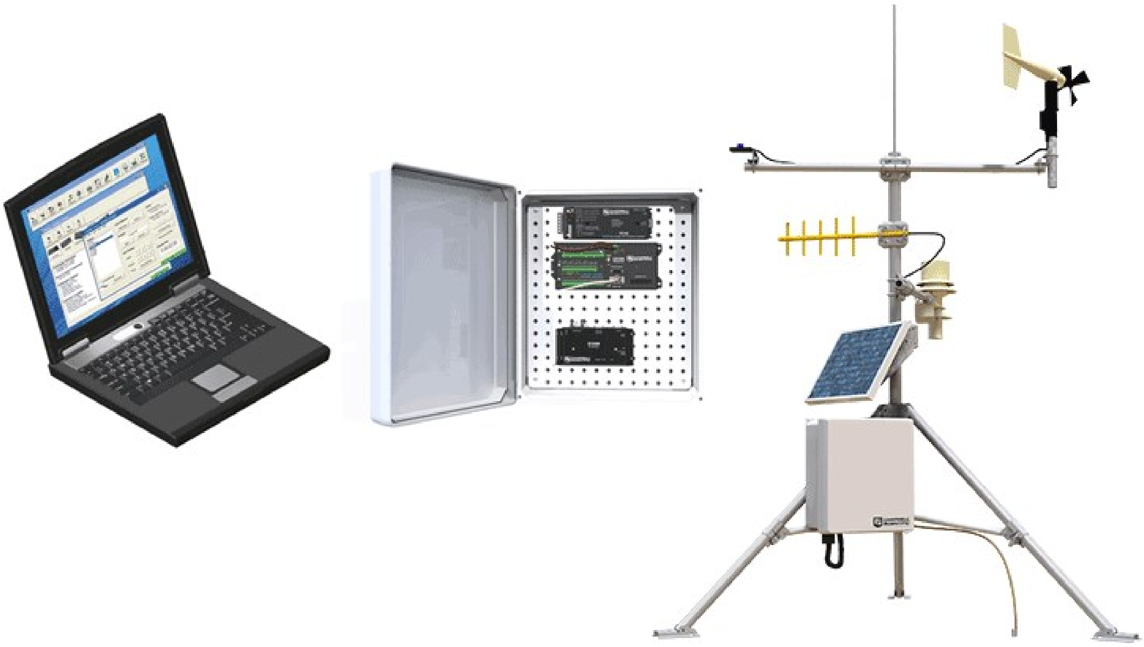
Immediately check package contents. Thoroughly check all packaging material for product that may be concealed. Check model numbers, part numbers, and product descriptions against the shipping documents. Model or part numbers are found on each product. Report any discrepancies to Campbell Scientific.

Check the CR1000X operating system version as outlined in Updating the operating system (p. 135), and update as needed. CR1000X data loggers with Serial Numbers 34000 and newer have hardware requiring the use of OS version 5.02 or newer.

4. CR1000X data acquisition system components

A basic data acquisition system consists of sensors, measurement hardware, and a computer with programmable software. The objective of a data acquisition system should be high accuracy, high precision, and resolution as high as appropriate for a given application.

The components of a basic data acquisition system are shown in the following figure.



Following is a list of typical data acquisition system components:

- **Sensors** - Electronic sensors convert the state of a phenomenon to an electrical signal (see Sensors (p. 6) for more information).
- **Data logger** - The data logger measures electrical signals or reads serial characters. It converts the measurement or reading to engineering units, performs calculations, and reduces data to statistical values. Data is stored in memory to await transfer to a computer by way of an external storage device or a communications link.

- **Data Retrieval and Communications** - Data is copied (not moved) from the data logger, usually to a computer, by one or more methods using data logger support software. Most communications options are bi-directional, which allows programs and settings to be sent to the data logger. For more information, see Sending a program to the data logger (p. 32).
- **Datalogger Support Software** - Software retrieves data, sends programs, and sets settings. The software manages the communications link and has options for data display.
- **Programmable Logic Control** - Some data acquisition systems require the control of external devices to facilitate a measurement or to control a device based on measurements. This data logger is adept at programmable logic control. See Programmable logic control (p. 19) for more information.
- **Measurement and Control Peripherals** - Sometimes, system requirements exceed the capacity of the data logger. The excess can usually be handled by addition of input and output expansion modules.

4.1 The CR1000X Datalogger

The CR1000X is used in a broad range of measurement and control projects. Rugged enough for extreme conditions and reliable enough for remote environments, it plays a critical role in numerous complex applications. Used in applications all over the world, it is a powerful core component for your data acquisition system.

4.1.1 Overview

The CR1000X data logger is the main part of a data acquisition system (see CR1000X data acquisition system components (p. 4) for more information). It has a central-processing unit (CPU), analog and digital measurement inputs, analog and digital outputs, and memory. An operating system (firmware) coordinates the functions of these parts in conjunction with the onboard clock and the CRBasic application program.

The CR1000X can simultaneously provide measurement and communications functions. Low power consumption allows the data logger to operate for extended time on a battery recharged with a solar panel, eliminating the need for ac power. The CR1000X temporarily suspends operations when primary power drops below 9.6 V, reducing the possibility of inaccurate measurements.

The electronics are RF shielded and protected by the sealed, stainless-steel canister, making the CR1000X economical, small, and very rugged. A battery-backed clock assures accurate timekeeping.

4.1.2 Operations

The CR1000X measures almost any sensor with an electrical response, drives direct communications and telecommunications, reduces data to statistical values, performs calculations, and controls external devices. After measurements are made, data is stored in onboard, nonvolatile memory. Because most applications do not require that every measurement be recorded, the program usually combines several measurements into computational or statistical summaries, such as averages and standard deviations.

4.1.3 Programs

A program directs the data logger on how and when sensors are measured, calculations are made, data is stored, and devices are controlled. The application program for the CR1000X is written in CRBasic, a programming language that includes measurement, data processing, and analysis routines, as well as the standard BASIC instruction set. For simple applications, ***Short Cut***, a user-friendly program generator, can be used to generate the program. See also:

- Creating a Short Cut data logger program (p. 29)
- https://www.campbellsci.com/videos/datalogger-programming

For more demanding programs, use the full-featured ***CRBasic Editor***. The ***CRBasic Editor*** help contains program structure details, instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

4.2 Sensors

Sensors transduce phenomena into measurable electrical forms by modulating voltage, current, resistance, status, or pulse output signals. Suitable sensors do this with accuracy and precision. Smart sensors have internal measurement and processing components and simply output a digital value in binary, hexadecimal, or ASCII character form.

Most electronic sensors, regardless of manufacturer, will interface with the data logger. Some sensors require external signal conditioning. The performance of some sensors is enhanced with specialized input modules. The data logger, sometimes with the assistance of various peripheral devices, can measure or read nearly all electronic sensor output types.

The following list may not be comprehensive. A library of sensor manuals and application notes is available at www.campbellsci.com/support to assist in measuring many sensor types.

- Analog
  - Voltage
  - Current

    - Strain
    - Thermocouple
    - Resistive bridge
- Pulse
    - High frequency
    - Switch-closure
    - Low-level ac
    - Quadrature
- Period average
- Vibrating wire (through interface modules)
- Smart sensors
    - SDI-12
    - RS-232
    - Modbus
    - DNP3
    - TCP/IP
    - RS-422
    - RS-485

5. Wiring panel and terminal functions

The CR1000X wiring panel provides ports and removable terminals for connecting sensors, power, and communications devices. It is protected against surge, over-voltage, over-current, and reverse power. The wiring panel is the interface to most data logger functions so studying it is a good way to get acquainted with the data logger. Functions of the terminals are broken down into the following categories:

- Analog input
- Pulse counting
- Analog output
- Communications
- Digital I/O
- Power input
- Power output
- Power ground
- Signal ground

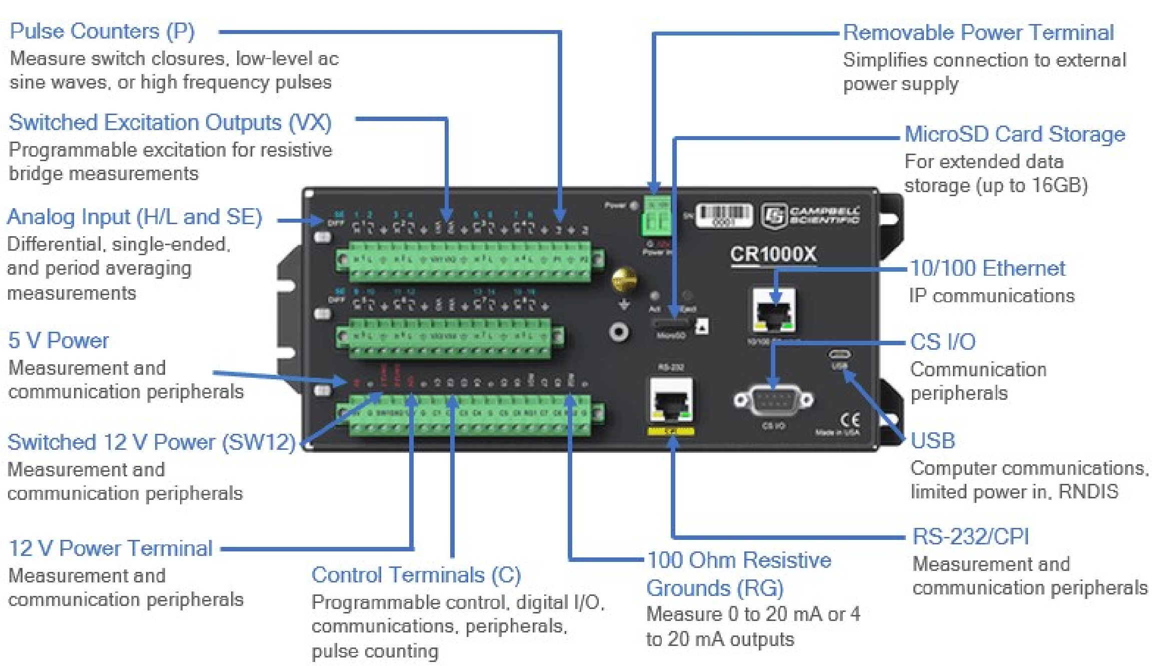


Table 5-1: Analog input terminal functions																		
SE DIFF	1 H (1)	2 L (1)	3 H (2)	4 L (2)	5 H (3)	6 L (3)	7 H (4)	8 L (4)	9 H (5)	10 L (5)	11 H (6)	12 L (6)	13 H (7)	14 L (7)	15 H (8)	16 L (8)	RG1	RG2
Single-Ended Voltage	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Differential Voltage	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L		
Ratiometric/Bridge	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Thermocouple	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Current Loop																	✓	✓
Period Average	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		

Table 5-2: Pulse counting terminal functions			
	P1	P2	C1-C8
Switch-Closure	✓	✓	✓
High Frequency	✓	✓	✓
Low-level Ac	✓	✓	

NOTE:
Conflicts can occur when a control port pair is used for different instructions (`TimerInput()`, `PulseCount()`, `SDI12Recorder()`, `WaitDigTrig()`). For example, if **C1** is used for `SDI12Recorder()`, **C2** cannot be used for `TimerInput()`, `PulseCount()`, or `WaitDigTrig()`.

Table 5-3: Analog output terminal functions	
	VX1-VX4
Switched Voltage Excitation	✓

Table 5-4: Voltage Output						
	C1-C8[1]	VX1-VX4	5V	12V	SW12-1	SW12-2
5 VDC	✓	✓	✓			
3.3 VDC	✓	✓				
12 VDC				✓	✓	✓

[1] C terminals have limited drive capacity. Voltage levels are configured in pairs.

Table 5-5: Communications terminal functions									
	C1	C2	C3	C4	C5	C6	C7	C8	RS-232/CPI
SDI-12	✓		✓		✓		✓		
GPS	PPS	Rx	Tx	Rx	Tx	Rx	Tx	Rx	
TTL 0-5 V	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	
LVTTL 0-3.3 V	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	
RS-232					Tx	Rx	Tx	Rx	✓
RS-485 (Half Duplex)					A-	B+	A-	B+	
RS-485 (Full Duplex)					Tx-	Tx+	Rx-	Rx+	
I2C	SDA	SCL	SDA	SCL	SDA	SCL	SDA	SCL	
SPI	MOSI	SCLK	MISO		MOSI	SCLK	MISO		
SDM[1]	Data	Clk	Enabl		Data	Clk	Enabl		
CPI/CDM									✓

[1] SDM can be on either **C1**-**C3** or **C5**-**C7**, but not both at the same time.

Communications functions also include Ethernet and USB.

Table 5-6: Digital I/O terminal functions	
	C1-C8
General I/O	✓
Pulse-Width Modulation Output	✓
Timer Input	✓

Table 5-6: Digital I/O terminal functions	
	C1-C8
Interrupt	✓
Quadrature	✓

5.1 Power input

The data logger requires a power supply. It can receive power from a variety of sources, operate for several months on non-rechargeable batteries, and supply power to many sensors and devices. The data logger operates with external power connected to the green **POWER IN** port on the face of the wiring panel Wiring panel and terminal functions (p. 8). The positive power wire connects to the **12V** terminal. The negative wire connects to **G**. The power terminals are internally protected against polarity reversal and high voltage transients. If the voltage on the **POWER IN** terminals exceeds 19 V, power is shut off to certain parts of the data logger to prevent damaging connected sensors or peripherals.

The primary power source, which is often a transformer, power converter, or solar panel, connects to the charging regulator, as does a nominal 12 VDC sealed rechargeable battery. A third connection connects the charging regulator to the **12V** and **G** terminals of the **POWER IN** port. UPS (uninterruptible power supply) is often the best power source for long-term installations. If external alkaline power is used, the alkaline battery pack is connected directly to the **POWER IN** port. External UPS consists of a primary-power source, a charging regulator external to the data logger, and an external battery.

WARNING:
Sustained input voltages in excess of those listed in the Power requirements (p. 209), can damage the transient voltage suppression.

Ensure that power supply components match the specifications of the device to which they are connected. When connecting power, switch off the power supply, insert the connector, then turn the power supply on. Troubleshooting power supplies (p. 152)

The CR1000X can receive power via the **POWER IN** port as well as 5 VDC via a **USB** connection. If both **POWER IN** and **USB** are connected, power will be supplied by whichever has the highest voltage. If **USB** is the only power source, then the **CS I/O** port and the **12V**, **SW12**, and **5V** terminals will not be operational. When powered by USB (no other power supplies connected) **Status** field **Battery** = **0**. Functions that will be active with a 5 VDC source (**USB**) include sending programs, adjusting data logger settings, and making some measurements.

> **NOTE:**
> The **Status** field **Battery** value and the destination variable from the `Battery()` instruction (often called `batt_volt` in the **Public** table) reference the external battery voltage. For information about the internal battery, see Internal battery (p. 132).

5.1.1 Powering a data logger with a vehicle

If a data logger is powered by a motor-vehicle power supply, a second power supply may be needed. When starting the motor of the vehicle, battery voltage often drops below the voltage required for data logger operation. This may cause the data logger to stop measurements until the voltage again equals or exceeds the lower limit. A second supply or charge regulator can be provided to prevent measurement lapses during vehicle starting.

In vehicle applications, the earth ground lug should be firmly attached to the vehicle chassis with 12 AWG wire or larger.

5.1.2 Power LED indicator

When the data logger is powered, the Power LED will turn on according to power and program states:

- **Off**: No power, no program running.
- **1 flash every 10 seconds**: Powered from **BAT**, program running.
- **3 flashes every 10 seconds**: Powered via USB, program running.
- **Always on**: Powered, no program running.

5.2 Power output

The data logger can be used as a power source for communications devices, sensors and peripherals. Take precautions to prevent damage to these external devices due to over- or under-voltage conditions, and to minimize errors. Additionally, exceeding current limits causes voltage output to become unstable. Voltage should stabilize once current is again reduced to within stated limits. The following are available:

- **12V**: unregulated nominal 12 VDC. This supply closely tracks the primary data logger supply voltage; so, it may rise above or drop below the power requirement of the sensor or peripheral. Precautions should be taken to minimize the error associated with measurement of underpowered sensors.
- **5V**: regulated 5 VDC. The 5 VDC supply is regulated to within a few millivolts of 5 VDC as long as the main power supply for the data logger does not drop below the minimum

supply voltage. It is intended to power sensors or devices requiring a 5 VDC power supply. It is not intended as an excitation source for bridge measurements. Current output is shared with the CS I/O port; so, the total current must be within the current limit. See 5 V fixed output (p. 211) specifications.

- **SW12**: program-controlled, switched 12 VDC terminals. It is often used to power devices such as sensors that require 12 VDC during measurement. Voltage on a **SW12** terminal will change with data logger supply voltage. CRBasic instruction `SW12()` controls the **SW12** terminal. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.
- **CS I/O** port: used to communicate with and often supply power to Campbell Scientific peripheral devices.

CAUTION:
Voltage levels at the **12V** and switched **SW12** terminals, and pin **8** on the **CS I/O** port, are tied closely to the voltage levels of the main power supply. Therefore, if the power received at the **POWER IN 12V** and **G** terminals is 16 VDC, the **12V** and **SW12** terminals and pin **8** on the **CS I/O** port will supply 16 VDC to a connected peripheral. The connected peripheral or sensor may be damaged if it is not designed for that voltage level.

- **VX** terminals: supply precise output voltage used by analog sensors to generate high resolution and accurate signals. In this case, these terminals are regularly used with resistive-bridge measurements (see Resistance measurements (p. 61) for more information). Using the `SWVX()` instruction, **VX** terminals can also supply a selectable, switched, regulated 3.3 or 5 VDC power source to power digital sensors and toggle control lines.
- **C** terminals: can be set low or high as output terminals . With limited drive capacity, digital output terminals are normally used to operate external relay-driver circuits. See also Digital input/output specifications (p. 217).

See also Power output specifications (p. 210).

5.3 Grounds

Proper grounding lends stability and protection to a data acquisition system. Grounding the data logger with its peripheral devices and sensors is critical in all applications. Proper grounding will ensure maximum ESD protection and measurement accuracy. It is the easiest and least expensive insurance against data loss, and often the most neglected. The following terminals are provided for connection of sensor and data logger grounds:

- **Signal Ground (⏚)** - reference for single-ended analog inputs, excitation returns, and a ground for sensor shield wires.
    - 11 common terminals
- **Power Ground (G)** - return for 3.3 V, 5 V, 12 V, and digital sensors. Use of **G** grounds for these outputs minimizes potentially large current flow through the analog-voltage-measurement section of the wiring panel, which can cause single-ended voltage measurement errors.
    - 4 common terminals
- **Resistive Ground (RG)** - used for non-isolated 0-20 mA and 4-20 mA current loop measurements (see Current-loop measurements (p. 59) for more information). Also used for decoupling ground on RS-485 signals. Includes 100 Ω resistance to ground. Maximum voltage for RG terminals is ±16 V.
    - 2 common terminals
- **Earth Ground Lug (⏚)** - connection point for heavy-gage earth-ground wire. A good earth connection is necessary to secure the ground potential of the data logger and shunt transients away from electronics. Campbell Scientific recommends 14 AWG wire, minimum.

> NOTE:
> Several ground wires can be connected to the same ground terminal.

A good earth (chassis) ground will minimize damage to the data logger and sensors by providing a low-resistance path around the system to a point of low potential. Campbell Scientific recommends that all data loggers be earth grounded. All components of the system (data loggers, sensors, external power supplies, mounts, housings) should be referenced to one common earth ground.

In the field, at a minimum, a proper earth ground will consist of a 5-foot copper-sheathed grounding rod driven into the earth and connected to the large brass ground lug on the wiring panel with a 14 AWG wire. In low-conductive substrates, such as sand, very dry soil, ice, or rock, a single ground rod will probably not provide an adequate earth ground. For these situations, search for published literature on lightning protection or contact a qualified lightning-protection consultant.

In laboratory applications, locating a stable earth ground is challenging, but still necessary. In older buildings, new VAC receptacles on older VAC wiring may indicate that a safety ground exists when, in fact, the socket is not grounded. If a safety ground does exist, good practice dictates to verify that it carries no current. If the integrity of the VAC power ground is in doubt, also ground the system through the building plumbing, or use another verified connection to earth ground.

See also:

- Ground loops (p. 158)
- Minimizing ground potential differences (p. 163)

5.4 Communications ports

The data logger is equipped with ports that allow communications with other devices and networks, such as:

- Computers
- Smart sensors
- Modbus and DNP3 networks
- Ethernet
- Modems
- Campbell Scientific PakBus® networks
- Other Campbell Scientific data loggers

Campbell Scientific data logger communications ports include:

- CS I/O
- RS-232/CPI
- USB Device
- Ethernet
- **C** terminals

5.4.1 USB device port

The USB device port supports communicating with a computer through data logger support software or through virtual Ethernet (RNDIS), and provides 5 VDC power to the data logger (powering through the USB port has limitations - details are available in the specifications). The data logger USB device port does not support USB flash or thumb drives. Although the USB connection supplies 5 V power, a 12 VDC battery will be needed for field deployment.

5.4.2 Ethernet port

The RJ45 **10/100 Ethernet** port is used for IP communications.

5.4.3 C terminals for communications

C terminals are configurable for the following communications types:

- SDI-12
- RS-232
- RS-422
- RS-485
- TTL (0 to 5 V)
- LVTTL (0 to 3.3 V)
- SDM

Some communications types require more than one terminal, and some are only available on specific terminals. See Communications specifications (p. 219) for more information.

5.4.3.1 SDI-12 ports

SDI-12 is a 1200 baud protocol that supports many smart sensors. **C1**, **C3**, **C5**, and **C7** can be configured as **SDI-12** ports. Maximum cable lengths depend on the number of sensors connected, the type of cable used, and the environment of the application. Refer to the sensor manual for guidance.

For more information, see SDI-12 communications (p. 113).

5.4.3.2 RS-232, RS-422, RS-485, TTL, and LVTTL ports

RS-232, RS-422, RS-485, TTL, and LVTTL communications are typically used for the following:

- Reading sensors with serial output
- Creating a multi-drop network
- Communications with other data loggers or devices over long cables

Configure **C** terminals as serial ports using ***Device Configuration Utility*** or by using the `SerialOpen()` CRBasic instruction. Terminals are configured in pairs for TTL, LVTTL, RS-232, and half-duplex RS-422 and RS-485 communications. For full-duplex RS-422 and RS-485, four terminals are required. See also Communications protocols (p. 79).

5.4.3.3 SDM ports

SDM is a protocol proprietary to Campbell Scientific that supports several Campbell Scientific digital sensor and communications input and output expansion peripherals and select smart sensors. It uses a common bus and addresses each node. CRBasic SDM device and sensor instructions configure terminals **C1**, **C2**, and **C3** together to create an SDM port. Alternatively, terminals **C5**, **C6**, and **C7** can be configured together to be used as the SDM port by using the `SDMBeginPort()` instruction.

See also Communications specifications (p. 219).

5.4.4 CS I/O port

One nine-pin port, labeled **CS I/O**, is available for communicating with a computer through Campbell Scientific communications interfaces, modems, and peripherals. Campbell Scientific recommends keeping CS I/O cables short (maximum of a few feet). See also Communications specifications (p. 219).

Table 5-7: CS I/O pinout

Pin Number	Function	Input (I) Output (O)	Description
1	5 VDC	O	5 VDC: sources 5 VDC, used to power peripherals.
2	SG		Signal ground: provides a power return for pin 1 (5V), and is used as a reference for voltage levels.
3	RING	I	Ring: raised by a peripheral to put the CR1000X in the telecom mode.
4	RXD	I	Receive data: serial data transmitted by a peripheral are received on pin 4.
5	ME	O	Modem enable: raised when the CR1000X determines that a modem raised the ring line.
6	SDE	O	Synchronous device enable: addresses synchronous devices (SD); used as an enable line for printers.
7	CLK/HS	I/O	Clock/handshake: with the SDE and TXD lines addresses and transfers data to SDs. When not used as a clock, pin 7 can be used as a handshake line; during printer output, high enables, low disables.

Table 5-7: CS I/O pinout			
Pin Number	Function	Input (I) Output (O)	Description
8	12 VDC		Nominal 12 VDC power. Same power as **12V** and **SW12** terminals.
9	TXD	O	Transmit data: transmits serial data from the data logger to peripherals on pin 9; logic-low marking (0V), logic-high spacing (5V), standard-asynchronous ASCII: eight data bits, no parity, one start bit, one stop bit. User selectable baud rates: 300, 1200, 2400, 4800, 9600, 19200, 38400, 115200.

5.4.5 RS-232/CPI port

The data logger includes one RJ45 module jack labeled RS-232/CPI. CPI is a proprietary interface for communications between Campbell Scientific data loggers and Campbell Scientific CDM peripheral devices and smart sensors. It consists of a physical layer definition and a data protocol. CDM devices are similar to Campbell Scientific SDM devices in concept, but the CPI bus enables higher data-throughput rates and use of longer cables. CDM devices require more power to operate in general than do SDM devices. CPI ports also enable networking between compatible Campbell Scientific data loggers. Consult the manuals for CDM modules for more information.

CPI port power levels are controlled automatically by the CR1000X:

- **Off**: Not used.
- **High power**: Fully active.
- **Low-power standby**: Used whenever possible.
- **Low-power bus**: Sets bus and modules to low power.

When used with a Campbell Scientific RJ45-to-DB9 converter cable, the **RS-232/CPI** port can be used as an RS-232 port. It defaults to 115200 bps (in autobaud mode), 8 data bits, no parity, and 1 stop bit. Use ***Device Configuration Utility*** or the `SerialOpen()` CRBasic instruction to change these options.

Table 5-8: RS-232/CPI pinout	
Pin Number	Description
1	RS-232: Transmit (Tx)
2	RS-232: Receive (Rx)

Table 5-8: RS-232/CPI pinout	
Pin Number	Description
3	100 Ω Res Ground
4	CPI: Data
5	CPI: Data
6	100 Ω Res Ground
7	RS-232 CTS CPI: Sync
8	RS-232 DTR CPI: Sync
9	Not Used

5.5 Programmable logic control

The data logger can control instruments and devices such as:

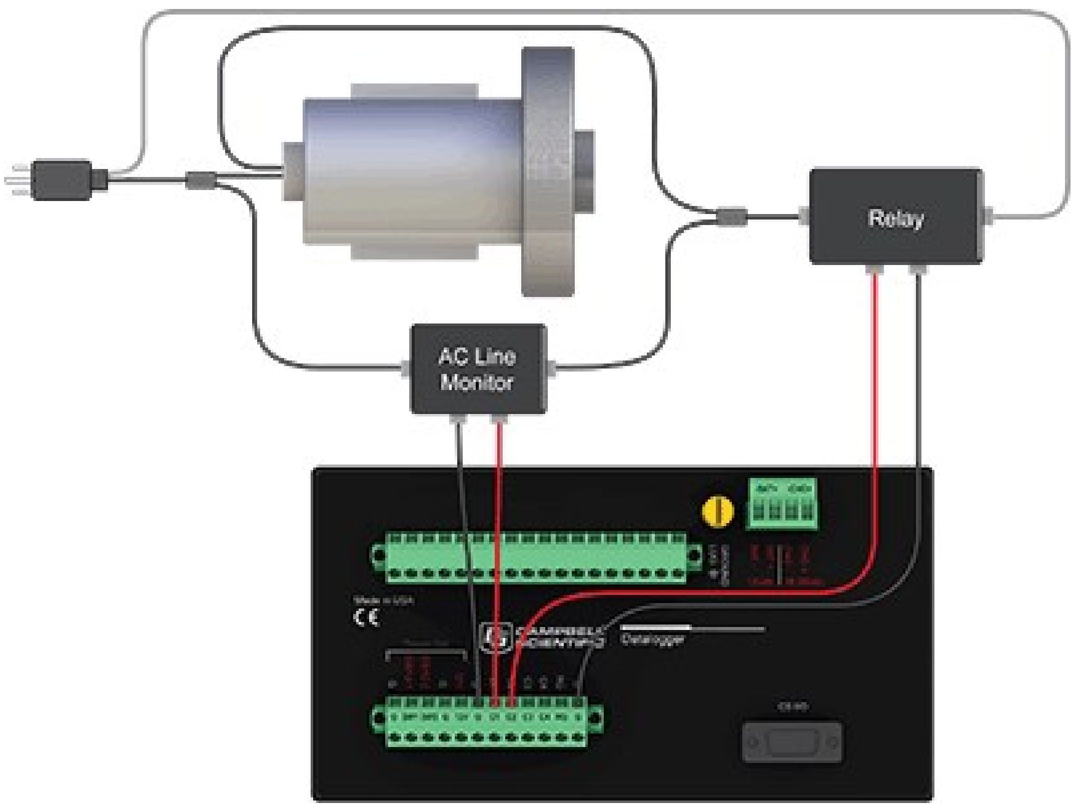
- Controlling cellular modem or GPS receiver to conserve power.
- Triggering a water sampler to collect a sample.
- Triggering a camera to take a picture.
- Activating an audio or visual alarm.
- Moving a head gate to regulate water flows in a canal system.
- Controlling pH dosing and aeration for water quality purposes.
- Controlling a gas analyzer to stop operation when temperature is too low.
- Controlling irrigation scheduling.

Control decisions can be based on time, an event, or a measured condition. Controlled devices can be physically connected to **C**, **VX**, or **SW12** terminals. ***Short Cut*** has provisions for simple on/off control. Control modules and relay drivers are available to expand and augment data logger control capacity.

- **C** terminals are selectable as binary inputs, control outputs, or communications ports. These terminals can be set low (0 VDC) or high (3.3 or 5 VDC) using the `PortSet()` or `WriteIO()` instructions. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/. Other functions include device-driven interrupts, asynchronous communications and SDI-12 communications. The high voltage for these terminals defaults to 5 V, but it can be changed to 3.3 V using the PortPairConfig() instruction. Terminals **C4**, **C5**, and **C7** can also be configured for pulse width modulation with a maximum period of 36.4 s. A **C** terminal configured for digital I/O is normally used to operate an external relay-driver circuit because the terminal itself has limited drive capacity.

- **VX** terminals can be set low or high using the PortSet() or SWVX() instruction. For more information on these instructions, see the CRBasic help.
- **SW12** terminals can be set low (0 V) or high (12 V) using the SW12() instruction (see the CRBasic help for more information).

The following image illustrates a simple application wherein a **C** terminal configured for digital input, and another configured for control output are used to control a device (turn it on or off) and monitor the state of the device (whether the device is on or off).



In the case of a cell modem, control is based on time. The modem requires 12 VDC power, so connect its power wire to a data logger **SW12** terminal. The following code snip turns the modem on for the first ten minutes of every hour using the TimeIsBetween() instruction embedded in an If/Then logic statement:

```
If TimeIsBetween (0,10,60,Min)Then
     SW12(SW12_1,1,1) 'Turn phone on.
Else
     SW12(SW12_1,0,1) 'Turn phone off.
EndIf
```

6. Setting up the CR1000X

The basic steps for setting up your data logger to take measurements and store data are included in the following sections:

6.1 Setting up communications with the data logger

The first step in setting up and communicating with your data logger is to configure your connection. Communications peripherals, data loggers, and software must all be configured for communications. Additional information is found in your specific peripheral manual, and the data logger support software manual and help.

You can configure your connection using any of the following options. The simplest is via USB. For detailed instruction, see:

For other configurations, see the ***LoggerNet*** EZSetup Wizard help. Context-specific help is given in each step of the wizard by clicking the **Help** button in the bottom right corner of the window. For complex data logger networks, use Network Planner. For more information on using the Network Planner, watch a video at https://www.campbellsci.com/videos/loggernet-software-network-planner.

6.1.1 USB or RS-232 communications

Setting up a USB or RS-232 connection is a good way to begin communicating with your data logger. Because these connections do not require configuration (like an IP address), you need only set up the communications between your computer and the data logger. Use the following instructions or watch the Quickstart videos at https://www.campbellsci.com/videos.

Follow these steps to get started. These settings can be revisited using the data logger support software **Edit Datalogger Setup** option.

1. Using data logger support software, launch the EZSetup Wizard.
   - *LoggerNet* users, click **Setup**, click the **View** menu to ensure you are in the **EZ (Simplified)** view, then click **Add Datalogger**.
   - *PC400* users, click **Add Datalogger**.
2. Click **Next**.
3. Select your data logger from the list, type a meaningful name for your data logger (for example, a site identifier or project name), and click **Next**.
4. Select the **Direct Connect** connection type and click **Next**.
5. If this is the first time connecting this computer to a CR1000X via USB, click **Install USB Driver**, select your data logger, click **Install**, and follow the prompts to install the USB drivers.
6. Plug the data logger into your computer using a USB or RS-232 cable. The USB connection supplies 5 V power as well as a communications link, which is adequate for setup. A 12V battery will be needed for field deployment. If using RS-232, external power must be provided to the data logger and a CPI/RS-232 RJ45 to DB9 cable is required to connect to the computer.

   > NOTE:
   > The Power LED on the data logger indicates the program and power state. Because the data logger ships with a program set to run on power-up, the Power LED flashes 3 times every 10 seconds when powered over USB. When powered with a 12 V battery, it flashes 1 time every 10 seconds. When no program is running, the LED is always on.

7. From the **COM Port** list, select the COM port used for your data logger. It will appear as CR1000X (COM number).
8. USB and RS-232 connections do not typically require a **COM Port Communication Delay** - which allows time for hardware devices to "wake up" and negotiate a communications link. Accept the default value of **00 seconds** and click **Next**.
9. The baud rate and PakBus address **must match** the hardware settings for your data logger. The default PakBus address is **1**. A USB connection does not require a baud rate selection. RS-232 connections default to 115200 baud.

10. Set an **Extra Response Time** if you have a difficult or marginal connection and you want the data logger support software to wait a certain amount of time before returning a communications failure error. Accept the default value of **00 seconds**.
11. Set a **Max Time On-Line** to limit the amount of time the data logger remains connected. When the data logger is connected, communications with it are terminated when this time limit is exceeded. A value of **0** in this field indicates that there is no time limit for maintaining a connection to the data logger.
12. Leave the **Neighbor PakBus Address** as the default of **0**.
13. Click **Next**.
14. By default, the data logger does not use a security code or a PakBus encryption key. Therefore, the **Security Code** can be set to **0** and the **PakBus Encryption Key** can be left blank. If either setting has been changed, enter the new code or key. See Data logger security (p. 122) for more information.
15. Click **Next**.
16. Review the **Setup Summary**. If you need to make changes, click **Previous** to return to a previous window and change the settings.
17. Setup is now complete, and the EZSetup Wizard allows to you finish, or click **Next** to test communications, set the data logger clock, and send a program to the data logger. See Testing communications with EZSetup (p. 27) for more information.

6.1.2 Virtual Ethernet over USB (RNDIS)

The data logger supports RNDIS (virtual Ethernet over USB). This allows the data logger to communicate via TCP/IP over USB. Watch a video at https://www.campbellsci.com/videos/ethernet-over-usb or use the following instructions.

1. Supply power to the data logger. If connecting via USB for the first time, you must first install USB drivers by using ***Device Configuration Utility*** (select your data logger, then on the main page, click **Install USB Driver**). Alternately, you can install the USB drivers using EZ Setup. A USB connection supplies 5 V power (as well as a communications link), which is adequate for setup, but a 12 V battery will be needed for field deployment.

> **NOTE:**
> Ensure the data logger is connected directly to the computer USB port (not to a USB hub). We recommended always using the same USB port on your computer.

2. Physically connect your data logger to your computer using a USB cable, then in ***Device Configuration Utility*** select your data logger.
3. Retrieve your IP Address. On the bottom, left side of the screen, select **IP** as the Connection Type, then click the browse button next to the **Server Address** box. Note the IP Address (default is **192.168.66.1**). If you have multiple data loggers in your network, more than one data logger may be returned. Ensure you select the correct data logger by verifying the data logger serial number or station name (if assigned).
4. A virtual IP address can be used to connect to the data logger using ***Device Configuration Utility*** or other computer software, or to view the data logger internal web page in a browser. To view the web page, open a browser and enter linktodevice.com or the IP address you retrieved in the previous step (for example, **192.168.66.1**) into the address bar.

To secure your data logger from others who have access to your network, we recommend that you set security. For more information, see Data logger security (p. 122).

NOTE:
Ethernet over USB (RNDIS) is considered a direct communications connection. Therefore, it is a trusted connection and **Administrator** privileges are automatically granted for all functionality (csipasswd does not apply).

6.1.3 Ethernet communications option

The CR1000X offers a 10/100 Ethernet connection. Use ***Device Configuration Utility*** to enter the data logger IP Address, Subnet Mask, and IP Gateway address. After this, use the EZSetup Wizard to set up communications with the data logger. If you already have the data logger IP information, you can skip these steps and go directly to Setting up Ethernet communications between the data logger and computer (p. 26). Watch a video at https://www.campbellsci.com/videos/datalogger-ethernet-configuration or use the following instructions.

6.1.3.1 Configuring data logger Ethernet settings

1. Supply power to the data logger. If connecting via USB for the first time, you must first install USB drivers by using ***Device Configuration Utility*** (select your data logger, then on the main page, click **Install USB Driver**). Alternately, you can install the USB drivers using EZ Setup. A USB connection supplies 5 V power (as well as a communications link), which is adequate for setup, but a 12 V battery will be needed for field deployment.
2. Connect an Ethernet cable to the **10/100 Ethernet** port on the data logger. The yellow and green **Ethernet** port LEDs display activity approximately one minute after connecting. If you

do not see activity, contact your network administrator. For more information, see Ethernet LEDs (p. 25).

3. Using data logger support software (***LoggerNet***, or ***PC400***), open ***Device Configuration Utility***.
4. Select the **CR1000X Series** data logger from the list
5. Select the port assigned to the data logger from the **Communication Port** list. If connecting via Ethernet, select **Use IP Connection**.
6. By default, this data logger does not use a PakBus encryption key; so, the **PakBus Encryption Key** box can be left blank. If this setting has been changed, enter the new code or key. See Data logger security (p. 122) for more information.
7. Click **Connect**.
8. On the **Deployment** tab, click the **Ethernet** subtab.
9. The **Ethernet Power** setting allows you to reduce the power consumption of the data logger. If there is no Ethernet connection, the data logger will turn off its Ethernet interface for the time specified before turning it back on to check for a connection. Select **Always On**, **1 Minute**, or **Disable**.
10. Enter the **IP Address**, **Subnet Mask**, and **IP Gateway**. These values should be provided by your network administrator. A static IP address is recommended. If you are using DHCP, note the IP address assigned to the data logger on the right side of the window. When the IP Address is set to the default, 0.0.0.0, the information displayed on the right side of the window updates with the information obtained from the DHCP server. Note, however, that this address is not static and may change. An IP address here of **169.254.###.###** means the data logger was not able to obtain an address from the DHCP server. Contact your network administrator for help.
11. **Apply** to save your changes.

6.1.3.2 Ethernet LEDs

When the data logger is powered, and **Ethernet Power** setting is not disabled, the **10/100 Ethernet** LEDs will show the Ethernet activity:

- **Solid Yellow**: Valid Ethernet link.
- **No Yellow**: Invalid Ethernet link.
- **Flashing Yellow**: Ethernet activity.
- **Solid Green**: 100 Mbps link.
- **No Green**: 10 Mbps link.

6.1.3.3 Setting up Ethernet communications between the data logger and computer

Once you have configured the Ethernet settings or obtained the IP information for your data logger, you can set up communications between your computer and the data logger over Ethernet. Watch a video at https://www.campbellsci.com/videos/ezsetup-ethernet-connection or use the following instructions.

This procedure only needs to be followed once per data logger. However, these settings can be revised using the data logger support software **Edit Datalogger Setup** option.

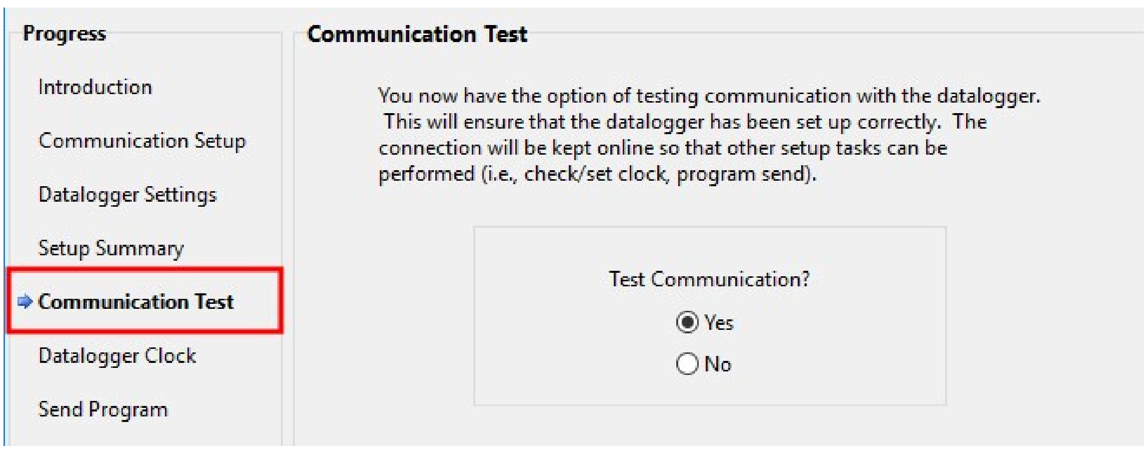
1. Using data logger support software, open **EZSetup**.
    - *LoggerNet* users, select **Setup** from the **Main** category on the toolbar, click the **View** menu to ensure you are in the **EZ (Simplified)** view, then click **Add Datalogger**.
    - *PC400* users, click **Add Datalogger**.
2. Click **Next**.
3. Select the **CR1000X Series** from the list, enter a name for your station (for example, a site or project name), **Next**.
4. Select the **IP Port** connection type and click **Next**.
5. Type the data logger IP address followed by a colon, then the port number of the data logger in the **Internet IP Address** box (these were set up through the Ethernet communications option (p. 24)) step. They can be accessed in ***Device Configuration Utility*** on the **Ethernet** subtab. Leading 0s must be omitted. For example:
    - IPv4 addresses are entered as *192.168.1.2:6785*
    - IPv6 addresses must be enclosed in square brackets. They are entered as *[2001:db8::1234:5678]:6785*
6. The PakBus address must match the hardware settings for your data logger. The default PakBus address is **1**.
    - Set an **Extra Response Time** if you want the data logger support software to wait a certain amount of time before returning a communications failure error.
    - *LoggerNet* and *PC400* users can set a **Max Time On-Line** to limit the amount of time the data logger remains connected. When the data logger is contacted, communications with it is terminated when this time limit is exceeded. A value of **0** in this field indicates that there is no time limit for maintaining a connection to the data logger. **Next**.

7. By default, the data logger does not use a security code or a PakBus encryption key. Therefore the **Security Code** can be set to **0** and the **PakBus Encryption Key** can be left blank. If either setting has been changed, enter the new code or key. See Data logger security (p. 122). **Next**.
8. Review the **Communication Setup Summary**. If you need to make changes, click **Previous** to return to a previous window and change the settings.

Setup is now complete, and the EZSetup Wizard allows you **Finish** or select **Next**. The **Next** steps take you through testing communications, setting the data logger clock, and sending a program to the data logger. See Testing communications with EZSetup (p. 27) for more information.

6.2 Testing communications with EZSetup

1. Advance to, or select, the **Communication Test** step in EZ Setup. See USB or RS-232 communications (p. 21) for more information.



2. Ensure the data logger is physically connected to the computer, select **Yes** to test communications, then click **Next** to initiate the test. To troubleshoot an unsuccessful test, see Tips and troubleshooting (p. 143).
3. With a successful connection, the **Connection Time** with the data logger is displayed in the lower left corner of the wizard. Click **Next**.
4. The **Datalogger Clock** window displays the time for both the data logger and the computer (server).
   - The **Adjusted Server Date/Time** displays the current reading of the clock for the computer running your data logger support software. If the **Datalogger Date/Time** and **Adjusted Server Date/Time** don't match, click **Set Datalogger Clock** to set the data logger clock to the computer clock.

- Optionally, specify a positive or negative **Time Zone Offset** to apply when setting the data logger clock. This offset allows you to set the clock for a data logger that is in a different time zone than the computer (or to accommodate for changes in daylight saving time).

5. Click **Next**.
6. The data logger ships with a default **GettingStarted** program. If the data logger does not have a program, you can choose to send one by clicking **Select and Send Program**. Click **Next**.
7. ***LoggerNet*** only - Use the following instructions or watch the Scheduled/Automatic Data Collection video:
    - The **Datalogger Table Output Files** window displays the data tables available to be collected from the data logger and the output file name. By default, all data tables set up in the data logger program will be included for collection. Make note of the **Output File Name** and location. Click **Next**.
    - Check **Scheduled Collection Enabled** to have ***LoggerNet*** automatically collect data from the data logger on the **Collection Interval** entered. When the **Base Date** and **Time** are in the past, scheduled collection will begin immediately after finishing the EZSetup wizard. Do not setup a scheduled collection for this tutorial. Click **Next**.
8. Click **Finish**.

6.3 Making the software connection

Once you have configured your hardware connection (see Setting up communications with the data logger (p. 21), your data logger and computer can communicate. Use the **Connect** screen to send a program, set the clock, view real-time data, and manually collect data.

- ***LoggerNet*** users, select **Main** and **Connect** on the ***LoggerNet*** toolbar, select the data logger from the **Stations** list, then **Connect**.
- ***PC400*** users, select the data logger from the list and click **Connect**.

To disconnect, click **Disconnect**.

For more information see the Connect Window Tutorial.

6.4 Creating a *Short Cut* data logger program

You must provide a program for the data logger in order for it to make measurements, store data, or control external devices. There are several ways to write a program. The simplest is to use the program generator called **Short Cut**. For more complex programming the ***CRBasic Editor*** is used. The program file may use the extension `.CR1X, .CRB` or `.DLD`.

Data logger programs are executed on a precise schedule termed the scan interval, based on the data logger internal clock.

Measurements are first stored in temporary memory called variables in the Public table. Data stored in variables is usually overwritten each scan. Periodically, generally on a time interval, the data logger stores data in tables. The data tables are later copied to a computer using your data logger support software.

Use ***Short Cut*** software to generate a program for your data logger. ***Short Cut*** is included with your data logger support software.

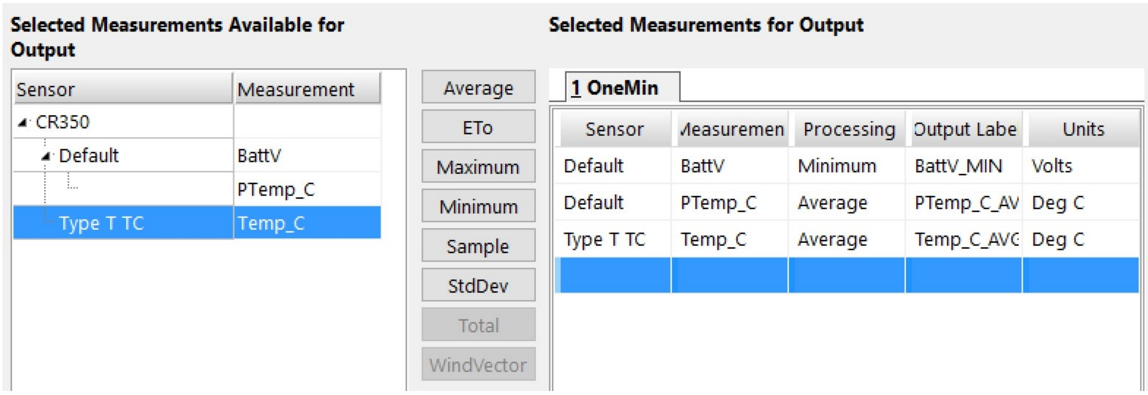
This section guides you through programming a CR1000X data logger to measure the voltage of the data logger power supply, the internal temperature of the data logger, and a thermocouple. With minor changes, these steps can apply to other measurements. Use the following instructions or watch the Quickstart part 3 video.

1. Using data logger support software, launch ***Short Cut***.
   - ***LoggerNet*** users, click **Program** then ***Short Cut***.
   - ***PC400*** users, click ***Short Cut***.
2. Click **Create New Program**.
3. Select **CR1000X Series** and click **Next**.

> NOTE:
> The first time ***Short Cut*** is run, a prompt asks for a noise rejection choice. Select **60 Hz Noise Rejection** for North America and areas using 60 Hz ac voltage. Select **50 Hz Noise Rejection** for most of the Eastern Hemisphere and areas that operate at 50 Hz.
>
> A second prompt lists sensor support options. **Campbell Scientific, Inc. (US)** is usually the best fit outside of Europe.
>
> To change the noise rejection or sensor support option for future programs, use the **Program** menu.

4. A list of **Available Sensors and Devices** and **Selected Measurements Available for Output** are displayed. Battery voltage `BattV` and internal temperature `PTemp_C` are selected by default. During operation, battery and temperature should be recorded at least daily to assist in monitoring system status.
5. Use the Search feature or expand folders to locate your sensor or device. Double-click on a sensor or measurement in the **Available Sensors and Devices** list to configure the device (if needed) and add it to the **Selected** list. For the example program, expand the **Sensors/Temperature** folder and double-click **Type T Thermocouple**.
6. If the sensor or device requires configuration, a window displays with configuration options. Click **Help** at the bottom of the window to learn more about any field or option. For the example program, accept the default options:
   - **1 Type T TC** sensor
   - **Temp_C** as the **Temperature** label, and set the units to **Deg C**
   - **PTemp_C** as the **Reference Temperature Measurement**.
7. Click the **Wiring Diagram** tab to see how to wire the sensor to the data logger. With the power disconnected from the data logger, insert the wires as directed in the diagram. Ensure you clamp the terminal on the wire, not the colored insulation. Use the included flat-blade screwdriver to open and close the terminals.
8. Click **OK**.
9. Click **Next**.
10. Use the **Output Setup** options to specify how often to make measurements and how often outputs are to be stored. Type **1** in the **How often should the data logger measure its sensor(s)?** box. Leave the units as **Seconds**.
11. Multiple output intervals can be specified, one for each output table (**Table1** and **Table2** tabs). For the example program, only one table is needed. Click the **Table2** tab and click **Delete Table**.
12. In the **Table Name** box, type a name for the table. For example: **OneMin**.
13. Select a **Data Output Storage Interval**. For example: **1** minute.
14. Click **Next**.
15. Select a measurement from the **Selected Measurements Available for Output** list, then click an output processing option to add the measurement to the **Selected Measurements for Output** list. For the example program, select **BattV** and click the **Minimum** button to add it to the **Selected Measurements for Output** list. Do not store the exact time that the

minimum occurred. Repeat this procedure for an **Average PTemp_C** and **Average Temp_C**.



16. Click **Finish** and give the program a meaningful name such as a site identifier. Click **Save**.
17. If ***LoggerNet*** or other data logger support software is running on your computer, and the data logger is connected to the computer (see Making the software connection (p. 28) for more information), you can choose to send the program. Generally it is best to collect data first; so, we recommend sending the program using the instructions in Sending a program to the data logger (p. 32). Click **No**, do not send the program to the data logger.

> TIP:
> It is good practice to always retrieve data from the data logger before sending a program; otherwise, data may be lost. See Collecting data (p. 35) for detailed instruction.

18. Make note of the newly generated program location and filename. By default, programs created with ***Short Cut*** are stored in `C:\Campbellsci\SCWin\`.
19. Close ***Short Cut***.

If your data acquisition requirements are simple, you can probably create and maintain a data logger program exclusively with ***Short Cut***. If your data acquisition needs are more complex, the files that ***Short Cut*** creates are a great source for programming code to start a new program or add to an existing custom program using CRBasic. See the ***CRBasic Editor*** help for detailed information on program structure, syntax, and each instruction available to the data logger https://help.campbellsci.com/crbasic/cr1000x/.

> NOTE:
> Once a ***Short Cut*** generated program has been edited with ***CRBasic Editor***, it can no longer be modified with ***Short Cut***.

6.5 Sending a program to the data logger

TIP:
It is good practice to always retrieve data from the data logger before sending a program; otherwise, data may be lost. See Collecting data (p. 35) for detailed instruction.

Some methods of sending a program give the option to retain data when possible. Regardless of the program upload tool used, data will be erased when a new program is sent if any change occurs to one or more data table structures in the following list:

- Data table name(s)
- Data output interval or offset
- Number of fields per record
- Number of bytes per field
- Field type, size, name, or position
- Number of records in table

Use the following instructions or watch the Quickstart part 4 video.

1. Connect the data logger to your computer (see Making the software connection (p. 28) for more information).
   - *LoggerNet* users, select **Main** and **Connect** on the *LoggerNet* toolbar, select the data logger from the **Stations** list, then **Connect**.
   - *PC400* users, select the data logger from the list and click **Connect**.
2. *LoggerNet* users, click **Send New...** (located in the **Current Program** section on the right side of the window).

   PC400 users, click **Send Program...** (located in the **Datalogger Program** section on the right side of the window).
3. *PC400* users, confirm that you would like to proceed and erase all data tables saved on the data logger. Click **Yes**.
4. Navigate to the program, select it, and click **Open**. For example: navigate to **C:\Campbellsci\SCWin** and select **MyTemperature.CR1X**. Click **Open**.
5. *LoggerNet* users, confirm that you would like to proceed and erase all data tables saved on the data logger. Click **Yes**.
6. The program is sent and compiled.
7. Review the **Compile Results** window for errors, messages and warnings.

8. ***LoggerNet*** users, click **Details**, select the **Table Fill Times** tab.

   PC400 user click **OK** then click ***Station Status*** , select the **Table Fill Times** tab.

   Ensure that the times shown are expected for your application. Click **OK**.

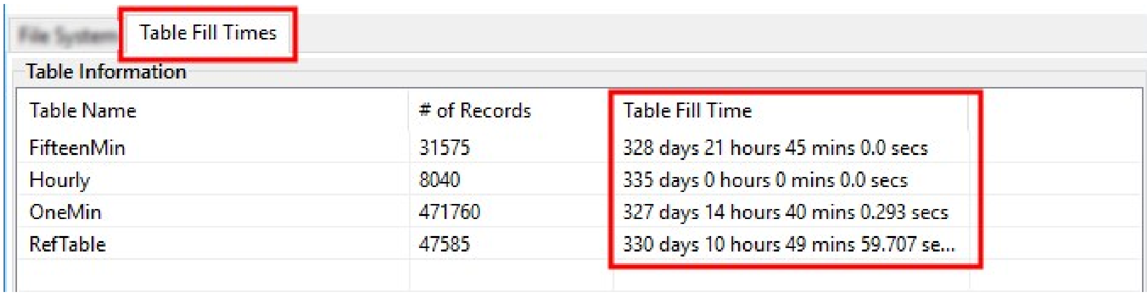


Table Name	# of Records	Table Fill Time
FifteenMin	31575	328 days 21 hours 45 mins 0.0 secs
Hourly	8040	335 days 0 hours 0 mins 0.0 secs
OneMin	471760	327 days 14 hours 40 mins 0.293 secs
RefTable	47585	330 days 10 hours 49 mins 59.707 se...

After sending a program, it is a good idea to monitor the Public table to make sure sensors are taking good measurements. See Working with data (p. 34) for more information.

7. Working with data

7.1 Default data tables

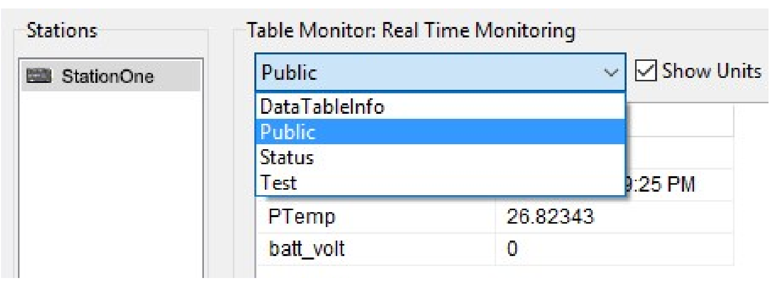
By default, the data logger includes three tables: **Public**, **Status**, and **DataTableInfo**. Each of these tables only contains the most recent measurements and information.

- The **Public** table is configured by the data logger program, and updated at the scan interval set within the data logger program. It shows measurement and calculation results as they are made.
- The **Status** table includes information about the health of the data logger and is updated only when viewed.
- The **DataTableInfo** table reports statistics related to data tables. It also only updates when viewed.
- User-defined data tables update at the schedule set within the program.

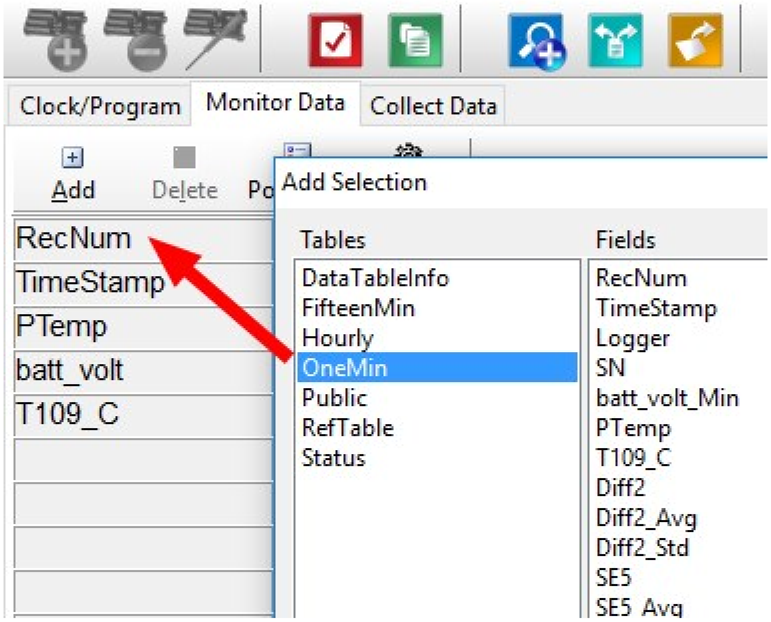
For information on collecting your data, see Collecting data (p. 35).

Use these instructions or follow the Connect Window tutorial to monitor real-time data.

LoggerNet users, select the **Main** category and **Connect** on the ***LoggerNet*** toolbar, then select the data logger from the **Stations** list, then click **Connect**. Once connected, select a table to view in the **Table Monitor**.



PC400 users click **Connect**, then **Monitor Data**. When this tab is first opened for a data logger, values from the **Public** table are displayed. To view data from other tables, click **Add**, select a table or field from the list, then drag it into a cell on the **Monitor Data** tab.



7.2 Collecting data

The data logger writes to data tables based on intervals and conditions set in the CRBasic program (see Creating data tables in a program (p. 43) for more information). After the program has been running for enough time to generate data records, data may be collected by using data logger support software. During data collection, data is copied to the computer and still remains on the data logger. Collections may be done manually, or automatically through scheduled collections set in ***LoggerNet* Setup**. Use these instruction or follow the Collect Data Tutorial.

7.2.1 Collecting data using *LoggerNet*

1. From the ***LoggerNet*** toolbar, click **Main** and **Connect**, select the data logger from the **Stations** list, then **Connect**.
2. Click **Collect Now**.
3. After the data is collected, the **Data Collection Results** window displays the tables collected and where they are stored on the computer.
4. Select a data file, then **View File** to view the data. See Viewing historic data (p. 36)

7.2.2 Collecting data using *PC400*

1. Click **Connect** on the main ***PC400*** window.
2. Go to the **Collect Data** tab.

3. By default, all output tables set up in the data logger program are selected for collection. Typically, the default tables (DataTableInfo, Public, and Status) are not collected.
4. Select an option for **What to Collect**. Either option creates a new file if one does not already exist.
   - **New data from data logger (Append to data files)**: This is the default, and most often used option. Collect only the data, in the selected tables, stored since the last data collection from this instance of ***PC400*** and append this data to the end of the existing files on the computer.
   - **All data from data logger (Overwrite data files)**: Collects all of the data in the selected tables and overwrites (or replaces) the existing data files on the computer.
5. Click **Start Data Collection**.
6. After the data is collected, the **Data Collection Results** window displays the tables collected and where they are stored on the computer.
7. Select a data file, then **View File** to view the data. See Viewing historic data (p. 36)

7.3 Viewing historic data

View Pro contains tools for reviewing data in tabular form as well as several graphical layouts for visualization. Use these instructions or follow the View Data Tutorial.

Once the data logger has had enough time to store multiple records collect and review the data.

1. To view the most recent data, connect the data logger to your computer and collect your data (see Collecting data (p. 35) for more information).
2. Open View Pro:
   - ***LoggerNet*** users click **Data** then **View Pro** on the ***LoggerNet*** toolbar.
   - ***PC400*** users click **View Data Files via View Pro**.
3. Click **Open**, navigate to the directory where you saved your tables (the default directory is **C:\Campbellsci***[your data logger software application]*). For example: navigate to the **C:\Campbellsci\LoggerNet** folder and select **OneMin.dat**.
4. Click **Open**.

7.4 Data types and formats

Data takes different formats as it is created and manipulated in the data logger, as it is displayed through software, and as it is retrieved to a computer file. It is important to understand the different data types, formats and ranges, and where they are used.

Table 7-1: Data types, ranges and resolutions

Data type	Description	Range	Resolution	Where used
Float	IEEE four-byte floating point	+/–1.8 *10^–38 to +/–3.4 *10^38	24 bits (about 7 digits)	variables
Long	four-byte signed integer	–2,147,483,648 to +2,147,483,647	1 bit	variables, output
Boolean	four-byte signed integer	–1, 0	True (–1) or False (0)	variables, sample output
String	ASCII String			variables, sample output
IEEE4	IEEE four-byte floating point	+/–1.8 *10^–38 to +/–3.4 *10^38	24 bits (about 7 digits)	internal calculations, output
IEEE8	IEEE eight-byte floating point	+/–2.23 *10^–308 to +/–1.8 *10^308	53 bits (about 16 digits)	internal calculations, output
FP2	Campbell Scientific two-byte floating point	–7999 to +7999	13 bits (about 4 digits)	output
NSEC	eight-byte time stamp		nanoseconds	variables, output

7.4.1 Variables

In CRBasic, the declaration of variables (via the `DIM` or the `PUBLIC` statement) allows an optional type descriptor `As` that specifies the data type. The data types are `Float`, `Long`, `Boolean`, and `String`. The default type is `Float`.

Example variables declared with optional data types

```
Public PTemp As Float, Batt_volt
Public Counter As Long
Public SiteName As String * 24
```

`As Float` specifies the default data type. If no data type is explicitly specified with the `As` statement, then `Float` is assumed. Measurement variables are stored and calculations are performed internally in IEEE 4 byte floating point with some operations calculated in double precision. A good rule of thumb is that resolution will be better than 1 in the seventh digit.

`As Long` specifies the variable as a 32 bit integer. There are two possible reasons a user would do this: (1) speed, since the CR1000X Operating System can do math on integers faster than with `Float`s, and (2) resolution, since the `Long` has 31 bits compared to the 24 bits in the `Float`. A good application of the `As Long` declaration is a counter that is expected to get very large.

`As Boolean` specifies the variable as a 4 byte Boolean. Boolean variables are typically used for flags and to represent conditions or hardware that have only 2 states (e.g., On/Off, High/Low). A Boolean variable uses the same 32 bit long integer format as a `Long` but can set to only one of two values: True, which is represented as –1, and false, which is represented with 0. When a `Float` or `Long` integer is converted to a `Boolean`, zero is False (0), any non-zero value will set the Boolean to True (-1). The Boolean data type allows application software to display it as an On/Off, True/False, Red/Blue, etc.

The CR1000X uses –1 rather than some other non-zero number because the `AND` and `OR` operators are the same for logical statements and binary bitwise comparisons. The number -1 is expressed in binary with all bits equal to 1, the number 0 has all bits equal to 0. When –1 is anded with any other number the result is the other number, ensuring that if the other number is non-zero (true), the result will be non-zero.

`As String * size` specifies the variable as a string of ASCII characters, NULL terminated, with an optional size specifying the maximum number of characters in the string. A string is convenient in handling serial sensors, dial strings, text messages, etc. When size is not specified, a default of 24 characters will be used (23 usable bytes and 1 terminating byte).

As a special case, a string can be declared `As String` * 1. This allows the efficient storage of a single character. The string will take up 4 bytes in memory and when stored in a data table, but it will hold only one character.

Structures (`StructureType`/`EndStructureType`) are an advanced technique used to organize variables and display data in a structured manner. They can significantly shorten program code, especially for instructions that output an array of values, such as `AVW200()`, `GPS()`, and `SDI12Recorder()`. For example, a single `StructureType` may be used to organize and display data for multiple vibrating wire sensors or many SDI-12 sensors without creating aliases for each sensor. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

7.4.2 Constants

The `Const` declaration is used to assign a name that can be used in place of a value in the data logger CRBasic program. Once a value is assigned to a constant, each time the value is needed in the program, the programmer can type in the constant name instead of the value itself. The use of the Const declaration can make the program easier to follow, easier to modify, and more secure against unintended changes. Unlike variables, constants cannot be changed while the program is running.

Constants must be defined before they are used in the program. Constants can be defined in a ConstTable/EndConstTable construct allowing them to be changed using the keyboard display, the **C** command in terminal mode, or via a custom menu.

Constants can also be typed For example: Const A as Long = 9999, and Const B as String = “MyString”. Valid data types for constants are: Long, Float, Double, and String. Other data types return a compile error.

When the CRBasic program compiles, the compiler determines the type of the constant (Long, Float, Double, or String) from the expression. This data type is communicated to the software. The software formats or restricts the input based on the data type communicated to it by the data logger.

You can declare a constant with or without specifying a data type. If a data type is not specified, the compiler determines the data type from the expression. For example: Const A = 9999 will use the Long data type. Const A = 9999.0 will use the Floatdata type.

7.4.3 Data storage

Data can be stored in IEEE4 or FP2 formats. The format is selected in the program instruction that outputs the data, such as Minimum() and Maximum().

Additionally, data can be stored in IEEE8 format when high precision is needed. For more information on double-precision math, watch an instructional video at: http://www.campbellsci.com/videos/double-precision.

While Float (IEEE 4 byte floating point) is used for variables and internal calculations, FP2 is adequate for most stored data. Campbell Scientific 2 byte floating point (FP2) provides 3 or 4 significant digits of resolution, and requires half the memory space as IEEE4 (2 bytes per value vs 4).

Table 7-2: Resolution and range limits of FP2 data

Zero	Minimum magnitude	Maximum Magnitude
0.000	±0.001	±7999.

The resolution of FP2 is reduced to 3 significant digits when the first (left most) digit is 8 or greater. Thus, it may be necessary to use IEEE4 output or an offset to maintain the desired resolution of a measurement. For example, if water level is to be measured and output to the nearest 0.01 foot, the level must be less than 80 feet for FP2 output to display the 0.01 foot increment. If the water level is expected to range from 50 to 90 feet the data could either be output in IEEE4 or could be offset by 20 feet (transforming the range to 30 to 70 feet).

Table 7-3: FP2 decimal location

Absolute value	Decimal location
0 – 7.999	X.XXX
8 – 79.99	XX.XX
80 – 799.9	XXX.X
800 – 7999.	XXXX.

NOTE:
String and Boolean variables can be output with the Sample() instruction. Results of Sampling a Boolean variable will be either -1 or 0 in the collected Data Table. A Boolean displays in the **Numeric Monitor** Public and Data Tables as **true** or **false**.

7.5 About data tables

A data table is essentially a file that resides in data logger memory (for information on data table storage, see Data memory (p. 46)). The file consists of five or more rows. Each row consists of columns, or fields. The first four rows constitute the file header. Subsequent rows contain data records. Data tables may store individual measurements, individual calculated values, or summary data such as averages, maximums, or minimums.

Typically, files are written to based on time or event. The number of data tables is limited to 250, which includes the **Public**, **Status**, **DataTableInfo**, and **ConstTable**. You can retrieve data based on a schedule or by manually choosing to collect data using data logger support software (see Collecting data (p. 35)).

Table 7-4: Example data

TOA5, MyStation, CR1000X, 1142, CR1000X.Std.01, CPU:MyTemperature.CR1X, 1958, OneMin				
TIMESTAMP TS	RECORD RN	BattV_Avg Volts	PTemp_C_Avg Deg C	Temp_C_Avg Deg C
		Avg	Avg	Avg
2019-03-08 14:24:00	0	13.68	21.84	20.71
2019-03-08 14:25:00	1	13.65	21.84	20.63

Table 7-4: Example data				
TOA5, MyStation, CR1000X, 1142, CR1000X.Std.01, CPU:MyTemperature.CR1X, 1958, OneMin				
TIMESTAMP TS	RECORD RN	BattV_Avg Volts	PTemp_C_Avg Deg C	Temp_C_Avg Deg C
		Avg	Avg	Avg
2019-03-08 14:26:00	2	13.66	21.84	20.63
2019-03-08 14:27:00	3	13.58	21.85	20.62
2019-03-08 14:28:00	4	13.64	21.85	20.52
2019-03-08 14:29:00	5	13.65	21.85	20.64

7.5.1 Table definitions

Each data table is associated with descriptive information, referred to as a"table definition," that becomes part of the file header (first few lines of the file) when data is downloaded to a computer. Table definitions include the data logger type and OS version, name of the CRBasic program associated with the data, name of the data table (limited to 20 characters), and alphanumeric field names.

7.5.1.1 Header rows

The first header row of the data table is the environment line, which consists of eight fields. The following list describes the fields using the previous table entries as an example:

- **TOA5** - Table output format. Changed via ***LoggerNet*** **Setup** **Standard View**, **Data Files** tab.
- **MyStation** - Station name. Changed via ***LoggerNet*** **Setup**, ***Device Configuration Utility***, or CRBasic program.
- **CR1000X** - Data logger model.
- **1142** - Data logger serial number.
- **CR1000X.Std.01** - Data logger OS version.
- **CPU:MyTemperature.CR1X** - Data logger program name. Changed by sending a new program (see Sending a program to the data logger (p. 32) for more information).
- **1958** - Data logger program signature. Changed by revising a program or sending a new program (see Sending a program to the data logger (p. 32) for more information).
- **OneMin** - Table name as declared in the running program (see Creating data tables in a program (p. 43) for more information).

The second header row reports field names. Default field names are a combination of the variable names (or aliases) from which data is derived, and a three-letter suffix. The suffix is an abbreviation of the data process that outputs the data to storage. A list of these abbreviations follows in Data processing abbreviations (p. 42).

If a field is an element of an array, the field name will be followed by a indices within parentheses that identify the element in the array. For example, a variable named `Values`, which is declared as a two-by-two array in the data logger program, will be represented by four field names: `Values(1,1)`, `Values(1,2)`, `Values(2,1)`, and `Values(2,2)`. There will be one value in the second header row for each scalar value defined by the table.

If the default field names are not acceptable to the programmer, the `FieldNames()` instruction can be used in the CRBasic program to customize the names. `TIMESTAMP`, `RECORD`, `BattV_Avg`, `PTemp_C_Avg`, and `Temp_C_Avg` are the default field names in the previous Example data (p. 40).

The third header row identifies engineering units for that field. These units are declared at the beginning of a CRBasic program using the optional `Units()` declaration. In ***Short Cut***, units are chosen when sensors or measurements are added. Units are strictly for documentation. The data logger does not make use of declared units, nor does it check their accuracy.

The fourth header row reports abbreviations of the data process used to produce the field of data.

Table 7-5: Data processing abbreviations

Data processing name	Abbreviation
Totalize	`Tot`
Average	`Avg`
Maximum	`Max`
Minimum	`Min`
Sample at Max or Min	`SMM`
Standard Deviation	`Std`
Moment	`MMT`
Sample	No abbreviation
Histogram[1]	`Hst`
Histogram4D	`H4D`
FFT	`FFT`

Table 7-5: Data processing abbreviations	
Data processing name	**Abbreviation**
Covariance	`Cov`
Level Crossing	`LCr`
WindVector	`WVc`
Median	`Med`
ET	`ETsz`
Solar Radiation (from ET)	`RSo`
Time of Max	`TMx`
Time of Min	`TMn`

7.5.1.2 Data records

Subsequent rows are called data records. They include observed data and associated record keeping. The first field is a time stamp (**TS**), and the second field is the record number (**RN**).

The time stamp shown represents the time at the beginning of the scan in which the data is written. Therefore, in record number 3 in the previous Example data (p. 40), **Temp_C_Avg** shows the average of the measurements taken over the minute beginning at 14:26:01 and ending at 14:27:00. As another example, consider rainfall measured every second with a daily total rainfall recorded in a data table written at midnight. The record time stamped 2019-03-08 00:00:00 will contain the total rainfall beginning at 2019-03-07 00:00:01 and ending at 2019-03-08 00:00:00.

7.6 Creating data tables in a program

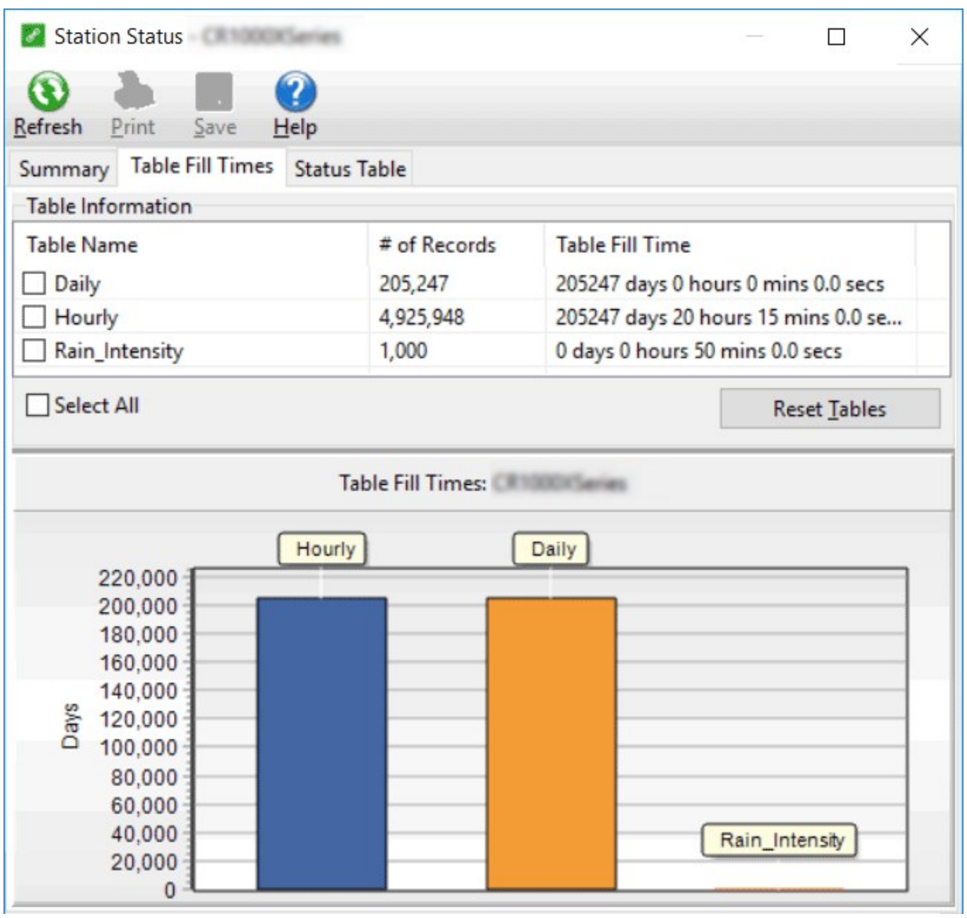
Data is stored in tables as directed by the CRBasic program. In ***Short Cut***, data tables are created in the **Output** steps (see Creating a Short Cut data logger program (p. 29)). Data tables are created within the CRBasic data logger program using the `DataTable()/EndTable` instructions. They are placed after variable declarations and before the `BeginProg` instruction.

```
Public 'Declare Public Variables

DataTable()
   'Output Trigger Condition(s)
    'Output Processing Instructions
EndTable

'Main Program
BeginProg
```

Between `DataTable()` and `EndTable()` are instructions that define what data to store and under what conditions data is stored. A data table must be called by the CRBasic program for data processing and storage to occur. Typically, data tables are called by the `CallTable()` instruction once each program scan.

See the *CRBasic Editor* help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

Use the `DataTable()` instruction to define the number of records, or rows, allocated to a data table. You can set a specific number of records, which is recommended for conditional tables, or allow your data logger to auto-allocate table size. With auto-allocation, the data logger balances the memory so the tables "fill up" (newest data starts to overwrite the oldest data) at about the same time. It is recommended you reserve the use of auto-allocation for data tables that store data based only on time (tables that store data based on the `DataInterval()` instruction). Event or conditional tables are usually set to a fixed number of records. View data table fill times for your program on the **Station Status** > **Table Fill Times** tab (see Checking station status (p. 144) for more information). An example of the Table Fill Times tab follows. For information on data table storage see Data memory (p. 46).



For additional information on data logger memory, visit the Campbell Scientific blog article, How to Know when Your Datalogger Memory is Getting Full.

8. Data memory

The data logger includes three types of memory: SRAM, Flash, and Serial Flash. A memory card slot is also available for an optional microSD card. Note that the data logger USB port does not support USB flash or thumb drives (see Communications ports (p. 15) for more information).

- Total onboard: 128 MB of flash + 4 MB battery-backed SRAM
  - Data storage: 4 MB SRAM + 72 MB flash (extended data storage automatically used for auto-allocated Data Tables not being written to a card)
  - CPU drive: 30 MB flash
  - OS load: 8 MB flash
  - Settings: 1 MB flash
  - Reserved (not accessible): 10 MB flash
- Data storage expansion: Removable microSD flash memory, up to 16 GB

8.1 Data tables

Measurement data is primarily stored in data tables within SRAM. Data is usually erased from this area when a program is sent to the data logger.

During data table initialization, memory sectors are assigned to each data table according to the parameters set in the program. Program options that affect the allocation of memory include the `Size` parameter of the `DataTable()` instruction, the `Interval` and `Units` parameters of the `DataInterval()` instruction. The data logger uses those parameters to assign sectors in a way that maximizes the life of its memory. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

By default, data memory sectors are organized as ring memory. When the ring is full, oldest data is overwritten by newest data. Using the `FillStop` statement sets a program to stop writing to the data table when it is full, and no more data is stored until the table is reset. To see the total number of records that can be stored before the oldest data is overwritten, or to reset tables, go to **Station Status** > **Table Fill Times** in your data logger support software.

Data concerning the data logger memory are posted in the **Status** and **DataTableInfo** tables. For additional information on these tables, see Information tables and settings (advanced) (p. 178).

For additional information on data logger memory, visit the Campbell Scientific blog article, How to Know when Your Datalogger Memory is Getting Full.

8.2 Memory allocation

Data table SRAM and the CPU drive are automatically partitioned by the data logger. The USR drive can be partitioned as needed. The CRD drive is automatically partitioned when a memory card is installed.

The CPU and USR drives use the FAT file system. There is no limit, beyond practicality and available memory, to the number of files that can be stored. While a FAT file system is subject to fragmentation, performance degradation is not likely to be noticed since the drive has a relatively small amount of solid state RAM and is accessed very quickly.

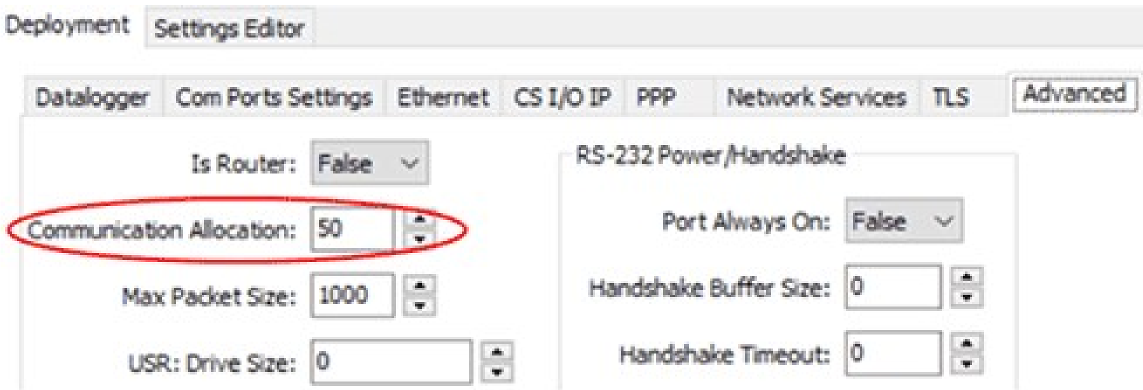
8.3 SRAM

SRAM holds program variables, communications buffers, final-data memory, and, if allocated, the USR drive. An internal lithium battery retains this memory when primary power is removed.

The structure of the data logger SRAM memory is as follows:

- **Static Memory**: This is memory used by the operating system, regardless of the running program. This sector is rebuilt at power-up, program recompile, and watchdog events.
- **Operating Settings and Properties**: Also known as the "Keep" memory, this memory is used to store settings such as PakBus address, station name, beacon intervals, and allowed neighbor lists. This memory also stores dynamic properties such as known routes and communications timeouts.
- **CRBasic Program Operating Memory**: This memory stores the currently compiled and running user program. This sector is rebuilt on power-up, recompile, and watchdog events.
- **Variables & Constants**: This memory stores constants and public variables used by the CRBasic program. Variables may persist through power-up, recompile, and watchdog events if the `PreserveVariables` instruction is in the running program.
- **Final-Data Memory**: This memory stores data. Auto-allocated tables fill whatever memory remains after all other demands are satisfied. A compile error occurs if insufficient memory is available for user-allocated data tables. This memory is given lowest priority in SRAM memory allocation.
- **Communication Memory 1**: Memory used for construction and temporary storage of PakBus packets.
- **Communication Memory 2:** Memory used to store the list of known nodes and routes to nodes. Routers use more memory than leaf nodes because routes store information about

other routers in the network. You can increase the **Communication Allocation** field in ***Device Configuration Utility*** to increase this memory allocation.



- **USR drive:** Optionally allocated. Holds image files. Holds a copy of final-data memory when `TableFile()` instruction used. Provides memory for `FileRead()` and `FileWrite()` operations. Managed in **File Control**. Status reported in **Status** table fields **USRDriveSize** and **USRDriveFree**.

8.3.1 USR drive

Battery-backed SRAM can be partitioned to create a FAT USR drive, analogous to partitioning a second drive on a computer hard disk. Certain types of files are stored to USR to reserve limited CPU drive memory for data logger programs and calibration files. Partitioning also helps prevent interference from data table SRAM. The USR drive holds any file type within the constraints of the size of the drive and the limitations on filenames. Files typically stored include image files from cameras, certain configuration files, files written for FTP retrieval, HTML files for viewing with web access, and files created with the `TableFile()` instruction. Measurement data can also be stored on USR as discrete files by using the `TableFile()` instruction. Files on USR can be collected using data logger support software **Retrieve** command in File Control, or automatically using the ***LoggerNet*** **Setup** > **File Retrieval** tab functions.

USR is not affected by program recompilation or formatting of other drives. It will only be reset if the USR drive is formatted, a new operating system is loaded, or the size of USR is changed. USR size is set manually by accessing it in the Settings Editor, or programmatically by loading a CRBasic program with a USR drive size entered in a `SetSetting()` instruction. Partition the USR drive to at least 11264 bytes in 512-byte increments. If the value entered is not a multiple of 512 bytes, the size is rounded up. Maximum size of USR 2990080 bytes.

WARNING:
Partitioning or changing the size of the USR drive will delete stored data from tables. Collect data first.

NOTE:
Placing an optional USR size setting in the CRBasic program overrides manual changes to USR size. When USR size is changed manually, the CRBasic program restarts and the programmed size for USR takes immediate effect.

Files in the USR drive can be managed through data logger support software **File Control** or through the `FileManage()` instruction in CRBasic program.

8.4 Flash memory

The data logger operating system is stored in a separate section of flash memory. To update the operating system, see Updating the operating system (p. 135).

Serial flash memory holds the CPU drive, web page, and data logger settings. Because flash memory has a limited number of write/erase cycles, care must be taken to avoid continuously writing to files on the CPU drive.

8.4.1 CPU drive

The serial flash memory CPU drive contains data logger programs and other files. This memory is managed in File Control.

NOTE:
When writing to files under program control, take care to write infrequently to prevent premature failure of serial flash memory. Internal chip manufacturers specify the flash technology used in Campbell Scientific CPU: drives at about 100,000 write/erase cycles. While Campbell Scientific's in-house testing has found the manufacturers' specifications to be very conservative, it is prudent to note the risk associated with repeated file writes via program control.

Also, see System specifications (p. 208) for information on data logger memory.

8.5 MicroSD (CRD: drive)

The data logger has a microSD card slot for removable, supplemental memory. The card can be configured as an extension of the data logger final-data memory or as a repository of discrete data files.

When storing high-frequency data, or when storing data to cards greater than 2 GB, `TableFile()` with **Option 64** is recommended to write final storage data to a card. In other applications `CardOut()` can be used to store data to a card.

> **NOTE:**
> Sub-folders are not supported.

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

The CRD: drive uses microSD cards exclusively. Campbell Scientific recommends and supports only the use of microSD cards obtained from Campbell Scientific. These cards are industrial-grade and have passed Campbell Scientific hardware testing. Use of consumer-grade cards substantially increases the risk of data loss. Following are advantages Campbell Scientific cards have over less expensive commercial-grade cards:

- Verified compatibility with Campbell Scientific data loggers
- Less susceptible to failure and data loss
- Match the data logger operating temperature range
- Provide faster read/write times
- Include vibration and shock resistance
- Have longer life spans (more read/write cycles)

A "card controller error" indicates that the data logger has failed to communicate with the card. It is an error caused by the micro-controller built into the microSD card. Sometimes this error may be resolved by reformatting the card. If the error repeats itself, try an industrial-grade card. For more information on errors, see File system error codes (p. 175).

A maximum of 30 data tables can be created using `CardOut()` on a microSD card. When a data table is sent to a microSD card, a data table of the same name in SRAM is used as a buffer for transferring data to the card. Note that with `TableFile()`, the number of files stored on the card is controlled by the **MaxFiles** parameter.

When a new program is compiled that sends data to the card, the data logger checks if a card is present and if the card has adequate space for the data tables. If no card is present, or if space is inadequate, the data logger will warn that the card is not being used. However, the CRBasic program runs anyway and data is stored to SRAM. When a card is inserted later, data accumulated in the SRAM table is copied to the card.

> **NOTE:**
> A card must be exchanged before it fills, or the oldest data will be overwritten, by incoming new records, and lost. During the card exchange, once the old card is removed, the new card

> must be inserted before the data table in data logger CPU memory rings, or data will be overwritten and lost.

A microSD card can also facilitate the use of **powerup.ini** (see File management via powerup.ini (p. 139) for more information).

8.5.1 Formatting microSD cards

The data logger accepts microSD cards formatted as FAT16 or FAT32; however, **FAT32 is recommended**. Otherwise, some functionality, such as the ability to manage large numbers of files (>254) is lost. There are several ways to format cards such as using: File Control, CR1000KD, and Windows. Formatting on the data logger is recommended because this ensures correct FAT32 format.

8.5.2 MicroSD card precautions

Observe the following precautions when using optional memory cards:

- Before removing a card from the data logger, disable the card by pressing the **Eject** button and wait for the green LED. You then have 15 seconds to remove the card before normal operations resume.
- Do not remove a memory card while the drive is active, or data corruption and damage to the card may result.
- Prevent data loss by collecting data before sending a program. Sending a program to the data logger often erases all data.
- See System specifications (p. 208) for information on maximum card size.

8.5.3 Act LED indicator

When the data logger is powered and a microSD card installed, the Act (Activity) LED will turn on according to card activity or status:

- **Red flash**: Card read/write activity
- **Solid green**: This LED indicates it is OK to remove card. The **Eject** button must be pressed before removing a card to allow the data logger to store buffered data to the card and then power it off.
- **Solid orange**: Error
- **Dim/flashing orange**: Card has been removed and has been out long enough that CPU memory has wrapped and data is being overwritten without being stored to the card.

8.5.4 Card data retrieval

Data stored on cards can be retrieved through a communications link to the data logger or by removing the card and carrying it to a computer with a card adapter. With large files, transferring the card to a computer may be faster than collecting the data over a communications link.

> **CAUTION:**
> Removing a card while it is active can cause corrupted data and can damage the card. **Always** press the **Eject** button and wait for a green light before removing card. Do not switch off the data logger power if a card is present and active.

> **CAUTION:**
> **File Control** (in ***LoggerNet*** or ***PC400***) should not be used to retrieve an open file (for example, a file created by using `CardOut()` or the latest file created by `TableFile()`, **Option 64**) from a card. Using **File Control** to retrieve the data can result in a corrupted data file. However, **File Control** can be used to retrieve closed files such as JPEG images or files (other than the latest) created by `TableFile()`, **Option 64**.

8.5.4.1 Via a communications link

Data can be copied to a computer via a communications link by using one of Campbell Scientific data logger support software packages (for example, ***LoggerNet*** or ***PC400***). There is no need to distinguish whether the data is to be collected from the CPU memory or a card. The software package will look for data in both the CPU memory and the card.

The data logger manages data on a card as final-storage data, accessing the card as needed to fill data-collection requests initiated with the **Collect** button in data logger support software. If desired, binary data can be collected by using the **File Control** utility in data logger support software. Before collecting data this way, stop the data logger program to ensure data is not written to the card while data is retrieved; this will avoid data corruption.

Fast storage/data-collection constraints

Factors affecting how fast the data logger stores data include the data storage rate, number of table values, and number of tables. For more information, see Creating data tables in a program (p. 43).

When data logger support software collects data from ring tables that have filled, there is the possibility of missing records due to the collection process. When a ring table has filled, the oldest data is overwritten by the newest data. ***LoggerNet*** and ***PC400*** use a collection algorithm that collects data from multiple tables in small blocks as they collect from all the tables. Collection starts with the oldest data for each table.

With filled ring tables, as collection begins, the data collection software queries the data logger for the oldest data starting with the first table. When this data block is returned, the software goes to the next table and so on until all of the tables are initially collected. By the time ***LoggerNet*** or ***PC400*** make the second pass requesting more data from the tables, the possibility exists that some of that data may have been overwritten.

Normally, data is collected without gaps; however, if the data logger is storing data fast enough, it is possible to get into an always-behind scenario where the data collection never catches up and the data logger repeatedly overwrites uncollected data.

> CAUTION:
> The possibility of missing records is greater when collecting data over high-latency communications links, such as RF or busy IP networks. This is due to the high demand of communications on processor time.

8.5.4.2 Card transport to computer

With large files, transferring the card to a computer may be faster than collecting the data over a communications link.

> CAUTION:
> Removing a card while it is active can cause corrupted data and can damage the card. **Always** press the **Eject** button and wait for a green light before removing card. Do not switch off the data logger power if a card is present and active.

To remove a card, first press the **Eject** button. The data logger will copy any buffered data to the card and then power the card off. The Act LED will turn green when it is OK to physically remove the card. The card will be reactivated after 15 seconds if it is not removed.

When the card is inserted into a computer, the data files can be copied to another drive or used directly from the card just as one would from any other disk. In most cases, however, it will be necessary to convert the file format before using the data.

Note that for both `CardOut()` and `TableFile()` **Option 64**, data is stored on the card in binary (TOB3) format. TOB3 is a binary format that incorporates features to improve reliability of cards. TOB3 format is different from the data file formats created when data is collected via a communications link, which is ASCII (TOA5) format. Hence, data files that are read directly from the card need to be converted into another format to be human readable. You can convert files from binary or other formats using ***CardConvert*** software that is included in your data logger support software.

Converting file formats

Use ***CardConvert*** to convert data to a different format.

1. Open ***CardConvert***.
   - On the ***LoggerNet*** toolbar select the **Data** category.
   - In ***PC400*** select the **Tools** menu.
2. Click **Select Card Drive**.
3. Select where the files to be converted are stored and press **OK**.
4. Click **Change Output Dir** and select where to store the converted files.
5. Place check marks next to the files to be converted. A default destination *filename* is given. It can be changed by right-clicking with the *filename* highlighted.
6. Press **Destination File Options** to select what file format to convert to and other options.
7. Press **Start Conversion** to begin converting files. Green check marks will appear next to each *filename* as conversion is complete. Refer to the data logger support software manual or built-in ***CardConvert*** help for more information.

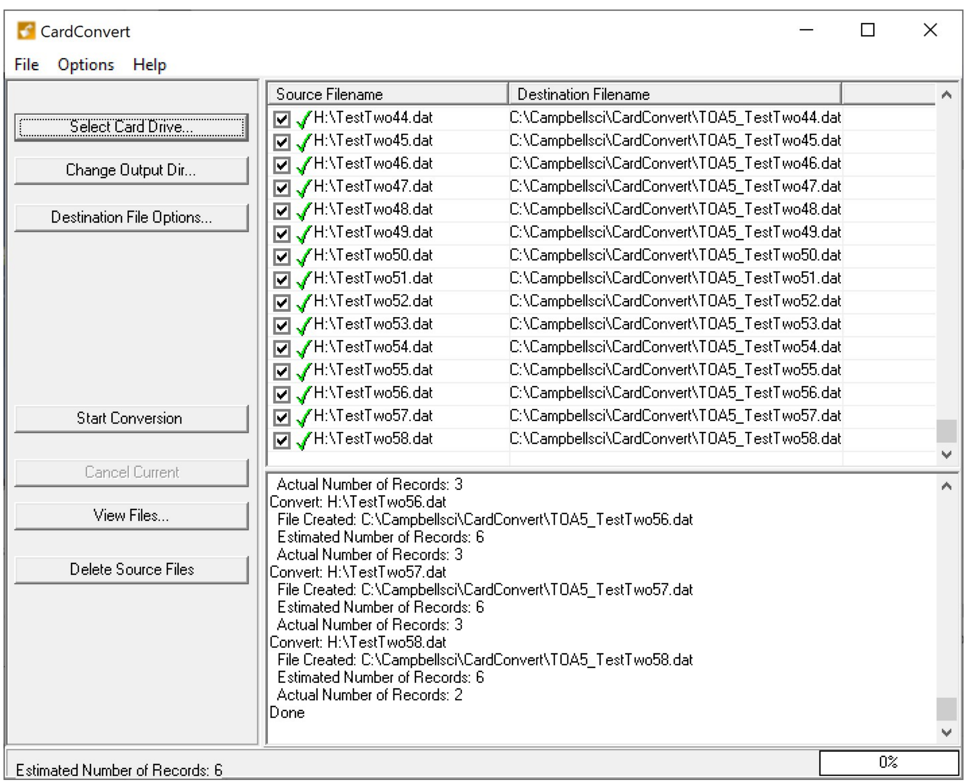


*FIGURE 8-1. **CardConvert***

Reinserting the card

If the same card is inserted again into the data logger, the data logger will store all data to the card that has been generated since the card was removed that is still in the CPU memory. If the data tables have been left on the card, new data will be appended to the end of the old files. If the data tables have been deleted, new ones will be created.

> **CAUTION:**
> Check the status of the card before leaving the data logger. If a card was not properly accepted, the LED will flash orange. In that case, reformat and erase all data contained on the card. Formatting or erasing a card might be done on a computer or data logger. See MicroSD (CRD: drive) (p. 49) for information on formatting a card.

Card swapping

When transporting a card to a computer to retrieve data, most users will want to use a second card to ensure that no data is lost. For this method of collection, use the following steps.

1. Insert formatted card ("card-A") into the data logger card slot. See Formatting microSD cards (p. 51).
2. Send program containing `TableFile()` or `CardOut()` instruction(s).
3. When ready to retrieve data (hours, days, or months later), press the **Eject** button. The LED will be red while the most-current data is stored to the card and then turn green. Remove the card while the LED is green.
4. Insert the clean card ("card-B").
5. Use ***CardConvert*** to copy data from card-A to computer and convert. The default ***CardConvert*** filename will be TOA5_*stationname*_*tablename*.dat. Once the data is copied, use Windows Explorer to **delete all data files from the card**.
6. At the next card swap, eject card-B, press the **Eject** button. The LED will be red while the most-current data is stored to the card and then turn green. Remove the card while the LED is green.
7. Insert the clean card-A.
8. Running ***CardConvert*** on card-B will result in separate data files containing records since card-A was ejected. ***CardConvert*** can increment the *filename* to TOA5_*stationname*_*tablename*_0.dat.
9. The data files can be joined by using text editing software such as ***WordPad*** or a spreadsheet such as ***Excel***.

CardConvert file	Card-A record numbers	Card-B record numbers
TOA5_*tablename*.dat	0-100	
TOA5_*tablename*.dat		101-1234

CardConvert file	Card-A record numbers	Card-B record numbers
TOA5_*tablename*.dat	1235-....	

9. Measurements

9.1 Voltage measurements

Voltage measurements are made using an Analog-to-Digital Converter (ADC). A high-impedance Programmable-Gain Amplifier (PGA) amplifies the signal. Internal multiplexers route individual terminals within the amplifier. The CRBasic measurement instruction controls the ADC gain and configuration – either single-ended or differential input. Information on the differences between single-ended and differential measurements can be found here: Deciding between single-ended or differential measurements (p. 162).

A voltage measurement proceeds as follows:

1. Set PGA gain for the voltage range selected with the CRBasic measurement instruction parameter `Range`. Set the ADC for the first notch frequency selected with `fN1`.
2. If used, such as with bridge measurements, turn on excitation to the level selected with `ExmV`.
3. Multiplex selected terminals (`SEChan` or `DiffChan`).
4. Delay for the entered settling time (`SettlingTime`).
5. Perform the analog-to-digital conversion.
6. Repeat for input reversal as determined by parameters `RevEx` and `RevDiff`.
7. Apply multiplier (`Mult`) and offset (`Offset`) to measured result.

Conceptually, analog voltage sensors output two signals: high and low. For example, a sensor that outputs 1000 mV on the high signal and 0 mV on the low has an overall output of 1000 mV. A sensor that outputs 2000 mV on the high signal and 1000 mV on the low also has an overall output of 1000 mV. Sometimes, the low signal is simply sensor ground (0 mV). A single-ended measurement measures the high signal with reference to ground; the low signal is tied to ground. A differential measurement measures the high signal with reference to the low signal. Each configuration has a purpose, but the differential configuration is usually preferred.

In general, use the smallest input range that accommodates the full-scale output of the sensor. This results in the best measurement accuracy and resolution (see Analog measurement specifications (p. 212) for more information).

A set overhead reduces the chance of overrange. Overrange limits are available in the specifications. The data logger indicates a measurement overrange by returning a **NAN** for the measurement.

> **WARNING:**
> Sustained voltages in excess of ±20 V applied to terminals configured for analog input will damage CR1000X circuitry.

9.1.1 Single-ended measurements

A single-ended measurement measures the difference in voltage between the terminal configured for single-ended input and the reference ground. For example, single-ended channel 1 is comprised of terminals **SE 1** and ⏚. Single-ended terminals are labeled in blue. For more information, see Wiring panel and terminal functions (p. 8). The single-ended configuration is used with the following CRBasic instructions:

- `VoltSE()`
- `BrHalf()`
- `BrHalf3W()`
- `TCSE()`
- `Therm107()`
- `Therm108()`
- `Therm109()`

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

9.1.2 Differential measurements

A differential measurement measures the difference in voltage between two input terminals. For example, **DIFF** channel **1** is comprised of terminals **1H** and **1L**, with **1H** as high and **1L** as low. For more information, see Wiring panel and terminal functions (p. 8). The differential configuration is used with the following CRBasic instructions:

- `VoltDiff()`
- `BrFull()`
- `BrFull6W()`
- `BrHalf4W()`
- `TCDiff()`

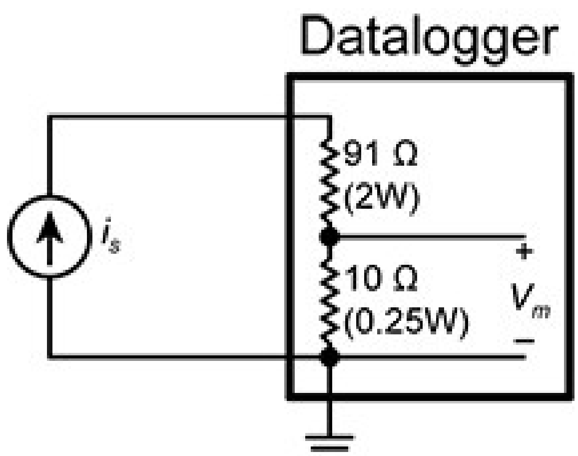
9.1.2.1 Reverse differential

Differential measurements have the advantage of an input reversal option, `RevDiff`. When `RevDiff` is set to **True**, two differential measurements are made, the first with a positive polarity and the second reversed. Subtraction of opposite polarity measurements cancels some offset voltages associated with the measurement.

For more information on voltage measurements, see Improving voltage measurement quality (p. 162) and Analog measurement specifications (p. 212).

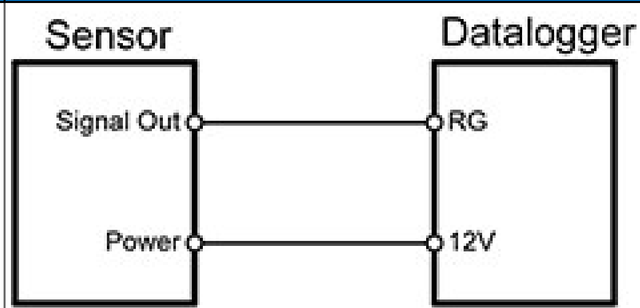
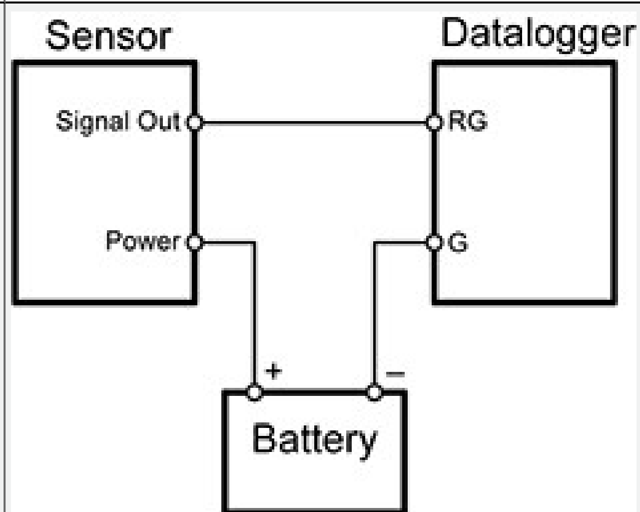
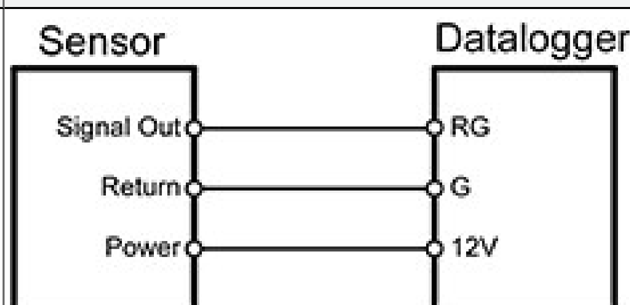
9.2 Current-loop measurements

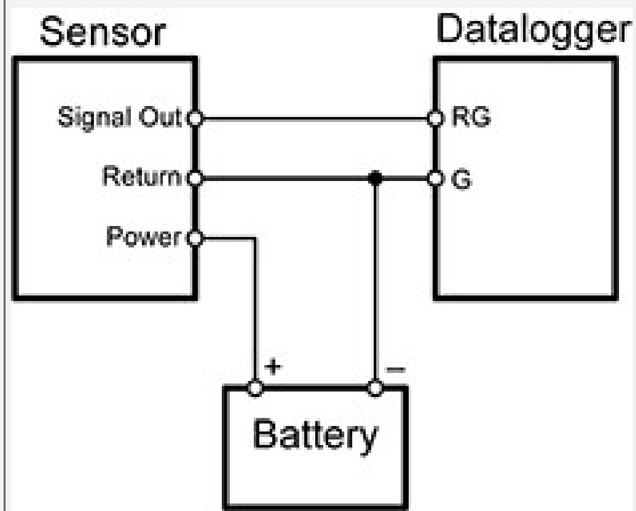
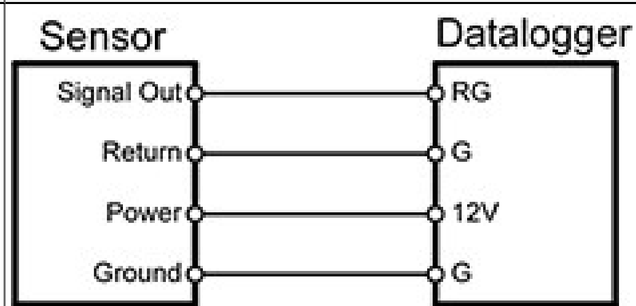
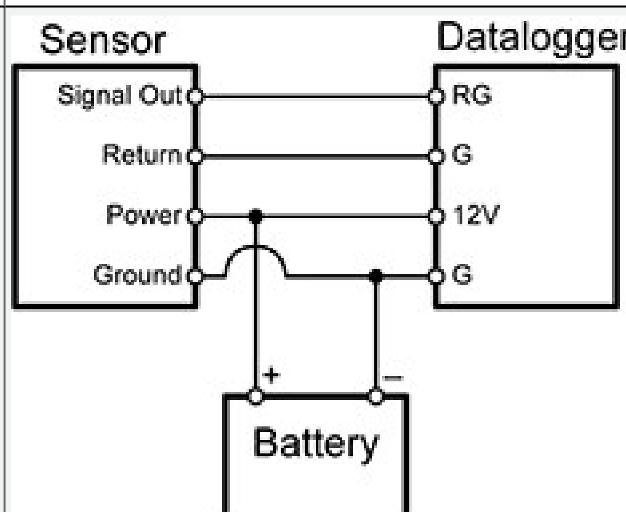
RG terminals can be configured to make analog current measurements using the `CurrentSE()` instruction. When configured to measure current, terminals each have an internal resistance of 101 Ω in the current measurement loop. The return path of the sensor must be connected directly to the **RG** terminal. The following image shows a simplified schematic of a current measurement.



9.2.1 Example current-loop measurement connections

The following table shows example schematics for connecting typical current sensors and devices. See also Current-loop measurement specifications (p. 215).

Sensor Type	Connection Example
2-wire transmitter using data logger power	
2-wire transmitter using external power	
3-wire transmitter using data logger power	

Sensor Type	Connection Example
3-wire transmitter using external power	
4-wire transmitter using data logger power	
4-wire transmitter using external power	

9.3 Resistance measurements

Bridge resistance is determined by measuring the difference between a known voltage applied to the excitation (input) of a resistor bridge and the voltage measured on the output arm. The data logger supplies a precise voltage excitation via **VX** terminals. Return voltage is measured on analog input terminals configured for single-ended (**SE**) or differential (**DIFF**) input. The result of the measurement is a ratio of measured voltages.

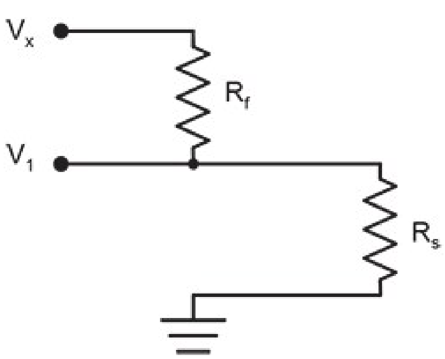
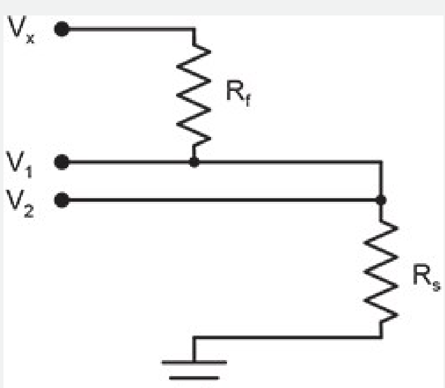
See also Resistance measurement specifications (p. 214).

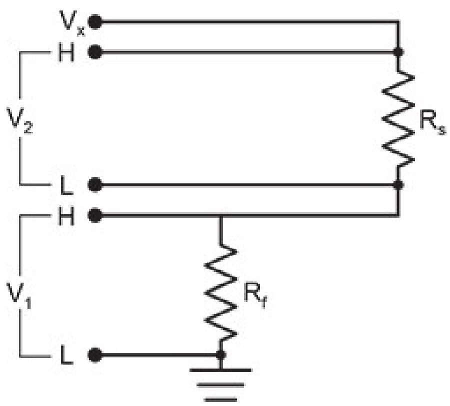
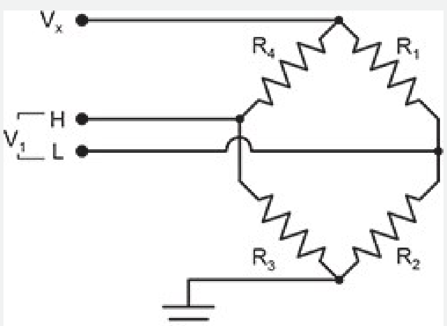
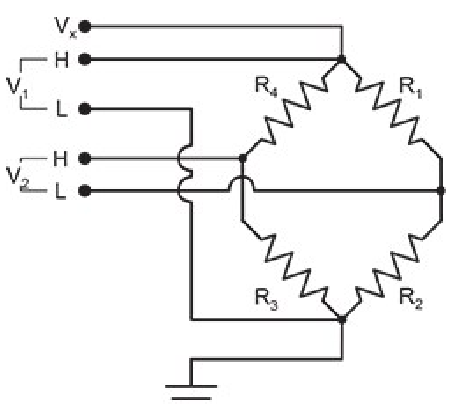
9.3.1 Resistance measurements with voltage excitation

CRBasic instructions for measuring resistance with voltage excitation include:

- `BrHalf()` - half bridge
- `BrHalf3W()` - three-wire half bridge
- `BrHalf4W()` - four-wire half bridge
- `BrFull()` - four-wire full bridge
- `BrFull6W()` - six-wire full bridge

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

<table>
<tr><th>Resistive-Bridge Type and Circuit Diagram</th><th>CRBasic Instruction and Fundamental Relationship</th><th>Relational Formulas</th></tr>
<tr><td>Half Bridge[1]

</td><td>CRBasic Instruction:
<code>BrHalf()</code>
Fundamental Relationship:
X = result w/mult = 1, offset = 0
$X = \frac{V_1}{V_x} = \frac{R_S}{R_S + R_f}$</td><td>$R_s = R_f \frac{X}{1 - X}$
$R_f = \frac{R_s(1 - X)}{X}$</td></tr>
<tr><td>Three Wire Half Bridge[1,2]

</td><td>CRBasic Instruction:
<code>BrHalf3W()</code>
Fundamental Relationship:
X = result w/mult = 1, offset = 0
$X = \frac{2V_2 - V_1}{V_x - V_1} = \frac{R_S}{R_f}$</td><td>$R_s = R_f X$
$R_f = \frac{R_s}{X}$</td></tr>
</table>

<table>
<tr><th>Resistive-Bridge Type and Circuit Diagram</th><th>CRBasic Instruction and Fundamental Relationship</th><th>Relational Formulas</th></tr>
<tr><td>Four Wire Half Bridge[1,2]
</td><td>CRBasic Instruction:
`BrHalf4W()`
Fundamental Relationship:
X = result w/mult = 1, offset = 0
$X = \frac{V_2}{V_1} = \frac{R_s}{R_f}$</td><td>$R_f = \frac{R_s}{X}$
$R_s = R_f X$</td></tr>
<tr><td>Full Bridge[1,2]
</td><td>CRBasic Instruction:
`BrFull()`
Fundamental Relationship:
X = result w/mult = 1, offset = 0
$X = 1000\,\frac{V_1}{V_x} = 1000\left(\frac{R_3}{R_3+R_4} - \frac{R_2}{R_1+R_2}\right)$</td><td rowspan="2">These relationships apply to
`BrFull()`
and `BrFull6W()`
$R_1 = \frac{R_2(1-X_1)}{X_1}$
$R_2 = \frac{R_1 X_1}{1-X_1}$
where $X_1 = \frac{-X}{1000} + \frac{R_3}{R_3+R_4}$
$R_3 = \frac{R_4 X_2}{1-X_2}$
$R_4 = \frac{R_3(1-X_2)}{X_2}$
where $X_2 = \frac{X}{1000} + \frac{R_2}{R_1+R_2}$</td></tr>
<tr><td>Six Wire Full Bridge[1]
</td><td>CRBasic Instruction:
`BrFull6W()`
Fundamental Relationship:
X = result w/mult = 1, offset = 0
$X = 1000\,\frac{V_2}{V_1} = 1000\left(\frac{R_3}{R_3+R_4} - \frac{R_2}{R_1+R_2}\right)$</td></tr>
<tr><td colspan="3">1 Key: V_x = excitation voltage; V_1, V_2 = sensor return voltages; R_f = fixed, bridge or completion resistor; R_s = variable or sensing resistor.
2 Campbell Scientific offers terminal input modules to facilitate this measurement.</td></tr>
</table>

Offset voltage compensation applies to bridge measurements. In addition to `RevDiff` and `MeasOff` parameters discussed in Minimizing offset voltages (p. 171), CRBasic bridge measurement instructions include the RevEx parameter that provides the option to program a second set of measurements with the excitation polarity reversed. Much of the offset error inherent in bridge measurements is canceled out by setting RevDiff, RevEx, and MeasOff to **True**.

Measurement speed may be reduced when using RevDiff, MeasOff, and RevEx. When more than one measurement per sensor is necessary, such as occurs with the BrHalf3W(), BrHalf4W(), and BrFull6W() instructions, input and excitation reversal are applied separately to each measurement. For example, in the four-wire half-bridge (BrHalf4W()), when excitation is reversed, the differential measurement of the voltage drop across the sensor is made with excitation at both polarities and then excitation is again applied and reversed for the measurement of the voltage drop across the fixed resistor. The results of the measurements (X) must then be processed further to obtain the resistance value, which requires additional program execution time.

CRBasic Example 1: Four-Wire Full Bridge Measurement and Processing

```
'This program example demonstrates the measurement and
'processing of a four-wire resistive full bridge.
'In this example, the default measurement stored
'in variable X is deconstructed to determine the
'resistance of the R1 resistor, which is the variable
'resistor in most sensors that have a four-wire
'full-bridge as the active element.
'Declare Variables
Public X
Public X_1
Public R_1
Public R_2 = 1000 'Resistance of fixed resistor R2
Public R_3 = 1000 'Resistance of fixed resistor R3
Public R_4 = 1000 'Resistance of fixed resistor R4
'Main Program
BeginProg
  Scan(500,mSec,1,0)
    'Full Bridge Measurement:
    BrFull(X,1,mV250,1,Vx1,1,4000,True,True,0,60,1.0,0.0)
    X_1 = ((-1 * X) / 1000) + (R_3 / (R_3 + R_4))
    R_1 = (R_2 * (1 - X_1)) / X_1
  NextScan
EndProg
```

9.3.2 Strain measurements

A principal use of the four-wire full bridge is the measurement of strain gages in structural stress analysis. StrainCalc() calculates microstrain (με) from the formula for the specific bridge configuration used. All strain gages supported by `StrainCalc()` use the full-bridge schematic. 'Quarter-bridge', 'half-bridge' and 'full-bridge' refer to the number of active elements in the bridge schematic. In other words, a quarter-bridge strain gage has one active element, a half-bridge has two, and a full-bridge has four.

`StrainCalc()` requires a bridge-configuration code. The following table shows the equation used by each configuration code. Each code can be preceded by a dash (-). Use a code without the dash when the bridge is configured so the output decreases with increasing strain. Use a dashed code when the bridge is configured so the output increases with increasing strain. A dashed code sets the polarity of V_r to negative.

Table 9-1: StrainCalc() configuration codes

BrConfig Code	Configuration
1	Quarter-bridge strain gage: $$\mu\varepsilon = \frac{-4 * 10^6 V_r}{GF(1 + 2V_r)}$$
2	Half-bridge strain gage. One gage parallel to strain, the other at 90° to strain: $$\mu\epsilon = \frac{-4 * 10^6 V_r}{GF[(1 + v) - 2V_r(v - 1)]}$$
3	Half-bridge strain gage. One gage parallel to +ε, the other parallel to -ε: $$\mu\varepsilon = \frac{-2 * 10^6 V_r}{GF}$$
4	Full-bridge strain gage. Two gages parallel to +ε, the other two parallel to -ε: $$\mu\varepsilon = \frac{-10^6 V_r}{GF}$$

Table 9-1: StrainCalc() configuration codes	
BrConfig Code	Configuration
5	Full-bridge strain gage. Half the bridge has two gages parallel to +ε and -ε, and the other half to +νε and -νε $$\mu\varepsilon = \frac{-2 * 10^6 V_r}{GF(v+1)}$$
6	Full-bridge strain gage. Half the bridge has two gages parallel to +ε and -νε , and the other half to -νε and +ε: $$\mu\varepsilon = \frac{-2 * 10^6 V_r}{GF[(v+1) - V_r(v-1)]}$$

Where:

ν : Poisson's Ratio (0 if not applicable).

GF: Gage Factor.

V_r: 0.001 (Source-Zero) if `BRConfig` code is positive (+).

V_r: –0.001 (Source-Zero) if `BRConfig` code is negative (–).

and where:

"source": the result of the full-bridge measurement (X = 1000 • V1 / Vx) when multiplier = 1 and offset = 0.

"zero": gage offset to establish an arbitrary zero.

9.3.3 AC excitation

Some resistive sensors require AC excitation. AC excitation is defined as excitation with equal positive (+) and negative (–) duration and magnitude. These include electrolytic tilt sensors, soil moisture blocks, water-conductivity sensors, and wetness-sensing grids. The use of single polarity DC excitation with these sensors can result in polarization of sensor materials and the substance measured. Polarization may cause erroneous measurement, calibration changes, or rapid sensor decay.

Other sensors, for example, LVDTs (linear variable differential transformers), require AC excitation because they require inductive coupling to provide a signal. DC excitation in an LVDT will result in no measurement.

CRBasic bridge-measurement instructions have the option to reverse polarity to provide AC excitation by setting the `RevEx` parameter to **True**.

NOTE:
Take precautions against ground loops when measuring sensors that require AC excitation. See also Ground loops (p. 158).

For more information, see Accuracy for resistance measurements (p. 67).

9.3.4 Accuracy for resistance measurements

Consult the following technical papers for in-depth treatments of several topics addressing voltage measurement quality:

- Preventing and Attacking Measurement Noise Problems
- Benefits of Input Reversal and Excitation Reversal for Voltage Measurements
- Voltage Measurement Accuracy, Self- Calibration, and Ratiometric Measurements

NOTE:
Error discussed in this section and error-related specifications of the CR1000X do not include error introduced by the sensor, or by the transmission of the sensor signal to the data logger.

For accuracy specifications of ratiometric resistance measurements, see Resistance measurement specifications (p. 214). Voltage measurement is variable V_1 or V_2 in resistance measurements. Offset is the same as that for simple analog voltage measurements.

Assumptions that support the ratiometric-accuracy specification include:

- Data logger is within factory calibration specification.
- Input reversal for differential measurements and excitation reversal for excitation voltage are within specifications.
- Effects due to the following are not included in the specification:
  - Bridge-resistor errors
  - Sensor noise
  - Measurement noise

9.4 Thermocouple Measurements

Thermocouple measurements are special case voltage measurements.

NOTE: Thermocouples are inexpensive and easy to use. However, they pose several challenges to the acquisition of accurate temperature data, particularly when using external reference junctions.

A thermocouple consists of two wires, each of a different metal or alloy, joined at one end to form the measurement junction. At the opposite end, each wire connects to terminals of a voltage measurement device, such as the data logger. These connections form the reference junction. If the two junctions (measurement and reference) are at different temperatures, a voltage proportional to the difference is induced in the wires. This phenomenon is known as the Seebeck effect.

Measurement of the voltage between the positive and negative terminals of the voltage-measurement device provides a direct measure of the **temperature difference** between the measurement and reference junctions. A third metal (for example, solder or data logger terminals) between the two dissimilar-metal wires form parasitic-thermocouple junctions, the effects of which cancel if the two wires are at the same temperature. Consequently, the two wires at the reference junction are placed in close proximity so they remain at the same temperature.

Knowledge of the reference junction temperature provides the determination of a reference junction compensation voltage, corresponding to the temperature difference between the reference junction and 0°C. This compensation voltage, combined with the measured thermocouple voltage, can be used to compute the absolute temperature of the thermocouple junction.

`TCDiff()` and `TCSE()` thermocouple instructions determine thermocouple temperatures using the following sequence. First, the temperature (°C) of the reference junction is determined. Next, a reference junction compensation voltage is computed based on the temperature difference between the reference junction and 0°C. If the reference junction is the data logger analog-input terminals, the temperature is conveniently measured with the `PanelTemp()` instruction. The actual thermocouple voltage is measured and combined with the reference junction compensation voltage. It is then used to determine the thermocouple-junction temperature based on a polynomial approximation of NIST thermocouple calibrations.

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

9.5 Period-averaging measurements

Use `PeriodAvg()` to measure the period (in microseconds) or the frequency (in Hz) of a signal on a single-ended channel. For these measurements, the data logger uses a high-frequency digital clock to measure time differences between signal transitions, whereas pulse-count measurements simply accumulate the number of counts. As a result, period-average measurements offer much better frequency resolution per measurement interval than pulse-count measurements. See also Pulse measurements (p. 69).

SE terminals on the data logger are configurable for measuring the period of a signal.

The measurement is performed as follows: low-level signals are amplified prior to a voltage comparator. The internal voltage comparator is referenced to the programmed threshold. The threshold parameter allows referencing the internal voltage comparator to voltages other than 0 V. For example, a threshold of 2500 mV allows a 0 to 5 VDC digital signal to be sensed by the internal comparator without the need for additional input conditioning circuitry. The threshold allows direct connection of standard digital signals, but it is not recommended for small-amplitude sensor signals.

A threshold other than zero results in offset voltage drift, limited accuracy (approximately ±10 mV) and limited resolution (approximately 1.2 mV).

See also Period-averaging measurement specifications (p. 215).

> **TIP:**
> Both pulse count and period-average measurements are used to measure frequency output sensors. However, their measurement methods are different. Pulse count measurements use dedicated hardware - pulse count accumulators, which are always monitoring the input signal, even when the data logger is between program scans. In contrast, period-average measurements use program instructions that only monitor the input signal during a program scan. Consequently, pulse count scans can occur less frequently than period-average scans. Pulse counters may be more susceptible to low-frequency noise because they are always "listening", whereas period-averaging measurements may filter the noise by reason of being "asleep" most of the time.
>
> Pulse count measurements are not appropriate for sensors that are powered off between scans, whereas period-average measurements work well since they can be placed in the scan to execute only when the sensor is powered and transmitting the signal.

9.6 Pulse measurements

The output signal generated by a pulse sensor is a series of voltage waves. The sensor couples its output signal to the measured phenomenon by modulating wave frequency. The data logger detects the state transition as each wave varies between voltage extremes (high-to-low or low-to-high). Measurements are processed and presented as counts, frequency, or timing data. Both pulse count and period-average measurements are used to measure frequency-output sensors. For more information, see Period-averaging measurements (p. 68).

The data logger includes terminals that are configurable for pulse input as shown in the following image.

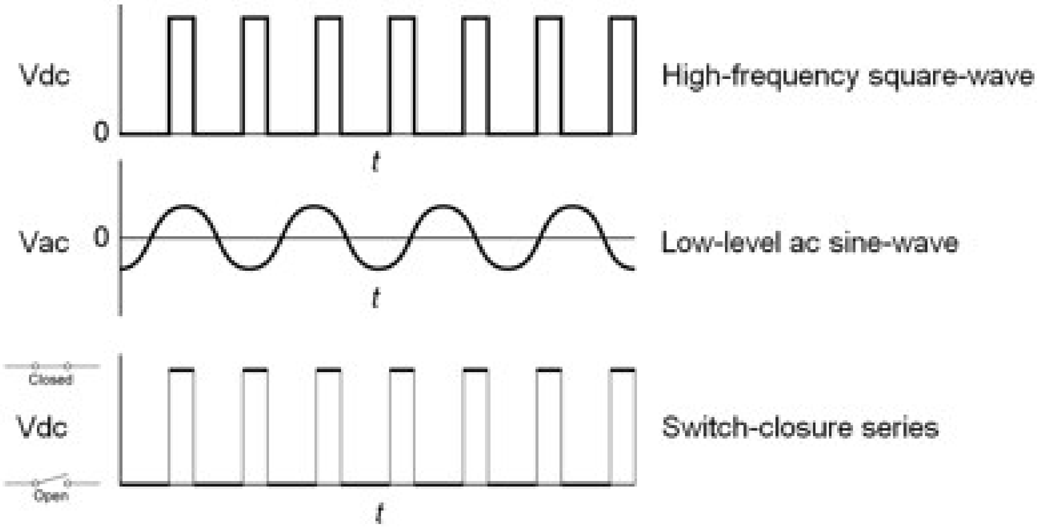


Table 9-2: Pulse input terminals and the input types they can measure

Input Type	Pulse Input Terminal
High-frequency	**P1** **P2** **C** (all)
Low-level AC	**P1** **P2**
Switch-closure	**P1** **P2** **C** (all)

Using the `PulseCount()` instruction, **P C** terminals are configurable for pulse input to measure counts or frequency. Maximum input frequency is dependent on input voltage. If pulse input voltages exceed the maximum voltage, third-party external-signal conditioners should be employed. Do not measure voltages greater than 20 V.

NOTE:
Conflicts can occur when a control port pair is used for different instructions (`TimerInput()`, `PulseCount()`, `SDI12Recorder()`, `WaitDigTrig()`). For example, if **C1** is used for `SDI12Recorder()`, **C2** cannot be used for `TimerInput()`, `PulseCount()`, or `WaitDigTrig()`.

Terminals configured for pulse input have internal filters that reduce electronic noise, and thus reduce false counts. Internal AC coupling is used to eliminate DC offset voltages. For tips on working with pulse measurements, see Pulse measurement tips (p. 75).

Output can be recorded as counts, frequency or a running average of frequency.

For more information, see Pulse measurement specifications (p. 216).

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

9.6.1 Low-level AC measurements

Low-level AC (alternating current or sine-wave) signals can be measured on **P** terminals. AC generator anemometers typically output low-level AC.

Measurement output options include the following:

- Counts
- Frequency (Hz)
- Running average

Rotating magnetic-pickup sensors commonly generate ac voltage ranging from millivolts at low-rotational speeds to several volts at high-rotational speeds.

CRBasic instruction: `PulseCount()`. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

Low-level AC signals cannot be measured directly by **C** terminals. Peripheral terminal expansion modules, such as the Campbell Scientific **LLAC4**, are available for converting low-level AC signals to square-wave signals measurable by **C** terminals.

For more information, see Pulse measurement specifications (p. 216).

9.6.2 High-frequency measurements

High-frequency (square-wave) signals can be measured on terminals:

- **P** or **C**

Common sensors that output high-frequency pulses include:

- Photo-chopper anemometers
- Flow meters

Measurement output optionss include counts, frequency in hertz, and running average. Note that the resolution of a frequency measurement can be different depending on the terminal used in the `PulseCount()` instruction. See the CRBasic help for more information.

The data logger has built-in pull-up and pull-down resistors for different pulse measurements which can be accessed using the `PulseCount()` instruction. Note that pull down options are usually used for sensors that source their own power.

9.6.2.1 P terminals

- CRBasic instruction: `PulseCount()`

High-frequency pulse inputs are routed to an inverting CMOS input buffer with input hysteresis. See Pulse measurement specifications (p. 216) for more information.

9.6.2.2 C terminals

- CRBasic instructions: `PulseCount()`

See Pulse measurement specifications (p. 216) for more information.

9.6.3 Switch-closure and open-collector measurements

Switch-closure and open-collector (also called current-sinking) signals can be measured on terminals:

- **P** or **C**

Mechanical switch-closures have a tendency to bounce before solidly closing. Unless filtered, bounces can cause multiple counts per event. The data logger automatically filters bounce. Because of the filtering, the maximum switch-closure frequency is less than the maximum high-frequency measurement frequency. Sensors that commonly output a switch-closure or an open-collector signal include:

- Tipping-bucket rain gages
- Switch-closure anemometers
- Flow meters

The data logger has built-in pull-up and pull-down resistors for different pulse measurements which can be accessed using the `PulseCount()` instruction. Note that pull down options are usually used for sensors that source their own power.

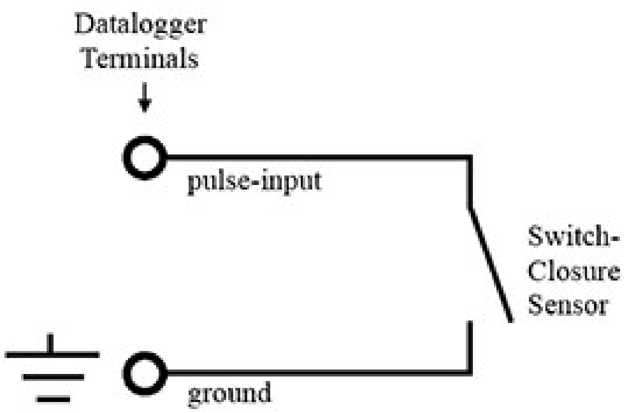
Data output options include counts, frequency (Hz), and running average.

9.6.3.1 P Terminals

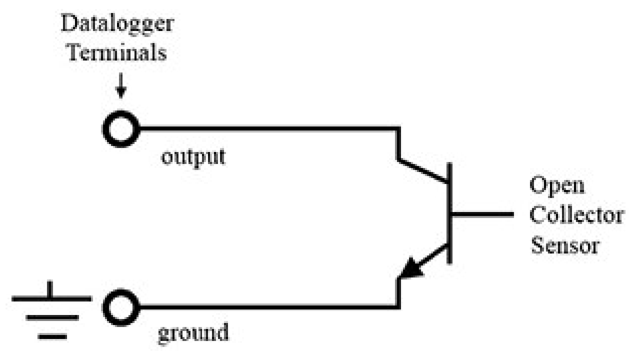
An internal 100 kΩ pull-up resistor pulls an input to 5 VDC with the switch open, whereas a switch-closure to ground pulls the input to 0 V.

- CRBasic instruction: `PulseCount()`. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

Switch Closure on **P** Terminal



Open Collector on **P** Terminal



9.6.3.2 C terminals

Switch-closure mode is a special case edge-count function that measures dry-contact switch-closures or open collectors. The operating system filters bounces.

- CRBasic instruction: `PulseCount()`.

See also Pulse measurement specifications (p. 216).

9.6.4 Edge timing and edge counting

Edge time, period, and counts can be measured on **P** or **C** terminals. Feedback control using pulse-width modulation (PWM) is an example of an edge timing application.

9.6.4.1 Single edge timing

A single edge or state transition can be measured on **C** terminals. Measurements can be expressed as a time (µs), frequency (Hz) or period (µs).

CRBasic instruction: `TimerInput()`

9.6.4.2 Multiple edge counting

Time between edges, time from an edge on the previous terminal, and edges that span the scan interval can be measured on **C** terminals. Measurements can be expressed as a time (μs), frequency (Hz) or period (μs).

- CRBasic instruction: `TimerInput()`

9.6.4.3 Timer input NAN conditions

NAN is the result of a `TimerInput()` measurement if one of the following occurs:

- Measurement timer expires
- The signal frequency is too fast

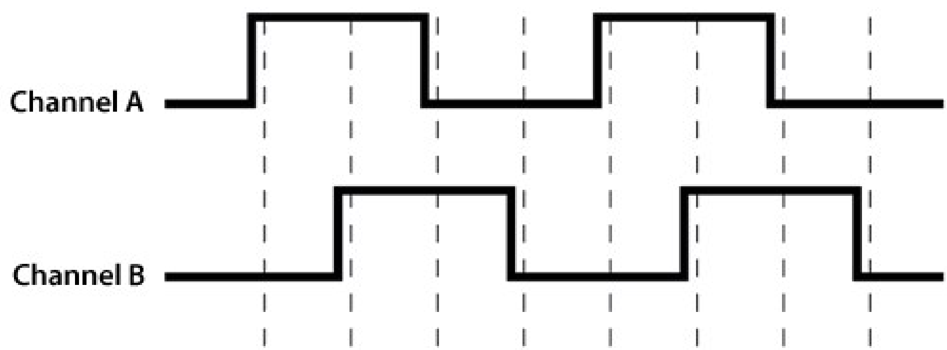
For more information, see:

- Pulse measurement specifications (p. 216)
- Digital input/output specifications (p. 217)
- Period-averaging measurement specifications (p. 215)

9.6.5 Quadrature measurements

The `Quadrature()` instruction is used to measure shaft or rotary encoders. A shaft encoder outputs a signal to represent the angular position or motion of the shaft. Each encoder will have two output signals, an A line and a B line. As the shaft rotates the A and B lines will generate digital pulses that can be read, or counted, by the data logger.

In the following example, channel A leads channel B, therefore the encoder is determined to be moving in a clockwise direction. If channel B led channel A, it would be determined that the encoder was moving in a counterclockwise direction.



Terminals **C1-C8** can be configured as digital pairs to monitor the two channels of an encoder. The `Quadrature()` instruction can return:

- The accumulated number of counts from channel A and channel B. Count will increase if channel A leads channel B. Count will decrease if channel B leads channel A.
- The net direction.
- Number of counts in the A-leading-B direction.
- Number of counts in the B-leading-A direction.

Counting modes:

- Counting the increase on rising edge of channel A when channel A leads channel B. Counting the decrease on falling edge of channel A when channel B leads channel A.
- Counting the increase at each rising and falling edge of channel A when channel A leads channel B. Counting the decrease at each rising and falling edge of channel A when channel A leads channel B.
- Counting the increase at each rising and falling edge of both channels when channel A leads channel B. Counting the decrease at each rising and falling edge of both channels when channel B leads channel A.

For more information, see Digital input/output specifications (p. 217).

9.6.6 Pulse measurement tips

The `PulseCount()` instruction uses dedicated 32-bit counters to accumulate all counts over the programmed scan interval. The resolution of pulse counters is one count. Counters are read at the beginning of each scan and then cleared. Counters will overflow if accumulated counts exceed 4,294,967,296 (2^{32}), resulting in erroneous measurements. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

Counts are the preferred `PulseCount()` output option when measuring the number of tips from a tipping-bucket rain gage or the number of times a door opens. Many pulse-output sensors, such as anemometers and flow meters, are calibrated in terms of frequency (Hz) so are usually measured using the `PulseCount()` frequency-output option.

Use the **LLAC4** module to convert non-TTL-level signals, including low-level ac signals, to TTL levels for input to **C** terminals

Conflicts can occur when a control port pair is used for different instructions (`TimerInput()`, `PulseCount()`, `SDI12Recorder()`, `WaitDigTrig()`). For example, if **C1** is used for

`SDI12Recorder()`, C2 cannot be used for `TimerInput()`, `PulseCount()`, or `WaitDigTrig()`.

Understanding the signal to be measured and compatible input terminals and CRBasic instructions is helpful. See Pulse input terminals and the input types they can measure (p. 70).

9.6.6.1 Input filters and signal attenuation

Terminals configured for pulse input have internal filters that reduce electronic noise. The electronic noise can result in false counts. However, input filters attenuate (reduce) the amplitude (voltage) of the signal. Attenuation is a function of the frequency of the signal. Higher-frequency signals are attenuated more. If a signal is attenuated too much, it may not pass the detection thresholds required by the pulse count circuitry. See Pulse measurement specifications (p. 216) for more information. The listed pulse measurement specifications account for attenuation due to input filtering.

9.6.6.2 Pulse count resolution

Longer scan intervals result in better resolution. `PulseCount()` resolution is 1 pulse per scan. On a 1 second scan, the resolution is 1 pulse per second. The resolution on a 10 second scan interval is 1 pulse per 10 seconds, which is 0.1 pulses per second. The resolution on a 100 millisecond interval is 10 pulses per second.

For example, if a flow sensor outputs 4.5 pulses per second and you use a 1 second scan, one scan will have 4 pulses and the next 5 pulses. Scan to scan, the flow number will bounce back and forth. If you did a 10 second scan (or saved a total to a 10 second table), you would get 45 pulses. The total is 45 pulses for every 10 seconds. An average will correctly show 4.5 pulses per second. You wouldn't see the reading bounce on the longer time interval.

9.7 Vibrating wire measurements

The data logger can measure vibrating wire sensors through vibrating-wire interface modules. Vibrating wire sensors are the sensor of choice in many environmental and industrial applications that need sensor stability over very long periods, such as years or even decades. A thermistor included in most sensors can be measured to compensate for temperature errors.

9.7.1 VSPECT®

Measuring the resonant frequency by means of period averaging is the classic technique, but Campbell Scientific has developed static and dynamic spectral-analysis techniques (VSPECT) that produce superior noise rejection, higher resolution, diagnostic data, and, in the case of dynamic

VSPECT, measurements up to 333.3 Hz. For detailed information on VSPECT, see Vibrating Wire Spectral Analysis Technology.

9.8 Sequential and pipeline processing modes

The data logger has two processing modes: sequential mode and pipeline mode. In sequential mode, data logger tasks run more or less in sequence. In pipeline mode, data logger tasks run more or less in parallel. Mode information is included in a message returned by the data logger, which is displayed by software when the program is sent and compiled, and it is found in the **Status Table**, **CompileResults** field. The ***CRBasic Editor*** pre-compiler returns a similar message.

The default mode of operation is pipeline mode. However, when the data logger program is compiled, the data logger analyzes the program instructions and automatically determines which mode to use. The data logger can be forced to run in either mode by placing the `PipeLineMode` or `SequentialMode` instruction at the beginning of the program (before the `BeginProg` instruction).

For additional information, visit the Campbell Scientific blog article, "Understanding CRBasic Program Compile Modes: Sequential and Pipeline." Or watch an instructional video at: http://www.campbellsci.com/videos/pipeline-sequential.

9.8.1 Sequential mode

Sequential mode executes instructions in the sequence in which they are written in the program. After a measurement is made, the result is converted to a value determined by processing arguments that are included in the measurement instruction, and then program execution proceeds to the next instruction. This line-by-line execution allows writing conditional measurements into the program.

> **NOTE:**
> The exact time at which measurements are made in sequential mode may vary if other measurements or processing are made conditionally, if there is heavy communications activity, or if other interrupts occur (such as accessing a Campbell Scientific memory card).

9.8.2 Pipeline mode

Pipeline mode handles measurement, most digital, and processing tasks separately, and, in many cases, simultaneously. Measurements are scheduled to execute at exact times and with the highest priority, resulting in more precise timing of measurements, and usually more efficient processing and power consumption.

In pipeline mode, it will take less time for the data logger to execute each scan of the program. However, because processing can lag behind measurements, there could be instances, such as when turning on a sensor using the `SW12()` instruction, that the sensor might not be on at the correct time to make the measurement.

Pipeline scheduling requires that the program be written such that measurements are executed every scan. Because multiple tasks are taking place at the same time, the sequence in which the instructions are executed may not be in the order in which they appear in the program. Therefore, conditional measurements are not allowed in pipeline mode. Because of the precise execution of measurement instructions, processing in the current scan (including updating public variables and data storage) is delayed until all measurements are complete. Some processing, such as transferring variables to control instructions, like `PortSet()` and `ExciteV()`, may not be completed until the next scan.

When a condition is true for a task to start, it is put in a queue. Because all tasks are given the same priority, the task is put at the back of the queue. Every 1 ms (or faster if a new task is triggered) the task currently running is paused and put at the back of the queue, and the next task in the queue begins running. In this way, all tasks are given equal processing time by the data logger.

9.8.3 Slow Sequences

Priority of a slow sequence (`SlowSequence`) in the data logger will vary, depending upon whether the data logger is executing its program in pipeline mode or sequential mode. With the important exception of measurements, when running in pipeline mode all sequences in the program have the same priority. When running in sequential mode, the main scan has the highest priority for measurements, followed by background calibration (which is automatically run in a slow sequence), then the first slow sequence, the second slow sequence, and so on. The effects of this priority are negligible; however, since, once the tasks begin running, each task is allotted a 1 msec time slice, after which, the next task in the queue runs for 1 msec. The data logger cycles through the queue until all instructions for all sequences are complete.

10. Communications protocols

Data loggers communicate with data logger support software, other Campbell Scientific data loggers, and other hardware and software using a number of protocols including PakBus, Modbus, DNP3, CPI, SPI, and TCP/IP. Several industry-specific protocols are also supported. CAN-bus is supported when using the Campbell Scientific SDM-CAN communications module. See also Communications specifications (p. 219).

Some communications services, such as satellite networks, can be expensive to send and receive information. Best practices for reducing expense include:

- Declare `Public` only those variables that need to be public. Other variables should be declared as `Dim`.
- Be conservative with use of string variables and string variable sizes. Make string variables as big as they need to be and no more. The default size, if not specified, is 24 bytes, but the minimum is 4 bytes. Declare string variables `Public` and sample string variables into data tables only as needed.
- When using `GetVariables()` / `SendVariables()` to send values between data loggers, put the data in an array and use one command to get the multiple values. Using one command to get 10 values from an array and swath of 10 is more efficient (requires only 1 transaction) than using 10 commands to get 10 single values (requires 10 transactions). See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

- Set the data logger to be a PakBus router only as needed. When the data logger is a router, and it connects to another router like ***LoggerNet***, it exchanges routing information with that router and, possibly (depending on your settings), with other routers in the network. Network Planner set this appropriately when it is used. This is also set through the **IsRouter** setting in the Settings Editor. For more information, see the Device Configuration **Settings Editor** Information tables and settings (advanced) (p. 178).
- Set PakBus beacons and verify intervals properly. For example, there is no need to verify routes every five minutes if communications are expected only every 6 hours. Network Planner will set this appropriately when it is used. This is also set through the **Beacon** and **Verify** settings in the **Settings Editor**. For more information, see the Device Configuration **Settings Editor** Beacon() and Verify() settings.

For information on Designing a PakBus network using the Network Planner tool in ***LoggerNet***, watch the following video: https://www.campbellsci.com/videos/loggernet-software-network-planner.

10.1 General serial communications

The data logger supports two-way serial communications. These communications ports can be used with smart sensors that deliver measurement data through serial-data protocols, or with devices such as modems, that communicate using serial data protocols.

CRBasic instructions for general serial communications include:

- `SerialOpen()`
- `SerialClose()`
- `SerialIn()`
- `SerialInRecord()`
- `SerialInBlock()`
- `SerialInChk()`
- `SerialOut()`
- `SerialOutBlock()`
- `SerialBrk()`
- `SerialFlush()`

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

To communicate over a serial port, it is important to be familiar with the protocol used by the device with which you will be communicating. Refer to the manual of the sensor or device to find its protocol and then select the appropriate options for each CRBasic parameter. See the application note Interfacing Serial Sensors with Campbell Scientific Dataloggers for more programming details and examples.

Configure **C** terminals as serial ports using ***Device Configuration Utility*** or by using the SerialOpen() CRBasic instruction. Terminals are configured in pairs for TTL, LVTTL, RS-232, and half-duplex RS-422 and RS-485 communications. For full-duplex RS-422 and RS-485, four terminals are required.

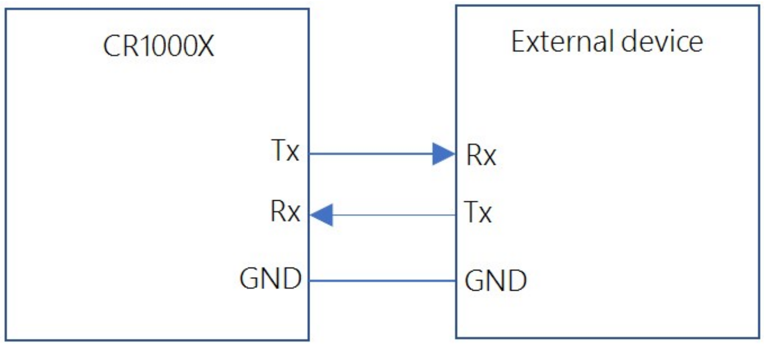


FIGURE 10-1. RS-232 single-ended full-duplex communications

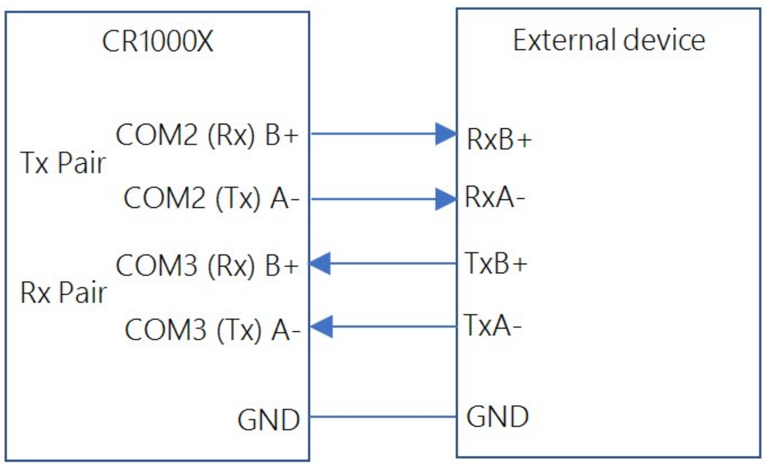


FIGURE 10-2. RS-485/RS-422 differential-pair full-duplex communications

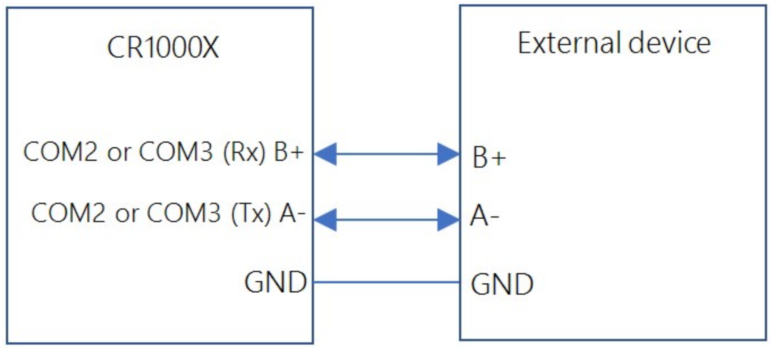


FIGURE 10-3. RS-485 differential-pair half-duplex communications

10.1.1 RS-232

RS-232 supports point-to-point communications between one base (usually the data logger) and one external device. See FIGURE 10-1 (p. 81). Data bits are sent from the base to external devices across the transmit (Tx) line with respect to DC ground. The Tx line idle state is between –25 V and –3 V, depending on the transmitter. The transition from negative voltage to above 3 V begins data transmission.

> **NOTE:**
> Most RS-232 devices are also compatible with the data logger using TTL-inverted communications.

> **NOTE:**
> The data logger uses about -7 V to represent logic 1, and about 5.8 V to represent logic 0.

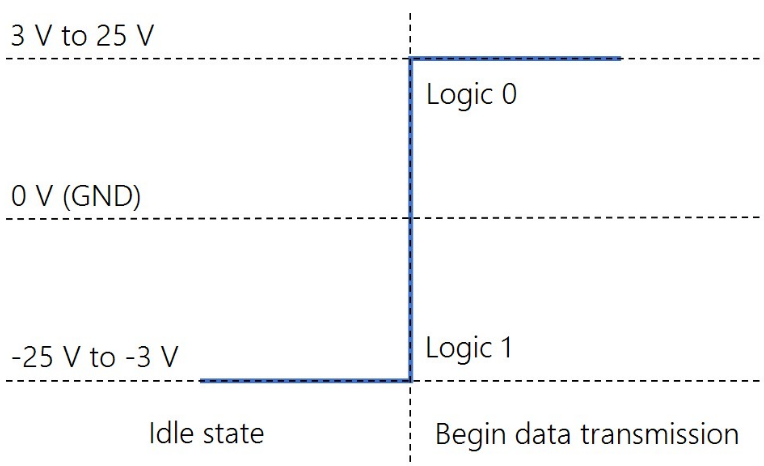


FIGURE 10-4. RS-232 Tx voltage with respect to GND

10.1.2 RS-485

RS-485 supports communications between 32 base and 32 external devices. See FIGURE 10-3 (p. 82) and FIGURE 10-2 (p. 81). Differential voltage between two lines (A & B) transmit data. When the voltage of B with respect to A is between -0.2 V and -6 V that is interpreted as logic 0. When the differential voltage in the range of positive 0.2 V to 6 V that is interpreted as logic 1.

> **NOTE:**
> The CR1000X uses about -1 V to represent logic 0, and about 1 V to represent logic 1.

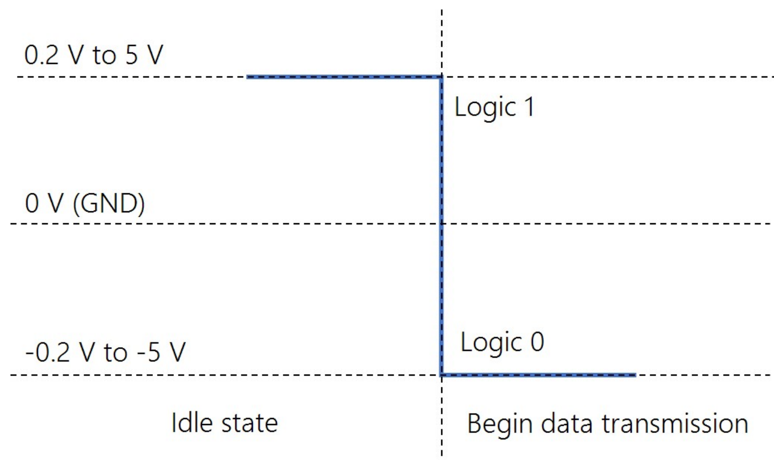


FIGURE 10-5. RS-485 Voltage B with respect to A

10.1.3 RS-422

RS-422 communications protocol is similar to RS-485. The difference is that RS-422 ranges from -6 V to 6 V instead of -5 V to 5 V. Also, RS-422 only supports communications from 1 base to 10 external devices, but not return communications from all 10 external devices. In full-duplex point-to-point (1 base, 1 external) RS-422 communications, both devices can transmit and receive. Half-duplex can be used in cases where sensors broadcast data to a receiving data logger. See FIGURE 10-3 (p. 82) and FIGURE 10-2 (p. 81).

> **NOTE:**
> Use the RS-485 communications type when setting up the data logger for RS-422 communications. Most RS-422 sensors will work with RS-485 protocol.

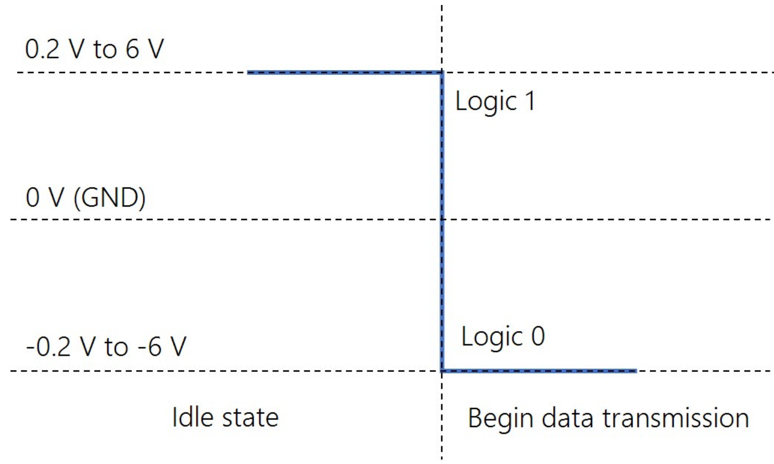


FIGURE 10-6. RS-422 Voltage B with respect to A

10.1.4 TTL

TTL supports point-to-point communications between one base and one external device. See FIGURE 10-1 (p. 81). Data bits are sent from base to external device with a voltage between transmit (Tx) and ground. The transmit line idle state is 5 V (logic 1). Data is sent after one clock cycle once the voltage is pulled low (to 0 V).

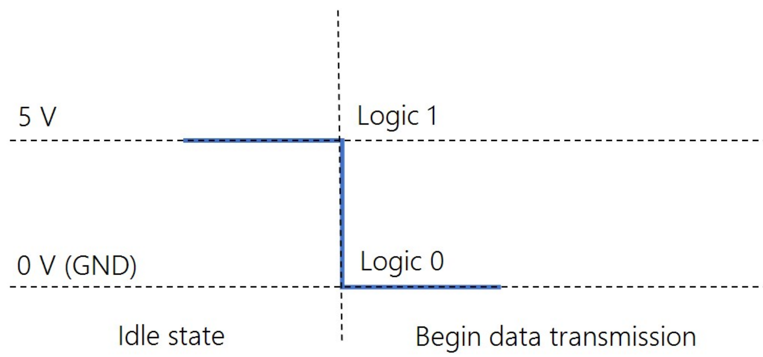


FIGURE 10-7. TTL Tx voltage with respect to GND

10.1.5 LVTTL

The only difference between low-voltage TTL (LVTTL) and TTL is that the voltage range is 0 V to 3.3 V. See FIGURE 10-1 (p. 81).

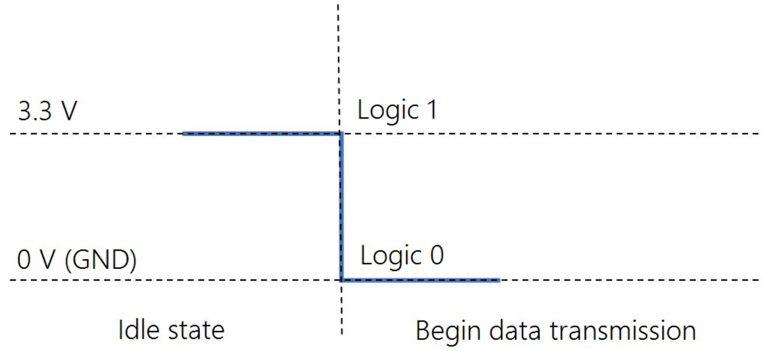


FIGURE 10-8. LVTTL Tx voltage with respect to GND

10.1.6 TTL-Inverted

The only difference between TTL-inverted and TTL is that the logic is inverted. The idle state for TTL-inverted is 0 V instead of 5 V. See FIGURE 10-1 (p. 81). Data is sent after the voltage is pulled high (to 5 V).

NOTE:
Many RS-232 devices are compatible with this communications protocol.

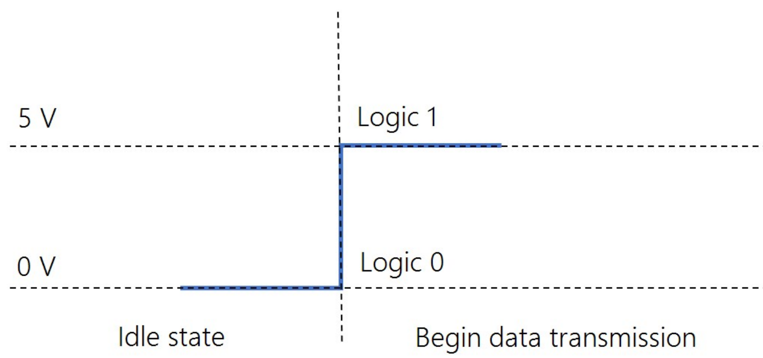


FIGURE 10-9. TTL-inverted Tx voltage with respect to GND

10.1.7 LVTTL-Inverted

The only difference between LVTTL-inverted and TTL-inverted is that the voltage range is 0 V to 3.3 V. See FIGURE 10-1 (p. 81).

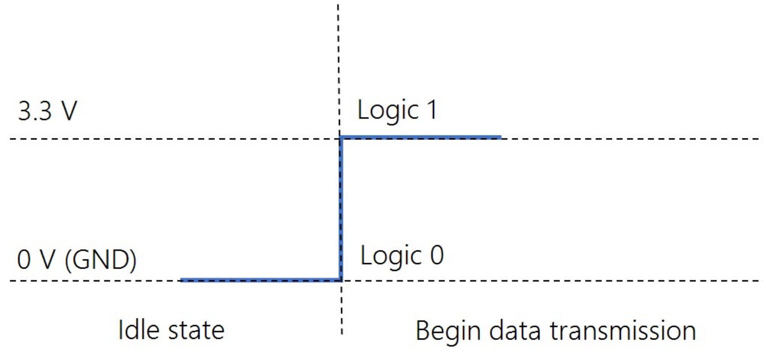


FIGURE 10-10. LVTTL-inverted Tx voltage with respect to GND

10.2 Modbus communications

The data logger supports Modbus RTU, Modbus ASCII, and Modbus TCP protocols and can be programmed as a Modbus client (master) or Modbus server (slave). These protocols are often used in SCADA networks. Data loggers can communicate using Modbus on all available communications ports. The data logger supports RTU and ASCII communications modes on RS-232 and RS-485 connections.

CRBasic Modbus instructions include:

- `ModbusClient()`
- `ModbusServer()`
- `MoveBytes()`

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

For additional information on Modbus, see:

- About Modbus (p. 87)
- Why Modbus Matters: An Introduction
- How to Access Live Measurement Data Using Modbus
- Using Campbell Scientific Dataloggers as Modbus Slave Devices in a SCADA Network

Because Modbus has a set command structure, programming the data logger to get data from field instruments can be much simpler than from some other serial sensors. Because Modbus uses a common bus and addresses each node, field instruments are effectively multiplexed to a data logger without additional hardware.

When doing Modbus communications over RS-232, the data logger, through ***Device Configuration Utility*** or the **Settings** editor, can be set to keep communications ports open and awake, but at higher power usage. Set **RS-232Power** to **Always on**. Otherwise, the data logger goes into sleep mode after 40 seconds of communications inactivity. Once asleep, two packets are required before it will respond. The first packet awakens the data logger; the second packet is received as data. This would make a Modbus client fail to poll the data logger, if not using retries.

More information on Modbus can be found at:

- www.simplyModbus.ca/FAQ.htm
- www.Modbus.org/tech.php
- www.lammertbies.nl/comm/info/modbus.html

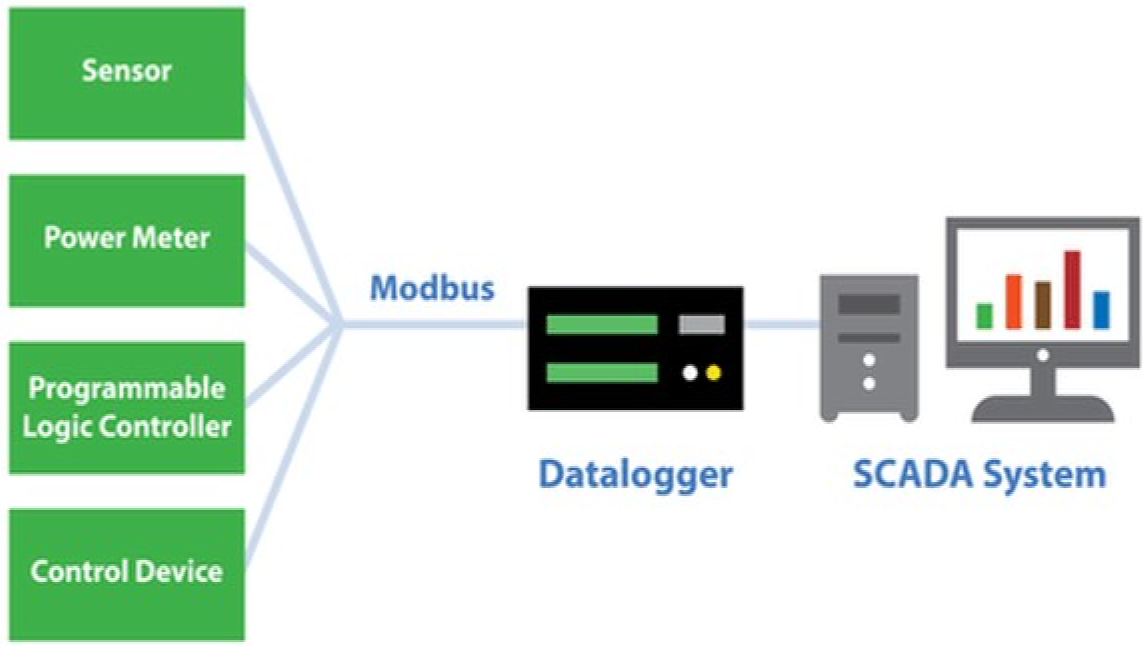
10.2.1 About Modbus

Modbus is a communications protocol that enables communications among many devices connected to the same network. Modbus is often used in supervisory control and data acquisition (SCADA) systems to connect remote terminal units (RTUs) with a supervisory computer - allowing them to relay measurement data, device status, control commands, and configuration information.

The popularity of Modbus has grown because it is freely available and because its messaging structure is independent of the type of physical interface or connection that is used. Modbus can coexist with other types of connections on the same physical interface at the same time. You can operate the protocol over several data links and physical layers.

Modbus is supported by many industrial devices, including those offered by Campbell Scientific. Not only can intelligent devices such as microcontrollers and programmable logic controllers (PLCs) communicate using Modbus, but many intelligent sensors have a Modbus interface that enables them to send their data to host systems. Examples of using Modbus with Campbell Scientific data loggers include:

- Interfacing data loggers and Modbus-enabled sensors.
- Sending and retrieving data between data loggers and other industrial devices.
- Delivering environmental data to SCADA systems.
- Integrating Modbus data into PakBus networks, or PakBus data into Modbus networks.



10.2.2 Modbus protocols

There are three standard variants of Modbus protocols:

- **Modbus RTU** — Modbus RTU is the most common implementation available for Modbus. Used in serial communications, data is transmitted in a binary format. The RTU format follows the commands/data with a cyclic redundancy check checksum.

  > NOTE:
  > The Modbus RTU protocol standard does not allow a delay between characters of 1.5 times or more the length of time normally required to receive a character. This is analogous to “pizza” being understood, and “piz za” being gibberish. It's important to note that communications hardware used for Modbus RTU, such as radios, must transfer data as entire packets without injecting delays in the middle of Modbus messages.

- **Modbus ASCII** — Used in serial communications, data is transmitted as an ASCII representation of the hexadecimal values. Timing requirements are loosened, and a simpler longitudinal redundancy check checksum is used.
- **Modbus TCP/IP or Modbus TCP** — Used for communications over TCP/IP networks. The TCP/IP format does not require a checksum calculation, as lower layers already provide

checksum protection. The packet structure is similar to RTU, but uses a different header. Devices labeled as Modbus gateways will convert from Modbus TCP to Modbus RTU.

Campbell Scientific data loggers support Modbus RTU, Modbus ASCII, and Modbus TCP protocols. If the connection is over IP, Campbell Scientific data loggers always use Modbus TCP. Modbus server functionality over other comports use RTU. When acting as a client, the data logger can be switched between ASCII and RTU protocols using an option in the `ModbusClient()` instruction. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

10.2.3 Understanding Modbus Terminology

Many of the object types are named from using Modbus in driving relays: a single-bit physical output is called a coil, and a single-bit physical input is called a discrete input or a contact.

Information is stored in the server device in up to four different tables. Two tables store on/off discrete values (coils) and two store numerical values (registers). The coils and registers each have a read-only table and read/write table.

10.2.4 Connecting Modbus devices

Data loggers can communicate with Modbus on all available communications ports. Consideration should be given to proper surge protection of any cabled connection. Between systems of significantly different ground potential, optical isolation may be appropriate. For additional information on grounds, see Grounds (p. 13).

The common serial interface used for Modbus RTU connections is RS-485 half-duplex, or two-wire RS-485. This connection uses one differential pair for data, and another wire for a signal ground. When twisted pair cable is used, the signal can travel long distances. Resistors are often used to reduce noise. Bias resistors are used to give a clean default state on the signal lines. For long cable lengths, termination resistors, which are usually 120 ohms, are needed to stop data corruption due to reflections. Signal grounds are terminated to earth ground with resistors to prevent ground loops, but allow a common mode signal. The resistors to ground are usually integral to the equipment. The resistive ground is labeled as **RG** on Campbell Scientific equipment.

10.2.5 Modbus client-server protocol

Modbus is a client-server protocol. The device requesting the information is called the Modbus client, and the devices supplying information are Modbus servers. In a standard Modbus network, there is one client and up to 247 servers. A client does not have a Modbus address. However, each Modbus server on a shared network has a unique address from 1 to 247.

A single Modbus client device initiates commands (requests for information), sending them to one or more Modbus server devices on the same network. Only the Modbus client can initiate communications. Modbus servers, in turn, remain silent, communicating only when responding to requests from the Modbus client.

Every message from the client will begin with the server address, followed by the function code, function parameters, and a checksum. The server will respond with a message beginning with its address, followed by the function code, data, and a checksum. The amount of data in the packet will vary, depending on the command sent to the server. Server devices only process one command at a time. So, the client needs to wait for a response, or timeout before sending the next command.

A broadcast address is specified to allow simultaneous communications with all servers. Because response time of server devices is not specified by the standard, and device manufacturers also rarely specify a maximum response time, broadcast features are rarely used. When implementing a system, timeouts in the client will need to be adjusted to account for the observed response time of the servers.

Campbell Scientific data loggers can be programmed to be a Modbus client or Modbus server - or even both at the same time! This proves particularly helpful when your data logger is a part of two wider area networks. In one it uses Modbus to query data (as a client) from localized sensors or other data sources, and then in the other, it serves that data up (as a server) to another Modbus client.

10.2.6 About Modbus programming

Modbus capability of the data logger must be enabled through configuration or programming. See the ***CRBasic Editor*** help for detailed information on program structure, syntax, and each instruction available to the data logger.

CRBasic Modbus instructions include:

- `ModbusClient()`
- `ModbusServer()`
- `MoveBytes()`

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

10.2.6.1 Endianness

Endianness refers to the sequential order in which bytes are arranged into larger numerical values when stored in memory. Words may be represented in big-endian or little-endian format, depending on whether bits or bytes or other components are ordered from the big end (most significant bit) or the little end (least significant bit).

In big-endian format, the byte containing the most significant bit is stored first, then the following bytes are stored in decreasing significance order, with the byte containing the least significant bit stored last. Little-endian format reverses this order: the sequence stores the least significant byte first and the most significant byte last. Endianness is used in some Modbus programming so it is important to note that the CR1000X is a big-endian instrument.

10.2.6.2 Function codes

A function code tells the server which storage entity to access and whether to read from or write to that entity. Different devices support different functions (consult the device documentation for support information). The most commonly used functions (codes 01, 02, 03, 04, 05, 15, and 16) are supported by Campbell Scientific data loggers.

Most users only require the read- register functions. Holding registers are read with function code **03**. Input registers are read with function code **04**. This can be confusing, because holding registers are usually listed with an offset of 40,000 and input registers with an offset of 30,000. Don’t mix up the function codes. Double check the register type in the device documentation.

Function Code	Action	Entity
01 (01 hex)	Read	Discrete Output Coils
05 (05 hex)	Write single	Discrete Output Coil
15 (0F hex)	Write multiple	Discrete Output Coils
02 (02 hex)	Read	Discrete Input
04 (04 hex)	Read	Input Registers
03 (03 hex)	Read	Holding Registers
06 (06 hex)	Write single	Holding Register
16 (10 hex)	Write multiple	Holding Registers

The write-register functions will only work on holding registers. Function **06** only changes one 16-bit register, whereas function 16, changes multiple registers. Note, when writing registers, the `Variable` parameter for the `ModbusClient()` instruction refers to a source, not a destination.

10.2.7 Modbus information storage

With the Modbus protocol, most of the data values you want to transmit or receive are stored in registers. Information is stored in the server device in four different entities. Two store on/off discrete values (coils) and two store numerical values (registers). The four entities include:

- Coils – 1-bit registers, used to control discrete outputs (including Boolean values), read/write.
- Discrete Input – 1-bit registers, used as inputs, read only.
- Input Registers – 16-bit registers, used as inputs, read only.
- Holding Registers – 16-bit registers; used for inputs, output, configuration data, or any requirement for "holding" data; read/write.

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

10.2.7.1 Registers

In a 16-bit memory location, a 4-byte value takes up two registers. The Modbus protocol always refers to data registers with a starting address number, and a length to indicate how many registers to transfer.

Campbell Scientific uses 1-based numbering (a common convention for numbering registers in equipment) in the `ModbusClient()` instruction. With 1-based numbering, the first data location is referred to as register number 1. Some equipment uses 0-based numbering (check the equipment documentation). With 0-based numbering, the first register is referred to as 0.

Reading register numbers can be complicated by the fact that register numbers are often written with an offset added. Input registers are written with an offset of 30000. So, the first input register is written as 30001, with 1-based numbering. Holding registers are numbered with an offset of 40000. You must remove the offset before writing the number as the `Start` parameter of `ModbusClient()`.

There are rare instances when equipment is designed with the registers mapped including the offset. That means 40001 in the documentation is really register number 40001. Those are rare instances, and the equipment is deviating from standards. If 1 or 2 don't work for the Start parameter, try 40001 and 40002.

10.2.7.2 Coils

Discrete digital I/O channels in Modbus are referred to as coils. The term coil has its roots in digital outputs operating solenoid coils in an industrial environment. Coils may be read only or read/write. A read only coil would be a digital input. A read/write coil is used as an output. Coils are read and manipulated with their own function codes, apart from the registers. Many modern devices do not use coils at all.

When working with coils, the data logger requires Boolean variables. When reading coils, each Boolean in an array will hold the state of one coil. A value of **True** will set the coil, a value of **False** will unset the coil.

10.2.7.3 Data Types

Modbus does not restrict what data types may be contained within holding and input registers. Equipment manufacturers need to indicate what binary data types they are using to store data. Registers are 16-bit, so 32-bit data types use 2 registers each. Some devices combine more registers together to support longer data types like strings. The `ModbusClient()` instruction has a `ModbusOption` parameter that supports several different data types.

When data types use more than 1 register per value, the register order within the data value is important. Some devices will swap the high and low bytes between registers. You can compensate for this by selecting the appropriate `ModbusOption`.

Byte order is also important when communicating data over Modbus. Big Endian byte order is the reverse of Little Endian byte order. It may not always be apparent which a device uses. If you receive garbled data, try reversing the byte order. Reversing byte order is done using the `MoveBytes()` instruction. There is an example in CRBasic help for reversing the bytes order of a 32-bit variable.

After properly reading in a value from a Modbus device, you might have to convert the value to proper engineering units. With integer data types, it is common to have the value transmitted in hundredths or thousandths.

Unsigned 16-bit integer

The most basic data type used with Modbus is unsigned 16-bit integers. It is the original Modbus data type with 1 register per value. On the data logger, declare your destination variable as type **Long**. A **Long** is a 32-bit signed integer that contains the value received. Select the appropriate `ModbusOption` to avoid post-processing.

Signed 16-bit integer

Signed 16-bit integers use 1 register per value. On the data logger, declare your destination variable as type **Long**. A **Long** is a 32-bit signed integer that contains the value received . Select the appropriate `ModbusOption` to avoid post-processing.

Signed 32-bit integer

Signed 32-bit integers require two registers per value. This data type corresponds to the native **Long** variable type in Campbell data loggers. Declare your variables as type **Long** before using them as the Variable parameter in `ModbusClient()`. Select the appropriate `ModbusOption` to avoid post-processing.

Unsigned 32-bit integer

Unsigned 32-bit integers require two registers per value. Declare your variables as type **Long** before using them as the `Variable` parameter in `ModbusClient()`. The **Long** data type is a signed integer, and does not have a range equal to that of an unsigned integer. If the integer value exceeds 2,147,483,647 it will display incorrectly as a negative number. If the value does not exceed that number, there are no issues with a variable of type **Long** holding it.

32-Bit floating point

32-bit floating point values use 2 registers each. This is the default FLOAT data type in Campbell Scientific data loggers. Select the appropriate `ModbusOption` to avoid post-processing.

10.2.8 Modbus tips and troubleshooting

Most of the difficulties with Modbus communications arise from deviations from the standards, which are not enforced within Modbus. Whether you are connecting via Modbus to a solar inverter, power meter, or flow meter, the information provided here can help you overcome the challenges, and successfully gather data into a Campbell data logger. Further information on Modbus can be found at:

- www.simplyModbus.ca/FAQ.htm
- www.Modbus.org/tech.php
- www.lammertbies.nl/comm/info/modbus.html

10.2.8.1 Error codes

Modbus defines several error codes, which are reported back to a client from a server. `ModbusClient()` displays these codes as a negative number. A positive result code indicates no response was received.

Result code -01: illegal function

The illegal function error is reported back by a Modbus server when either it does not support the function at all, or does not support that function code on the requested registers. Different devices support different functions (consult the device documentation). If the function code is supported, make sure you are not trying to write to a register labeled as read-only. It is common for devices to have holding registers where read-only and read/write registers are mapped next to each other.

An uncommon cause for the **-01** result is a device with an incomplete implementation of Modbus. Some devices do not fully implement parsing Modbus commands. Instead, they are hardcoded to respond to certain Modbus messages. The result is that the device will report an error when you try selectively polling registers. Try requesting all of the registers together.

Result code -02: illegal data address

The illegal data address error occurs if the server rejects the combination of starting register and length used. One possibility, is a mistake in your program on the starting register number. Refer to the earlier section about register number and consult the device documentation for support information. Also, too long of a length can trigger this error. The `ModbusClient()` instruction uses length as the number of values to poll. With 32-bit data types, it requests twice as many registers as the length.

An uncommon cause for the **-02** result is a device with an incomplete implementation of Modbus. Some devices do not fully implement parsing Modbus commands. Instead, they are hard coded to respond to certain Modbus messages. The result is that the device will report an error when you try selectively polling registers. Try requesting all of the registers together.

Result code -11: COM port error

Result code **-11** occurs when the data logger is unable to open the COM port specified. For serial connections, this error may indicate an invalid COM port number. For Modbus TCP, it indicates a failed socket connection.

If you have a failed socket connection for Modbus TCP, check your `TCPOpen()` instruction. The socket returned from `TCPOpen()` should be a number less than 99. Provided the data logger has a working network connection, further troubleshooting can be done with a computer running Modbus software. Connect the computer to the same network and attempt to open a Modbus TCP connection to the problem server device. Once you resolve the connection between the computer and the server device, the connection from the data logger should work.

10.3 Internet communications

See the Communications specifications (p. 219) for a list of the internet protocols supported by the data logger. The most up-to-date information on implementing these protocols is contained in ***CRBasic Editor*** help.

CRBasic instructions for internet communications include:

- `EmailRelay()`
- `EmailSend()`
- `EmailRecv()`
- `FTPClient()`
- `HTTPGet()`
- `HTTPOut()`
- `HTTPPost()`
- `HTTPPut`
- `IPInfo()`
- `PPPOpen()`
- `PPPClose()`
- `TCPOpen()`
- `TCPClose()`

Once the hardware has been configured, PakBus communications over TCP/IP are possible. These functions include the following:

- Sending programs
- Retrieving programs
- Setting the data logger clock
- Collecting data
- Displaying the current record in a data table

Data logger callback to ***LoggerNet*** and data logger-to-data logger communications are also possible over TCP/IP. For details and example programs see the CRBasic help.

See the FTP streaming technical paper for information on using `FTPClient()` or `HTTPPut()` to stream data.

10.3.1 IP address

When connected to a server with a list of IP addresses available for assignment, the data logger will automatically request and obtain an IP address through DHCP. Once the address is assigned, look in the **Settings Editor: Ethernet | {information box}** to see the assigned IP address.

The CR1000X provides a DNS client that can query a DNS server to determine if an IP address has been mapped to a hostname. If it has, then the hostname can be used interchangeably with the IP address in some data logger instructions.

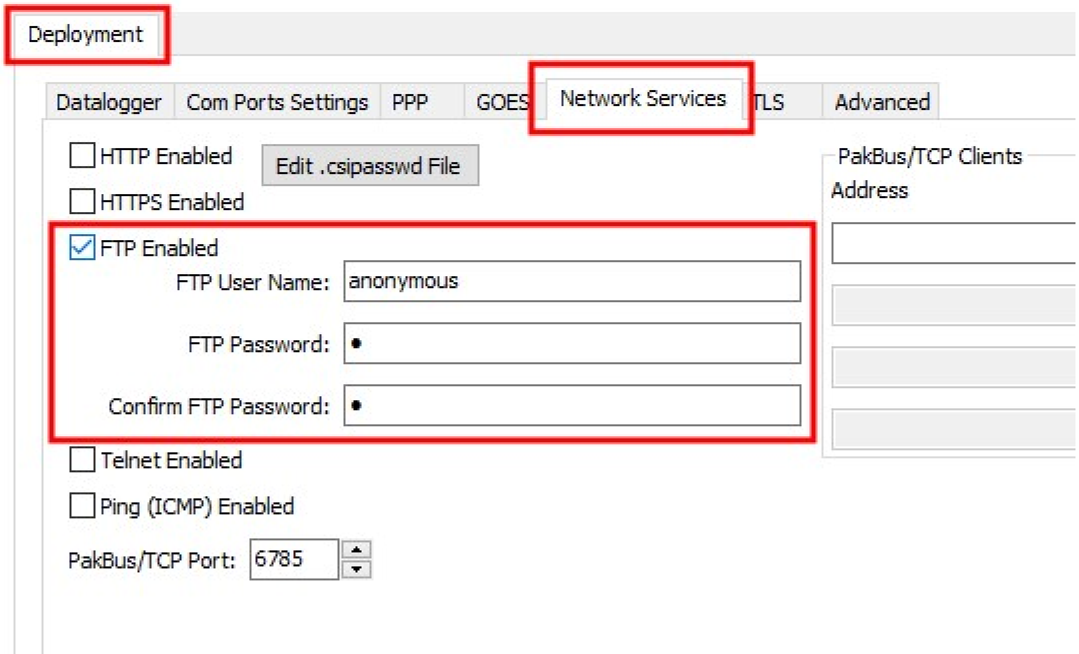
10.3.2 HTTPS server

Use ***Device Configuration Utility*** to configure the data logger to act as an HTTPS server.

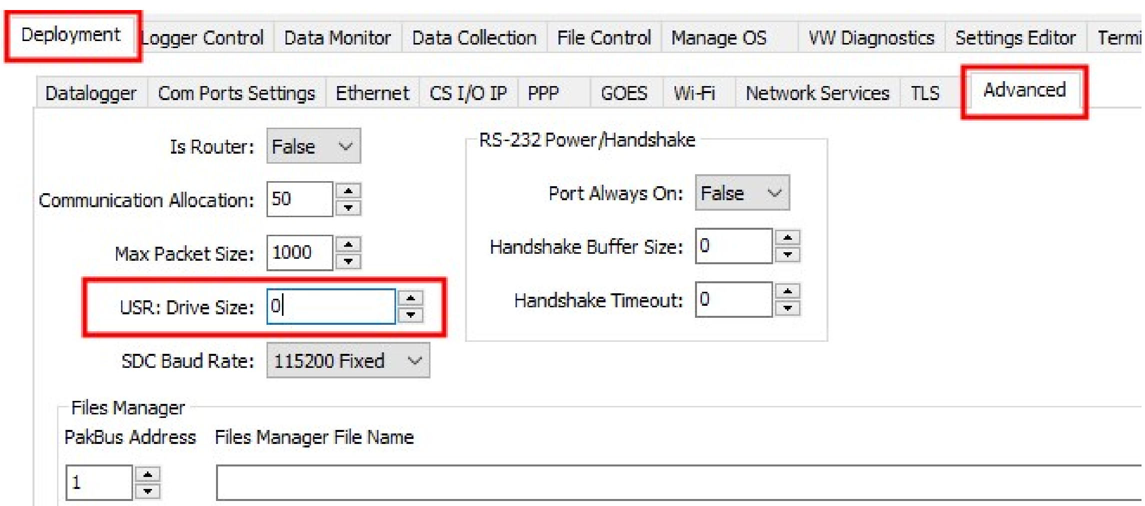
10.3.3 FTP server

An FTP server facilitates file transfers. Use ***Device Configuration Utility*** to configure the data logger to act as an FTP server. This is useful when receiving and storing images from an Ethernet enabled device such as a camera.

Select FTPEnabled (p. 192) and assign a **User Name** and **Password**.



Allocate memory where the received files will be stored. Often this is on the USR drive. Data memory (p. 46)



WARNING:
Partitioning or changing the size of the USR drive will delete stored data from tables. Collect data first.

Specify the memory drive in the path when putting or getting files. For example, to put a file named *image.jpg* on the USR drive, use a command similar to **put image.jpg /USR/image.jpg**.

NOTE:
Use `FTPclient()` to send files to a remote server. This is different than setting up the data logger to act as an FTP server. See the FTP streaming technical paper for more information.

10.4 MQTT

MQTT is an open communications protocol often used in the Internet of Things (IoT). It uses a publish/subscribe architecture to send and receive data. A broker facilitates the communications between publishers and subscribers by receiving published messages and distributing them to subscribers. One advantage of MQTT is that communications are initiated by the CR1000X so firewalls do not cause problems.

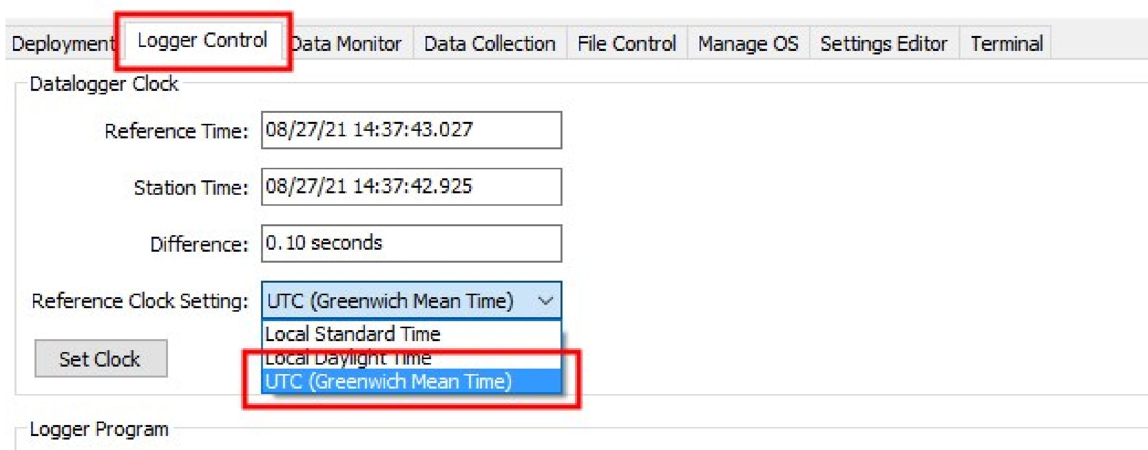
For full MQTT specifications see: https://mqtt.org/.

10.4.1 Sending data to *CAMPBELL CLOUD*

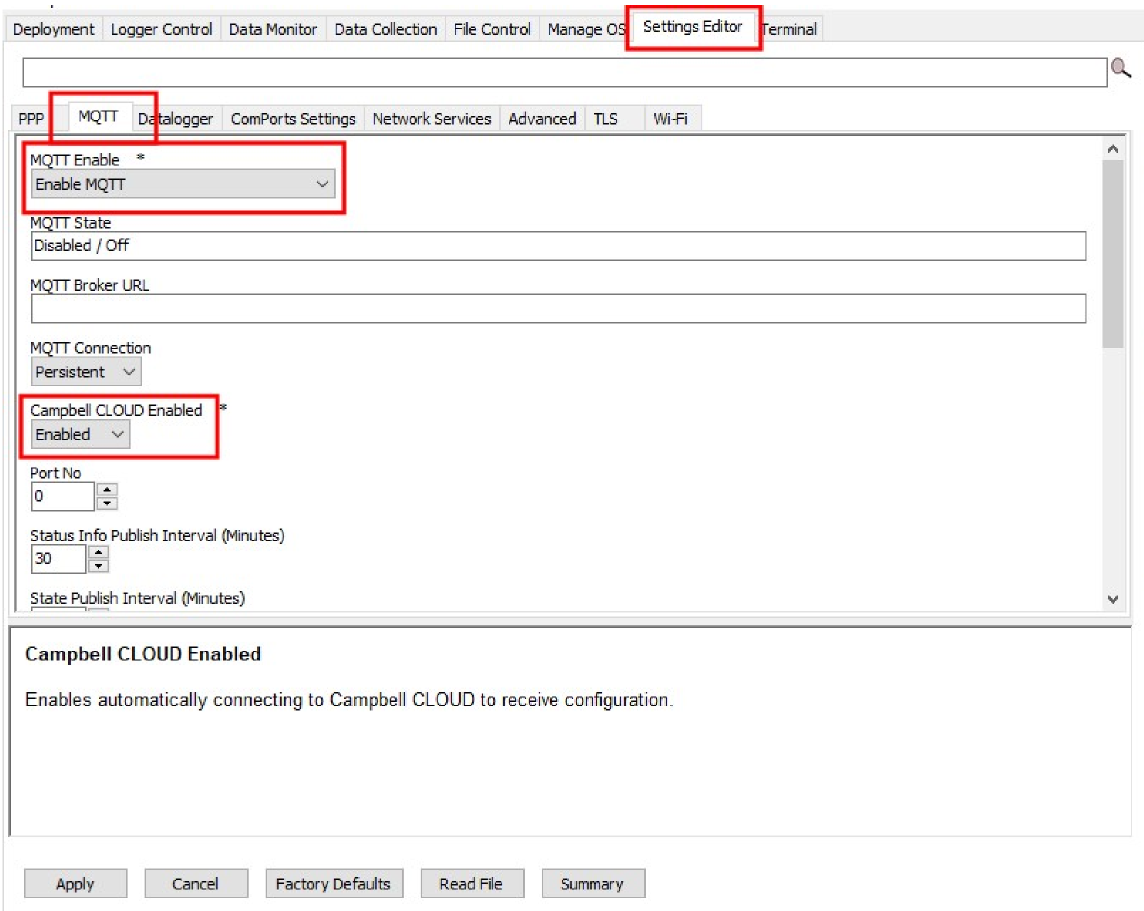
CAMPBELL CLOUD (*CLOUD*), www.campbellsci.com/campbellcloud, is a group of applications, one of which is an MQTT broker. Using MQTT with the CLOUD makes it easy to get your data securely to the web. The CR1000X must have a reliable internet connection.

10.4.1.1 Configure the data logger

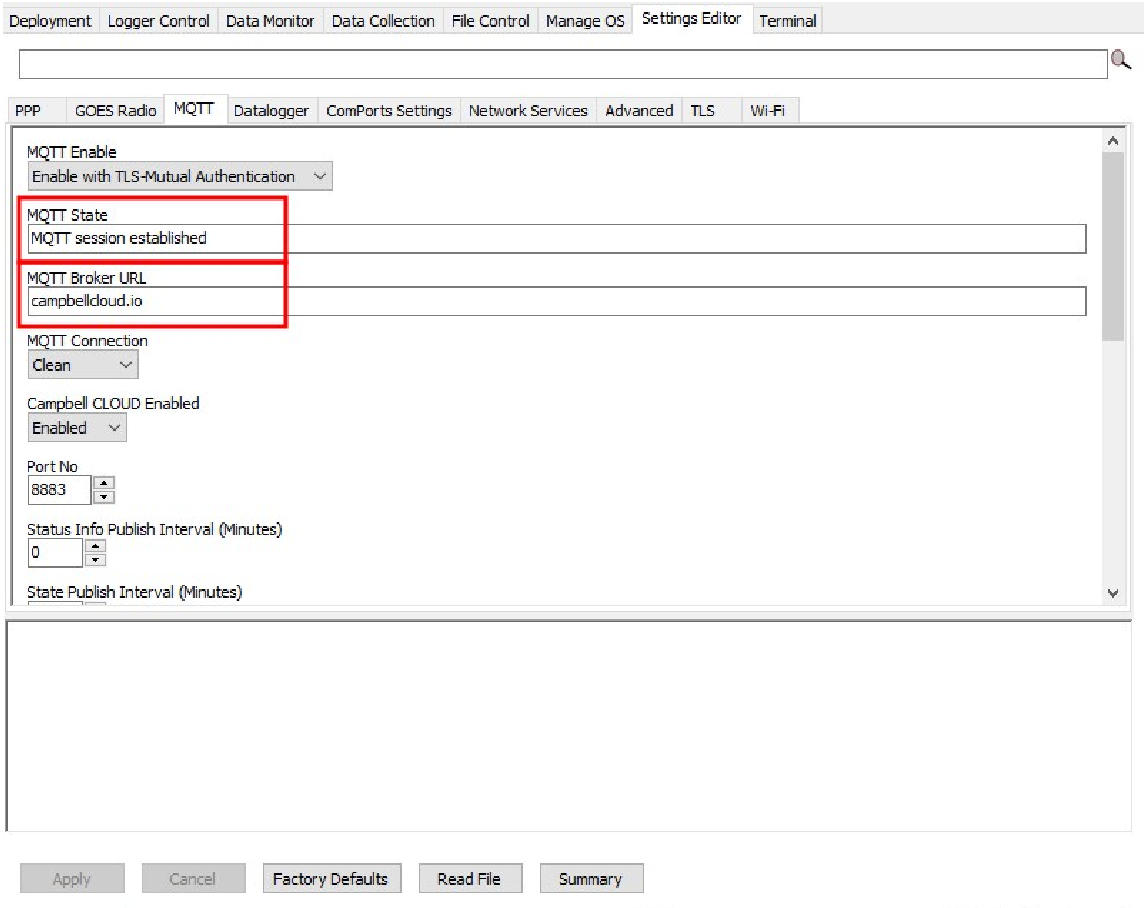
1. Ensure your data logger is connected to the internet.
2. Using ***Device Configuration Utility***, connect to the data logger.
3. (Recommended) On the **Logger Control** tab, set the **Reference Clock Setting** to **UTC** in order to ensure correct timestamps for data ingestion by the ***CLOUD***. Note: the preferred timezone displayed in the ***CLOUD*** may be set in the **CLOUD User Settings**.



4. On the **Settings Editor** tab, click the **MQTT** sub-tab.
5. **Enable MQTT** and set **Campbell Cloud Enabled** to **Enabled**. Keep all other MQTT settings as their defaults. The ***CLOUD*** will automatically change some of these when it connects to the CR1000X.



6. Click **Apply**.
7. Wait while the data logger reboots two times. This may take up to two minutes. If your computer has speakers turned on you may hear two distinct Windows chimes.
8. Confirm that the CR1000X has connected to the MQTT broker by reconnecting in the ***Device Configuration Utility*** and checking the MQTT settings. Several settings will have been populated by the CLOUD broker. The **MQTT State** should read **MQTT session established** and the **MQTT Broker URL** should read **campbellcloud.io**. See MQTT settings (p. 203) for more information.



9. Click **Disconnect** and close ***Device Configuration Utility***.

10.4.1.2 Program the data logger

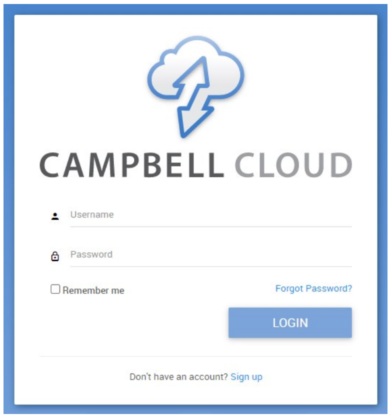
Use `MQTTPublishTable()` within a `DataTable/EndTable` declaration to publish stored data via MQTT. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

```
DataTable(Five_Min,True,-1)
  DataInterval(0,5,Min,10)
    Average(1,Temp_C,FP2,False)
    Minimum(1,BattV,FP2,False,False)
    'Publish every 5 min in GeoJSON format. The last three
    'parameters are optional to specify longitude, latitude,
    'and altitude. Here we use NaN as placeholders for these
    'values.
    MQTTPublishTable(0,0,5,Min,2,NaN,NaN,NaN)
EndTable
```

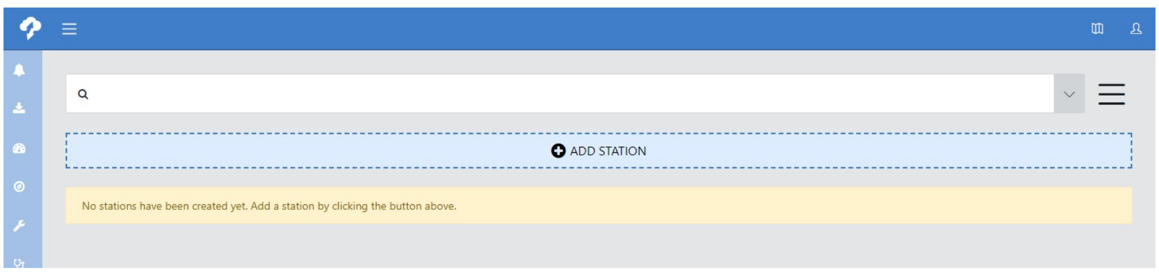
Five minutes is the fastest recommended publishing interval in order to ensure that ingestion and processing of data sent to the ***CLOUD*** are completed before new data is received.

10.4.1.3 Set up the CLOUD

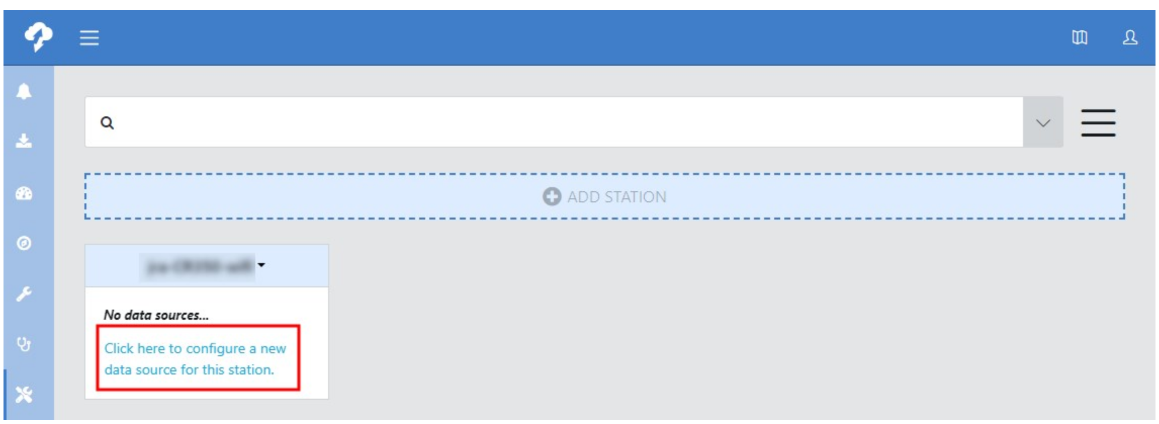
1. Open a web browser and go to www.campbellcloud.io.
2. If you don't already have an account then **Sign up**, otherwise, **LOGIN**.



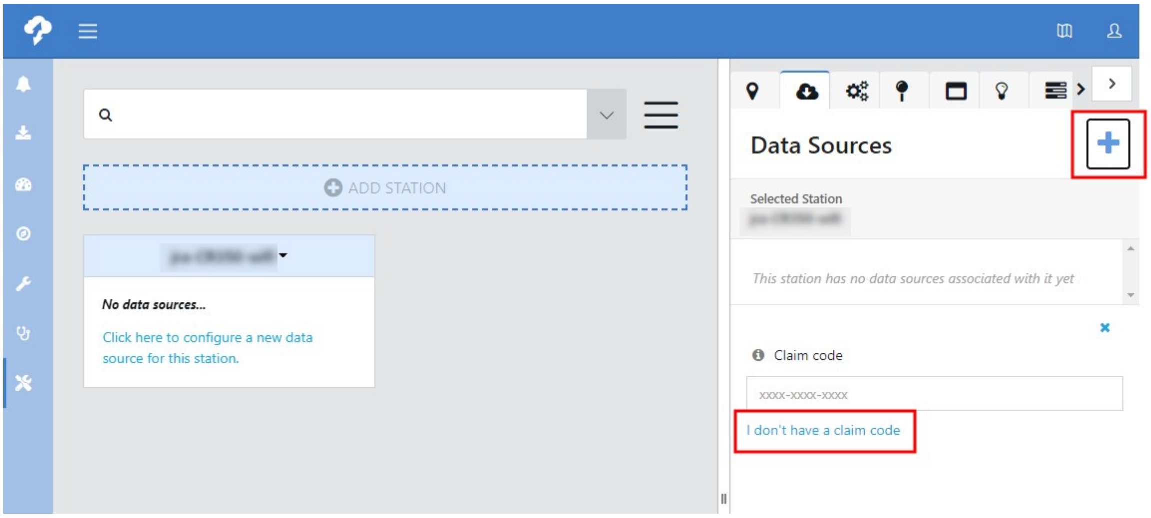
3. Click **ADD STATION**.



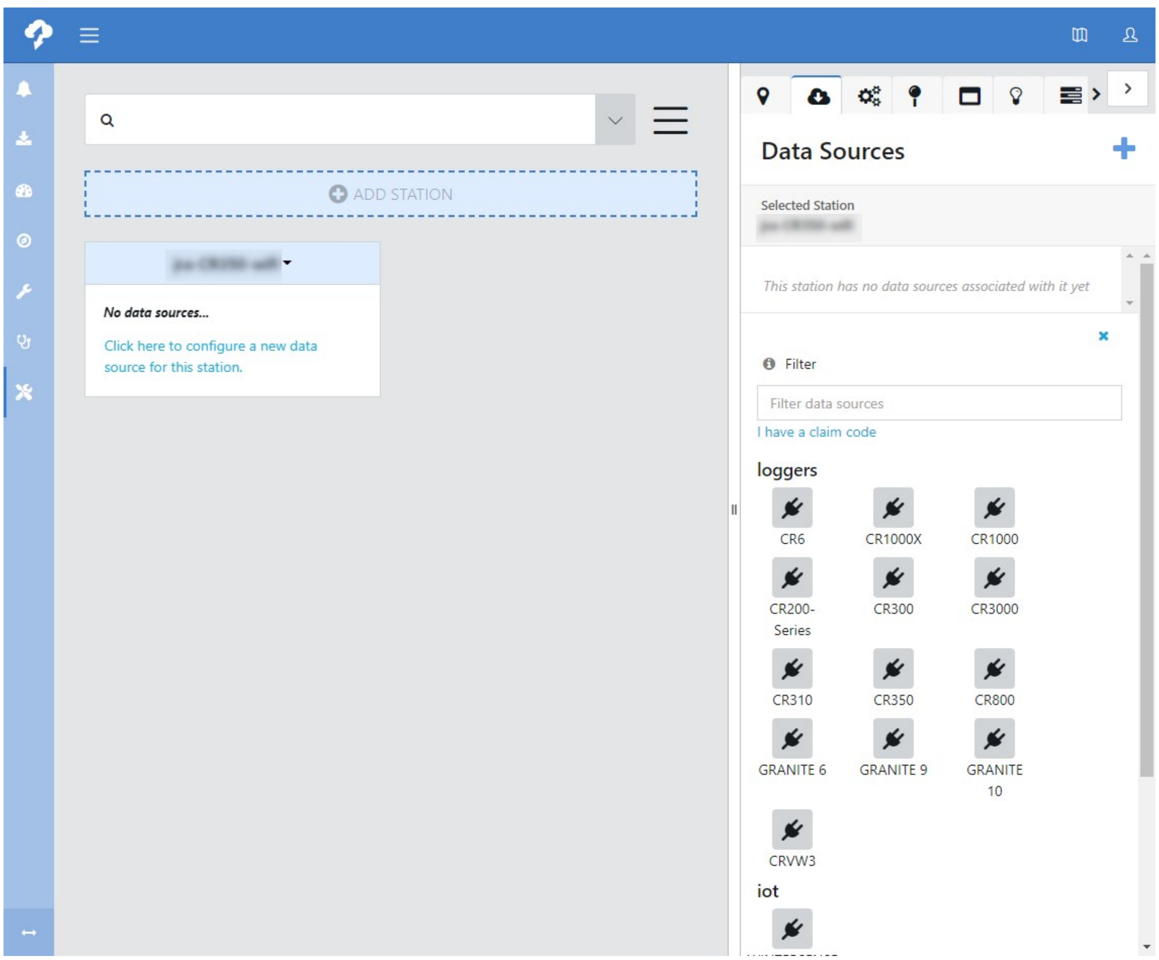
4. Click the Station tile to add a Data Source.



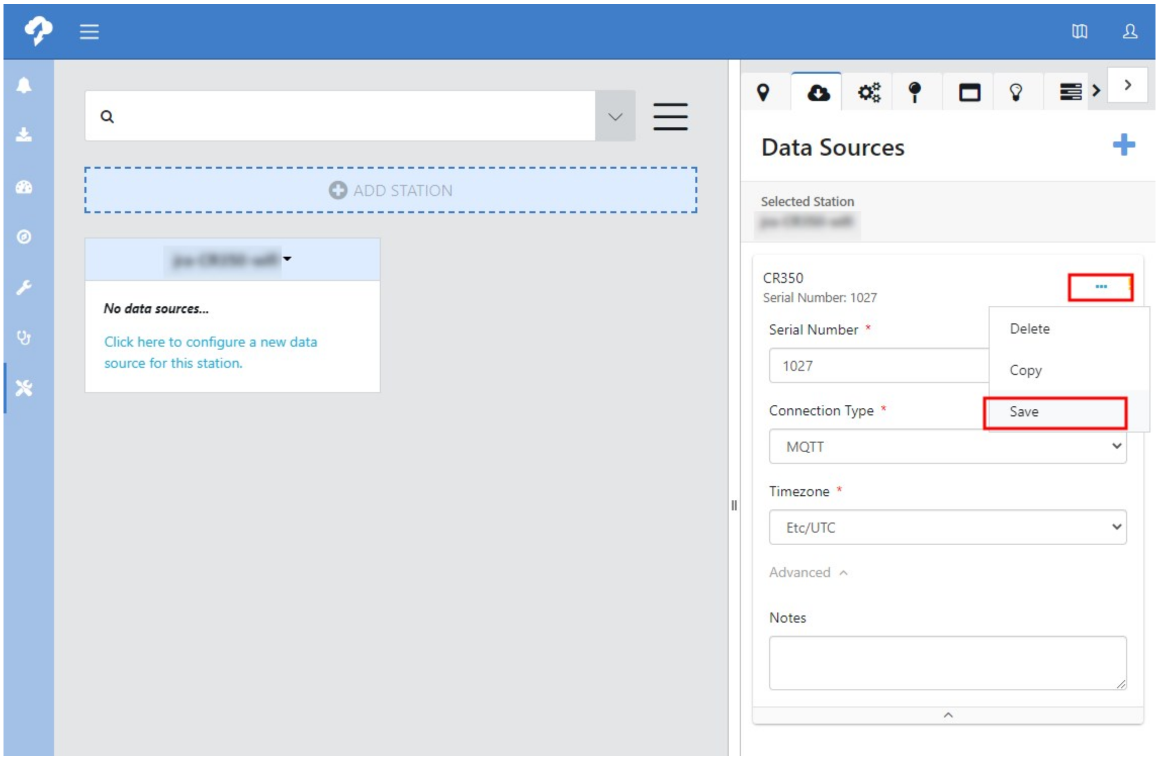
5. Click **+** and **I don't have a claim code**.



6. Select your data logger type.

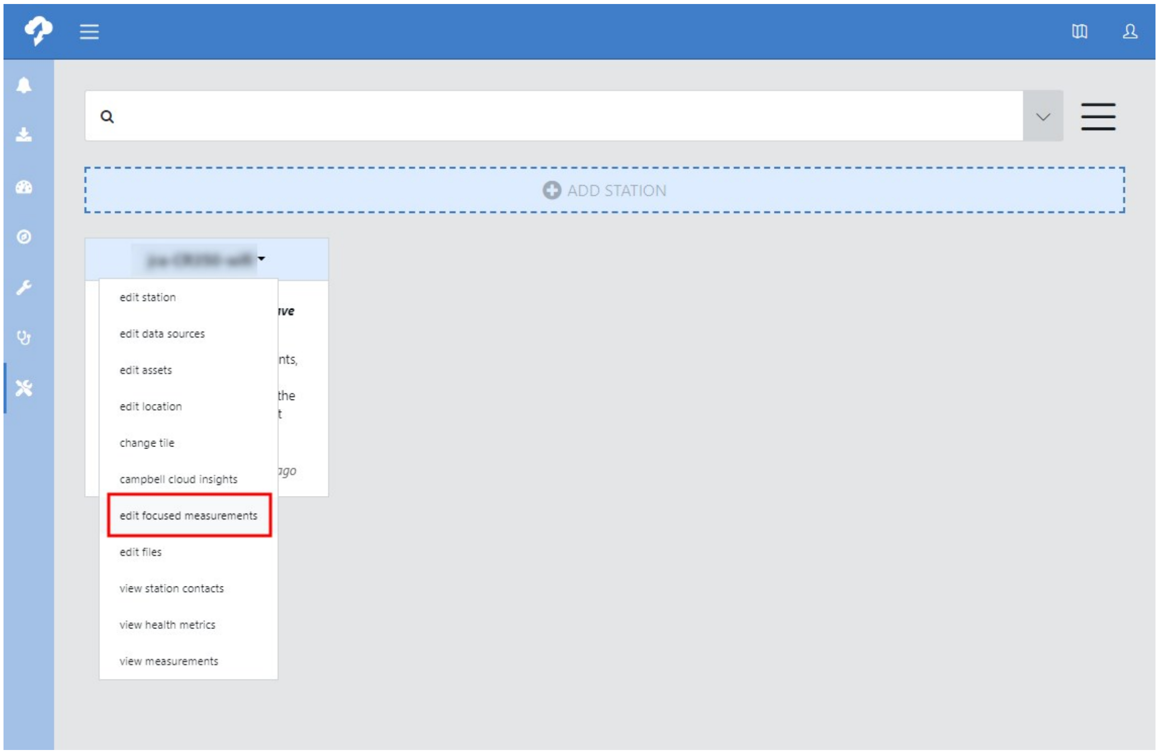


7. Expand the dialog, enter the CR1000X information. Click **...** then **Save**.



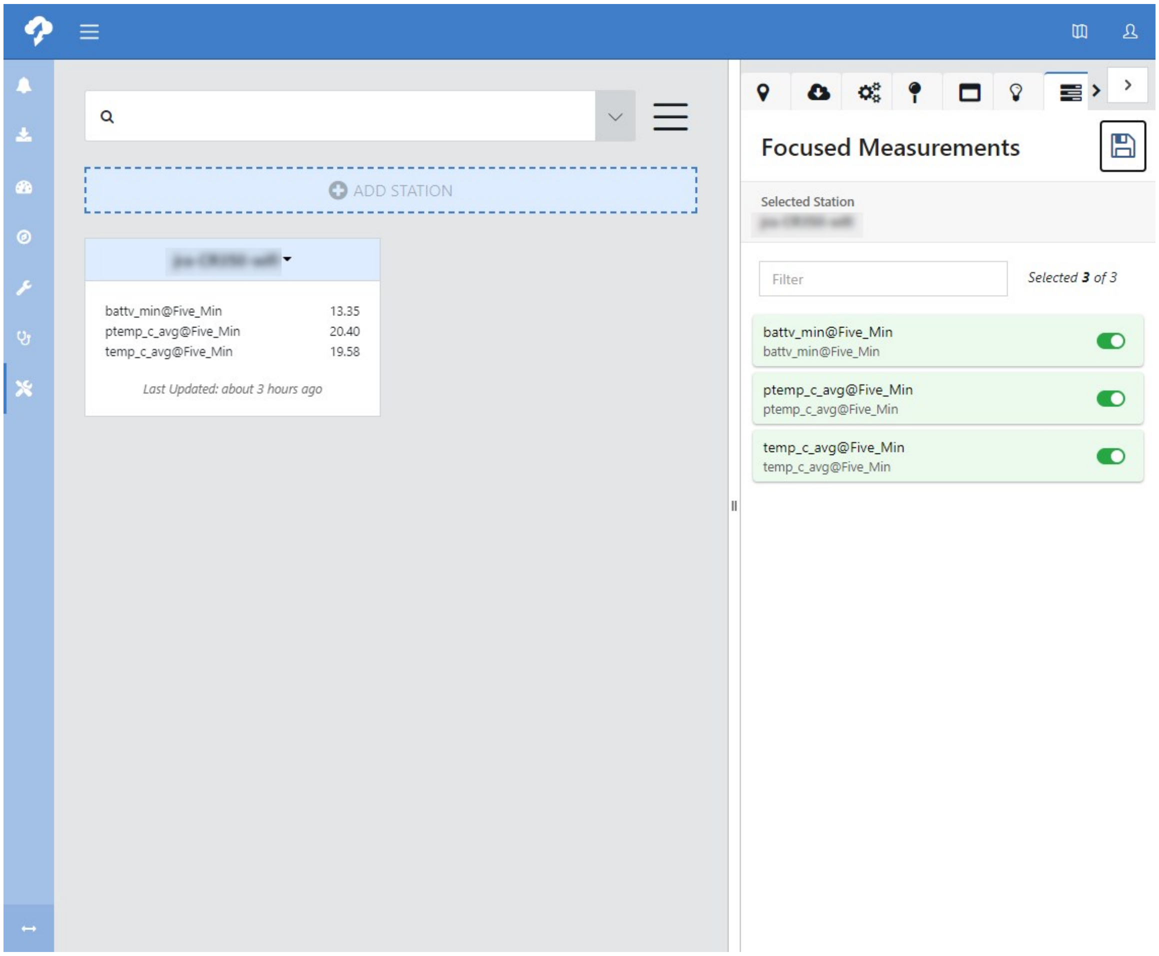
TIP:
The timing of the next step depends on the `MQTTPublishTable()` interval in your *CRBasic* program. Allow at least one interval to elapse before proceeding. In our example, this is five minutes (Program the data logger (p. 100)).

8. Click the Station Name on the Station tile and **edit focused measurements**.



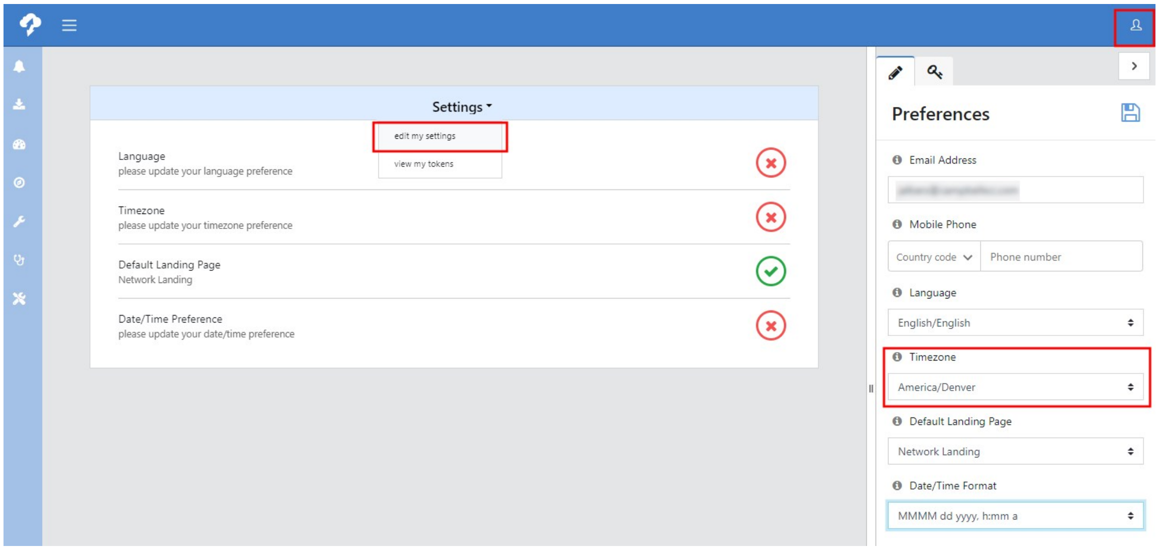
9. Select measurements to appear on the Station tile. Click .

   If a list of measurements is not available and the **MQTT State** in the ***Device Configuration Utility*** read **MQTT session established** please contact support@campbellcloud.io.



> **NOTE:**
> It may take 30 minutes or more, depending on the ***CRBasic*** program, for data to become available.

10. Go to **User settings** > **edit my settings** > **Timezone** to change the timezone that data is displayed, from UTC to your preferred timezone.



11. See the CAMPBELL CLOUD online help and manual for details on additional features.

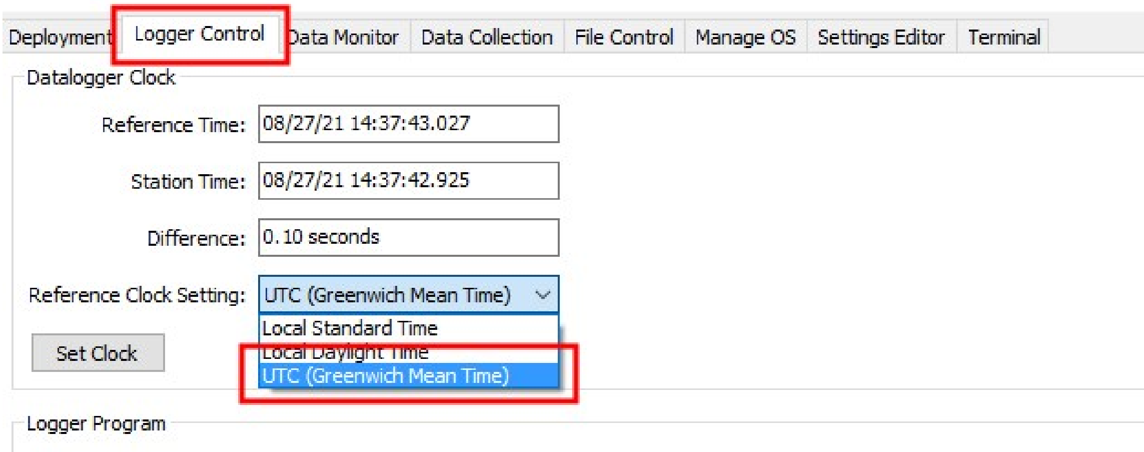
10.4.2 Sending data to another MQTT broker

If you are not using the CAMPBELL CLOUD and its MQTT broker you will need to provide and configure one. There are many available; it is recommended that you consult with an IT professional. This example uses the public Mosquitto test broker https://test.mosquitto.org/ for testing.

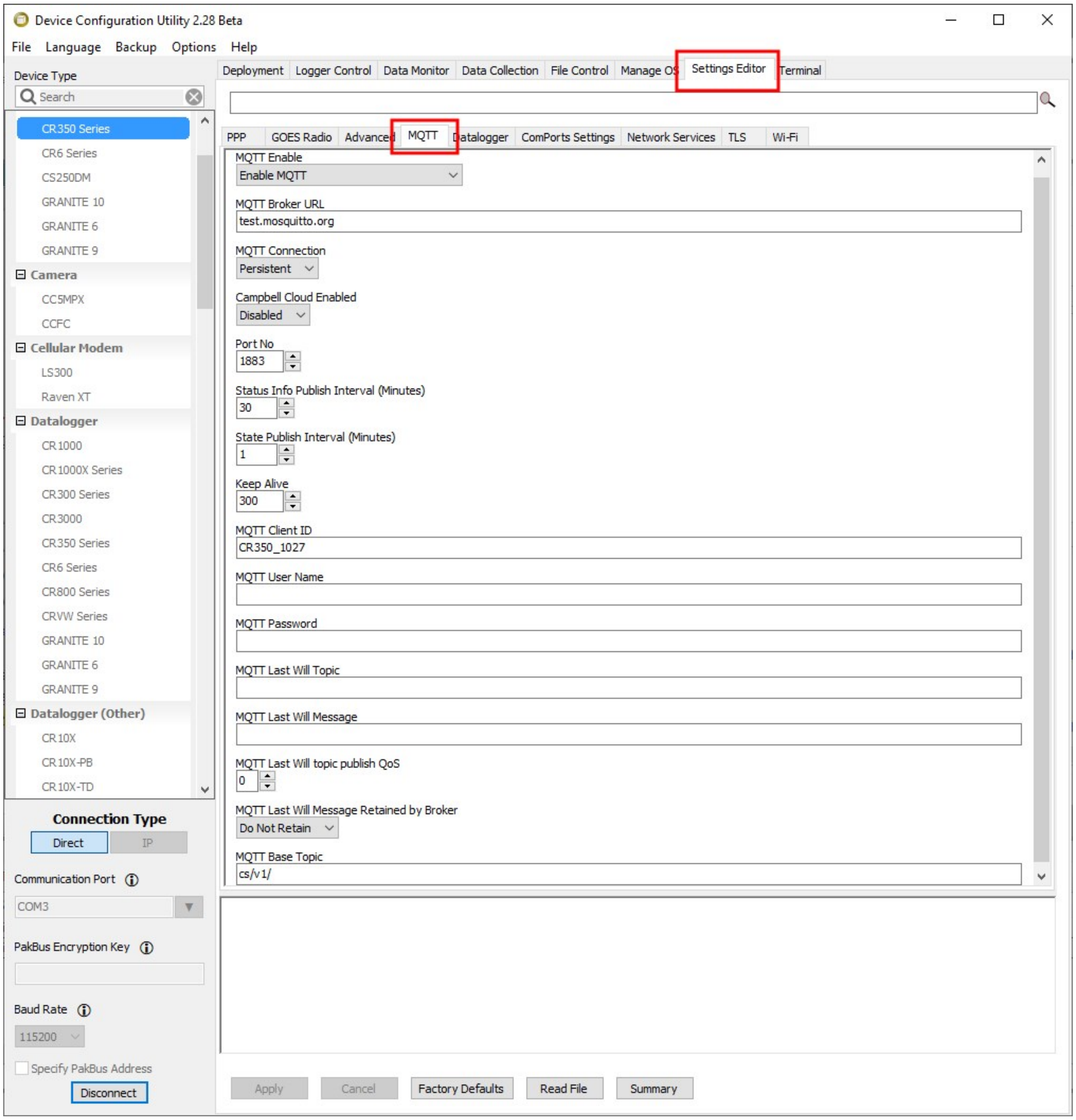
For more information on MQTT topic structure see MQTT commands (p. 221).

10.4.2.1 Configure the data logger

1. Ensure your data logger is connected to the internet.
2. Using ***Device Configuration Utility***, connect to the data logger.
3. (Recommended) On the **Logger Control** tab, set the **Reference Clock Setting** to **UTC** in order to ensure correct timestamps for data ingestion by the ***CLOUD***. Note: the preferred timezone displayed in the ***CLOUD*** may be set in the **CLOUD User Settings**.



4. On the **Settings Editor** tab, click the **MQTT** sub-tab.



a. **Enable MQTT**.

b. Enter the **Broker URL**. Enter `test.mosquitto.org` for this example.

c. Select **Persistent** for **MQTT Connection** type.

d. Enter `1883` for the **Port Number**.

e. Write down the **MQTT Base Topic**; it is case sensitive. By default it is `cs/v1/`.

f. Keep all other MQTT settings as their defaults.

5. Click **Apply**.

10.4.2.2 Program the data logger

Use `MQTTPublishTable()` within a `DataTable/EndTable` declaration to publish stored data via MQTT. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

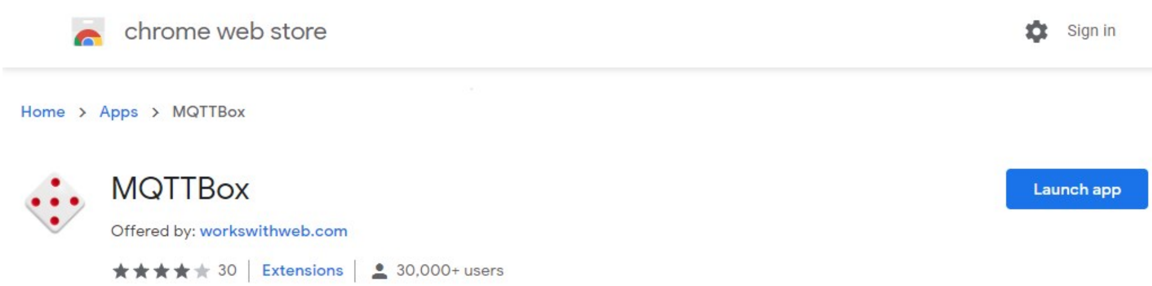
```
DataTable(Five_Min,True,-1)
  DataInterval(0,5,Min,10)
    Average(1,Temp_C,FP2,False)
    Minimum(1,BattV,FP2,False,False)
    Publish every 5 min in CSJSON format. The last three
    parameters are optional to specify longitude, latitude, and
    altitude. Here we use NaN as placeholders for these values.
    MQTTPublishTable(0,0,5,Min,1,NaN,NaN,NaN)
EndTable
```

Five minutes is the fastest recommended publishing interval in order to ensure that ingestion and processing of data sent to the MQTT broker are completed before new data is received.

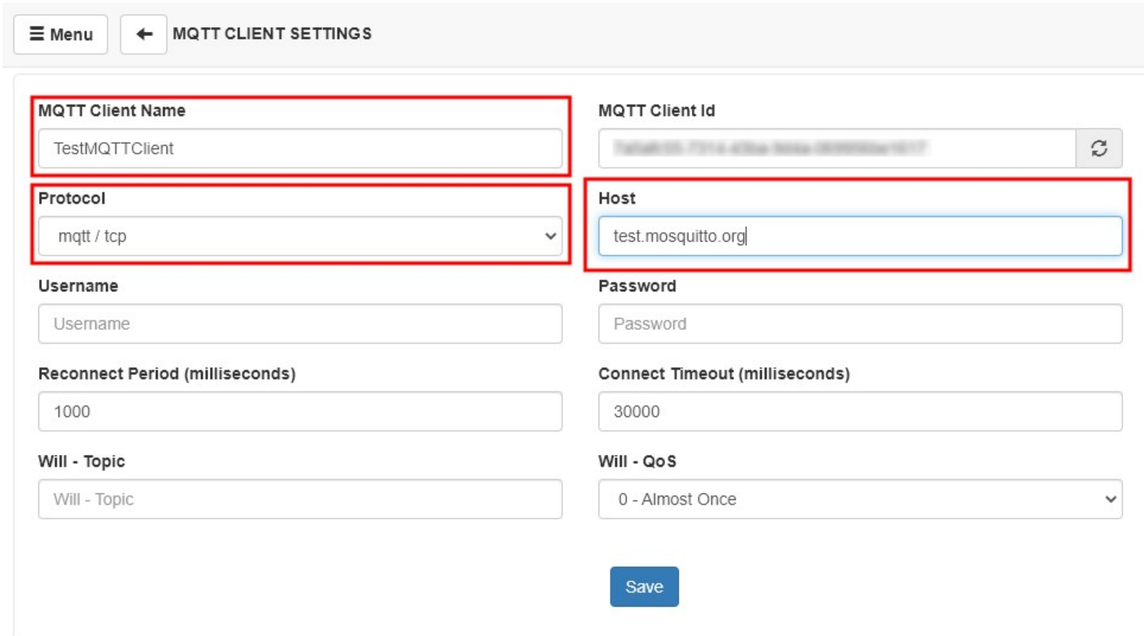
10.4.2.3 Check broker for incoming data

To subscribe to MQTT topics an MQTT client is required. There are many available; it is recommended that you consult with an IT professional. This example uses the Google Chrome extension MQTTBox.

1. Launch MQTTBox.



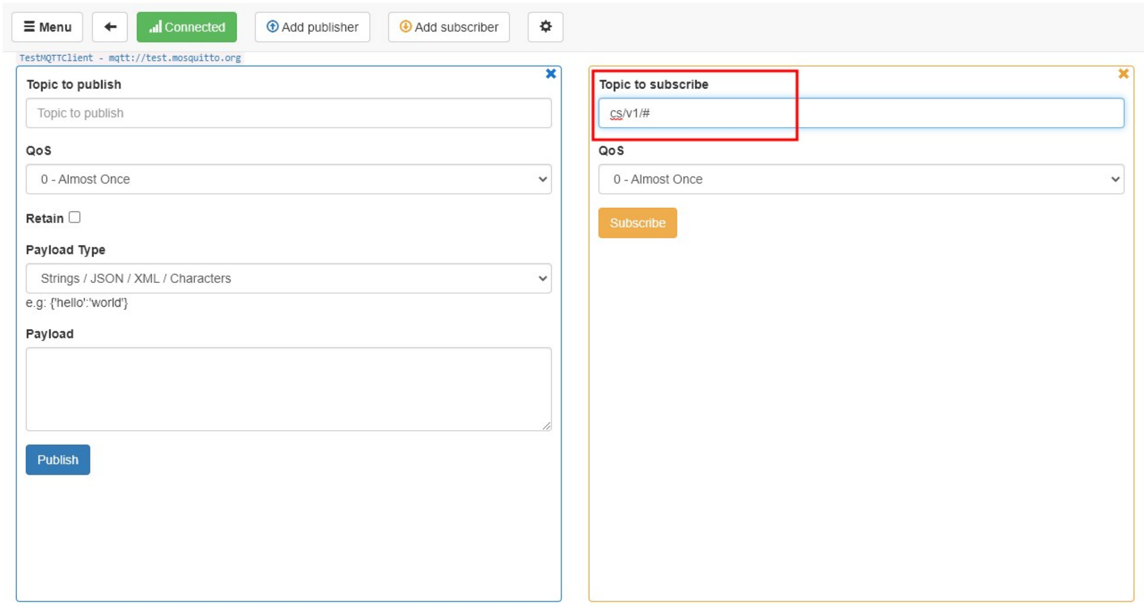
2. Configure the client.



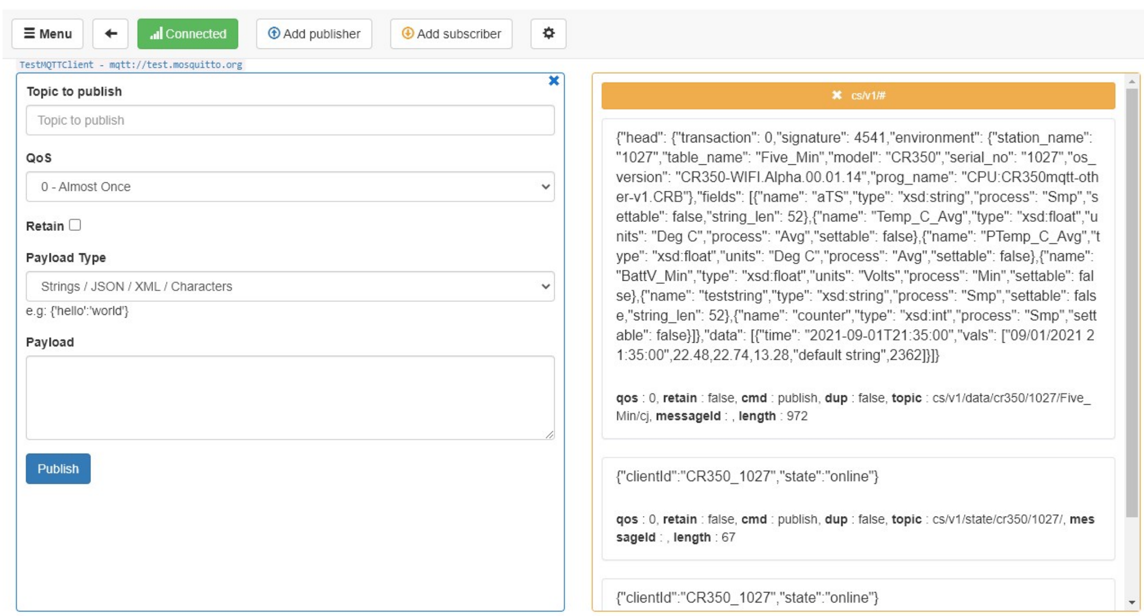
   a. Give the MQTT client a name.
   b. Select **mqtt/tcp** for the **Protocol**.
   c. Enter `test.mosquitto.org` for the **Host**.
   d. Keep all other settings as their defaults.
   e. Click **Save**.

3. Type `cs/v1/#` in the **Topic to subscribe** field to subscribe to all topics. This is the Base MQTT Topic noted from the ***Device Configuration Utility*** > **MQTT** > **Settings Editor**.

4. Click **Subcribe**.



5. Confirm data is being received.



6. For more information on MQTT topic structure see MQTT commands (p. 221).

10.5 DNP3 communications

DNP3 is designed to optimize transmission of data and control commands from a master computer to one or more remote devices or outstations. The data logger allows DNP3 communications on all available communications ports. CRBasic DNP3 instructions include:

- DNP()
- DNPUpdate()
- DNPVariable()

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

When DNPUpdate() is used to set up the data logger as a remote (slave) device, up to three DNP3 clients (masters) are supported.

For additional information on DNP3 see:

- DNP3 with Campbell Scientific Dataloggers
- Getting to Know DNP3
- How to Access Your Measurement Data Using DNP3

10.6 Serial peripheral interface (SPI) and I2C

Serial Peripheral Interface is a clocked synchronous interface, used for short distance communications, generally between embedded devices. I2C is a multi-controller (master), multi-peripheral (slave), packet switched, single-ended, serial computer bus. I2C is typically used for attaching lower-speed peripheral ICs to processors and microcontrollers in short-distance, intra-board communications. I2C and SPI are protocols supported by the operating system. See ***CRBasic Editor*** help for instructions that support these protocols.

For additional information on I2C, see www.i2c-bus.org.

10.7 PakBus communications

PakBus is a Campbell Scientific communications protocol. By using signed data packets, PakBus increases the number of communications and networking options available to the data logger. The data logger allows PakBus communications on all available communications ports. For additional information, see The Many Possibilities of PakBus Networking blog article.

Advantages of PakBus include:

- Simultaneous communications between the data logger and other devices.
- Peer-to-peer communications - no computer required. Special CRBasic instructions simplify transferring data between data loggers for distributed decision making or control.
- Data consolidation - other PakBus data loggers can be used as "sensors" to consolidate all data into one data logger.

- Routing - the data logger can act as a router, passing on messages intended for another Campbell Scientific data logger. PakBus supports automatic route detection and selection.
- Short distance networks - a data logger can talk to another data logger over distances up to 30 feet by connecting transmit, receive, and ground wires between the data loggers.

In a PakBus network, each data logger is assigned a unique address. The default PakBus address in most devices is **1**. To communicate with the data logger, the data logger support software must know the data logger PakBus address. The PakBus address is changed using ***Device Configuration Utility***, data logger **Settings Editor**, or **PakBus Graph** software.

10.8 SDI-12 communications

SDI-12 is a 1200 baud communications protocol that supports many smart sensors, probes and devices. The data logger supports SDI-12 communications through two modes — transparent mode and programmed mode (see SDI-12 ports (p. 16) for wiring terminal information).

Conflicts can occur when a control port pair is used for different instructions (`TimerInput()`, `PulseCount()`, `SDI12Recorder()`, `WaitDigTrig()`). For example, if **C1** is used for `SDI12Recorder()`, **C2** cannot be used for `TimerInput()`, `PulseCount()`, or `WaitDigTrig()`.

Transparent mode facilitates sensor setup and troubleshooting. It allows commands to be manually issued and the full sensor response viewed. Transparent mode does not record data. See SDI-12 transparent mode (p. 155) for more information.

Programmed mode automates much of the SDI-12 protocol and provides for data recording. See SDI-12 programmed mode/recorder mode (p. 117) for more information.

CRBasic SDI-12 instructions include:

- `SDI12Recorder()`
- `SDI12SensorSetup()`
- `SDI12SensorResponse()`

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

The data logger uses SDI-12 version 1.4.

10.8.1 SDI-12 transparent mode

All SDI-12 probes have just three wires—a signal, ground, and 12 V power line. They are connected to the data logger according to the following table.

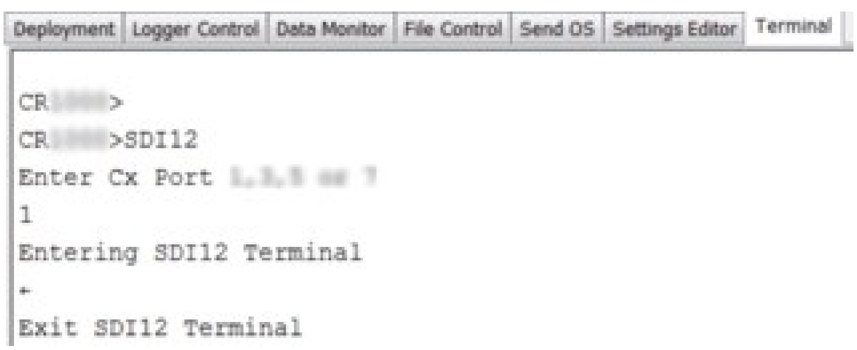
Table 10-1: SDI-12 probe connections	
Wire function	Data logger connection
SDI-12 signal	C
Shield	⏚ (analog ground)
Power	12V
Power ground	G

System operators can manually interrogate and enter settings in probes, connected to the data logger, using transparent mode. Transparent mode is useful in troubleshooting SDI-12 systems because it allows direct communications with probes.

Transparent mode may need to wait for commands issued by the programmed mode to finish before sending responses. While in transparent mode, the data logger programs may not execute. Data logger security may need to be unlocked before transparent mode can be activated.

Transparent mode is entered while the computer is communicating with the data logger through a terminal emulator program such as through ***Device Configuration Utility*** or other data logger support software. Keyboard displays cannot be used. For how-to instructions for communicating directly with an SDI-12 sensor using a terminal emulator, watch this video: https://www.campbellsci.com/videos/sdi12-sensors-transparent-mode.

To enter the SDI-12 transparent mode, enter the data logger support software terminal emulator:



1. Press **Enter** until the data logger responds with the prompt **`CR1000X>`**.
2. Type **`SDI12`** at the prompt and press **Enter**.
3. In response, the query **`Select SDI12 Port`** is presented with a list of available ports. Enter the port number assigned to the terminal to which the SDI-12 sensor is connected, and press **Enter**. For example, **`1`** is entered for terminal **C1**.

4. An `Entering SDI12 Terminal` response indicates that SDI-12 transparent mode is active and ready to transmit SDI-12 commands and display responses.

10.8.1.1 Watch command (sniffer mode)

The terminal-mode utility allows monitoring of SDI-12 traffic by using the watch command (sniffer mode). Watch an instructional video: https://www.campbellsci.com/videos/sdi12-sensors-watch-or-sniffer-mode or use the following instructions.

1. Enter the transparent mode as described previously.
2. Press **Enter** until a `CR1000X>` prompt appears.
3. Type `W` and then press **Enter**.
4. In response, the query `Select SDI12 Port:` is presented with a list of available ports. Enter the port number assigned to the terminal to which the SDI-12 sensor is connected, and press **Enter**.
5. In answer to `Enter timeout (secs):` type `100` and press **Enter**.
6. In response to the query `ASCII (Y)?`, type `Y` and press **Enter**.
7. SDI-12 communications are then opened for viewing.

10.8.1.2 SDI-12 transparent mode commands

SDI-12 commands and responses are defined by the SDI-12 Support Group (www.sdi-12.org) and are available in the SDI-12 Specification. Sensor manufacturers determine which commands to support. Commands have three components:

- Sensor address (**a**): A single character and the first character of the command. Sensors are usually assigned a default address of zero by the manufacturer. The wildcard address (**?**) is used in the `Address Query` command. Some manufacturers may allow it to be used in other commands. SDI-12 sensors accept addresses 0 through 9, a through z, and A through Z.
- Command body (for example, **M1**): An upper case letter (the "command") followed by alphanumeric qualifiers.
- Command termination (**!**): An exclamation mark.

An active sensor responds to each command. Responses have several standard forms and terminate with <CR><LF> (carriage return–line feed).

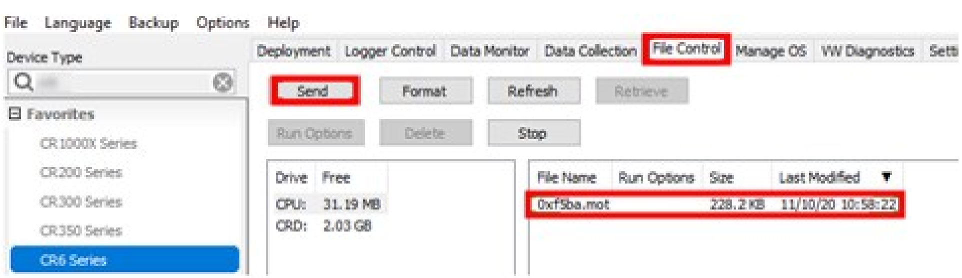
10.8.1.3 aXLOADOS! command

aXLOADOS! is an example of an SDI-12 transparent mode command. It is used to send an operating system (OS) update from a data logger to an SDI-12 sensor.

> NOTE:
> Verify with the sensor manufacturer that the sensor supports this command.

Use **aXLOADOS!** in the following procedure to send an OS update to an SDI-12 sensor.

1. Supply power to the data logger. If connecting via USB for the first time, you must first install USB drivers by using ***Device Configuration Utility*** (select your data logger, then on the main page, click **Install USB Driver**). Alternately, you can install the USB drivers using EZ Setup. A USB connection supplies 5 V power (as well as a communications link), which is adequate for setup, but a 12 V battery will be needed for field deployment.
2. Physically connect your data logger to your computer using a USB cable, then in ***Device Configuration Utility*** select your data logger.
3. Copy the sensor OS file from the computer to the data logger.
   a. Select **File Control** > **CPU:** drive > **Send** and navigate to the file on the computer.
   b. Click **Open**.
   c. Click **OK**.



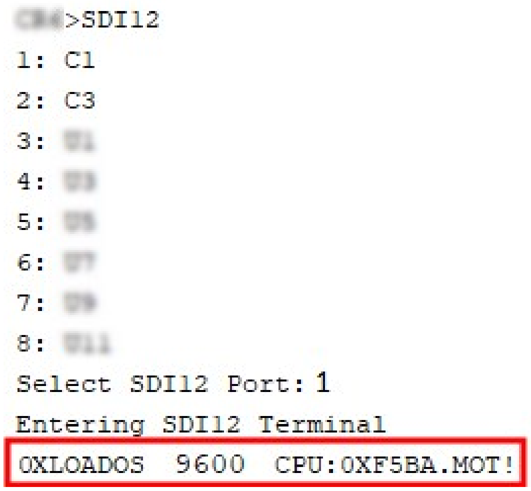
4. Enter the transparent mode as described in SDI-12 transparent mode (p. 155).
5. An `Entering SDI12 Terminal` response indicates that SDI-12 transparent mode is active and ready to transmit SDI-12 commands and display responses.

   The load OS command has the following format:

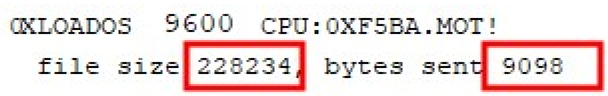
   `aXLOADOS Baudrate drive:filename!`.

   For example: `0XLOADOS 9600 CPU:0XF5BA.MOT!`.

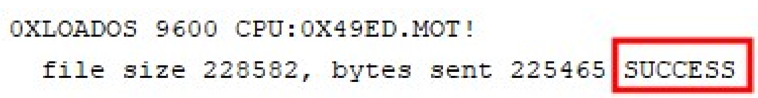
   Type the command, including the ending exclamation point (!) then press **Enter**.



6. The screen will show OS send updates and the **bytes sent** will continue to increase. The process is slow, it can take several minutes, but not hours.



7. A **SUCCESS** message indicates the process is complete.



10.8.2 SDI-12 programmed mode/recorder mode

The data logger can be programmed to read SDI-12 sensors or act as an SDI-12 sensor itself. The `SDI12Recorder()` instruction automates sending commands and recording responses. With this instruction, the commands to poll sensors and retrieve data is done automatically with proper elapsed time between the two. The data logger automatically issues retries. See ***CRBasic Editor*** help for more information on this instruction.

Commands entered into the `SDIRecorder()` instruction differ slightly in function from similar commands entered in transparent mode. In transparent mode, for example, the operator manually enters `aM!` and `aD0!` to initiate a measurement and get data, with the operator providing the proper time delay between the request for measurement and the request for data. In programmed mode, the data logger provides command and timing services within a single line of code. For example, when the `SDI12Recorder()` instruction is programmed with the `M!` command (note that the SDI-12 address is a separate instruction parameter), the data logger issues the `aM!` and `aD0!` commands with proper elapsed time between the two. The data logger automatically issues retries and performs other services that make the SDI-12 measurement work as trouble free as possible.

For troubleshooting purposes, responses to SDI-12 commands can be captured in programmed mode by placing a variable declared `As String` in the variable parameter. Variables not declared `As String` will capture only numeric data.

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

10.8.3 Programming the data logger to act as an SDI-12 sensor

The `SDI12SensorSetup()` / `SDI12SensorResponse()` instruction pair programs the data logger to behave as an SDI-12 sensor. A common use of this feature is to copy data from the data logger to other Campbell Scientific data loggers over a single data-wire interface (terminal configured for SDI-12 to terminal configured for SDI-12), or to copy data to a third-party SDI-12 recorder.

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

When programmed as an SDI-12 sensor, the data logger will respond to SDI-12 commands `M`, `MC`, `C`, `CC`, `R`, `RC`, `V`, `?`, and `I`.

When acting as a sensor, the data logger can be assigned only one SDI-12 address per SDI-12 port. For example, a data logger will not respond to both `0M!` and `1M!` on SDI-12 port **C1**. However, different SDI-12 ports can have unique SDI-12 addresses. Use a separate `SlowSequence` for each SDI-12 port configured as a sensor.

10.8.4 SDI-12 power considerations

When a command is sent by the data logger to an SDI-12 probe, all probes on the same SDI-12 port will wake up. However, only the probe addressed by the data logger will respond. All other probes will remain active until the timeout period expires.

Example:

Probe: Water Content

Power Usage:

- Quiescent: 0.25 mA
- Active: 66 mA
- Measurement: 120 mA

Measurement time: 15 s

Timeout: 15 s

Probes 1, 2, 3, and 4 are connected to SDI-12 port **C1**.

The time line in the following table shows a 35-second power-usage profile example.

For most applications, total power usage of 318 mA for 15 seconds is not excessive, but if 16 probes were wired to the same SDI-12 port, the resulting power draw would be excessive. Spreading sensors over several SDI-12 terminals helps reduce power consumption.

Table 10-2: Example power use for a network of SDI-12 probes

Time into Measurement Processes	Command	All Probes Awake	Time Out Expires	Probe 1 (mA)	Probe 2 (mA)	Probe 3 (mA)	Probe 4 (mA)	Total (mA)
Sleep				0.25	0.25	0.25	0.25	1
1	`1M!`	Yes		120	66	66	66	318
2–14				120	66	66	66	318
15			Yes	120	66	66	66	318
16	`1D0!`	Yes		66	66	66	66	264
17-29				66	66	66	66	264
30			Yes	66	66	66	66	264
Sleep				0.25	0.25	0.25	0.25	1

11. Installation

Campbell Scientific data loggers support research and operations all over the world in a variety of applications. The limits of the CR1000X are defined by your application needs. Therefore, every installation will be unique. See www.campbellsci.com/solutions.

> **TIP:**
> Time spent in the office, setting up and testing hardware and software, will make time in the field more efficient.

Recommended tools:

- Voltmeter
- Screwdrivers
  - Flat-blade
  - Phillips-head
  - Small flat-blade
- Wire cutter/stripper
- Crescent wrench
- Pliers
- Pad and pen
- Laptop computer, fully charged, with software and drivers installed
- USB cable

Tools required to install a Campbell Scientific tripod or tower:

- Shovel
- Rake
- Open-end wrench set
- Socket wrench set
- Magnetic compass
- Tape measure
- Nut driver

- Level
- Sledgehammer
- Pliers
- Flat-bladed screwdrivers
- Phillips screwdrivers

For more information, watch a video at: http://www.campbellsci.com/videos/toolbox-for-installation-and-maintenance.

11.1 Default program

Many data logger settings can be changed remotely over a communications link. This convenience comes with the risk of inadvertently changing settings and disabling communications. For example, external cellular modems are often controlled by a switched 12 VDC (**SW12**) terminal. **SW12** is normally off; so, if the program controlling **SW12** is disabled, such as by changing a setting or sending a new operating system, the cellular modem is switched off and the remote data logger will not turn it on. This could require an on-site visit to correct the problem unless a special program called `default` has been installed.

Having a `default.CR1X` program stored on the data logger will also ensure that a non-compiling CRBasic program does not lock out a remote user.

> **NOTE:**
> The default program may use the extension `.CR1X`, `.CRB` or `.DLD`.

When a file named `default.CR1X` is stored on the data logger CPU: drive, it is loaded if no other program takes priority. Program execution priorities are as follows:

- When the CR1000X powers up, it executes commands in the `powerup.ini` file (on an attached mass storage device or memory card) including commands to set the CRBasic program file attributes to **Run Now** or **Run on Power Up**.
- When the CR1000X powers up, a program file marked as **Run on Power Up** will be the current program.
- If the program cannot be compiled or if no program is specified, the data logger will attempt to run the program named `default.CR1X` on its CPU: drive.
- If there is no `default.CR1X` file or it cannot be compiled, the CR1000X will not automatically run any program.

See File management via powerup.ini (p. 139) for more information.

The `default.CR1X` program generally contains instructions to preserve critical datalogger settings such as communications settings, but should not be more than a few lines of code.

CRBasic Example 2: `default.CR1X` example

```
'This program turns ON the SW12 switched
'power terminal, for 30 seconds every 60 seconds.
BeginProg
  Scan(1,Sec,0,0)
    If TimeIsBetween (15,45,60,Sec) Then SW12(SW12_1,1)
  NextScan
EndProg
```

Downloading operating systems over communications requires much of the available CR1000X memory. If the intent is to load operating systems via a communications link and have a `default.CR1X` file in the CR1000X, the `default.CR1X` program should not allocate significant memory, as might happen by allocating a large USR: drive. Also, do not auto-allocate tables in `DataTable()` instructions; if it is necessary to use `DataTable()` instructions, set small fixed table sizes. Refer to Sending an operating system to a remote data logger (p. 137) for information about sending the operating system.

Execution of `default.CR1X` at power-up can be aborted by holding down the DEL key on a CR1000KD Keyboard/Display.

11.2 Data logger security

Data logger security concerns include:

- Collection of sensitive data
- Operation of critical systems
- Networks that are accessible to many individuals

Some options to secure your data logger from mistakes or tampering include:

- Sending the latest operating system to the data logger. See Updating the operating system (p. 135) for more information.
- Disabling unused services and securing those that are used. This includes disabling HTTP, HTTPS, FTP, Telnet, and Ping network services (***Device Configuration Utility*** > **Deployment** > **Network Services** tab). These services can be used to discover your data logger on an IP network.

> **NOTE:**
> FTP, Telnet, and Ping services are disabled by default.

- Setting security codes (see following information under "Security Codes").
- Setting a PakBus/TCP password. The PakBus TCP password controls access to PakBus communications over a TCP/IP link. PakBusTCP passwords can be set in ***Device Configuration Utility***.
- Disabling FTP or setting an FTP username and password in ***Device Configuration Utility***.
- Setting a PakBus encryption (AES-128) key in ***Device Configuration Utility***. This forces PakBus data to be encrypted during transmission.
- Disabling HTTP/HTTPS or creating a `.csipasswd` file to secure HTTP/HTTPS (see Creating a .csipasswd file (p. 125) for more information).
- Enabling HTTPS and disabling HTTP. To prevent data collection via the web interface, both HTTP and HTTPS must be disabled.
- Using a public/private key pair for SFTP authentication. Load a .PEM format file through the ***Device Configuration Utility*** **Settings Editor** > **Advanced** tab.
- Tracking Operating System, Run, and Program signatures.
- Encrypting program files if they contain sensitive information (see CRBasic help `FileEncrypt()` instruction or use the ***CRBasic Editor*** **File** menu, **Save and Encrypt** option).
- Hiding program files for extra protection (see CRBasic help `FileManage()` instruction).
- Monitoring your data logger for changes by tracking program and operating system signatures, as well as CPU, USR, and CRD file contents.
- Securing the physical data logger and power supply under lock and key.

WARNING:
All security features can be subverted through physical access to the data logger. If absolute security is a requirement, the physical data logger must be kept in a secure location.

11.2.1 TLS

Transport Layer Security (TLS) is an internet communications security protocol. TLS settings are necessary for **server** applications, not for client applications.

Example server application instructions include:

- HTTPS server
- `DNP3()`

Example client application instructions include:

- `HTTPGet()`, `HTTPPut()` and `HTTPPost()`
- `EmailRelay()`
- `EmailSend()` and `EmailRecv()`
- `FTPClient()`

Use the ***Device Configuration Utility*** to enable and set up TLS. See **Deployment** > **Datalogger** > **TLS** tab.

11.2.2 Security codes

The data logger employs a security scheme that includes three levels of security. Security codes can effectively lock out innocent tinkering and discourage wannabe hackers on all communications links. However, any serious hacker with physical access to the data logger or to the communications hardware can, with only minimal trouble, overcome the five-digit security codes. Security codes are held in the data logger Settings Editor.

The preferred methods of enabling security include the following:

- ***Device Configuration Utility***: Security codes are set on the **Deployment**> **Datalogger** tab.
- Network Planner: Security codes can be set as data loggers are added to the network.

Alternatively, in CRBasic the `SetSecurity()` instruction can be used. It is only executed at program compile time. This is not recommended because deleting `SetSecurity()` from a CRBasic program is not equivalent to `SetSecurity(0,0,0)`. Settings persist when a new program is downloaded that has no `SetSecurity()` instruction.

Up to three levels of security can be set. Valid security codes are **1** through **65535** (**0** confers no security). **Security 1** must be set before **Security 2**. **Security 2** must be set before **Security 3**. If any one of the codes is set to **0**, any security code level greater than it will be set to **0**. For example, if **Security 2** is **0** then **Security 3** is automatically set to **0**. Security codes are unlocked in reverse order: **Security 3** before **Security 2**, **Security 2** before **Security 1**.

Table 11-1: Functions affected by security codes

Function	Security code 1 set	Security code 2 set	Security code 3 set
data logger program	Cannot change or retrieve		All communications prohibited
Settings editor and Status table	Writable variables cannot be changed		
Setting clock	unrestricted	Cannot change or set	
Public table	unrestricted	Writable variables cannot be changed	
Collecting data	unrestricted	unrestricted	

See Security(1), Security(2), Security(3) (p. 200) for the related fields in the Settings Editor.

For additional information on data logger security, see:

- 4 Ways to Make your Data More Secure
- Available Security Measures for Internet-Connected Dataloggers
- How to Use Datalogger Security Codes
- How Can Data be Made More Secure on a CRBasic PakBus Datalogger

11.2.3 Creating a .csipasswd file

The data logger employs a security code scheme that includes three levels of security (see Data logger security (p. 122) for more information). This scheme can be used to limit access to a data logger that is publicly available. However, the security codes are visible in ***Device Configuration Utility***. In addition, the range of codes is relatively small. To provide a more robust means of security, basic access authentication was implemented with the HTTP API interface in the form of an encrypted password file named `.csipasswd`. See the ***CRBasic Editor*** help for information about the data logger web server and API commands: https://help.campbellsci.com/crbasic/cr1000x/#Info/webserverapicommands1.htm.

> NOTE:
> Ethernet over USB (RNDIS) is considered a direct communications connection. Therefore, it is a trusted connection and **Administrator** privileges are automatically granted for all functionality (csipasswd does not apply).

When a file named `.csipasswd` is stored on the data logger CPU drive, basic access authentication is enabled in the data logger and read/write access to the web interface can be defined. Multiple user accounts with differing levels of access can be defined for one data logger. Four levels of access are available:

- **None**: Disable a user account.
- **Read Only**: Data collection is unrestricted. Clock and writable variables cannot be changed. Programs cannot be viewed, stopped, deleted, or retrieved.
- **Read/Write**: Data collection is unrestricted. Clock and writable variables can be changed. Programs cannot be viewed, stopped, deleted, or retrieved.
- **All (Administrator)**: Data collection is unrestricted. Clock, writable variables and settings can be changed. Programs can be viewed, stopped, deleted, and retrieved. Hidden tables can be viewed. Files, including programs can be sent to the data logger.

> NOTE:
> All levels of access allow data collection.

Create an encrypted password file or modify an existing password file using ***Device Configuration Utility***:

1. Connect to your device in ***Device Configuration Utility***.
2. Click the **Network Services** tab, then the **Edit .csipasswd File** button.
3. Define user accounts and access levels.
4. Click **Apply**. The `.csipasswd` file is automatically saved to the data logger CPU drive.

When a `.csipasswd` file is used, the PakBus/TCP Password security setting is not used when accessing the data logger via HTTP. If the `.csipasswd` file is blank or does not exist, the default user name is "anonymous" with no password and a user level of read only.

When access to the data logger web interface is attempted without the appropriate security level, the data logger will prompt for a username and password. If an invalid username or password is entered, the data logger will default to the level of access assigned to "anonymous". As noted previously, anonymous is assigned a user level of read-only, though this can be changed using ***Device Configuration Utility***.

If the numeric security code has been enabled, and no `.csipasswd` file is on the data logger, then that numeric security code must be entered to access the data logger. If a `.csipasswd` file is on the data logger, the username and password employed by the basic access authentication will eliminate the need for entering the numeric security code.

11.3 Web interface

For data loggers with an IP connection, the built-in web interface provides access to real-time and stored data logger data. For more information on the web interface, watch an instructional video at: http://www.campbellsci.com/videos/web-interface ▶.

Read/write access to the web interface requires a `.csipasswd` file. See Creating a .csipasswd file (p. 125) for more information.

> **NOTE:**
> Ethernet over USB (RNDIS) is considered a direct communications connection. Therefore, it is a trusted connection and **Administrator** privileges are automatically granted for all functionality (csipasswd does not apply).

11.4 Power budgeting

In low-power situations, the data logger can operate for several months on non-rechargeable batteries. Power systems for longer-term remote applications typically consist of a charging source, a charge controller, and a rechargeable battery. When ac line power is available, a VAC-to-VDC wall adapter, charging regulator, and a rechargeable battery can be used to construct an uninterruptible power supply (UPS).

When designing a power supply, consider worst-case power requirements and environmental extremes. For example, the power requirement of a weather station may be substantially higher during extreme cold, while at the same time, the extreme cold constricts the power available from the power supply. System operating time for batteries can be estimated by dividing the battery capacity (ampere hours) by the average system current drain (amperes).

For more information see:

- Power Supplies Application Note
- Battery Care Blog
- Troubleshooting Your Solar Panel blog
- Power Budget Spreadsheet
- Power Budgeting Video

See also:

- Power input (p. 11)
- Power output (p. 12)
- Power requirements (p. 209)
- Power output specifications (p. 210)

11.5 Field work

Field installation is site- and application- specific. This section lists resources to aid with system installation.

- Data logger enclosures (p. 128)
- Grounds (p. 13)
- Electrostatic discharge and lightning protection (p. 128)
- Weather Station Siting and Installation Technical Paper
- Protect Station from Birds Blog
- Tripod Manual
- Tripod Installation Videos
- Tower Manual (UT20 and UT30)
- UTBASE Installation Video
- Surge Protector Kits: Installation and Troubleshooting White Paper

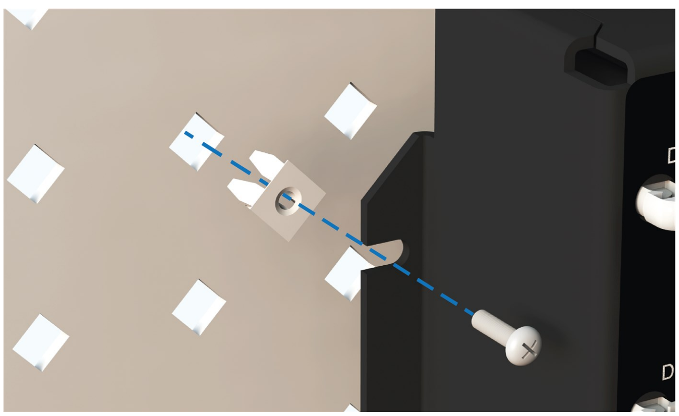
11.6 Data logger enclosures

The data logger and most of its peripherals must be protected from moisture and humidity. Moisture in the electronics will seriously damage the data logger. In most cases, protection from moisture is easily accomplished by placing the data logger in a weather-tight enclosure with desiccant and elevating the enclosure above the ground. Desiccant in enclosures should be changed periodically.

> **WARNING:**
> Do not completely seal the enclosure if lead-acid batteries are present; hydrogen gas generated by the batteries may build to an explosive concentration.

The following details a typical installation using a Campbell Scientific enclosure. The data logger has mounting holes through which small screws are inserted into nylon anchors in the backplate.

1. Insert the included nylon anchors into the backplate. Position them to align with the mounting holes on the base of the data logger.
2. Holding the data logger to the backplate, screw the screws into the nylon anchors.

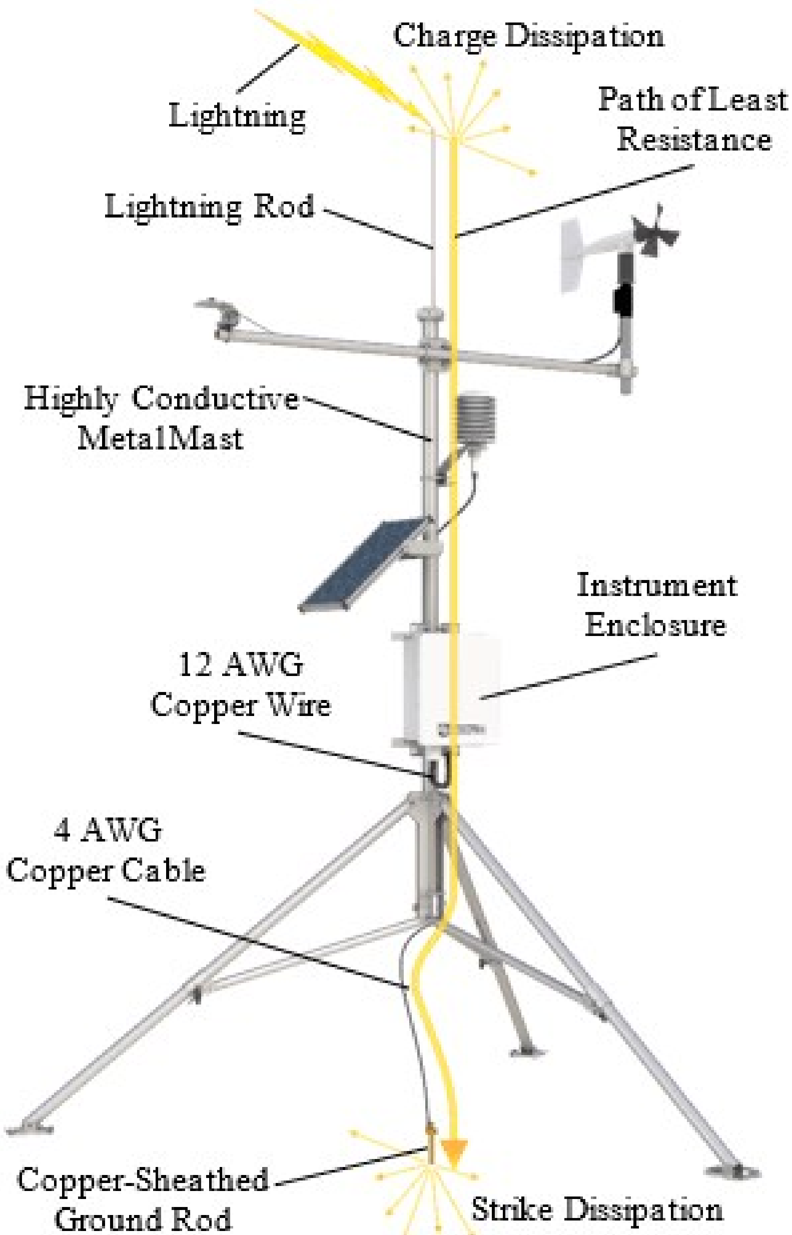


See also Physical specifications (p. 209).

11.7 Electrostatic discharge and lightning protection

> **WARNING:**
> Lightning strikes may damage or destroy the data logger, associated sensors and power supplies.

Electrostatic discharge (ESD) can originate from several sources, the most common and destructive are primary and secondary lightning strikes. Primary lightning strikes hit instrumentation directly. Secondary strikes induce voltage in power lines or wires connected to instrumentation. While elaborate, expensive, and nearly infallible lightning protection systems are on the market, Campbell Scientific, for many years, has employed a simple and inexpensive design that protects most systems in most circumstances. The system consists of a lightning rod, metal mast, heavy-gauge ground wire, and ground rod to direct damaging current away from the data logger. This system, however, is not infallible. The following image displays a typical application of the system:



All critical inputs and outputs on the data logger are ESD protected. To be effective, the earth ground lug must be properly connected to earth (chassis) ground.

Communications ports are another path for transients. You should provide communications paths, such as telephone or short-haul modem lines, with spark-gap protection. Spark-gap protection is usually an option with these products; so, request it when ordering. Spark gaps must be connected to earth (chassis) ground.

For detailed information on grounding, see Grounds (p. 13).

12. CR1000X maintenance

Protect the data logger from humidity and moisture. When humidity levels reach the dewpoint, condensation occurs, and damage to data logger electronics can result. Adequate desiccant should be placed in instrumentation enclosure to provide protection, and control humidity. Desiccant should be changed periodically.

If sending the data logger to Campbell Scientific for calibration or repair, consult first with Campbell Scientific. If the data logger is malfunctioning, be prepared to perform some troubleshooting procedures (see Tips and troubleshooting (p. 143)). See: Does Your Data Logger Need to be Repaired Blog and Troubleshooting Data Acquisition System Blog.

Also, consider checking, or posting your question to, the Campbell Scientific user forum https://www.campbellsci.com/forum. Our web site www.campbellsci.com has additional manuals (with example programs), FAQs, specifications and compatibility information for all of our products.

Video tutorials www.campbellsci.com/videos and blog articles www.campbellsci.com/blog are also useful troubleshooting resources.

If calibration or repair is needed, the procedure shown on: https://www.campbellsci.com/repair should be followed when sending the product.

12.1 Data logger calibration

Campbell Scientific recommends factory recalibration every three years. During calibration, all the input terminals, peripheral and communications ports, operating system, and memory areas are checked; and the internal battery is replaced. The data logger is checked to ensure that all hardware operates within published specifications before it is returned. To request recalibration for a product, see https://www.campbellsci.com/repair.

It is recommended that you maintain a level of calibration appropriate to the data logger application. Consider the following factors when setting a calibration schedule:

- The importance of the measurements
- How long the data logger will be used
- The operating environment
- How the data logger will be handled

See also About background calibration (p. 132).

You can download and print calibration certificates for many products you have purchased by logging in to the Campbell Scientific website and going to: https://www.campbellsci.com/calcerts.

> **NOTE:**
> Note, you will need your product's serial number to access its certificate.

Watch an instructional video: http://www.campbellsci.com/videos/calibration-certs.

12.1.1 About background calibration

The data logger uses an internal voltage reference to routinely self-calibrate and compensate for changes caused by changing operating temperatures and aging. Background calibration calibrates only the coefficients necessary to the running CRBasic program. These coefficients are reported in the **Status** table as **CalVolts()**, **CalGain()**, **CalOffset()**, and **CalCurrent()**.

Background calibration will be disabled automatically when the scan rate is too fast for the background calibration measurements to occur in addition to the measurements in the program. The `Calibrate()` instruction can be used to override or disable background calibration. Disable background calibration when it interferes with execution of very fast programs and less accuracy can be tolerated. With background calibration disabled, measurement accuracy over the operational temperature range is specified as less accurate by a factor of 10. That is, over the extended temperature range of –55 °C to 85 °C, the accuracy specification of ±0.08 % of reading can degrade to ±0.8 % of reading with background calibration disabled. If the temperature of the data logger remains the same, there is little calibration drift when background calibration is disabled.

12.2 Internal battery

The lithium battery powers the internal clock and SRAM when the data logger is not powered. This voltage is displayed in the LithiumBattery (see Information tables and settings (advanced) (p. 178)) field in the **Status** table. Replace the battery when voltage is approximately 2.7 VDC. The internal lithium battery life is extended when the data logger is installed with an external power source. If the data logger is used in a high-temperature application, the battery life is shortened.

To prevent clock and memory issues, it is recommended you proactively replace the battery every 2 to 3 years, or more frequently when operating continuously in high temperatures.

> **NOTE:**
> The battery is replaced during regular factory recalibration, which is recommended every 3 years. For more information, see Data logger calibration (p. 131).

When the lithium battery is removed (or is depleted and primary power to the data logger is removed), the CRBasic program and most settings are maintained, but the following are lost:

- Run-now and run-on power-up settings.
- Routing and communications logs (relearned without user intervention).
- Time. Clock will need resetting when the battery is replaced.
- Final-memory data tables.

A replacement lithium battery can be purchased from Campbell Scientific or another supplier.

- AA, 2.4 Ah, 3.6 VDC (Tadiran TL 5903/S) for battery-backed SRAM and clock. 3-year life with no external power source.

See Power requirements (p. 209) for more information.

WARNING:
Misuse or improper installation of the internal lithium battery can cause severe injury. Fire, explosion, and severe burns can result. Do not recharge, disassemble, heat above 100 °C (212 °F), solder directly to the cell, incinerate, or expose contents to water. Dispose of spent lithium batteries properly.

NOTE:
The **Status** field **Battery** value and the destination variable from the `Battery()` instruction (often called `batt_volt`) in the **Public** table reference the external battery voltage.

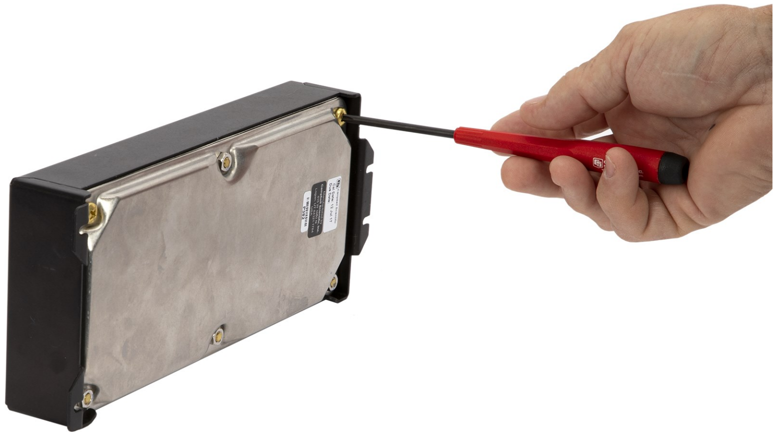
For additional information on the internal battery, visit the Campbell Scientific blog article, Get to Know Your Data Logger's Spare Tire: The Lithium Battery.

12.2.1 Replacing the internal battery

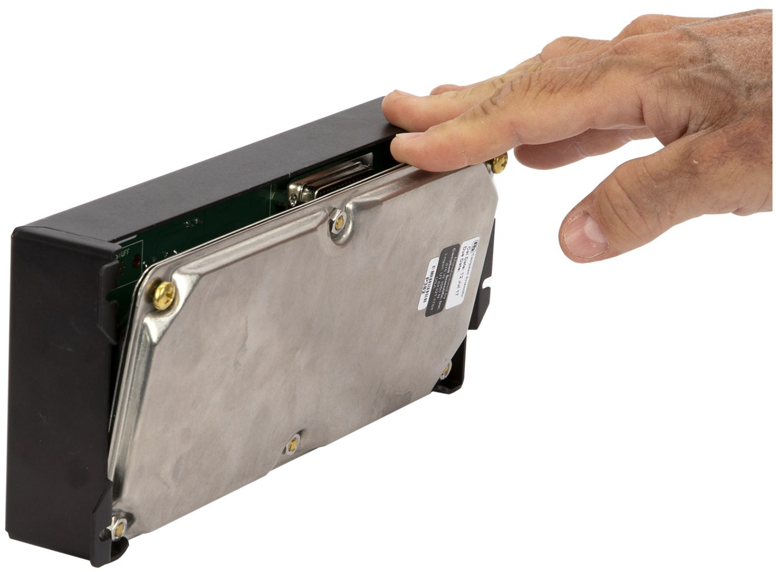
It is recommended that you send the data logger in for scheduled calibration, which includes internal battery replacement (see Data logger calibration (p. 131)).

WARNING:
Any damage made to the data logger during user replacement of the internal battery is not covered under warranty.

1. Remove the two screws from the back of the panel.

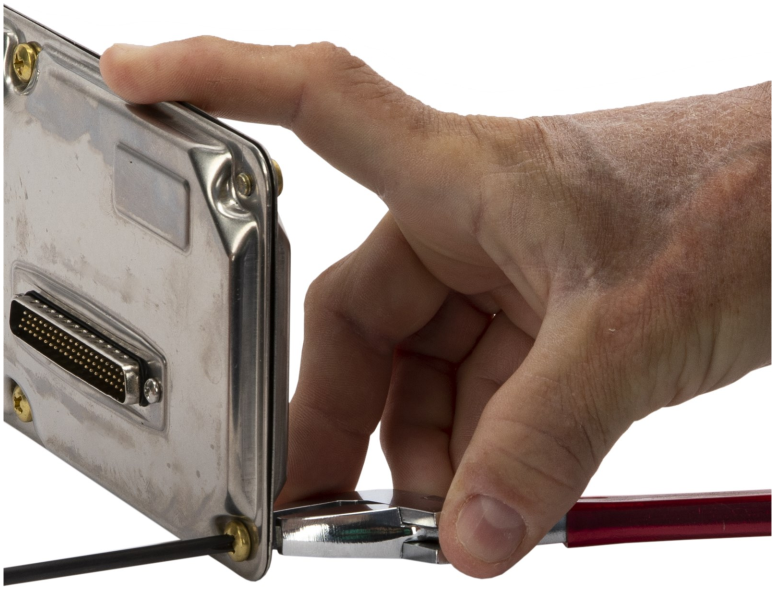


2. Pull one edge of the canister away from the wiring panel to loosen it from the internal connectors.



3. Lift the canister edge out of the enclosure tabs.

4. Remove the nuts, then open the clam shell.



5. Remove the lithium battery by gently prying it out with a small flat-bladed screwdriver. Replace it with a new battery.

6. Reassemble the data logger. Take particular care to ensure the canister is reseated tightly into the connectors by firmly pressing them together by hand.

12.3 Updating the operating system

Campbell Scientific posts operating system (OS) updates at https://www.campbellsci.com/downloads when they become available. It is recommended that before deploying instruments, you check operating system versions and update them as needed. The data logger operating system version is shown in the **Status** table, **Station Status Summary**, and ***Device Configuration Utility*** **Deployment** > **Datalogger**. An operating system may be sent through ***Device Configuration Utility*** or through program-send procedures.

CAUTION:
CR1000X data loggers with Serial Numbers 34000 and newer have hardware requiring the use of OS version 5.02 or newer.

WARNING:
Because sending an OS resets data logger memory and resets all settings on the data logger to factory defaults, data loss will certainly occur. Depending on several factors, the data logger may also become incapacitated until the new OS is programmed into memory.

TIP:
It is recommended that you retrieve data from the data logger and back up your programs and settings before updating your OS. To collect data using ***LoggerNet***, connect to your data logger and click **Collect Now**. To backup your data logger, connect to it in ***Device Configuration Utility***, click the **Backup** menu and select **Backup Datalogger**.

12.3.1 Sending an operating system to a local data logger

Send an OS using ***Device Configuration Utility***. This method requires a direct connection between your data logger and computer.

1. Download the latest Operating System at https://www.campbellsci.com/downloads.
2. Locate the .exe download and double-click to run the file. This will extract the .obj OS file to the **C:\Campbellsci\Lib\OperatingSystems** folder.
3. Supply power to the data logger. If connecting via USB for the first time, you must first install USB drivers by using ***Device Configuration Utility*** (select your data logger, then on the main page, click **Install USB Driver**). Alternately, you can install the USB drivers using EZ Setup. A USB connection supplies 5 V power (as well as a communications link), which is adequate for setup, but a 12 V battery will be needed for field deployment.
4. Physically connect your data logger to your computer using a USB cable, then open ***Device Configuration Utility*** and select your data logger.
5. Select the communications port used to communicate with the data logger from the **COM Port** list (you do not need to click **Connect**).
6. Click the **Send OS** tab. At the bottom of the window, click **Start**.
7. On the **Avoid Conflicts with the Local Server** window, click **OK**.
8. Navigate to the **C:\Campbellsci\Lib\OperatingSystems** folder.

9. Ensure **Datalogger Operating System Files (*.obj)** is selected in the **Files of type** list, select the new OS .obj file, and click **Open** to update the OS on the data logger.

Watch a video: Sending an OS to a Local Datalogger.

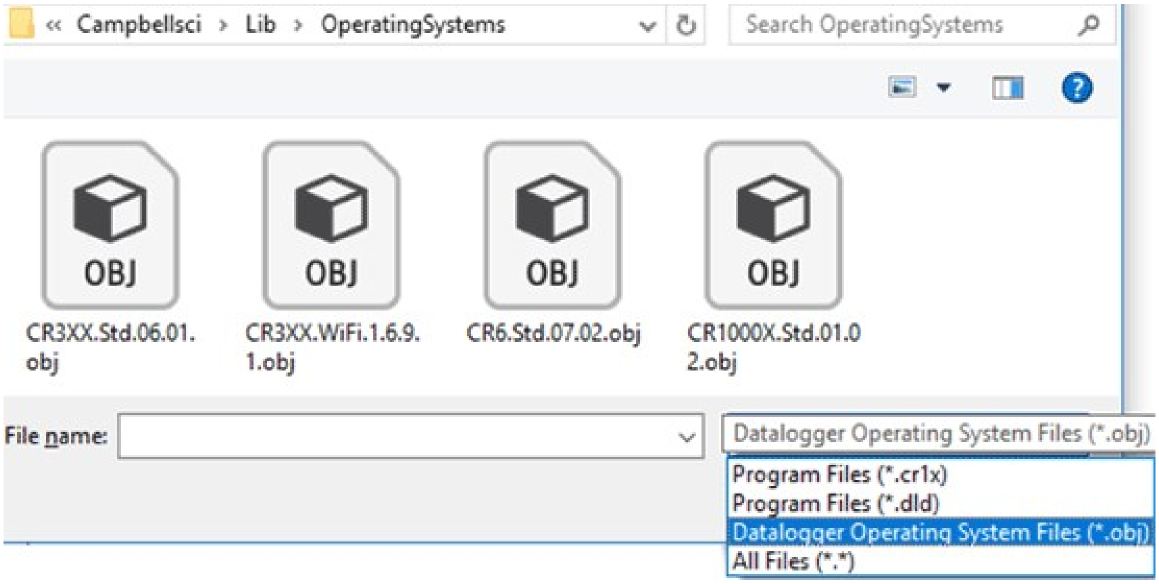
12.3.2 Sending an operating system to a remote data logger

If you have a data logger that is already deployed, you can update the OS over a telecommunications link by sending the OS to the data logger as a program. In most instances, sending an OS as a program preserves settings. This allows for sending supported operating systems remotely (check the release notes). However, this should be done with great caution as updating the OS may reset the data logger settings, even settings critical to supporting the telecommunication link.

The `default.CR1X` program can be edited to preserve critical datalogger settings such as communications settings. See Default program (p. 121) for more information.

1. Download the latest Operating System at https://www.campbellsci.com/downloads.
2. Locate the .exe download and double-click to run the file. This will extract the .obj OS file to the **C:\Campbellsci\Lib\OperatingSystems** folder.
3. Using data logger support software, connect to your data logger.
   - ***LoggerNet*** users, select **Main** and click **Connect** on the ***LoggerNet*** toolbar, select the data logger from the **Stations** list, then click **Connect**.
   - ***PC400*** users, select the data logger from the list and click **Connect**.
4. Select **File Control** at the top of the Connect window.
5. Click **Send** at the top of the File Control window.
6. Navigate to the **C:\Campbellsci\Lib\OperatingSystems** folder.

7. Ensure **Datalogger Operating System Files (*.obj)** is selected in the files of type list, select the new OS .obj file, and click **Open** to update the OS on the data logger.



Note the following precautions when sending as a program:

- Any peripherals being powered through the **SW12** terminals will be turned off until the program logic turns them on again.
- Operating systems are very large files. Be cautious of data charges. Sending over a direct serial or USB connection is recommended, when possible.

12.4 gzip

The CR1000X supports the ability to extract the contents of program, operating system, and other files that have been created using `gzip`. The file name must be in the format: *filename.fileextension.gz* (for example: `TestPgm.CR1X.gz`, `CR1000X.Std.01.obj.gz`, or `CR1000X.Std.01.web.obj.gz`).

For more information see: www.gzip.org.

Zipping a file can significantly reduce its size, resulting in fewer bytes to transfer when sending a zipped file to a data logger. This is especially beneficial over slow, high-latency, or costly telecommunications links. Therefore, those using low-baud-rate radios, satellite, or restricted cellular data plans should consider gzipping operating systems and large programs before sending.

Compatible files can be created using any utility that supports the `gzip` file format. Use a file `tarball` (*`filename`*`.tar.gz`) to compress multiple files. Several free utilities provide zipping to these formats.

Send the zipped file to the **CPU:**, **CRD:** or **USB:** drive using data logger support software. Files sent using **Connect** > **Send Program** will be unzipped automatically. However, the data logger will not automatically unzip files that are sent using **File Control** > **Send File**. To unzip files sent with **File Control**, mark them as **Run Now**.

Unzipping and installing file contents takes a long time; expect several minutes for operating systems and additional time for `.web` files. The details of unzipping and installing files from a `gzip` file are as follows:

1. The data logger receives the `gzip` file and restarts.
2. The data logger unzips the .gz file to the same drive to which it was sent.
3. The .tar portion of the file, if available, is processed.
4. Operating system (.obj or .iobj files) are programmed to the respective destination.
5. The data logger restarts.
6. When an .obj file is involved the OS will be loaded by the boot code resulting in another restart.
7. Web user interface (`.web`) files, if available, are installed. This may take over ten minutes.

NOTE:
Compression has little effect on an encrypted program (`FileEncrypt()`) and on files that already employ compression such as JPEG or MP4.

TIP:
The data logger also has the ability to compress files using `GZip()`. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

12.5 File management via powerup.ini

Another way to upload a program, install a data logger OS, or format a drive is to create a `powerup.ini` file. The file is created with a text editor and saved to a memory card or SC115 with the associated files. Alternatively, the `powerup.ini` file and associated files can be saved to the data logger using the data logger support software **File Control** > **Send** command. With the memory card or SC115 connected, or with the `powerup.ini` file saved in the data logger memory, a power cycle to the data logger begins the process chosen in the `powerup.ini` file.

- When the CR1000X powers up, it executes commands in the `powerup.ini` file (on an attached mass storage device or memory card) including commands to set the CRBasic

program file attributes to **Run Now** or **Run on Power Up**.
- When the CR1000X powers up, a program file marked as **Run on Power Up** will be the current program.
- If the program cannot be compiled or if no program is specified, the data logger will attempt to run the program named `default.CR1X` on its CPU: drive.
- If there is no `default.CR1X` file or it cannot be compiled, the CR1000X will not automatically run any program.

See Default program (p. 121) for more information.

Syntax for the **powerup.ini** file and available options follow.

12.5.1 Syntax

Syntax for `powerup.ini` is:

`Command,File,Device`

where,

- `Command` is one of the numeric commands in the following table.
- `File` is the accompanying operating system or user program file.
- `Device` is the data logger memory drive to which the accompanying operating system or user program file is copied (usually CPU). If left blank or with an invalid option, default device will be CPU. Use the same drive designation as the transporting external device if the preference is to not copy the file.

WARNING:
Uploading a program, installing a data logger OS, or formatting a drive may result in data loss. Depending on several factors, the data logger may also become incapacitated for a time. It is recommended that you retrieve data from the data logger and back up your programs before sending a powerup.ini file; otherwise, data may be lost. To collect data using ***LoggerNet***, connect to your data logger and click **Collect Now**. To backup your data logger, connect to it in ***Device Configuration Utility***, click the **Backup** menu and select **Backup Datalogger**.

Table 12-1: Powerup.ini commands		
Command	**Action**	**Details**
1	Run always, preserve data	Copies a program file to a drive and sets the program to both **Run Now** and **Run on Power Up**. Data on a memory card from the previously running program will be preserved if table structures have not changed.
2	Run on power up	Copies a program file to a drive and sets the program to **Run Always** unless command **6** or **14** is used to set a separate **Run Now** program.
5	Format	Formats a drive.
6	Run now, preserve data	Copies a program file to a drive and sets the program to **Run Now**. Data on a memory card from the previously running program will be preserved if table structures have not changed.
7	Copy support files	Copies a file, such as an Include or program support file, to the specified drive.
9	Load OS (File= .obj)	Loads an `.obj` file to the CPU drive and then loads the `.obj` file as the new data logger operating system.
13	Run always, erase data	Copies a program to a drive and sets the program to both **Run Now** and **Run on Power Up**. Data on a memory card from the previously running program will be erased.
14	Run now, erase data	Copies a program to a drive and sets the program to **Run Now**. Data on a memory card from the previously running program will be erased.
15	Move file	Moves a file, such as an Include or program support file, to the specified drive.

12.5.2 Example powerup.ini files

Comments can be added to the file by preceding them with a single-quote character ('). All text after the comment mark on the same line is ignored.

> TIP:
> Test the `powerup.ini` file and procedures in the lab before going to the field. Always carry a laptop or mobile device (with data logger support software) into difficult- or expensive-to-

access places as backup.

Example: Code Format and Syntax

```
'Command = numeric power up command
'File = file associated with the action
'Device = device to which File is copied. Defaults to CPU
'Command,File,Device
13,Write2CRD_2.CR1X,cpu:
```

Example: Run Program on Power Up

```
'Copy program file pwrup.CR1X from the external drive to CPU:
'File will run only when the data logger is powered-up later.
2,pwrup.CR1X,cpu:
```

Example: Format the USR Drive

5,,usr:

Example: Send OS on Power Up

```
'Load an operating system (.obj) file into FLASH as the new OS
9,CR1000X.Std.01.obj
```

Example: Run Program from SC115 Flash Memory Drive

```
'A program file is carried on an SC115 Flash Memory drive.
'Do not copy program file from SC115
'Run program always, erase data.

13,toobigforcpu.CR1X,usb:
```

Example: Always Run Program, Erase Data

```
13,pwrup_1.CR1X,cpu:
```

Example: Run Program Now and Erase Data Now

```
14,run.CR1X,cpu:
```

13. Tips and troubleshooting

Start with these basic procedures if a system is not operating properly.

1. Ensure your system is well grounded. See Grounds (p. 13). The symptoms of a poorly grounded system range from bad measurements, to intermittent communications, to damaged hardware.
2. Using a voltmeter, check the voltage of the primary power source at the **POWER IN** terminals on the face of the data logger, it should be 10 to 18 VDC.
3. Check wires and cables for the following:
   - Incorrect wiring connections. Make sure each sensor and device are wired to the terminals assigned in the program. If the program was written in ***Short Cut***, check wiring against the generated wiring diagram. If written in ***CRBasic Editor***, check wiring against each measurement and control instruction.
   - Loose connection points
   - Faulty connectors
   - Cut wires
   - Damaged insulation, which allows water to migrate into the cable. Water, whether or not it comes in contact with wire, can cause system failure. Water may increase the dielectric constant of the cable sufficiently to impede sensor signals, or it may migrate into the sensor, which will damage sensor electronics.
4. Check the CRBasic program. If the program was written solely with ***Short Cut***, the program is probably not the source of the problem. If the program was written or edited with ***CRBasic Editor***, logic and syntax errors could easily have crept in. To troubleshoot, create a simpler version of the program, or break it up into multiple smaller units to test individually. For example, if a sensor signal-to-data conversion is faulty, create a program that only measures that sensor and stores the data, absent from all other inputs and data.
5. Reset the data logger. Sometimes the easiest way to resolve a problem is by resetting the data logger (see Resetting the data logger (p. 150) for more information).

For additional troubleshooting options, see:

Also, consider checking, or posting your question to, the Campbell Scientific user forum https://www.campbellsci.com/forum. Our web site www.campbellsci.com has additional manuals (with example programs), FAQs, specifications and compatibility information for all of our products.

Video tutorials www.campbellsci.com/videos and blog articles www.campbellsci.com/blog are also useful troubleshooting resources.

13.1 Checking station status

View the condition of the data logger using **Station Status**. Here you see the operating system version of the data logger, the name of the current program, program compile results, and other key indicators. Items that may need your attention appear in red or blue. The following information describes the significance of some entries in the station status window. Watch a video at: https://www.campbellsci.com/videos/connect-station-status or use the following instructions.

13.1.1 Viewing station status

Using your data logger support software, access the **Station Status** to view the condition of the data logger.

- From ***LoggerNet***: Click **Connect**, then **Station Status** to view the **Summary** tab.
- From ***PC400***: Select the **Datalogger** menu and **Station Status** to view the **Summary** tab.

13.1.2 Watchdog errors

Watchdog errors indicate that the data logger has crashed and reset itself. Experiencing occasional watchdog errors is normal. You can reset the Watchdog error counter in the **Station Status** > **Status Table**.

> **TIP:**
> Before resetting the counter, make note of the number accumulated and the date.

Watchdog errors could be due to:

- Transient voltage
- Incorrectly wired or malfunctioning sensor
- Poor ground connection on the power supply
- Numerous `PortSet()` instructions back-to-back with no delay
- High-speed serial data on multiple ports with very large data packets or bursts of data

The error "Results for Last Program Compiled: Warning: Watchdog Timer IpTask Triggered" can result from:

- The IP communications on the data logger got stuck, and the data logger had to reboot itself to recover. Or communications failures may cause the data logger to reopen the IP connections more than usual. Check your data logger operating system version; recent operating system versions have improved stability of IP communications.

If any of these are not the apparent cause, contact Campbell Scientific for assistance (see https://www.campbellsci.com/support). Causes that may require assistance include:

- Memory corruption
- Operating System problem
- Hardware problem
- IP communications problem

13.1.3 Results for last program compiled

Messages generated by the data logger at program upload and as the program runs are reported here. Warnings indicate that an expected feature may not work, but the program will still operate. Errors indicate that the program cannot run. For more information, see CRBasic program errors (p. 149).

13.1.4 Skipped scans

Skipped scans are caused when a program takes longer to process than the scan interval allows. If any scan skips repeatedly, the data logger program may need to be optimized or reduced. For more information, see: How to Prevent Skipped Scans and a Sunburn.

13.1.5 Skipped records

Skipped records usually occur because a scan is skipped. They indicate that a record was not stored to the data table when it should have been.

13.1.6 Variable out of bounds

Variable-out-of-bounds errors happen when an array is not sized to the demands of the program. The data logger attempts to catch out-of-bounds errors at compile time. However, it is not always possible; when these errors occur during runtime the variable-out-of-bounds field increments. Variable-out-of-bounds errors are always caused by programming problems.

13.1.7 Battery voltage

If powering through USB, reported battery voltage should be 0 V. If connecting to an external power source, battery voltage should be reported at or near 12 V. See also:

- Power input (p. 11)
- Power requirements (p. 209)

13.2 Understanding NAN and INF occurrences

NAN (not a number) and INF (infinite) are data words indicating an exceptional occurrence in data logger function or processing. **INF** indicates that the program has encountered an undefined arithmetic expression, such as 0 ÷ 0. **NAN** indicates an invalid measurement. For more information, see Tips and Tricks: Who's NAN?.

NANs are expected in the following conditions:

- Input signals exceed the voltage range chosen for the measurement.
- An invalid SDI-12 command is sent.
- An SDI-12 sensor does not respond or aborts without sending data.

NAN is a constant that can be used in expressions. This is shown in the following example code that sets a CRBasic variable to False when the wind direction is **NAN**:

```
If WindDir = NAN Then
 WDFlag = False
Else
 WDFlag = True
EndIf
```

If an output processing instruction encounters a **NAN** in the values being processed, **NAN** will be stored. For example, if one measurement in a data storage interval results in **NAN**, then the average, maximum and minimum will record **NAN**. However, because **NAN** is a constant, it can be used in conjunction with the disable variable parameter (`DisableVar`) in output processing instructions. Use *variable* = **NAN** in the `DisableVar` parameter to discard **NAN**s from affecting the other good values. The following example code discards NAN WindSpeed measurements from the Minimum output:

```
Minimum (1,WindSpeed,FP2,WindSpeed=NAN,False)
```

> NOTE:
> There is no such thing as **NAN** for integers. Values that are converted from float to integer will be expressed in data tables as the most negative number for a given data type. For example, the most negative number of data type FP2 is –7999; so, **NAN** for FP2 data will appear in a data table as –7999. If the data type is Long, **NAN** will appear in the data table as –2147483648.

13.3 Timekeeping

Measurement of time is an essential data logger function. Time measurement with the onboard clock enables the data logger to run on a precise interval, attach time stamps to data, measure the interval between events, and time the initiation of control functions. Details on clock accuracy and resolution are available in the System specifications (p. 208). An internal lithium battery backs the clock when the data logger is not externally powered (see Internal battery (p. 132)).

13.3.1 Clock best practices

When setting the clock with ***LoggerNet***, initiate it manually during a maintenance period when the data logger is not actively writing to Data Tables. Click **Set** in the Clocks field of the ***LoggerNet*** Connect Screen.

If you are going to use automated clock check with ***LoggerNet*** (clock settings can be found on the ***LoggerNet*** Setup Standard View **Clock** tab). it is recommended that you do this on the order of days (not hours). Set an allowed clock deviation that is appropriate for the expected jitter in the network, and use the initial time setting to offset the clock check away from storage and measurement intervals.

The amount of time required for a **Clock Check** command to reach the data logger, be processed, and for it to send its response is called round-trip time, or time-of-flight. To calculate an estimate of this time-of-flight, ***LoggerNet*** maintains a history (in order) of the round-trip times for the ten previous successful clock check transactions. It adds this average to the time values received from the data logger and subtracts it from any adjustment that it might make.

13.3.2 Time stamps

A measurement without an accurate time reference often has little meaning. Data collected from data loggers is stored with time stamps. How closely a time stamp corresponds to the actual time a measurement is taken depends on several factors.

The time stamp in common CRBasic programs matches the time at the beginning of the current scan as measured by the real-time data logger clock. If a scan starts at 15:00:00, data output during that scan will have a time stamp of **15:00:00** regardless of the length of the scan, or when in the scan a measurement is made. The possibility exists that a scan will run for some time before a measurement is made. For instance, a scan may start at 15:00:00, execute a time-consuming part of the program, then make a measurement at 15:00:00.51. The time stamp attached to the measurement, if the `CallTable()` instruction is called from within the `Scan()` / `NextScan` construct, will be **15:00:00**, resulting in a time-stamp skew of 510 ms.

13.3.3 Avoiding time skew

Time skew between consecutive measurements is a function of settling and integration times, ADC, and the number entered into the `Reps` parameter of CRBasic instructions. A close approximation is:

> time skew = reps * (settling time + integration time + ADC time) + instruction setup time
> where ADC time equals 170 μs, and instruction setup time is 15 μs.
> If reps (repetitions) > 1 (multiple measurements by a single instruction), no setup time is required. If reps = 1 for consecutive voltage instructions, include the setup time for each instruction.

Time-stamp skew is not a problem with most applications because:

- Program execution times are usually short; so, time-stamp skew is only a few milliseconds. Most measurement requirements allow for a few milliseconds of skew.
- Data processed into averages, maxima, minima, and so forth are composites of several measurements. Associated time stamps only reflect the time of the scan when processing

calculations were completed; so, the significance of the exact time a specific sample was measured diminishes.

Applications measuring and storing sample data wherein exact time stamps are required can be adversely affected by time-stamp skew. Skew can be avoided by:

- Making measurements in the scan before time-consuming code.
- Programming the data logger such that the time stamp reflects the system time rather than the scan time using the `DataTime()` instruction. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

13.4 CRBasic program errors

Analyze data soon after deployment to ensure the data logger is measuring and storing data as intended. Most measurement and data-storage problems are a result of one or more CRBasic program bugs. Watch a video: CRBasic | Common Errors - Identifying and fixing common errors in the CRBasic programming language.

13.4.1 Program does not compile

When a program is compiled, the ***CRBasic Editor*** checks the program for syntax errors and other inconsistencies. The results of the check are displayed in a message window at the bottom of the main window. If an error can be traced to a specific line in the program, the line number will be listed before the error. Double-click an error preceded by a line number and that line will be highlighted in the program editing window. Correct programming errors and recompile the program.

Occasionally, the ***CRBasic Editor*** compiler states that a program compiles OK; however, the program may not compile in the data logger itself. This is rare, but reasons may include:

- The data logger has a different operating system than the computer compiler. Check the two versions if in doubt. The computer compiler version is shown on the first line of the compile results. Update the computer compiler by first downloading the executable OS file from www.campbellsci.com. When run, the executable file updates the computer compiler. To update the data logger operating system, see Updating the operating system (p. 135).
- The program has large memory requirements for data tables or variables and the data logger does not have adequate memory. This normally is flagged at compile time in the compile results. If this type of error occurs:

- Check the CPU drive for copies of old programs. The data logger keeps copies of all program files unless they are deleted, the drive is formatted, or a new operating system is loaded with ***Device Configuration Utility***.
- Check the USR drive size. If it is too large it may be using memory needed for the program.
- Ensure a memory card is available when a program is attempting to access the CRD drive.

13.4.2 Program compiles but does not run correctly

If the program compiles but does not run correctly, timing discrepancies may be the cause. If a program is tight on time, look further at the execution times. Check the measurement and processing times in the **Status** table (**MeasureTime**, **ProcessTime**, **MaxProcTime**) for all scans, then try experimenting with the `InstructionTimes()` instruction in the program. Analyzing `InstructionTimes()` results can be difficult due to the multitasking nature of the data logger, but it can be a useful tool for fine-tuning a program. For more information, see Information tables and settings (advanced) (p. 178).

See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

13.5 Resetting the data logger

A data logger reset is sometimes referred to as a "memory reset." Backing up the current data logger configuration before a reset makes it easy to revert to the old settings. To back up the data logger configuration, connect to the data logger using Device Configuration Utility, and click **Backup** > **Back Up Datalogger**. To restore a configuration after the data logger has been reset, connect and click **Backup** > **Restore Datalogger**.

The following features are available for complete or selective reset of data logger memory:

- Processor reset
- Program send reset
- Manual data table reset
- Formatting memory drives
- Full memory reset

13.5.1 Processor reset

To reset the processor, simply power cycle the data logger. This resets its short-term memory, restarts the current program, sets variables to their starting values, and clears communications buffers. This does not clear data tables but may result in a skipped record. If the data logger is remote, a power cycle can be mimicked in a **Terminal Emulator** program (type REBOOT <Enter>).

13.5.2 Program send reset

Final-data memory is erased when user programs are uploaded, unless preserve / erase data options are used and the program was not altered. Preserve / erase data options are presented when sending programs using File Control **Send** command and ***CRBasic Editor*** **Compile, Save and Send**.

> **TIP:**
> It is good practice to always retrieve data from the data logger before sending a program; otherwise, data may be lost. See Collecting data (p. 35) for detailed instruction.

When a program compiles, all variables are initialized. A program is recompiled after a power failure or a manual stop. For instances that require variables to be preserved through a program recompile, consider `PreserveVariables()`.

13.5.3 Manual data table reset

Data table memory is selectively reset from:

- Datalogger support software: **Station Status** > **Table Fill Times** tab, **Reset Tables**.
- ***Device Configuration Utility***: **Data Monitor** tab, **Reset Table** button.
- CR1000KD Keyboard/Display add-on: **Data** > **Reset Data Tables**.

13.5.4 Formatting drives

CPU, USR, CRD (memory card required), and USB (module required) drives can be formatted individually. Formatting a drive erases all files on that drive. If the currently running user program is on the drive to be formatted, the program will cease running and data associated with the program are erased. Drive formatting is performed through the data logger support software **File Control** > **Format** command.

13.5.5 Full memory reset

Full memory reset occurs when an operating system is sent to the data logger using ***Device Configuration Utility*** or when entering `98765` in the **Status** table field **FullMemReset** (see Information tables and settings (advanced) (p. 178)). A full memory reset does the following:

- Clears and formats CPU drive (all program files erased)
- Clears data tables.
- Clears **Status** table fields.

- Restores settings to default.
- Initializes system variables.
- Clears communications memory.

Full memory reset does not affect the CRD drive directly. Subsequent user program uploads, however, can erase CRD. See Updating the operating system (p. 135) for more information.

13.6 Troubleshooting power supplies

Power supply systems may include batteries, charging regulators, and a primary power source such as solar panels or ac/ac or ac/dc transformers attached to mains power. All components may need to be checked if the power supply is not functioning properly. Check connections and check polarity of connections.

Base diagnostic: connect the data logger to a new 12 V battery. (A small 12 V battery carrying a full charge would be a good thing to carry in your maintenance tool kit.) Ensure correct polarity of the connection. If the data logger powers up and works, troubleshoot the data logger power supply.

When diagnosing or adjusting power equipment supplied by Campbell Scientific, it is recommended you consider:

- Battery-voltage test
- Charging-circuit test (when using an unregulated solar panel)
- Charging-circuit test (when using a transformer)
- Adjusting charging circuit

If power supply components are working properly and the system has peripherals with high current drain, such as a satellite transmitter, verify that the power supply is designed to provide adequate power. For additional information, see Power budgeting (p. 126).

13.7 Using terminal mode

Table 13-1 (p. 153) lists terminal mode options. With exception of perhaps the **C** command, terminal options are not necessary to routine CR1000X operations.

To enter terminal mode, connect a computer to the CR1000X. See Setting up communications with the data logger (p. 21). Open a terminal emulator program from Campbell Scientific data logger support software:

- **Connect** window > **Datalogger** menu item> **Terminal Emulator...**
- ***Device Configuration Utility*** **Terminal** tab

After entering a terminal emulator, press **Enter** a few times until the prompt **CR1000X>** is returned. Terminal commands consist of specific characters followed by **Enter**. Sending an **H** and **Enter** will return the terminal emulator menu.

ESC or a 40 second timeout will terminate on-going commands. Concurrent terminal sessions are not allowed and will result in dropped communications.

Terminal commands are subject to change. Please consult Campbell Scientific for assistance if you are not familiar with the effects of a command.

Table 13-1: CR1000X terminal commands

Command	Description	Use
0	Scan processing time; real time in seconds	Lists technical data concerning program scans.
1	Serial FLASH data dump	Campbell Scientific engineering tool
2	Read clock chip	Lists binary data concerning the CR1000X clock chip.
3	Status	Lists the CR1000X **Status** table.
4	Card status and compile errors	Lists technical data concerning an installed memory card.
5	Scan information	Technical data regarding the CR1000X scan.
6	Raw A/D values	Technical data regarding analog-to-digital conversions.
7	VARS	Lists **Public** table variables.
8	Suspend / start data output	Outputs all table data. This is not recommended as a means to collect data, especially over comms. Data are dumped as non-error checked ASCII.
9	Read inloc binary	Lists binary form of **Public** table.
A	Operating system copyright	Lists copyright notice and version of operating system.
B	Task sequencer op codes	Technical data regarding the task sequencer.
C	Modify constant table	Edit constants defined with **ConstTable** / **EndConstTable**. Only active when **ConstTable** / **EndConstTable** in the active program.
D	MTdbg() task monitor	Campbell Scientific engineering tool

Table 13-1: CR1000X terminal commands		
Command	Description	Use
E	Compile errors	Lists compile errors for the current program download attempt.
F	Settings and predefined constants names	Lists predefined constants and settings
G	CPU serial flash dump	Campbell Scientific engineering tool
H	Terminal emulator menu	Lists main menu.
I	Calibration data	Lists gains and offsets resulting from internal calibration of analog measurement circuitry.
J	Download file dump	Sends text of current program including comments.
L	Peripheral bus read	Campbell Scientific engineering tool
M	Memory check	Lists memory-test results
N	File system information	Lists files in CR1000X memory.
O	Data table sizes	Lists technical data concerning data-table sizes.
P	Serial talk through	Issue commands from keyboard that are passed through the logger serial port to the connected device. Similar in concept to SDI12 Talk Through. No timeout when connected via PakBus.
REBOOT	Program recompile	Typing “REBOOT” rapidly will recompile the CR1000X program immediately after the last letter, "T", is entered. Table memory is retained. NOTE: When typing **REBOOT**, characters are not echoed (printed on terminal screen).
SDI12	SDI12 talk through	Issue commands from keyboard that are passed through the CR1000X SDI-12 port to the connected device. Similar in concept to Serial Talk Through. See also SDI-12 transparent mode (p. 155)
T	Unused	
U	Data recovery	Provides the means by which data lost when a new program is loaded may be recovered. Contact Campbell Scientific support.

Table 13-1: CR1000X terminal commands		
Command	Description	Use
V	Low level memory dump	Campbell Scientific engineering tool
W	Comms Watch (Sniff)	Enables monitoring of CR1000X communications traffic. No timeout when connected via PakBus.
X	Peripheral bus module identify	Campbell Scientific engineering tool

13.7.1 Serial talk through and comms watch

The **P: Serial Talk Through** and **W: Comms Watch** ("sniff") modes do not have a timeout when connected in terminal mode via PakBus. Otherwise, the timeout can be changed from the default of 40 seconds to any value ranging from 1 to 86400 seconds (86400 seconds = 1 day).

When using options **P** or **W** in a terminal session, consider the following:

- Concurrent terminal sessions are not allowed by the CR1000X.
- Opening a new terminal session will close the current terminal session.
- The data logger will attempt to enter a terminal session when it receives non-PakBus characters on the **RS-232** port or **CS I/O** port, unless the port is first opened with the `SerialOpen()` instruction.

If the data logger attempts to enter a terminal session on the **RS-232** port or **CS I/O** port because of an incoming non-PakBus character, and that port was not opened using `SerialOpen()`, any currently running terminal function, including the comms watch, will immediately stop. So, in programs that frequently open and close a serial port, the probability is higher that a non-PakBus character will arrive at the closed serial port, thus closing an existing talk-through or comms watch session. If this occurs, use the **FilesManager** setting to send comms watch or sniffer to a file.

For more information on Comms Watch, see a video at: https://www.campbellsci.com/videos/sdi12-sensors-watch-or-sniffer-mode ▶.

13.7.2 SDI-12 transparent mode

All SDI-12 probes have just three wires—a signal, ground, and 12 V power line. They are connected to the data logger according to the following table.

Table 13-2: SDI-12 probe connections

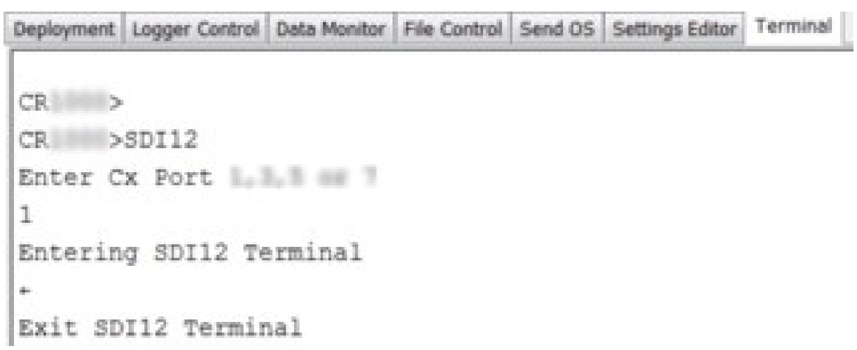
Wire function	Data logger connection
SDI-12 signal	C
Shield	⏚ (analog ground)
Power	12V
Power ground	G

System operators can manually interrogate and enter settings in probes, connected to the data logger, using transparent mode. Transparent mode is useful in troubleshooting SDI-12 systems because it allows direct communications with probes.

Transparent mode may need to wait for commands issued by the programmed mode to finish before sending responses. While in transparent mode, the data logger programs may not execute. Data logger security may need to be unlocked before transparent mode can be activated.

Transparent mode is entered while the computer is communicating with the data logger through a terminal emulator program such as through ***Device Configuration Utility*** or other data logger support software. Keyboard displays cannot be used. For how-to instructions for communicating directly with an SDI-12 sensor using a terminal emulator, watch this video: https://www.campbellsci.com/videos/sdi12-sensors-transparent-mode.

To enter the SDI-12 transparent mode, enter the data logger support software terminal emulator:



1. Press **Enter** until the data logger responds with the prompt **`CR1000X>`**.
2. Type **`SDI12`** at the prompt and press **Enter**.
3. In response, the query **`Select SDI12 Port`** is presented with a list of available ports. Enter the port number assigned to the terminal to which the SDI-12 sensor is connected, and press **Enter**. For example, **`1`** is entered for terminal **C1**.

4. An `Entering SDI12 Terminal` response indicates that SDI-12 transparent mode is active and ready to transmit SDI-12 commands and display responses.

13.7.2.1 Watch command (sniffer mode)

The terminal-mode utility allows monitoring of SDI-12 traffic by using the watch command (sniffer mode). Watch an instructional video: https://www.campbellsci.com/videos/sdi12-sensors-watch-or-sniffer-mode or use the following instructions.

1. Enter the transparent mode as described previously.
2. Press **Enter** until a **CR1000X>** prompt appears.
3. Type `W` and then press **Enter**.
4. In response, the query `Select SDI12 Port:` is presented with a list of available ports. Enter the port number assigned to the terminal to which the SDI-12 sensor is connected, and press **Enter**.
5. In answer to `Enter timeout (secs):` type `100` and press **Enter**.
6. In response to the query `ASCII (Y)?`, type `Y` and press **Enter**.
7. SDI-12 communications are then opened for viewing.

13.7.2.2 SDI-12 transparent mode commands

SDI-12 commands and responses are defined by the SDI-12 Support Group (www.sdi-12.org) and are available in the SDI-12 Specification. Sensor manufacturers determine which commands to support. Commands have three components:

- Sensor address (**a**): A single character and the first character of the command. Sensors are usually assigned a default address of zero by the manufacturer. The wildcard address (**?**) is used in the `Address Query` command. Some manufacturers may allow it to be used in other commands. SDI-12 sensors accept addresses 0 through 9, a through z, and A through Z.
- Command body (for example, **M1**): An upper case letter (the “command”) followed by alphanumeric qualifiers.
- Command termination (**!**): An exclamation mark.

An active sensor responds to each command. Responses have several standard forms and terminate with <CR><LF> (carriage return–line feed).

13.8 Ground loops

A ground loop is a condition in an electrical system that contains multiple conductive paths for the flow of electrical current between two nodes. Multiple paths are usually associated with the ground or 0 V-potential point of the circuit. Ground loops can result in signal noise, communications errors, or a damaging flow of ground current on long cables. Most often, ground loops do not have drastic negative effects and may be unavoidable. Special cases exist where additional grounding helps shield noise from sensitive signals; however, in these cases, multiple ground conductors are usually run tightly in parallel without conductive shielding material placed between the parallel grounds. If possible, ground loops should be avoided. When problems arise in a system, ground loops may be the source of the problems.

See also Grounds (p. 13).

13.8.1 Common causes

Some of the common causes of ground loops include the following:

- The drain wire of a shielded cable is connected to the local ground at both ends, and the ground is already being carried by a conductor inside the cable. In this case, two wires, one on either side of the cable shield, are connected to the ground nodes at both ends of the cable.
- A long cable connects the grounds of two electrical devices, and the mounting structure or grounding rod also directly connects the grounds of each device to the local earth ground. The two paths, in this case, are the connecting cable and earth itself.
- When electrical devices are connected to a common metal chassis such as an instrument tower, the structure can create a ground path in parallel to the ground wires in sensor cables running over the structure.
- Conductors connected to ground are found in most cables that connect to a data logger. These include sensors cables, communications cables, and power cables. Any time one of these cables connects to the same two endpoints as another cable, a ground loop is formed.

13.8.2 Detrimental effects

The harm from a ground loop can be seen in different ways. One consideration is the electromagnetically induced effect. This will manifest as AC noise or an AC pulse. As seen in FIGURE 13-1 (p. 159) the parallel conductive paths form an electrical loop that acts as an antenna to pick up electromagnetic energy.

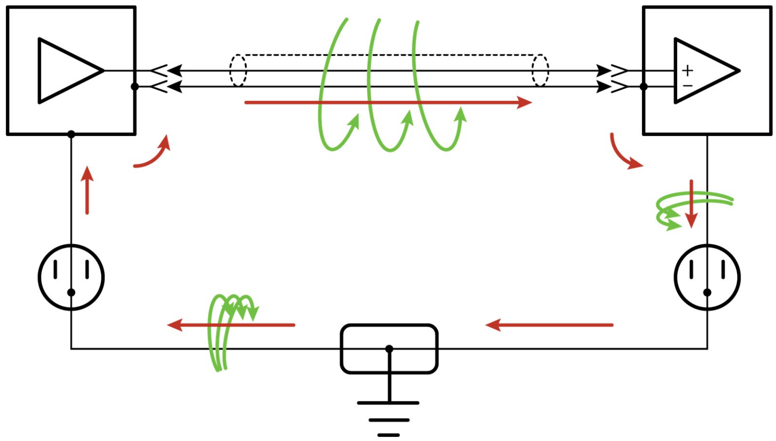


FIGURE 13-1. Stray AC magnetic fields picked up in loop antenna

- Relatively small electromagnetic energy: This could come from AC current on a nearby power cable, or RF energy transmitting through the air, and can cause electrical noise that either corrupts an analog signal or disrupts digital communications.
- Larger electromagnetic energy: The antenna loop scenario can have a more damaging effect when a large current is discharged nearby. The creation of an electromagnetic pulse can induce a surge that damages attached electronic devices.

Another way ground loops affect a system is by allowing ground current to flow between devices. This can be either a DC or AC effect. For various reasons, the voltage potential between two different points on the surface of the earth is not always 0 V. Therefore, when two electrical devices are both connected to a local earth ground, there may exist a voltage difference between the two devices. When a cable is connected between the two devices at different voltages, physics dictates than an electrical current must flow between the two points through the cable. See FIGURE 13-2 (p. 159).

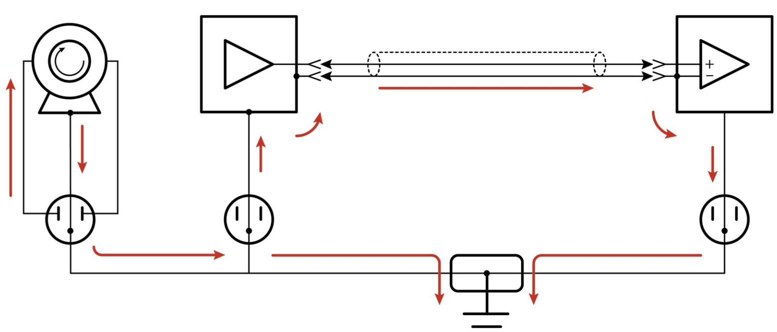


FIGURE 13-2. Leakage current (AC or DC) from nearby load

- One effect of this DC ground current-flow is a voltage offset error in analog measurements. Errors of this sort are usually not obvious but can have meaningful effects on measurements.
- For digital communications, an offset in the ground voltage reduces the dynamic range of the digital signals. This makes them more susceptible to noise corruption. If the ground voltage changes by one volt or more, the digital communications could stop working because the signals no longer reach the thresholds for determining the state of each bit.
- If the ground voltage differences reach several volts, damaging effects may occur at the terminals of the electronics devices. Damage occurs when the maximum allowable voltage on the internal components is exceeded.

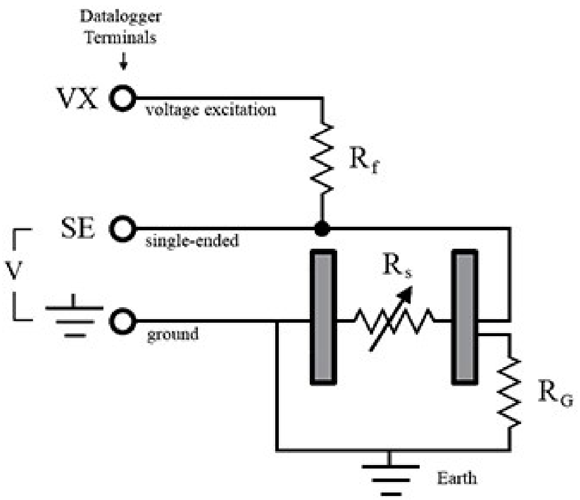
13.8.3 Severing a ground loop

To avoid or eliminate ground loops, when they are detected, requires severing the loop. Suggestions for severing ground loops include:

- Connect the shield wire of a signal cable to ground only at one end of the cable. Leave the other end floating (not connected to ground).
- Never intentionally use the shield (or drain wire) of a cable as a signal ground or power ground.
- Use the mechanical support structure only as a connection for the safety ground (usually the ground lug). Do not intentionally return power ground through the structure.
- Do not use shielded Cat5e cables for Ethernet, CPI or EPI communications.
- For long distance communications protocols such as RS-485, RS-422, and CAN, use a Resistive Ground (**RG**) terminal for the ground connection. The **RG** terminal has a 100-ohm resistor in series with ground to limit the amount of DC current that can flow between the two endpoints while keeping the common-mode voltage in range of the transceivers. The transceivers themselves have enhanced voltage range inputs allowing for ground voltage differences of up to 7 V between endpoints.
- For exceptional cases, use optical or galvanic isolation devices to provide a signal connection without any accompanying ground connection. These should be used only when ground loops are causing system problems and the other methods of breaking a ground loop don’t apply. These devices add expense and tend to consume large amounts of power.

13.8.4 Soil moisture example

When measuring soil moisture with a resistance block, or water conductivity with a resistance cell, the potential exists for a ground loop error. In the case of an ionic soil matric potential (soil moisture) sensor, a ground loop arises because soil and water provide an alternate path for the excitation to return to data logger ground. This example is modeled in the following image:



With R_g in the resistor network, the signal measured from the sensor is described by the following equation:

$$V_1 = V_x \frac{R_s}{(R_s + R_f) + R_s R_f / R_g}$$

where

- V_x is the excitation voltage
- R_f is a fixed resistor
- R_s is the sensor resistance
- R_g is the resistance between the excited electrode and data logger earth ground.

$R_s R_f / R_g$ is the source of error due to the ground loop. When R_g is large, the error is negligible. Note that the geometry of the electrodes has a great effect on the magnitude of this error. The Delmhorst gypsum block used in the Campbell Scientific 227 probe has two concentric cylindrical electrodes. The center electrode is used for excitation; because it is encircled by the ground electrode, the path for a ground loop through the soil is greatly reduced. Moisture blocks that consist of two parallel plate electrodes are particularly susceptible to ground loop problems. Similar considerations apply to the geometry of the electrodes in water conductivity sensors.

The ground electrode of the conductivity or soil moisture probe and the data logger earth ground form a galvanic cell, with the water/soil solution acting as the electrolyte. If current is allowed to flow, the resulting oxidation or reduction will soon damage the electrode, just as if DC excitation was used to make the measurement. Campbell Scientific resistive soil probes and conductivity probes are built with series capacitors to block this DC current. In addition to preventing sensor deterioration, the capacitors block any DC component from affecting the measurement.

13.9 Improving voltage measurement quality

The following topics discuss methods of generally improving voltage measurements:

Read More: Consult the following technical papers at www.campbellsci.com/app-notes for in-depth treatments of several topics addressing voltage measurement quality:

- Preventing and Attacking Measurement Noise Problems
- Benefits of Input Reversal and Excitation Reversal for Voltage Measurements
- Voltage Accuracy, Self-Calibration, and Ratiometric Measurements

13.9.1 Deciding between single-ended or differential measurements

Deciding whether a differential or single-ended measurement is appropriate is usually, by far, the most important consideration when addressing voltage measurement quality. The decision requires trade-offs of accuracy and precision, noise cancellation, measurement speed, available measurement hardware, and fiscal constraints.

In broad terms, analog voltage is best measured differentially because these measurements include the following noise reduction features that are not included in single-ended measurements.

- Passive Noise Rejection
  - No voltage reference offset
  - Common-mode noise rejection, which filters capacitively coupled noise
- Active Noise Rejection
  - Input reversal
  - For more information, see Compensating for offset voltage (p. 173).

Reasons for using single-ended measurements, however, include:

- Not enough differential terminals are available. Differential measurements use twice as many analog input terminals as do single-ended measurements.
- Rapid sampling is required. Single-ended measurement time is about half that of differential measurement time.
- Sensor is not designed for differential measurements. Some Campbell Scientific sensors are not designed for differential measurement, but the drawbacks of a single-ended measurement are usually mitigated by large programmed excitation and/or sensor output voltages.

Sensors with a high signal-to-noise ratio, such as a relative-humidity sensor with a full-scale output of 0 to 1000 mV, can normally be measured as single-ended without a significant reduction in accuracy or precision.

Sensors with a low signal-to-noise ratio, such as thermocouples, should normally be measured differentially. However, if the measurement to be made does not require high accuracy or precision, such as thermocouples measuring brush-fire temperatures, which can exceed 2500 °C, a single-ended measurement may be appropriate. If sensors require differential measurement, but adequate input terminals are not available, an analog multiplexer should be acquired to expand differential input capacity.

Because a single-ended measurement is referenced to data logger ground, any difference in ground potential between the sensor and the data logger will result in an error in the measurement. For more information on grounds, see Grounds (p. 13) and Minimizing ground potential differences (p. 163).

13.9.2 Minimizing ground potential differences

Low-level, single-ended voltage measurements (<200 mV) are sensitive to ground potential fluctuation due to changing return currents from **5V**,**12V**, **SW12**, and **C** terminals. The data logger grounding scheme is designed to minimize these fluctuations by separating signal grounds (⏚) from power grounds (**G**). For more information on data logger grounds, see Grounds (p. 13). To take advantage of this design, observe the following rules:

- Connect grounds associated with **5V**,**12V**, **SW12**, and **C** terminals to **G** terminals.
- Connect excitation grounds to the nearest ⏚ terminal on the same terminal block.
- Connect the low side of single-ended sensors to the nearest ⏚ terminal on the same terminal block.
- Connect shield wires to the ⏚ terminal nearest the terminals to which the sensor signal wires are connected.

If offset problems occur because of shield or ground wires with large current flow, tying the problem wires into terminals next to terminals configured for excitation and pulse-count should help. Problem wires can also be tied directly to the ground lug to minimize induced single-ended offset voltages.

13.9.2.1 Ground potential differences

Because a single-ended measurement is referenced to data logger ground, any difference in ground potential between the sensor and the data logger will result in a measurement error. Differential measurements MUST be used when the input ground is known to be at a different ground potential from data logger ground.

Ground potential differences are a common problem when measuring full-bridge sensors (strain gages, pressure transducers, etc), and when measuring thermocouples in soil.

- **Soil Temperature Thermocouple**: If the measuring junction of a thermocouple is not insulated when in soil or water, and the potential of earth ground is, for example, 1 mV greater at the sensor than at the point where the data logger is grounded, the measured voltage will be 1 mV greater than the thermocouple output. With a Type T (copper-constantan) thermocouple, 1 mV equates to approximately 25 °C measurement error.
- **External Signal Conditioner**: External instruments with integrated signal conditioners, such as an infrared gas analyzer (IRGA), are frequently used to make measurements and send analog information to the data logger. These instruments are often powered by the same VAC-line source as the data logger. Despite being tied to the same ground, differences in current drain and wire resistance result in different ground potentials at the two instruments. For this reason, a differential measurement should be made on the analog output from the external signal conditioner.

For additional information, see Minimizing offset voltages (p. 171).

13.9.3 Detecting open inputs

A useful option available to single-ended and differential measurements is the detection of open inputs due to a broken or disconnected sensor wire. This prevents otherwise undetectable measurement errors. Range codes appended with C enable open-input detection. For detailed information, see the CRBasic help (VoltSE() and VoltDiff() instructions, Range parameter)

The C option may not detect an open circuit in the following situations:

- When the input is not a truly open circuit, such as might occur on a wet cut cable end, the open circuit may not be detected because the input capacitor discharges to a normal voltage through external leakage to ground within the settling time of the measurement. This problem is worse when a long settling time is selected, as more time is given for the input capacitors to discharge to a "normal" level.
- If the open circuit is at the end of a very long cable, the test pulse may not charge the cable (with its high capacitance) up to a voltage that generates NAN or a distinct error voltage. The cable may even act as an aerial and inject noise which also might not read as an error voltage.
- The sensor may "object" to the test pulse being connected to its output, even for 100 µs. There is little or no risk of damage, but the sensor output may be caused to temporarily oscillate. Programming a longer settling time in the CRBasic measurement instruction to allow oscillations to decay before the ADC may mitigate the problem.

13.9.4 Minimizing power-related artifacts

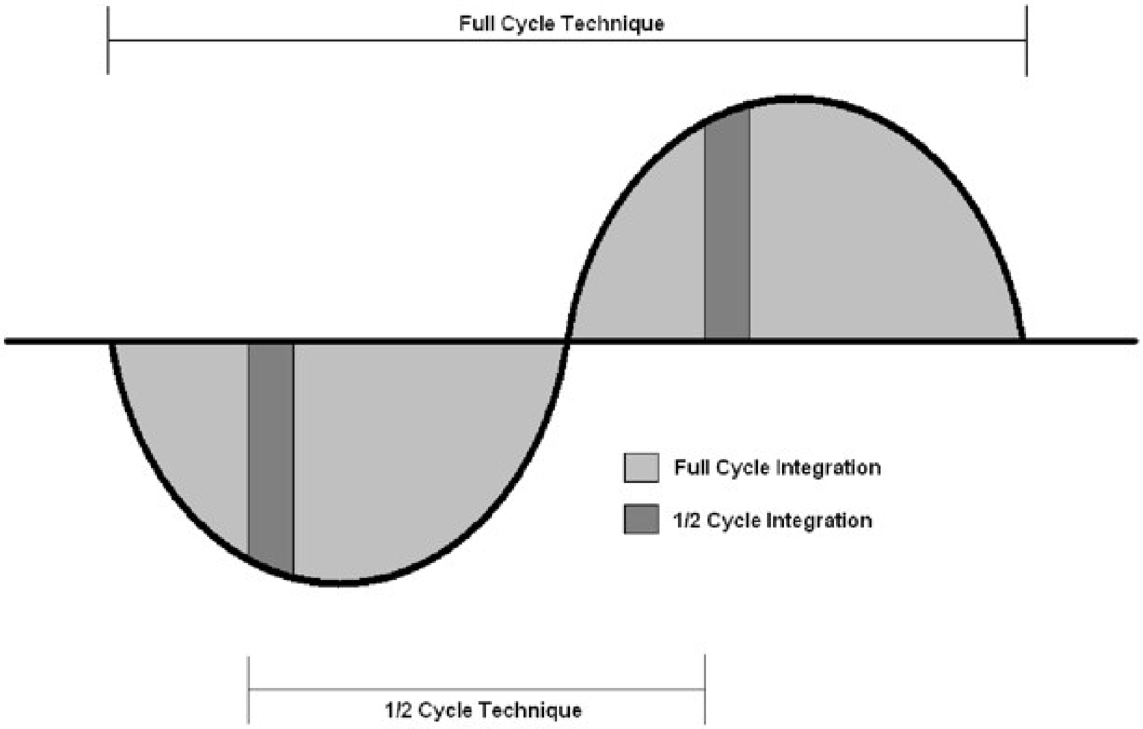
Some VAC-to-VDC power converters produce switching noise or AC ripple as an artifact of the ac-to-dc rectification process. Excessive switching noise on the output side of a power supply can increase measurement noise, and so increase measurement error. Noise from grid or mains power also may be transmitted through the transformer, or induced electromagnetically from nearby motors, heaters, or power lines.

High-quality power regulators typically reduce noise due to power regulation. Using the 50 Hz or 60 Hz first notch frequency (f_{N1}) option for CRBasic analog input measurement instructions often improves rejection of noise sourced from power mains. The CRBasic standard deviation output instruction, StdDev(), can be used to evaluate measurement noise.

The data logger includes adjustable digital filtering, which serves two purposes:

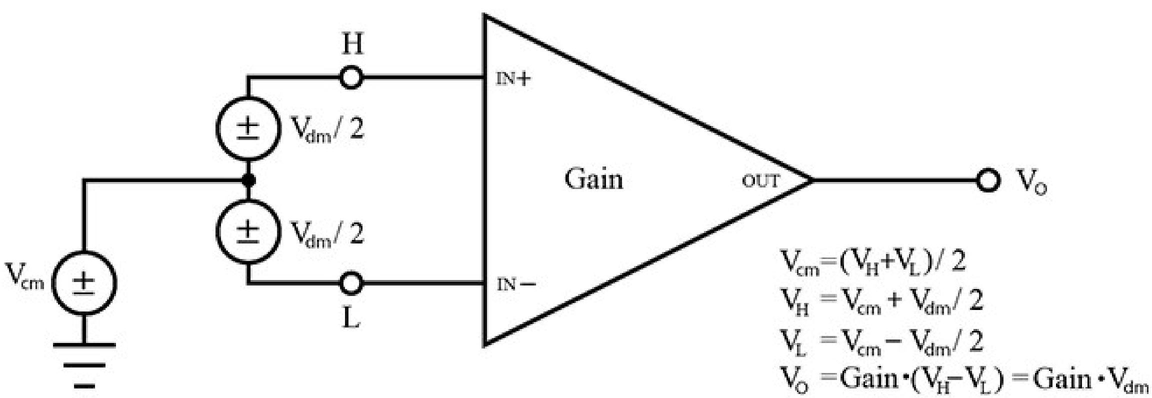
- Arrive as close as possible to the true input signal
- Filter out measurement noise at specific frequencies, the most common being noise at 50 Hz or 60 Hz, which originate from mains-power lines.

Filtering time is inversely proportional to the frequency being filtered.



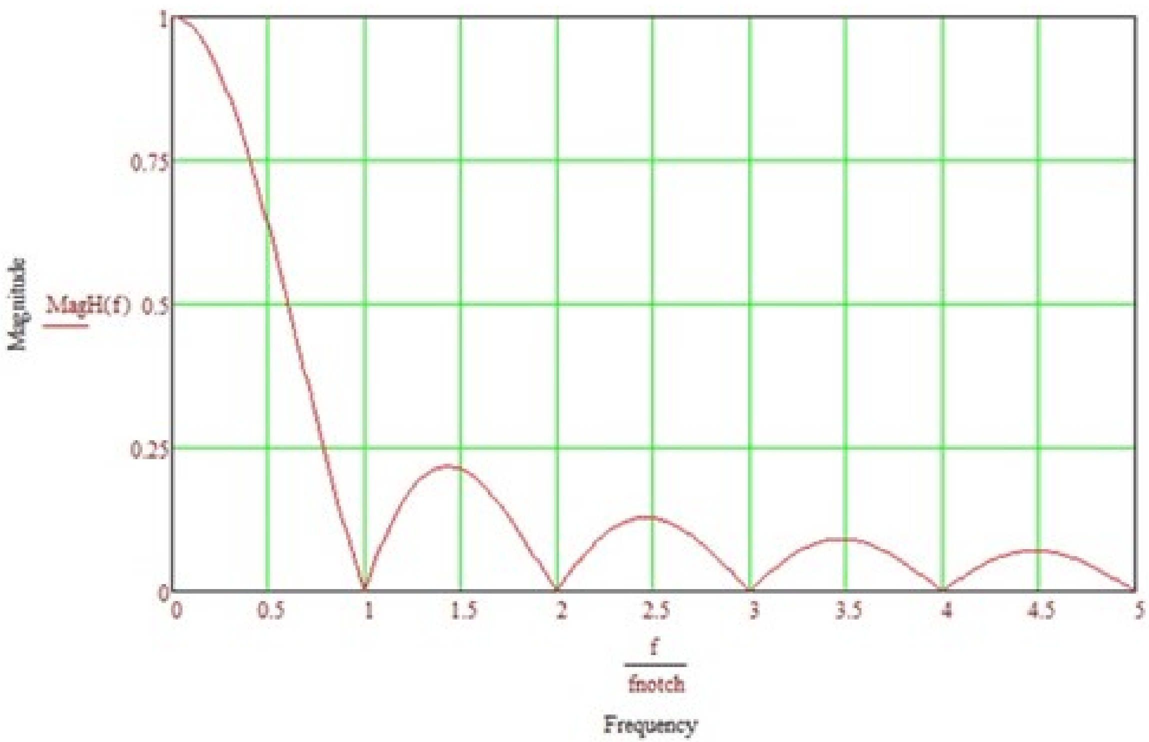
13.9.4.1 Minimizing electronic noise

Electronic noise can cause significant error in a voltage measurement, especially when measuring voltages less than 200 mV. So long as input limitations are observed, the PGA ignores voltages, including noise, that are common to each side of a differential-input pair. This is the common-mode voltage. Ignoring (rejecting or canceling) the common-mode voltage is an essential feature of the differential input configuration that improves voltage measurements. The following image illustrates the common-mode component (V_{cm}) and the differential-mode component (V_{dm}) of a voltage signal. V_{cm} is the average of the voltages on the V+ and V– inputs. So, V_{cm} = (V+ + V–)/2 or the voltage remaining on the inputs when V_{dm} = 0. The total voltage on the V+ and V– inputs is given as $V_H = V_{cm} + V_{dm}/2$, and $V_L = V_{cm} - V_{dm}/2$, respectively.



13.9.5 Filtering to reduce measurement noise

An adjustable filter is applied to analog measurements, reducing signal components at selected frequencies. The following figure shows the filter frequency response. Using the first notch frequency (`fN1`) parameter, users can select the placement of the filter notches. The first notch falls at the specified `fN1`, and subsequent notches fall at integer multiples of `fN1`. Commonly, `fN1` is set at 50 or 60 Hz to filter 50 or 60 Hz signal components, reducing noise from ac power mains.



Filtering comes at the expense of measurement time. The time required for filtering is equal to $1/f_{N1}$. For example, setting `fN1` equal to 50 will require 1/50 sec (20 ms) for filtering. As `fN1` is set to smaller values, random noise in the measurement results decreases, while measurement time increases. The total time required for a single result includes settling + filtering + overhead.

Consult the following technical paper at www.campbellsci.com/app-notes for in-depth treatment of measurement noise: Preventing and Attacking Measurement Noise Problems.

13.9.5.1 CR1000X filtering details

The data logger utilizes a sigma-delta ADC that outputs digitized data at a rate of 31250 samples per second. User-specified filtering is achieved by averaging several samples from the ADC. Recall that averaging the signal over a period of $1/f_{N1}$ seconds will filter signal components at f_{N1} Hz. The final result, then, is the average calculated from $31250/f_{N1}$ samples. For example, if `fN1` is set to 50 Hz, 625 samples (31250 / 50) are averaged to generate the final filtered result.

The actual f_{N1} may deviate from the user-specified setting since a whole integer number of samples must be averaged. For example, if `fN1` is set to 60 Hz, 521 samples (31250 / 60 = 520.83) will be averaged to produce the filtered result. The rounding of 520.83 to 521 moves the actual f_{N1} to 31250 / 521 = 59.98 Hz.

13.9.6 Minimizing settling errors

Settling time allows an analog voltage signal to rise or fall closer to its true magnitude prior to measurement. Default settling times, those resulting when the `SettlingTime` parameter is set to `0`, provide sufficient settling in most cases. Additional settling time is often programmed when measuring high-resistance (high-impedance) sensors, or when sensors connect to the input terminals by long cables. The time to complete a measurement increases with increasing settling time. For example, a 1 ms increase in settling time for a bridge instruction with input reversal and excitation reversal results in a 4 ms increase in time to perform the instruction.

When sensors require long cable lengths, use the following general practices to minimize settling errors:

- Do not use leads with PVC-insulated conductors. PVC has a high dielectric constant, which extends input settling time.
- Where possible, run excitation leads and signal leads in separate shields to minimize transients.
- When measurement speed is not a prime consideration, additional time can be used to ensure ample settling time.
- In difficult cases where measurement speed is a consideration, an appropriate settling time can be determined through testing.

13.9.6.1 Measuring settling time

Settling time for a particular sensor and cable can be measured with the CR1000X. Programming a series of measurements with increasing settling times will yield data that indicate at what settling time a further increase results in negligible change in the measured voltage. The programmed settling time at this point indicates the settling time needed for the sensor / cable combination.

The following **CRBasic Example: Measuring Settling Time** presents CRBasic code to help determine settling time for a pressure transducer using a high-capacitance semiconductor. The code consists of a series of full-bridge measurements () with increasing settling times. The pressure transducer is placed in steady-state conditions so changes in measured voltage are attributable to settling time rather than changes in pressure.

CRBasic Example 3: Measuring Settling Time

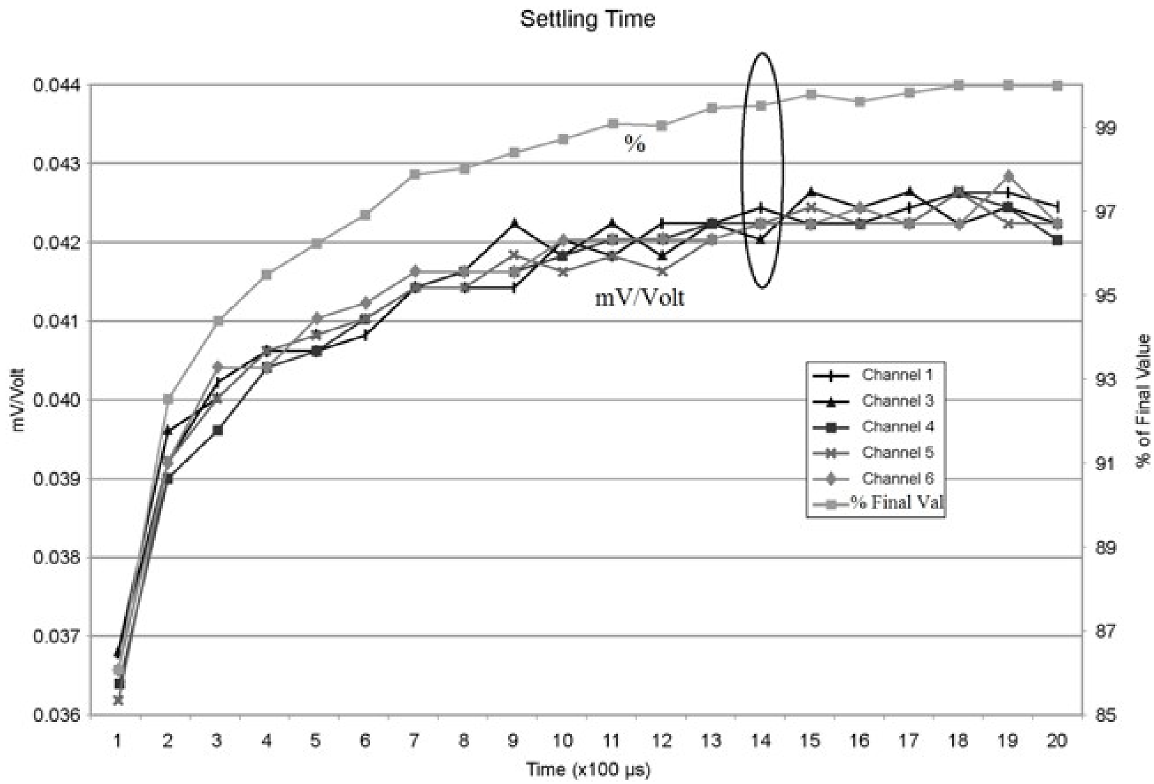
```
'This program example demonstrates the measurement of settling time
'using a single measurement instruction multiple times in succession.
Public PT(20) 'Variable to hold the measurements
DataTable(Settle,True,100)
  Sample(20,PT(),IEEE4)
EndTable
BeginProg
  Scan(1,Sec,3,0)
    BrFull(PT(1), 1,mV200,1,Vx1,1,2500,True,True, 100,15000,1.0,0)
    BrFull(PT(2), 1,mV200,1,Vx1,1,2500,True,True, 200,15000,1.0,0)
    BrFull(PT(3), 1,mV200,1,Vx1,1,2500,True,True, 300,15000,1.0,0)
    BrFull(PT(4), 1,mV200,1,Vx1,1,2500,True,True, 400,15000,1.0,0)
    BrFull(PT(5), 1,mV200,1,Vx1,1,2500,True,True, 500,15000,1.0,0)
    BrFull(PT(6), 1,mV200,1,Vx1,1,2500,True,True, 600,15000,1.0,0)
    BrFull(PT(7), 1,mV200,1,Vx1,1,2500,True,True, 700,15000,1.0,0)
    BrFull(PT(8), 1,mV200,1,Vx1,1,2500,True,True, 800,15000,1.0,0)
    BrFull(PT(9), 1,mV200,1,Vx1,1,2500,True,True, 900,15000,1.0,0)
    BrFull(PT(10),1,mV200,1,Vx1,1,2500,True,True,1000,15000,1.0,0)
    BrFull(PT(11),1,mV200,1,Vx1,1,2500,True,True,1100,15000,1.0,0)
    BrFull(PT(12),1,mV200,1,Vx1,1,2500,True,True,1200,15000,1.0,0)
    BrFull(PT(13),1,mV200,1,Vx1,1,2500,True,True,1300,15000,1.0,0)
    BrFull(PT(14),1,mV200,1,Vx1,1,2500,True,True,1400,15000,1.0,0)
    BrFull(PT(15),1,mV200,1,Vx1,1,2500,True,True,1500,15000,1.0,0)
    BrFull(PT(16),1,mV200,1,Vx1,1,2500,True,True,1600,15000,1.0,0)
    BrFull(PT(17),1,mV200,1,Vx1,1,2500,True,True,1700,15000,1.0,0)
    BrFull(PT(18),1,mV200,1,Vx1,1,2500,True,True,1800,15000,1.0,0)
    BrFull(PT(19),1,mV200,1,Vx1,1,2500,True,True,1900,15000,1.0,0)
    BrFull(PT(20),1,mV200,1,Vx1,1,2500,True,True,2000,15000,1.0,0)
    CallTable Settle
  NextScan
EndProg
```

The first six measurements are shown in the following table:

Table 13-3: Example data from Measuring Settling Time Program

Timestamp	Record Number	PT(1) Smp	PT(2) Smp	PT(3) Smp	PT(4) Smp	PT(5) Smp	PT(6) Smp
8/3/2017 23:34	0	0.03638599	0.03901386	0.04022673	0.04042887	0.04103531	0.04123745
8/3/2017 23:34	1	0.03658813	0.03921601	0.04002459	0.04042887	0.04103531	0.0414396
8/3/2017 23:34	2	0.03638599	0.03941815	0.04002459	0.04063102	0.04042887	0.04123745
8/3/2017 23:34	3	0.03658813	0.03941815	0.03982244	0.04042887	0.04103531	0.04103531
8/3/2017 23:34	4	0.03679027	0.03921601	0.04022673	0.04063102	0.04063102	0.04083316

Each trace in the following image contains all twenty PT() mV/V values (left axis) for a given record number and an average value showing the measurements as percent of final reading (right axis). The reading has settled to 99.5% of the final value by the fourteenth measurement, which is contained in variable PT(14). This is suitable accuracy for the application, so a settling time of 1400 µs is determined to be adequate.



13.9.7 Factors affecting accuracy

Accuracy describes the difference between a measurement and the true value. Many factors affect accuracy. This topic discusses the effect percent-of-reading, offset, and resolution have on the accuracy of an analog voltage measurement. Accuracy is defined as follows:

accuracy = percent-of-reading + offset

where percents-of-reading and offsets are displayed in the Analog measurement specifications (p. 212).

NOTE:
Error discussed in this section and error-related specifications of the data logger do not include error introduced by the sensor, or by the transmission of the sensor signal to the data logger.

13.9.7.1 Measurement accuracy example

The following example illustrates the effect percent-of-reading and offset have on measurement accuracy. The effect of offset is usually negligible on large signals.

Example:

- Sensor-signal voltage: approximately 1050 mV
- CRBasic measurement instruction: `VoltDiff()`
- Programmed input-voltage range (`Range`) **: mV 5000** (±5000 mV)
- Input measurement reversal (`RevDiff`): **True**
- Data logger circuitry temperature: 10° C

Accuracy of the measurement is calculated as follows:

accuracy = percent-of-reading + offset

where

percent-of-reading = 1050 mV • ±0.04%

=±0.42 mV

and

offset = 0.5 μV

Therefore,

accuracy = ±(0.42 mV + 0.5 μV) = ±0.4205 mV

13.9.8 Minimizing offset voltages

Voltage offset can be the source of significant error. For example, an offset of 3 μV on a 2500 mV signal causes an error of only 0.00012%, but the same offset on a 0.25 mV signal causes an error of 1.2%. Measurement offset voltages are unavoidable, but can be minimized. Offset voltages originate with:

- Ground currents (see Minimizing ground potential differences (p. 163)).
- Seebeck effect
- Residual voltage from a previous measurement

Remedies include:

- Connecting power grounds to power ground terminals (**G**).
- Using input reversal (`RevDiff = True`) with differential measurements.
- Automatic offset compensation for differential measurements when `RevDiff = False`.

- Automatic offset compensation for single-ended measurements when `MeasOff = False`.
- Using `MeasOff = True` for better offset compensation.
- Using excitation reversal (`RevEx = True`) with bridge measurements.
- Programming longer settling times.

Single-ended measurements are susceptible to voltage drop at the ground terminal caused by return currents from another device that is powered from the data logger wiring panel, such as another manufacturer's communications modem, or a sensor that requires a lot of power. Currents greater than 5 mA are usually undesirable. The error can be avoided by routing power grounds from these other devices to a power ground **G** terminal, rather than using a signal ground (⏚) terminal. Ground currents can be caused by the excitation of resistive-bridge sensors, but these do not usually cause offset error. These currents typically only flow when a voltage excitation is applied. Return currents associated with voltage excitation cannot influence other single-ended measurements because the excitation is usually turned off before the data logger moves to the next measurement. However, if the CRBasic program is written in such a way that an excitation terminal is enabled during an unrelated measurement of a small voltage, an offset error may occur.

The Seebeck effect results in small thermally induced voltages across junctions of dissimilar metals as are common in electronic devices. Differential measurements are more immune to these than are single-ended measurements because of passive voltage cancellation occurring between matched high and low pairs such as **1H/1L**. So, use differential measurements when measuring critical low-level voltages, especially those below 200 mV, such as are output from pyranometers and thermocouples.

When analog voltage signals are measured in series by a single measurement instruction, such as occurs when `VoltSE()` is programmed with `Reps = 2` or more, measurements on subsequent terminals may be affected by an offset, the magnitude of which is a function of the voltage from the previous measurement. While this offset is usually small and negligible when measuring large signals, significant error, or NAN, can occur when measuring very small signals. This effect is caused by dielectric absorption of the integrator capacitor and cannot be overcome by circuit design. Remedies include the following:

- Programing longer settling times.
- Using an individual instruction for each input terminal, the effect of which is to reset the integrator circuit prior to filtering.
- Avoiding preceding a very small voltage input with a very large voltage input in a measurement sequence if a single measurement instruction must be used.

The following table lists some of the tools available to minimize the effects of offset voltages:

Table 13-4: Offset voltage compensation options

CRBasic Measurement Instruction	Input Reversal (RevDiff=True)	Excitation Reversal (RevEx=True)	Measure Offset During Measurement (MeasOff=True)	Measure Offset During Background Calibration (RevDiff=False) (RevEx=False) (MeasOff=False)
BrHalf()		✓		✓
BrHalf3W()		✓		✓
BrHalf4W()	✓	✓		✓
BrFull()	✓	✓		✓
BrFull6W()	✓	✓		✓
TCDiff()	✓			✓
TCSe()			✓	✓
VoltDiff()	✓			✓
VoltSe()			✓	✓

13.9.8.1 Compensating for offset voltage

Differential measurements also have the advantage of an input reversal option, `RevDiff`. When `RevDiff` is `True`, two differential measurements are made, the first with a positive polarity and the second reversed. Subtraction of opposite polarity measurements cancels some offset voltages associated with the measurement.

Ratiometric measurements use an excitation voltage to excite the sensor during the measurement process. Reversing excitation polarity also reduces offset voltage error. Setting the `RevEx` parameter to `True` programs the measurement for excitation reversal. Excitation reversal results in a polarity change of the measured voltage so that two measurements with opposite polarity can be subtracted and divided by 2 for offset reduction similar to input reversal for differential measurements.

For example, if 3 μV offset exists in the measurement circuitry, a 5 mV signal is measured as 5.003 mV. When the input or excitation is reversed, the second sub-measurement is –4.997 mV. Subtracting the second sub-measurement from the first and then dividing by 2 cancels the offset:

5.003 mV – (–4.997 mV) = 10.000 mV

10.000 mV / 2 = 5.000 mV

Ratiometric differential measurement instructions allow both `RevDiff` and `RevEx` to be set `True`. This results in four measurement sequences, which the data logger processes into the reported measurement:

- positive excitation polarity with positive differential input polarity
- negative excitation polarity with positive differential input polarity
- positive excitation polarity with negative differential input polarity
- negative excitation polarity with negative differential input polarity

For ratiometric single-ended measurements, such as a `BrHalf()`, setting `RevEx = True` results in two measurements of opposite excitation polarity that are subtracted and divided by 2 for offset voltage reduction. For `RevEx = False` for ratiometric single-ended measurements, an offset-voltage measurement is determined from self-calibration.

When the data logger reverses differential inputs or excitation polarity, it delays the same settling time after the reversal as it does before the first sub-measurement. So, there are two delays per measurement when either `RevDiff` or `RevEx` is used. If both `RevDiff` and `RevEx` are True, four sub-measurements are performed; positive and negative excitations with the inputs one way and positive and negative excitations with the inputs reversed. The automatic procedure then is as follows:

1. Switch to the measurement terminals.
2. Set the excitation, settle, and then measure.
3. Reverse the excitation, settle, and then measure.
4. Reverse the excitation, reverse the input terminals, settle, measure.
5. Reverse the excitation, settle, measure.

There are four delays per measurement. In cases of excitation reversal, excitation time for each polarity is exactly the same to ensure that ionic sensors do not polarize with repetitive measurements.

Read More: The Benefits of Input Reversal and Excitation Reversal for Voltage Measurements.

13.9.8.2 Measuring ground reference offset voltage

Single-ended and differential measurements without input reversal use an offset voltage measurement with the PGIA inputs grounded. This offset voltage is subtracted from the subsequent measurement. For differential measurements without input reversal, this offset voltage measurement is performed as part of the routine background calibration of the data logger (see About background calibration (p. 132)). Single-ended measurement instructions `VoltSE()` and `TCSe()` include the `MeasOff` parameter determines whether the offset voltage measured is done at the beginning of the measurement instruction, or as part of self-calibration. This option provides you with the opportunity to weigh measurement speed against measurement accuracy. When `MeasOff = True`, a measurement of the single-ended offset voltage is made at the beginning of the `VoltSE()` or `TCSe()` instruction. When `MeasOff = False`, measurements will be corrected for the offset voltage determined during self-calibration. For installations experiencing fluctuating offset voltages, choosing `MeasOff = True` for the `VoltSE()` or `TCSe()` instruction results in better offset voltage performance.

If `RevDiff`, `RevEx`, or `MeasOff` is disabled (**= False**), offset voltage compensation is automatically performed, albeit less effectively, by using measurements from the background calibration. Disabling `RevDiff`, `RevEx`, or `MeasOff` speeds up measurement time; however, the increase in speed comes at the cost of accuracy because of the following:

- `RevDiff`, `RevEx`, and `MeasOff` are more effective.
- Background calibrations are performed only periodically, so more time skew occurs between the background calibration offsets and the measurements to which they are applied.

> NOTE:
> When measurement duration must be minimal to maximize measurement frequency, consider disabling `RevDiff`, `RevEx`, and `MeasOff` when data logger temperatures and return currents are slow to change.

13.10 Field calibration

Calibration increases accuracy of a measurement device by adjusting its output, or the measurement of its output, to match independently verified quantities. Adjusting sensor output directly is preferred, but not always possible or practical. By adding the `FieldCal()` or `FieldCalStrain()` instruction to a CRBasic program, measurements of a linear sensor can be adjusted by modifying the programmed multiplier and offset applied to the measurement, without modifying or recompiling the CRBasic program. See the ***CRBasic Editor*** help for detailed instruction information and program examples: https://help.campbellsci.com/crbasic/cr1000x/.

13.11 File system error codes

Errors can occur when attempting to access files on any of the available drives. All occurrences are rare, but they are most likely to occur when using optional memory cards. Often, formatting the drive will resolve the error. The errors display in the **File Control** messages box or in the **CardStatus** field of the **Status** table. See Information tables and settings (advanced) (p. 178) for more information.

1 Invalid format
2 Device capabilities error
3 Unable to allocate memory for file operation
4 Max number of available files exceeded
5 No file entry exists in directory
6 Disk change occurred
7 Part of the path (subdirectory) was not found
8 File at EOF
9 Bad cluster encountered
10 No file buffer available
11 Filename too long or has bad chars
12 File in path is not a directory
13 Access permission, opening DIR or LABEL as file, or trying to open file as DIR or mkdir existing file
14 Opening read-only file for write
15 Disk full (can't allocate new cluster)
16 Root directory is full
17 Bad file ptr (pointer) or device not initialized
18 Device does not support this operation
19 Bad function argument supplied
20 Seek out-of-file bounds
21 Trying to mkdir an existing dir
22 Bad partition sector signature
23 Unexpected system ID byte in partition entry
24 Path already open
25 Access to uninitialized ram drive
26 Attempted rename across devices
27 Subdirectory is not empty
31 Attempted write to Write Protected disk
32 No response from drive (Door possibly open)
33 Address mark or sector not found
34 Bad sector encountered
35 DMA memory boundary crossing error
36 Miscellaneous I/O error
37 Pipe size of 0 requested
38 Memory-release error (relmem)
39 FAT sectors unreadable (all copies)
40 Bad BPB sector
41 Time-out waiting for filesystem available

42 Controller failure error
43 Pathname exceeds _MAX_PATHNAME

13.12 File name and resource errors

The maximum file name size that can be stored, run as a program, or FTP transferred in the data logger is 59 characters. If the name + file extension is longer than 59 characters, an **Invalid Filename** error is displayed. If several files are stored, each with a long file name, memory allocated to the root directory can be exceeded before the actual memory of storing files is exceeded. When this occurs, an **Insufficient resources or memory full** error is displayed.

13.13 Background calibration errors

Background calibration errors are rare. When they do occur, the cause is usually an analog input that exceeds the input limits of the data logger.

- Check all analog inputs to make sure they are not greater than ±5 VDC by measuring the voltage between the input and a **G** terminal. Do this with a multimeter.
- Check for condensation, which can sometimes cause leakage from a 12 VDC source terminal.
- Check for a lose ground wire on a sensor powered from a **12V** or **SW12** terminal.
- If a multimeter is not available, disconnect sensors, one at a time, that require power from 9 to 16 VDC. If measurements return to normal, you have found the cause.

14. Information tables and settings (advanced)

Information tables and settings consist of fields, settings, and system information essential to setup, programming, and debugging of many advanced CR1000X systems. In many cases, the info tables and settings keyword can be used to pull that field into a running CRBasic program. There are several locations where this system information and settings are stored or changed:

- **Status table**: The **Status** table is an automatically created data table. View the **Status** table by connecting the data logger to your computer (see Making the software connection (p. 28) for more information) **Station Status** ☑, then clicking the **Status Table** tab.
- **DataTableInfo table**: The **DataTableInfo** table is automatically created when a program produces other data tables. View the **DataTableInfo** table by connecting the data logger to your computer (see Making the software connection (p. 28) for more information).
    - *PC400* users, click the **Monitor Data** tab and add the **DataTableInfo** to display it.
    - *LoggerNet* users, select **DataTableInfo** from the **Table Monitor** list.
- **Settings**: Settings can be accessed from the *LoggerNet* Connect Screen **Datalogger** > **Settings Editor**, or using *Device Configuration Utility* **Settings Editor** tab. Clicking on a setting in *Device Configuration Utility* also provides information about that setting.
- **Terminal Mode**: A list of setting field names is also available from the data logger terminal mode (from *Device Configuration Utility*, click the **Terminal** tab) using command "**F**".
- Status, DataTableInfo and Settings values may be accessed programmatically using `Tablename.Fieldname` syntax. For example: `Variable = Settings.Fieldname`. For more information see: https://www.campbellsci.com/blog/programmatically-access-stored-data-values.

Communications and processor bandwidth are consumed when generating the **Status** and other information tables. If data logger is very tight on processing time, as may occur in very fast, long, or complex operations, retrieving these tables repeatedly may cause skipped scans.

Settings that affect memory usage force the data logger program to recompile, which may cause loss of data. Before changing settings, it is a good practice to collect your data (see Collecting data (p. 35) for more information). Examples of settings that force the data logger program to recompile:

- IP address
- IP default gateway
- Subnet mask
- PPP interface
- PPP dial string
- PPP dial response
- Baud rate change on control ports
- Maximum number of TLS server connections
- USR drive size
- PakBus encryption key
- PakBus/TCP server port
- HTTP service port
- FTP service port
- PakBus/TCP service port
- PakBus/TCP client connections
- Communications allocation

14.1 DataTableInfo table system information

The **DataTableInfo** table is automatically created when a program produces other data tables. View the **DataTableInfo** table by connecting the data logger to your computer (see Making the software connection (p. 28) for more information).

Most fields in the **DataTableInfo** table are **read only** and of a **numeric data type** unless noted. Error counters (for example **SkippedRecord**) may be reset to **0** for troubleshooting purposes.

- ***LoggerNet*** users, select **DataTableInfo** from the **Table Monitor** list.
- ***PC400*** users, click the **Monitor Data** tab and add the **DataTableInfo** to display it.

14.1.1 DataFillDays

Reports the time required to fill a data table. Each table has its own entry in a two-dimensional array. First dimension is for on-board memory. Second dimension is for card memory.

14.1.2 DataRecordSize

Reports the number of records allocated to a data table.

14.1.3 DataTableName

Reports the names of data tables. Array elements are in the order the data tables are declared in the CRBasic program.

- String data type

14.1.4 RecNum

Record number is incremented when any one of the DataTableInfo fields change, for example **SkippedRecord**.

14.1.5 SecsPerRecord

Reports the data output interval for a data table.

14.1.6 SkippedRecord

Reports how many times records have been skipped in a data table. Array elements are in the order that data tables are declared in the CRBasic program. Enter **0** to reset.

14.1.7 TimeStamp

Scan time that a record was generated.

- NSEC data type

14.2 Status table system information

The **Status** table is an automatically created data table. View the **Status** table by connecting the data logger to your computer (see Making the software connection (p. 28) for more information).

Most fields in the **Status** table are **read only** and of a **numeric data type** unless noted. Error counters (for example, **WatchdogErrors** or **SkippedScan**) may be reset to **0** for troubleshooting purposes.

Status table values may be accessed programatically using `SetStatus()` or `Tablename.Fieldname` syntax. For example: `Variable = Status.Fieldname`. For more information see: https://www.campbellsci.com/blog/programmatically-access-stored-data-values.

14.2.1 Battery

Voltage (VDC) of the battery powering the system. Updates once per minute, when viewing the **Status** table, or programatically.

14.2.2 BuffDepth

Shows the current pipeline mode processing buffer depth, which indicates how far the processing task is currently behind the measurement task. Updated at the conclusion of scan processing, prior to waiting for the next scan.

14.2.3 CalCurrent

Shows the offset calibration factor for the resistor used in 0-20 and 4-20 mA measurements on RG terminals. Measured once during production calibration.

14.2.4 CalGain

Array of floating-point values reporting calibration gain (mV) for each integration / range combination.

14.2.5 CalOffset

Displays the offset calibration factor for the different voltage ranges.

14.2.6 CalRefOffset

Displays voltage reference temperature compensation offset.

14.2.7 CalRefSlope

Displays voltage reference temperature compensation slope.

14.2.8 CalVolts

Array of floating-point values reporting a factory calibrated correction factor for the different voltage ranges.

14.2.9 CardStatus

Contains a string with the most recent status information for the removable memory card.

- String data type

14.2.10 CommsMemFree

Memory allocations for communications. Numbers outside of parentheses reflect current memory allocation. Numbers inside parentheses reflect the lowest memory size reached.

14.2.11 CompileResults

Contains messages generated at compilation or during runtime. Updated after compile and for runtime errors such as variable out of bounds.

- String data type

14.2.12 ErrorCalib

Number of erroneous calibration values measured. Erroneous values are discarded. Updated at startup.

14.2.13 FullMemReset

Enter **98765** to start a full-memory reset, all data and programs will be erased.

14.2.14 LastSystemScan

Reports the time of the of the last auto (background) calibration, which runs in a hidden slow-sequence type scan. See MaxSystemProcTime, SkippedSystemScan, and SystemProcTime.

14.2.15 LithiumBattery

Voltage of the internal lithium battery. Updated at CR1000X power up. For battery information, see Internal battery (p. 132).

14.2.16 Low12VCount

Counts the number of times the primary CR1000X supply voltage drops below ≈9.0 VDC. Updates with each **Status** table update. Range = 0 to 99. Reset by entering 0. Incremented prior to scan (slow or fast) with measurements if the internal hardware signal is asserted.

14.2.17 MaxBuffDepth

Maximum number of buffers the CR1000X will use to process lagged measurements. Enter **0** to reset.

14.2.18 MaxProcTime

Maximum time (µs) required to run through processing for the current scan. Value is reset when the scan exits. Enter **0** to reset. Updated at the conclusion of scan processing, prior to waiting for the next scan.

14.2.19 MaxSystemProcTime

Maximum time (µs) required to process the auto (background) calibration, which runs in a hidden slow-sequence type scan. Displays **0** until a background calibration runs. Enter **0** to reset.

- Numeric data type

14.2.20 MeasureOps

Reports the number of task-sequencer opcodes required to do all measurements. Calculated at compile time. Includes operation codes for calibration (compile time), auto (background) calibration (system), and Slow Sequences. Assumes all measurement instructions run each scan. Updated after compile and before running.

14.2.21 MeasureTime

Reports the time (µs) needed to make measurements in the current scan. Calculated at compile time. Includes integration and settling time. In pipeline mode, processing occurs concurrent with this time so the sum of **MeasureTime** and **ProcessTime** is not equal to the required scan time. Assumes all measurement instructions will run each scan. Updated when a main scan begins.

14.2.22 MemoryFree

Unallocated final-data memory on the CPU (bytes). All free memory may not be available for data tables. As memory is allocated and freed, holes of unallocated memory, which are unusable for final-data memory, may be created. Updated after compile completes.

14.2.23 MemorySize

Total final-data memory size (bytes) in the CR1000X. Updated at startup.

14.2.24 Messages

Contains a string of manually entered messages.

- String data type

14.2.25 OSDate

Release date of the operating system in the format mm/dd/yyyy. Updated at startup.

- String data type

14.2.26 OSSignature

Signature of the operating system.

14.2.27 OSVersion

Version of the operating system in the CR1000X. Updated at OS startup.

- String data type

14.2.28 PakBusRoutes

Lists routes or router neighbors known to the data logger at the time the setting was read. Each route is represented by four components separated by commas and enclosed in parentheses: (port, via neighbor address, pakbus address, response time in ms). Updates when routes are added or deleted.

- String data type

14.2.29 PanelTemp

Current wiring-panel temperature (°C). Updates once per minute, when viewing the **Status** table, or programatically.

14.2.30 PortConfig

Provides information on the configuration settings (input, output, SDM, SDI-12, COM port) for **C** terminals in numeric order of terminals. Default = **Input**. Updates when the port configuration changes.

- String data type

14.2.31 PortStatus

States of **C** terminals configured for control. On/high (**true**) or off/low (**false**). Array elements in numeric order of **C** terminals. Default = **false**. Updates when state changes. Enter **-1** to set to **true**. Enter **0** to set to **false**.

- Boolean data type

14.2.32 ProcessTime

Processing time (µs) of the last scan. Time is measured from the end of the `EndScan` instruction (after the measurement event is set) to the beginning of the `EndScan` (before the wait for the measurement event begins) for the subsequent scan. Calculated on-the-fly. Updated at the conclusion of scan processing, prior to waiting for the next scan.

14.2.33 ProgErrors

Number of compile or runtime errors for the running program. Updated after compile.

14.2.34 ProgName

Name of current (running) program; updates at startup.

- String data type

14.2.35 ProgSignature

Signature of the running CRBasic program including comments. Does not change with operating-system changes. Updates after compiling the program.

14.2.36 RecNum

Record number increments when the Status Table is requested by support software. Range = 0 to 2^{32}.

- Long data type

14.2.37 RevBoard

Electronics board revision in the form **xxx.yyy**, where **xxx** = hardware revision number; **yyy** = clock chip software revision. Stored in flash memory. Updated at startup.

- String data type

14.2.38 RunSignature

Signature of the running binary (compiled) program. Value is independent of comments or non-functional changes. Often changes with operating-system changes. Updates after compiling and before running the program.

14.2.39 SerialNumber

CR1000X serial number assigned by the factory when the data logger was calibrated. Stored in flash memory. Updated at startup.

14.2.40 SkippedScan

Number of skipped program scans (see Checking station status (p. 144) for more information) that have occurred while running the CRBasic program. Does not include scans intentionally skipped as may occur with the use of `ExitScan` and `Do` / `Loop` instructions. Updated when they occur. Enter **0** to reset.

14.2.41 SkippedSystemScan

Number of scans skipped in the background calibration. Enter **0** to reset. See LastSystemScan, MaxSystemProcTime, and SystemProcTime.

14.2.42 StartTime

Time (date and time) the CRBasic program started. Updates at beginning of program compile.

- NSEC data type

14.2.43 StartUpCode

Indicates how the running program was compiled. Updated at startup. 65 = Run on powerup is running and normal powerup occurred.

14.2.44 StationName

Station name stored in flash memory. This is not the same name as that is entered into your data logger support software. This station name can be sampled into a data table, but it is not the name that appears in data file headers. Updated at startup or when the name is changed. This value is read-only if the data logger is currently running a program with a `CardOut()` instruction.

- String data type

14.2.45 SW12Volts

Status of switched, 12 VDC terminal(s). On/high (**true**) or off/low (**false**) Enter **-1** to set to **true**. Enter **0** to set to **false**. Updates when the state changes.

- Boolean data type

14.2.46 SystemProcTime

Time (µs) required to process auto (background) calibration. Default is 0 until background calibration runs.

14.2.47 TimeStamp

Scan-time that a record was generated.

- NSEC data type

14.2.48 VarOutOfBound

Number of attempts to write to an array outside of the declared size. The write does not occur. Indicates a CRBasic program error. If an array is used in a loop or expression, the pre-compiler and compiler do not check to see if an array is accessed out-of-bounds (i.e., accessing an array with a variable index such as **arr(index) = arr(index–1)**, where **index** is a variable). Updated at runtime when the error occurs. Enter **0** to reset.

14.2.49 WatchdogErrors

Number of watchdog errors that have occurred while running this program. Resets automatically when a new program is compiled. Enter **0** to reset. Updated at startup and at occurrence.

14.2.50 WiFiUpdateReq

Shows if WiFi operating system update is available. Update available (**true**) or not (**false**). Updates when state changes.

- Boolean data type

14.3 CPIStatus system information

The **CPIStatus** table is automatically created when a program uses the CPI bus. View the **CPIStatus** table by connecting the data logger to your computer (see Making the software connection (p. 28) for more information).

Most fields in the **CPIStatus** table are **read/write** and of a **numeric data type** unless noted. Error counters (for example **BuffErr**) may be reset to **0** for troubleshooting purposes.

- *LoggerNet* users, select **DataTableInfo** from the **Table Monitor** list.
- *PC400* users, click the **Monitor Data** tab and add **DataTableInfo**.

For more information on the CPI bus and how to design a CDM network, see the technical paper at: https://s.campbellsci.com/documents/us/technical-papers/cpi-bus.pdf.

14.3.1 BusLoad

Percentage of the possible CPI network bandwidth use over the scan interval. BusLoad = Used capacity / Maximum capacity.

- Read only
- Percentage (0.000 to 100)

TIP:
Use `CPISpeed()` to change the CPI bit rate. The default bit rate is 250 kbps. Use a higher bit rate if the **BusLoad** exceeds 75 percent.

14.3.2 ModuleReportCount

Reports the number of times measurement modules report in to the CPI bus. Modules report in on program send or when settings in the CPIStatus table are edited remotely. Activity that could cause the number of modules to be reported differently will cause ModuleReportCount to increment. Also, if there are devices on the network that are connected but not active, (such as those not in the running program) they will report in once minute, advertising their presence, and incrementing ModuleReportCount.

14.3.3 ActiveModules

Reports the number of measurement modules that are active on the CPI bus.

- Read only

14.3.4 BuffErr (buffer error)

Reports how many times there is an error in the buffer. Enter **0** to reset.

14.3.5 RxErrMax

Reports the maximum number of receive errors. Enter **0** to reset.

14.3.6 TxErrMax

Reports the maximum number of transmit errors. Enter **0** to reset.

14.3.7 FrameErr (frame errors)

Reports how many times a frame has an error. Enter **0** to reset.

14.3.8 ModuleInfo array

Reports: CDM Type, Serial Number, Device Name, CPI Address, Activity, OS Version.

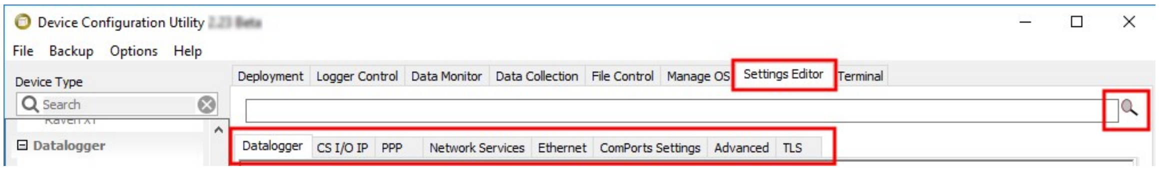
- String data type
- Read only

Possible responses and meanings in the **Activity** field are below:

- **Active**: The module is connected to the CPI bus and is making measurements according to the data logger program.
- **Offline**: The module was present after startup but is no longer responding.
- **Unused**: The module is or was connected and powered but is not included in the data logger program.
- **Wait Config**: The module has not yet responded to a data logger attempts to configure it.
- **Config Fail**: The module could not be configured. A configuration error message is appended to this response.
- **CAN Errors, resetting CPI**: The CDM module is not used in the data logger program.

14.4 Settings

Settings can be accessed from the ***LoggerNet*** Connect Screen **Datalogger** > **Setting Editor**, or using ***Device Configuration Utility*** **Settings Editor** tab. **Settings** are organized in tabs and can be searched for.



Most **Settings** are **read/write** and of a **numeric data type** unless noted.

Settings may be accessed programatically using `SetSetting()` or `Tablename.Fieldname` syntax. For example: `Variable = Settings.Fieldname`. For more information see: https://www.campbellsci.com/blog/programmatically-access-stored-data-values.

> NOTE:
> A list of **Settings** fieldnames is also available from the data logger terminal mode using command **F**.

14.4.1 Baudrate

This setting governs the baud rate that the data logger will use for a given port in order to support serial communications. For some ports (COM), this setting also controls whether the port will be enabled for serial communications.

Some ports (RS-232 and CS I/O ME) support auto-baud synchronization while the other ports support only fixed baud. With auto-baud synchronization, the data logger will attempt to match the baud rate to the rate used by another device based upon the receipt of serial framing errors and invalid packets.

14.4.2 Beacon

This setting, in units of seconds, governs the rate at which the data logger will broadcast PakBus messages on the associated port in order to discover any new PakBus neighboring nodes. If this setting value is set to a value of 0 or 65,535, the data logger will not broadcast beacon messages on this port.

This setting will also govern the default verification interval if the value of the **Verify()** setting for the associated port is zero. If the value of this setting is non-zero, and the value of the Verify setting is zero, the effective verify interval will be calculated as 2.5 times the value for this setting. If both the value of this setting and the value of the Verify setting is zero, the effective verify interval will be 300 seconds (five minutes).

14.4.3 CentralRouters

This setting specifies a list of PakBus addresses for routers that are able to work as Central Routers. By specifying a non-empty list for this setting, the data logger will be configured as a Branch Router meaning that it will not be required to keep track of neighbors of any routers except those in its own branch. Configured in this fashion, the data logger will ignore any neighbor lists received from addresses in the central routers setting and will forward any messages that it receives to the nearest default router if it does not have the destination address for those messages in its routing table.

- String data type

14.4.4 CommsMemAlloc

Replaces **PakBusNodes**. Controls the amount of memory allocated for PakBus routing and communications in general. Increase the value of this setting if you require more memory dedicated to communications. Increase this value if the data logger will be used for routing a large number of PakBus nodes (>50). Increase this value if your data logger is dropping connections during short periods of high TCP/IP traffic. This setting will effect the values reported in CommsMemFree.

14.4.5 ConfigCom*x*

Specifies the configuration for a data logger control port as it relates to serial communications. It is significant only when the associated port baud rate setting is set to something other than **Disabled**. This setting denotes the physical layer properties used for communications. It does not indicate the port's current configuration as it relates to standard or inverted logic. Options include:

- **RS-232**: Configures the port as RS-232 with standard voltage levels.
- **TTL**: The port is configured to use TTL, 0 to 5V voltage levels. By default, the port will use inverted logic levels. Use `SerialOpen()` to configure this port for standard TTL logic levels.
- **LVTTL**: The port is configured to use Low Voltage TTL (LVTTL), 0 to 3.3V voltage levels. By default, the port will use inverted logic levels. Use `SerialOpen()` to configure this port for standard TTL logic levels.
- **RS-485 Half-Duplex PakBus**: The port is configured as RS-485 half-duplex (two wire) and uses the PakBus/MDROP protocol. This allows reliable PakBus peer-to-peer networking of multiple devices including the MD485 and NL100 using the RS-485 interface.
- **RS-485 Half-Duplex Transparent**: The port is configured as RS-485 half-duplex (two wire). This setting is most commonly used when communicating with other non-PakBus RS-485

devices. Use this setting when communicating with devices such as Modbus RTUs or third-party serial sensors with RS-485 interfaces.

- **RS-485 Full Duplex Transparent**: The port is configured as RS-485 full-duplex (four wire). In this configuration, four adjacent control ports will be required.

14.4.6 CSIO*x*netEnable

Controls whether the CS I/O IP #1 or #2 TCP/IP interface should be enabled.

14.4.7 CSIOInfo

Reports the IP address, network mask, and default gateway for each of the data logger's active network interfaces. If DHCP is used for the interface, this setting will report the value that was configured by the DHCP server.

- String data type

14.4.8 DisableLithium

Controls whether the data logger will maintain its real time clock and battery backed memory when it loses power. Setting this value to one will cause the data logger clock to lose time on power loss. If this value is set to one, the data logger will not maintain its program or data after it powers down.

This value is useful when the data logger needs to be stored as it will prolong the shelf life of the lithium battery almost indefinitely.

If this value is set to one, the data logger will set it to zero when it powers up.

14.4.9 DeleteCardFilesOnMismatch

Controls the behavior of the data logger when it restarts with a different program and it detects that data files created by the `CardOut()` are present but do not match the new program. If this value is set to one, the data logger will delete these files so that new files can be stored. If set to a value of zero, the data logger will retain the existing files and prevent any data from being appended to these files.

14.4.10 DNS

This setting specifies the addresses of up to two domain name servers that the data logger can use to resolve domain names to IP addresses. Note that if DHCP is used to resolve IP information, the addresses obtained via DHCP will be appended to this list.

- String data type

14.4.11 EthernetInfo

Reports the IP address, network mask, and default gateway for each of the data logger's active network interfaces. If DHCP is used for the interface, this setting will report the value that was configured by the DHCP server.

- String data type
- Read only

14.4.12 EthernetPower

This setting specifies how the data logger controls power to its Ethernet interface. This setting provides a means of reducing the data logger power consumption while Ethernet is not connected. Always on, 1 Minute, or Disable.

14.4.13 FilesManager

This setting controls how the data logger will handle incoming files with specific extensions from various sources. There can be up to four specifications. Each specification has three required fields: **PakBus Address**, **File Name**, and **Count**.

- String data type

14.4.14 FTPEnabled

Set to **1** if to enable FTP service. Default is **0**.

14.4.15 FTPPassword

Specifies the password that is used to log in to the FTP server.

- String data type

14.4.16 FTPPort

Configures the TCP port on which the FTP service is offered. The default value is usually sufficient unless a different value needs to be specified to accommodate port mapping rules in a network address translation firewall. Default = **21**.

14.4.17 FTPUserName

Specifies the user name that is used to log in to the FTP server. An empty string (the default) inactivates the FTP server.

- String data type

14.4.18 HTTPEnabled

Specifies additions to the HTTP header in the web service response. It can include multiple lines. Set to **1** to enable HTTP (web server) service or **0** to disable it.

14.4.19 HTTPHeader

Specifies additions to the HTTP header in the web service response. It can include multiple lines. Example: `Access-Control-Allow-Origin: *`

- String data type

14.4.20 HTTPPort

Configures the TCP port on which the HTTP (web server) service is offered. Generally, the default value is sufficient unless a different value needs to be specified to accommodate port-mapping rules in a network-address translation firewall. Default = 80.

14.4.21 HTTPSEnabled

Set to 1 to enable the HTTPS (secure web server) service.

14.4.22 HTTPSPort

Configures the TCP port on which the HTTPS (secure web server) service is offered. Generally, the default value is sufficient unless a different value needs to be specified to accommodate port mapping rules in a network address translation firewall.

14.4.23 IncludeFile

This setting specifies the name of a file to be implicitly included at the end of the current CRBasic program or can be run as the default program. In order to work as an include file, the file referenced by this setting cannot contain a `BeginProg()` statement or define any variable names or tables that are defined in the main program file.

This setting must specify both the name of the file to run as well as on the device (CPU:, USR:, or CRD:) on which the file is located. The extension of the file must also be valid for a data logger program (.CRB, .DLD, .CR1X).

See also File management via powerup.ini (p. 139).

- String data type

14.4.24 IPAddressCSIO

Arrays that specify the IP addresses of the internet interfaces that use the CS I/O bridge protocol. If a value is specified as zero (the default), the data logger will use DHCP to configure the IP address, network mask, and default gateway for that interface.

- String data type

14.4.25 IPAddressEth

Specifies the IP address for the internet interface connected via the peripheral port to devices such as the NL115 and NL120. If this value is specified as "0.0.0.0" (the default), the data logger will use DHCP to configure the effective value for this setting as well as the `Ethernet Default Gateway` and `Ethernet Subnet Mask` settings. This setting is the equivalent to the `IPAddressEth` status table variable.

- String data type

14.4.26 IPGateway

Specifies the IP address of the network gateway on the same subnet as the Ethernet interface. If the value of the Ethernet IP Address setting is set to "0.0.0.0" (the default), the data logger will configure the effective value of this setting using DHCP. This setting is the equivalent to the IPGateway status table variable.

- String data type

14.4.27 IPGatewayCSIO

These settings specify the IP addresses of the router on the subnet to which the first or second CS I/O bridge internet interface is connected. The data logger will forward all non-local IP packets to this address when it has no other route. If the CS I/O IP Address setting is set to a value of "0.0.0.0", the data logger will configure the effective value of this setting using DHCP.

- String data type

14.4.28 IPMaskCSIO

These settings specify the subnet masks for the CS I/O bridge mode internet interface. If the corresponding CS I/O Address setting is set to a value of "0.0.0.0", the data logger will configure the effective value of this setting using DHCP.

- String data type

14.4.29 IPMaskEth

Specifies the subnet mask for the Ethernet interface. If the value of the Ethernet IP Address setting is set to "0.0.0.0" (the default), the data logger will configure the effective value of this setting using DHCP.

- String data type

14.4.30 IPTrace

Discontinued; aliased to **IPTraceComport**

14.4.31 IPTraceCode

Controls what type of information is sent on the port specified by **IPTraceComport** and via Telnet. Each bit in this integer represents a certain aspect of tracing that can be turned on or off. Values for particular bits are described in the ***Device Configuration Utility***. Default = **0**, no messages generated.

14.4.32 IPTraceComport

Specifies the port (if any) on which TCP/IP trace information is sent. Information type is controlled by **IPTraceCode**.

14.4.33 IsRouter

This setting controls whether the data logger is configured as a router or as a leaf node. If the value of this setting is **true**, the data logger will be configured to act as a PakBus router. That is, it will be able to forward PakBus packets from one port to another. To perform its routing duties, a data logger configured as a router will maintain its own list of neighbors and send this list to other routers in the PakBus network. It will also obtain and receive neighbor lists from other routers.

If the value of this setting is **false**, the data logger will be configured to act as a leaf node. In this configuration, the data logger will not be able to forward packets from one port to another and it will not maintain a list of neighbors. Under this configuration, the data logger can still communicate with other data loggers and wireless sensors. It cannot, however, be used as a means of reaching those other data loggers. The default value is false.

- Boolean data type

14.4.34 KeepAliveURL (Ping keep alive URL)

The URL to send a ping to when there has been no network activity for the **KeepAliveMin** interval. If there is no ping response then the network connection is reestablished.

- String data type

14.4.35 KeepAliveMin (Ping keep alive timeout value)

When there has been no network activity for this amount of time, in seconds, a ping will be sent to the **KeepAliveURL**. Default = **0** which disables keep alive pings.

- Long data type (allowed values: 0,5,10,15,30,60,120,180,240,300,360,480,720)

14.4.36 MaxPacketSize

Specifies the maximum number of bytes per data collection packet.

14.4.37 Neighbors

This setting specifies, for a given port, the explicit list of PakBus node addresses that the data logger will accept as neighbors. If the list is empty (the default value) any node will be accepted as a neighbor. This setting will not affect the acceptance of a neighbor if that neighbor's address is greater than 3999.

- String data type

14.4.38 NTPServer

This setting specifies an NTP Server to be queried (once per day) to adjust the data logger clock. This setting uses the **UTC Offset** setting. If UTC Offset setting is not set, it is assumed to be 0.

- String data type

14.4.39 PakBusAddress

This setting specifies the PakBus address for this device. Valid values are in the range 1 to 4094. The value for this setting must be chosen such that the address of the device will be unique in the scope of the data logger network. Duplication of PakBus addresses can lead to failures and unpredictable behavior in the PakBus network.

When a device has an allowed neighbor list for a port, any device that has an address greater than or equal to 4000 will be allowed to connect to that device regardless of the allowed neighbor list.

14.4.40 PakBusEncryptionKey

This setting specifies text that will be used to generate the key for encrypting PakBus messages sent or received by this data logger. If this value is specified as an empty string, the data logger will not use PakBus encryption. If this value is specified as a non-empty string, however, the data logger will not respond to any PakBus message unless that message has been encrypted.

- String data type

14.4.41 PakBusNodes

Discontinued; aliased to **CommsMemAlloc**

14.4.42 PakBusPort

This setting specifies the TCP service port for PakBus communications with the data logger. Unless firewall issues exist, this setting probably does not need to be changed from its default value. Default 6785.

14.4.43 PakBusTCPClients

This setting specifies outgoing PakBus/TCP connections that the data logger should maintain. Up to four addresses can be specified.

- String data type

14.4.44 PakBusTCPEnabled

By default, PakBus TCP communications are enabled. To disable PakBus TCP communications, set the PakBusPort setting to **65535**.

14.4.45 PakBusTCPPassword

This setting specifies a password that, if not empty, will make the data logger authenticate any incoming or outgoing PakBus/TCP connection. This type of authentication is similar to that used by CRAM-MD5.

- String data type

14.4.46 PingEnabled

Set to one to enable the ICMP ping service.

14.4.47 PCAP

PCAP is a packet capture (PCAP) file of network packet data (network traffic) that can be opened by Wireshark. This setting specifies the network interface, file name, and maximum size of the PCAP file. For example:

- "usr:debug.pcap" saves the file to the USR drive with the file type .pcap.
- ".ring." found in name will create new files once the file size has been reached. "crd:debug.ring.pcap" creates crd:debug001.pcap, crd:debug002.pcap...
- If a number follows .ring. then only that number of files will be saved, with the oldest deleted. For example: "usr:debug.ring.3.pcap" will save three files.

If **All Networks** is selected as the Network Interface and PPP/Cell is active, then separate files will be opened for the PPP/Cell network with "ppp." prefixed on the file name.

14.4.48 pppDial

Specifies the dial string that would follow the ATD command (#777 for the Redwing CDMA).

Alternatively, this value can specify a list of AT commands where each command is separated by a semi-colon (;). When specified in this fashion, the data logger will transmit the string up to the semicolon, transmit a carriage return to the modem, and wait for two seconds before proceeding with the rest of the dial string (or up to the next semicolon). If multiple semicolons are specified in succession, the data logger will add a delay of one second for each additional semicolon.

If a value of PPP is specified for this setting, will configure the data logger to act as a PPP client without any modem dialing. Finally, an empty string (the default) will configure the data logger to listen for incoming PPP connections also without any modem dialing.

- String data type

14.4.49 pppDialResponse

Specifies the response expected after dialing a modem before a PPP connection can be established.

- String data type

14.4.50 pppInfo

Reports the IP address, network mask, and default gateway for each of the data logger's active network interfaces. If DHCP is used for the interface, this setting will report the value that was configured by the DHCP server.

- String data type
- Read only

14.4.51 pppInterface

This setting controls which data logger port PPP service will be configured to use.

14.4.52 pppIPAddr

Specifies the IP address that will be used for the PPP interface if that interface is active (the PPP Interface setting needs to be set to something other than Inactive).

- String data type

14.4.53 pppPassword

Specifies the password that will be used for PPP connections when the value of **PPP Interface** is set to something other than **Inactive**.

- String data type

14.4.54 pppUsername

Specifies the user name that is used to log in to the PPP server.

- String data type

14.4.55 RouteFilters

This setting configures the data logger to restrict routing or processing of some PakBus message types so that a "state changing" message can only be processed or forwarded by this data logger if the source address of that message is in one of the source ranges and the destination address of that message is in the corresponding destination range. If no ranges are specified (the default), the data logger will not apply any routing restrictions. "State changing" message types include set variable, table reset, file control send file, set settings, and revert settings.

If a message is encoded using PakBus encryption, the router will forward that message regardless of its content. If, however, the routes filter setting is active in the destination node and the unencrypted message is of a state changing type, the route filter will be applied by that end node.

- String data type

14.4.56 RS232Handshaking

If non-zero, hardware handshaking is active on the RS-232 port. This setting specifies the maximum packet size sent between checking for CTS.

14.4.57 RS232Power

Controls whether the RS-232 port will remain active even when communications are not taking place. Note that if **RS232Handshaking** is enabled (handshaking buffer size is non-zero), that this setting must be set to **Yes**.

- Boolean data type

14.4.58 RS232Timeout

RS-232 hardware handshaking timeout. Specifies the time (tens of ms) that the CR1000X will wait between packets if CTS is not asserted.

14.4.59 Security(1), Security(2), Security(3)

An array of three security codes. A value of zero for a given level will grant access to that level's privileges for any given security code. For more information, see Data logger security (p. 122).

14.4.60 ServicesEnabled

Discontinued; replaced by/aliased to **HTTPEnabled**, **PingEnabled**, **TelnetEnabled**.

14.4.61 TCPClientConnections

Discontinued; replaced by / aliased to **PakBusTCPClients**.

14.4.62 TCP_MSS

The maximum TCP segment size. This value represents the maximum TCP payload size. It is used to limit TCP packet size. A maximum TCP transmission unit (MTU) can be calculated by adding the IP Header size (20 bytes), the TCP Header size (20 bytes), and the payload size.

14.4.63 TCPPort

Discontinued; replaced by / aliased to **PakBusPort**.

14.4.64 TelnetEnabled

Enables (**1**) or disables (**0**) the Telnet service.

14.4.65 TLSConnections (Max TLS Server Connections)

This setting controls the number of concurrent TLS (secure or encrypted) client socket connections that the data logger will be capable of handling at any given time. This will affect FTPS and HTTPS services. This count will be increased by the number of `DNP()` instructions in the data logger program.

This setting will control the amount of RAM that the data logger will use for TLS connections. For every connection, approximately 20KBytes of RAM will be required. This will affect the amount of memory available for program and data storage. Changing this setting will force the data logger to recompile its program so that it can reallocate memory

14.4.66 TLSPassword

This setting specifies the password that will be used to decrypt the TLS Private Key setting.

- String data type

14.4.67 TLSStatus

Reports the current status of the data logger TLS network stack.

- String data type
- Read only

14.4.68 UDPBroadcastFilter

Set to one if all broadcast IP packets should be filtered from IP interfaces. Do not set this if you use the IP discovery feature of the device configuration utility or of LoggerLink. If this is set, the data logger will fail to respond to the broadcast requests.

Default = 0.

14.4.69 USBConfig (Configure USB)

Controls the configuration of the data logger USB (host) port. When set to a value of 1 it configures the data logger to enumerate USB as a virtual com port only. A value of 0 (the default) causes the data logger to enumerate as a composite device with both a virtual com port and a virtual Ethernet port (RNDIS) available.

Default = 0.

14.4.70 USBEnumerate

Controls the behavior of the data logger when its USB connector is plugged into the computer. If set to a value of **1**, the data logger will use its own serial number for identification in the USB enumeration. If set to a value of **0** (the default), the data logger will use a fixed serial number in the USB enumeration. This behavior controls whether the computer will allocate a new virtual serial port for the data logger USB connection or will use a previously allocated (but not currently used) virtual serial port.

Default = **0**.

14.4.71 USRDriveFree

Provides information on the available bytes for the USR drive.

- Read only

14.4.72 USRDriveSize

Specifies the size in bytes allocated for the USR: ram disk drive. This memory is allocated from the memory that the data logger would normally use to store its compiled program or RAM based data tables. If this setting is too large, some programs may not be able to compile on the data logger.

Setting the USR: Drive Size setting will force the data logger to recompile its program and may result in the loss of data.

This setting controls the amount of memory set aside for the USR: size and is only indirectly related to the amount of storage within that file system. The amount of space available for storing files is always going to be less than this value because of the overhead of file system structures.

14.4.73 UTCOffset

Specifies the offset, in seconds, of the data logger's clock from Coordinated Universal Time (UTC, or GMT). For example, if the clock is set to Mountain Standard Time in the U.S. (-7 Hours offset from UTC) then this setting should be -25200 (-7*3600). This setting is used by the **NTP Server** setting as well as `EmailSend()` and **HTTP()**, which require Universal Time in their headers. This setting will also be adjusted by the Daylight Savings functions if they adjust the clock.

If a value of **-1** is supplied for this setting, no UTC offset will be applied.

14.4.74 Verify

This setting specifies the interval, in units of seconds, that will be reported as the link verification interval in the PakBus hello transaction messages. It will indirectly govern the rate at which the data logger will attempt to start a hello transaction with a neighbor if no other communications have taken place within the interval.

14.5 MQTT settings

Access MQTT settings using ***Device Configuration Utility***. Clicking on a setting in ***Device Configuration Utility*** also provides information about that setting.

Where to find:

- All settings: **Settings Editor** tab in ***Device Configuration Utility***: **MQTT** tab, unless noted.

See also MQTT (p. 98).

> NOTE:
> A list of **Settings** fieldnames is also available from the data logger terminal mode using command **F**.

14.5.1 CampbellCloudEnable (Enable or disable CAMPBELL CLOUD)

By default, automatic connection to the CAMPBELL CLOUD to receive configuration is disabled.

- Long data type, allowed values:
  - **0** = Disable (default)
  - **1** = Enable

14.5.2 CloudConfigURL (CLOUD configuration URL)

This setting is located: **Settings Editor** tab in ***Device Configuration Utility***: **Advanced** tab.

Specifies the URL the data logger will use when it cannot connect to CAMPBELL CLOUD. This URL is used to retrieve CLOUD configuration settings, it is ignored unless CLOUD is enabled.

- String data type

14.5.3 MQTTBaseTopic (MQTT base topic)

This is the base topic which will automatically be used. Use this setting to override the default format: CS/{CAMPBELL CLOUD Account ID}/{MQTT Client Id}/. The CLOUD Account level is only used when connecting to the CAMPBELL CLOUD Account.

- String data type

14.5.4 MQTTCleanSession (MQTT connection)

Assigns the MQTT broker connection type. **Persistent** sessions save all relevant client information on the broker. The client gets messages that it misses offline.

If the connection between the client and broker is interrupted during a **Clean** session, topics may be lost and the client needs to subscribe again. The client does not get messages that it misses offline.

- Long data type, allowed values:
  - **0** = Clean
  - **1** = Persistent (default)

14.5.5 MQTTClientID (MQTT client identifier)

Unique identifier the data logger uses to connect to MQTT broker. The default is the hardware type_serial number. Example: CR1000X_123.

- String data type, maximum number of characters is 64

14.5.6 MQTTEnable (Enable or disable MQTT)

By default, MQTT is disabled.

- Long data type, allowed values:
  - **0** = Disable (default)
  - **1** = Enable with TLS-Mutual Authentication
  - **2** = Enable with TLS
  - **3** = Enable MQTT

14.5.7 MQTTEndpoint (MQTT broker URL)

Server URL for MQTT broker.

- String data type

14.5.8 MQTTKeepAlive (MQTT keep alive)

When there has been no network activity for this amount of time, in seconds, a ping will be sent to the **MQTTBrokerURL**. Default = **0** which disables keep alive pings. Valid values are in the range **0** to **65535**.

- Long data type

14.5.9 MQTTPassword (MQTT password)

Password, in association with **MQTTUserName**, required to connect to the MQTT broker.

- String data type

14.5.10 MQTTPortNumber (MQTT port number)

Port number to connect to the MQTT broker.

- Long data type, maximum number of characters is 256

14.5.11 MQTTStatusInterval (Status information publish interval)

Time (in minutes) between publishing MQTT status information. This interval determines how often the data logger publishes to the topic: {System Base Topic/}statusInfo. Valid values are in the range **0** to **1440**.

- Long data type

14.5.12 MQTTState (MQTT state)

This is a read-only field indicating the current state of the data logger connection to the MQTT broker.

- Long data type, possible results:
  - **0** = Disabled / Off
  - **8** = Disconnected. Sleeping
  - **10** = Waiting for an IP network interface
  - **11** = Connection retry wait
  - **20** = Opening TCP connection
  - **11** = TCP Open failed

- **22** = TCP connection opened
- **24** = Closing TCP connection
- **26** = TCP connection closed
- **30** = TLS handshake started
- **31** = TLS handshake failed
- **32** = TLS handshake success
- **50** = MQTT session established
- **51** = Waiting for session start response
- **52** = Publishing
- **100** = Onboard started
- **101** = Onboard retry
- **102** = Onboard processing
- **200** = Waiting for modem startup
- **201** = Configuring SSL
- **202** = Configuring MQTT
- **203** = Opening network
- **204** = Connecting to MQTT broker

14.5.13 MQTTStateInterval (State publish interval)

Time (in minutes) between publishing MQTT state information. This interval determines how often the data logger publishes to the topic: {System Base Topic/}State. Valid values are in the range **0** to **1440**. Setting the value to **0** will not disable normal state publishing activity, only interval publishing.

- Long data type

14.5.14 MQTTUserName (MQTT user name)

User name, in association with **MQTTPassword**, used to connect to MQTT broker.

- String data type, maximum number of characters is 256

14.5.15 MQTTWillMessage (MQTT last will message)

Message published on last will topic by broker if disconnected without a disconnect command.

- String data type, maximum number of characters is 256

14.5.16 MQTTWillQoS (Quality of service)

This is an agreement that defines the guarantee of delivery for a specific message. Higher QoS levels are more reliable, but take more time and bandwidth.

- Long data type, allowed values:
  - **0** = At most once (default), no confirmation
  - **1** = At least once, confirmation required
  - **2** = Exactly once using a multi-step handshake

14.5.17 MQTTWillRetain (MQTT last will message retained by broker)

Enables or disables the broker to retain **MQTTWillMessage**.

- Long data type, allowed values:
  - **0** = Do not retain (default)
  - **1** = Retain

14.5.18 MQTTWillTopic (MQTT last will topic)

Broker will publish the **MQTTWillMessage** to this topic if disconnected without a disconnect command.

- String data type, maximum number of characters is 64

15. CR1000X specifications

Electrical specifications are valid over a -40 to +70 °C, non-condensing environment, unless otherwise specified. Extended electrical specifications (noted as XT in specifications) are valid over a -55 to +85 °C non-condensing environment. Recalibration is recommended every three years. Critical specifications and system configuration should be confirmed with Campbell Scientific before purchase.

15.1 System specifications

Processor: Renesas RX63N (32-bit with hardware FPU, running at 100 MHz)

Memory (see Data memory (p. 46) for more information):

- Total onboard: 128 MB of flash + 4 MB battery-backed SRAM
  - Data storage: 4 MB SRAM + 72 MB flash (extended data storage automatically used for auto-allocated Data Tables not being written to a card)
  - CPU drive: 30 MB flash
  - OS load: 8 MB flash
  - Settings: 1 MB flash
  - Reserved (not accessible): 10 MB flash
- Data storage expansion: Removable microSD flash memory, up to 16 GB

Program Execution Period: 1 ms to 1 day

Real-Time Clock:

- Battery backed while external power is disconnected
- **Resolution**: 1 ms
- **Accuracy**: ±3 min. per year, optional GPS correction to ±10 µs

Wiring Panel Temperature: Measured using a 10K3A1A BetaTHERM thermistor, located between the two rows of analog input terminals.

15.2 Physical specifications

Dimensions: 23.8 x 10.1 x 6.2 cm (9.4 x 4.0 x 2.4 in); additional clearance required for cables and wires. For CAD files, see CR1000X Images and CAD 2D Drawings.

Weight/Mass: 0.86 kg (1.9 lb)

Case Material: Powder-coated aluminum

15.3 Power requirements

Protection: Power inputs are protected against surge, over-voltage, over-current, and reverse power. IEC 61000-4 Class 4 level.

Power In Terminal:

- **Voltage Input**: 10 to 18 VDC
- **Input Current Limit at 12 VDC**:
  - 4.35 A at -40 °C
  - 3 A at 20 °C
  - 1.56 A at 85 °C
- 30 VDC sustained voltage limit without damage. Transient voltage suppressor (TVS) diodes at the **POWER IN** terminal clamps transients to 36 to 40 V. Input voltages greater than 18 V and less than 32 V are tolerated; however, the 12 V output **SW12-1** and **SW12-2** are disabled and will not function until the input voltage falls below 16 V. Sustained input voltages in excess of 32 V can damage the TVS diodes. If the voltage on the **POWER IN** terminals exceeds 19 V, power is shut off to certain parts of the data logger to prevent damaging connected sensors or peripherals.

USB Power: Functions that will be active with USB 5 VDC include sending programs, adjusting data logger settings, and making some measurements. If USB is the only power source, then the **CS I/O** port and the **5V**, **12V**, and **SW12** terminals will not be operational. When powered by USB (no other power supplies connected) **Status table** field **Battery** = **0**.

Internal Lithium Battery: AA, 2.4 Ah, 3.6 VDC (Tadiran TL 5903/S) for battery-backed SRAM and clock. 3-year life with no external power source. See also Internal battery (p. 132).

Average Current Drain:

Assumes 12 VDC on **POWER IN** terminals.

- **Idle**: <1 mA
- **Active 1 Hz Scan**: 1 mA
- **Active 20 Hz Scan**: 55 mA
- **Serial** (RS-232/RS-485): Active + 25 mA
- **Ethernet Power Requirements**:
  - **Ethernet 1 Minute**: Active + 1 mA
  - **Ethernet Idle**: Active + 4 mA
  - **Ethernet Link**: Active + 47 mA

Vehicle Power Connection: When primary power is pulled from the vehicle power system, a second power supply OR charge regulator may be required to overcome the voltage drop at vehicle start-up.

15.4 Power output specifications

15.4.1 System power out limits (when powered with 12 VDC)

Temperature (°C)	Current Limit[1] (A)
–40°	4.53
20°	3.00
70°	1.83
85°	1.56

[1] Limited by self-resetting thermal fuse

15.4.2 12 V and SW12 V power output terminals

12V, **SW12-1**, and **SW12-2:** Provide unregulated 12 VDC power with voltage equal to the Power Input supply voltage. These are disabled when operating on USB power only. The **12V** terminal is limited to the current shown in the previous table.

SW12 current limits	
Temperature (°C)	Current Limit [1] (mA)
–40°	1310
0°	1004
20°	900
50°	690
70°	550
80°	470
[1] Thermal fuse hold current. Overload causes voltage drop. Disconnect and let cool to reset. Operate at limit if the application can tolerate some fluctuation.	

15.4.3 5 V fixed output

5V: One regulated 5 V output. Supply is shared between the **5V** terminal and **CS I/O** DB9 5 V output.

- **Voltage Output**: Regulated 5 V output (±5%)
- **Current Limit**: 230 mA

15.4.4 C as power output

Operating at the current limit is OK if voltage fluctuation can be tolerated. Drive capacity is determined by the logic level of the VDC supply and the output resistance (R_O) of the **C** terminal. It is expressed as: $V_O = 5\ V - (R_O \cdot I_O)$, where V_O is the drive limit, and I_O is the current required by the external device. For example: at the maximum current limit of 10 mA on **C1** the voltage level would reduce from 5 V to 3.5 V.

- **C** Terminals:
  - **Output Resistance (R_O)**: 150 Ω
  - **5 V Logic Level Drive Capacity**: 10 mA @ 3.5 VDC; $V_O = 5\ V - (150\ \Omega \cdot I_O)$
  - **3.3 V Logic Level Drive Capacity**: 10 mA @ 1.8 VDC; $V_O = 3.3\ V - (150\ \Omega \cdot I_O)$

15.4.5 CS I/O pin 1

5 V Logic Level Max Current: 200 mA

15.4.6 Voltage excitation

VX: Four independently configurable voltage terminals (**VX1**-**VX4**). When providing voltage excitation, a single 16-bit DAC shared by all **VX** outputs produces a user-specified voltage during measurement only. In this case, these terminals are regularly used with resistive-bridge measurements (see Resistance measurements (p. 61) for more information). **VX** terminals can also be used to supply a selectable, switched, regulated 3.3 or 5 VDC power source to power digital sensors and toggle control lines.

	Range	Resolution	Accuracy	Maximum Source/Sink Current[1]
Voltage Excitation	±4 V	0.06 mV	±(0.1% of setting + 2 mV)	±40 mA
Switched, Regulated	+3.3 or 5 V	3.3 or 5 V	±5%	50 mA
[1] Exceeding current limits causes voltage output to become unstable. Voltage should stabilize when current is reduced to within stated limits.				

15.5 Analog measurement specifications

16 single-ended (**SE**) or 8 differential (**DIFF**) terminals individually configurable for voltage, thermocouple, current loop, ratiometric, and period average measurements, using a 24-bit ADC. One channel at a time is measured.

15.5.1 Voltage measurements

Terminals:

- **Differential Configuration**: DIFF 1H/1L – 8H/8L
- **Single-Ended Configuration**: SE1 – SE16

Input Resistance: 20 GΩ typical

Input Voltage Limits: ±5 V

Sustained Input Voltage without Damage: ±20 VDC

DC Common Mode Rejection:

- > 120 dB with input reversal
- ≥ 86 dB without input reversal

Normal Mode Rejection: > 70 dB @ 60 Hz

Input Current @ 25 °C: ±1 nA typical

Filter First Notch Frequency (f_{N1}) Range: 0.5 Hz to 31.25 kHz (user specified)

Analog Range and Resolution:

		Differential with Input Reversal		Single-Ended and Differential without Input Reversal	
Notch Frequency (f_{N1}) (Hz)	Range[1] (mV)	RMS (µV)	Bits[2]	RMS (µV)	Bits[2]
15000	±5000 ±1000 ±200	8.2 1.9 0.75	20 20 19	11.8 2.6 1.0	19 19 18
50/60[3]	±5000 ±1000 ±200	0.6 0.14 0.05	24 23 22	0.88 0.2 0.08	23 23 22
5	±5000 ±1000 ±200	0.18 0.04 0.02	25 25 24	0.28 0.07 0.03	25 24 23

[1] Range overhead of ~5% on all ranges guarantees that full-scale values will not cause over range

[2] Typical effective resolution (ER) in bits; computed from ratio of full-scale range to RMS resolution.

[3] 50/60 corresponds to rejection of 50 and 60 Hz ac power mains noise.

Accuracy (does not include sensor or measurement noise):

- 0 to 40 °C: ±(0.04% of measurement + offset)
- –40 to 70 °C: ±(0.06% of measurement + offset)

Voltage Measurement Accuracy Offsets:

	Typical Offset (µV RMS)	
Range (mV)	Differential with Input Reversal	Single-Ended or Differential without Input Reversal
±5000	±0.5	±2
±1000	±0.25	±1
±200	±0.15	±0.5

Measurement Settling Time: 20 µs to 600 ms; 500 µs default

Multiplexed Measurement Time:

These are not maximum speeds. Multiplexed denotes circuitry inside the data logger that switches signals into the ADC.

Measurement time = INT(multiplexed measurement time • (reps+1) + 2ms

	Differential with Input Reversal	Single-Ended or Differential without Input Reversal
Example fN1[1] (Hz)	Time[2] (ms)	Time[2] (ms)
15000	2.04	1.02
60	35.24	17.62
50	41.9	20.95
5	401.9	200.95

[1] Notch frequency (1/integration time).

[2] Default settling time of 500 µs used.

See also Voltage measurements (p. 57).

15.5.2 Resistance measurement specifications

The data logger makes ratiometric-resistance measurements for four- and six-wire full-bridge circuits and two-, three-, and four-wire half-bridge circuits using voltage excitation. Excitation polarity reversal is available to minimize dc error. Typically, at least one terminal is configured for excitation output. Multiple sensors may be able to use a common excitation terminal.

Accuracy:

Assumes input reversal for differential measurements `RevDiff` and excitation reversal `RevEx` for excitation voltage <1000 mV. Does not include bridge resistor errors or sensor and measurement noise.

Ratiometric accuracy, rather than absolute accuracy, determines overall measurement accuracy. Offset is the same as specified for analog voltage measurements.

- **0 to 40 °C**: ±(0.01% of voltage measurement + offset)
- **–40 to 70 °C**: ±(0.015% of voltage measurement + offset)
- **–55 to 85 °C (XT)**: ±(0.02% of voltage measurement + offset)

15.5.3 Period-averaging measurement specifications

Use `PeriodAvg()` to measure the period (in microseconds) or the frequency (in Hz) of a signal on a single-ended channel.

Terminals: **SE1-SE16**

Accuracy: ±(0.01% of measurement + resolution), where resolution is 0.13 µs divided by the number of cycles to be measured

Ranges:

- Minimum signal centered around specified period average threshold.
- Maximum signal centered around data logger ground.
- Maximum frequency = 1/(2 * (minimum pulse width)) for 50% duty cycle signals

Gain Code Option	Voltage Gain	Minimum Peak to Peak Signal (mV)	Maximum Peak to Peak Signal (V)	Minimum Pulse Width (µs)	Maximum Frequency (kHz)
0	1	500	10	2.5	200
1	2.5	50	2	10	50
2	12.5	10	2	62	8
3	64	2	2	100	5

See also Period-averaging measurements (p. 68).

15.5.4 Current-loop measurement specifications

The data logger makes current-loop measurements by measuring across a current-sense resistor associated with the RS-485 resistive ground terminal.

Terminals: **RG1** and **RG2**

Maximum Input Voltage: ±16 V

Resistance to Ground: 101 Ω

Current Measurement Shunt Resistance: 10 Ω

Maximum Current Measurement Range: ±80 mA

Absolute Maximum Current: ±160 mA

Resolution: ≤ 20 nA

Accuracy: ±(0.1% of reading + 100 nA) @ -40 to 70 °C

See also Current-loop measurements (p. 59).

15.6 Pulse measurement specifications

Two inputs (**P1-P2**) individually configurable for switch closure, high-frequency pulse, or low-level AC measurements. See also Digital input/output specifications (p. 217). Each terminal has its own independent 32-bit counter.

> **NOTE:**
> Conflicts can occur when a control port pair is used for different instructions (`TimerInput()`, `PulseCount()`, `SDI12Recorder()`, `WaitDigTrig()`). For example, if **C1** is used for `SDI12Recorder()`, **C2** cannot be used for `TimerInput()`, `PulseCount()`, or `WaitDigTrig()`.

Maximum Input Voltage: ±20 VDC

Maximum Counts Per Channel: 2^{32}

Maximum Counts Per Scan: 2^{32}

Input Resistance: 5 kΩ

Accuracy: ±(0.02% of reading + 1/scan)

15.6.1 Switch closure input

Terminals: **C1-C8**

Pull-Up Resistance: 100 kΩ to 5 V

Event: Low (<0.8 V) to High (>2.5 V)

Maximum Input Frequency: 150 Hz

Minimum Switch Closed Time: 5 ms

Minimum Switch Open Time: 6 ms

Maximum Bounce Time: 1 ms open without being counted

15.6.2 High-frequency input

Terminals: C1-C8

Pull-Up Resistance: 100 kΩ to 5 V

Event: Low (<0.8 V) to High (>2.5 V)

Maximum Input Frequency: 250 kHz

15.6.3 Low-level AC input

Minimum Pull-Down Resistance: 10 kΩ to ground

DC-offset rejection: Internal AC coupling eliminates DC-offset voltages up to ±0.05 VDC

Input Hysteresis: 12 mV at 1 Hz

Low-Level AC Pulse Input Ranges:

Sine wave (mV RMS)	Range (Hz)
20	1.0 to 20
200	0.5 to 200
2000	0.3 to 10,000
5000	0.3 to 20,000

15.7 Digital input/output specifications

Terminals configurable for digital input and output (I/O) including status high/low, pulse width modulation, external interrupt, edge timing, switch closure pulse counting, high-frequency pulse counting, UART, RS-232, RS-422, RS-485, SDM, SDI-12, I2C, and SPI function. Terminals are configurable in pairs for 5 V or 3.3 V logic for some functions.

> NOTE:
> Conflicts can occur when a control port pair is used for different instructions (`TimerInput()`, `PulseCount()`, `SDI12Recorder()`, `WaitDigTrig()`). For example, if **C1** is used for `SDI12Recorder()`, **C2** cannot be used for `TimerInput()`, `PulseCount()`, or `WaitDigTrig()`.

Terminals: C1-C8

Maximum Input Voltage: ±20 V

Logic Levels and Drive Current:

Terminal Pair Configuration	5 V Source	3.3 V Source
Logic low	≤ 1.5 V	≤ 0.8 V
Logic high	≥ 3.5 V	≥ 2.5 V

15.7.1 Switch closure input

Terminals: C1-C8

Pull-Up Resistance: 100 kΩ to 5 V

Event: Low (<0.8 V) to High (>2.5 V)

Maximum Input Frequency: 150 Hz

Minimum Switch Closed Time: 5 ms

Minimum Switch Open Time: 6 ms

Maximum Bounce Time: 1 ms open without being counted

15.7.2 High-frequency input

Terminals: C1-C8

Pull-Up Resistance: 100 kΩ to 5 V

Event: Low (<0.8 V) to High (>2.5 V)

Maximum Input Frequency: 250 kHz

15.7.3 Edge timing

Terminals: C1-C8

Maximum Input Frequency: ≤ 1 kHz

Resolution: 500 ns

15.7.4 Edge counting

Terminals: C1-C8

Maximum Input Frequency: ≤ 2.3 kHz

15.7.5 Quadrature input

Terminals: **C1-C8** can be configured as digital pairs to monitor the two sensing channels of an encoder.

Maximum Frequency: 2.5 kHz

Resolution: 31.25 µs or 32 kHz

15.7.6 Pulse-width modulation

Maximum Period: 36.4 seconds

Resolution:

- **0 – 5 ms**: 83.33 ns
- **5 – 325 ms**: 5.33 µs
- **> 325 ms**: 31.25 µs

See also Pulse measurements (p. 69) and Pulse measurement specifications (p. 216).

15.8 Communications specifications

A data logger is normally part of a two-way conversation started by a computer. In applications with some types of interfaces, the data logger can also initiate the call (callback) when needed. In satellite applications, the data logger may simply send bursts of data at programmed times without waiting for a response.

Ethernet Port: RJ45 jack, 10/100Base Mbps, full and half duplex, Auto-MDIX, magnetic isolation, and TVS surge protection. See also Ethernet communications option (p. 24).

Internet Protocols: Ethernet, PPP, RNDIS, ICMP/Ping, Auto-IP(APIPA), IPv4, IPv6, UDP, TCP, TLS (v1.2), DNS, DHCP, SLAAC, Telnet, HTTP(S), SFTP, FTP(S), POP3/TLS, NTP, SMTP/TLS, SNMPv3, CS I/O IP, MQTT

Additional Protocols: CPI, PakBus, PakBus Encryption, SDM, SDI-12, Modbus RTU / ASCII / TCP, DNP3, custom user definable over serial, NTCIP, NMEA 0183, I2C, SPI

USB Device: Micro-B device for computer connectivity

CS I/O: 9-pin D-sub connector to interface with Campbell Scientific CS I/O peripherals.

SDI-12 (**C1**, **C3**, **C5**, **C7**): Four independent SDI-12 compliant terminals are individually configured and meet SDI-12 Standard v 1.4.

RS-485 (**C5** to **C8**): One full duplex or two half duplex

RS-422 (**C5** to **C8**): One full duplex or two half duplex

RS-232/CPI: Single RJ45 module port that can operate in one of two modes: CPI or RS-232. CPI interfaces with Campbell Scientific CDM measurement peripherals and sensors. RS-232 connects, with an adapter cable, to computer, sensor, or communications devices serially.

CPI: One CPI bus. Up to 1 Mbps data rate. Synchronization of devices to 5 µS. Total cable length up to 610 m (2000 ft). Up to 20 devices. CPI is a proprietary interface for communications between Campbell Scientific data loggers and Campbell Scientific CDM peripheral devices. It consists of a physical layer definition and a data protocol.

Hardwired: Multi-drop, short haul, RS-232, fiber optic

Satellite: GOES, Argos, Inmarsat Hughes, Irridium

15.9 Standards compliance specifications

View compliance and conformity documents at www.campbellsci.com/cr1000x.

Shock and Vibration: MIL-STD 810G methods 516.6 and 514.6

Protection:

- Wiring panel: IP40
- Measurement module when connected to the wiring panel: IP65

EMI and ESD protection:

- **Immunity**: Meets or exceeds following standards:
  - **ESD**: per IEC 61000-4-2; ±15 kV air, ±8 kV contact discharge
  - **Radiated RF**: per IEC 61000-4-3; 10 V/m, 80-1000 MHz
  - **EFT**: per IEC 61000-4-4; 4 kV power, 4 kV I/O
  - **Surge**: per IEC 61000-4-5; 4 kV power, 4kV I/O
  - **Conducted RF**: per IEC 61000-4-6; 10 V power, 10 V I/O
- Emissions and immunity performance criteria available on request.

Appendix A. MQTT commands

A.1 MQTT topic structure

The topic structure transitions from "coarse to fine" using the form `<groupID>/msgType/<deviceID>`. This allows the configurable `groupID` to be defined in a "coarse" manner, followed by a defined `msgType` and `deviceID` string. This topic naming follows a pattern similar to the Sparkplug specification sparkplug.eclipse.org used in SCADA applications. The Sparkplug namespace elements for a topic use the following structure:

```
namespace/group_id/message_type/edge_node_id/[device_id]
```

The `message_type` is fixed and provides a defined set of messages described in the Sparkplug specification.

Following this idea and making the `groupID` portion of the topic structure settings inside the data logger allows MQTT application developers to define their own "coarse to fine" topic definitions.

The `<deviceID>` portion of the topic will take the form:

```
model/UID
```

Where `model` will be: GRANITE10, GRANITE9, GRANITE6, CR6, CR1000X, CR350.

UID (unique identifier) is a placeholder for future functionality. If the internal UID has not yet been set the serial number will be used as the UID. If the UID is set, the default base topic will be: `cs/v2/`. If not set the default will be `cs/v1`. This allows the MQTT broker ingestion to differentiate between serial number and UID.

This topic structure allows the data ingestion stream to more easily route the topics published by the data logger. Taking advantage of the MQTT broker's topic parsing via the use of wildcards `+` and `#`, the messages can be ingested by small function specific micro-services.

This example shows a `namespace, version, msgType, model, UID, Data Source` as the "coarse to fine" transition within the topic.

```
cs/v2/data/model/UID/tableName
```

Which is a generic representation of:

```
<groupID>/data/<deviceID>/tableName
```

> **NOTE:**
> Both `<groupID>` and `<deviceID>` can be defined as needed for the intended use case.

> **NOTE:**
> The MQTT api uses the camelCase naming convention. The first character of the first word is lowercase and subsequent words within a name have the first letter capitalized. This applies to topics as well as JSON key:value names. All characters in the MQTT topics are sent as part of the MQTT packet; therefore, keep topic lengths to a minimum.

A.2 MQTT automatic publish topics

The data logger automatically publishes to topics:

- `<groupID>/state/<deviceID>`
- `<groupID>/state/<deviceID>/watchdogEvent`
- `<groupID>/state/<deviceID>/statusInfo`

A.2.1 state

This topic is used as a "heartbeat" to verify that the data logger is operating properly. The interval at which the topic is published to is controlled by the state publish interval setting. This topic is also used to report different result information for command and control topic actions.

Example:

Topic: `<groupID>/state/<deviceID>/statusInfo`

JSON:


```
{
"clientId" : "CR1000X_A399",
"state" : "online"
}
```


A.2.2 statusInfo

This topic is published at program startup and contains a subset of information from the status table.

Example:

Topic: `<groupID>/state/<deviceID>/statusInfo`

JSON:


```
{
  "state" : {
    "reported" : {
      "clientId" : "CR6_966",
      "OS_Version" : "CR6.10.02.2020.12.14.0955",
      "Program_Name" : "",
      "Program_Signature" : "43690",
      "Compile_Errors" : "1",
      "Compile_Results" : "No Program",
      "Low_12volt" : "0",
      "Battery" : "11.11",
      "Skipped_Scan" : "0",
      "Watchdog_Errors" : "0"
    }
  }
}
```


A.2.3 watchdogEvent

If a watchdog event occurs, the data logger will reset and increment the watchdog count. Depending on the type of watchdog, a WatchdogInfo.txt file may be created on the data logger. When a watchdog happens a watchdog event notification will be published on the following topic:

```
<groupID>/state/<deviceID>/watchdogEvent
```

The payload published when a watchdog event occurs is a JSON object containing the watchdog count and the watchdog file name, if a file is present on the data logger. Under certain error conditions, the data logger will trigger a watchdog and increment the watchdog count without creating a watchdog file. If a watchdog file is not present, the JSON key “file” value will be an empty string.

Below is an example of the event payload:

```
{
“count”: “3”,
“file”: “” (When a watchdog file is present the file name is always
WatchdogInfo.txt.)
}
```

A.3 MQTT command and control (automatic subscription topics)

When the data logger successfully connects to an MQTT broker, it will subscribe to a single topic to perform command and control.

`<groupID>/cc/<deviceID>/#`

The command and control functionality consist of the following topics:

A.3.1 Command response

For commands that elicit a response, the response will come on either the `<groupID>/state/<deviceID>` or on the targeted topic: `<groupID>/cr/<deviceID>/ccCmd`. The use of `state` vs. `cr` depends on the nature of the data returned in the response. If the response is just an acknowledgment, it is returned on `state`. If there is specific information to be returned, it is published on a targeted topic.

Command and control	Topic	Description
OS	`<groupID>/cc/<deviceID>/OS`	Download OS
program	`<groupID>/cc/<deviceID>/program`	Download CRBasic program
mqttConfig	`<groupID>/cc/<deviceID>/mqttConfig`	Download new MQTT configuration
fileControl	`<groupID>/cc/<deviceID>/fileControl`	Perform file control actions
editConst	`<groupID>/cc/<deviceID>/editConst`	Update the constant table values

Command and control	Topic	Description
setting	`<groupID>/cc/<deviceID>/setting`	Set/Retrieve a Device Configuration setting
historicData	`<groupID>/cc/<deviceID>/historicData`	Retrieve past data from a Data Table
talkThru	`<groupID>/cc/<deviceID>/talkThru`	Perform serial talk thru to a sensor
setVar	`<groupID>/cc/<deviceID>/setVar`	Set a variables value in a Public, Status or Structure table
getVar	`<groupID>/cc/<deviceID>/getVar`	Get variable from table
reboot	`<groupID>/cc/<deviceID>/reboot`	Reboot the data logger

A.3.2 OS download

An OS can be updated by publishing the following JSON object to:

`<groupID>/cc/<deviceID>/OS`

```
{
“url”: “url of OS file location”
}
```

Example:

```
{
“url” : “https://example.123.xyz”
}
```

A.3.3 CRBasic program download

A CRBasic Program file can be downloaded and run by publishing the following JSON object to:

Publish on `<groupID>/cc/<deviceID>/program` with the following JSON payload:

```
{
“url” : ”https://example.123.xyz”,
“filename”:”MyProg.crb”
}
```

The data logger will issue a HTTP(s) GET to the specified URL and report success or failure on the `<groupID>/state/<deviceID>` topic. If successful, the program will be set to `run now` and `run on power up` and the data logger will restart and compile and run the program.

Example: With a GRANITE6 using the Base topic: cs/v1/ and a serial number of 123.

Publish to topic: `cs/v1/cc/granite6/123/program`

```
{
"url":"https://s3.us-west-2.amazonaws.com/bucket.cr-basic/mqttPub27.cr6?X-Amz-Expires=3593&X-Amz-Algorithm=AWS4-HMAC-SHA256&X-Amz-Credential=AKIA4MADCTNFDCYIQHED/20200826/us-west-2/s3/aws4_request&X-Amz-Date=20200826T150138Z&X-Amz-SignedHeaders=host&X-Amz-Signature=496fccd4d14edfe39d270ccee8ae0247ee1b256d01e1810b2c288de940b58507",
"fileName":"MyPub.crb"
}
```

A.3.4 New mqtt configuration

The `mqttConfig` command is used to set up the data logger. The file received from this command must follow the proprietary binary format expected by the parsing routine.

Example:

Publish on `<groupID>/cc/<deviceID>/mqttConfig` with the following JSON payload:

```
{
“url” : “https://example.123.xyz”
}
```

The data logger will issue an HTTP(s) GET to the specified URL and report success or failure on the `<groupID>/state/<deviceID>` topic. Once this file is received, it will be parsed as a binary settings file and if valid, the settings applied, and the data logger restarted.

A.3.5 Edit constant table (`editConst`)

To edit the constant table via MQTT, publish the new Const table values in a JSON object. The JSON keys and the values must be a string. The string values will be converted to the appropriate types by the data logger. Only the values to be changed are required in the JSON object.

Example:

Publish on `<groupID>/cc/<deviceID>/editConst` with the following JSON payload:

```
{
“key1” : “value1”,
“key2” : “value2”,
“keyN” : “valueN”
}
```

The data logger will publish results on `<groupID>/state/<deviceID>/`.

A.3.6 Reboot data logger

To remotely reboot (restart) the data logger, use the topic `<groupID>/cc/<deviceID>/reboot` with the following JSON payload:

```
{
"action” : "reboot",
}
```

The additional JSON provides more safety when rebooting.

If successful, the data logger will report on `<groupID>/state/<deviceID>`, that it is rebooting:


```
{
"clientId" : "CR6_966",
"state" : "online",
"fileTransfer" : "Rebooting Datalogger"
}
```


A.3.7 File control

Use the `fileControl` topic to perform file manipulation commands. Part of the payload will be the action indicating which file function to perform. Since file control, in the full context of data logger capability, is too complex for the thing shadow, file control will be best handled while the data logger is online. The file control functions can be automated by triggering file transfer events via AWS lifecycle events.

Each file control action has a unique JSON object payload. Each of the unique JSON objects must contain the `cmd` key and `fileControl` value to perform the file control functions. Each file control function is described below:

A.3.7.1 list

The data logger can store more files than can be listed in one MQTT publish packet. Therefore, a file list request will return a list of file names containing a maximum of 4800 characters. The names will be published on the `fileList` topic.

Publish on `<groupID>/cc/<deviceID>`/fileControl/ with the following JSON payload:

```
{
“action” : “list”
“drive” :”USR”, (optional – default is CPU)
}
```

The data logger will publish on the topic:

`<groupID>/cr/<deviceID>/fileControl/list`

Example:

Publish topic: `cs/v2/cc/cr6/ABCDEF/fileControl`

JSON:

```
{"action" : "List"}
```

Response topic: `cs/v2/cr/cr6/ABCDEF/fileControl/list`

JSON:

```
{
"drive" : "CPU",
"clientID" : "CR6_966",
"fileList" : [ "simple.CR6", "spectrum_krohn_cal.crb", "spectrum_cal.crb",
"PeriodAvg_testingDaveI.CR6", "spectrum_cal_check.crb", "mqttPub27.cr6",
"WatchdogInfo.txt" ]
}
```

A.3.8 Settings

An individual ***Device Configuration Utility*** setting can be set or published via MQTT by publishing the following JSON object.

A.3.8.1 set

A single setting can be changed in each message. To set multiple settings, a series of messages will be sent with the last having apply set to true.

```
{
“action” : “set”,
“name” :”Setting name”,
“value” : “XXX”,
“apply” :”true” { this is optional }
}
```

The data logger will notify success or failure on the topic <groupID>/state/<deviceID>/.

Example:

Publish Topic: cs/v2/cc/cr6/ABCDEF/setting

JSON:

```
{"name": "PakBusAddress", "action" : "set", "value" : "3", "apply" : "true"}
```

Response topic: cs/v2/state/cr6/ABCDEF/

```
{
"clientId" : "CR6_966",
"state" : "Set Setting Succeeded"
}

{
"clientId" : "CR6_966",
"state" : "Applying Settings"
}
```

A.3.8.2 download from CLOUD

Send files to the **CPU** drive of the data logger by publishing the download URL of the file and the file name to a topic. These can be **include files** which will be used by the main CRBasic program.

The CLOUD will publish one file URL at a time to a `FileManager` topic.

> **NOTE:**
> All **include files** must be downloaded before the main program can be set to run.

download

Publish on `<groupID>/cc/<deviceID>/fileControl` with the following JSON payload:

```
{
"action" : "download",
"url" : "https://example.123.xyz",
"fileName" : "name of local file",
"drive" :"USR", (optional - default is CPU)
}
```

The data logger will perform an HTTP(s) GET to the specified URL. Any state or error information will be published on the topic `<groupID>/state/<deviceID>/`.

A.3.8.3 Delete a file

Action to delete a file on the data logger. If the file being deleted is the running program, the program will not be stopped, only the associated text file will be deleted.

```
{
"action" : "delete"
"filename" : "name of file on device"
"drive" :"USR", (optional - default is CPU)
}
```

The data logger will publish on topic `<groupID>/state/<deviceID>/`.

A.3.8.4 Stop

Action to stop the currently running program.

```
{
"action" : "stop"
}
```

The data logger will publish on topic `<groupID>/state/<deviceID>/`.

A.3.8.5 Run

Action to stop the currently running program.

```
{
"action" : "run",
"filename" : "name of file on device"
}
```

The data logger will publish on topic `<groupID>/state/<deviceID>/`.

A.3.8.6 Upload to CLOUD

Action to upload a file (HTTP PUT) from the data logger to the CLOUD. This action uses the AWS S3 bucket pre-signed URL.

```
{
“action” : “upload”,
“url” : “https://example.123.xyz”,
“filename” : “name of file on device”
}
```

The url will be used to issue HTTP(s) POST and the file will be sent. The data logger will publish result information on topic `<groupID>/state/<deviceID>/`.

A.3.8.7 publish

To read the value of a setting the topic `<groupID>/cc/<deviceID>/setting` is used with a payload:

```
{
“action” : “publish”,
“name” :”Setting name”,
}
```

The setting value will be published on:

`<groupID>/cr/<deviceID>/setting`

Example:

Publish topic: `cs/v2/cc/cr6/ABCDEF/setting`

JSON:

```
{"name" : "PakBusAddress", "action" : "Publish"}
```

Response topic: `cs/v2/cr/cr6/ABCDEF/setting`

JSON:

```
{
"setting" : "PakBusAddress",
"value" : " 3"
}
```

A.3.8.8 apply

To apply previously set settings, `<groupID>/cc/<deviceID>/setting` is used with a payload:

```
{
“apply” :”true”
}
```

The data logger will notify success or failure on the topic `<groupID>/state/<deviceID>`. If successful, this will commit settings to non-volatile memory and restart the data logger.

A.3.9 Historic Data Collection

Historic data can be requested via MQTT by publishing the appropriate JSON payload on the following topic:

`<groupID>/cc/<deviceID>/historicData`

The payload published on the topic must be in the JSON format as follows:

```
{
“table”: “{table name}”,
“start”: “{utc time stamp}”,
“end”: “{utc time stamp}”
}
```

Only data from a `DataTable` containing the `MQTTPublishTable` instruction will be published. The data will be published in the same format as indicated in the table publish instruction. In the case of GEOJSON, the point coordinates used when re-publishing the data will be the latest values passed into the table publish instruction. GEOJSON coordinates are not stored.

The historic data will be published on the following topic:

`<groupID>/cr/<deviceID>/historicData/TableName`

```
{
"cmd" : "HistoricData",
"table" : "ThirtySecond",
"start" : "2020-04-14T10:10:24.865Z",
"end" : "2020-04-14T10:20:32.176Z"
}
```

A.3.10 Set Public Variable

A value can be set in a CRBasic program Public table by using the a `setVar` topic. To set the value of the public table variable, publish associate JSON object to the following topic.

A.3.10.1 setVar

To change a variable in the running program of the data logger publish to `<groupID>/cc/<deviceID>/getVar` with a payload like:

```
{
"name” : "VarOne",
"Value" : "12.345"
}
```

The data logger will report on `<groupID>/state/<deviceID>`.

> **NOTE:**
> The stringified value will be converted to the type of the variable by the data logger.

A.3.11 Get Public variable

A value can be set in a CRBasic programs Public table by using a getVar topic. To get the value of the public table variable, publish associate JSON object to the following topic.

A.3.11.1 getVar

To read a variable in the running program of the data logger publish to <groupID>/cc/<deviceID>/getVar with a payload similar to this, where VarOne is the variable name:

```
{
"name” : "VarOne",
}
```

The data logger will report on <groupID>/state/<deviceID>.

> **NOTE:**
> The value will be converted from the type of the variable to a string by the data logger.

A.3.12 Serial talkThru

Serial talkThru allows remote interaction with sensors connected to data logger serial ports. It works similar to the terminal mode serial talk through.

A.3.12.1 Talk through to sensor

Serial talk through is initiated by sending a JSON payload to the topic <groupID>/cc/<deviceID>/talkThru. The data logger will transmit to the serial sensor and receive one response. One transmission is required for each response from sensor. This feature is not designed to sniff serial sensor output. The desired communications port must be configured prior to using serial talk through. This command causes the data logger to enter a “talk through session”. The session will stay active, meaning that the sensor port will remain in a state of not transferring data through to the instructions using the port until it is aborted or times out. The timeout associated with a talkThru session is 1 minute. If no further talkThru commands are received within a minute, the session will end, and normal communications port operations will resume. The session can also be ended by publishing to the talkThru topic with the JSON key value pair with the key of “abort” (the value does not matter).

The talk thru payload must follow the described format and be published to:

<groupID>/cc/<deviceID>/talkThru

```
{
“comPort”: “{Port Description}”,
“outString”: “{ASCII string to be sent to sensor}”,
“numberTries”: “{ASCII number string indicating number of transmissions of
outString}” (Optional),
“respDelay”: “{ASCII number string indicating time (milliseconds) to wait for the
complete response from sensor}” (Optional)
“abort” : “true”
}
```


A.3.12.2 TalkThru from sensor

A serial string response from a smart sensor can only be received as a response to a transmission to a sensor. The response will be published to the following topic in the specified JSON format.

`<groupID>/cr/<deviceID>/talkThru`

`TalkThru` response JSON payload:


```
{
“response”: “{String response from Sensor}”
}
```


If an error occurred, the response will contain an error message:

- Illegal ComPort
- ComPort must be open to use MQTT `talkThru`
- No response received

A.3.12.3 Allowable Com port values

The Com port values must follow the case shown.

- ComRS232
- ComC1
- ComC3

- ComC5
- ComC7

SDM

- ComXX of SDM com port selected by SDM-SIO module

Appendix B. Glossary

A

AC

Alternating current (see VAC).

accuracy

The degree to which the result of a measurement, calculation, or specification conforms to the correct value or a standard.

ADC

Analog to digital conversion. The process that translates analog voltage levels to digital values.

alias

A second name assigned to variable in CRBasic.

allowed neighbor list

In PakBus networking, an allowed neighbor list is a list of neighbors with which a device will communicate. If a device address is entered in an allowed neighbor list, a hello exchange will be initiated with that device. Any device with an address between 1 and 3999 that is not entered in the allowed neighbor list will be filtered from communicating with the device using the list.

amperes (A)

Base unit for electric current. Used to quantify the capacity of a power source or the requirements of a power-consuming device.

analog

Data presented as continuously variable electrical signals.

argument

Part of a procedure call (or command execution).

array

A group of variables as declared in CRBasic.

ASCII/ANSI

Abbreviation for American Standard Code for Information Interchange / American National Standards Institute. An encoding scheme in which numbers from 0-127 (ASCII) or 0-255 (ANSI) are used to represent pre-defined alphanumeric characters. Each number is usually stored and transmitted as 8 binary digits (8 bits), resulting in 1 byte of storage per character of text.

asynchronous

The transmission of data between a transmitting and a receiving device occurs as a series of zeros and ones. For the data to be "read" correctly, the receiving device must begin reading at the proper point in the series. In asynchronous communications, this coordination is accomplished by having each character surrounded by one or more start and stop bits which designate the beginning and ending points of the information. Also indicates the sending and receiving devices are not synchronized using a clock signal.

AWG

AWG ("gauge") is the accepted unit when identifying wire diameters. Larger AWG values indicate smaller cross-sectional diameter wires. Smaller AWG values indicate large-diameter wires. For example, a 14 AWG wire is often used for grounding because it can carry large currents. 22 AWG wire is often used as sensor wire since only small currents are carried when measurements are made.

B

baud rate

The rate at which data is transmitted.

beacon

A signal broadcasted to other devices in a PakBus network to identify "neighbor" devices. A beacon in a PakBus network ensures that all devices in the network are aware of other devices that are viable.

binary

Describes data represented by a series of zeros and ones. Also describes the state of a switch, either being on or off.

BOOL8

A one-byte data type that holds eight bits (0 or 1) of information. BOOL8 uses less space than the 32 bit BOOLEAN data type.

boolean

Name given a function, the result of which is either true or false.

boolean data type

Typically used for flags and to represent conditions or hardware that have only two states (true or false) such as flags and control ports.

burst

Refers to a burst of measurements. Analogous to a burst of light, a burst of measurements is intense, such that it features a series of measurements in rapid succession, and is not continuous.

C

calibration wizard

The calibration wizard facilitates the use of the CRBasic field calibration instructions FieldCal () and FieldCalStrain(). It is found in LoggerNet (4.0 and later) or RTDAQ.

callback

A name given to the process by which the data logger initiates communications with a computer running appropriate Campbell Scientific data logger support software. Also known as "Initiate Comms."

CardConvert software

A utility to retrieve binary final data from memory cards and convert the data to ASCII or other formats.

CD100

An optional enclosure mounted keyboard/display for use with data loggers.

CDM/CPI

CPI is a proprietary interface for communications between Campbell Scientific data loggers and Campbell Scientific CDM peripheral devices. It consists of a physical layer definition and a data protocol.

CF

CompactFlash®

code

A CRBasic program, or a portion of a program.

Collect button

Button or command in data logger support software that facilitates collection-on-demand of final-data memory. This feature is found in PC400, LoggerNet, and RTDAQ software.

Collect Now button

Button or command in data logger support software that facilitates collection-on-demand of final-data memory. This feature is found in PC400, LoggerNet, and RTDAQ software.

COM port

COM is a generic name given to physical and virtual serial communications ports.

COM1

When configured as a communications port, terminals C1 and C2 act as a pair to form Com1.

command

An instruction or signal that causes a computer to perform one of its basic functions (usually in CRBasic).

command line

One line in a CRBasic program. Maximum length, even with the line continuation characters <space> <underscore> (_), is 512 characters. A command line usually consists of one program statement, but it may consist of multiple program statements separated by a <colon> (:).

CompactFlash

CompactFlash® (CF) is a memory-card technology used in some Campbell Scientific card-storage modules.

compile

The software process of converting human-readable program code to binary machine code. Data logger user programs are compiled internally by the data logger operating system.

conditioned output

The output of a sensor after scaling factors are applied.

connector

A connector is a device that allows one or more electron conduits (wires, traces, leads, etc) to be connected or disconnected as a group. A connector consists of two parts — male and female. For example, a common household ac power receptacle is the female portion of a connector. The plug at the end of a lamp power cord is the male portion of the connector.

constant

A packet of memory given an alpha-numeric name and assigned a fixed number.

control I/O

C terminals configured for controlling or monitoring a device.

CoraScript

CoraScript is a command-line interpreter associated with LoggerNet data logger support software.

CPU

Central processing unit. The brains of the data logger.

cr

Carriage return.

CRBasic

Campbell Scientific's BASIC-like programming language that supports analog and digital measurements, data processing and analysis routines, hardware control, and many communications protocols.

CRBasic Editor

The CRBasic programming editor; stand-alone software and also included with LoggerNet, PC400, and RTDAQ software.

CRC

Cyclic Redundancy Check

CRD

An optional memory drive that resides on a memory card.

CS I/O

Campbell Scientific proprietary input/output port. Also, the proprietary serial communications protocol that occurs over the CS I/O port.

CVI

Communications verification interval. The interval at which a PakBus® device verifies the accessibility of neighbors in its neighbor list. If a neighbor does not communicate for a period of time equal to 2.5 times the CVI, the device will send up to four Hellos. If no response is received, the neighbor is removed from the neighbor list.

D

DAC

Digital to analog conversion. The process that translates digital voltage levels to analog values.

data bits

Number of bits used to describe the data and fit between the start and stop bit. Sensors typically use 7 or 8 data bits.

data cache

The data cache is a set of binary files kept on the hard disk of the computer running the data logger support software. A binary file is created for each table in each data logger. These files mimic the storage areas in data logger memory, and by default are two times the size of the data logger storage area. When the software collects data from a data logger, the data is stored in the binary file for that data logger. Various software functions retrieve data from the data cache instead of the data logger directly. This allows the simultaneous sharing of data among software functions.

data logger support software

LoggerNet, RTDAQ, and PC400 - these Campbell Scientific software applications include at least the following functions: data logger communications, downloading programs, clock setting, and retrieval of measurement data.

data output interval

The interval between each write of a record to a final-storage memory data table.

data output processing instructions

CRBasic instructions that process data values for eventual output to final-data memory. Examples of output-processing instructions include Totalize(), Maximize(), Minimize(), and Average(). Data sources for these instructions are values or strings in variable memory. The results of intermediate calculations are stored in data output processing memory to await the output trigger. The ultimate destination of data generated by data output processing instructions is usually final-storage memory, but the CRBasic program can be written to divert to variable memory by the CRBasic program for further processing. The transfer of processed summaries to final-data memory takes place when the Trigger argument in the DataTable() instruction is set to True.

data output processing memory

Memory automatically allocated for intermediate calculations performed by CRBasic data output processing instructions. Data output processing memory cannot be monitored.

data point

A data value which is sent to final-data memory as the result of a data-output processing instruction. Data points output at the same time make up a record in a data table.

data table

A concept that describes how data is organized in memory, or in files that result from collecting data in memory. The fundamental data table is created by the CRBasic program as a result of the DataTable() instruction and resides in binary form in memory. The data table structure resides in the data cache, in discrete data files, and in files that result from collecting final-data memory with data logger support software.

DC

Direct current.

DCE

Data Communications Equipment. While the term has much wider meaning, in the limited context of practical use with the data logger, it denotes the pin configuration, gender, and function of an RS-232 port. The RS-232 port on the data logger is DCE. Interfacing a DCE device to a DCE device requires a null-modem cable.

desiccant

A hygroscopic material that absorbs water vapor from the surrounding air. When placed in a sealed enclosure, such as a data logger enclosure, it prevents condensation.

Device Configuration Utility

Software tool used to set up data loggers and peripherals, and to configure PakBus settings before those devices are deployed in the field and/or added to networks.

DHCP

Dynamic Host Configuration Protocol. A TCP/IP application protocol.

differential

A sensor or measurement terminal wherein the analog voltage signal is carried on two wires. The phenomenon measured is proportional to the difference in voltage between the two wires.

Dim

A CRBasic command for declaring and dimensioning variables. Variables declared with Dim remain hidden during data logger operations.

dimension

To code a CRBasic program for a variable array as shown in the following examples: DIM example(3) creates the three variables example(1), example(2), and example(3); DIM example(3,3) creates nine variables; DIM example(3,3,3) creates 27 variables.

DNP3

Distributed Network Protocol is a set of communications protocols used between components in process automation systems. Its main use is in utilities such as electric and water companies.

DNS

Domain name server. A TCP/IP application protocol.

DTE

Data Terminal Equipment. While the term has much wider meaning, in the limited context of practical use with the data logger, it denotes the pin configuration, gender, and function of an RS-232 port. The RS-232 port on the data logger is DCE. Attachment of a null-modem cable to a DCE device effectively converts it to a DTE device.

duplex

A serial communications protocol. Serial communications can be simplex, half-duplex, or full-duplex.

duty cycle

The percentage of available time a feature is in an active state. For example, if the data logger is programmed with 1 second scan interval, but the program completes after only 100 milliseconds, the program can be said to have a 10% duty cycle.

E

earth ground

A grounding rod or other suitable device that electrically ties a system or device to the earth. Earth ground is a sink for electrical transients and possibly damaging potentials, such as those produced by a nearby lightning strike. Earth ground is the preferred reference potential for analog voltage measurements. Note that most objects have a "an electrical potential" and the potential at different places on the earth - even a few meters away - may be different.

endian

The sequential order in which bytes are arranged into larger numerical values when stored in memory.

engineering units

Units that explicitly describe phenomena, as opposed to, for example, the data logger base analog-measurement unit of millivolts.

ESD

Electrostatic discharge.

ESS

Environmental sensor station.

excitation

Application of a precise voltage, usually to a resistive bridge circuit.

execution interval

The time interval between initiating each execution of a given Scan() of a CRBasic program. If the Scan() Interval is evenly divisible into 24 hours (86,400 seconds), it is synchronized with the 24 hour clock, so that the program is executed at midnight and every Scan() Interval thereafter. The program is executed for the first time at the first occurrence of the Scan() Interval after compilation. If the Scan() Interval does not divide evenly into 24 hours, execution will start on the first even second after compilation.

execution time

Time required to execute an instruction or group of instructions. If the execution time of a program exceeds the Scan() Interval, the program is executed less frequently than programmed and the Status table SkippedScan field will increment.

expression

A series of words, operators, or numbers that produce a value or result.

F

FAT

File Allocation Table - a computer file system architecture and a family of industry-standard file systems utilizing it.

FFT

Fast Fourier Transform. A technique for analyzing frequency-spectrum data.

field

Data tables are made up of records and fields. Each row in a table represents a record and each column represents a field. The number of fields in a record is determined by the number and configuration of output processing instructions that are included as part of the DataTable() declaration.

File Control

File Control is a feature of LoggerNet, PC400, Device Configuration Utility, and RTDAQ data logger support software. It provides a view of the data logger file system and a menu of file management commands.

fill and stop memory

A memory configuration for data tables forcing a data table to stop accepting data when full.

final-data memory

The portion of memory allocated for storing data tables. Once data is written to final-data memory, it cannot be changed but only overwritten when it becomes the oldest data. Final-data memory is configured as ring memory by default, with new data overwriting the oldest data.

final-storage data

Data that resides in final-data memory.

Flash

A type of memory media that does not require battery backup. Flash memory, however, has a lifetime based on the number of writes to it. The more frequently data is written, the shorter the life expectancy.

FLOAT

Four-byte floating-point data type. Default data logger data type for Public or Dim variables. Same format as IEEE4.

FP2

Two-byte floating-point data type. Default data logger data type for stored data. While IEEE4 four-byte floating point is used for variables and internal calculations, FP2 is adequate for most stored data. FP2 provides three or four significant digits of resolution, and requires half the memory as IEEE4.

frequency domain

Frequency domain describes data graphed on an X-Y plot with frequency as the X axis. VSPECT vibrating wire data is in the frequency domain.

frequency response

Sample rate is how often an instrument reports a result at its output; frequency response is how well an instrument responds to fast fluctuations on its input. By way of example, sampling a large gage thermocouple at 1 kHz will give a high sample rate but does not ensure the measurement has a high frequency response. A fine-wire thermocouple, which changes output quickly with changes in temperature, is more likely to have a high frequency response.

FTP

File Transfer Protocol. A TCP/IP application protocol.

full-duplex

A serial communications protocol. Simultaneous bi-directional communications. Communications between a serial port and a computer is typically full duplex.

G

garbage

The refuse of the data communications world. When data is sent or received incorrectly (there are numerous reasons why this happens), a string of invalid, meaningless characters (garbage) often results. Two common causes are: 1) a baud-rate mismatch and 2) synchronous data being sent to an asynchronous device and vice versa.

global variable

A variable available for use throughout a CRBasic program. The term is usually used in connection with subroutines, differentiating global variables (those declared using Public or Dim) from local variables, which are declared in the Sub() and Function() instructions.

ground

Being or related to an electrical potential of 0 volts.

ground currents

Pulling power from the data logger wiring panel, as is done when using some communications devices from other manufacturers, or a sensor that requires a lot of power, can cause voltage potential differences between points in data logger circuitry that are supposed to be at ground or 0 Volts. This difference in potentials can cause errors when measuring single-ended analog voltages.

H

half-duplex

A serial communications protocol. Bi-directional, but not simultaneous, communications. SDI-12 is a half-duplex protocol.

handshake

The exchange of predetermined information between two devices to assure each that it is connected to the other.

hello exchange

In a PakBus network, this is the process of verifying a node as a neighbor.

hertz

SI unit of frequency. Cycles or pulses per second.

HTML

Hypertext Markup Language. Programming language used for the creation of web pages.

HTTP

Hypertext Transfer Protocol. A TCP/IP application protocol.

HTTPS

Hypertext Transfer Protocol Secure. A secure version of HTTP.

hysteresis

The dependence of the state of the system on its history.

Hz

SI unit of frequency. Cycles or pulses per second.

I

I2C

Inter-Integrated Circuit is a multi-controller, multi-peripheral, packet switched, single-ended, serial computer bus.

IEEE4

Four-byte, floating-point data type. IEEE Standard 754. Same format as Float.

Include file

A file containing CRBasic code to be included at the end of the current CRBasic program, or it can be run as the default program.

INF

A data word indicating the result of a function is infinite or undefined.

initiate comms

A name given to a processes by which the data logger initiates communications with a computer running LoggerNet. Also known as Callback.

input/output instructions

Used to initiate measurements and store the results in input storage or to set or read control/logic ports.

instruction

Usually refers to a CRBasic command.

integer

A number written without a fractional or decimal component. 15 and 7956 are integers; 1.5 and 79.56 are not.

intermediate memory

Memory automatically allocated for intermediate calculations performed by CRBasic data output processing instructions. Data output processing memory cannot be monitored.

IP

Internet Protocol. A TCP/IP internet protocol.

IP address

A unique address for a device on the internet.

IP trace

Function associated with IP data transmissions. IP trace information was originally accessed through the CRBasic instruction IPTrace() and stored in a string variable. Files Manager setting is now modified to allow for creation of a file in data logger memory.

isolation

Hardwire communications devices and cables can serve as alternate paths to earth ground and entry points into the data logger for electromagnetic noise. Alternate paths to ground and electromagnetic noise can cause measurement errors. Using opto-couplers in a connecting device allows communications signals to pass, but breaks alternate ground paths and may filter some electromagnetic noise.

J

JSON

Java Script Object Notation. A data file format available through the data logger or LoggerNet.

K

keep memory

Keep memory is non-volatile memory that preserves some settings during a power-up or program start up reset. Examples include PakBus address, station name, beacon intervals, neighbor lists, routing table, and communications timeouts.

keyboard/display

The data logger has an optional external keyboard/display.

L

leaf node

A PakBus node at the end of a branch. When in this mode, the data logger is not able to forward packets from one of its communications ports to another. It will not maintain a list of neighbors, but it still communicates with other PakBus data loggers and wireless sensors. It cannot be used as a means of reaching (routing to) other data loggers.

lf

Line feed. Often associated with carriage return (<cr>). <cr><lf>.

linearity

The quality of delivering identical sensitivity throughout the measurement.

local variable

A variable available for use only by the subroutine in which it is declared. The term differentiates local variables, which are declared in the Sub() and Function() instructions, from global variables, which are declared using Public or Dim.

LoggerLink

Mobile applications that allow a mobile device to communicate with IP, wi-fi, or Bluetooth enabled data loggers.

LoggerNet

Campbell Scientific's data logger support software for programming, communications, and data retrieval between data loggers and a computer.

LONG

Data type used when declaring integers.

loop

A series of instructions in a CRBasic program that are repeated for a programmed number of times. The loop ends with an End instruction.

loop counter

Increments by one with each pass through a loop.

LSB

Least significant bit (the trailing bit).

LVDT

The linear variable differential transformer (LVDT) is a type of electrical transformer used for measuring linear displacement (position).

M

mains power

The national power grid.

manually initiated

Initiated by the user, usually with a Keyboard/Display, as opposed to occurring under program control.

mass storage device

A mass storage device may also be referred to as an auxiliary storage device. The term is commonly used to describe USB mass storage devices.

MD5 digest

16 byte checksum of the TCP/IP VTP configuration.

micro SD

Removable memory-card technology.

milli

The SI prefix denoting 1/1000 of a base SI unit.

Modbus

Communications protocol published by Modicon in 1979 for use in programmable logic controllers (PLCs).

modem/terminal

Any device that has the following: ability to raise the ring line or be used with an optically isolated interface to raise the ring line and put the data logger in the communications command state, or an asynchronous serial communications port that can be configured to communicate with the data logger.

modulo divide

A math operation. Result equals the remainder after a division.

MQTT

An open communications protocol for the Internet of Things (IoT). MQTT is not an acronym, it is simply the name of the protocol. Source: https://www.hivemq.com/blog/mqtt-essentials-part-1-introducing-mqtt/

MSB

Most significant bit (the leading bit).

multimeter

An inexpensive and readily available device useful in troubleshooting data acquisition system faults.

multiplier

A term, often a parameter in a CRBasic measurement instruction, that designates the slope (aka, scaling factor or gain) in a linear function. For example, when converting °C to °F, the equation is °F = °C*1.8 + 32. The factor 1.8 is the multiplier.

mV

The SI abbreviation for millivolts.

N

NAN

Not a number. A data word indicating a measurement or processing error. Voltage overrange, SDI-12 sensor error, and undefined mathematical results can produce NAN.

neighbor device

Device in a PakBus network that communicates directly with a device without being routed through an intermediate device.

Network Planner

Campbell Scientific software designed to help set up datal oggers in PakBus networks so that they can communicate with each other and the LoggerNet server. For more information, see https://www.campbellsci.com/loggernet.

NIST

National Institute of Standards and Technology.

node

Devices in a network — usually a PakBus network. The communications server dials through, or communicates with, a node. Nodes are organized as a hierarchy with all nodes accessed by the same device (parent node) entered as child nodes. A node can be both a parent and a child.

NSEC

Eight-byte data type divided up as four bytes of seconds since 1990 and four bytes of nanoseconds into the second.

null modem

A device, usually a multi-conductor cable, which converts an RS-232 port from DCE to DTE or from DTE to DCE.

Numeric Monitor

A digital monitor in data logger support software or in a keyboard/display.

O

offset

A term, often a parameter in a CRBasic measurement instruction, that designates the y-intercept (aka, shifting factor or zeroing factor) in a linear function. For example, when converting °C to °F, the equation is °F = °C*1.8 + 32. The factor 32 is the offset.

ohm

The unit of resistance. Symbol is the Greek letter Omega (Ω). 1.0 Ω equals the ratio of 1.0 volt divided by 1.0 ampere.

Ohm's Law

Describes the relationship of current and resistance to voltage. Voltage equals the product of current and resistance (V = I • R).

on-line data transfer

Routine transfer of data to a peripheral left on-site. Transfer is controlled by the program entered in the data logger.

operating system

The operating system (also known as "firmware") is a set of instructions that controls the basic functions of the data logger and enables the use of user written CRBasic programs. The operating system is preloaded into the data logger at the factory but can be re-loaded or upgraded by you using Device Configuration Utility software. The most recent data logger operating system .obj file is available at www.campbellsci.com/downloads.

output

A loosely applied term. Denotes a) the information carrier generated by an electronic sensor, b) the transfer of data from variable memory to final-data memory, or c) the transfer of electric power from the data logger or a peripheral to another device.

output array

A string of data values output to final-data memory. Output occurs when the data table output trigger is True.

output interval

The interval between each write of a record to a data table.

output processing instructions

CRBasic instructions that process data values for eventual output to final-data memory. Examples of output-processing instructions include Totalize(), Maximum(), Minimum(), and Average(). Data sources for these instructions are values or strings in variable memory. The results of intermediate calculations are stored in data output processing memory to await the output trigger. The ultimate destination of data generated by data output processing instructions is usually final-data memory, but the CRBasic program can be written to divert to variable memory for further processing. The transfer of processed summaries to final-data memory takes place when the Trigger argument in the DataTable() instruction is set to True.

output processing memory

Memory automatically allocated for intermediate calculations performed by CRBasic data output processing instructions. Data output processing memory cannot be monitored.

P

PakBus

® A proprietary communications protocol developed by Campbell Scientific to facilitate communications between Campbell Scientific devices. Similar in concept to IP (Internet Protocol), PakBus is a packet-switched network protocol with routing capabilities. A registered trademark of Campbell Scientific, Inc.

PakBus Graph

Software that shows the relationship of various nodes in a PakBus network and allows for monitoring and adjustment of some registers in each node.

parameter

Part of a procedure (or command) definition.

PC200W

Retired basic data logger support software for direct connect.

PC400

Free entry-level data logger support software that supports a variety of communications options, manual data collection, and data monitoring displays. Short Cut and CRBasic Editor are included for creating data logger programs. PC400 does not support scheduled data collection or complex communications options such as phone-to-RF.

period average

A measurement technique using a high-frequency digital clock to measure time differences between signal transitions. Sensors commonly measured with period average include water-content reflectometers.

peripheral

Any device designed for use with the data logger. A peripheral requires the data logger to operate. Peripherals include measurement, control, and data retrieval and communications modules.

PGA

Programmable Gain Amplifier

ping

A software utility that attempts to contact another device in a network.

pipeline mode

A CRBasic program execution mode wherein instructions are evaluated in groups of like instructions, with a set group prioritization.

PLC

Programmable Logic Controllers

Poisson ratio

A ratio used in strain measurements.

ppm

Parts per million.

precision

The amount of agreement between repeated measurements of the same quantity (AKA repeatability).

PreserveVariables

CRBasic instruction that protects Public variables from being erased when a program is recompiled.

print device

Any device capable of receiving output over pin 6 (the PE line) in a receive-only mode. Printers, "dumb" terminals, and computers in a terminal mode fall in this category.

print peripheral

Any device capable of receiving output over pin 6 (the PE line) in a receive-only mode. Printers, "dumb" terminals, and computers in a terminal mode fall in this category.

processing instructions

CRBasic instructions used to further process input-data values and return the result to a variable where it can be accessed for output processing. Arithmetic and transcendental functions are included.

program control instructions

Modify the execution sequence of CRBasic instructions. Also used to set or clear flags.

Program Send command

Program Send is a feature of data logger support software.

program statement

A complete program command construct confined to one command line or to multiple command lines merged with the line continuation characters <space><underscore> (_). A command line, even with line continuation, cannot exceed 512 characters.

public

A CRBasic command for declaring and dimensioning variables. Variables declared with Public can be monitored during data logger operation.

pulse

An electrical signal characterized by a rapid increase in voltage follow by a short plateau and a rapid voltage decrease.

R

ratiometric

Describes a type of measurement or a type of math. Ratiometric usually refers to an aspect of resistive-bridge measurements - either the measurement or the math used to process it. Measuring ratios and using ratio math eliminates several sources of error from the end result.

record

A record is a complete line of data in a data table or data file. All data in a record share a common time stamp. Data tables are made up of records and fields. Each row in a table represents a record and each column represents a field. The number of fields in a record is determined by the number and configuration of output processing instructions that are included as part of the DataTable() declaration.

regulator

A setting, a Status table element, or a DataTableInformation table element. Also a device for conditioning an electrical power source. Campbell Scientific regulators typically condition ac or dc voltages greater than 16 VDC to about 14 VDC.

resistance

A feature of an electronic circuit that impedes or redirects the flow of electrons through the circuit.

resistor

A device that provides a known quantity of resistance.

resolution

The smallest interval measurable.

ring line

Ring line is pulled high by an external device to notify the data logger to commence communications. Ring line is pin 3 of the CS I/O port.

ring memory

A memory configuration that allows the oldest data to be overwritten with the newest data. This is the default setting for data tables.

ringing

Oscillation of sensor output (voltage or current) that occurs when sensor excitation causes parasitic capacitances and inductances to resonate.

RMS

Root-mean square, or quadratic mean. A measure of the magnitude of wave or other varying quantities around zero.

RNDIS

Remote Network Driver Interface Specification - a Microsoft protocol that provides a virtual Ethernet link via USB.

router

A device configured as a router is able to forward PakBus packets from one port to another. To perform its routing duties, a data logger configured as a router maintains its own list of neighbors and sends this list to other routers in the PakBus network. It also obtains and receives neighbor lists from other routers. Routers maintain a routing table, which is a list of known nodes and routes. A router will only accept and forward packets that are destined for known devices. Routers pass their lists of known neighbors to other routers to build the network routing system.

RS-232

Recommended Standard 232. A loose standard defining how two computing devices can communicate with each other. The implementation of RS-232 in Campbell Scientific data loggers to computer communications is quite rigid, but transparent to most users. Features in the data logger that implement RS-232 communications with smart sensors are flexible.

RS-422

Communications protocol similar to RS-485. Most RS-422 sensors will work with RS-485 protocol.

RS-485

Recommended Standard 485. A standard defining how two computing devices can communicate with each other.

RTDAQ

Real Time Data Acquisition software for high-speed data acquisition applications. RTDAQ supports a variety of telecommunication options, manual data collection, and extensive data display. It includes Short Cut for creating data logger programs, as well as full-featured program editors.

RTU

Remote Telemetry Units

Rx

Receive

S

sample rate

The rate at which measurements are made by the data logger. The measurement sample rate is of interest when considering the effect of time skew, or how close in time are a series of measurements, or how close a time stamp on a measurement is to the true time the phenomenon being measured occurred. A 'maximum sample rate' is the rate at which a measurement can repeatedly be made by a single CRBasic instruction. Sample rate is how often an instrument reports a result at its output; frequency response is how well an instrument responds to fast fluctuations on its input. By way of example, sampling a large gage thermocouple at 1 kHz will give a high sample rate but does not ensure the measurement has a high frequency response. A fine-wire thermocouple, which changes output quickly with changes in temperature, is more likely to have a high frequency response.

SCADA

Supervisory Control And Data Acquisition

scan interval

The time interval between initiating each execution of a given Scan() of a CRBasic program. If the Scan() Interval is evenly divisible into 24 hours (86,400 seconds), it is synchronized with the 24 hour clock, so that the program is executed at midnight and every Scan() Interval thereafter. The program is executed for the first time at the first occurrence of the Scan() Interval after compilation. If the Scan() Interval does not divide evenly into 24 hours, execution will start on the first even second after compilation.

scan time

When time functions are run inside the Scan() / NextScan construct, time stamps are based on when the scan was started according to the data logger clock. Resolution of scan time is equal to the length of the scan.

SDI-12

Serial Data Interface at 1200 baud. Communications protocol for transferring data between the data logger and SDI-12 compatible smart sensors.

SDK

Software Development Kit

SDM

Synchronous Device for Measurement. A processor-based peripheral device or sensor that communicates with the data logger via hardwire over a short distance using a protocol proprietary to Campbell Scientific.

Seebeck effect

Induces microvolt level thermal electromotive forces (EMF) across junctions of dissimilar metals in the presence of temperature gradients. This is the principle behind thermocouple temperature measurement. It also causes small, correctable voltage offsets in data logger measurement circuitry.

semaphore

(Measurement semaphore.) In sequential mode, when the main scan executes, it locks the resources associated with measurements. In other words, it acquires the measurement semaphore. This is at the scan level, so all subscans within the scan (whether they make measurements or not), will lock out measurements from slow sequences (including the auto self-calibration). Locking measurement resources at the scan level gives non-interrupted measurement execution of the main scan.

send button

Send button in data logger support software. Sends a CRBasic program or operating system to a data logger.

sequential mode

A CRBasic program execution mode wherein each statement is evaluated in the order it is listed in the program.

serial

A loose term denoting output of a series of ASCII, HEX, or binary characters or numbers in electronic form.

Settings Editor

An editor for observing and adjusting settings. Settings Editor is a feature of LoggerNet|Connect, PakBus Graph, and Device Configuration Utility.

Short Cut

A CRBasic programming wizard suitable for many data logger applications. Knowledge of CRBasic is not required to use Short Cut.

SI

Système Internationale. The uniform international system of metric units. Specifies accepted units of measure.

signature

A number which is a function of the data and the sequence of data in memory. It is derived using an algorithm that assures a 99.998% probability that if either the data or the data sequence changes, the signature changes.

simplex

A serial communications protocol. One-direction data only. Serial communications between a serial sensor and the data logger may be simplex.

single-ended

Denotes a sensor or measurement terminal wherein the analog voltage signal is carried on a single wire and measured with respect to ground (0 V).

skipped scans

Occur when the CRBasic program is too long for the scan interval. Skipped scans can cause errors in pulse measurements.

slow sequence

A usually slower secondary scan in the CRBasic program. The main scan has priority over a slow sequence.

SMS

Short message service. A text messaging service for web and mobile device systems.

SMTP

Simple Mail Transfer Protocol. A TCP/IP application protocol.

SNP

Snapshot file.

SP

Space.

SPI

Serial Peripheral Interface - a clocked synchronous interface, used for short distance communications, generally between embedded devices.

SRAM

Static Random-Access Memory

start bit

The bit used to indicate the beginning of data.

state

Whether a device is on or off.

Station Status command

A command available in most data logger support software.

stop bit

The end of the data bits. The stop bit can be 1, 1.5, or 2.

string

A datum or variable consisting of alphanumeric characters.

support software

Campbell Scientific software that includes at least the following functions: data logger communications, downloading programs, clock setting, and retrieval of measurement data.

synchronous

The transmission of data between a transmitting and a receiving device occurs as a series of zeros and ones. For the data to be "read" correctly, the receiving device must begin reading at the proper point in the series. In synchronous communications, this coordination is accomplished by synchronizing the transmitting and receiving devices to a common clock signal (see also asynchronous).

system time

When time functions are run outside the Scan() / NextScan construct, the time registered by the instruction will be based on the system clock, which has a 10 ms resolution.

T

table

See data table.

task

Grouping of CRBasic program instructions automatically by the data logger compiler. Tasks include measurement, SDM or digital, and processing. Tasks are prioritized when the CRBasic program runs in pipeline mode. Also, a user-customized function defined through LoggerNet Task Master.

TCP/IP

Transmission Control Protocol / Internet Protocol.

TCR

Temperature Coefficient of Resistance. TCR tells how much the resistance of a resistor changes as the temperature of the resistor changes. The unit of TCR is ppm/°C (parts-per-million per degree Celsius). A positive TCR means that resistance increases as temperature increases. For example, a resistor with a specification of 10 ppm/°C will not increase in resistance by more than 0.000010 Ω per ohm over a 1 °C increase of the resistor temperature or by more than .00010 Ω per ohm over a 10 °C increase.

Telnet

A software utility that attempts to contact and interrogate another specific device in a network. Telnet is resident in Windows OS.

terminal

Point at which a wire (or wires) connects to a wiring panel or connector. Wires are usually secured in terminals by screw- or lever-and-spring actuated gates with small screw- or spring-loaded clamps.

terminal emulator

A command-line shell that facilitates the issuance of low-level commands to a data logger or some other compatible device. A terminal emulator is available in most data logger support software available from Campbell Scientific.

thermistor

A thermistor is a temperature measurement device with a resistive element that changes in resistance with temperature. The change is wide, stable, and well characterized. The output of a thermistor is usually non-linear, so measurement requires linearization by means of a Steinhart-Hart or polynomial equation. CRBasic instructions Therm107(), Therm108(), and Therm109() use Steinhart-Hart equations.

throughput rate

Rate that a measurement can be taken, scaled to engineering units, and the stored in a final-memory data table. The data logger has the ability to scan sensors at a rate exceeding the throughput rate. The primary factor determining throughput rate is the processing programmed into the CRBasic program. In sequential-mode operation, all processing called for by an instruction must be completed before moving on to the next instruction.

time domain

Time domain describes data graphed on an X-Y plot with time on the X axis. Time series data is in the time domain.

TLS

Transport Layer Security. An Internet communications security protocol.

toggle

To reverse the current power state.

TTL

Transistor-to-Transistor Logic. A serial protocol using 0 VDC and 5 VDC as logic signal levels.

Tx

Transmit

U

UART

Universal Asynchronous Receiver/Transmitter for asynchronous serial communications.

UINT2

Data type used for efficient storage of totalized pulse counts, port status (status of 16 ports stored in one variable, for example) or integer values that store binary flags.

unconditioned output

The fundamental output of a sensor, or the output of a sensor before scaling factors are applied.

UPS

Uninterruptible Power Supply. A UPS can be constructed for most data logger applications using ac line power, a solar panel, an ac/ac or ac/dc wall adapter, a charge controller, and a rechargeable battery.

URI

Uniform Resource Identifier

URL

Uniform Resource Locator

user program

The CRBasic program written by you in Short Cut program wizard.

USR drive

A portion of memory dedicated to the storage of image or other files.

V

VAC

Volts alternating current.

variable

A packet of memory given an alphanumeric name.

VDC

Volts direct current.

VisualWeather

Data logger support software specialized for weather and agricultural applications. The software allows you to initialize the setup, interrogate the station, display data, and generate reports from one or more weather stations.

volt meter

An inexpensive and readily available device useful in troubleshooting data acquisition system faults.

voltage divider

A circuit of resistors that ratiometrically divides voltage. For example, a simple two-resistor voltage divider can be used to divide a voltage in half. So, when fed through the voltage divider, 1 mV becomes 500 μV, 10 mV becomes 5 mV, and so forth. Resistive-bridge circuits are voltage dividers.

volts

SI unit for electrical potential.

VSPECT®

® A registered trademark for Campbell Scientific's proprietary spectral-analysis, frequency domain, vibrating wire measurement technique.

W

watchdog timer

An error-checking system that examines the processor state, software timers, and program-related counters when the CRBasic program is running. The following will cause watchdog timer resets, which reset the processor and CRBasic program execution: processor bombed, processor neglecting standard system updates, counters are outside the limits, voltage surges, and voltage transients. When a reset occurs, a counter is incremented in the WatchdogTimer entry of the Status table. A low number (1 to 10) of watchdog timer resets is of concern, but normally indicates that the situation should just be monitored. A large number of errors (>10) accumulating over a short period indicates a hardware or software problem. Consult with a Campbell Scientific support engineer.

weather-tight

Describes an instrumentation enclosure impenetrable by common environmental conditions. During extraordinary weather events, however, seals on the enclosure may be breached.

web API

Application Programming Interface

wild card

A character or expression that substitutes for any other character or expression.

X

XML

Extensible markup language.

T

τ

Time constant

Warranty and Acknowledgements

The data logger is warranted by Campbell Scientific to be free from defects in materials and workmanship under normal use and service, from the date of shipment, for:

- Standard: Three years against defects in materials and workmanship.
- Extended (optional): An additional four years, bringing the total to seven years.

See Product Details on the Ordering Information pages at www.campbellsci.com.

Refer to www.campbellsci.com/terms#warranty for more information.

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Acknowledgements

lwIP

mbed TLS

Assistance

Products may not be returned without prior authorization.

Products shipped to Campbell Scientific require a Returned Materials Authorization (RMA) or Repair Reference number and must be clean and uncontaminated by harmful substances, such as hazardous materials, chemicals, insects, and pests. Please complete the required forms prior to shipping equipment.

Campbell Scientific regional offices handle repairs for customers within their territories. Please see the back page for the Global Sales and Support Network or visit www.campbellsci.com/contact to determine which Campbell Scientific office serves your country.

To obtain a Returned Materials Authorization or Repair Reference number, contact your CAMPBELL SCIENTIFIC regional office. Please write the issued number clearly on the outside of the shipping container and ship as directed.

For all returns, the customer must provide a "Statement of Product Cleanliness and Decontamination" or "Declaration of Hazardous Material and Decontamination" form and comply with the requirements specified in it. The form is available from your CAMPBELL SCIENTIFIC regional office. Campbell Scientific is unable to process any returns until we receive this statement. If the statement is not received within three days of product receipt or is incomplete, the product will be returned to the customer at the customer's expense. Campbell Scientific reserves the right to refuse service on products that were exposed to contaminants that may cause health or safety concerns for our employees.

Safety

DANGER — MANY HAZARDS ARE ASSOCIATED WITH INSTALLING, USING, MAINTAINING, AND WORKING ON OR AROUND **TRIPODS, TOWERS, AND ANY ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.** FAILURE TO PROPERLY AND COMPLETELY ASSEMBLE, INSTALL, OPERATE, USE, AND MAINTAIN TRIPODS, TOWERS, AND ATTACHMENTS, AND FAILURE TO HEED WARNINGS, INCREASES THE RISK OF DEATH, ACCIDENT, SERIOUS INJURY, PROPERTY DAMAGE, AND PRODUCT FAILURE. TAKE ALL REASONABLE PRECAUTIONS TO AVOID THESE HAZARDS. CHECK WITH YOUR ORGANIZATION'S SAFETY COORDINATOR (OR POLICY) FOR PROCEDURES AND REQUIRED PROTECTIVE EQUIPMENT PRIOR TO PERFORMING ANY WORK.

Use tripods, towers, and attachments to tripods and towers only for purposes for which they are designed. Do not exceed design limits. Be familiar and comply with all instructions provided in product manuals. Manuals are available at www.campbellsci.com. You are responsible for conformance with governing codes and regulations, including safety regulations, and the integrity and location of structures or land to which towers, tripods, and any attachments are attached. Installation sites should be evaluated and approved by a qualified engineer. If questions or concerns arise regarding installation, use, or maintenance of tripods, towers, attachments, or electrical connections, consult with a licensed and qualified engineer or electrician.

General

- Protect from over-voltage.
- Protect electrical equipment from water.
- Protect from electrostatic discharge (ESD).
- Protect from lightning.
- Prior to performing site or installation work, obtain required approvals and permits. Comply with all governing structure-height regulations.
- Use only qualified personnel for installation, use, and maintenance of tripods and towers, and any attachments to tripods and towers. The use of licensed and qualified contractors is highly recommended.
- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a **hardhat** and **eye protection**, and take **other appropriate safety precautions** while working on or around tripods and towers.
- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

Utility and Electrical

- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, 6 meters (20 feet), or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.
- Only use power sources approved for use in the country of installation to power Campbell Scientific devices.

Elevated Work and Weather

- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance

- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

Internal Battery

- Be aware of fire, explosion, and severe-burn hazards.
- Misuse or improper installation of the internal lithium battery can cause severe injury.
- Do not recharge, disassemble, heat above 100 °C (212 °F), solder directly to the cell, incinerate, or expose contents to water. Dispose of spent batteries properly.

WHILE EVERY ATTEMPT IS MADE TO EMBODY THE HIGHEST DEGREE OF SAFETY IN ALL CAMPBELL SCIENTIFIC PRODUCTS, THE CUSTOMER ASSUMES ALL RISK FROM ANY INJURY RESULTING FROM IMPROPER INSTALLATION, USE, OR MAINTENANCE OF TRIPODS, TOWERS, OR ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.

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CR1000X Specifications

Datalogger

Electrical specifications are valid over a -40 to +70 °C, non-condensing environment, unless otherwise specified. Extended electrical specifications (noted as XT in specifications) are valid over a -55 to +85 °C non-condensing environment. Recalibration is recommended every three years. Critical specifications and system configuration should be confirmed with Campbell Scientific before purchase.

System specifications

Processor: Renesas RX63N (32-bit with hardware FPU, running at 100 MHz)

Memory:

- Total onboard: 128 MB of flash + 4 MB battery-backed SRAM
    - Data storage: 4 MB SRAM + 72 MB flash (extended data storage automatically used for auto-allocated Data Tables not being written to a card)
    - CPU drive: 30 MB flash
    - OS load: 8 MB flash
    - Settings: 1 MB flash
    - Reserved (not accessible): 10 MB flash
- Data storage expansion: Removable microSD flash memory, up to 16 GB

Program Execution Period: 1 ms to 1 day

Real-Time Clock:

- Battery backed while external power is disconnected
- **Resolution**: 1 ms
- **Accuracy**: ±3 min. per year, optional GPS correction to ±10 µs

Wiring Panel Temperature: Measured using a 10K3A1A BetaTHERM thermistor, located between the two rows of analog input terminals.

Physical specifications

Dimensions: 23.8 x 10.1 x 6.2 cm (9.4 x 4.0 x 2.4 in); additional clearance required for cables and wires.

Weight/Mass: 0.86 kg (1.9 lb)

Case Material: Powder-coated aluminum

Power requirements

Protection: Power inputs are protected against surge, over-voltage, over-current, and reverse power. IEC 61000-4 Class 4 level.

Power In Terminal:

- **Voltage Input**: 10 to 18 VDC
- **Input Current Limit at 12 VDC**:
    - 4.35 A at -40 °C
    - 3 A at 20 °C
    - 1.56 A at 85 °C
- 30 VDC sustained voltage limit without damage.

USB Power: Functions that will be active with USB 5 VDC include sending programs, adjusting data logger settings, and making some measurements. If USB is the only power source, then the CS I/O port and the 5V, 12V, and SW12 terminals will not be operational.

Internal Lithium Battery: AA, 2.4 Ah, 3.6 VDC (Tadiran TL 5903/S) for battery-backed SRAM and clock. 3-year life with no external power source.

Average Current Drain:

Assumes 12 VDC on POWER IN terminals.

- **Idle**: <1 mA
- **Active 1 Hz Scan**: 1 mA
- **Active 20 Hz Scan**: 55 mA
- **Serial** (RS-232/RS-485): Active + 25 mA
- **Ethernet Power Requirements**:
    - **Ethernet 1 Minute**: Active + 1 mA
    - **Ethernet Idle**: Active + 4 mA
    - **Ethernet Link**: Active + 47 mA

Vehicle Power Connection: When primary power is pulled from the vehicle power system, a second power supply OR charge regulator may be required to overcome the voltage drop at vehicle start-up.

Power output specifications

System power out limits (when powered with 12 VDC)

Temperature (°C)	Current Limit[1] (A)
–40°	4.53
20°	3.00
70°	1.83
85°	1.56
[1] Limited by self-resetting thermal fuse	

12 V and SW12 V power output terminals

12V, SW12-1, and SW12-2: Provide unregulated 12 VDC power with voltage equal to the Power Input supply voltage. These are disabled when operating on USB power only.

SW12 current limits	
Temperature (°C)	**Current Limit [1] (mA)**
–40°	1310
0°	1004
20°	900
50°	690
70°	550
80°	470
[1] Thermal fuse hold current.	

5 V fixed output

5V: One regulated 5 V output. Supply is shared between the 5V terminal and CS I/O DB9 5 V output.

- **Voltage Output**: Regulated 5 V output (±5%)
- **Current Limit**: 230 mA

C as power output

- C Terminals:
  - **Output Resistance (R_O)**: 150 Ω
  - **5 V Logic Level Drive Capacity**: 10 mA @ 3.5 VDC
  - **3.3 V Logic Level Drive Capacity**: 10 mA @ 1.8 VDC

CS I/O pin 1

5 V Logic Level Max Current: 200 mA

Voltage excitation

VX: Four independently configurable voltage terminals (VX1-VX4). When providing voltage excitation, a single 16-bit DAC shared by all VX outputs produces a user-specified voltage during measurement only.VX terminals can also be used to supply a selectable, switched, regulated 3.3 or 5 VDC power source to power digital sensors and toggle control lines.

	Range	Resolution	Accuracy	Maximum Source/Sink Current[1]
Voltage Excitation	±4 V	0.06 mV	±(0.1% of setting + 2 mV)	±40 mA
Switched, Regulated	+3.3 or 5 V	3.3 or 5 V	±5%	50 mA
[1] Exceeding current limits causes voltage output to become unstable. Voltage should stabilize when current is reduced to within stated limits.				

Analog measurement specifications

16 single-ended (SE) or 8 differential (DIFF) terminals individually configurable for voltage, thermocouple, current loop, ratiometric, and period average measurements, using a 24-bit ADC. One channel at a time is measured.

Voltage measurements

Terminals:

- **Differential Configuration**: DIFF 1H/1L – 8H/8L
- **Single-Ended Configuration**: SE1 – SE16

Input Resistance: 20 GΩ typical

Input Voltage Limits: ±5 V

Sustained Input Voltage without Damage: ±20 VDC

DC Common Mode Rejection:

- > 120 dB with input reversal
- ≥ 86 dB without input reversal

Normal Mode Rejection: > 70 dB @ 60 Hz

Input Current @ 25 °C: ±1 nA typical

Filter First Notch Frequency (f_{N1}) Range: 0.5 Hz to 31.25 kHz (user specified)

Analog Range and Resolution:

		Differential with Input Reversal		Single-Ended and Differential without Input Reversal	
Notch Frequency (f_{N1}) (Hz)	Range[1] (mV)	RMS (µV)	Bits[2]	RMS (µV)	Bits[2]
15000	±5000 ±1000 ±200	8.2 1.9 0.75	20 20 19	11.8 2.6 1.0	19 19 18
50/60[3]	±5000 ±1000 ±200	0.6 0.14 0.05	24 23 22	0.88 0.2 0.08	23 23 22
5	±5000 ±1000 ±200	0.18 0.04 0.02	25 25 24	0.28 0.07 0.03	25 24 23

[1] Range overhead of ~5% on all ranges guarantees that full-scale values will not cause over range

[2] Typical effective resolution (ER) in bits; computed from ratio of full-scale range to RMS resolution.

[3] 50/60 corresponds to rejection of 50 and 60 Hz ac power mains noise.

Accuracy (does not include sensor or measurement noise):

- 0 to 40 °C: ±(0.04% of measurement + offset)
- –40 to 70 °C: ±(0.06% of measurement + offset)

Voltage Measurement Accuracy Offsets:

	Typical Offset (µV RMS)	
Range (mV)	Differential with Input Reversal	Single-Ended or Differential without Input Reversal
±5000	±0.5	±2
±1000	±0.25	±1
±200	±0.15	±0.5

Measurement Settling Time: 20 µs to 600 ms; 500 µs default

Multiplexed Measurement Time:

Measurement time = INT(multiplexed measurement time • (reps+1) + 2ms

	Differential with Input Reversal	Single-Ended or Differential without Input Reversal
Example fN1[1] (Hz)	Time[2] (ms)	Time[2] (ms)
15000	2.04	1.02
60	35.24	17.62
50	41.9	20.95
5	401.9	200.95

[1] Notch frequency (1/integration time).

[2] Default settling time of 500 µs used.

Resistance measurement specifications

The data logger makes ratiometric-resistance measurements for four- and six-wire full-bridge circuits and two-, three-, and four-wire half-bridge circuits using voltage excitation. Excitation polarity reversal is available to minimize dc error.

Accuracy:

Assumes input reversal for differential measurements `RevDiff` and excitation reversal `RevEx` for excitation voltage <1000 mV. Does not include bridge resistor errors or sensor and measurement noise.

- **0 to 40 °C**: ±(0.01% of voltage measurement + offset)
- **–40 to 70 °C**: ±(0.015% of voltage measurement + offset)
- **–55 to 85 °C (XT)**: ±(0.02% of voltage measurement + offset)

Period-averaging measurement specifications

Terminals: SE1-SE16

Accuracy: ±(0.01% of measurement + resolution), where resolution is 0.13 µs divided by the number of cycles to be measured

Ranges:

- Minimum signal centered around specified period average threshold.
- Maximum signal centered around data logger ground.
- Maximum frequency = 1/(2 * (minimum pulse width)) for 50% duty cycle signals

Gain Code Op-tion	Volt-age Gain	Min-imum Peak to Peak Signal (mV)	Max-imum Peak to Peak Signal (V)	Min-imum Pulse Width (µs)	Max-imum Fre-quency (kHz)
0	1	500	10	2.5	200
1	2.5	50	2	10	50
2	12.5	10	2	62	8
3	64	2	2	100	5

Current-loop measurement specifications

The data logger makes current-loop measurements by measuring across a current-sense resistor associated with the RS-485 resistive ground terminal.

Terminals: RG1 and RG2

Maximum Input Voltage: ±16 V

Resistance to Ground: 101 Ω

Current Measurement Shunt Resistance: 10 Ω

Maximum Current Measurement Range: ±80 mA

Absolute Maximum Current: ±160 mA

Resolution: ≤ 20 nA

Accuracy: ±(0.1% of reading + 100 nA) @ -40 to 70 °C

Pulse measurement specifications

Two inputs (P1-P2) individually configurable for switch closure, high-frequency pulse, or low-level AC measurements. See also Digital input/output specifications (p. 4). Each terminal has its own independent 32-bit counter.

> NOTE:
> Conflicts can occur when a control port pair is used for different instructions (`TimerInput()`, `PulseCount()`, `SDI12Recorder()`, `WaitDigTrig()`). For example, if C1 is used for `SDI12Recorder()`, C2 cannot be used for `TimerInput()`, `PulseCount()`, or `WaitDigTrig()`.

Maximum Input Voltage: ±20 VDC

Maximum Counts Per Channel: 2^{32}

Maximum Counts Per Scan: 2^{32}

Input Resistance: 5 kΩ

Accuracy: ±(0.02% of reading + 1/scan)

Switch closure input

Terminals: C1-C8

Pull-Up Resistance: 100 kΩ to 5 V

Event: Low (<0.8 V) to High (>2.5 V)

Maximum Input Frequency: 150 Hz

Minimum Switch Closed Time: 5 ms

Minimum Switch Open Time: 6 ms

Maximum Bounce Time: 1 ms open without being counted

High-frequency input

Terminals: C1-C8

Pull-Up Resistance: 100 kΩ to 5 V

Event: Low (<0.8 V) to High (>2.5 V)

Maximum Input Frequency: 250 kHz

Low-level AC input

Minimum Pull-Down Resistance: 10 kΩ to ground

DC-offset rejection: Internal AC coupling eliminates DC-offset voltages up to ±0.05 VDC

Input Hysteresis: 12 mV at 1 Hz

Low-Level AC Pulse Input Ranges:

Sine wave (mV RMS)	Range (Hz)
20	1.0 to 20
200	0.5 to 200
2000	0.3 to 10,000
5000	0.3 to 20,000

Digital input/output specifications

Terminals configurable for digital input and output (I/O) including status high/low, pulse width modulation, external interrupt, edge timing, switch closure pulse counting, high-frequency pulse counting, UART[1], RS-232[2], RS-422[3], RS-485[4], SDM[5], SDI-12[6], I2C[7], and SPI[8] function. Terminals are configurable in pairs for 5 V or 3.3 V logic for some functions.

> NOTE:
> Conflicts can occur when a control port pair is used for different instructions (`TimerInput()`, `PulseCount()`, `SDI12Recorder()`, `WaitDigTrig()`). For example, if C1 is used for `SDI12Recorder()`, C2 cannot be used for `TimerInput()`, `PulseCount()`, or `WaitDigTrig()`.

Terminals: C1-C8

Maximum Input Voltage: ±20 V

Logic Levels and Drive Current:

Terminal Pair Configuration	5 V Source	3.3 V Source
Logic low	≤ 1.5 V	≤ 0.8 V
Logic high	≥ 3.5 V	≥ 2.5 V

Edge timing

Terminals: C1-C8

---

[1]Universal Asynchronous Receiver/Transmitter for asynchronous serial communications.

[2]Recommended Standard 232. A loose standard defining how two computing devices can communicate with each other. The implementation of RS-232 in Campbell Scientific data loggers to computer communications is quite rigid, but transparent to most users. Features in the data logger that implement RS-232 communications with smart sensors are flexible.

[3]Communications protocol similar to RS-485. Most RS-422 sensors will work with RS-485 protocol.

[4]Recommended Standard 485. A standard defining how two computing devices can communicate with each other.

[5]Synchronous Device for Measurement. A processor-based peripheral device or sensor that communicates with the data logger via hardwire over a short distance using a protocol proprietary to Campbell Scientific.

[6]Serial Data Interface at 1200 baud. Communications protocol for transferring data between the data logger and SDI-12 compatible smart sensors.

[7]Inter-Integrated Circuit is a multi-controller, multi-peripheral, packet switched, single-ended, serial computer bus.

[8]Serial Peripheral Interface - a clocked synchronous interface, used for short distance communications, generally between embedded devices.

Maximum Input Frequency: ≤ 1 kHz

Resolution: 500 ns

Edge counting

Terminals: C1-C8

Maximum Input Frequency: ≤ 2.3 kHz

Quadrature input

Terminals: C1-C8 can be configured as digital pairs to monitor the two sensing channels of an encoder.

Maximum Frequency: 2.5 kHz

Resolution: 31.25 µs or 32 kHz

Pulse-width modulation

Maximum Period: 36.4 seconds

Resolution:

- **0 – 5 ms**: 83.33 ns
- **5 – 325 ms**: 5.33 µs
- **> 325 ms**: 31.25 µs

Communications specifications

Ethernet Port: RJ45 jack, 10/100Base Mbps, full and half duplex, Auto-MDIX, magnetic isolation, and TVS surge protection.

Internet Protocols: Ethernet, PPP, RNDIS, ICMP/Ping, Auto-IP (APIPA), IPv4, IPv6, UDP, TCP, TLS (v1.2), DNS, DHCP, SLAAC, Telnet, HTTP(S), SFTP, FTP(S), POP3/TLS, NTP, SMTP/TLS, SNMPv3, CS I/O IP, MQTT

Additional Protocols: CPI, PakBus, PakBus Encryption, SDM, SDI-12, Modbus RTU / ASCII / TCP, DNP3, custom user definable over serial, NTCIP, NMEA 0183, I2C, SPI

USB Device: Micro-B device for computer connectivity

CS I/O: 9-pin D-sub connector to interface with Campbell Scientific CS I/O peripherals.

SDI-12 (C1, C3, C5, C7): Four independent SDI-12 compliant terminals are individually configured and meet SDI-12 Standard v 1.4.

RS-485 (C5 to C8): One full duplex or two half duplex

RS-422 (C5 to C8): One full duplex or two half duplex

RS-232/CPI: Single RJ45 module port that can operate in one of two modes: CPI or RS-232. CPI interfaces with Campbell Scientific CDM measurement peripherals and sensors. RS-232 connects, with an adapter cable, to computer, sensor, or communications devices serially.

CPI: One CPI bus. Up to 1 Mbps data rate. Synchronization of devices to 5 µS. Total cable length up to 610 m (2000 ft). Up to 20 devices. CPI is a proprietary interface for communications between Campbell Scientific data loggers and Campbell Scientific CDM peripheral devices. It consists of a physical layer definition and a data protocol.

Hardwired: Multi-drop, short haul, RS-232, fiber optic

Satellite: GOES, Argos, Inmarsat Hughes, Irridium

Standards compliance specifications

View compliance and conformity documents at www.campbellsci.com/cr1000x.

Shock and Vibration: MIL-STD 810G methods 516.6 and 514.6

Protection:

- Wiring panel: IP40
- Measurement module when connected to the wiring panel: IP65

EMI and ESD protection:

- **Immunity**: Meets or exceeds following standards:
  - **ESD**: per IEC 61000-4-2; ±15 kV air, ±8 kV contact discharge
  - **Radiated RF**: per IEC 61000-4-3; 10 V/m, 80-1000 MHz
  - **EFT**: per IEC 61000-4-4; 4 kV power, 4 kV I/O
  - **Surge**: per IEC 61000-4-5; 4 kV power, 4kV I/O
  - **Conducted RF**: per IEC 61000-4-6; 10 V power, 10 V I/O
- Emissions and immunity performance criteria available on request.

Warranty

Standard: Three years against defects in materials and workmanship.

Extended (optional): An additional four years, bringing the total to seven years.

Terminal functions

Analog input terminal functions

SE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	RG1	RG2
DIFF	1 H	1 L	2 H	2 L	3 H	3 L	4 H	4 L	5 H	5 L	6 H	6 L	7 H	7 L	8 H	8 L		
Single-Ended Voltage	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Differential Voltage	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L		
Ratiometric/Bridge	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Thermocouple	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Current Loop																	✓	✓
Period Average	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		

Pulse counting terminal functions

	P1	P2	C1-C8
Switch-Closure	✓	✓	✓
High Frequency	✓	✓	✓
Low-level Ac	✓	✓	

Analog output terminal functions

	VX1-VX4
Switched Voltage Excitation	✓

Voltage Output

	C1-C8[1]	VX1-VX4	5V	12V	SW12-1	SW12-2
5 VDC	✓	✓	✓			
3.3 VDC	✓	✓				
12 VDC				✓	✓	✓

[1] C terminals have limited drive capacity. Voltage levels are configured in pairs.

Communications terminal functions

	C1	C2	C3	C4	C5	C6	C7	C8	RS-232/CPI
SDI-12	✓		✓		✓		✓		
GPS	PPS	Rx	Tx	Rx	Tx	Rx	Tx	Rx	
TTL 0-5 V	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	
LVTTL 0-3.3 V	Tx	Rx	Tx	Rx	Tx	Rx	Tx	Rx	
RS-232					Tx	Rx	Tx	Rx	✓
RS-485 (Half Duplex)					A-	B+	A-	B+	

Communications terminal functions									
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**RS-232/CPI**
RS-485 (Full Duplex)					Tx-	Tx+	Rx-	Rx+	
I2C	SDA	SCL	SDA	SCL	SDA	SCL	SDA	SCL	
SPI	MOSI	SCLK	MISO		MOSI	SCLK	MISO		
SDM[1]	Data	Clk	Enabl		Data	Clk	Enabl		
CPI/CDM									✓

[1] SDM can be on either C1-C3 or C5-C7, but not both at the same time.

Communications functions also include Ethernet and USB.

Digital I/O terminal functions	
	C1-C8
General I/O	✓
Pulse-Width Modulation Output	✓
Timer Input	✓
Interrupt	✓
Quadrature	✓

INFO

CAMPBELL SCIENTIFIC
WHEN MEASUREMENTS MATTER

Global Sales & Support Network

A worldwide network to help meet your needs

Campbell Scientific Regional Offices

Australia

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Website:	www.campbellsci.com.br

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Website:	www.campbellsci.ca

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Email:	sales@campbellsci.co.uk
Website:	www.campbellsci.co.uk

USA

Location:	Logan, UT USA
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Product Manual

Communications Device

CELL200-Series

4G LTE Cellular Module

Revision: 08/2022

RELIABLE SINCE 1974 MONITORING

CAMPBELL SCIENTIFIC

Table of contents

1. Cellular communications

This manual provides information for interfacing CELL200 Series 4G LTE Cellular Modules to Campbell Scientific data loggers.

Use of the CELL200 series requires a cellular line of service. The products compatible with Verizon, AT&T, T-Mobile, Vodafone, and Telstra are shown in the following table.

Product	Cellular protocol	Market	Verizon	AT&T	T-Mobile	Vodafone	Telstra	Other[1]
CELL205	4G LTE with automatic 3G fallback[2]	North America		✓	✓			✓
CELL210	4G LTE CAT-1	United States	✓					
CELL215	4G LTE with automatic 3G and 2G fallback	EMEA				✓		✓
CELL220	4G LTE with automatic 3G fallback	Australia and New Zealand					✓	✓
CELL225	4G LTE	Japan						✓

[1] More than 600 other providers are available worldwide through Campbell Scientific. See Establish cellular service (p. 3) for more information.

[2] AT&T ended support of their 3G network service on February 22, 2022. To continue operation the CELL200 series requires operating system 2.030 or newer. Use the web interface to find the CELL200 series OS version on the OS Date field of the Status Tab. See Updating the operating system and firmware (p. 65) for more information.

Before using the CELL200 series, please review:

- Safety
- Pre-installation (p. 2)

2. Precautions

- READ AND UNDERSTAND the Safety section at the back of this manual.
- An authorized technician shall verify that the installation and use of this product is in accordance with the manufacturer's instructions, recommendations and intended use.
- Although the CELL200 series is rugged, it should be handled as a precision instrument.
- Follow local regulations (see Compliance in Specifications [p. 24]).
- Protect from over-voltage.
- Protect from water.
- Protect from ESD (electrostatic discharge).

3. Initial inspection

- Upon receipt of the CELL200 series, inspect the packaging and contents for damage. File any damage claims with the shipping company.
- Immediately check package contents. Thoroughly check all packaging material for product that may be concealed. Check model numbers, part numbers, and product descriptions against the shipping documents. Model or part numbers are found on each product. Report any discrepancies to Campbell Scientific.

4. Pre-installation

TIP:
Check www.campbellsci.com to ensure you are using the latest data logger support software and data logger operating system (OS).

Updating the OS during system setup and testing, or onsite is recommended. Sending an OS to a remote data logger will interrupt the data logger program. If you have questions, contact Campbell Scientific for assistance (https://www.campbellsci.com/support).

4.1 Establish cellular service

For better security, we recommend using Konect PakBus® Router with a private dynamic IP address. This method allows only incoming PakBus communications. No other incoming communications are supported. However, all forms of outbound communications from the data logger are supported, including but not limited to PakBus, email, and FTP.

> **NOTE:**
> When the data logger is connected to both Ethernet and a cellular modem, `IPRoute()` may be used to specify which interface to use for the outbound communications, such as email, FTP, and HTTP.

A public static IP address can also be used. This provides more incoming communications functionality, but is less secure and more vulnerable to unsolicited traffic.

> **NOTE:**
> A public static IP account must be used when the module is set up in serial server mode. Private dynamic IP accounts do not support the serial server mode.

4.1.1 Campbell Scientific cellular data service

Campbell Scientific can provide subscriptions to cellular service through Verizon, AT&T, T-Mobile, Vodafone, Telstra, and over 600 other providers worldwide. When this cellular service is purchased with the module, the module will come pre-provisioned with the required SIM card and APN. If you have already purchased the CELL200 series, call Campbell Scientific to set up service.

4.1.2 Other service providers

While using Campbell Scientific is the simplest way to obtain cellular data service for your module, you can go directly to a provider. For more information on obtaining service directly from Verizon and AT&T, see Verizon Wireless and AT&T (p. 80).

> **TIP:**
> Prepaid cellular data plans may experience service slow downs when data limits are reached. If file transfer from a cellular-connected data logger works initially, but later has problems, check for data overage on the cellular plan.
>
> This does not apply to Campbell Scientific cellular data services.

4.2 Install the SIM card

NOTE:
If you purchased cellular service from Campbell Scientific with the module, it will come with the SIM (Subscriber Identity Module) card already installed. Proceed to Konect PakBus Router setup (p. 5).

NOTE:
Some SIM cards, particularly those purchased in Germany, come with an active personal identification number (PIN). The PIN must be deactivated before proceeding. Often, an easy way to deactivate the PIN is to install the SIM card in a mobile phone and use the device settings.

The CELL200 series requires a Micro-SIM (3FF) (6 position / contacts); a smartcard that securely stores the key identifying a mobile subscriber. You should only need to install the SIM card once in the life of the module.

To install the SIM card:

1. Remove the SIM card cover.
2. Note the location of the notched corner for correct alignment. The gold contact points of the SIM face down when inserting the SIM card as shown in the following figure. **Gently** slide the card into the slot until it stops and locks into place. To eject the SIM card, press it in slightly and release.
3. Replace the SIM card cover.

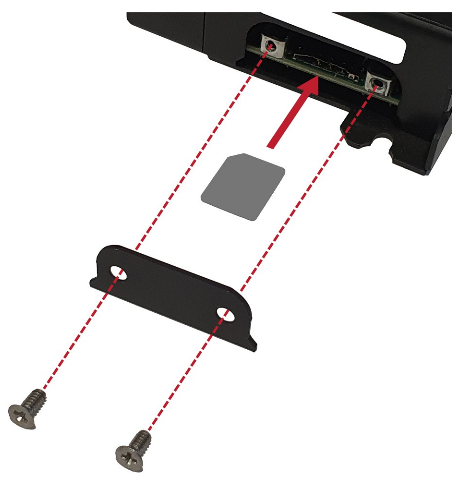


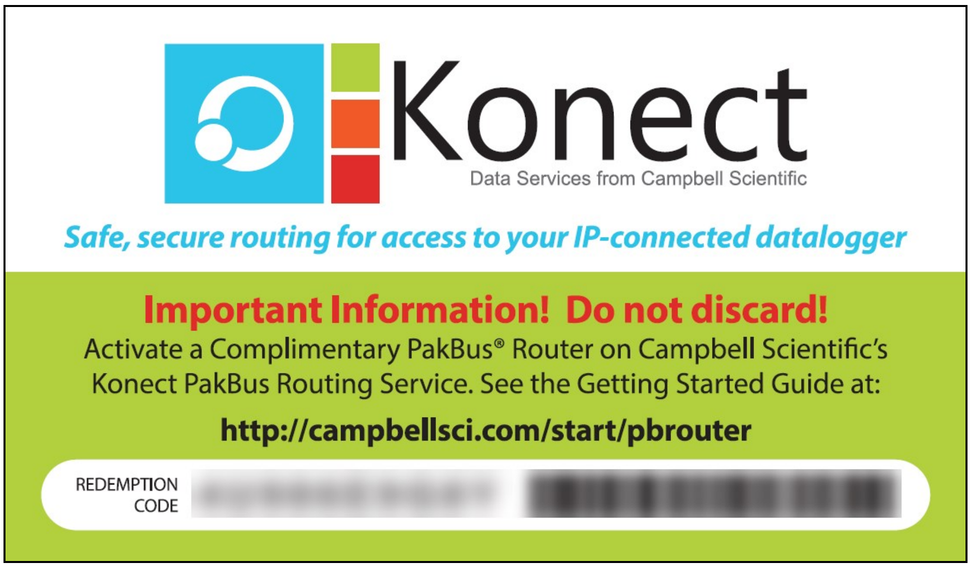
Figure 4-1. SIM card installation

4.3 Konect PakBus Router setup

For better security, we recommend using Konect PakBus® Router with a private dynamic IP address. This method allows only incoming PakBus communications. No other incoming communications are supported. However, all forms of outbound communications from the data logger are supported, including but not limited to PakBus, email, and FTP.

4.3.1 Get started

You will need the Konect PakBus Router redemption code that came on a card with the CELL200 series.

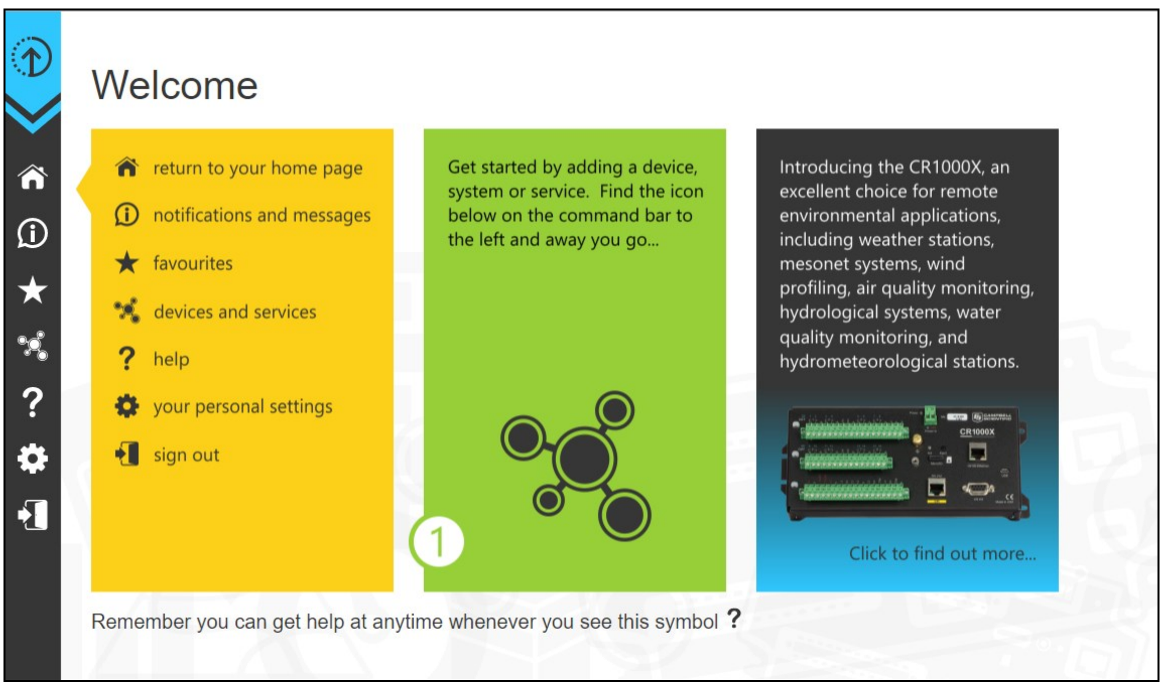


Open a web browser and go to www.konectgds.com.

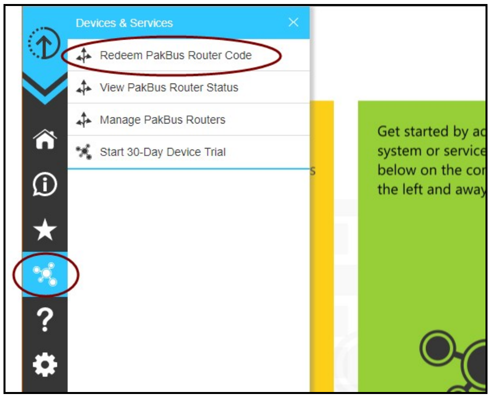
First-time users need to create a **free account**. After you submit your information, you will receive two emails up to five minutes apart. One email will contain a Passport ID and the other your Password. If emails are not received, check your email junk folder.

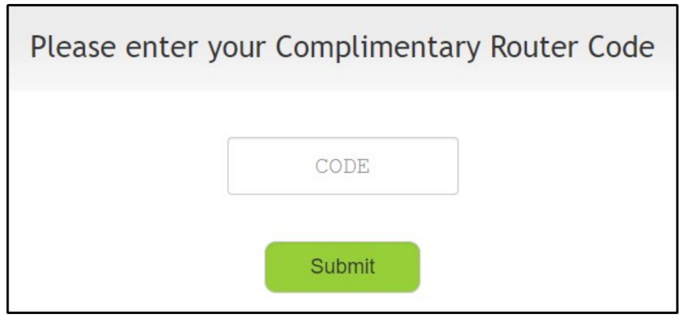
4.3.2 Set up Konect PakBus Router

1. Sign in to www.konectgds.com using your Passport ID and Password found in the two received emails. Once logged in, you will be at the Welcome page.



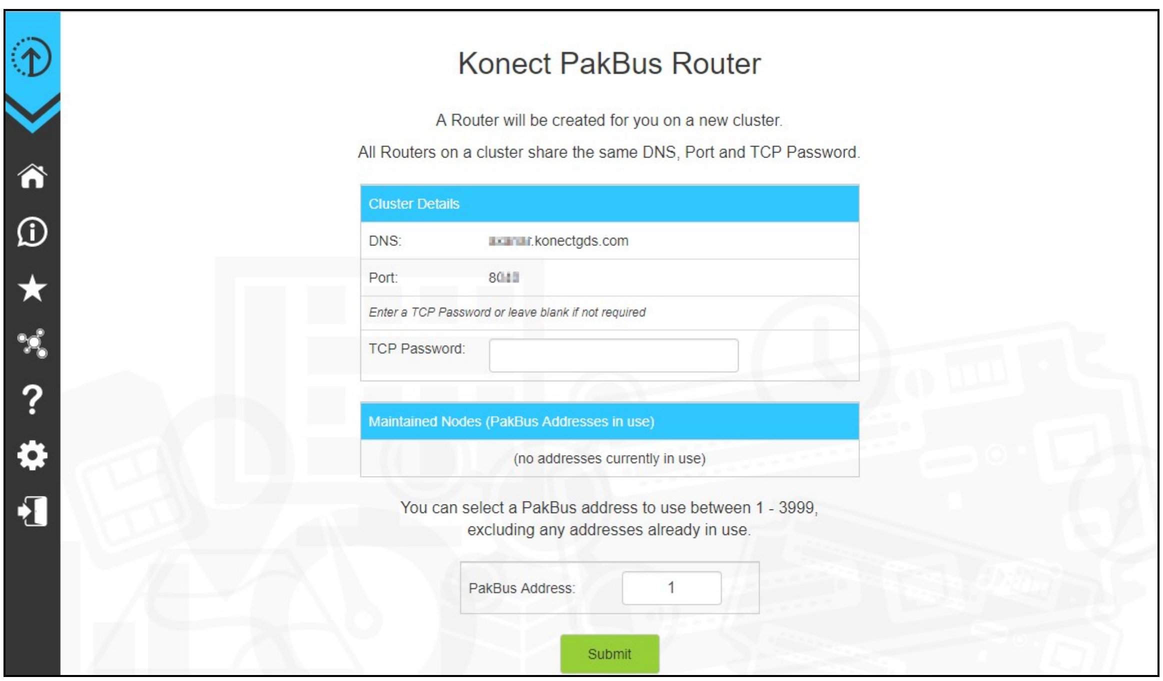
2. Click **Devices and services**  on the command bar to the left and select **Redeem PakBus Router Code**. Enter your complimentary Router Code found on the included card with your cellular-enabled device and click **Submit**.





3. The next screen shows the assigned **DNS** address and **Port** for the router. Enter a **TCP Password** and select a unique **PakBus Address** for your data logger.

> **TIP:**
> **Make note of this information**; it will be required for data logger configuration as well as *LoggerNet* setup. Please note your **DNS**, **Port**, **TCP Password** and **PakBus address**; you will need them later.



4. Click **Submit**.

5. To edit settings at a later date, click **devices and services** on the command bar and select **Manage PakBus Routers**.

> **NOTE:**
> The **DNS** address and **Port** number, assigned when your account was setup, cannot be edited.

5. Overview

The CELL200-series modules may be configured in one of five ways, depending on the data logger, communications type, and needs of the user.

- Integrated: The module mimics the behavior of our integrated cell modems. No settings are configured directly in the module. All settings are configured in the attached data logger.
- Non-integrated: The module mimics the behavior of our older cellular modems. Settings must be configured in both the module and the data logger.
- Serial Server: In this mode, the module receives IP communications over the cellular network and converts those to serial communications to pass on to the data logger. From the perspective of the data logger, this is no different than a serial cable connecting it to a computer.

> **NOTE:**
> A public static IP account must be used when the module is set up in serial server mode. Private dynamic IP accounts do not support the serial server mode.

- Serial Client: Use this mode when the module is behind a cellular provider firewall and it has a private dynamic IP address. In serial client mode the module will connect to the cellular network and initiate a TCP client socket connection.
- Serial Server/Client: In serial server/client mode the module connects to the cellular network and opens a listening port. When a client connects to the listening port, the CELL200 series will be in "**Serial Server**" mode, as described earlier. When no client is connected to the listening port, the CELL200 series will be in "**Serial Client**" mode, as described earlier, and all data on the active port will be sent and received through the initiated TCP client socket connection.

Data loggers compatible with each mode are shown in the following table.

	Integrated PPP	Non-integrated PPP	Serial server[2]	Serial client[3]	Serial server/ client[3]
GRANITE series/CR6 series/CR1000X/ CR300 series[1]	✓		✓	✓	✓
CR1000/CR3000/CR800 series		✓	✓	✓	✓
CR200(X) series			✓	✓	✓
Array-based (Edlog) data loggers			✓	✓	✓

1 Integrated PPP mode requires operating system 03.00 or later for the CR1000X, 09.00 or greater for the CR6 series, and 08.00 or later for the CR300 series.

2 Serial server mode requires a public static IP account.

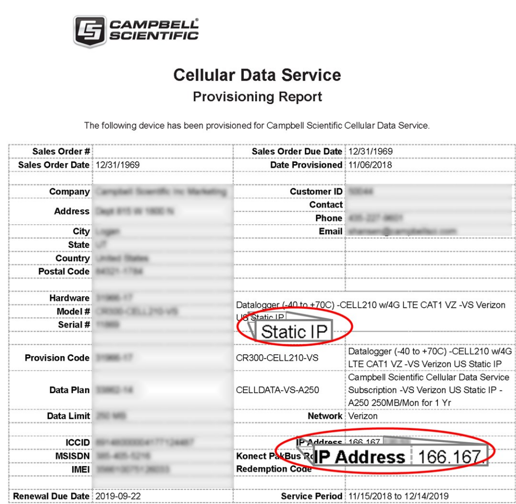
3 Requires CELL200 series OS 2.00 or later.

NOTE:
PakBus data loggers include the following models: GRANITE-series, CR6, CR3000, CR1000X, CR800-series, CR300-series, CR1000, and CR200(X)-series.

6. QuickStart (integrated mode)

> **NOTE:**
> This QuickStart describes configuring the CELL200 series in integrated mode (mimicking our internal cell modems) with its default settings. It can also be configured in non integrated or serial server mode.
>
> This QuickStart section does not apply to CR3000, CR1000 and CR800-series users. See Overview (p. 8) for more information on the different modes. See CELL200 series and data logger configuration (p. 35) for more information on configuring the module in the different modes.

The Provisioning Report received with your Cellular Data Service shows whether the module was configured with a private dynamic or public static IP address. See Figure 6-1 (p. 10) for an example of a Campbell Scientific Provisioning Report. Other cellular providers should provide similar information.



CAMPBELL SCIENTIFIC

Cellular Data Service
Provisioning Report

The following device has been provisioned for Campbell Scientific Cellular Data Service.

Sales Order #		**Sales Order Due Date**	12/31/1969
Sales Order Date	12/31/1969	**Date Provisioned**	11/06/2018
Company	[illegible]	**Customer ID**	[illegible]
Address	[illegible]	**Contact**	
		Phone	[illegible]
City	[illegible]	**Email**	[illegible]
State	[illegible]		
Country	[illegible]		
Postal Code	[illegible]		
Hardware	[illegible]	Datalogger (-40 to +70C) -CELL210 w/4G LTE CAT1 VZ -VS Verizon US Static IP	
Model #	[illegible]		
Serial #	[illegible]		
Provision Code	[illegible]	CR300-CELL210-VS	Datalogger (-40 to +70C) -CELL210 w/4G LTE CAT1 VZ -VS Verizon US Static IP
Data Plan	[illegible]	CELLDATA-VS-A250	Campbell Scientific Cellular Data Service Subscription -VS Verizon US Static IP - A250 250MB/Mon for 1 Yr
Data Limit	[illegible]	**Network**	Verizon
ICCID	[illegible]	**IP Address**	166.167.[illegible]
MSISDN	[illegible]	**Konect PakBus Ro[illegible]**	
IMEI	[illegible]	**Redemption Code**	
Renewal Due Date	2019-09-22	**Service Period**	11/15/2018 to 12/14/2019

Figure 6-1. Static IP provisioning report

Additionally, Campbell Scientific cellular modules configured with a public static IP address will have two stickers on the module, as shown in Figure 6-2 (p. 11). One sticker will show the module phone number and data plan. The second sticker will show the static IP address.

Campbell Scientific cellular modules configured with a private dynamic IP address will have one sticker on the module. It will show the module phone number and data plan.

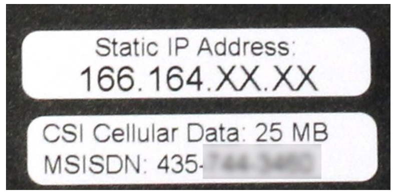


Figure 6-2. Module with public static IP address

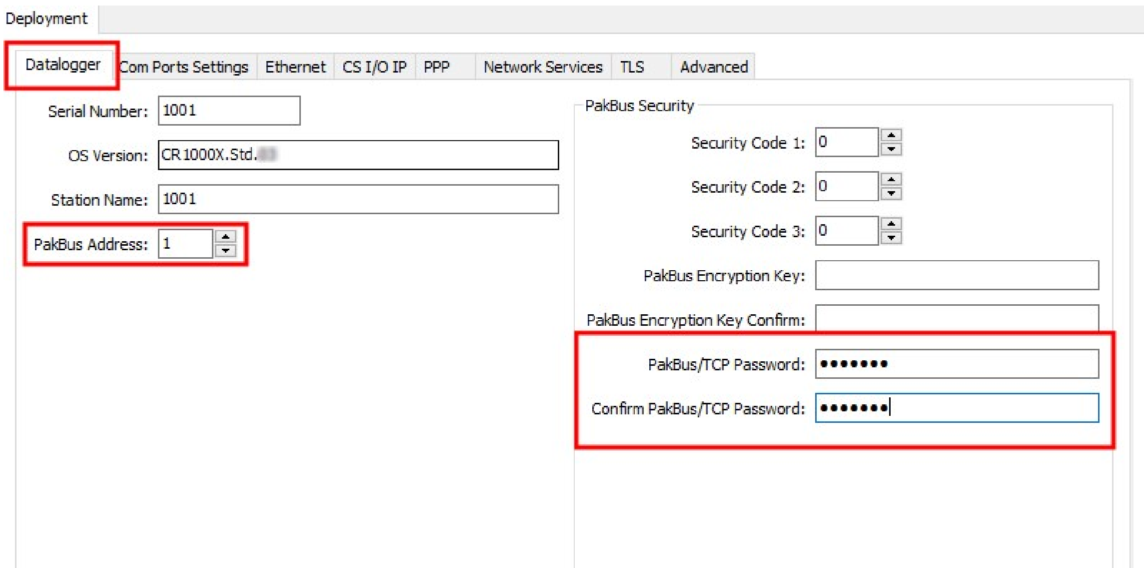
6.1 Modules using Konect PakBus Router (private dynamic IP)

6.1.1 Set up hardware

1. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port.
2. Connect your data logger RS-232 or CS I/O port to the CELL200-series module RS-232 or CS I/O port. Ensure the same port is used for each device, for example RS-232 to RS-232. See Wiring and connections (p. 29).
3. If not connecting through CS I/O, provide power to the CELL200 series. The data logger provides power through the CS I/O port. USB power is not sufficient to power the CELL200 series; 12 V is required.

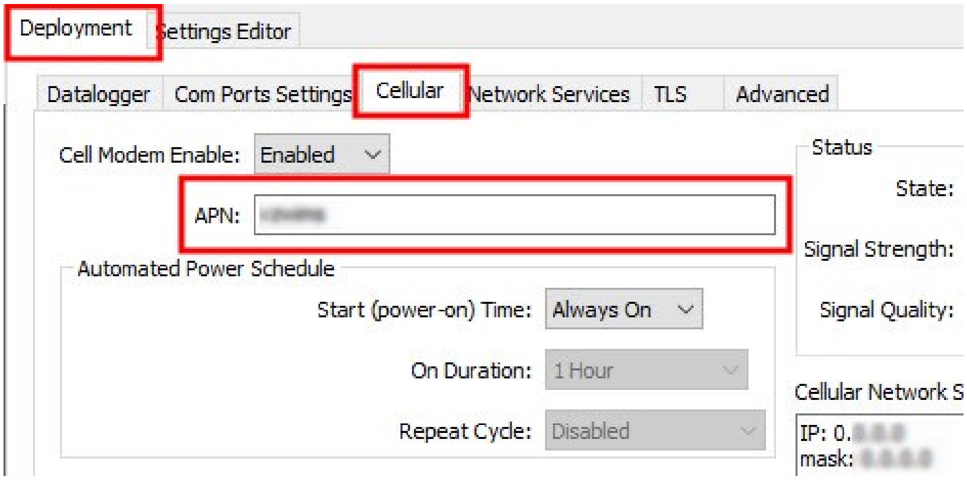
6.1.2 Configure data logger

1. Connect to your data logger by using ***Device Configuration Utility***.
2. On the **Datalogger** tab, change the data logger **PakBus Address** and **PakBus/TCP Password** to match the values entered in the Konect PakBus Router setup. The **PakBus/TCP Password** will make the data logger authenticate any incoming or outgoing PakBus/TCP connection.



3. On the **Network Services** tab in the **PakBus/TCP Client** field, enter the DNS address and Port number noted during the Konect PakBus Router setup.
4. On the **PPP** tab, set **Config/Port Used** to **CS I/O SDC8** or **RS-232**, depending on how you are connected to the data logger.
5. (Optional) On the **PPP** tab, set **User Name** and **Password** if required by your cellular carrier (usually outside of the United Sates).
6. Verify the **Modem Dial String** setting is blank.
7. If connecting through RS-232, on the **Comport Settings** tab, set **RS232 BaudRate** to **115200 Fixed**.
8. Click **Apply** to save the changes. Verify the settings in the summary window. (Recommended) **Save** a copy of the settings to a file on the computer. Click **OK**.
9. Shut down ***Device Configuration Utility*** and start it again. This will activate the **Cellular** tab needed for the next step.

10. On the **Cellular** tab, enter the **APN** provided by your cellular provider.

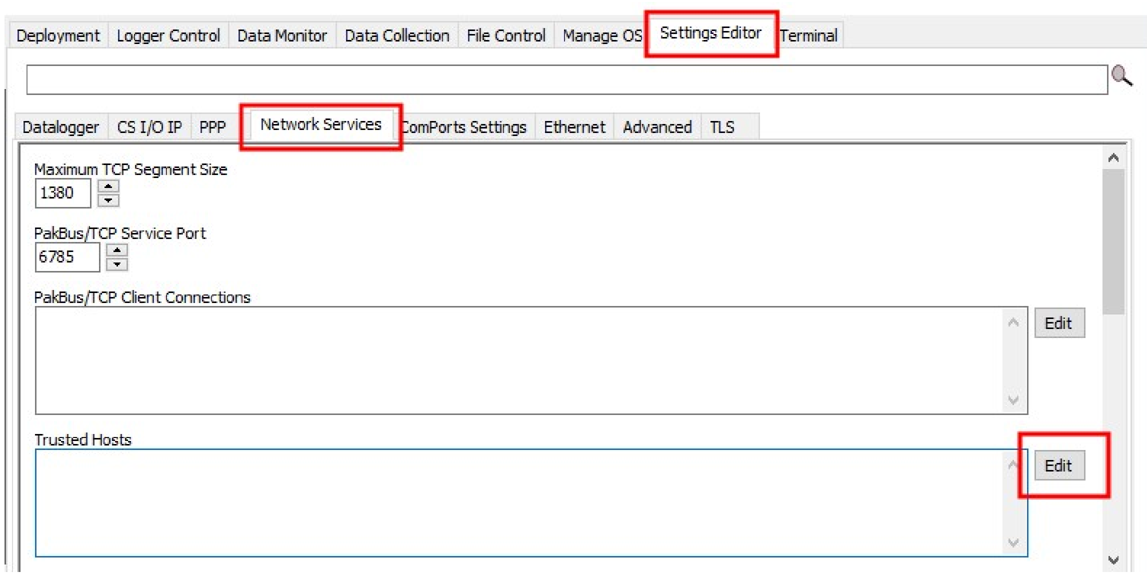


11. Click **Apply** to save the changes. Verify the settings in the summary window. (Recommended) **Save** a copy of the settings to a file on the computer. Click **OK**.
12. Click **Connect** to reconnect in the ***Device Configuration Utility***.
13. (Optional) By default, the CELL200 series will accept incoming communications from any IP address. This can be a security risk. You may specify up to four IP addresses, with wild cards, to limit connections to only those trusted sources. Use an asterisk (*) as a wild card. For example, a setting of 166.22.*.* would allow connections from devices that have IP addresses starting with 166.22. Both IPv4 and IPv6 addresses are supported.

    CAUTION:
    Only set a Trusted IP address if you are familiar with their use. Consult your IT department or Campbell Scientific for assistance.

    NOTE:
    This setting does not affect outbound connections, only incoming connections.

In the **Settings Editor** > **Network Services** tab, next to the **Trusted Hosts** field, click **Edit** and **Add** your trusted IP addresses, one at a time.



14. Click **Apply** to save the changes. Verify the settings in the summary window. (Recommended) **Save** a copy of the settings to a file on the computer. Click **OK**.
15. Click **Disconnect** and close ***Device Configuration Utility***.

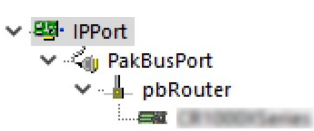
6.1.3 Set up *LoggerNet*

The ***LoggerNet*** Network Map is configured from the **LoggerNet Setup** screen.

> **NOTE:**
> Setup has two options, EZ (simplified) and Standard. Click on the **View** menu at the top of the **Setup** screen, and select **Standard** view.

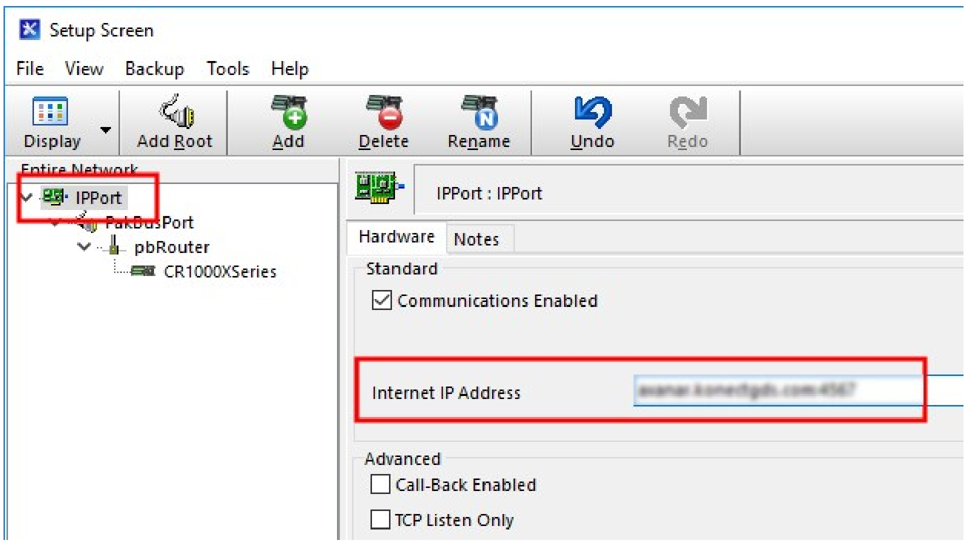
From the ***LoggerNet*** toolbar, click **Main** > **Setup** and configure the Network Map as described in the following steps:

1. Select **Add Root** > **IPPort**.
2. Select **PakBusPort** and **pbRouter** for PakBus data loggers such as the CR6 or CR1000X.

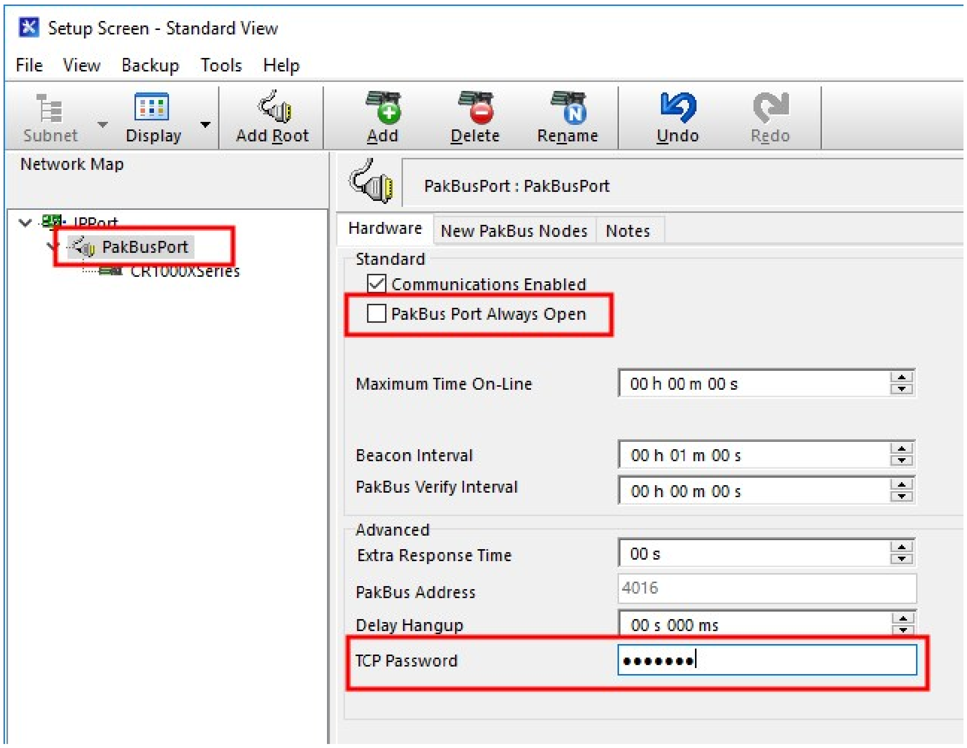


> **NOTE:**
> PakBus data loggers include the following models: GRANITE-series, CR6, CR3000, CR1000X, CR800-series, CR300-series, CR1000, and CR200(X)-series.

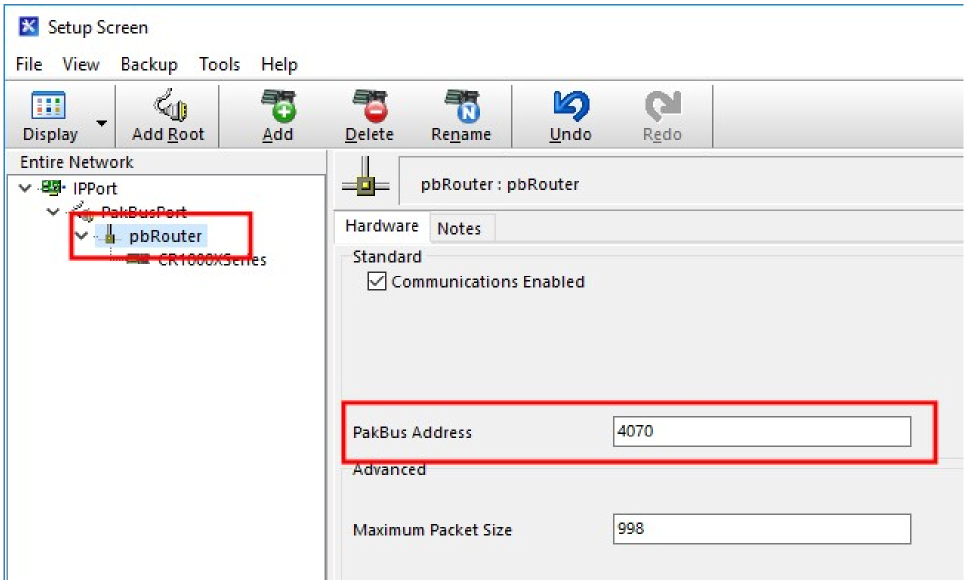
3. Add a data logger to the **pbRouter**.
4. From the Entire Network, on the left side, select the **IPPort**. Enter the Konect PakBus Router DNS address and port number as noted in the Konect PakBus Router setup (Set up Konect PakBus Router [p. 6]). Enter them into the **Internet IP Address** field in the format DNS:Port with a colon separating DNS and Port. For example, axanar.konectgds.com:pppp where pppp is the port number.



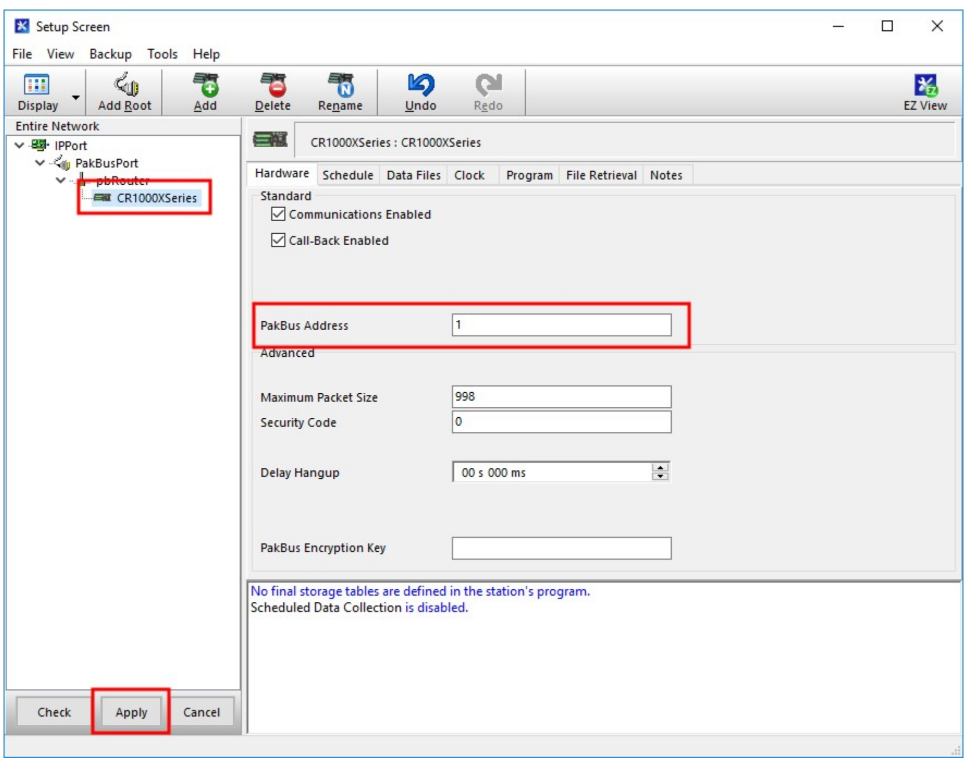
5. Leave the default settings for the **PakBusPort**. **PakBus Port Always Open** should **not** be checked. In the **TCP Password** field enter the TCP Password; this must match the value entered in the Konect PakBus Router setup and ***LoggerNet*** setup.



6. For PakBus data loggers, select the pbRouter in the Network Map and set the **PakBus Address** to **4070**.



7. For PakBus data loggers, select the data logger in the Network Map and set the **PakBus Address** to match that of the data logger (default address in the data logger is 1). If a **PakBus Encryption Key** was entered during data logger setup, also enter it here. Click **Apply** to save the changes.

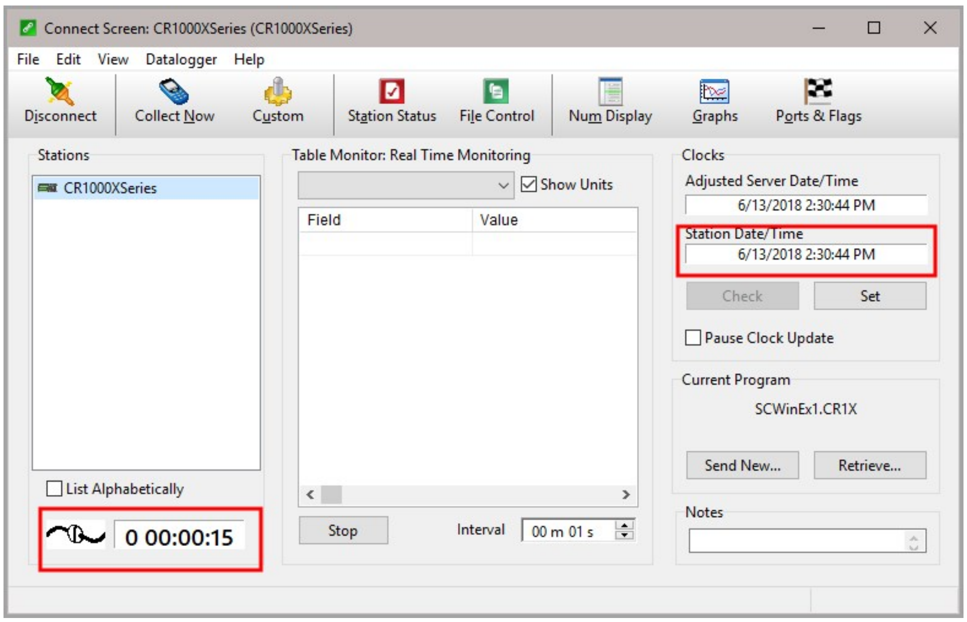


6.1.4 Test the connection

After the Network Map has been configured, test the cellular connection by using the **Connect** screen as shown in the following image. Click on the appropriate station and click **Connect** to initiate a call to the data logger.

> **TIP:**
> The connection time is subject to many external factors. It is often less than 30 seconds but could be up to 15 minutes. Be patient.

If the connection is successful, the connectors icon at the bottom of the screen will come together and clock information from the data logger will be displayed in the **Station Date/Time** field. If the connection fails, a **Communications Failure** message will be displayed.



6.2 Modules using a public static IP

6.2.1 Set up hardware

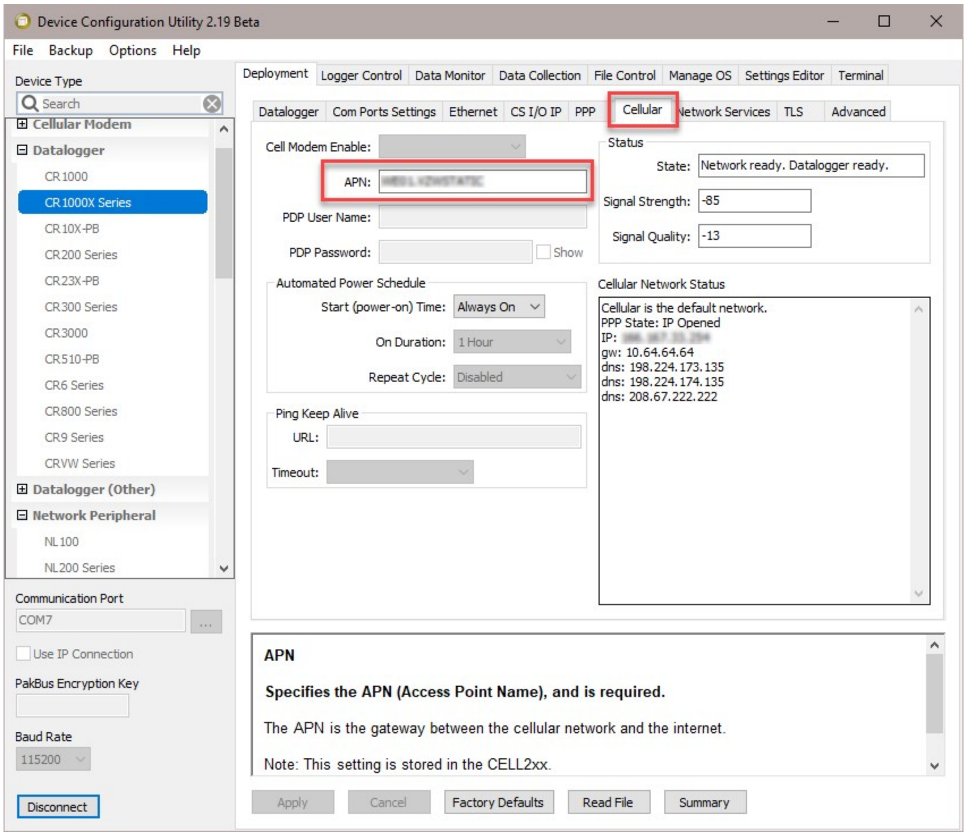
1. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port.

2. Connect your data logger RS-232 or CS I/O port to the CELL200-series module RS-232 or CS I/O port. Ensure the same port is used for each device, for example RS-232 to RS-232. See Wiring and connections (p. 29).
3. If not connecting through CS I/O, provide power to the CELL200 series. The data logger provides power through the CS I/O port. USB power is not sufficient to power the CELL200 series; 12 V is required.

6.2.2 Configure data logger

1. Connect to your data logger by using ***Device Configuration Utility***.
2. On the **PPP** tab, set **Config/Port Used** to **CS I/O SDC8** or **RS-232**, depending on how you are connected to the data logger.
3. (Optional) On the **PPP** tab, set **User Name** and **Password** if required by your cellular carrier (usually outside of the United Sates).
4. Verify the **Modem Dial String** setting is blank.
5. If connecting through RS-232, on the **Comport Settings** tab, set **RS232 BaudRate** to **115200 Fixed**.

6. On the **Cellular** tab, enter the **APN** provided by your cellular provider.

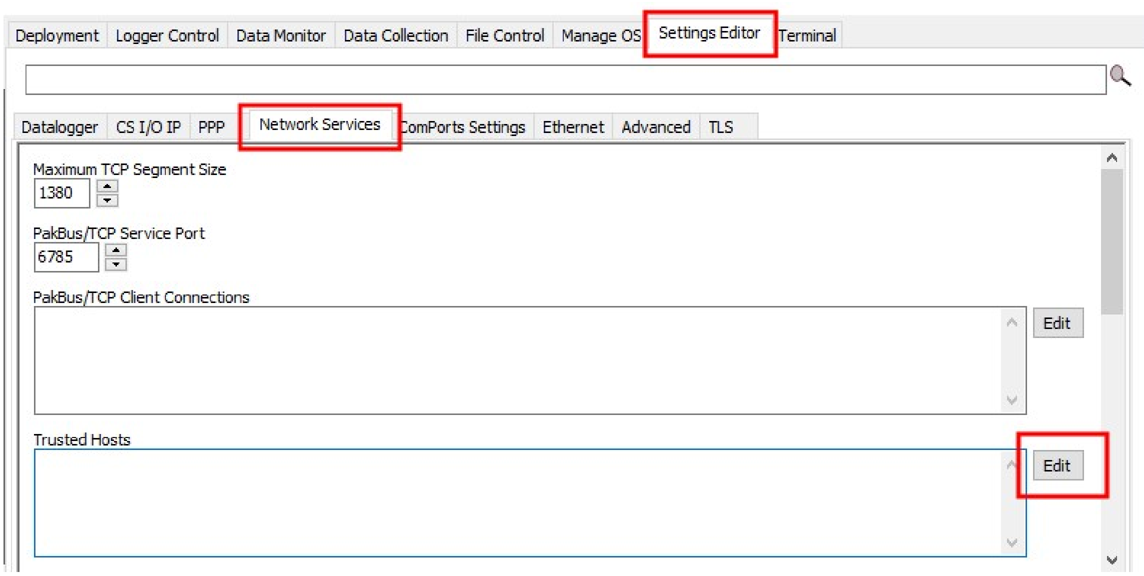


7. (Optional) By default, the CELL200 series will accept incoming communications from any IP address. This can be a security risk. You may specify up to four IP addresses, with wild cards, to limit connections to only those trusted sources. Use an asterisk (*) as a wild card. For example, a setting of 166.22.*.* would allow connections from devices that have IP addresses starting with 166.22. Both IPv4 and IPv6 addresses are supported.

> **CAUTION:**
> Only set a Trusted IP address if you are familiar with their use. Consult your IT department or Campbell Scientific for assistance.

> **NOTE:**
> This setting does not affect outbound connections, only incoming connections.

In the *Device Configuration Utility* go to the **Settings Editor** then **Network Services**. Next to the **Trusted Hosts** field, click **Edit** and **Add** your trusted IP addresses, one at a time.



8. Click **Apply** to save the changes.

6.2.3 Set up *LoggerNet*

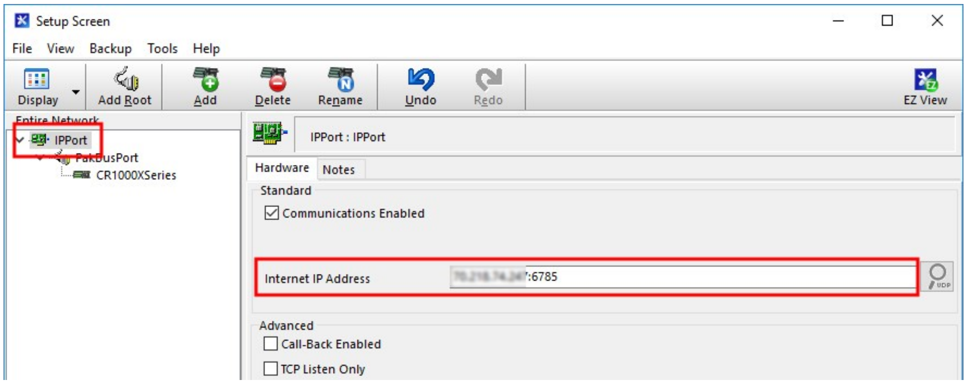
The *LoggerNet* Network Map is configured from the **LoggerNet Setup** screen.

> NOTE:
> Setup has two options, EZ (simplified) and Standard. Click on the **View** menu at the top of the **Setup** screen, and select **Standard** view.

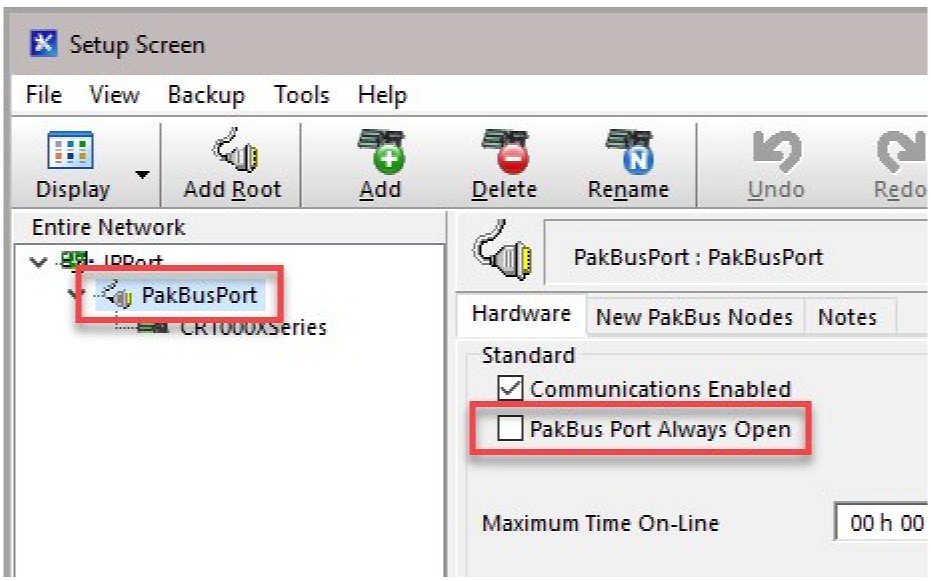
From the *LoggerNet* toolbar, click **Main** > **Setup** and configure the Network Map as described in the following steps:

1. Select **Add Root** > **IPPort**.
2. Select **PakBusPort**.
3. Add a data logger to the **PakBusPort**.

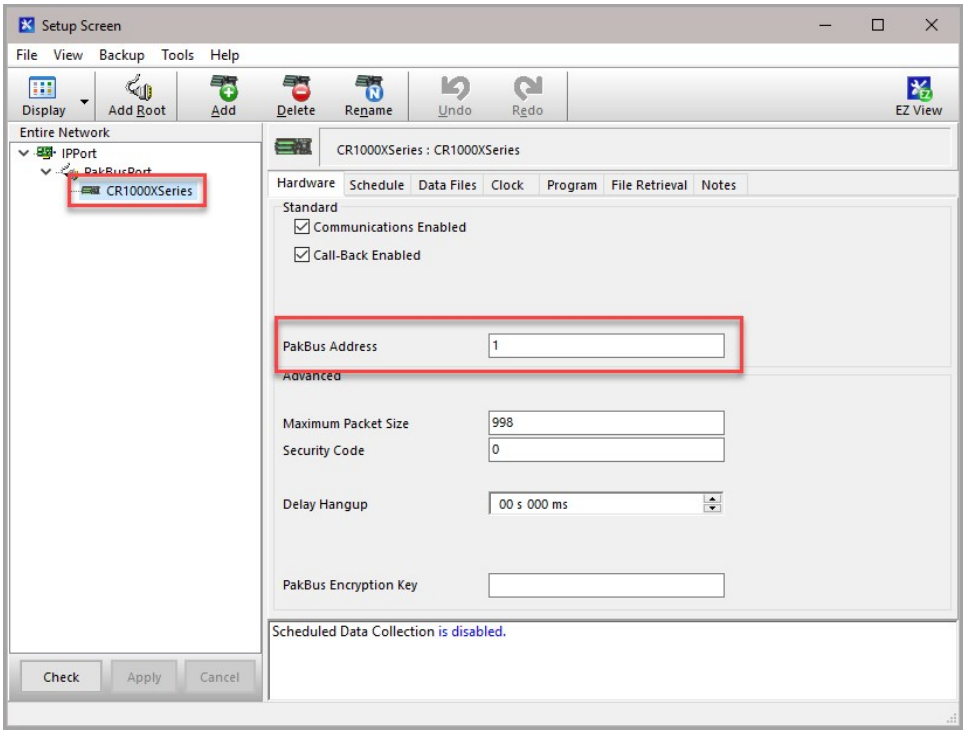
4. Select the **IPPort** in the Network Map. Enter the CELL200 series IP address and port number. The IP address and port number are input in the **Internet IP Address** field separated by a colon. Preceding zeros are not entered in the **Internet IP Address** (for example, 070.218.074.247 is entered as 70.218.74.247). The default port number is 6785.



5. For PakBus data loggers, leave the default settings for the **PakBusPort. PakBus Port Always Open** should **not** be checked. If a **TCP Password** is used, enter it.



6. For PakBus data loggers, select the data logger in the Network Map and set the **PakBus Address** to match that of the data logger (default address in the data logger is 1). If a **PakBus Encryption Key** was entered during data logger setup, also enter it here. Click **Apply** to save the changes.

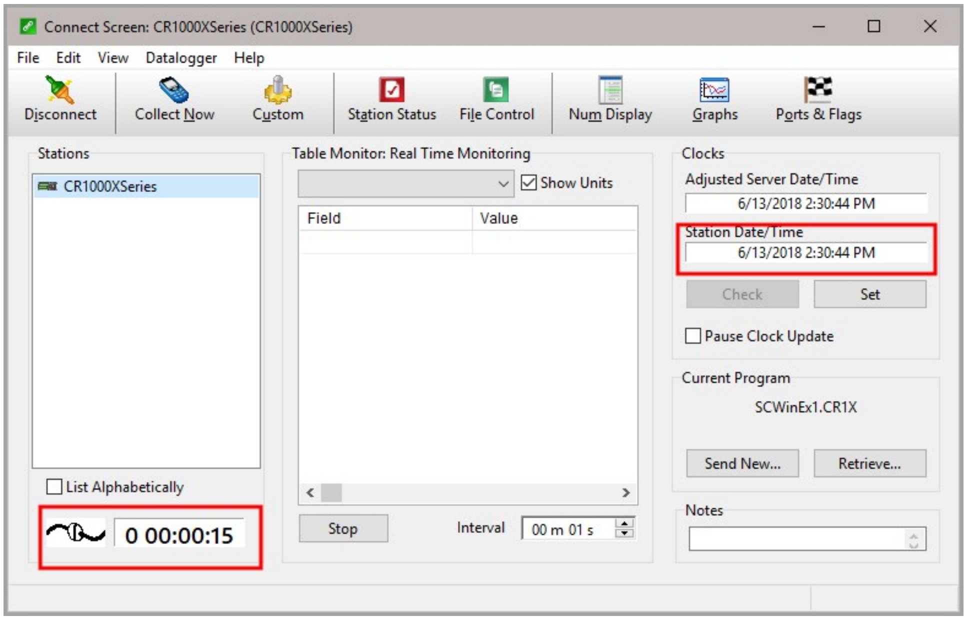


6.2.4 Test the connection

After the Network Map has been configured, test the cellular connection by using the **Connect** screen as shown in the following image. Click on the appropriate station and click **Connect** to initiate a call to the data logger.

TIP:
The connection time is subject to many external factors. It is often less than 30 seconds but could be up to 15 minutes. Be patient.

If the connection is successful, the connectors icon at the bottom of the screen will come together and clock information from the data logger will be displayed in the **Station Date/Time** field. If the connection fails, a **Communications Failure** message will be displayed.



7. Specifications

Data Logger Compatibility

The CELL200 series is compatible with the GRANITE-series, CR6, CR3000, CR1000X, CR800-series, CR300-series, CR1000, CR200(X) series, CR5000, CR10X, CR10X-PB, CR510, CR510-PB, CR23X, and CR23X-PB. See Module communications connections (p. 29) for information on communications options with each data logger model.

Cellular WAN

See https://s.campbellsci.com/documents/us/miscellaneous/Cellular Modem Frequency Bands.pdf for a complete list of supported frequency bands.

Host Interfaces

- CS I/O communications port, DB9 male
- RS-232 serial port, DB9 female
- USB version 2.0 with micro-B connector

RF Connectors

- 2 SMA antenna connectors (primary and diversity)

Power

- Operating Voltage: 10 to 30 VDC
- Low Power Mode: 300 µA
- Typical Idle: 14 mA @ 12 VDC
- Typical Active: 39 mA @ 12 VDC (CELL205, CELL215, CELL220, CELL225)
  25 mA @ 12 VDC (CELL210)

Size

- Dimensions: 13.46 X 8.1 X 2.86 cm (5.3 X 3.19 X 1.13 in)
- Weight: 215.5 g (7.6 oz)

Environmental

- Operating Temperature Range: –40 to 80 °C
- Storage Temperature: –45 to 80 °C
- Humidity: 10 to 90%

Industry Certifications

- Environmental: RoHS

SIM (Subscriber Identity Module) card interface

- Micro-SIM (3FF) (6 position / contacts)
- Supports SIMs that require 1.8 or 3 VDC

Data Speeds

- LTE: Max 10 Mbps (download) / Max 5 Mbps (upload)
- WCDMA: Max 384 Kbps (download) / Max 384 Kbps (upload)
- GSM
  - EDGE: Max 296 Kbps (download) / Max 236.8 Kbps (upload)
  - GPRS: Max 107 Kbps (download) / Max 85.6 Kbps (upload)

Compliance

- Industry Canada (IC): 10224A-201611EC21A
- View Declaration of Conformity at:

  www.campbellsci.com/cell205

  www.campbellsci.com/cell210

  www.campbellsci.com/cell215

  www.campbellsci.com/cell220

  www.campbellsci.com/cell225

8. Installation

8.1 Base station requirements

A computer running Campbell Scientific ***LoggerNet*** software with access to the Internet is needed.

8.2 Data logger site equipment

- CELL200-series module with power cable (included with module)
- Data logger — GRANITE series, CR6 series, CR3000, CR1000X series, CR300 series, CR1000, CR800 series, and CR5000
- Module Interface, see Module communications connections (p. 29)
- Environmental Enclosure — ENC10/12, ENC12/14, ENC14/16 or ENC16/18

If connecting to CS I/O port:

SC12 cable (preferred for GRANITE series, CR6 series, CR3000, CR1000X series, CR1000, CR800 series, and CR5000 data loggers) — connects the module to current data logger with a **CS I/O** port. See CS I/O connection (p. 31)

SC105 Interface — connects the module to any data logger with a **CS I/O** port. It must be configured using ***Device Configuration Utility***. Settings should be:

- CS I/O Mode: SDC Address 8
- CS I/O ME Baud Rate: 115.2k
- RS-232 Mode: Modem (default)
- Baud Rate:
  - 115.2k fixed for GRANITE series, CR6 series, CR3000, CR1000X series, CR1000, CR800 series, and CR5000 data loggers
  - 9600 for CR10X, CR10X-PB, CR510, CR510-PB, CR23X, and CR23X-PB data loggers
- 8 data bits, 1 stop bit, no parity

If connecting to RS-232 port:

Null Modem Cable (9 pin, male-to-male) — connects the module to the CR300 series, CR1000, CR3000, CR800 series, and CR200(X) series **RS-232** port.

CPI/RS-232 RJ45 to DB9 Cable — connects the module to the CR6 series or CR1000X series **CPI/RS-232** port.

- Antenna — the following antennas are available from Campbell Scientific. Contact Campbell Scientific for help in determining the best antennas for your application.
  - 2 dBd 4G/3G Omnidirectional Antenna: An omnidirectional antenna with mounting bracket that is ideally suited for use with 4G and 3G cellular gateways. The mounting bracket attaches to a mast or crossarm, and it serves as the antenna ground plane. The antenna has an N type (female) threaded permanent stud for easy mounting to the included bracket or through an enclosure wall. A coaxial cable, sold separately, is required to connect this antenna to the inline surge suppression or module antenna

jack. The antenna includes a mount/U-bolt assembly for attaching the antenna to a mast, post, or crossarm up to 3.8 cm (1.5 in) in diameter.

- The 38485 antenna is a wideband, dual-port, directional-panel antenna with slant 45 polarization that covers US LTE700/Cellular/PCS/AWS/MDS and global GSM900/GSM1800/UMTS/LTE2600 bands. The antenna is designed for fixed installations and is ideal for both indoor and outdoor applications. It includes a UV-stable enclosure that provides years of use without degradation to either mechanical properties or aesthetics. It also includes a mount assembly that secures the antenna to a mast or pole using hose clamps and mast mount adapter. The antenna can also be directly mounted on a wall.

- 8 dBd Yagi Wideband Antenna: A higher gain antenna that should be "aimed" at the service provider antenna. It covers both the 800-MHz band and the 1.9-GHz band. The antenna comes with bracket/U-bolt assembly for attaching the antenna to a mast or post. A coaxial cable, sold separately, is required to connect this antenna to the inline surge suppression or module antenna jack. This antenna is recommended for areas that require a higher gain antenna.

- 4G/3G Cellular Whip Antenna with SMA Connector: A wideband termination antenna with SMA connector and articulating base. This antenna is intended for short-term testing use only. It is not intended for long-term use. Campbell Scientific recommends that customers use external antennas for the best reception and transmission of cellular signals.

NOTE:
When antennas are located away from the CELL200 series, keep the cables as short as possible to prevent the loss of antenna gain. Route the cables to protect them from damage and so they will not be snagged or pulled on. Avoid binding or sharp corners in the cable routing. Bundle and tie off excess cable. Make sure the cables are secured so their weight will not loosen the connector from the CELL200 series over time.

TIP:
Cellular phone apps, such as OpenSignal (https://opensignal.com/), show the direction to point an antenna to get the best signal strength.

8.3 Wiring and connections

This section explains how to connect the module for different communications methods. It also describes how to power the module and connect an antenna.

8.3.1 Module communications connections

The following table shows communications options for each Campbell Scientific data logger model.

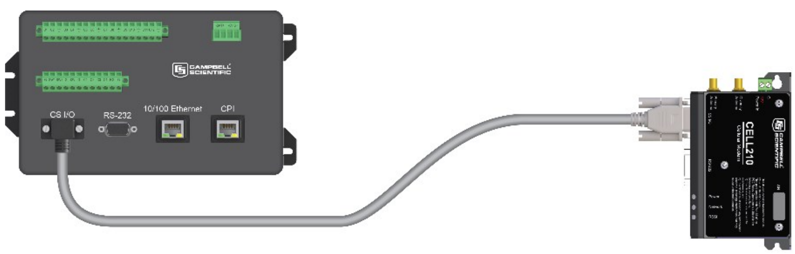
Table 8-1: CELL200 series data logger compatibility chart		
Data logger model	Connecting to CELL200 series via its CS I/O port	Connecting to CELL200 series via its RS- 232 port
CR300	N/A	RS-232 null modem cable, or C-port to RS-232 cable (PPP or serial server)
CR310	N/A	RS-232 null modem cable, or C-port to RS-232 cable (PPP or serial server)
GRANITE 6 CR6	SC12 CS I/O cable (PPP and serial server)	CPI/RS-232 cable, or C- or U-port to RS-232 cable, or SC105 CS I/O to RS-232 interface
GRANITE 10/9 CR1000X	SC12 CS I/O cable (PPP and serial server)	CPI/RS-232 cable, or C-port to RS-232 cable, or SC105 CS I/O to RS-232 interface
CR200(X)	N/A	RS-232 null modem cable (serial server only)
CR800	SC12 CS I/O cable (PPP and serial server)	RS-232 null modem cable (PPP or serial server), or C-port to RS-232 cable, or SC105 CS I/O to RS-232 interface
CR1000	SC12 CS I/O cable (PPP and serial server)	RS-232 null modem cable (PPP or serial server), or C-port to RS-232 cable, or SC105 CS I/O to RS-232 interface
CR3000	SC12 CS I/O cable (PPP and serial server)	RS-232 null modem cable (PPP or serial server), or C-port to RS-232 cable, or SC105 CS I/O to RS-232 interface
CR5000	N/A	RS-232 null modem cable (serial server only)
CR510 and CR10X	N/A	SC105 CS I/O to RS-232 interface

Table 8-1: CELL200 series data logger compatibility chart

Data logger model	Connecting to CELL200 series via its CS I/O port	Connecting to CELL200 series via its RS- 232 port
CR510-PB and CR10X-PB	SC12 CS I/O cable (serial server only) (SDC7 and SDC8 only)	SC105 CS I/O to RS-232 interface
CR23X	N/A	RS-232 null modem cable (serial server only), or SC105 CS I/O to RS-232 interface
CR23X-PB	SC12 CS I/O cable (serial server only) (SDC7 and SDC8 only)	RS-232 null modem cable (serial server only), or SC105 CS I/O to RS-232 interface

Figure 8-1 (p. 31), Figure 8-2 (p. 32), and Figure 8-3 (p. 32) illustrate the most common communications connections between a data logger and a CELL200 series.

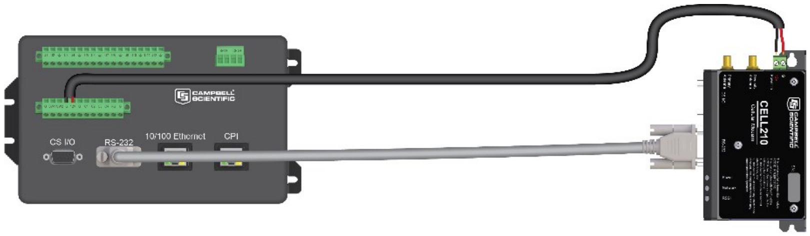
CS I/O connection using an SC12 cable



The SC12 is used to connect the module to a data logger **CS I/O** port.

Figure 8-1. CS I/O connection

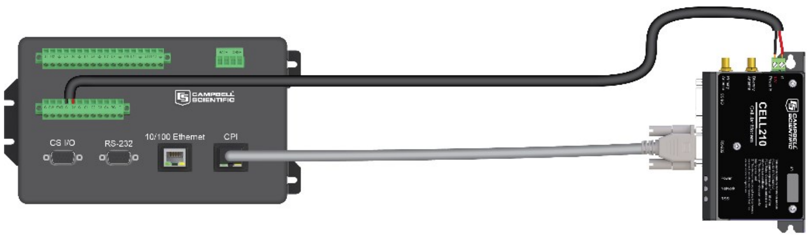
RS-232 connection using a null modem cable



Null Modem Cable is used to connect the module to the CR3000, CR800, CR2XX, CR300 series, or CR1000 **RS-232** port. Power is provided from the **12V** or **SW12V** port of the data logger.

Figure 8-2. RS-232 connection

CR1000X or CR6 RS-232 connection using a CPI/RS-232 cable



RS-232/CPI RJ45 to DB9 Male DTE is used to connect the module to the CR6 or CR1000X. Power is provided from the **12V** or **SW12V** port of the data logger.

Figure 8-3. CR6/CR1000X RS-232 connection

8.3.2 Module power connections

When connecting through the **CS I/O port**, power for the module is provided by the data logger. When connecting through the **RS-232** port, power must be supplied through the **Power In** connector.

Controlling power to the CELL200 series (p. 62) provides an example CRBasic program using the `IPNetPower()` instruction to control power to the CELL200 series. This functionality is available in the CR300 series (all operating systems), the CR6 series with operating system 09.00 or greater, and the CR1000X with operating system 03.00 or greater. To control power in these data loggers with older operating systems or any CR1000, CR800 series, or CR3000, you will need to use a **SW12V** port on the data logger and communicate over RS-232.

Alternatively, GRANITE series, CR6 series, CR3000, CR1000X series, CR300 series, CR1000, CR800 series, and CR5000 can use terminal commands to control power. Downloadable example programs are available at www.campbellsci.com/downloads/cell200-example-programs. Search for `"deep sleep"` and `"wakeup"` in the `CELL2XX-Settings` program.

CR1000, CR800 series, and CR3000 CRBasic programs require `PPPClose` before the `"deep sleep"` command and `PPPOpen` before the `"wakeup"` command.

The **USB** port provides power for module configuration, but is not sufficient for normal operation.

8.3.3 Antenna connections

Use of a diversity antenna can improve system performance. It is required in 4G networks, but not 2G or 3G.

Figure 8-4. Antenna connections

1. Connect the cellular antenna to the **Primary Antenna** connector. Mount the cellular antenna so there is at least 20 cm between the antenna and the user or any bystander.
2. Connect a second antenna, if used, to the **Diversity Antenna** connector.

Antenna diversity, also called space diversity, is a scheme that uses two or more antennas to improve the quality and reliability of a wireless link. Often, especially in urban and indoor environments, there is no clear line of sight between transmitter and receiver. Instead, the signal is reflected along multiple paths before finally being received. Each bounce can introduce phase shifts, time delays, attenuations, and distortions that can destructively interfere with one another at the aperture of the receiving antenna. Diversity-antenna-capable devices support multiple antennas (usually two) in order to combat this phenomenon and minimize its effects.

Diversity antennas are not required for 2G/3G connections; however, they are highly recommended in order to get the most reliable connection, especially in areas of low coverage. Identical or very similar antennas should also be used for the best results.

For 4G networks, the second antenna operates as a MIMO (multiple input, multiple output) antenna, providing a second receive path. This connection is required for operation on 4G/LTE networks.

Table 8-2: Recommended antenna separation

Service	Frequency (MHz)	Wavelength (λ) (mm)	Best antenna separation (mm) (1/2 λ)	Good antenna separation (mm) (1/4 λ)
LTE	700	428	214	107
LTE	800	375	187	94
LTE	900	333	167	83
LTE	1800	167	83	42
LTE	2100	143	71	36
LTE	2600	115	58	29
WCDMA	850	353	176	88
WCDMA	900	333	167	83
WCDMA	1900	158	79	39
WCDMA	2100	143	71	36
CDMA/EV-DO	800	375	187	94
CDMA/EV-DO	1900	158	79	39
GSM/GPRS/EDGE	850	353	176	88
GSM/GPRS/EDGE	900	333	167	83
GSM/GPRS/EDGE	1800	167	83	42
GSM/GPRS/EDGE	1900	158	79	39

WARNING:
Antenna may not exceed the maximum gain specified in RF exposure (p. 82).

In more complex installations, such as those requiring long cable lengths or multiple connections, you must follow the maximum dBi gain guidelines specified by the radio communications regulations of the Federal Communications Commission (FCC), Industry Canada, ACMA in Australia, or your country's regulatory body.

8.4 CELL200 series and data logger configuration

> **NOTE:**
> Instructions in this section assume that the steps in Pre-installation (p. 2) have been completed. Cellular service must be setup before web access using cell.linktodevice.com is available.

Select the installation option that best suits your application. The Overview (p. 8) section describes the differences.

8.4.1 Integrated mode option

QuickStart (integrated mode) (p. 10) describes setting up the CELL200 series in integrated mode with its default settings.

If the module is not in its default settings, the settings in the CELL200 series must match those in the data logger for integrated mode to work. This includes the **SDC Address** for CS I/O communications or the **RS-232 Baud Rate** for RS 232 communications. Once these settings match, all other configuration changes can be done in the data logger as described in QuickStart (integrated mode) (p. 10).

See Non-integrated mode option (p. 35) for information on changing these settings in the CELL200 series and data logger.

8.4.2 Non-integrated mode option

In non-integrated mode, the module mimics the behavior of our older cellular modems. This mode should be used when doing a direct replacement of a Raven or an RV50 modem.

> **NOTE:**
> This section only applies to CR3000, CR1000 and CR800-series users.

8.4.2.1 Configure CELL200 series

1. Connect a USB cable between your module and computer.
2. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port. See Antenna connections (p. 33).
3. Open a web browser and go to: cell.linktodevice.com.

   > **TIP:**
   > If this doesn't work browse to 192.168.86.1.

4. On the **Settings** tab, enter the **APN** provided by your cellular provider.
5. If you will be connecting through CS I/O, select the desired **SDC Address**.
6. If you will be connecting through RS-232, select the desired **RS232 Baud Rate**.

8.4.2.2 Configure data logger

1. Connect to your data logger using ***Device Configuration Utility***.
2. If using the Konect PakBus Router:
   a. On the **Datalogger** tab, change the data logger **PakBus Address** and optional **PakBus/TCP Password** to match the values entered in the Konect PakBus Router setup.
   b. On the **Network Services** tab in the **PakBus/TCP Client** field, enter the DNS address and Port number noted during the Konect PakBus Router setup.
3. On the **PPP** tab, set **Config/Port Used** to the CS I/O SDC address selected in the module or RS-232 depending on how you will be connected to the data logger.
4. Verify the **Modem Dial String** setting is blank.
5. (Optional) If using CS I/O communications, the throughput can be enhanced by changing the SDC Baud Rate from 115200 to 460800. On the **Advanced** tab, set the **SDC Baud Rate** to 460800. Note that if there are other devices on the **CS I/O** port, they all must be able to support this higher baud rate.

8.4.2.3 Set up hardware

1. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port.
2. Connect your data logger RS-232 or CS I/O port to the CELL200-series module RS-232 or CS I/O port. Ensure the same port is used for each device, for example RS-232 to RS-232. See Wiring and connections (p. 29).
3. If not connecting through CS I/O, provide power to the CELL200 series. The data logger provides power through the CS I/O port. USB power is not sufficient to power the CELL200 series; 12 V is required.

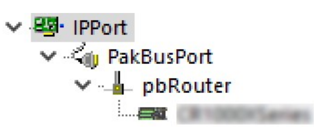
8.4.2.4 Set up *LoggerNet*

The ***LoggerNet*** Network Map is configured from the **LoggerNet Setup** screen.

> **NOTE:**
> Setup has two options, EZ (simplified) and Standard. Click on the **View** menu at the top of the **Setup** screen, and select **Standard** view.

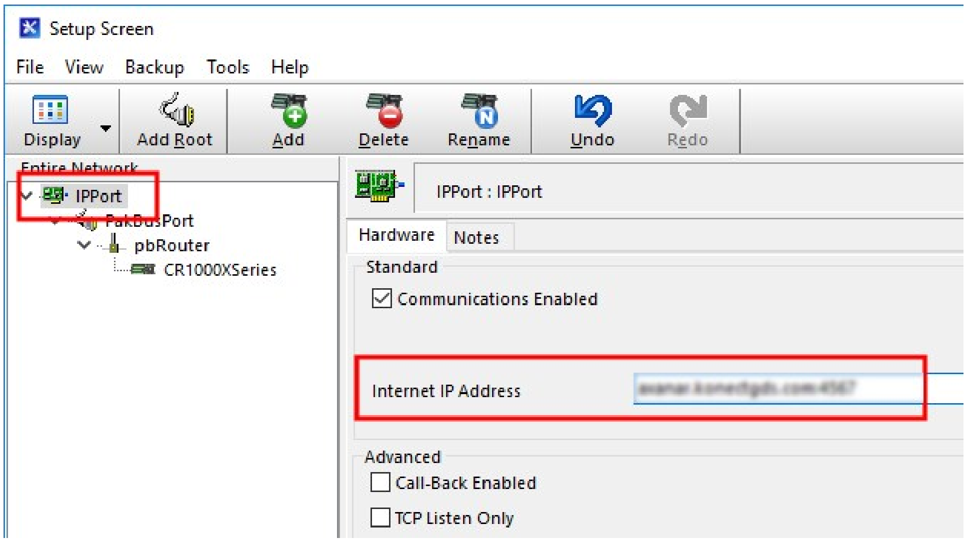
From the ***LoggerNet*** toolbar, click **Main** > **Setup** and configure the Network Map as described in the following steps:

1. Select **Add Root** > **IPPort**.
2. Select **PakBusPort** and **pbRouter**.

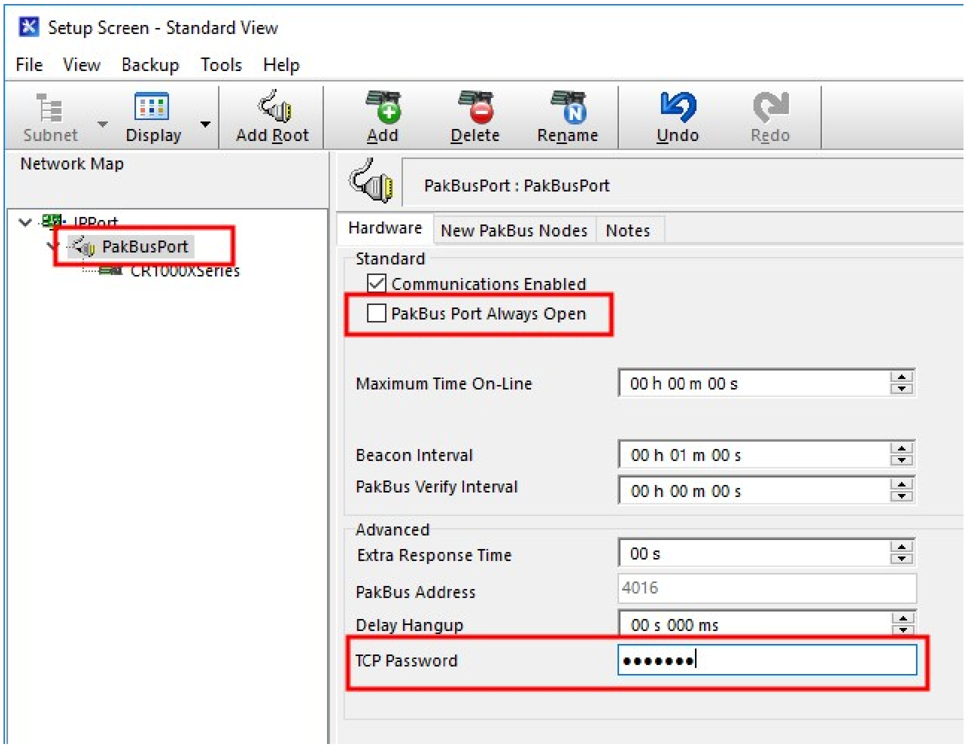


3. Add a data logger to the **pbRouter**.

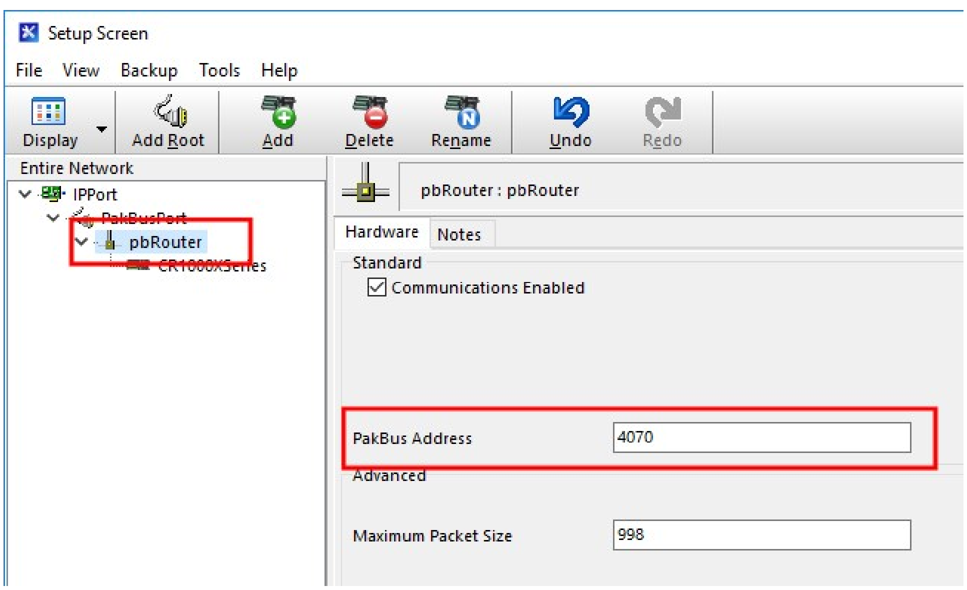
4. Select the **IPPort** in the Network Map. Enter the CELL200 series IP address (public static IP) or the Konect PakBus Router DNS address (private dynamic IP), along with the port number. The address and port number are input in the **Internet IP Address** field separated by a colon. Preceding zeros are not entered (for example, 070.218.074.247 is entered as 70.218.74.247). When not using Konect, the default port number is 6785.



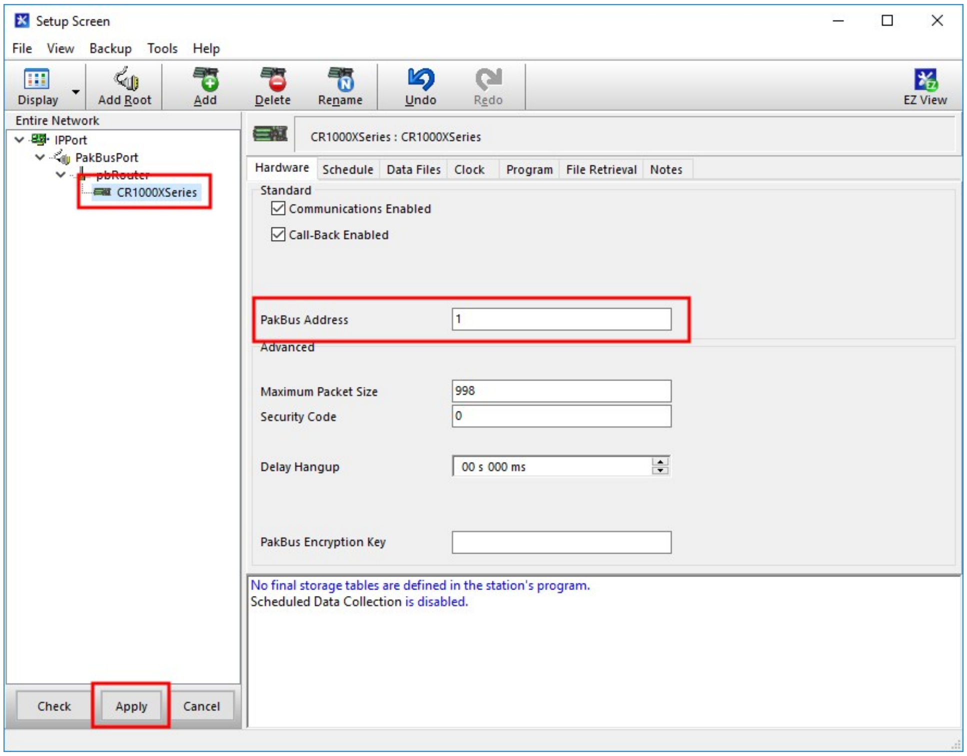
5. Leave the default settings for the **PakBusPort**. **PakBus Port Always Open** should **not** be checked. Enter the **TCP Password**; this must match the value entered in the Konect PakBus Router setup and ***LoggerNet*** setup.



6. Select the pbRouter in the Network Map and set the **PakBus Address** to **4070**.



7. Select the data logger in the Network Map and set the **PakBus Address** to match that of the data logger (default address in the data logger is 1). If a **PakBus Encryption Key** was entered during data logger setup, also enter it here. Click **Apply** to save the changes.

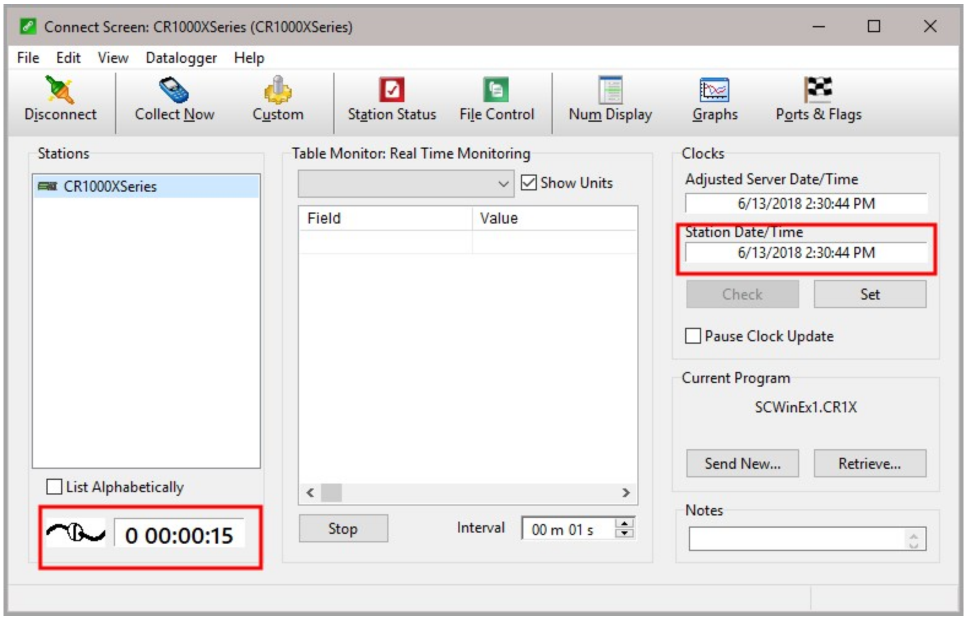


8.4.2.5 Test the connection

After the Network Map has been configured, test the cellular connection by using the **Connect** screen as shown in the following image. Click on the appropriate station and click **Connect** to initiate a call to the data logger.

> **TIP:**
> The connection time is subject to many external factors. It is often less than 30 seconds but could be up to 15 minutes. Be patient.

If the connection is successful, the connectors icon at the bottom of the screen will come together and clock information from the data logger will be displayed in the **Station Date/Time** field. If the connection fails, a **Communications Failure** message will be displayed.



8.4.3 Serial server mode option

In serial server mode, the module receives IP communications over the cellular network and converts those to serial communications to pass on to the data logger. From the perspective of the data logger, this is no different than a serial cable connecting it to a computer.

This is the mode used with CR200-Series and Edlog (CR23X, CR10X, and CR510) data loggers, and cellular-to-RF networks. Only one IP connection at a time is supported.

NOTE:
A public static IP account must be used when the module is set up in serial server mode. Private dynamic IP accounts do not support the serial server mode.

NOTE:
Instructions in this section assume that you have established cellular service and the SIM card has been installed as described in QuickStart (integrated mode) (p. 10).

8.4.3.1 Configure CELL200 series

To set up the CELL200 series in serial server mode:

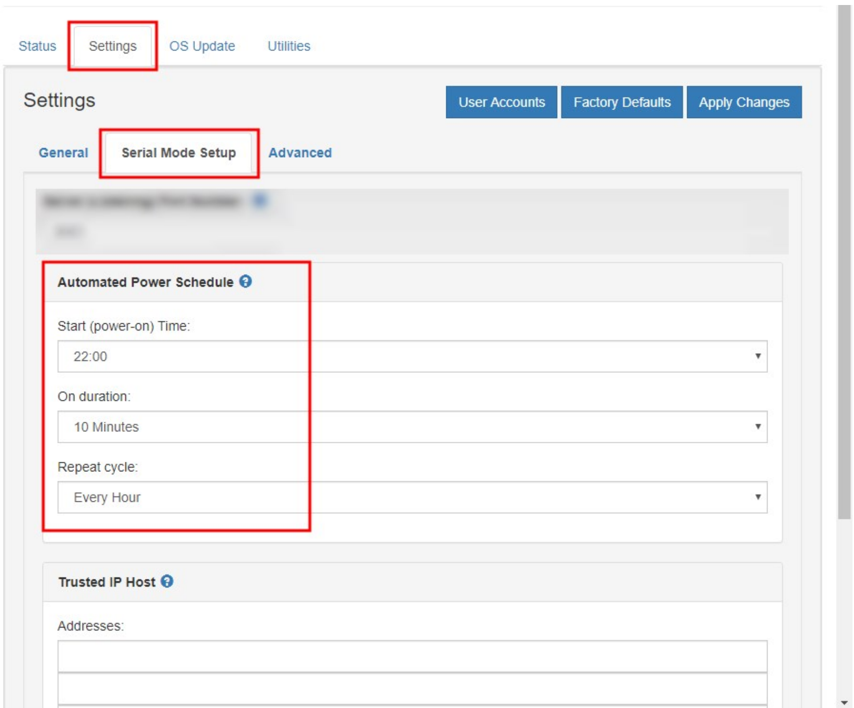
1. Connect a USB cable between your module and computer.
2. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port. See Antenna connections (p. 33).
3. Open a web browser and go to: cell.linktodevice.com.

   > **TIP:**
   > If this doesn't work browse to 192.168.86.1.

4. On the **Settings** > **General** tab, enter the **APN** provided by your cellular provider.
5. Set **Mode** to **Serial Server**.
6. On the **Settings** > **Serial Mode Setup** tab, set **Serial Server Listen Port Number**. Default is 3001. This is entered along with the IP address as part of the ***LoggerNet*** configuration.
7. When using a CR200(X), set **RS-232 baud rate** to **9600** baud.

8. (Optional) In this mode, an **Automated Power Schedule** can be setup to save on battery life or on cellular charges. Go to the **Settings** then **Serial Mode Setup** tab. Enter a **Start (power-on) Time**, **On duration**, and **Repeat cycle**.

   The modem automatically turns off at midnight. It turns on at the **Start (power-on) Time** for the **On duration**. It then turns on again every **Repeat cycle** until midnight, at which point it will turn off.

   For example: With the following settings of **Start (power-on) Time** of 22:00, **On Duration** of 10 minutes, and **Repeat Cycle** of Every Hour the cellular module will turn on for ten minutes only twice each day. It will turn on at 10:00 pm and 11:00 pm. It will not turn on at midnight since it is powered off at the start of the next day.

9. (Optional) By default, the CELL200 series will accept incoming communications from any IP address. This can be a security risk. You may specify up to four IP addresses, with wild cards, to limit connections to only those trusted sources. Use an asterisk (*) as a wild card. For example, a setting of 166.22.*.* would allow connections from devices that have IP addresses starting with 166.22. Both IPv4 and IPv6 addresses are supported.

   > **CAUTION:**
   > Only set a Trusted IP address if you are familiar with their use. Consult your IT department or Campbell Scientific for assistance.

> **NOTE:**
> This setting does not affect outbound connections, only incoming connections.

Staying on the **Settings** > **Serial Mode Setup** tab, enter your trusted IP addresses, one per line, in the **Trusted IP Host Addresses** box.

10. (Optional, for modules with static IP addresses.) To get remote access to the module you must first set up a **User Account**. For security purposes there is no default account. Select **Settings** > **User Accounts** > **Logon** > **Create a new Account**. Provide **Name**, **Password**, and select the **Permission Level**. **Close** then **Apply Changes**.

    Once the module has an account it can be accessed remotely using its static IP address. Type the IP address into a web browser to be prompted for the user name and password.

8.4.3.2 Configure data logger

1. Connect to your data logger by using ***Device Configuration Utility***.
2. On the **PPP** tab, set **Config/Port Used** to **Inactive**.
3. When using RS-232 serial server mode, it is recommended that you use a fixed baud rate on the data logger RS-232 port. On the **Com Ports Settings** tab, select the RS-232 port and set the **Baud Rate** to the fixed option to match the RS 232 baud rate set in the CELL200-series module.
4. If using CS I/O communication, the throughput can be enhanced by changing the SDC Baud Rate from 115200 to 460800. On the **Advanced** tab, set the **SDC Baud Rate** to 460800. Note that if there are other devices on the **CS I/O** port, they all must be able to support this higher baud rate.

8.4.3.3 Set up hardware

1. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port.
2. Connect your data logger RS-232 or CS I/O port to the CELL200-series module RS-232 or CS I/O port. Ensure the same port is used for each device, for example RS-232 to RS-232. See Wiring and connections (p. 29).
3. If not connecting through CS I/O, provide power to the CELL200 series. The data logger provides power through the CS I/O port. USB power is not sufficient to power the CELL200 series; 12 V is required.

8.4.3.4 Set up *LoggerNet*

The ***LoggerNet*** Network Map is configured from the **LoggerNet Setup** screen.

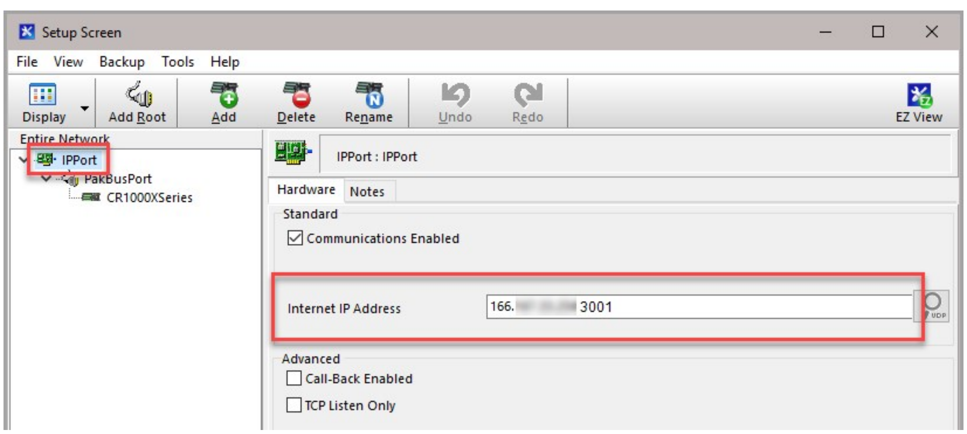
> **NOTE:**
> Setup has two options, EZ (simplified) and Standard. Click on the **View** menu at the top of the **Setup** screen, and select **Standard** view.

From the ***LoggerNet*** toolbar, click **Main** > **Setup** and configure the Network Map as described in the following steps:

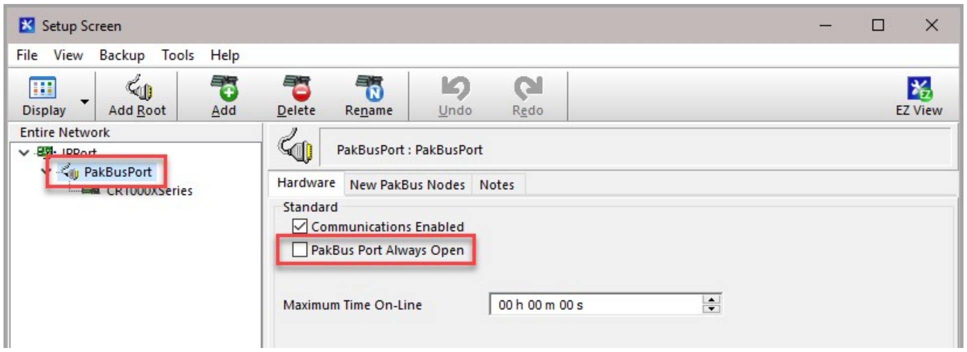
1. Select **Add Root** > **IPPort**.
2. For PakBus data loggers select **PakBusPort**.

   > **NOTE:**
   > PakBus data loggers include the following models: GRANITE-series, CR6, CR3000, CR1000X, CR800-series, CR300-series, CR1000, and CR200(X)-series.

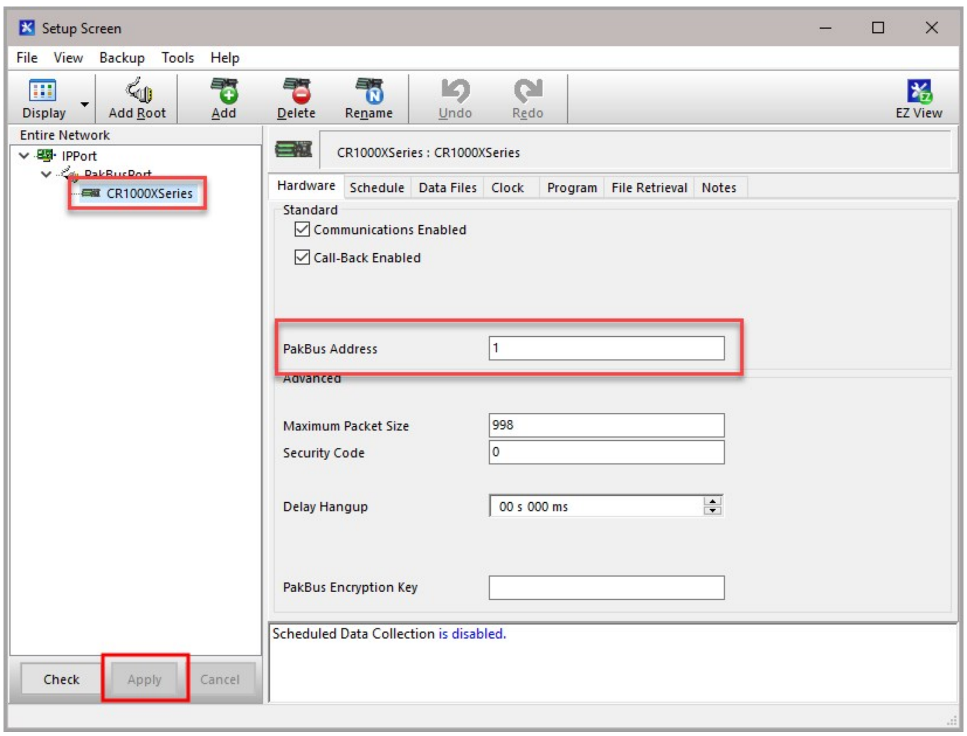
3. Add a data logger.
4. Select the **IPPort** in the Network Map. Enter the CELL200 series IP address (public static IP), along with the port number. The address and port number are input in the **Internet IP Address** field separated by a colon. Preceding zeros are not entered (for example, 070.218.074.247 is entered as 70.218.74.247). For serial server mode, the default port number is 3001.



5. For PakBus data loggers, leave the default settings for the **PakBusPort. PakBus Port Always Open** should not be checked. If used, enter the **TCP Password**.



6. For PakBus data loggers, select the data logger in the Network Map and set the **PakBus Address** to match that of the data logger (default address in the data logger is 1). Click **Apply** to save the changes.

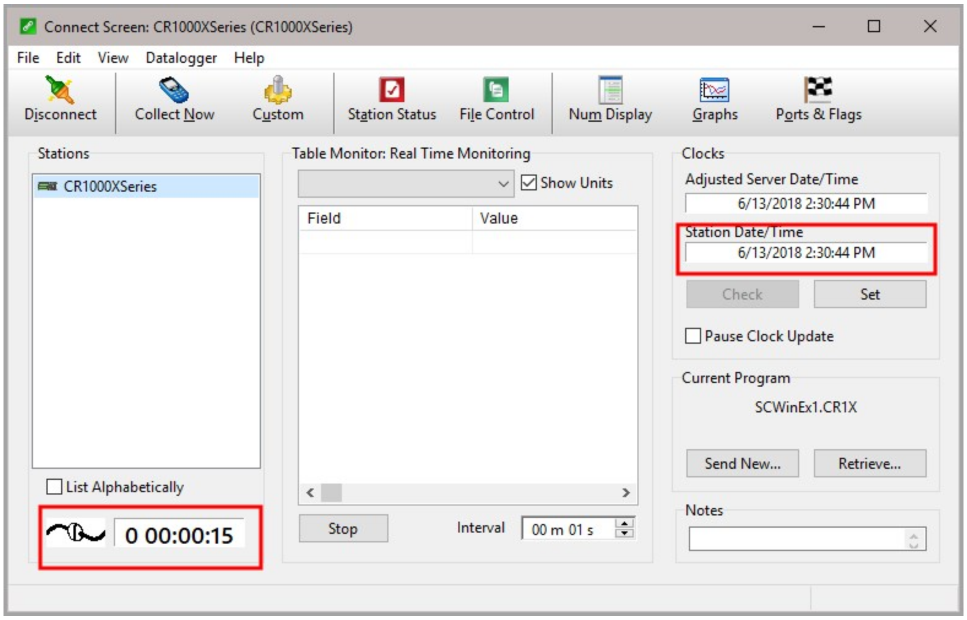


8.4.3.5 Test the connection

After the Network Map has been configured, test the cellular connection by using the **Connect** screen as shown in the following image. Click on the appropriate station and click **Connect** to initiate a call to the data logger.

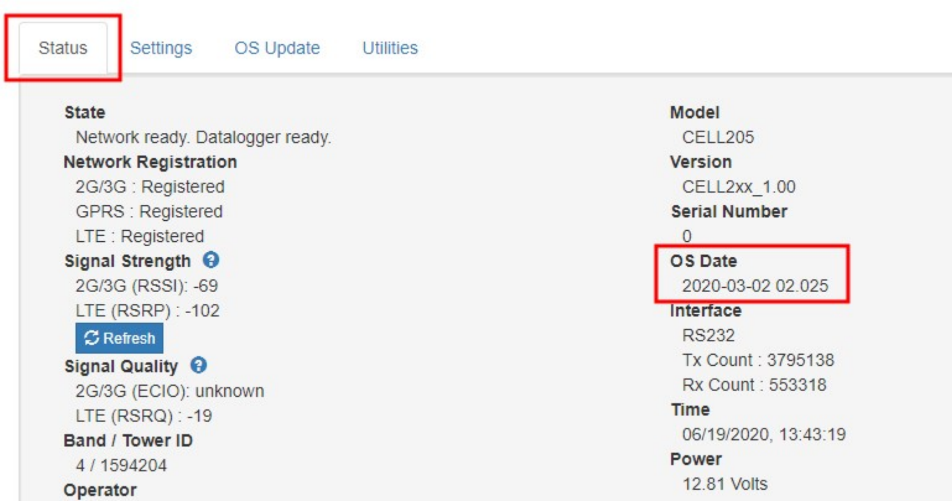
TIP:
The connection time is subject to many external factors. It is often less than 30 seconds but could be up to 15 minutes. Be patient.

If the connection is successful, the connectors icon at the bottom of the screen will come together and clock information from the data logger will be displayed in the **Station Date/Time** field. If the connection fails, a **Communications Failure** message will be displayed.



8.4.4 Serial client mode option

This mode requires CELL200 series operating system 2.00 or newer. Find the CELL200 series OS version in the **OS Date** field of the **Status** Tab. For more information, see Updating the operating system and firmware (p. 65).



In serial client mode the module will connect to the cellular network and initiate a TCP client socket connection. When data is sent to the active port (RS-232 or CS I/O) it will be sent out on the TCP client connection. When data is received on the TCP client socket connection, it is passed to the active port (RS-232 or CS I/O).

Use this mode when the module is behind a cellular provider firewall and it has a private dynamic IP address. This mode requires the receiving TCP/IP connection be on a public static IP address, on the same private cellular network, DNS name or there be a hole in the firewall. For connections involving firewalls, such as office networks, contact your IT department to ensure all relevant settings are configured correctly.

When the same server IP and port are used for multiple data logger connections, each data logger must have a unique PakBus address.

> NOTE:
> Instructions in this section assume that you have established cellular service and the SIM card has been installed as described in QuickStart (integrated mode) (p. 10).

8.4.4.1 Configure CELL200 series

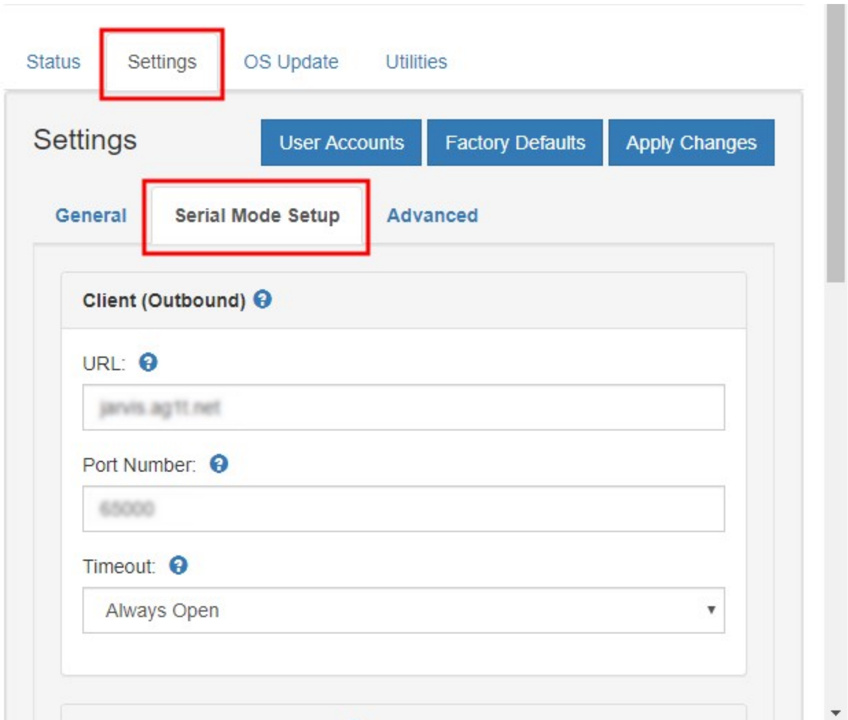
To set up the CELL200 series in serial client mode:

1. Connect a USB cable between your module and computer.
2. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port. See Antenna connections (p. 33).
3. Open a web browser and go to: cell.linktodevice.com.

   > TIP:
   > If this doesn't work browse to 192.168.86.1.

4. On the **Settings** tab, enter the **APN** provided by your cellular provider.
5. On the **General** tab, set **Mode** to **Serial Client**.
6. When using a CR200(X), set **RS-232 baud rate** to **9600** baud.

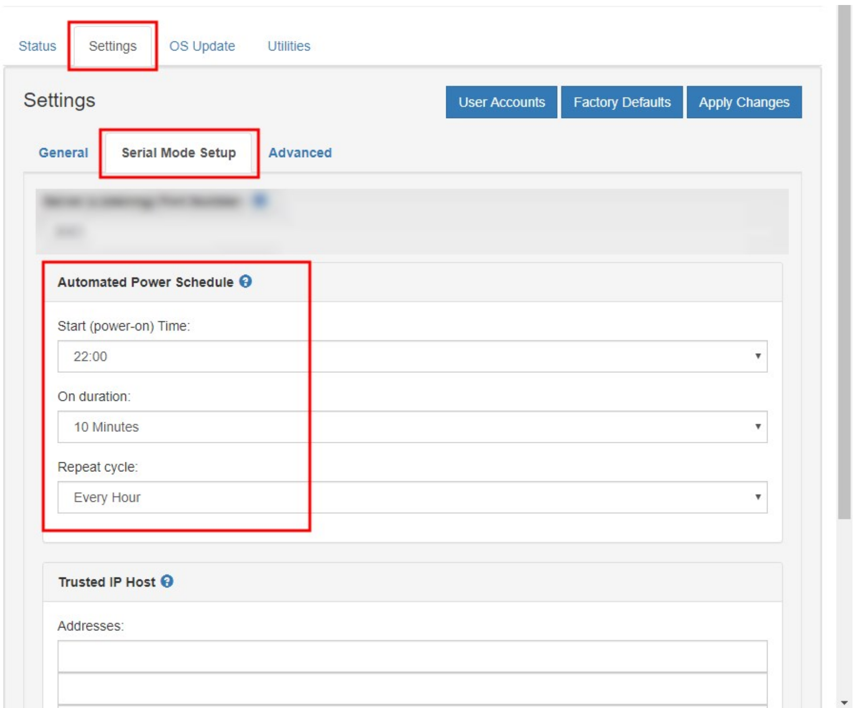
7. Select the **Serial Mode Setup** tab.



8. Enter the **URL** and **Port Number** of the server/device that the module will connect to.
9. (Optional) Select **Always Open** for the **Timeout** .

10. (Optional) In this mode, an **Automated Power Schedule** can be setup to save on battery life or on cellular charges. Go to the **Settings** then **Serial Mode Setup** tab. Enter a **Start (power-on) Time**, **On duration**, and **Repeat cycle**.

    The modem automatically turns off at midnight. It turns on at the **Start (power-on) Time** for the **On duration**. It then turns on again every **Repeat cycle** until midnight, at which point it will turn off.

    For example: With the following settings of **Start (power-on) Time** of 22:00, **On Duration** of 10 minutes, and **Repeat Cycle** of Every Hour the cellular module will turn on for ten minutes only twice each day. It will turn on at 10:00 pm and 11:00 pm. It will not turn on at midnight since it is powered off at the start of the next day.

8.4.4.2 Configure data logger (optional)

`SendVariables()` is used to initiate a data logger call-back attempt to a computer running ***LoggerNet***. It has the following syntax:

```
SendVariables (ResultCode, ComPort, NeighborAddr, PakBusAddr, Security, TimeOut,
"TableName", "FieldName", Variable, Swath )
```

The `ComPort` needs to be set to **ComRS232** or **ComSDC8** depending on how you have the module connected to the data logger. Set the `TableName` to **"Public"** and the `FieldName` to **"Callback"**. The remaining parameters in the instruction are ignored. The resulting instruction will look similar to:

```
SendVariables (SendResult, COMRS232, 0, 4094, 0000, 0, "Public", "Callback",
Scratch, 1)
```

After ***LoggerNet*** receives the variable **"Callback"** it will begin collecting data from the data logger and store it to a file based on the data collection settings in the Setup window. See the CRBasic help for more information.

8.4.4.3 Set up hardware

1. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port.
2. Connect your data logger RS-232 or CS I/O port to the CELL200-series module RS-232 or CS I/O port. Ensure the same port is used for each device, for example RS-232 to RS-232. See Wiring and connections (p. 29).
3. If not connecting through CS I/O, provide power to the CELL200 series. The data logger provides power through the CS I/O port. USB power is not sufficient to power the CELL200 series; 12 V is required.

8.4.4.4 Set up *LoggerNet*

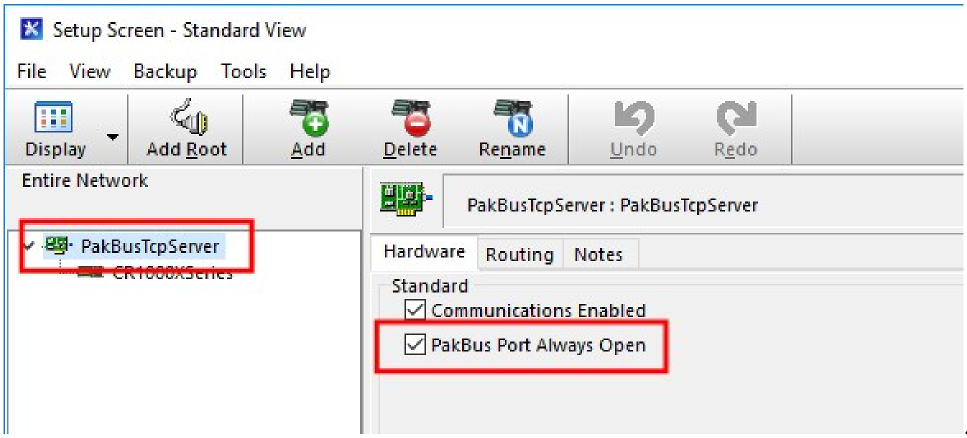
The ***LoggerNet*** Network Map is configured from the **LoggerNet Setup** screen.

> **NOTE:**
> Setup has two options, EZ (simplified) and Standard. Click on the **View** menu at the top of the **Setup** screen, and select **Standard** view.

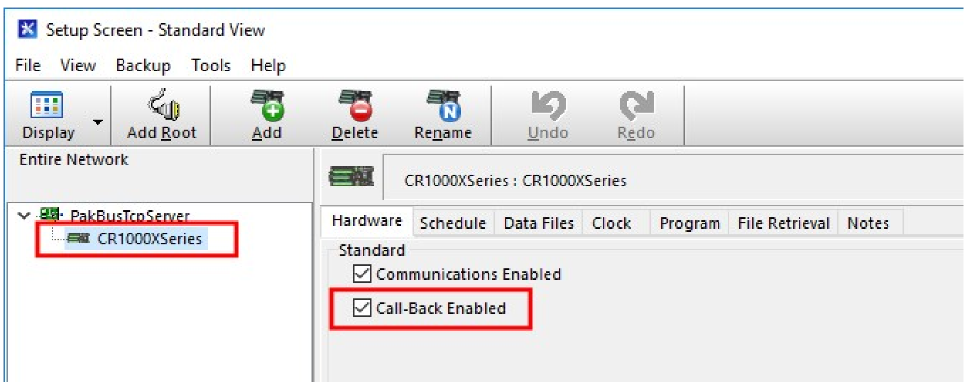
From the ***LoggerNet*** toolbar, click **Main** > **Setup** and configure the Network Map as described in the following steps:

1. Select **Add Root** > **PakBusTcpServer**.
2. Add a data logger to the **PakBusTcpServer**.

3. Select the **PakBusTcpServer** in the Network Map. **PakBus Port Always Open** should be checked.



4. Select the data logger in the Network Map. Select **Call-Back Enabled**; the box should have a check.

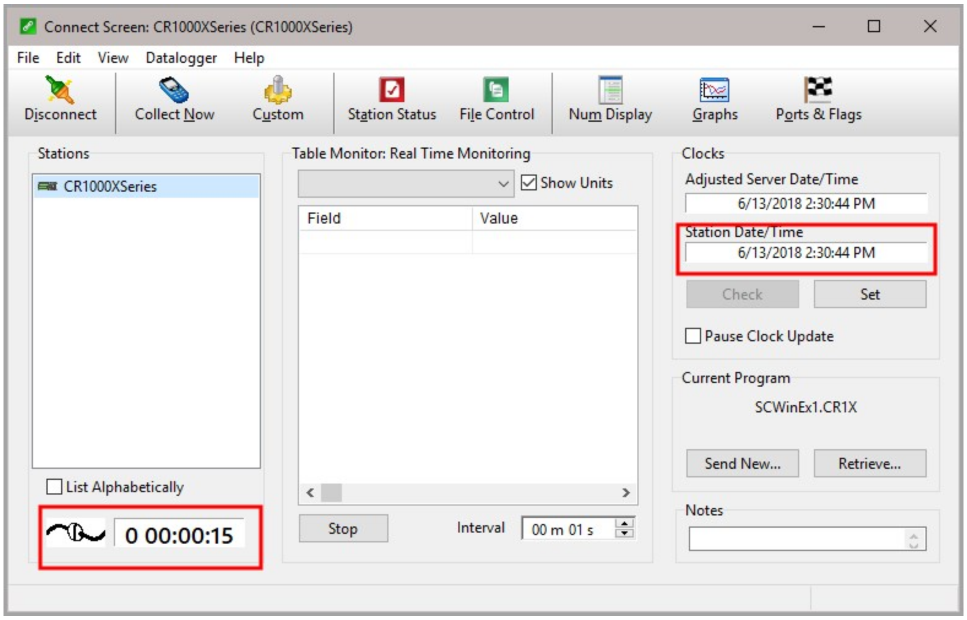


8.4.4.5 Test the connection

After the Network Map has been configured, test the cellular connection by using the **Connect** screen as shown in the following image. Click on the appropriate station and click **Connect** to initiate a call to the data logger.

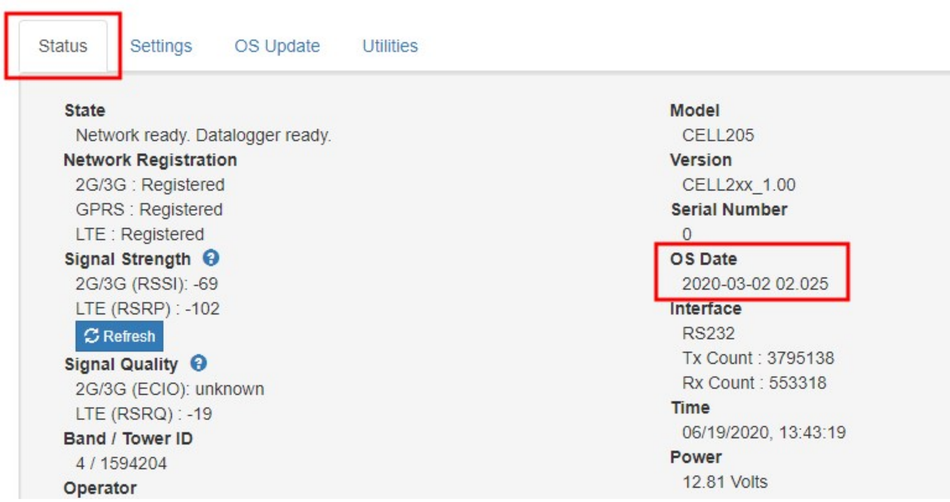
> **TIP:**
> The connection time is subject to many external factors. It is often less than 30 seconds but could be up to 15 minutes. Be patient.

If the connection is successful, the connectors icon at the bottom of the screen will come together and clock information from the data logger will be displayed in the **Station Date/Time** field. If the connection fails, a **Communications Failure** message will be displayed.



8.4.5 Serial server/client mode option

This mode requires CELL200 series operating system 2.00 or newer. Find the CELL200 series OS version in the **OS Date** field of the **Status** Tab. For more information, see Updating the operating system and firmware (p. 65).



In serial server/client mode the module connects to the cellular network and opens a listening port. When a client connects to the listening port, the CELL200 series will be in "**serial server**" mode. In serial server mode, all data on the active port (RS-232 or CS I/O) will be routed through the listening port. When no client is connected to the listening port, the CELL200 series will be in "**serial client**" mode and all data on the active port will be sent and received through the initiated TCP client socket connection.

The incoming connection, or serial server mode, takes precedence. An outbound, or client, connection will be interrupted if a connection is made on the incoming, or server, listening port.

> **NOTE:**
> Instructions in this section assume that you have established cellular service and the SIM card has been installed as described in QuickStart (integrated mode) (p. 10).

8.4.5.1 Configure CELL200 series

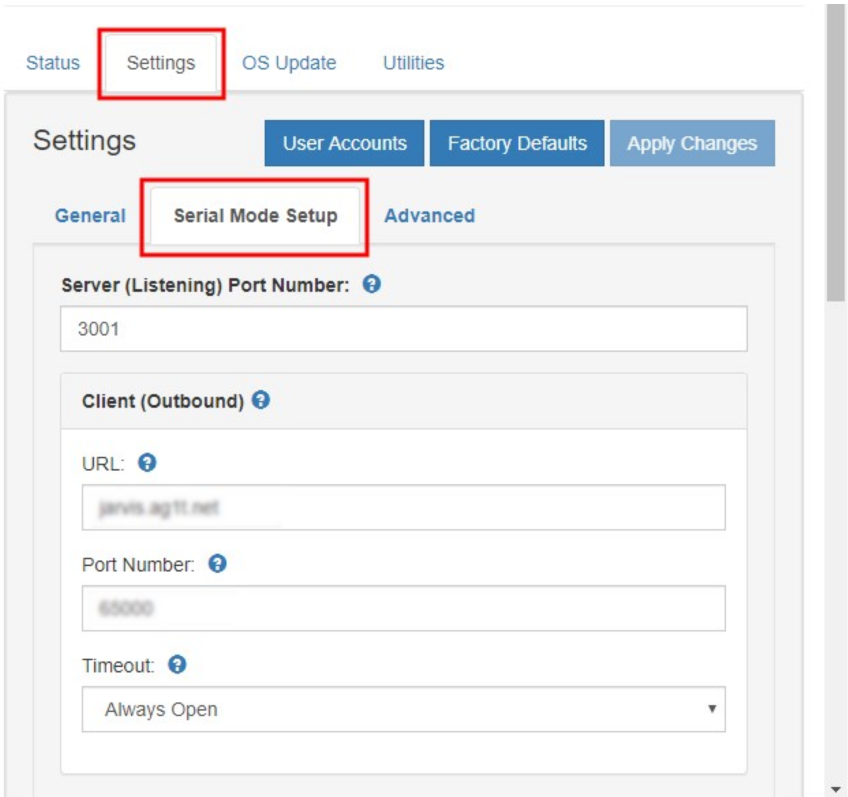
To set up the CELL200 series in serial server/client mode:

1. Connect a USB cable between your module and computer.
2. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port. See Antenna connections (p. 33).
3. Open a web browser and go to: cell.linktodevice.com.

   > **TIP:**
   > If this doesn't work browse to 192.168.86.1.

4. On the **Settings** tab, enter the **APN** provided by your cellular provider.
5. On the **General** tab, set **Mode** to **Serial Server/Client**.

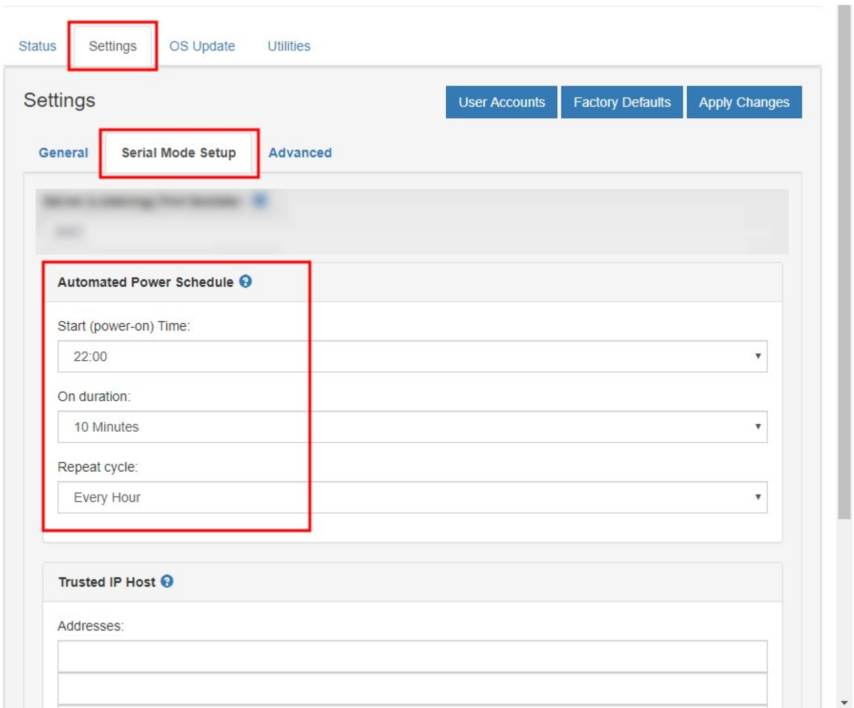
6. Select the **Serial Mode Setup** tab.



7. Set **Server (Listening) Port Number**. Default is 3001. This is entered along with the IP address as part of the ***LoggerNet*** configuration.
8. Enter the **URL** and **Port Number** that the module will connect with.
9. (Optional) Select **Always Open** for the **Timeout** .

10. (Optional) In this mode, an **Automated Power Schedule** can be setup to save on battery life or on cellular charges. Go to the **Settings** then **Serial Mode Setup** tab. Enter a **Start (power-on) Time**, **On duration**, and **Repeat cycle**.

    The modem automatically turns off at midnight. It turns on at the **Start (power-on) Time** for the **On duration**. It then turns on again every **Repeat cycle** until midnight, at which point it will turn off.

    For example: With the following settings of **Start (power-on) Time** of 22:00, **On Duration** of 10 minutes, and **Repeat Cycle** of Every Hour the cellular module will turn on for ten minutes only twice each day. It will turn on at 10:00 pm and 11:00 pm. It will not turn on at midnight since it is powered off at the start of the next day.

11. (Optional) By default, the CELL200 series will accept incoming communications from any IP address. This can be a security risk. You may specify up to four IP addresses, with wild cards, to limit connections to only those trusted sources. Use an asterisk (*) as a wild card. For example, a setting of 166.22.*.* would allow connections from devices that have IP addresses starting with 166.22. Both IPv4 and IPv6 addresses are supported.

    > **CAUTION:**
    > Only set a Trusted IP address if you are familiar with their use. Consult your IT department or Campbell Scientific for assistance.

> **NOTE:**
> This setting does not affect outbound connections, only incoming connections.

Staying on the **Settings** > **Serial Mode Setup** tab, enter your trusted IP addresses, one per line, in the **Trusted IP Host Addresses** box.

8.4.5.2 Configure data logger

1. Connect to your data logger by using ***Device Configuration Utility***.
2. On the **PPP** tab, set **Config/Port Used** to **Inactive**.
3. When using RS-232 serial server mode, it is recommended that you use a fixed baud rate on the data logger RS-232 port. On the **Com Ports Settings** tab, select the RS-232 port and set the **Baud Rate** to the fixed option to match the RS 232 baud rate set in the CELL200-series module.
4. If using CS I/O communication, the throughput can be enhanced by changing the SDC Baud Rate from 115200 to 460800. On the **Advanced** tab, set the **SDC Baud Rate** to 460800. Note that if there are other devices on the **CS I/O** port, they all must be able to support this higher baud rate.

8.4.5.3 Set up hardware

1. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port.
2. Connect your data logger RS-232 or CS I/O port to the CELL200-series module RS-232 or CS I/O port. Ensure the same port is used for each device, for example RS-232 to RS-232. See Wiring and connections (p. 29).
3. If not connecting through CS I/O, provide power to the CELL200 series. The data logger provides power through the CS I/O port. USB power is not sufficient to power the CELL200 series; 12 V is required.

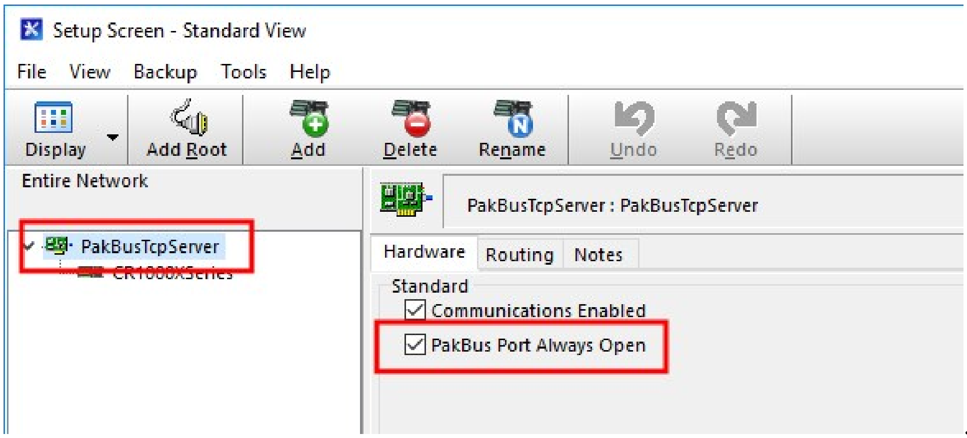
8.4.5.4 Set up *LoggerNet*

The *LoggerNet* Network Map is configured from the **LoggerNet Setup** screen.

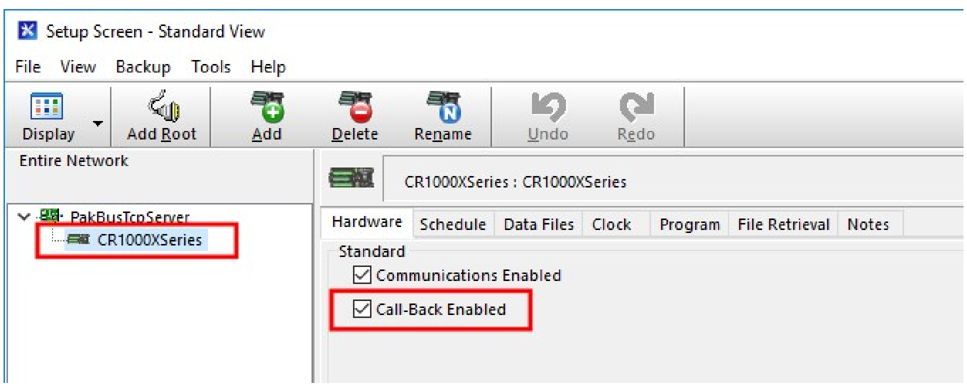
> **NOTE:**
> Setup has two options, EZ (simplified) and Standard. Click on the **View** menu at the top of the **Setup** screen, and select **Standard** view.

From the *LoggerNet* toolbar, click **Main** > **Setup** and configure the Network Map as described in the following steps:

1. Select **Add Root** > **PakBusTcpServer**.
2. Add a data logger to the **PakBusTcpServer**.
3. Select the **PakBusTcpServer** in the Network Map. **PakBus Port Always Open** should be checked.



4. Select the data logger in the Network Map. Select **Call-Back Enabled**; the box should have a check.

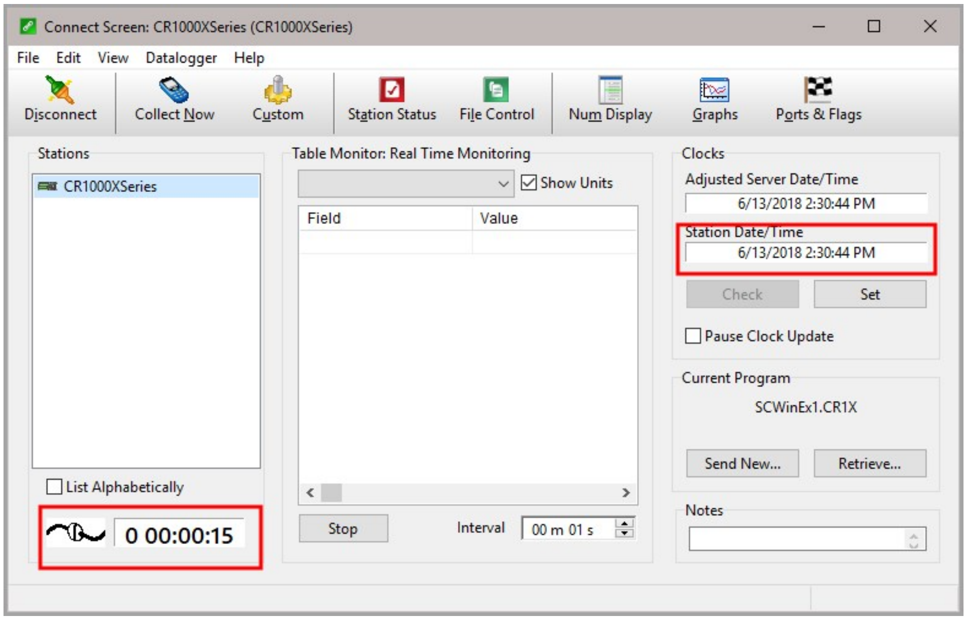


8.4.5.5 Test the connection

After the Network Map has been configured, test the cellular connection by using the **Connect** screen as shown in the following image. Click on the appropriate station and click **Connect** to initiate a call to the data logger.

TIP:
The connection time is subject to many external factors. It is often less than 30 seconds but could be up to 15 minutes. Be patient.

If the connection is successful, the connectors icon at the bottom of the screen will come together and clock information from the data logger will be displayed in the **Station Date/Time** field. If the connection fails, a **Communications Failure** message will be displayed.



9. Operation and maintenance

9.1 Ports

The **CS I/O** port is the main port used with Campbell Scientific data loggers. Its function is described throughout this manual.

The **RS-232** port can also be used with Campbell Scientific data loggers through a null modem cable (or CPI/RS-232 RJ45 to DB9 cable for the CR1000X and CR6 series).

The **USB** port is used to check the module status, configure the module, send a new operating system, or watch low-level communications. This is done by opening a web browser and using the following URL: cell.linktodevice.com.

TIP:
If your computer does not have access to a DNS server, browse to 192.168.86.1.

9.2 LED indicator lights

When your CELL200-series module is connected to power and an antenna, there is a specific pattern to the lights to indicate its operation mode as described in LED Indicator Lights (p. 60).

Table 9-1: LED Indicator Lights

	Green	Blue	Red
Network	Flashes every 8 seconds when authenticated with cellular network	Flashes with traffic to/from internal cell modem	Flashes every 8 seconds when issue with network/settings
Signal	Flashes every 8 seconds to indicate good signal strength	Flashes every 8 seconds to indicate fair signal strength	Flashes every 8 seconds to indicate marginal or no signal strength
Power/Traffic	Flashes every 8 seconds to indicate all is good in network	Flashes with traffic on RS-232 or CS I/O	Used to let user know it is in low power state (only LED flashing)

9.3 Signal strength and quality

Both signal strength and quality contribute to successful cellular data communications. The factors that influence signal strength and quality include but are not limited to:

- proximity to the cellular tower
- tower load
- competing signals
- physical barriers (mountains, buildings, vegetation)
- weather

Because signal strength and quality can vary due to many factors, they may not give a true indication of communications performance or range. However, they can be useful for activities such as:

- determining the optimal direction to aim a Yagi antenna
- determining the effects of antenna height and location
- trying alternate Yagi antenna (reflective) paths
- seeing the effect of vegetation and weather over time

9.3.1 Signal strength

Signal strength is how strong the received signal is. The closer your CELL200 series is to the cellular tower, the more signal the antenna will pick up. Signal strengths are lower the farther away from the tower the CELL200 series is.

For 3G networks, signal strength is reported as RSSI (Received Signal Strength Indicator). For 4G, it is RSRP (Reference Signal Received Power).

Signal strength units are –dBm; –70 is a stronger signal than –100.

Table 9-2: Signal strength

Strength estimate	RSSI (3G) dBm	RSRP (4G) dBm
Excellent	-70 or greater	-90 or greater
Good	-71 to -85	-91 to -105
Fair	-86 to -100	-106 to -115
Poor	less than -100	less than -115

9.3.2 Signal quality

Signal quality shows how much interference there is between the cellular tower and CELL200 series, or how noisy a band is. Cellular signal noise comes from reflections, ghosting and other interference. Better signal quality is an indicator of more successful communications during precipitation events such as rain and snow.

For 3G networks, signal quality is ECIO (Energy to Interference Ratio). For 4G, this is RSRQ (Reference Signal Received Quality).

Signal quality units are –dBm; 0 is a better signal than –10.

Table 9-3: Signal quality

Quality estimate	ECIO (3G) dBm	RSRQ (4G) dBm
Excellent	0 to -6	>-9
Good	-7 to -10	-9 to-12
Fair to poor	-11 to -20	-13 or less

Appendix A. Controlling power to the CELL200 series

This example shows how to control power to the CELL200 series by using the CRBasic `IPNetPower()` instruction. The program uses the `TimeIsBetween()` instruction to power the CELL200 series for 15 minutes every 60 minutes between 9:00 a.m. and 5:00 p.m.

Downloadable example programs are available at www.campbellsci.com/downloads/cell200-example-programs. See the `CELL2XX-Power` program.

NOTE:
The `IPNetPower()` functionality shown in this example is available in the CR300 series with operating system 08.00 or greater, the CR6 series with operating system 09.00 or greater, and the CR1000X with operating system 03.00 or greater. To control power in these data loggers with older operating systems or any CR1000, CR800 series, or CR3000, you will need to use a **SW12V** port on the data logger and communicate over RS-232. When using a **SW12V** port, we recommend using a `PPPClose()` instruction to shut down the network prior to powering down the CELL200 series.

NOTE:
`TimeIsBetween()` requires operating system version 28.00 or greater in the CR1000, CR3000, or CR800. It is supported in all CR1000X, CR6, and CR300 operating systems.

CRBasic Example 1: Turn CELL200 series ON and OFF under data logger control

```
'Declare Variables and Units
Public BattV
Public PTemp_C
Public ModuleState As Boolean

Units BattV=Volts
Units PTemp_C=Deg C

'Define Data Tables
DataTable(Daily,True,-1)
  DataInterval(0,1440,Min,10)
  Minimum(1,BattV,FP2,False,False)
EndTable
```

CRBasic Example 1: Turn CELL200 series ON and OFF under data logger control

```
'Main Program
BeginProg
  'Main Scan
  Scan(5,Sec,1,0)
    'Default Data Logger Battery Voltage measurement 'BattV'
    Battery(BattV)
    'Default Wiring Panel Temperature measurement 'PTemp_C'
    PanelTemp(PTemp_C,60)
    'Between the hours of 9:00 and 17:00, turn the CELL200 series
    'on for 15 minutes at the start of every hour
    If TimeIsBetween(9,17,24,Hr) AND TimeIsBetween(0,15,60,Min) Then
      ModuleState=True
      IPNETPower(5,1)
    Else
      ModuleState=False
      IPNETPower(5,0)
    EndIf
    'Always turn OFF CELL200 series if battery drops below 11.5 volts
    If BattV<11.5 Then
      'Set CELL200 series power to the state of 'ModuleState' variable
      IPNETPower(5,0)
    EndIf
    'Call Data Tables and Store Data
    CallTable Daily
 NextScan
EndProg
```

Appendix B. Configuring settings and retrieving status information with the CRBasic program

B.1 Using the SetSetting() instruction

NOTE:
This functionality is available in the CR1000X, CR300-series, and CR6 dataloggers only.

Downloadable example programs are available at www.campbellsci.com/downloads/cell200-example-programs. The `CELL2XX-SetSettings` example shows how to set up the cellular module using the `SetSetting()` instruction. It also illustrates how to retrieve status information from the module in the CRBasic program.

Appendix C. Updating the operating system and firmware

Campbell Scientific updates data logger and CELL200 series operating systems (OS) as new features are developed and bugs fixed. It is recommended that before deploying instruments, you check operating system versions and update them as needed. This section applies to updating the CELL200 series module operating system. Refer to your data logger manual for information on updating its OS.

The CELL200 series itself uses two operating systems. The first is the Campbell Scientific CELL200 series operating system. We will refer to that as the **CELL200 series OS**. The second is contained in the cellular radio module; we will refer to that one as the **module firmware**. One or both may need to be updated from time to time.

> **CAUTION:**
> To prevent data loss, collect all data from the data logger before proceeding to update the data logger operating system and cellular module firmware.

Updating the module firmware is done over the air (OTA), even with a direct USB connection to the data logger. Therefore, it can take from 5 minutes to several hours depending on signal strength between the cell tower and the CELL200 series, cellular network congestion, and OTA server availability. OTA updates use some of the cellular device data plan for each attempt. Care should be taken to plan accordingly to avoid cellular data plan overages.

C.1 Using the web interface (cell.linktodevice.com)

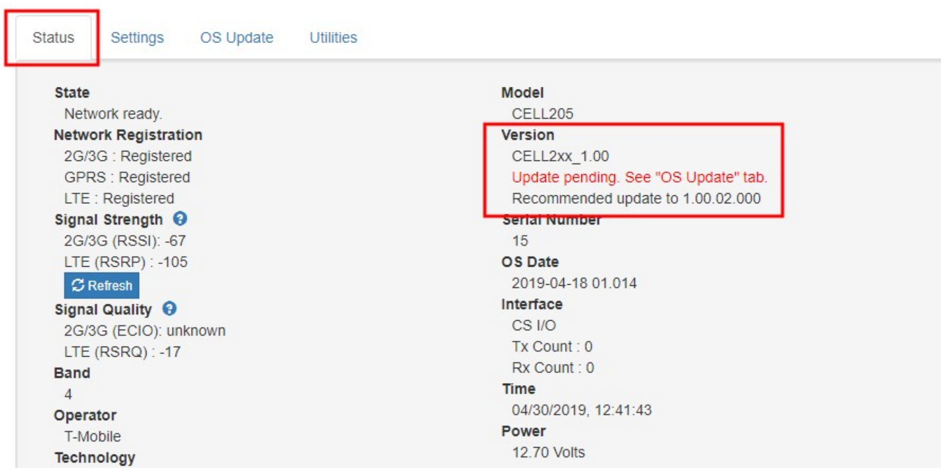
> **NOTE:**
> Instructions in this section assume that the steps in Pre-installation (p. 2) have been completed. Cellular service must be setup before web access using cell.linktodevice.com is available.

NOTE:
This section applies to modules set up in serial server mode with a public static IP account when connecting over the Internet using the cellular interface.

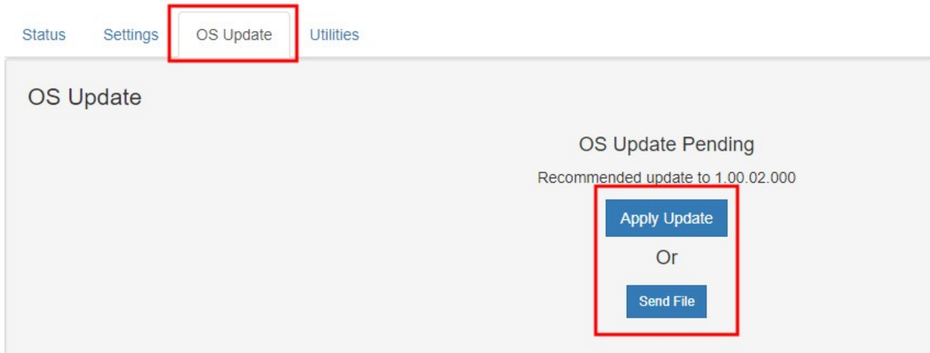
This section also applies to all modules when connecting via USB.

1. Connect the **Cellular** antenna.
2. Connect the **Diversity** antenna, if used. (Not required. See Antenna connections [p. 33].)
3. (Option 1, local connection) Connect a USB cable between your module and computer.
   a. Open a web browser and go to: cell.linktodevice.com.

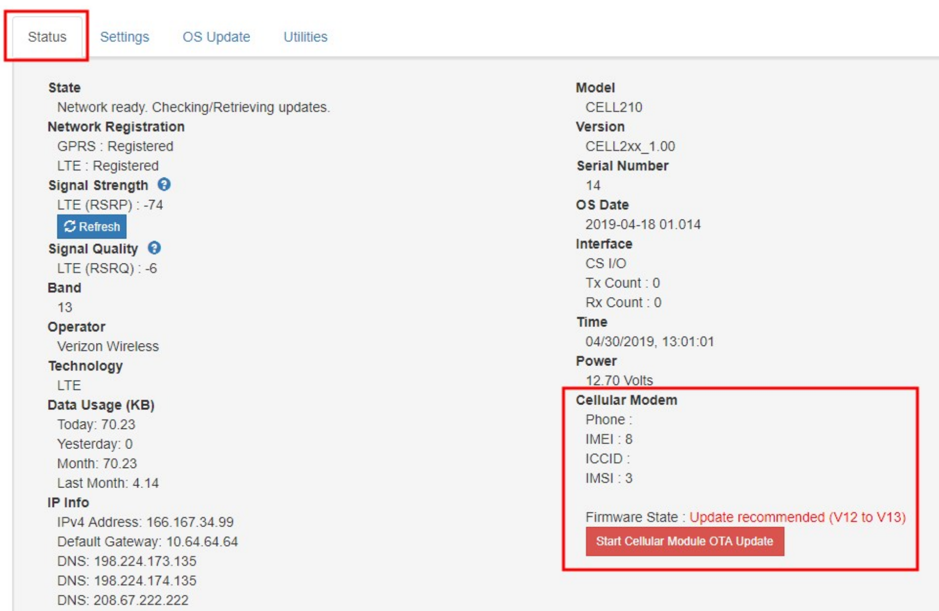
   TIP:
   If your computer does not respond to the DNS server correctly, browse to 192.168.86.1.
4. (Option 2, remote connection) No additional setup for modules connecting remotely.
   a. Open a web browser and enter the module static IP address.
5. Every 14 days, the module automatically checks for a CELL200 series OS update. When a new OS is available you will see a red notification in the **Version** field of the **Status** Tab.



6. Select the **OS Update** Tab. Clicking the **Apply Update** button will retrieve the CELL200 series OS from the Campbell Scientific website and begin the update process. If you already downloaded the OS from the Campbell Scientific website to you computer you can click the **Send File** button and follow the prompts.



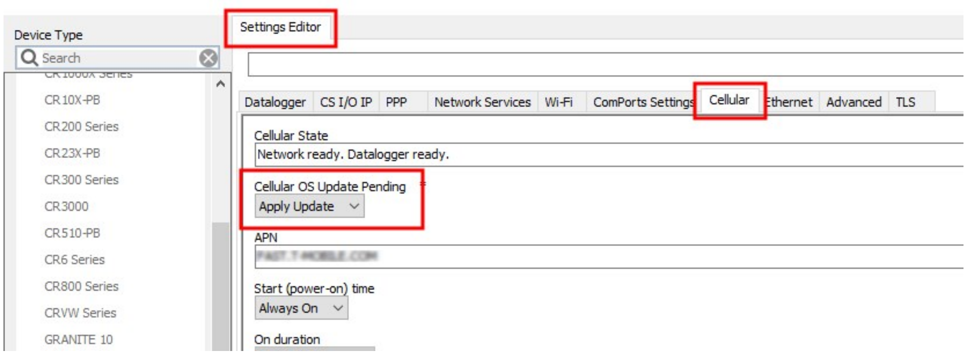
7. When new module firmware is available you will see a red notification in the **Celllar Modem** field of the **Status** Tab. To begin the update process, click the red **Start Cellular Module OTA Update** button.



C.2 Using *Device Configuration Utility*

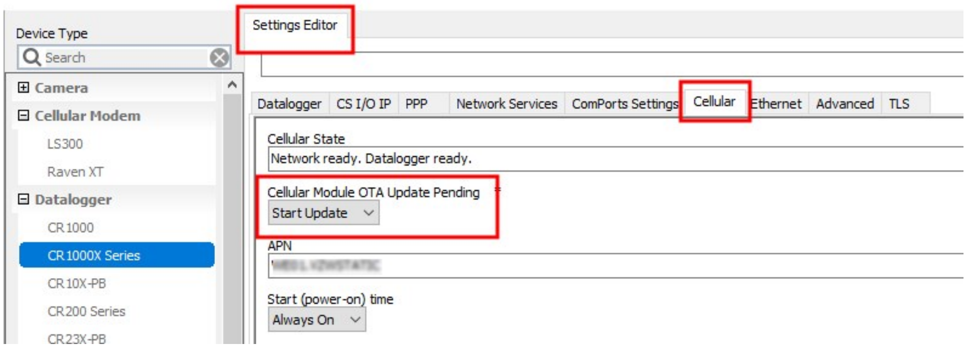
> **NOTE:**
> This section applies to modules set up in integrated PPP mode which requires data logger operating system 03.00 or later for the CR1000X, 09.00 or greater for the CR6 series, and 08.00 or later for the CR300 series.

1. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port. See Antenna connections (p. 33).
2. Connect your data logger to the CELL200-series module RS-232 or CS I/O port. See Wiring and connections (p. 29).
3. If not connecting through CS I/O, provide power to the CELL200 series.
4. Connect a USB cable between your data logger and computer.
5. Connect to your data logger by using ***Device Configuration Utility***.
6. When a new CELL200 series OS is available, in the **Settings Editor** on the **Cellular** Tab you will see a field called **Cellular OS Update Pending**. This field does not appear unless an update is available. Select **Apply Update** to begin the process, or **Ignore** to update at another time.
7. **Apply** to save your changes.



8. When new module firmware is available, in the **Settings Editor** on the **Cellular** Tab you will see a field called **Cellular Module OTA Update Pending**. This field does not appear unless an update is available. Select **Start Update** to begin the process, or **Ignore** to update at another time.

9. **Apply** to save your changes.



Appendix D. Cellular module terminal functionality

This appendix discusses the terminal functionality of the CELL200-series modules. This functionality requires a data logger with a CS I/O port.

To use the terminal functionality of the module, you must enable the terminal port. To do this:

1. Connect a USB cable between your module and computer.
2. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port. See Antenna connections (p. 33).
3. Open a web browser and go to: cell.linktodevice.com.

   > **TIP:**
   > If this doesn't work browse to 192.168.86.1.

4. On the **Settings** > **Advanced** tab, set the **Terminal Port CS I/O SDC Address**. (It must be set to a different address than the one used for the **CS I/O Port SDC Address**.)
5. Click **Apply Changes**.

Using the SetSetting() instruction (p. 64) illustrates how to use this functionality in a CRBasic program.

The functionality can also be accessed directly using the terminal emulator of the data logger in serial talk through mode. The data logger terminal emulator can be accessed by connecting to the data logger in ***Device Configuration Utility*** and selecting the **Terminal** tab. (It can also be accessed from the **Connect** screen by selecting **Datalogger | Terminal Emulator** and then clicking **Open Terminal**.) With the terminal window open, press return a few times until you receive the data logger prompt (for example, CR1000X>). Type P. Then type the number corresponding to the **Terminal Port CS I/O SDC Address** set in the CELL200-series module. You should receive a **CELL2xx>** prompt. The commands in this appendix can be used from this prompt to interact with the CELL200-series module.

help

Displays all the commands that are available in the cellular module terminal.

D.1 Using cell modem terminal functionality

> **NOTE:**
> This functionality is available in all CRBasic data loggers with a CS I/O port.

Using cell modem terminal functionality (p. 71) shows how to set up an attached CELL200-series module using the terminal functionality in the module. It also illustrates how to use the same functionality to retrieve status information from the CELL200 series and put the module into low power mode. Downloadable example programs are available at www.campbellsci.com/downloads/cell200-example-programs. See the `CELL2XX-Settings` program for details.

To use the terminal functionality of the module, you must enable the terminal port. To do this:

1. Connect a USB cable between your module and computer.
2. Connect the cellular antenna, if it is not already connected. When using a MIMO antenna with multiple cellular connections, connect the primary cable to **Cellular** and the secondary to **Diversity**. If the cables are not marked in this way, they can be connected to either antennna port. See Antenna connections (p. 33).
3. Open a web browser and go to: cell.linktodevice.com.

    > **TIP:**
    > If this doesn't work browse to 192.168.86.1.

4. On the **Settings | Advanced** tab, set the **Terminal Port CS I/O SDC Address**. (It must be set to a different address than the one used for the **CS I/O Port SDC Address**.)
5. Click **Apply Changes**.

D.2 Status commands

Status commands show current values of the information being requested. Some correspond to settings and others are tied to diagnostic information. All values returned are strings. Not all modems return all values. Values returned are also dependent on the network the device is connected to.

show acc tech	Returns the access technology of the network that the modem is connected to.
show apn	Displays the **APN** (Access Point Name) currently used by the cellular module. Corresponds with the APN setting in the cellular module web interface.
show arev	Returns the alternate or subversion revision of the CELL200 series OS.
show band	Returns the band number the modem is using to connect to the cellular network.
show bat	Returns the current modem battery voltage.
show baud	Displays the current baud rate of the cellular module RS-232 port. Corresponds with the **RS232 Baud Rate** setting in the cellular module web interface.
show billing	Displays the current value for the billing cycle day. Values can range from 1 to 31. Corresponds to the **Billing Cycle Day** field in the cellular module web interface.
show cell id	Returns the hexadecimal number of the cellular tower the modem is connected to.
show cellular errors	Returns an error information summary for troubleshooting.
show cellular Info	Returns the modem cellular information. Information returned is extensive and includes information from other terminal commands.
show cellular log	Returns a log of events for the device. Useful for troubleshooting.
show client port	Returns the port number in the modem when used in Serial Client Mode.
show client timeout	Returns the time, in seconds, used in Serial Client Mode.
show client url	Returns the cellular module Client (Outbound) URL setting (used in Serial Client Mode).
show device info	Returns the modem device information. Information returned is extensive and includes many values returned from other terminal commands.
show diagnostic report	Returns a diagnostic report that is useful for troubleshooting. Combines the output of many other terminal troubleshooting commands.

show diversity	Displays the current setting of cellular module antenna configuration. Results are **Disabled** or **Enabled**. Corresponds with the **Diversity Antenna** field in the cellular module web interface.
show ecio	Returns the modem 3G network signal quality (ECIO).
show euiccid	Returns the modem EUICCID (Embedded SIM identification) number.
show iccid	Returns the modem ICCID (SIM identification) number.
show imei	Returns the modem IMEI (International Mobile Equipment Identity) number.
show imsi	Returns the modem IMSI (International Mobile Subscriber Identity) number.
show ip info #net	Returns the modem TCP/IP information for each network. When using this command, replace #net with **1** for the PPP connection, or **2** for the Ethernet over USB (RNDIS) connection.
show ipprotocol	Displays the current value of the cellular module IP protocol configuration. Results are **IPv4**, **IPv6**, or **IPv4/IPv6**. Corresponds with the **IP Protocol** field in the cellular module web interface.
show listen port	Displays the current setting for the cellular module TCP/IP listening port (used in Serial Server mode). Values can range from 1 to 65535. Corresponds with the **Serial Server Listen Port Number** setting in the cellular module web interface.
show mod arev	Returns the alternate or sub revision of the modem radio chipset.
show mod manu	Returns the manufacturer of the modem radio chipset.
show mod model	Returns the model number of the modem radio chipset.
show mod rev	Returns the model revision of the modem radio chipset.
show mode	Displays the current operating mode of the cellular module. Results are **PPP**, **Serial Server**, **Serial Client**, or **Serial Server/Client**. Corresponds with the **Mode** setting in the cellular module web interface.
show model	Returns the model information of the modem. Returned values are **CELL205**, **CELL210**, **CELL215**, or **CELL220**, **CELL225**.
show modupdate description	Returns the description or revision history of the firmware update.

show modupdate description	Returns a description of the module firmware update for user review.
show modupdate pending	Returns information regarding the module firmware. Informs the user that an update is available.
show modupdate priority	Returns the priority of the module firmware update, whether it is required or recommended.
show modupdate progress	Returns the progress of the module firmware update.
show operator	Returns the name of the cellular provider or network operator the modem is connected to.
show osdate	Returns the build date and alternate version of the CELL200 series OS.
show osupdate description	Returns a description of the newer operating system for the user to review before installing.
show osupdate pending	Returns information indicating if a newer modem operating system is available.
show osupdate priority	Returns the priority of the operating system update.
show osupdate progress	Returns the progress of the CELL200 series OS update.
show pdp pass	Returns the modem PDP password.
show pdp user	Returns the modem PDP username.
show phone	Returns the modem phone number.
show ping	Returns the status of the cellular module ping setting.
show power duration	Returns the modem on-duration time, in minutes.
show power repeat	Returns the modem Repeat cycle setting.
show power start	Returns the modem Start (power-on) Time.
show ppp pass	Returns the modem PPP password.
show ppp user	Returns the modem PPP username.
show reg 3g	Returns information on whether or not the modem is registered on the 3G network.
show reg gprs	Returns information on whether or not the modem is registered on the GPRS network.
show reg lte	Returns information on whether or not the modem is registered on the LTE network.

show rev	Returns the revision of the CELL200 series OS.
show roaming	Displays the current setting for the modem roaming capabilities. Returned values are **Auto** and **Disabled**. Corresponds to the **Roaming** setting in the cellular module web interface
show rsrp	Returns the modem LTE network signal strength (RSRP).
show rsrq	Returns the modem LTE network signal quality (RSRQ).
show rssi	Returns the modem 3G signal strength information (RSSI).
show sdc	Displays the current setting for the modem SDC address. Values are **7**, **8**, **10**, or **11**. This value corresponds with the **CS I/O Port SDC Address** setting in the cellular module web interface.
show sdc term	Returns the current value for the SDC terminal interface in the modem. Returned values are **7**, **8**, **10**, and **11**. Corresponds to the **Terminal Port CS I/O SDC Address** setting in the cellular module web interface
show serial	Returns the serial number of the modem.
show settings	Returns all the settings of the cellular modem.
show sms log	Returns a log of SMS messaging logs.
show smssca	Returns the modem SMSSCA (SMS Service Center Address) number.
show sms rx	Returns the SMS receive queue.
show sms send (id)	Returns the status of an SMS message. The message ID is contained in the results of the **sms send** command. Result codes are the same as those returned by `SMSSend()`. A result code of `-1` means the message was successfully sent to the network. See the CRBasic help for more information.
show sms tx	Returns the SMS transmit queue.

show state	Returns the modem state in English. Values returned could include (but not limited to) "Power off.", "Powering up.", "Powered up.", "SIM authorized.", "Setting baud rate.", "Waiting for baud rate.", "Baud rate set.", "Baud rate failure.", "Power off. Waiting for retry.", "Powered up. SIM auth failure.", "Querying modem.", "Waiting for network registration.", "Configuring modem.", "Dialing.", "Dialing (retry).", "Dialed.", "PPP negotiation.", "Network ready.", "PPP closing.", "PPP paused.", "PPP dropped.", "Terminal AT command mode.", "Firmware update mode.", “Shutting down.”
show state num	Returns the state number associated with show state values.
show time	Returns the modem current time. Time returned by the modem is set by the cellular network.
show trusted 1	Returns the address or DNS Name in the 1st field of the cellular module Trusted IP Host setting.
show trusted 2	Returns the address or DNS Name in the 2nd field of the cellular module Trusted IP Host setting.
show trusted 3	Returns the address or DNS Name in the 3rd field of the cellular module Trusted IP Host setting.
show trusted 4	Returns the address or DNS Name in the 4th field of the cellular module Trusted IP Host setting.
show update check	Returns information concerning the last update check.
show update results	Returns the results of a modem operating system update.
show usage lastmonth	Returns the number of bytes used across the cellular network in the previous month.
show usage month	Returns the number of bytes used across the cellular network in the current month.
show usage today	Returns the number of bytes used across the cellular network since midnight.
show usage yesterday	Returns the number of bytes used across the cellular network during the previous day.

D.3 Set commands

Set commands are used to set specific settings in the device. Most settings will not take effect until the module is rebooted.

set apn ###	Sets the APN (Access Point Name) in the device. Corresponds to the **APN** setting in the modem web configuration interface. ### is a string the corresponds to the APN issued by the cellular provider when the cellular account was created.
set baud ###	Sets the modem baud rate for the RS-232 port. ### is a number corresponding to the desired baud rate. Accepted values are **460800**, **230400**, **115200**, **76800**, **57600**, **38400**, **19200**, **14400**, **9600**, **4800**, and **2400**.
set billing ###	Sets the billing day that will be used to roll over the data usage statistics in the modem. ### is a number. Accepted values are **1** through **31**.
set client port ###	Sets the client port number used in serial client and serial client/server modes. ### is a number. The accepted range is **1** through **65535**.
set client timeout ###	Sets the timeout, in seconds, used by serial client and serial client/server modes. ### is a number. The accepted range is **1** through **120**.
set client url ###	Sets the client URL or TCP/IP address used in serial client and serial client/server modes. ### is a string.
set comms watch	This command is interactive and allows the user to watch or do a trace on a specific modem interface. The user selects a number corresponding with the interface they wish to view.
set div ###	Sets the modem antenna configuration. ### is a string. **Disabled** and **Enabled** are the only two values that are accepted.
set ipprotocol ###	Sets the TCP/IP protocol used by the modem when communicating with the cellular network. ### is a string. Accepted values are **IPv4**, **IPv6**, and **IPv4/IPv6**.
set listen port ###	Sets the listening TCP/IP port of the modem for use in serial server and serial client/server modes. ### is a number. The accepted range is 1 through 65535.
set mode ###	Sets the modem operating mode. ### is a string. Accepted values are **PPP** and **Serial Server**.
set pdp pass ###	Sets the PDP password. ### is a string.
set pdp user ###	Sets the PDP username. ### is a string.

set power duration ###	Sets the on duration, in minutes. ### is a number. Accepted values are: **5**, **10**, **15**, **20**, **25**, **30**, **35**, **40**, **45**, **50**, **60**, **120**, **180**, **240**, **300**, **360**, **420**, **480**, **540**, **600**, **660**, **720**, **780**, **840**, **900**, **960**, **1020**, **1080**, **1140**, **1200**, **1260**, **1320**, **1380**, and **1439**.
set power repeat ###	Sets the modem repeat cycle. ### is a number. Accepted values are: **1441**, **15**, **20**, **30**, **40**, **50**, **60**, **120**, **180**, **240**, **300**, **360**, **420**, **480**, **540**, **600**, **660**, and **720**. A value of **1441** or greater will disable the repeat cycle.
set power start ###	Sets the modem Start (power-on) Time, in minutes. ### is a number. Only 15 min increments are accepted (**0**, **15**, **30** to **1440**). A value of **1440** will set the modem to “Always On”.
set ppp pass ###	Sets the PPP protocol password. ### is a string.
set ppp user ###	Sets the PPP protocol username. ### is a string.
set roaming ###	Sets the roaming capabilities of the cellular modem. ### is a string. Accepted values are **Auto** and **Disabled**.
set sdc ###	Sets the modem SDC address for the CS I/O port. ### is a number. Accepted values are **7**, **8**, **10**, and **11**.
set trusted 1 ###	Sets the address or DNS Names in the 1st Trusted IP Host field. ### is a string.
set trusted 2 ###	Sets the address or DNS Names in the 2nd Trusted IP Host field. ### is a string.
set trusted 3 ###	Sets the address or DNS Names in the 3rd Trusted IP Host field. ### is a string.
set trusted 4 ###	Sets the address or DNS Names in the 4th Trusted IP Host field. ### is a string.
set ping ###	Enables or disables ping in the modem. ### is a string. **Disabled** and **Enabled** are the only two values that are accepted.

D.4 Action commands

Action commands are used to perform actions on the modem such as entering low power mode, rebooting, checking for updates, clearing usage, and more.

check update	Starts the process that checks for both a new CELL200-series operating system, and module firmware.
clear logs	Resets all the logs in the modem.
clear usage	Resets the usage counts in the modem.
deep sleep	Puts the modem into low power mode. Modem will not respond across the cellular network.
ping ###	Used to ping a specific TCP/IP address or DNS name via the terminal. ### is a string. For example: ping 8.8.8.8 or ping jarvis.ag1t.net.
reboot	Forces the modem to reboot.
refresh network	Forces the modem to refresh its connection to the cellular network. Useful for when the network goes stale (long periods of inactivity).
reset module	Resets the cellular chipset only.
sms receive	Receives an SMS message. Example: sms receive 03/14/21 00:57:57 5557654321 Hi, SMS test
sms send *phone number message*	Sends an SMS message to a phone number. Result includes a message ID. Example: sms send 5551234567 Hi, SMS test SMS queued. ID:65536
start modupdate	Starts the over-the-air module firmware update.
start osupdate	Starts the over the air (OTA) CELL200-series operating system update process. Not for use with a direct connection.
wakeup	Brings the modem fully back online. Usually done on a schedule after a deep sleep command has been issued.

Appendix E. Verizon Wireless and AT&T

NOTE:
Campbell Scientific can provide Verizon Wireless or AT&T service. This is the simplest way to set up your module on the Verizon Wireless or AT&T network. See Campbell Scientific cellular data service (p. 3).

E.1 Verizon Wireless

What you need:

- Verizon Wireless 4G LTE CAT-1 coverage at the data logger site. For a coverage map, refer to: www.verizonwireless.com/landingpages/better-matters/#maps
- Verizon Wireless 4G LTE private dynamic IP account in conjunction with Campbell Scientific Konect PakBus Router Service. (A Verizon Wireless 4G LTE static unrestricted IP account can also be used. However, Verizon generally requires new users to have 50 lines of service to obtain the static unrestricted IP account. Also, there is generally a $500 one-time-per-customer charge to activate static IP on the account.)

To set up an account, you will need the IMEI number of the module. The IMEI number is listed on a label on the module. To set up an account with Verizon Wireless, call:

800-526-3178 for Business Sales
800-256-4646 for Personal Sales

Verizon Wireless will provide a SIM (Subscriber Identity Module) card for each module. The Micro-SIM (3FF) (6 position / contacts) card must be installed inside of the module as described in Install the SIM card (p. 4). In addition to the SIM card, you should receive:

- 10-digit MSISDN number (telephone number associated with the SIM, used for billing)
- An APN (Access Point Name) for 4G LTE CAT-1 service. A common APN used for this application is: VZWINTERNET. The user must program the APN into the module.
- For static IP accounts only, an IP Address will be included.

E.2 AT&T

What you need:

- AT&T 4G LTE CAT-1 coverage at the data logger site. For a coverage map refer to: www.att.com/maps/wireless-coverage.html.
- AT&T 4G LTE private dynamic IP account in conjunction with Campbell Scientific's Konect Router Service. (An AT&T 4G LTE static unrestricted IP account can also be used. However, AT&T charges $3/month/device for the static IP account.)

To set up an AT&T account, contact your AT&T Business Account Representative or Blu-Telecommunications.

Blu-Telecommunications is part of the Alliance Channel with AT&T and can assist any customer nationwide. Blu-Telecommunications will contact AT&T and work with an AT&T account manager to set up an account.

Contact information for Blu-Telecommunication:

Website: www.blu-tel.com
Phone number: (877) 422-2616, or Email box: i2gold@blu-tel.com
What to ask for: M2M Setup
Who to ask for: Carlos Morales or Andy Tran

An APN (Access Point Name) must be added onto the account to make the module accessible through the Internet. For networks with fewer than 30 modules, the standard 'I2Gold APN' can be used; networks with more than 30 modules will require a 'Custom APN'. A Custom APN has a setup fee starting at $500 and takes a minimum of 7 to 14 business days to complete. The user must program the APN into the module.

AT&T will provide a Subscriber Identity Module (SIM) card for each module. The Micro-SIM (3FF) (6 position / contacts) card must be installed inside of the module as described in Install the SIM card (p. 4). In addition to the SIM card, you should receive:

- 10-digit MSISDN number (telephone number associated with the SIM, used for billing)
- An APN (Access Point Name) for 4G LTE CAT-1 service. A common APN used for this application is: BROADBAND. The user must program the APN into the module.
- For static IP accounts only, an IP Address will be included.

Appendix F. Cellular module regulatory information

F.1 Important information for North American users

> **NOTE:**
> This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference, in which case the user will be required to correct the interference at his own expense.

> **WARNING:**
> Changes or modifications to this device not expressly approved by Campbell Scientific could void the user’s authority to operate this equipment.

F.2 RF exposure

In accordance with FCC/IC requirements of human exposure to radio frequency fields, the radiating element shall be installed such that a minimum separation distance of 20 cm should be maintained from the antenna and the user’s body.

> **WARNING:**
> This product is only to be installed by qualified personnel.

To comply with FCC/IC regulations limiting both maximum RF output power and human exposure to RF radiation, the maximum antenna gain must not exceed the specifications listed in the following tables for the device used.

Device	Frequency Band	FCC ID XMR201606EC21A
CELL205	WCDMA Band 2	9.5 dBi
	WCDMA Band 4	6.5 dBi
	WCDMA Band 5	14.9 dBi
	LTE Band 2	9.0 dBi
	LTE Band 4	6.0 dBi
	LTE Band 12	10.7 dBi
CELL210	LTE Band 4	6.5 dBi
	LTE Band 13	10.6 dBi

F.3 EU

Campbell Scientific hereby declares the CELL200-series devices are in compliance with the essential requirements and other relevant provisions of Directive 2014/53/EU" (RED Directive).

The CELL215 displays the CE mark.

CE

WARNING:
Changes or modifications to this device not expressly approved by Campbell Scientific could void the user's authority to operate this equipment.

WARNING:
This product is only to be installed by qualified personnel.

The Declaration of Conformity made under Directive 2014/53/EU" (RED Directive) is available for viewing at: www.campbellsci.com/cell215.

F.4 UK

Campbell Scientific hereby declares the CELL200-series devices are in compliance with the essential requirements and other relevant provisions of Regulation 2017 No. 1206 (The Radio Equipment Regulations 2017).

UK
CA

WARNING:
Changes or modifications to this device not expressly approved by Campbell Scientific could void the user's authority to operate this equipment.

WARNING:
This product is only to be installed by qualified personnel.

The Declaration of Conformity made under Regulation 2017 No. 1206 is available for viewing at: www.campbellsci.com/cell215.

Limited warranty

Products manufactured by Campbell Scientific are warranted by Campbell Scientific to be free from defects in materials and workmanship under normal use and service for twelve months from the date of shipment unless otherwise specified on the corresponding product webpage. See Product Details on the Ordering Information pages at www.campbellsci.com. Other manufacturer's products, that are resold by Campbell Scientific, are warranted only to the limits extended by the original manufacturer.

Refer to www.campbellsci.com/terms#warranty for more information.

CAMPBELL SCIENTIFIC EXPRESSLY DISCLAIMS AND EXCLUDES ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. Campbell Scientific hereby disclaims, to the fullest extent allowed by applicable law, any and all warranties and conditions with respect to the Products, whether express, implied or statutory, other than those expressly provided herein.

Assistance

Products may not be returned without prior authorization.

Products shipped to Campbell Scientific require a Returned Materials Authorization (RMA) or Repair Reference number and must be clean and uncontaminated by harmful substances, such as hazardous materials, chemicals, insects, and pests. Please complete the required forms prior to shipping equipment.

Campbell Scientific regional offices handle repairs for customers within their territories. Please see the back page for the Global Sales and Support Network or visit www.campbellsci.com/contact to determine which Campbell Scientific office serves your country.

To obtain a Returned Materials Authorization or Repair Reference number, contact your CAMPBELL SCIENTIFIC regional office. Please write the issued number clearly on the outside of the shipping container and ship as directed.

For all returns, the customer must provide a “Statement of Product Cleanliness and Decontamination” or “Declaration of Hazardous Material and Decontamination” form and comply with the requirements specified in it. The form is available from your CAMPBELL SCIENTIFIC regional office. Campbell Scientific is unable to process any returns until we receive this statement. If the statement is not received within three days of product receipt or is incomplete, the product will be returned to the customer at the customer’s expense. Campbell Scientific reserves the right to refuse service on products that were exposed to contaminants that may cause health or safety concerns for our employees.

Safety

DANGER — MANY HAZARDS ARE ASSOCIATED WITH INSTALLING, USING, MAINTAINING, AND WORKING ON OR AROUND **TRIPODS, TOWERS, AND ANY ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.** FAILURE TO PROPERLY AND COMPLETELY ASSEMBLE, INSTALL, OPERATE, USE, AND MAINTAIN TRIPODS, TOWERS, AND ATTACHMENTS, AND FAILURE TO HEED WARNINGS, INCREASES THE RISK OF DEATH, ACCIDENT, SERIOUS INJURY, PROPERTY DAMAGE, AND PRODUCT FAILURE. TAKE ALL REASONABLE PRECAUTIONS TO AVOID THESE HAZARDS. CHECK WITH YOUR ORGANIZATION'S SAFETY COORDINATOR (OR POLICY) FOR PROCEDURES AND REQUIRED PROTECTIVE EQUIPMENT PRIOR TO PERFORMING ANY WORK.

Use tripods, towers, and attachments to tripods and towers only for purposes for which they are designed. Do not exceed design limits. Be familiar and comply with all instructions provided in product manuals. Manuals are available at www.campbellsci.com. You are responsible for conformance with governing codes and regulations, including safety regulations, and the integrity and location of structures or land to which towers, tripods, and any attachments are attached. Installation sites should be evaluated and approved by a qualified engineer. If questions or concerns arise regarding installation, use, or maintenance of tripods, towers, attachments, or electrical connections, consult with a licensed and qualified engineer or electrician.

General

- Protect from over-voltage.
- Protect electrical equipment from water.
- Protect from electrostatic discharge (ESD).
- Protect from lightning.
- Prior to performing site or installation work, obtain required approvals and permits. Comply with all governing structure-height regulations.
- Use only qualified personnel for installation, use, and maintenance of tripods and towers, and any attachments to tripods and towers. The use of licensed and qualified contractors is highly recommended.
- Read all applicable instructions carefully and understand procedures thoroughly before beginning work.
- Wear a **hardhat** and **eye protection**, and take **other appropriate safety precautions** while working on or around tripods and towers.
- **Do not climb** tripods or towers at any time, and prohibit climbing by other persons. Take reasonable precautions to secure tripod and tower sites from trespassers.
- Use only manufacturer recommended parts, materials, and tools.

Utility and Electrical

- **You can be killed** or sustain serious bodily injury if the tripod, tower, or attachments you are installing, constructing, using, or maintaining, or a tool, stake, or anchor, come in **contact with overhead or underground utility lines**.
- Maintain a distance of at least one-and-one-half times structure height, 6 meters (20 feet), or the distance required by applicable law, **whichever is greater**, between overhead utility lines and the structure (tripod, tower, attachments, or tools).
- Prior to performing site or installation work, inform all utility companies and have all underground utilities marked.
- Comply with all electrical codes. Electrical equipment and related grounding devices should be installed by a licensed and qualified electrician.
- Only use power sources approved for use in the country of installation to power Campbell Scientific devices.

Elevated Work and Weather

- Exercise extreme caution when performing elevated work.
- Use appropriate equipment and safety practices.
- During installation and maintenance, keep tower and tripod sites clear of un-trained or non-essential personnel. Take precautions to prevent elevated tools and objects from dropping.
- Do not perform any work in inclement weather, including wind, rain, snow, lightning, etc.

Maintenance

- Periodically (at least yearly) check for wear and damage, including corrosion, stress cracks, frayed cables, loose cable clamps, cable tightness, etc. and take necessary corrective actions.
- Periodically (at least yearly) check electrical ground connections.

Internal Battery

- Be aware of fire, explosion, and severe-burn hazards.
- Misuse or improper installation of the internal lithium battery can cause severe injury.
- Do not recharge, disassemble, heat above 100 °C (212 °F), solder directly to the cell, incinerate, or expose contents to water. Dispose of spent batteries properly.

WHILE EVERY ATTEMPT IS MADE TO EMBODY THE HIGHEST DEGREE OF SAFETY IN ALL CAMPBELL SCIENTIFIC PRODUCTS, THE CUSTOMER ASSUMES ALL RISK FROM ANY INJURY RESULTING FROM IMPROPER INSTALLATION, USE, OR MAINTENANCE OF TRIPODS, TOWERS, OR ATTACHMENTS TO TRIPODS AND TOWERS SUCH AS SENSORS, CROSSARMS, ENCLOSURES, ANTENNAS, ETC.

CAMPBELL SCIENTIFIC

WHEN MEASUREMENTS MATTER

Global Sales & Support Network

A worldwide network to help meet your needs

Campbell Scientific Regional Offices

Australia

Location: Garbutt, QLD Australia
Phone: 61.7.4401.7700
Email: info@campbellsci.com.au
Website: www.campbellsci.com.au

Brazil

Location: São Paulo, SP Brazil
Phone: 11.3732.3399
Email: vendas@campbellsci.com.br
Website: www.campbellsci.com.br

Canada

Location: Edmonton, AB Canada
Phone: 780.454.2505
Email: dataloggers@campbellsci.ca
Website: www.campbellsci.ca

China

Location: Beijing, P. R. China
Phone: 86.10.6561.0080
Email: info@campbellsci.com.cn
Website: www.campbellsci.com.cn

Costa Rica

Location: San Pedro, Costa Rica
Phone: 506.2280.1564
Email: info@campbellsci.cc
Website: www.campbellsci.cc

France

Location: Vincennes, France
Phone: 0033.0.1.56.45.15.20
Email: info@campbellsci.fr
Website: www.campbellsci.fr

Germany

Location: Bremen, Germany
Phone: 49.0.421.460974.0
Email: info@campbellsci.de
Website: www.campbellsci.de

India

Location: New Delhi, DL India
Phone: 91.11.46500481.482
Email: info@campbellsci.in
Website: www.campbellsci.in

South Africa

Location: Stellenbosch, South Africa
Phone: 27.21.8809960
Email: sales@campbellsci.co.za
Website: www.campbellsci.co.za

Spain

Location: Barcelona, Spain
Phone: 34.93.2323938
Email: info@campbellsci.es
Website: www.campbellsci.es

Thailand

Location: Bangkok, Thailand
Phone: 66.2.719.3399
Email: info@campbellsci.asia
Website: www.campbellsci.asia

UK

Location: Shepshed, Loughborough, UK
Phone: 44.0.1509.601141
Email: sales@campbellsci.co.uk
Website: www.campbellsci.co.uk

USA

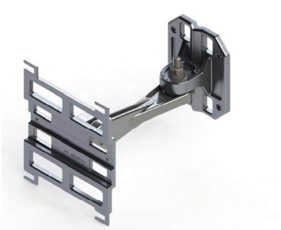
Location: Logan, UT USA
Phone: 435.227.9120
Email: info@campbellsci.com
Website: www.campbellsci.com

PAS69278P

698-960 MHz/1710-2700 MHz 2- Port MIMO Pole Mount Low-PIM Directional Panel Antenna

Patent Pending PAS69278P

Close-up of connector & bracket system



Optional mounting kit
Part Number: HKIT-PAx-001

MUTI-BAND LOW-PIM DIRECTIONAL PANEL ANTENNA

The Patent Pending PAS69278P antenna is a wide-band dual-port panel antenna with slant 45 polarization that covers the domestic LTE700/Cellular/PCS/AWS/MDS and global GSM900/GSM1800/UMTS/LTE2600 bands. The antenna is ideal for both indoor and outdoor applications. It includes a UV-stable radome enclosure that provides years of use without degradation to either the mechanical properties or aesthetics.

FEATURES

RoHS

- Applicable for 3G/4G, domestic LTE 700 band, Global LTE 2600 band, WiMax 2300/2500 band, domestic cellular and global GSM solutions
- Weatherproof UV stable radome
- Low Passive Intermodulation
- Conformance to RoHS

APPLICATIONS

- In-building Wireless Networks
- 802.11b/g/n
- iDAS/oDAS
- Wireless Terminal, Point-of-Sale, Machine-to-Machine
- Automatic meter reading and home security

SPECIFICATIONS

PARAMETERS								
Frequency Bands, MHz	**700**	**850**	**900**	**1800**	**1900**	**2100**	**2300**	**2600**
Peak Gain, dBi (Typ)	8.7	9.0	9.8	7.5	8.5	8.4	9.5	9.7
Peak Gain, dBi (Max)	9.1	9.7	10.4	8.5	9.1	9.1	10.1	10.0
PAS69278P-91NF Additional Loss, dB	0.5	0.6	0.6	0.9	0.9	1.0	1.1	1.1
VSWR (Typ)	<2.0:1	<1.9:1	<1.7:1	<1.6:1	<1.5:1	<1.5:1	<1.6:1	<1.8:1
Isolation, dB (Typ)	<-38	<-40	<-40	<-30	<-30	<-30	<-30	<-30
3 dB Beamwidth, Vertical Plane	66° to 70°	61° to 65°	56° to 60°	57° to 84°	46° to 62°	46° to 72°	57° to 66°	48° to 55°
3 dB Beamwidth, Horizontal Plane	65° to 74°	59° to 65°	57° to 60°	56° to 85°	52° to 64°	52° to 82°	58° to 63°	48° to 54°
PIM, 3rd Order, 2 x 20W (Typ)	< -151 dBc			< -153 dBc				
CPR at Boresight (Typ)	25 dB			23 dB				
CPR at Boresight (Min)	25 dB			17 dB				
F/B Ration, Co-pol	21 dB							
Isolation, (Min)	-28 dB							
PIM, 3rd Order, 2 x 20W (Max)	< -150 dBc							
Maximum VSWR	2.0:1							
Nominal Impedance	50 Ω							
Max Input Power per port	50 Watts							
Polarization	Slant ± 45°							
RF Connector	Dual Type N female							
Radome & Base color	White, color code (SABIC) WH9B034							
Flammability Rating (Radome)	UL 94V0 Materials							
Dimensions (width x length x height)	295 x 295 x 82 mm (11.6" x 11.6" x 3.2")							
Weight	1.46 kg (3.2 lbs)							
Storage Temperature	-40°C to 85°C (-40° F to 185° F)							
Operational Temperature	-30°C to 70°C (-22°F to 158°F)							
Environmental Conditions	ETSI EN300 019-2-4, class 4.1E.							
Wind Rating	150 km/hr (93 mph)							
Ingress Protection	PAS69278P-FNF model only for outdoor IP55							
Material Substance Compliance	RoHS Compliant							

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PAS69278P

698-960 MHz/1710-2700 MHz 2- Port MIMO Pole Mount Low-PIM Directional Panel Antenna

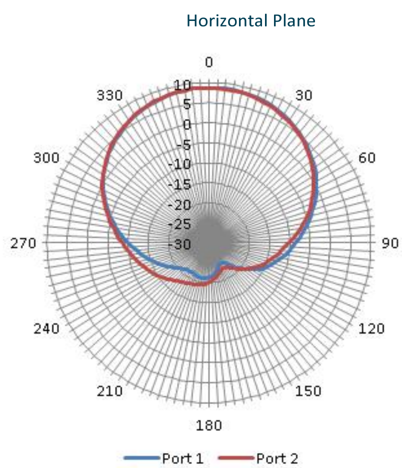
Smart Technology. Delivered.

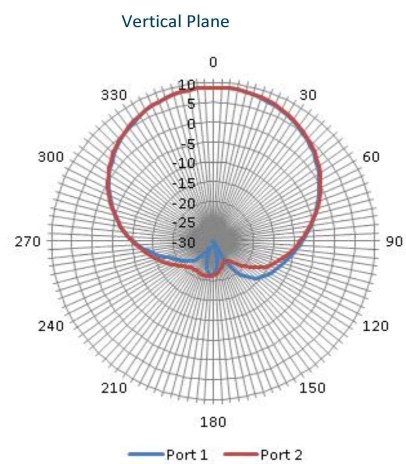
SPECIFICATIONS

MODEL NUMBER	CABLE LENGTH	CONNECTOR
PAS69278P-FNF	NA (Direct Connect)	Dual Type N Female
PAS69278P-91NF	91 cm, (36"), cable	Dual Type N Female
PAS69278P-30D41F	30 cm, (12”), cable	Dual Type 4.1-9.5 Female
PAS69278P-30D43F	30 cm, (12”), cable	Dual Type 4.3-10 Female

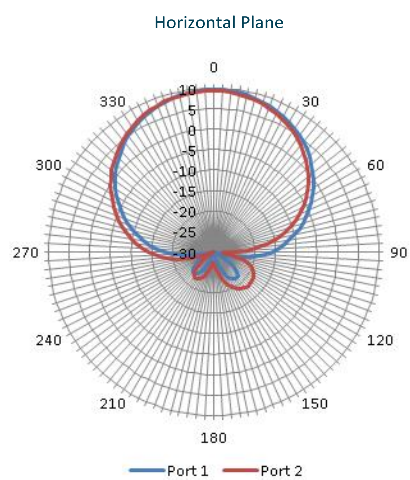
ANTENNA PATTERNS

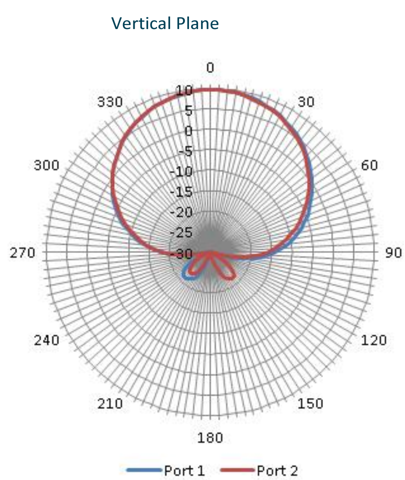
698 MHz





880 MHz





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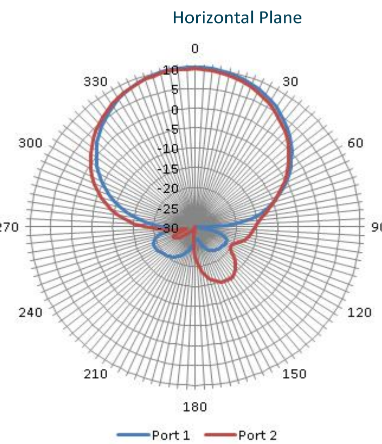
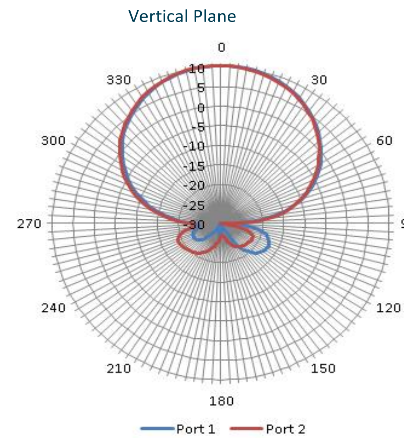
PAS69278P

698-960 MHz/1710-2700 MHz 2- Port MIMO Pole Mount Low-PIM Directional Panel Antenna

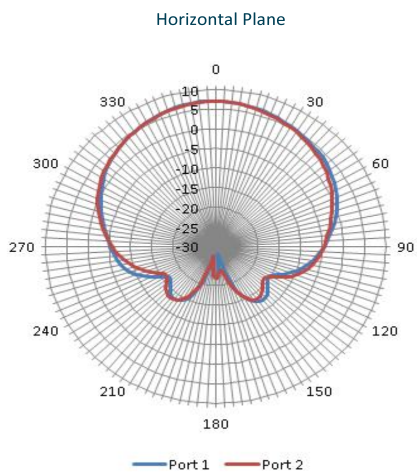
ANTENNA PATTERNS

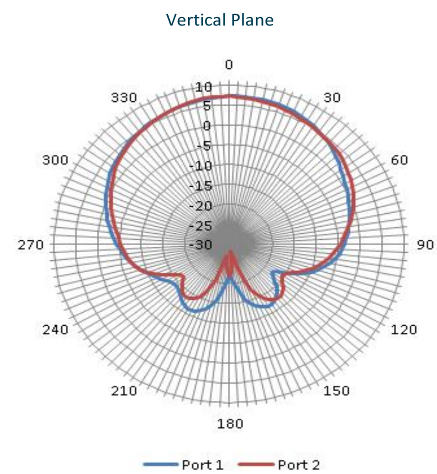
960 MHz



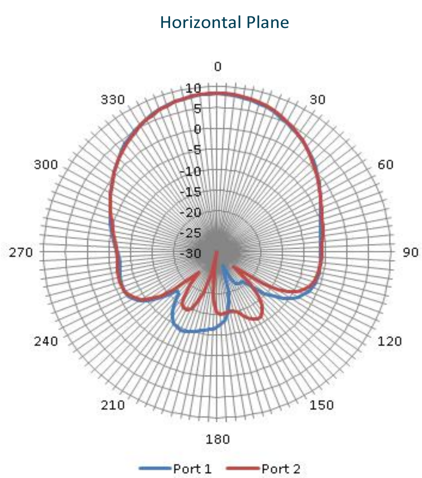


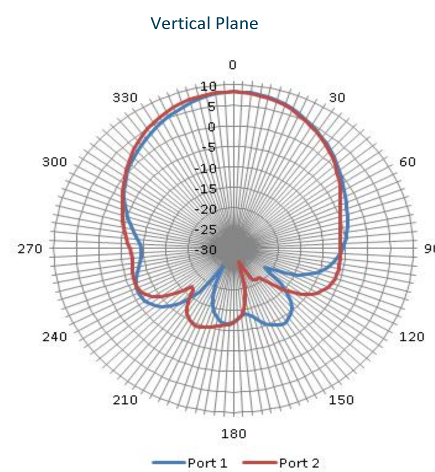
1710 MHz





1950 MHz





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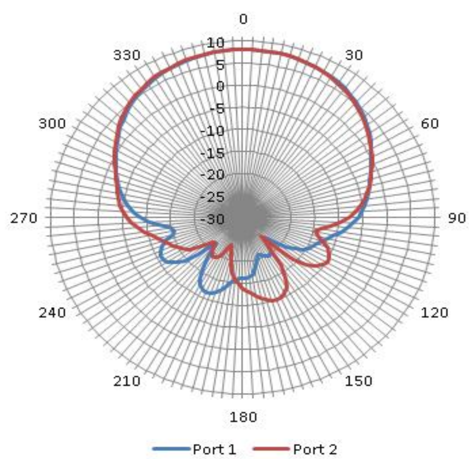
PAS69278P

698-960 MHz/1710-2700 MHz 2- Port MIMO Pole Mount Low-PIM Directional Panel Antenna

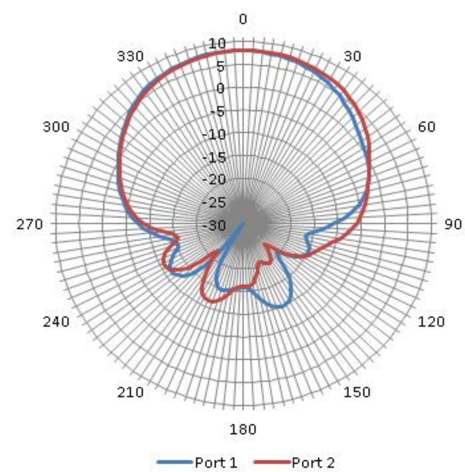
ANTENNA PATTERNS

2170 MHz

Horizontal Plane

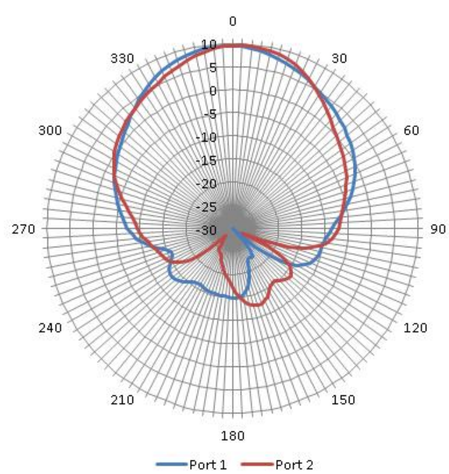


Vertical Plane

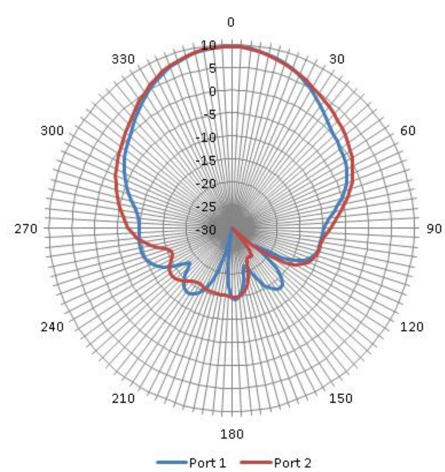


2700 MHz

Horizontal Plane



Vertical Plane



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www.lairdtech.com

APPENDIX E.1-2

NEAR SURFACE SOIL GAS/SURFACE AIR MONITORING FIELD METER MANUALS

GEM5000 Gas Analyzer

Operating Manual

QED Environmental Systems, Inc.
2355 Bishop Circle West
Dexter, MI. 48130
Tel: (800) 624-2026
Fax :(734) 995-1170
Email: info@qedenv.com
Website: www.landtecna.com

Table of contents

1.0 Manual guidelines

1.1 Hazard warnings and safety symbols

Warning	Information in this manual that may affect the safety of users and others is preceded by the warning symbol. Caution - Failure to follow the correct information may result in physical injury which in some cases could be fatal. If the equipment is used in a manner not specified by the manufacturer, the protection provided by the equipment may be impaired.

General product label symbols are listed as follows:

	CE conformity-The CE-marking is the manufacturer's statement to the EU authorities that the product complies with all relevant CE-marking Directives.		If the CSA mark appears with the indicator "US" or "NRTL" it means that the product is certified for the U.S. market, to the applicable U.S. standards.
	VDE mark is a symbol for electrical, mechanical, thermal, toxic, radiological and other hazards.		Separate collection, handling and disposal for waste electrical and electronic equipment and its components.
	Electric shock warning.		Refer to operators manual.
	Double insulated construction - does not require an Earth.		Specific marking of explosion protection (ATEX only).
II 2G	Equipment group and category. G = gases; the type of explosive atmosphere.		IECEx licenced mark (IECEx only).
	Fuse.		Equipment for indoor use only.

1.2 Notes

Important/useful information and instructions are shown clearly throughout the manual in a note format. For example:

✍ Note: For further information please contact Technical Support at (800) 968-2026 or email landtec_support@qedenv.com

2.0 Introduction

This manual explains how to use the GEM5000 landfill gas analyzer. The GEM5000 has additional functionality to the GA5000 gas analyzer. The GA5000 measures gas concentrations only, whereas the GEM5000 measures flow and gas concentrations. The GEM5000 measures flow and calculates the calorific values of the gas as well as being a useful tool for balancing the gas field. The GEM5000 gas analyzer may be used to monitor, calculate, adjust and record the flow at each monitoring point.

This instrument may also be used in GA5000 mode of operation if required. The operator may change the analyzer between a gas extraction monitor (a GEM5000 gas analyzer) or a landfill gas analyzer (a GA5000 gas analyzer). The mode of operation can be changed from the 'Special Action' menu. Please refer to section '8.0 – Taking Readings' for further instruction.

The 5000 series of gas analyzers complies with Part 15 of the FCC Rules. Operation is subject to the following two conditions:

1) This device may not cause harmful interference.

2) This device must accept any interference received, including interference that may cause undesired operation.

2.1 Safety instructions

⚠ Warning	The 5000 series of gas analyzers can be used for measuring gases from landfill sites and other sources as described in this manual. The operator may be exposed to harmful gases during the use of the instrument. Inhaling these gases may be harmful to health and in some cases may be fatal. It is the responsibility of the user to ensure that he/she is adequately trained in the safety aspects of the gases being used and appropriate procedures are followed. In particular, where hazardous gases are being used the gas exhausted from the analyzer must be piped to an area where it is safe to discharge the gas. Hazardous gas can also be expelled from the instrument when purging with clean air. The instrument has been designed to be used in explosive atmospheres as defined by the classification. The instrument can be configured to measure low levels of several gases, but may not be certified for use in potentially explosive atmospheres of these gases. It is the responsibility of the operator to determine the protection concept and classification of equipment required for a particular application and whether these gases create a potentially explosive atmosphere.

✍ Note: Gas analyzers are a sensitive piece of scientific equipment, and should be treated as such. If the equipment is used in a manner not specified by the manufacturer, the protection provided by the instrument may be impaired.

2.2 Instructions for safe use

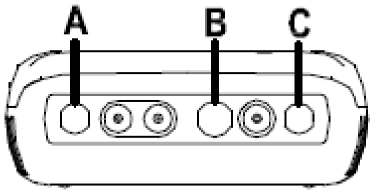
For ATEX and IECEx the 5000 series of gas analysers are certified to Hazardous Area Classification

II 2G Ex ib IIA T1 Gb (Ta = -10ºC to +50ºC)

It is vital instructions are followed closely. It is the responsibility of the operator to determine the protection concept and classification required for a particular application.

(Reference European ATEX directive 2014/34/EU)
The following instructions apply to equipment covered by certificate numbers SIRA 11ATEX2197X and IECEx SIR 11.0089X:

- The equipment may be used with flammable gases and vapours with apparatus group IIA and temperature class T1.
- The equipment can contain gas sensing heads for the detection of particular gases. The inclusion of a sensor does not infer that the equipment is suitable for the use of gases with a temperature class of less than T1.
- The equipment is only certified for use in ambient temperatures in the range -10ºC to +50ºC and should not be used outside this range.
- The equipment must not be used in an atmosphere of greater than 21% oxygen.
- Repair of this equipment shall be carried out in accordance with the applicable code of practice.
- When used in a hazardous area only use GF5.2 temperature probe (SIRA 11ATEX2197X and IECEx SIR11.0089X). For connector C, the GF5.4 anemometer (BVS 04ATEXE194) for use with ATEX only. The analyser should not be connected to any other devices in the hazardous area including the GF-USB lead (connector A) or GF3.9 battery charger (connector B) supplied with the analyzer.



Do not charge, recharge or open in a potentially explosive atmosphere.
In hazardous area only use "Temperature Probe GF5.2" in Connector B.
Connector C (Uo=10V,lo=5mA,Po=50mW,Ci=0,Li=0,Co=100uF,Lo=1000mH),
Connector B (Uo=5V,lo=6mA,Po=7mW,Ci=0,Li=0,Co=100uF,Lo=1000mH)

MAXIMUM NON-HAZARDOUS SUPPLIES:
Connector A - Um=6V Connector B - Um=10.1V

- The safe area apparatus that is to be connected to the USB Port shall be a Safety Extra Low Voltage (SELV) or Protective Extra Low Voltage (PELV) circuit.
- Only a Geotechnical Instrument battery pack part number 20087 or 2011113 is permitted as a replacement. This battery pack is not field replaceable and shall only be changed in a safe area by QED personnel.
- Only Battery Charger type GF3.9 shall be used to recharge the batteries via Connector 'B'.
- If the equipment is likely to come into contact with aggressive substances, e.g. acidic liquids or gases that may attack metals, or solvents that may affect polymeric materials, then it is the responsibility of the user to take suitable precautions, e.g. regular checks as part of routine inspections or establishing from the material's data sheet that it is resistant to specific chemicals that prevent it

from being adversely affected, thus ensuring that the type of protection is not compromised.

- The relative pressure range is +/-500 mbar. Note, however, that the input pressure should not exceed +/- 500 mbar relative to atmospheric pressure and the output pressure should not exceed +/- 100 mbar relative to atmospheric pressure.

For CSA (Canada) the 5000 series of gas analysers are certified to Hazardous Area Classification

CLASS 2258 03 - PROCESS CONTROL EQUIPMENT - Intrinsically Safe and Non-Incendive Systems - For Hazardous Locations

C US M.C.#243446

Ex ib IIA:

Model GA 5000, GEM 5000 and BIOGAS 5000 Methane Detectors; portable, battery powered with non-field-replaceable Battery Pack P/N 20087 or 2011113; intrinsically safe and providing intrinsically safe circuits ("[ib]" for Zone 1) to Model GF5.2 Temperature Probe (Connector B) and with entity output parameters as tabulated below; Temperature Code T1; -10 ºC ≤ Tamb. ≤ +50ºC.

Connector	Entity Parameters						
	Uo (V)	Io (mA)	Po (mW)	Co (uF)	Lo (mH)	Ci (uF)	Li (mH)
B	5.0	6	7	100	1000	0	0
C	10.0	5	50	100	1000	0	0

✍ Note: This device has been investigated for electrical safety features only.

For CSA (USA) the 5000 series of gas analysers are certified to Hazardous Area Classification

CLASS 2258 83 - PROCESS CONTROL EQUIPMENT - Intrinsically Safe and Non-Incendive Systems – For Hazardous Locations - CERTIFIED TO U.S. STANDARDS

C US M.C.#243446

AEx ib IIA:

Model GA 5000, GEM 5000 and BIOGAS 5000 Methane Detectors; portable, battery powered with non-field-replaceable Battery Pack P/N 20087 or 2011113; intrinsically safe and providing intrinsically safe circuits ("[ib]" for Zone 1) to Model GF5.2 Temperature Probe (Connector B) and with entity output parameters as tabulated below; Temperature Code T1; -10 ºC ≤ Tamb. ≤ +50ºC.

Connector	Entity Parameters						
	Uo (V)	Io (mA)	Po (mW)	Co (uF)	Lo (mH)	Ci (uF)	Li (mH)
B	5.0	6	7	100	1000	0	0
C	10.0	5	50	100	1000	0	0

✍ Note: This device has been investigated for electrical safety features only.

2.3 MCERTS

MCERTS is the UK Environment Agency's Monitoring Certification Scheme. The scheme provides a framework within which environmental measurements can be made in accordance with the Agency's quality requirements. The scheme covers a range of monitoring, sampling and inspection activities.

MCERTS promotes public confidence in monitoring data and provides industry with a proven framework for choosing monitoring systems and services that meet the Environment Agency's performance requirements.

The Environment Agency has established its Monitoring Certification Scheme (MCERTS) to deliver quality environmental measurements. The MCERTS product certification scheme provides for the certification of products according to Environment Agency performance standards, based on relevant CEN, ISO and national standards.

MCERTS certified instruments have been tested by an independent body to ensure that they meet certain performance requirements. In addition the manufacturer of an MCERTS product is regularly audited to ensure that the performance requirements of the certification are being continually met.

The 5000 series of gas analyzers have been certified to Version 3.1 of the 'Performance Standards for Portable Emission Monitoring Systems'.

2.4 CIRIA

The CIRIA guideline 'Assessing the risks posed by hazardous ground gases to buildings' proposes that gas concentrations and flow rates should be monitored.

As an example methodology, they suggest using a gas analyser to first measure flow and pressure and then afterwards to measure gas concentration.

The logging profile option offers frequency of data to be collected within a timed period which, in return, identifies a gas profile of the sample point being monitored, information about whether the sample point is performing correctly, when the peaks occur and whether air is drawn in after a certain period. This logging option is available on firmware software version 1.6.5
Versions of the GA5000 analyzer range with internal flow on firmware version 1.6.5 and above have the ability to take measurements according to the CIRIA guidelines, while still allowing other users to take the measurements as before.

3.0 The GEM5000 Gas Analyzer

3.1 The GEM5000

The GEM5000 gas analyzer is designed to monitor landfill gas extraction systems.

Benefits:

- Allows balancing of gas extraction site.
- Maximize power generation from site.
- Field proven.
- Standardizes monitoring routines.
- Easy transfer of data.
- GPS for compliance.

Features:

- ATEX certified.
- MCERTS certified.
- H_2 compensated CO.
- Calculates flow (m^3/hr) and calorific value (kW or BTU).
- Technician log-in.
- Event log.
- Two instruments in one (GA and GEM mode).
- Measures static and differential pressure.
- Simultaneous display of gases.
- Storage of changes in set-up of gas field.
- Data logging.

Applications:

- Gas extraction fields.
- Flare monitoring.
- Landfill sites.

3.2 GEM5000 standard product

Reference:

A	Hard carry case
B	In-line water trap tubing & filter
C	Gas analyser instrument
D	H2S filter (optional – if the compensated CO cell is fitted)
E	5000 series safety manual
F	Mains battery charger and adaptors: - UK - Europe - US - Australia

4.0 GEM5000 Optional Products and Accessories

4.1 Optional products

The GEM5000 gas analyzer has a number of optional products for purchase which enhance the usability and enable further analysis of data and reading information.

✍ Note: For more information on the features listed in this section please contact Sales at (800) 624-2026 or email info@qedenv.com

4.1.1 Pitot tube (optional)

The GEM5000 gas analyzer enables the use of a pitot tube to aid accurate flow measurement. The pitot tube is used for gas extraction systems and the pressure readings are taken in mbar. High gas flow is calculated in the analyzer in m^3/hr (metres cubed per hour).

4.1.2 Orifice plate (optional)

QED recommends the use of orifice plates as good practice when using the GEM5000 gas analyzer, enabling repeatability in flow measurement via a fixed method. Contact Sales at (800) 624-2026 or email info@qedenv.com if the use of Orifice plates is required.

4.1.3 Temperature probe (optional)

The GEM5000 gas analyzer has the facility to automatically display and record the borehole temperature via an optional temperature probe.

When a temperature probe is fitted the temperature reading will be displayed on the 'Main Gas Read Screen' and recorded with all other data.

✍ Note: Temperature probes with an Ex label are part of the GEM5000 Ex certification SIRA 11ATEX2197X and IECEx SIR11.0089X, and therefore certified for use under the same conditions as the analyzer.

4.1.4 Anemometer (optional)

The GEM5000 gas analyzer has the facility to automatically display and record high flow via an optional anemometer probe. It is designed to plug into the instrument and instantly provide a flow indication. An anemometer probe adds flow measurements to the professional reporting ability of the GEM5000 range along with gas concentrations, pressure and temperature.

The anemometer has a simple connection, a narrow diameter measurement head (11mm), a wide temperature operating range (up to 80^{o}C) and indicates flows up to 40 m/sec.

When an anemometer probe is fitted to the analyzer the flow will be displayed in the 'Main Gas Read Screen' and recorded with all other data.

Flow can be measured in either m/s (gas velocity) or m^3/hr (volume flow rate). In order to calculate the volume flow rate the pipe diameter will need to be entered into the instrument, either manually or via the Landtec Systems Gas Analyser Manager, (LSGAM), software.

✍ Note: The anemometer probe is ATEX certified for use in a potentially explosive atmosphere under Ex certificate BVS 04ATEXE194.

4.1.5 H_2S filter (optional)

The GEM5000 gas analyzer has the capability to use an H_2S filter and is required as standard if the compensated CO cell is fitted and configured at the time the instrument is manufactured. H_2S gas can have a cross-gas effect on the CO reading. By using a filter, the H_2S is removed from the gas sample, therefore providing a more accurate CO reading.

The filter only needs to be used when you are trying to get rid of any possible cross gas effects H_2S might have on other gases. Do not use the filter on all boreholes.

4.1.6 Landtec Systems Gas Analyzer Manager – LSGAM (optional)

Landtec Systems Gas Analyzer Manager (LSGAM) enables the operator to maximize the operation of the gas analyzer. It enables direct communication with the unit, features a simple upload and download facility and is fully compatible with the latest Microsoft™ operating systems.

Features:

- Organization and transfer of borehole IDs and readings to and from the gas analyzer.
- Configuration of the gas analyzer.
- Flexible grouping of the IDs.
- Structured organization of transferred data.
- Automatic detection of instrument type and available options.
- Secure data mode to prevent tampering.
- First time set-up wizard.
- Enable flow measurements for GEM5000 gas analyzers.

4.1.7 GPS (optional)

An optional GPS feature is available for the GEM5000 gas analyzer. It enables the site engineer to automatically locate borehole IDs using GPS satellite signal from predefined borehole IDs uploaded from LSGAM or set on the analyzer when out in the field prior to taking a reading. The GPS reading data is stored for each measurement reading providing an audit trail confirming that a reading was taken.

4.1.8 Bluetooth

The analyzers are fitted with a Bluetooth receiver which enables the operator to download readings and upload IDs without the need to connect the analyzer to a PC via a USB cable.

5.0 GEM5000 Instrument Features

5.1 Physical characteristics of the instrument panel

Front view:

Reference:

A Main Gas Read Screen

B Soft-keys

C Backlight Key

D Menu Key

E Pump key

F LED Light

G On/Off Key

H Assistance key

I Enter Key

J Scroll up key

K Scroll down key

L Key 0 – Space key

Back view:

Reference:

M Model Number

N Serial number

O Part number

P Certificate number

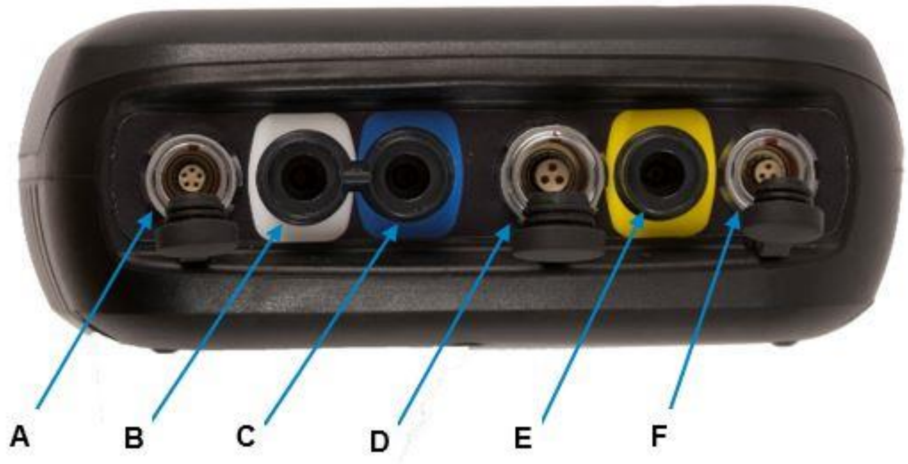
Q Recalibrated date

5.2 Analyzer features and keys

A	Main Gas Read Screen	Start and end screen when using the instrument.
B	Soft-keys	The function of the three 'soft-keys' on the front of the instrument panel is determined by menu options taken. Functions vary from screen to screen.
C	Backlight key	Enables the operator to turn the backlight on/off on the analyzer display panel.
D	Menu key	Press the 'Menu' key to view and maintain User, Device and Operation settings.
E	Pump key	Press the 'Pump' key to start or stop the pump.
F	LED light	LED power light is visible on the front of the analyzer when the instrument is powered on.
G	On/Off key	Press the 'On/Off' key for 2 seconds to switch the instrument on and off.
H	Assistance key	Press for on-screen assistance and help.
I	Enter key	Use to accept changes, options, user inputted answers etc.
J	Key 2 – Page Up	Also 'Key 2'. Press scroll up to view further information on the instrument screen.
K	Key 8 – Page down	Also 'Key 8'. Enables the operator to scroll down to display more information.
L	Key 0 – Space key	Also 'Key 0'. Press to enter a space when entering text on the instrument screen.
M	Model Number	Instrument model type identification.
N	Serial Number	Unique identification for the instrument. Verification of the serial number will be required if Technical Support assistance is needed.
O	Part Number	Manufacturer's part number.
P	Certification Number	Displays instrument certification information.
Q	Recalibrated Date	The date displayed is the date the instrument is due to be calibrated.

5.3 Instrument connection points

Top view:



Ref:	Connection Point:	Function:
A	Connector A	Attach the USB cable for PC-to-analyzer connectivity.
B	Inlet Port & Static Pressure Port (White port)	Attach the sample tube to take a gas sample. Also used to measure the static pressure.
C	Differential Pressure Port (Blue port)	Attach the sample tube to measure differential pressure.
D	Connector B	Attach the temperature probe and also used to attach the mains charger to the analyzer for charging.
E	Gas Outlet Port (Yellow port)	The gas outlet port is the point at which the sample gas is expelled. Tubing may also be attached to the port.
F	Connector C	Attach the anemometer.

6.0 General Operational Instructions

6.1 Switching the instrument on

1) To switch on the analyzer, press and hold the 'On/Off' key. The Landtec logo will display followed by the instrument warm up.

2) Following the instrument warm up, the 'Date and Time' screen is displayed prompting the technician to set the date and time and required format.

3) When complete, select the soft-key to 'Exit' and the 'Power On Self-test' screen is displayed followed by instrument status. Instrument status displays the instruments service due date, serial number, options, service scheme and software version. Text will also display stating 'Self-test complete'.

4) Select the soft-key 'Next' to move onto the next screen and the 'Technician Login' screen is displayed.

5) Use the cursor keys to move through the list of ID's. Select either the required 'Technician ID' from the list followed by the soft-key 'Accept', or select 'Default'' followed by the soft-key 'Accept' to continue to the 'Main Gas Read Screen'.

✍ Note: The selected technician ID is displayed at the top left corner of the Main Gas Read Screen.

6.1.1 Power on self-test

When switched on, the read-out will perform a pre-determined self-test sequence. During this time many of the analyzer's functions are tested, including:

- General operation
- Gas flow measurement
- Calibration
- Battery charge level

During the self-test the following information is also displayed:

- Manufacturer's service due date
- The last gas check date
- Software version programmed
- Date format
- Serial number
- Operating language
- The currently enabled sales option

✍ Note: The self-test should only be done with the analyzer sampling fresh air.

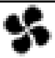
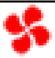
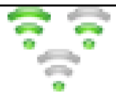
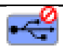
6.2 Switching the instrument off

1) To switch off the analyzer, press and hold the 'On/Off' key, at which point a clean air purge will be carried out and the instrument will then switch off.

2) If for any reason the analyzer 'locks up' and will not switch off in this manner, press and hold the 'On/Off' key for 15 seconds; this will force the instrument to switch off.

6.3 Instrument status icons

The following icons may be displayed on the instrument screen:

Icon	Description	Icon	Description
	**Battery charge state** Gives the operator an estimation of the battery charge state. For example 100% gives about 8 hours use in the field and 50% would mean that there is approximately 4 hours battery life remaining.		**Battery charge state** Indicates less than 2 hours of charge remaining.
	**Pump status** This icon is displayed along with a counter showing the pump run-time. This counts down where the operator has specified the pump run-time; if not it counts up; the icon turns red when stalled.		**Pump stalled** This icon is displayed when the pump stalls. The instrument's gas inlet (or outlet) may be blocked. This warning is most commonly caused by a water-logged or dirty sample filter. Change the sample filter and check for obvious blockages in the sample tubes. Alternatively, a small amount of adjustment can be made to the low flow detection point to compensate for minor changes in the performance of the pump fitted to the instrument.
	**GPS signal strength** This icon shows the signal strength the analyzer's GPS module is able to provide. Full, okay and fair strength respectively.		**GPS failure** The GPS was unable to get a line of sight lock on enough satellites. Or, it may be that it hasn't had time to get a lock.
	This indicates when Bluetooth has been enabled. The color changes from gray to blue when connected.		**Language** This icon indicates the currently selected operating language. This can be changed via the main menu.
	**Data logging** This icon indicates that the data logging feature is in operation.		**Service overdue** This icon indicates that the analyzer is overdue for service
	**Legacy mode** This icon indicates that the analyzer is in legacy mode and hence is ready to connect to a PC.		**USB disabled** This icon indicates that the analyzer has reached a battery critical state, and hence has turned off its USB connectivity.

6.4 Instrument LED power states

When the instrument is powered on a LED power light is visible on the front of the analyzer, located above the 'On/Off' key. The following LED power light states are as follows:

Steady yellow	Unit turning on. This will extinguish when software has loaded correctly.
Flashing (rapid)	Unit is powering off.
Flashing (slow)	Power off is being delayed for purge/shutdown handling.
Flashing yellow	Unit is turning off due to power button being pressed.
Flashing red	Unit is turning off due to critically low battery.

✍ Note: Pressing and holding the power button for ~20s resets the analyser.

6.5 Changing between parameters

By default, the instrument displays the 'Main Gas Read Screen' (for gas measurement). The instrument will return to this screen after power on or when returning from the menus. The 'Scroll' keys can be used to switch to another measurement screen.

6.6 Entering data

During normal operation the operator may be prompted to enter data or information via the keypad, i.e. entering an ID code or setting an alarm level.

When entering data into the instrument all fields are fixed format and are populated from the left.

Text:
Entering text uses similar multi-tap functionality as a mobile phone. Key the numeric/alpha key pad the required number of times to select the appropriate letter. To key numeric data continue to press the numeric/alpha key until the required number is displayed.

Numeric data:
To enter a new date 09/15/116 the operator would type in 091516 using the numeric keypad in the following sequence:-

* 0_/__/__
* 09/__/__
* 09/1_/__
* 09/15/__
* 09/15/1_
* 09/15/16

Press the 'Enter' key to confirm/accept data keyed.

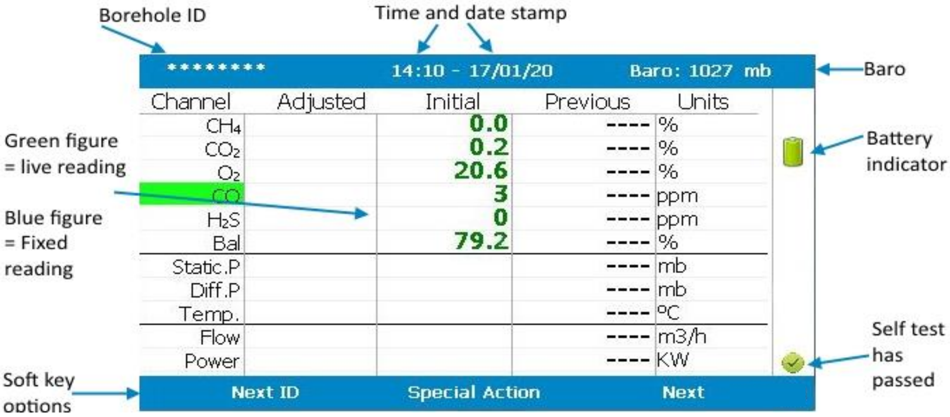
Any mistakes can be corrected using the soft-key 'Delete' which will delete the last digit typed. Alternatively, the sequence can be retyped before the 'Enter' key is pressed and the existing numbers will be pushed off the screen.

✍ Note: The instrument will not allow invalid data to be entered; this should be deleted and re-entered.

6.7 Instrument main gas read screen

The 'Main Gas Read Screen' is considered to be the normal operating screen and all operations are carried out from this starting point.

The actual data shown on this display will depend on the version of the instrument and the options that have been selected.



Main Gas Read Screen

You can also press key 2 and access a zoomed version of the main read screen, once you have entered this mode, simply use keys 4 and 6 to switch between the gases and pressures. Examples of both screens can be seen below:

Zoomed version

6.8 Storage

The analyzer should not be exposed to extreme temperature. For example, do not keep the analyzer in a hot car. When not in use, analyzers should be kept in a clean, dry and warm environment, such as an office. Protect the analyzer with either the soft carry case or store in the hard carry case provided with the instrument.

The instrument should be discharged and fully charged at least once every four weeks, regardless of indicated charge state.

6.9 Battery/charging

The battery used in the 5000 series of gas analyzers is nickel metal hydride and manufactured as a pack from six individual cells. This type of battery is not so susceptible to the top-off charging 'memory effects' as nickel cadmium batteries, although it is not recommended that the unit is given small top-off charges.

✍ Note: **To reach optimum charge, it is recommended that the instrument is switched off when being charged and remains switched off during the charging process.**

A full charge will take approximately 4 hours from a fully discharged battery.

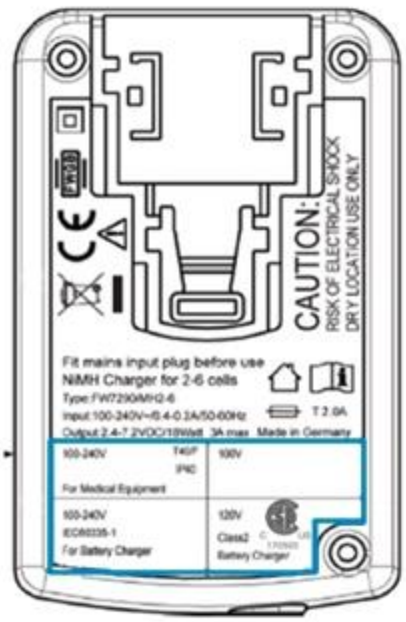
⚠ **Warning**	The battery charger is NOT covered by the Ex certification. The battery must be charged only in a safe area.

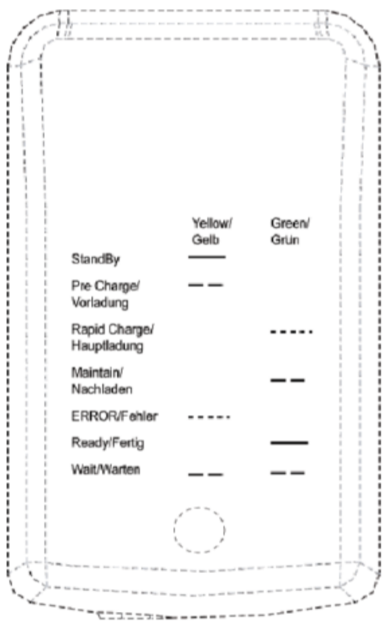
The battery charger is intelligent and will indicate when the unit is charging and charged.

The instrument must be charged ONLY using the battery charger supplied with the instrument. The battery charger supplied is intended for indoor use only. Please ensure adequate ventilation while charging. Typically, a fully charged battery will last 7-8 hours. A quick 30 minute charge can be used to give approximately one hours use in the field but this may shorten the battery life. Temperature can dramatically affect the battery life; please take this into account when estimating battery life.

✍ Note: Connect the charger to the mains attaching the appropriate adaptor.

Power supply front and back drawing:





Charger:	Input voltage:	100-240V AC +/- 10%
	Input frequency:	50-60Hz +/- 10%
	Input current:	0.4A@100VAC .. 0.2A@240VAC
	Output voltage:	10.1VDC max
	Output current:	1.5A max

✍ Note: This charger has been internally restricted to 1.5A

6.10 Cleaning instructions

Do NOT use any cleaning agents to clean the analyzer or battery charger as they may have an adverse effect on the safe use of these devices.

6.11 Memory

The analyzer's memory is stored in a readings and configuration database. The analyzer will prompt when its memory is full, and you will not be able to store any further readings. Please download your readings via LSGAM or the Basic Download Software and then clear the memory.

✍ Note: The analyzer should never be stored for prolonged periods with valuable data in its memory. It is advisable to download all readings to LSGAM at the end of each day's monitoring. To clear the memory, please refer to the LSGAM operating manual.

6.12 Warning and error codes

When switched on the instrument will perform a predetermined self-test sequence taking approximately ten seconds. During this time many of the instrument's working parameters and settings are checked. If any operational parameters are out of specification or if the pre-programmed recommended calibration/service date has passed, errors or warnings may be displayed.

✍ Note: For further information please refer to section '10.0 Problem Solving'.

7.0 Operator Settings

7.1 Menu key

The 'Menu' key enables the operator to select options to set up specific parameters and perform operational tasks prior to sample readings being taken or to view data and information stored in the instrument.

1) Select the 'Menu' key on the front of the analyzer and the following screen is displayed:

2) Press the relevant numeric key on the analyzer keypad to select the required option.

3) To exit this menu, select the soft-key 'Exit' on the front of the analyzer and the operator is returned to Main Gas Read Screen.

7.2 Operation settings

To access the 'Operation settings' menu, select the 'Menu' key on the front of the analyzer. The following menu is displayed:

7.2.1 Timers

The timers function enables the operator to set standard purge times and set auto-power off if the unit is untouched for the period of time specified.

1) Select 'Key 1 – Timers' and the following screen is displayed:

1) Select 'Key 1' to edit the purge time. Enter the 'Pump Running Time' in seconds; this is the length of time you wish to run the pump to draw the sample, e.g. key in 030 then press the 'Enter' key to accept.

2) Select 'Key 2' to edit the auto power off time. Enter the 'Auto power off' in minutes; the instrument will automatically power off to preserve the battery life after the specified time if no activity has occurred on the instrument. Press the 'Enter' key to accept.

3) Select the soft-key 'Exit' key to exit the screen and return to the 'Operation settings' menu.

✍ Note: Setting the purge time and auto power off functions to zero, disables the option. It is not recommended to reduce the purge time to below 30 seconds.

7.2.2 Gas Check

This option displays the 'Gas Check' menu and enables the operator to zero and span the gas channels on the instrument. Historical/previous gas checks data can also be viewed and factory settings can be restored.

1) Select the 'Menu' button on the front of the analyzer to display the 'Device Settings' menu. Press the soft key to display 'Operation Settings'.

2) Select 'Key 2 – Gas Check' and the following menu is displayed:

3) For more information about the Gas Check Menu please refer to section 9.0 – Calibration.

4) Select soft-key 'Exit' to exit operation settings and return to the main screen.

7.2.3 View data

This option enables the operator to view the readings collected and stored on the instrument. Readings many be downloaded to the optional LSGAM software if further analysis is required.

1) Select the 'Menu' button on the front of the analyzer to display the 'Device Settings' menu. Press the soft-key to display 'Operation Settings'.

2) Select 'Key 3 – View Data' and the following screen is displayed:

3) Toggle through the reading by selecting 'Key 4 – Scroll left' and 'Key 6 – Scroll right' on the analyzer. Select 'Key 2 – Page up' and 'Key 8 – Page down' to page through the auxiliary channels listed.

4) Select the soft-key 'Filter' to filter the data by sample point ID, or specify before or after date. Press the soft-key 'Exit' to exit the filter menu and return to the 'View Data' screen.

5) Select the soft-key 'Delete' followed by the appropriate soft-key to delete a single reading or all filtered readings. Press soft-key 'Cancel' to cancel the deletion request.

6) Select the soft-key 'Exit' to exit the view data screen.

7.2.4 Set alarms

This option enables the operator to define the conditions for which an alarm/target will be triggered. These conditions apply to the general operation of the instrument and are not ID specific. A summary of the alarm settings can be found in 'Key 3 – Summary'.

<u>Types of alarms</u>
Common Alarms – Are non-ID specific alarms which apply to all the readings taken with the analyzer.

ID specific alarms – Are ID specific, i.e. they will only trigger when a certain Id is being used.

Tuning/targets – You can also set targets for your gas channels; these will highlight gas channels green as oppose to when they alarm (yellow). These can be common or ID specific.

<u>Setting up alarms/targets</u>
1) Select the 'Menu' button on the front of the analyzer to display the 'Device Settings' menu. Press the soft key to display 'Operation Settings'.

2) Select 'Key 4 – Set Alarms' and the following menu is displayed:

3) Select the corresponding key to select the gas for which you wish to set an alarm/target trigger for, followed by 'Key 1' to change the trigger condition of an alarm.

4) To manually adjust the alarm/target set press (<) 'Key 4 – Scroll left' or 'Key 6 – Scroll right' (>) and enter the trigger value. Once you are happy, press the middle soft key for 'save'.

5) For pressure, temperature and flow alarms, press the left soft key for 'Secondary' and then select the corresponding key to select the channel for which you wish to set an alarm trigger for, followed by 'Key 1' to change the trigger condition of an alarm/target. Once you are happy, press the middle soft key for 'save'.

6) To disable all alarm settings select key 0 – 'Disable All'

✍ Note: ID specific alarms cannot be added/edited on the analyzer, to add/edit ID specific alarms, please use the optional LSGAM Software.

7.2.5 Adjust flow fail

This option enables the operator to adjust the flow fail tolerance of the instrument, i.e. the operator can adjust the sensitivity for when the pump will stop operating on the presence of a blockage or low flow.

1) Select the 'Menu' button on the front of the analyzer to display the 'Device Settings' menu. Press the soft-key to display 'Operation Settings'.

2) Select 'Key 5 – Adjust Flow Fail' and the following screen is displayed:

3) Manual adjustment of the flow fail is available via this option and can be carried out with use of 'Key 4 – Scroll left' (<) less sensitive and 'Key 6 – Scroll right' (>) more sensitive.

4) Select the soft-key 'Save' to store the setting or select soft-key 'Exit' to exit the screen without saving the change.

5) The operator will return to the 'Operation settings' menu.

✍ Note: The default setting displays the bar in the centre. BEFORE altering this setting, please contact Technical Support at (800) 968-2026 or email landtec_support@qedenv.com

7.2.6 Technician login

This option enables the operator to select or change a pre-defined technician login and all subsequent readings will be tagged with this Technician Login ID. The technician ID must already have been created using the LSGAM software and uploaded to the instrument.

1) Select the 'Menu' button on the front of the analyzer to display the 'Device Settings' menu. Press the soft key to display 'User Settings'.

2) Select 'Key 6 – Technician login' and the following screen is displayed:

3) Use the cursor keys to move throughout the list of IDs displayed; select the 'Enter' key to select choice of ID, default if no IDs are listed or soft-key 'Skip' to skip the selection.

4) The operator will return to the 'User settings' menu.

✍ Note: If no technicians are loaded via LSGAM, this section is skipped during start up and the 'Technician ID' icon is removed from the menu.

7.3 Device settings

To access the 'Device Settings' menu, select the 'Menu' key on the front of the analyzer to display the 'Operating Settings' menu followed by the soft-key to display 'Device Settings' menu. The following menu is displayed:

7.3.1 Date and time

This option enables the operator to set the instrument date and time or to receive and update the settings automatically from satellite signal.

1) Select the 'Menu' key on the front of the analyzer to display the 'Device Settings' menu followed by 'Key 1 – Date and Time' and the following screen is displayed:

2) Select 'Key 1 – Set Date' and key in the required date. Type the date using the numeric keypad. Press the soft-key 'Date Format' to toggle and select the required date format i.e. dd/mm/yy. Press the 'Enter' key to confirm and update the date setting.

3) Select 'Key 2 – Set Time' and key in the required time (hh:mm). Type the time using the numeric keypad and press the 'Enter' key to confirm the update.

4) The operator may also change the default time zone. Selecting the 'Key 4 Scroll-left' or 'Key 6 – Scroll right' to move through the different time zones. Press the 'Enter' key to confirm your default setting.

5) Select 'Key 3' to toggle between 'Manual Update' and 'Automatic Update' in order to choose how the date and time is set if updating from satellite signal.

Manual	Used to manually obtain and update the date and time from the satellite signal when requested. Select soft-key 'Set now' to set date and time from satellite when available.
Automatic	Used to automatically update the date and time received from the satellite signal when available. This option is only available when the GPS option is fitted to the analyser at the time of manufacture.

6) Select the soft-key 'Exit' to exit and return to the 'Device Settings' menu.

7.3.2 Bluetooth

This option enables the operator to set and utilize Bluetooth technology. This may be useful when downloading gas readings from the analyzer to the PC instead of connecting the analyzer to a PC via a USB cable. Bluetooth may also be used to transfer Site IDs to other 5000 series gas analyzers if required.

1) Select the 'Menu' key on the front of the analyzer to display the 'Device Settings' menu.

2) Select 'Key 2 – Bluetooth' and the following screen is displayed:

3) Enter the 'Pairing PIN' value when prompted by your computer for the device's pairing code.

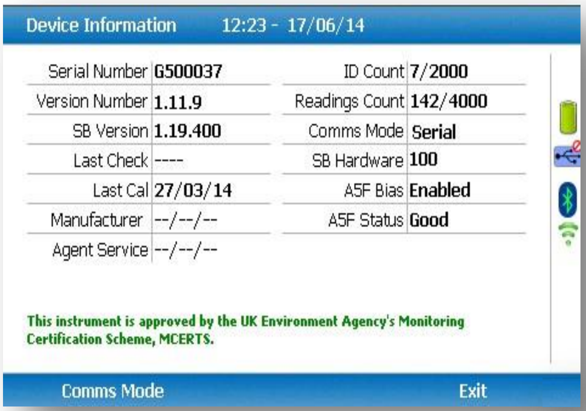
4) Select soft-key 'Exit' to exit the screen and return to the 'Device Settings' menu.

7.3.3 Device information

This option displays default instrument information and settings such as serial number, service due date, last zero calibration date and last span calibration date.

1) Select the 'Menu' key on the front of the analyser to display the 'Device Settings' menu.

2) Select 'Key 3 – Device Information' and the following screen is displayed:



3) The information displayed on this screen is informational only and cannot be edited by the operator. The operator may be asked serial number, service due date and version number information when contacting QED.

✍ Note: The communications setting 'Legacy' mode is for use with GAM >=v1.5. GA5K mode is reserved for future applications – use with 5000 series updater tool

4) Select soft-key 'Exit' to exit the screen and return to the 'Device Settings' menu.

7.3.4 Diagnostics

This option enables the Technical Support Team to identify and resolve issues with the instrument and settings. If required, the operator may be asked to confirm the diagnostics displayed.

1) Select the 'Menu' key on the front of the analyser to display the 'Device Settings' menu.

2) Select 'Key 4 – Diagnostics' and the following screen is displayed:

3) Select soft-key 'Next' to display the next screen, 'Previous' to return to the previous screen, or select soft-key 'Exit' to exit this screen and return to the 'Device Settings' menu.

✍ Note: For further information please contact Technical Support at (800) 968-2026 or email landtec_support@qedenv.com

7.3.5 Navigation (optional)


Navigation is On

This option enables the operator to switch the 'GPS Navigation' functionality on or off. (This is optional and dependent upon purchasing the navigation option).

1) Select the 'Menu' key and the 'Device Settings' menu is displayed.

2) Select 'Key 5 – Navigation On' to switch on the GPS navigation functionality or 'Key 5 – Navigation Off' to switch the GPS navigation functionality off.


Navigation is On


Navigation is Off

✍ Note: For further information please refer to section '8.0 – Taking Readings'.

7.4 User settings

To access the 'User settings' menu, select the 'Menu' key on the front of the analyzer to display the 'Operating Settings' menu followed by the soft-key to display 'User Settings' menu. The following menu is displayed:

To exit the user settings menu select the soft-key 'Exit'.

7.4.1 Operating language

This option enables the operator to specify the operating language displayed for the instrument.

1) Select 'Key 1 – Operating Language' and the following screen is displayed:

Set the required language for the gas analyser by selecting the appropriate function key. Choose from, on the first page:

Key 1	English
Key 2	Spanish
Key 3	French
Key 4	German
Key 5	Italian
Key 6	Portuguese

Use the soft-keys to move to the next page for further language options, including simplified Chinese

2) To exit this option, select the soft-key 'Exit' and the operator is returned to the 'User Settings' menu.

7.4.2 Units of measurement

This option enables the operator to specify the default units of measurement for the instrument.

1) Select 'Key 2 – Units of Measurement' and the following screen is displayed:

2) To set the required units of measurement toggle and choose from the following:

Key 1	Temperature	^{O}C ^{O}F
Key 2	Flow	scfm m3/hr
Key 3	Measurement	Inches Millimetres
Key 4	Pressure	mb "H2O
Key 5	Balance	Balance Residual N2

3) Select soft-key 'Exit' to exit this screen and return to the 'User Settings' menu.

7.4.3 ID selection

The ID selection screen allows the operator to scroll through all IDs, including those uploaded from LSGAM and added directly onto the instrument, and then make a selection. Detailed information regarding the currently selected ID, such as flow device type and pump runtime, are displayed below:-

By selecting 'Key 5' the operator can toggle between showing 30 IDs and showing 5 IDs with more detailed information relating to the chosen ID.

The technician can scroll between the IDs using the following keys on the instrument keypad:

Two (2) and eight (8) move the selection up/down
Four (4) and six (6) move the selection left/right on the list view
One (1) and three (3) move the selection left/right a page in the list view only
Seven (7) and nine (9) move the selection to first/last ID

Five (5) toggles between the 'ID with information' and 'ID list'
Return/enter key selects the desired ID and proceeds to the navigation or reading screen.

If there are no IDs present the technician can either add a new ID or press the enter key on the instrument keypad to return to the previous screen.

Soft keys:

Left - Select 'No ID' and go to the purge/reading screen.
Center - Enabled when there is a list of IDs, allowing the technician to dynamically filter the IDs displayed in the list.
Right - Allows the technician to add a new ID to the instrument 'in the field'.

✍ Note: If your analyzer has firmware version v1.12 or greater, used IDs will have a strikethrough.

Changing the sort order

By default the IDs are sorted in the order in which they were transferred to the instrument. To change the sort order between unsorted, sort by name or sorted by distance to travel press Key 0.

Sorted by original order (not sorted)

Sorted alphabetically

Sorted by distance to travel

✍ Note: Only available when GPS is enabled

For analyzers with firmware v1.12 and above:

1) Press the menu key

2) Press the middle soft key for 'User Settings'

3) Press key 3 – 'ID options

   a. Key 1 to change the sort order
   b. Key 2 to change how the IDs are displayed
   c. Key 3 to clear the line through on the current ID being used
   d. Key 4 to remove the line through on all IDs

7.4.4 Routes

Using the optional LSGAM Software, you can upload a route. This is a predefined list of IDs that you can go through in an order. This feature is useful if you have a certain order to complete your IDS in.

Furthermore if your GA5000 has v1.12 or higher firmware it will strike through your IDs once you have used them.

✍ Note: If the analyzer is set to "route mode" (v1.12 and above), the filter box will no longer be there, as you cannot filter in this mode. It will be replaced by "Route" and the route name.

7.4.5 Adjust backlight

This option enables the operator to adjust the backlight (brightness). Having this set to a darker setting will help preserve the battery power

1) Select 'Key 4 – Adjust Backlight' and the following screen is displayed:

2) Keys 4 and 6 can be used to adjust the brightness of the display screen.

   'Manual' disables the backlight timeout.

3) Select the soft-key 'Save' to store the setting or select soft-key 'Exit' to exit the screen without saving the change.

4) The operator will return to the 'User settings' menu.

Selecting 'Key 1' allows the operator to configure the dimmer settings from 'Auto Dim' to 'Auto Off' in order to help preserve power consumption when data logging.

This icon represents 'Auto Dim' – this enables the backlight idle timeout, which means the backlight will go dim after a specified period of inactivity. This will help save battery life.

This icon represents 'Auto Off' – this switches the backlight off, saving power.

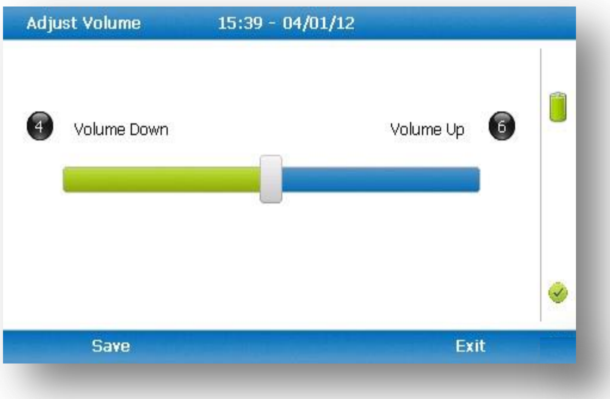
✍ Note: The manually set contrast setting is retained when the read-out is switched off and may require resetting when next switched on.

7.4.6 Adjust volume

This option enables the operator to adjust the volume for the internal speaker, for example the alarm tone. A lower setting will help preserve the battery power.

1) Select the 'Menu' button on the front of the analyzer to display the 'Device Settings' menu. Press the soft-key to display 'User Settings'.

2) Select 'Key 5 – Adjust Volume' and the following screen is displayed:



3) Manual adjustment of the volume is available via this option and can be carried out with use of 'Key 4 - Scroll left' (<) volume down and 'Key 6 - Scroll right' (>) volume up.

4) Select the soft-key 'Save' to store the setting or select soft-key 'Exit' to exit the screen without saving the change.

5) The operator will return to the 'User settings' menu.

7.4.7 User Prompts

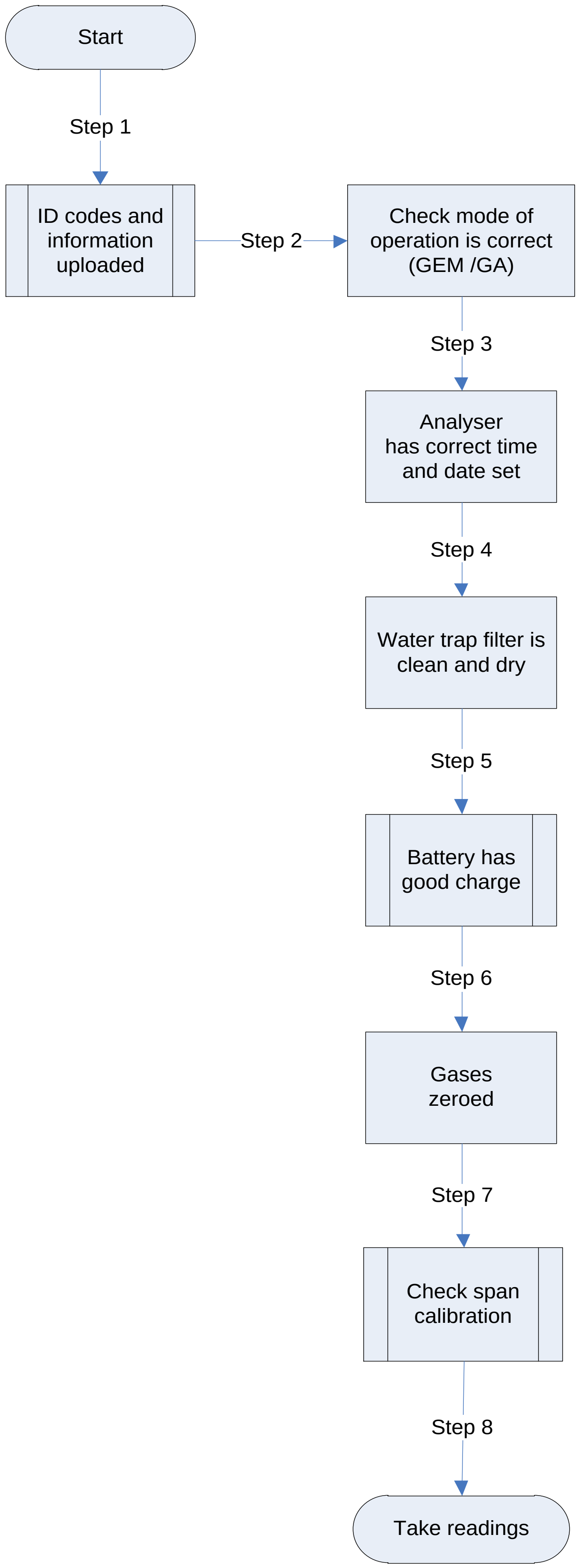
This option enables the operator to either turn on or off the context-sensitive user prompts which are displayed during the gas sample process. The analyzer will have the user prompts on when it is first used, so if they are no required they can be switched off by selecting soft-key '6' and this will now be its default setting. Prompts can be switched back on at any time by returning to this menu and selecting soft-key '6'.

7.5 Exit menu

1) Press the 'Menu' button on the front of the analyzer to exit settings.

8.0 Taking Readings

8.1 Preliminary checks before taking readings (best practice)



Prior to use, it is good practice to ensure that:

Step 1 If using LSGAM - all necessary ID codes and information have been uploaded from LSGAM to the analyzer. Please see section 8.1.1 for more information on this.

Step 2 Check the 'Mode of Operation' is correct. Choose either GEM5000 for gas extraction monitoring analyzer or GA5000 for landfill gas analyzer. Change using 'Special Actions'.

Step 3 The instrument has the correct time and date set.

Step 4 The water trap filter is fitted and is clean and dry.

Step 5 The battery has a good charge (minimum 25% charge, even if only a few readings are required).

Step 6 The gas channels have been zeroed, without gas concentration present.

Step 7 If necessary check the span calibration with a known concentration calibration gas.

Step 8 Take readings.

⚠ **Warning**	Inhaling hydrogen sulphide gas (H_2S) or other harmful gases can cause death. It is the responsibility of the user to ensure that he/she is adequately trained in the safety aspects of using H_2S and other harmful gases. In particular, where hazardous gases are being used the gas exhausted from the analyser must be piped to an area where it is safe to discharge the gas. Hazardous gas can also be expelled from the instrument when purging with clean air.

Good practice

- Travel to site with the gas analyzer in the vehicle's interior - not in the trunk or truck bed, where it may be subjected to extremes of temperature and possible shock damage. Do not place the gas analyzer against anything hot (e.g. gas extraction pipe, car body or in an unattended car during the summer) as this will cause a temperature increase in the gas analyzer and may cause erroneous readings.

- When moving around a site, protect the gas analyzer from strong direct sunlight and heavy rain.

- Always use the water trap! If the water trap becomes flooded, change the filter and ensure all tubes are clear of moisture before re-use.

  ✍ Note: If the exhaust of a 5000 series gas analyzer is connected to a pressurized system then this results in a flow of gas out of the inlet flow port.

8.1.1 Creating an ID

There are two different methods to creating an ID, either via LSGAM or via the instrument.

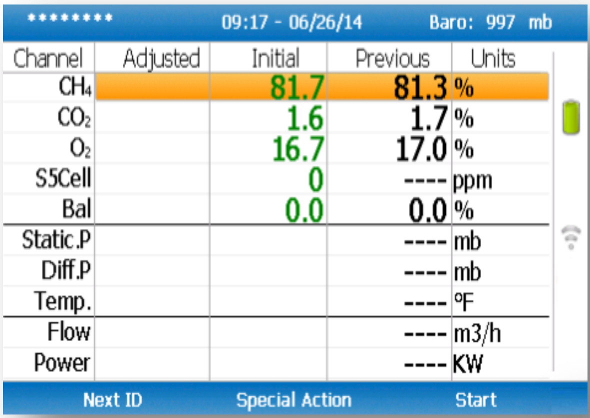
If created on the analyzer, you can only fill out basic information, such as ID code, description and ID type. Whereas on LSGAM, you can assign site and ID questions (please see below), assign flow devices, input GPS coordiantes etc.

To create an ID on LSGAM please consult the LSGAM operating manual. To create an ID on the instrument:

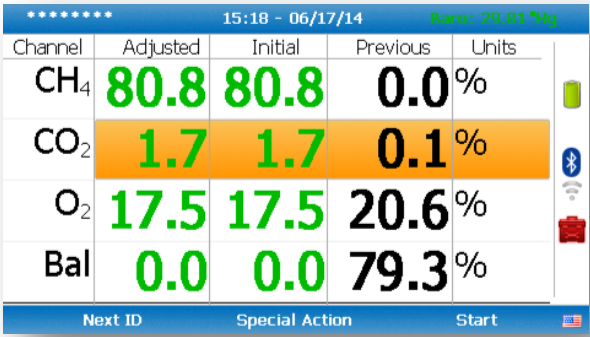
1) Press the left blue arrow key for ‘Next ID’
2) Press the right blue arrow key for ‘Add’
3) Input an ID code using the keypad
4) Press enter
5) Using the corresponding number to input different properties of the ID
6) Once you are happy, press the middle key for ‘add’

8.2 Change screen layout

Use key 2 to toggle between 2 different ways of viewing the gas reading screen:



Default view



You can use key 4 and key 6 to switch between the gases page and the pressure & flow page. This feature is only available on analyzers running on firmware version 1.11 or later.

8.3 Answering site questions

Prior to taking the readings at a particular site, the site questions should be populated, this is only necessary when using site questions, if not, please proceed with the reading as normal. This is accessed via the 'Special Action' menu. The answers to these questions are then stored and appended to each reading stored thereafter, until the site questions are updated for another site. You will need LSGAM software to create site questions and if you are using LSGAM, this data will be uploaded to LSGAM along with the reading data.

8.4 Answering ID questions

Prior to, or after, you have taken the reading, the ID questions should be populated, this is only necessary when using ID questions, if not, please proceed with the reading as normal. When you have uploaded IDs with ID questions assigned to them (LSGAM software required), you will be prompted to answer these questions at the end of the reading, this means that the answer only equates to that reading.

8.5 Special action

This menu enables the operator to perform the additional following functions out of sequence if so desired.

1) From the 'Main Gas Read Screen' select the soft-key 'Special Action' and the following menu is displayed:

✍ Note: The list of special action options displayed on the special action menu is dependent upon device type and sequence.

The following actions may be available:

Action	**Function**
Key 1 – Simple Gas	This action enables the operator to take a quick gas reading. The pump will start running automatically when this key is selected. The operator can stop the pump by pressing the pump key on the keypad at any time and the reading can then be stored by selecting soft-key 'Store'.
Key 2 – Site Questions	This action enables the operator to update site questions prior to taking a reading.
Key 3 – ID Questions	This action enables the operator to update ID questions specific to sample points prior to taking a reading.
Key 4 – Flow	This action enables the operator to measure internal flow first when taking a reading. Connect the blue hose to the sample point. The yellow hose can be vented a safe distance from the sample point or re-circulated back into the system. Select either soft-key 'Zero Flow',' Flow Options' or 'Start' to commence internal flow. Select soft-key 'Store' to store and record the reading.
Key 5 – Enter Temperature	This action enables the operator to manually enter a temperature reading if not using a temperature probe prior to taking a gas measurement.
Key 6 – Start Logging	This action enables the operator to leave the analyzer unattended to take samples at a predetermined time. The reading interval and pump run times may be edited prior to commencing the logging cycle.

8.5.1 Configuration of the data logging option

1) Connect the gas inlet (white port) to the sample point. The yellow exhaust hose can be vented a safe distance from the sample point; do NOT re-circulate back into the system.
2) By selecting 'Next ID' the operator can select the ID which is being sampled at present.
3) Once the ID has been chosen the analyzer will commence and complete its clean air purge cycle.
4) To gain access to the data logging option the operator will be required to select the 'Special Action' key to obtain the special user options. The data logging option can then be selected via 'Key 6' to configure the logging parameters.
5) Once the operator has confirmed the logging parameters, select soft-key 'Start Logging'.
6) Once the logging function has been activated the analyzer will carry out a 30 second warm-up (displayed below the temperature read out at the right of the main gas read screen) and begin the first sample.
7) If for any reason during the logging cycle the inlet port becomes blocked, the analyzer will sense this as a 'Flow Fail' and the pump will automatically retry until the reading can be obtained. As such care must be taken when positioning the sample tubing to ensure water/moisture ingress does not occur.
8) Select soft-key 'Stop Logging' to stop logging if required.

8.5.2 Profiling option

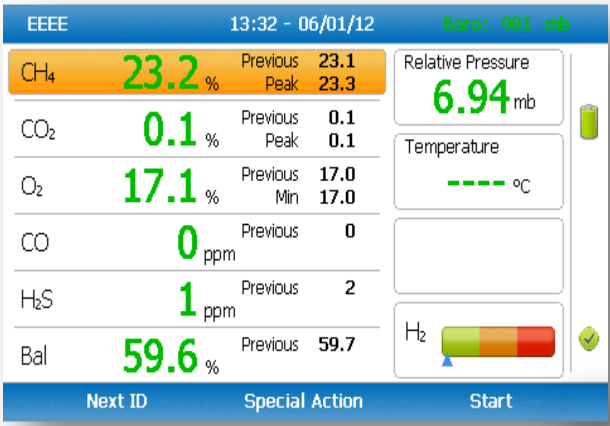
1) The 'Logging Mode' center soft-key toggles between 'Logging Mode' and 'Profiling Mode' and pressing it will change the mode to the one the soft-key describes. For example, when on the profiling page the key will display as 'Logging Mode' and when on the logging page the key will display as 'Profiling Mode'.

2) To edit the parameter the operator will be required to select 'Key 3' to select the number of reading required. Once the number of readings has been updated press the return key to confirm parameter setting.
3) By selecting 'Key 2' the operator can edit the logging interval of their logging preferences and then confirm the amendments by pressing the return key.
4) Once the logging parameters are confirmed, commence the logging by selecting the 'Start Logging' key.
5) If for any reason during the logging cycle the inlet port becomes blocked, the analyzer will sense this as a 'Flow Fail' and the pump will automatically retry until the reading can be obtained. As such care must be taken when positioning the sample tubing to ensure water/moisture ingress does not occur.
6) Select soft-key 'Stop Logging' to stop logging if required.

Select the soft-key 'Exit' to exit this menu and return to the 'Main Gas Read Screen'.

8.6 GEM analyzer in GA mode

The operator may toggle between GEM (a gas extraction monitor) and GA (a landfill gas analyzer) mode of operation if required. From the 'Special Action' menu, select the middle soft-key to toggle between GEM and GA Mode.



✍ Note: For operating instructions on how to use the GA5000 mode of operation, please refer to the GA5000 gas analyzer operating manual.

8.7 The gas flow measurement screen

The GEM5000 gas analyzer enables gas and flow measurements to be recorded by using:

- A flow device i.e. a PITOT tube, Orifice plate, Accu-Flo or anemometer.
- A temperature probe.

The GEM5000 instrument has the extra functionality to measure the calculated calorific value of the gas. The site engineer uses the information recorded by the analyzer to make adjustments to the gas flow for specific boreholes. The initial and adjusted flow rates are recorded.

8.8 How to use an anemometer (optional)

The GEM5000 gas analyzer has the facility to attach an anemometer device enabling the site engineer to measure the flow of gas within an extraction system. The anemometer can be set to display two values; m/s (meters per second) and m^3/hr (metres cubed per hour).

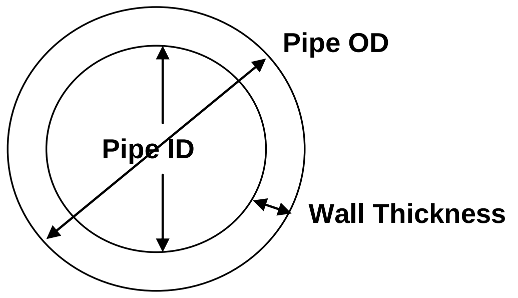
It is best practice to take the gas reading first before taking the flow reading with the anemometer attached.

If using a 'borehole ID' the internal pipe diameter can be predetermined in the optional LSGAM software. Once set, the site engineer cannot edit the pipe diameter setting.

If the site engineer is not using a borehole ID or the pipe diameter is not set in LSGAM the operator will be prompted to enter a pipe diameter with a new ID on the analyzer. Select soft-key 'Next ID' from the Main Gas Read screen, followed by soft-key 'Add' and add a new borehole location.

In order to use the anemometer it is important to know the internal diameter (ID) of the pipe if you want to calculate the flow in m^3/hr (metres cubed per hour). This must be the internal diameter not the outer diameter (OD) i.e. pipe outer diameter minus twice the pipe wall thickness.

For example:



If you do not have any suitable monitoring points you will need to drill (tap of ¾" BSP pipe thread) a hole in the piping of between 25mm and 30mm in diameter to seat the conical fitting on the anemometer (which is roughly between 20mm to 34mm). When not in use the hole can be re-sealed with a ¾" BSP male bung.

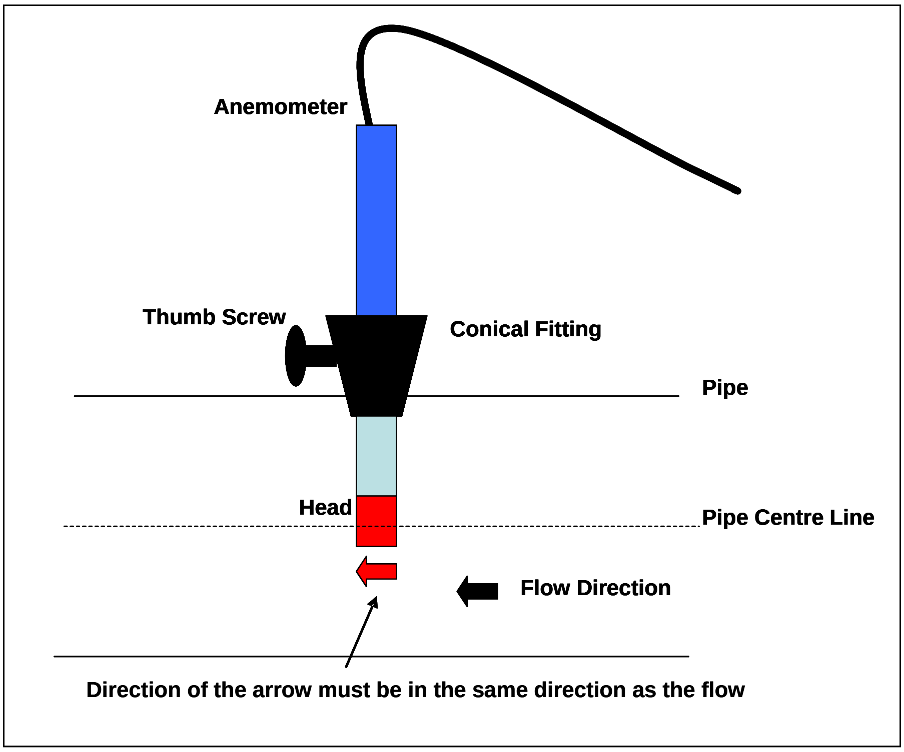
✍ Note: When the anemometer is not in use the conical fitting should be placed over the probe to protect it.

The anemometer must fit centrally (the conical fitting must be set on the probe to half the pipe ID before insertion). The arrow on the tip of the probe must point in the direction of the gas flow.

✍ Note: Use the thumb screw to help align the direction of the probe into the gas stream.

Flow readings are most accurate when there is laminar flow (not turbulent). Turbulence can be caused by a change in pipe direction or restriction. Ideally, upstream you want at least 20 times the pipe ID along the length of the pipe without restriction or bend. Downstream, you want at least five times the pipe ID along the length of the pipe i.e. for a 100mm ID you need 2000mm of clear pipe upstream, 500mm downstream.

Example to show anemometer fitting into the sample point:



Instructions for use:

1) Attach the anemometer to 'Connector C' (refer to section 5.3 – Instrument connection points).

2) Place the anemometer into the pipe (sample point) ready to take the reading.

3) To take a flow measurement when using an anemometer, follow the instructions displayed on the analyzer. When the reading has stabilized press the 'Enter' key to store the reading.

Anemometer cleaning instructions:

General handling tips:

- Protect the probes against severe vibration.
- Do not kink the connector cable (risk of cable breakage).
- Never allow hard objects to contact rotating impellers.
- Always carry out probe cleaning according to the cleaning instructions.
- Never immerse probes in solvent.
- Never blow probes through with compressed air.
- Allow hot probes to cool slowly, never cool by plunging them in cold water etc.

Cleaning instructions:

- Instrument and probe must be switched off or disconnected prior to cleaning.

Vane probes:

- As the probes are highly sensitive measuring instruments, they must be cleaned with great care.
- Fibres or other foreign bodies can be carefully removed with fine tweezers. When doing so, take care not to bend or otherwise damage the vanes or the spindle.
- The adjustment of the bearing screws must never be changed. This can result in an erroneous measurement.
- Never allow hard objects to contact rotating impellers.
- Cleaning agents that extract the plasticizer from the plastic are never to be used for plastic probes (practically all solvents).

Cleaning the probes – best practice:

✍ Note: Use soapy water.

Cleaning example:

1) Carefully, swish the top part of the impeller back and forth in clean soapy water for approximately 10 minutes. Then swish the top part of the impeller back and forth in clean soapy water. If soapy water is used as a cleaning agent it is advisable to wash out the soap solution thoroughly with distilled water.

2) After cleaning the probe, rub it dry with a clean, dry cloth.

8.9 How to use a pitot tube (optional)

The GEM5000 gas analyzer enables the site engineer to take gas measurements using a pitot tube. The pitot tube is used for gas extraction systems and the pressure readings are taken in mbar. Gas flow is calculated in the analyzer in m^3/hr (metres cubed per hour).

Example of a pitot tube

Fitting a pitot tube to the analyzer:

1) It is important to seat the pitot tube into the monitoring point with the tip facing into the gas flow. The pitot tube should also be housed half way down the monitoring pipe. (Please refer to the anemometer instructions, which detail how to calculate the pipe diameter correctly).

2) Make sure that the sample tubing attached to the pitot tube fits correctly.

3) Attach the sample tube from the top connection of the pitot tube to the 'blue port' (the differential port) on the analyser making sure that the gas port connector secure into place.

4) Attach the sample tube from the side of the pitot tube to the 'white port' (inlet port/static pressure port) on the analyser making sure that the gas port connector secures into place.

5) House the pitot gland correctly onto the monitoring point.

6) When taking a gas reading and flow measurement follow the instruction as displayed on the front of the instrument.

   ✍ Note: Please refer to the following section for a diagram showing how to fit the tubing to the pitot tube.

8.10 How to use an H_2S filter (optional)

8.8.1 Cross gas effects on chemical cells

Measurements of CO are important in landfill management. The GEM5000 analyzer incorporates an improved CO measurement.
Measurements of CO can be affected by two other gases that can be found in landfill gas – hydrogen and hydrogen sulphide.

To reduce the effect of hydrogen, the GEM5000 analyzer uses a technique that is hydrogen compensated. Hydrogen compensation is achievable up to a level of around 2000ppm. Above this level the CO reading will not be compensated for.

In order to assist the operator the GEM5000 instrument also indicates the level of hydrogen present as low, medium or high. If a high hydrogen reading is present then the CO reading may be affected.

The effect of hydrogen sulphide is eliminated by the use of a H_2S filter.

CO measurement

The CO measurement is sensitive to hydrogen sulphide. The presence of hydrogen sulphide can cause the CO reading to elevate (not to be the true value due to the interfering gas). If the presence of hydrogen sulphide is suspected to be causing false CO readings, then it is recommended that the external hydrogen sulphide filter is used while obtaining the CO measurement.

The H_2S filter only needs to be used when you are trying to remove of any possible cross gas effects H_2S might have on other gas channels. Do not use the filter on all boreholes.

When using the H_2S filter you will need to increase the gas sample and clean air purge run-time, as using an H_2S filter decreases the response time of the analyzer.

✍ Note: There is an internal H_2S filter incorporated in the chemical cell that removes the H_2S; however this has a limited life span.

The electrochemical cells used to measure H_2S and CO do suffer from cross-gas effects. Such effects are not accurately specified. However, the following table may be useful as a guide; it represents how many ppm would be read by a cell if 100 ppm of the interfering gas were applied, with no other cross-contaminates being present in the sample.

GEM5000

		Interfering Gas				
		CO	H_2S	SO_2	NO_2	H_2
Chemical Cell	**CO (H2 compensated**	100	0 / ~300*	0	0	<1
	CO	100	<4 /~300*	0	-20 to +5	<60
	H2S	<4	100	20	<-25	<0.2

*after internal filter depleted.

✍ Note: Other gases could cause cross-gas effects. If you suspect a cross sensitivity problem please contact Technical Support (800) 968-2026 or email landtec_support@qedenv.com

8.9.2 Cross-gas effects on methane, carbon dioxide and oxygen

Methane is measured using dual beam infrared absorption. Analyzers are calibrated using certified methane mixtures and will give correct readings provided there are no other hydrocarbon gases present within the sample (e.g. ethane, propane, butane, etc.). If there are other hydrocarbons present, the methane reading will be elevated (never lower) than the actual methane concentration being monitored.

The extent to which the methane reading is affected depends upon the concentration of the methane in the sample and the concentration of the other hydrocarbons. The effect is totally non-linear and difficult to predict.

✍ Note: The effect can be reduced by using an H_2S filter as it can reduce higher order hydrocarbons. When using the H_2S filter you will need to increase the gas sample and clean air purge run-time, as using an H_2S filter increases the response time of the analyzer.

Carbon dioxide is measured by infrared absorption at a wavelength specific to carbon dioxide. Therefore, the carbon dioxide reading will not be affected by any other gases usually found on landfill sites.

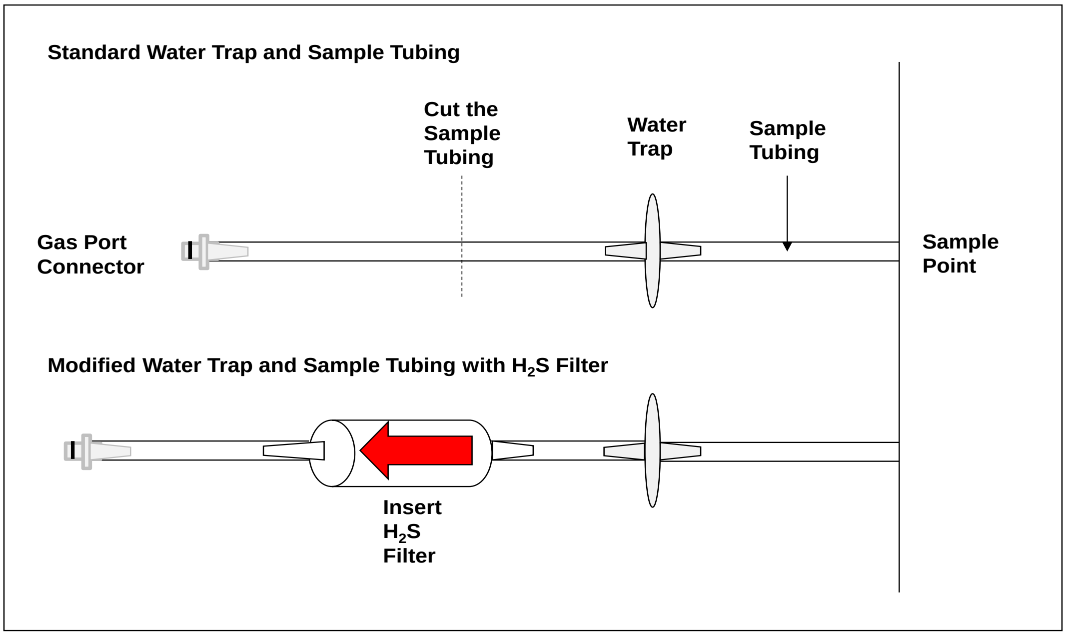
The oxygen sensor is a galvanic cell type and suffers virtually no influence from CO_2, CO, H_2S, NO_2, SO_2 or H_2, unlike many other types of oxygen cell.

The infrared sensors will not be 'poisoned' by other hydrocarbons and will revert to normal operation as soon as the gas sample has been 'purged'.

H_2S filter:

<u>Instructions for use:</u>

The following diagram shows how to modify the standard water trap and sample tubing to fit the H_2S filter.

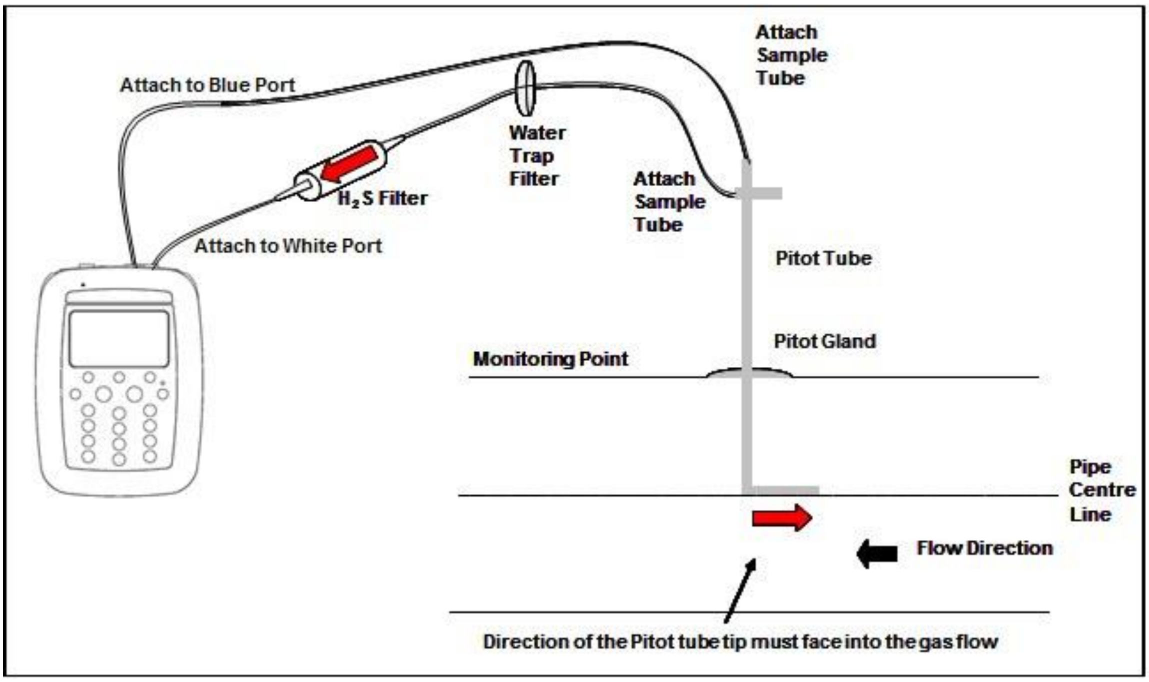


✍ Note: When onsite the site engineer must have an unmodified water trap assembly in addition to the modified water trap with a H_2S filter in order to take readings with and without a filter.

1) Once the H_2S filter is fitted follow the instructions as detailed on the front of the gas analyser displayed when taking readings using a H_2S filter.

✍ Note: This is only for analysers fitted with the CO compensated cell.

Fitting a pitot tube to a sample point when using an H_2S filter:



2) Make sure the water trap filter is fitted as close as possible to the pitot tube. This will help protect and trap moisture before it reaches the H_2S filter. Make sure that the water trap filter is clean and dry.

3) Attach the sample tubing into the analyzer.

4) To take flow readings using a pitot tube, please follow the instructions displayed on the front of the instrument. The user will be prompted to complete each step and should follow the instructions on screen.

✍ Note: It is important to fit the pitot tube central and parallel with the pipe.

8.11 How to use a temperature probe (optional)

The temperature probe enables the site engineer to measure the temperature of the gas within a sample point. The GEM5000 gas analyzer uses the temperature of the gas to give more accurate flow measurement readings as part of the instrument calculation.

Instructions for use:

1) The temperature probe reading is taken along with the gas measurement reading.

2) The analyzer must be at the 'Main Gas Read Screen'.

3) Attach the temperature probe to 'connector B' (refer to section 5.3 – Instrument connections points).

4) Insert the temperature probe into the sample point (borehole) at the same time as you attach the sample tube to the sample point (two sample points are required for the borehole).

5) Follow the instructions on the front of the instrument when taking your gas and measurement reading.

6) At the point in which the operator presses 'Enter' to store the gas reading the temperature is recorded.

✍ Note: Temperature probe readings can be analysed further when downloaded to LSGAM.

8.12 How to identify a borehole using the GPS feature (optional)

An optional GPS feature is available for the GEM5000 gas analyzer. It enables the site engineer to automatically locate borehole IDs using GPS satellite signal from predefined borehole IDs uploaded from LSGAM. The GPS reading data is stored for each measurement reading.

✍ Note: Borehole IDs may be uploaded from LSGAM with or without location information. If location details are not uploaded the location longitude and latitude coordinates can be stored when the borehole is located and downloaded to LSGAM with the reading measurements.

Screen navigation:

1) Switch on the analyzer and wait for the self-test warm-up to complete and the analyser will display the 'Main Gas Read Screen'.

2) In order to use the navigation function if configured, you must switch 'Navigation - On' on the analyzer. Select the 'Menu' key followed by 'Key 5' to toggle navigation to on. Select the 'Menu' key to exit and return to the 'Main Gas Read Screen'.

3) Select the soft-key 'Next ID', then select a borehole ID from the list displayed and press the 'Enter 'key to continue.

⚠ **Warning**	Before entering the GPS Navigation Screen for the first time the following health and safety message will be displayed. "Please be aware of the terrain when using this screen. You are responsible for your own safety whilst walking on-site!"

4) After reading the user warning message, select the soft-key 'Dismiss'. Use the tracking display to locate the borehole

✍ Note: There is often a wait time frame of between 30 seconds to two minutes while getting a satellite signal. Be aware that heavy rain, trees overhead etc. will give a bad fix.

5) Once the operator selects a borehole ID the 'GPS Navigation' screen is displayed.

6) If required, select soft-key 'Options' to go to the 'Navigation Options' menu and the following screen is displayed:

Navigation options

Key 1		Key 1 to toggle between 'Meters', 'Feet' or 'Yards' to define the unit of measurement.
Key 2		Key 2 to toggle between 'Manual Scaling' and 'Automatic Scaling' to locate a sample point using a satellite signal.
Key 3		Key 3 to display sample point information:
	Bearing:	Direction.
	UTC time:	'Universal Time Code' received from the satellite and displays GMT.
	Latitude:	Latitude displays as degrees, minutes, seconds and decimal seconds. The equator is 0.
	Longitude:	E (East) or W (West) displays the longitude as degrees, minutes, seconds and decimal seconds. The Greenwich meridian defines the zero point.
	Altitude:	Altitude displays in meters, feet or yards.
	Satellite:	This is the number of satellites that the system can select. Four satellites will give reasonable position accuracy; eight or more satellites will increase accuracy.
	Horizontal:	Estimate of horizontal error on the indicated position. The location is accurate to horizontal error 1.6m.
	Vertical:	Estimate of vertical error on the indicated position.
	HDOP:	'Horizontal Dilution of Precision' which measures the accuracy of the indicated position.

Changing the selected ID

It is possible to change the currently selected ID (identified by green icon ) by pressing the 2 and 8 and keys to move the cursor up and down the list of visible Ids. To change the selection press Enter. Notice that the selected ID moves to the top of the list and its icon turns green.

Changing the scale

You can change the display's scale by using the 4 and 6 keys to zoom in and out.

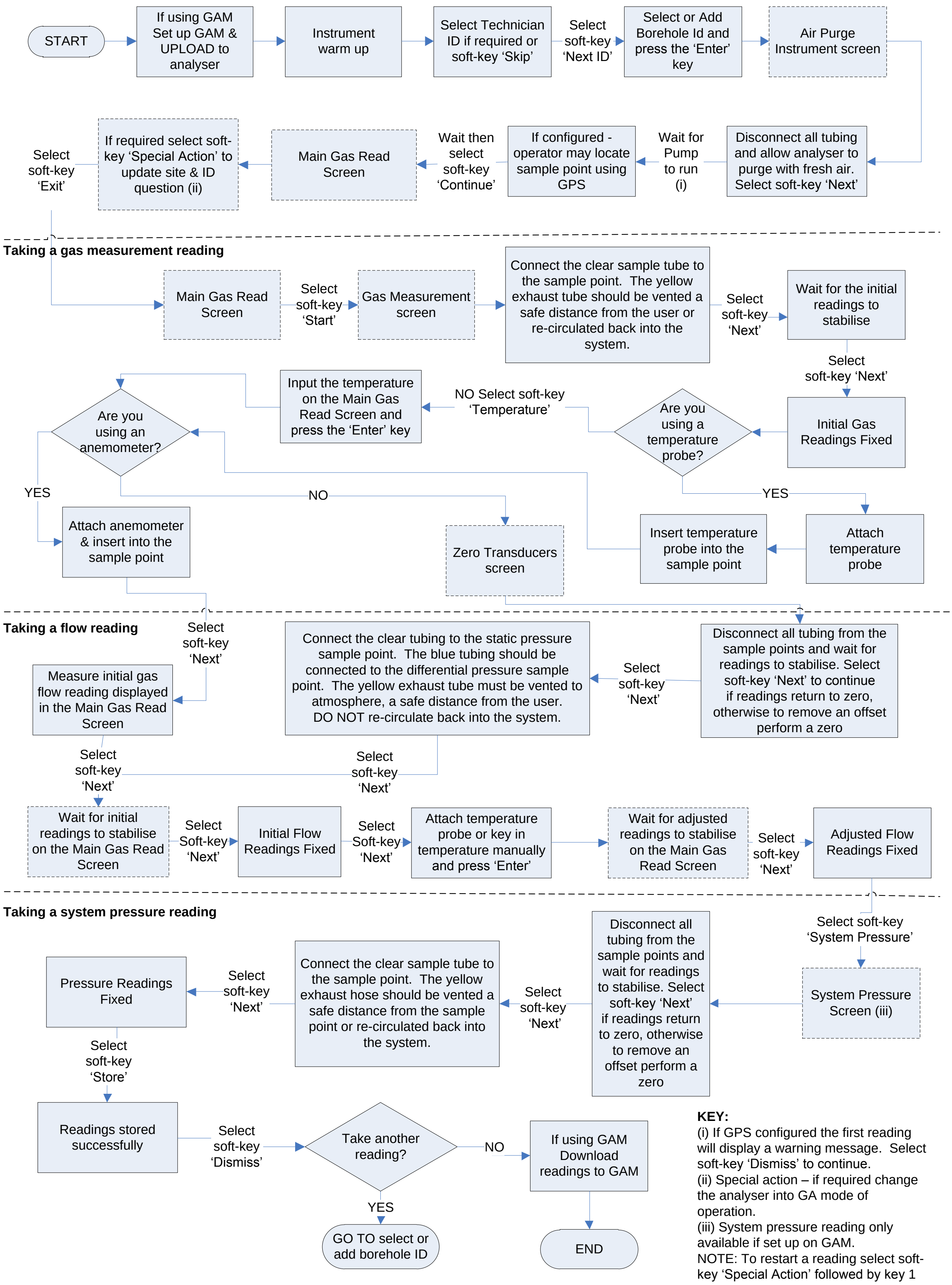
GPS signal strength:

This icon shows the signal strength the analyzer's GPS module is able to provide. Full, okay and fair strength respectively.

GPS failure - the GPS was unable to get a line of sight lock on enough satellites. Or, it may be that it hasn't had time to get a lock.

7) Select soft-key 'Continue' and the operator is returned to the 'Main Gas Read Screen'.

8.13 Taking gas and flow measurement



KEY:
(i) If GPS configured the first reading will display a warning message. Select soft-key 'Dismiss' to continue.
(ii) Special action – if required change the analyser into GA mode of operation.
(iii) System pressure reading only available if set up on GAM.
NOTE: To restart a reading select soft-key 'Special Action' followed by key 1 'Restart Process'.

9.0 Calibration

9.1 Calibration introduction

The GEM5000 gas analyzer is carefully calibrated at manufacture and when returned for service. However, it is sometimes desirable to be able to carry out a calibration process between services.

This section outlines the correct procedures to enable the site engineer to field calibrate the gas analyzer.

✍ Note: This does not replace the factory service and calibration. If this calibration is completed incorrectly it may decrease the accuracy of the gas analyzer.

CH_4, CO_2 and O_2 can be measured by GEM5000 gas analyzer as standard; these channels can be user calibrated. The analyzers have other gas channel options that are specified at manufacture; these too can be calibrated. This section will describe in detail how to calibrate the three standard gas channels plus the CO channel.

The GEM5000 instrument can have a H_2 compensated CO channel. This option requires that H_2 is used in the calibration process and is also set out within this section.

For the other gas channel options contact QED for advice.

Two important terms that are used within this section are 'Zero' and 'Span'.

Zero: The point at which the gas analyzer is calibrated when there is none of the target gases present.

Span: The point at which the gas analyzer is calibrated when a known quantity of the target gas is present.

9.2 Frequency of calibration – best practice

The GEM5000 gas analyzers can be checked against a known concentration of gas, to give confidence that the analyzer is operating as expected at the time and conditions in which it is being used.

It is recommended that the instrument is regularly serviced and calibrated by QED in accordance with the due date on the instrument.

When defining the frequency of user calibration, the following are factors to be considered:

- The frequency of use of the analyzer. (daily?/monthly?)
- The level of confidence and accuracy required for readings to be taken.
- Historical user calibration data.
- Site specific requirements or conditions.
- Historical understanding of expected readings on site.

Zeroing of the gas analyzer should be undertaken at the start of each day's monitoring.

Use historical data to drive your frequency of calibration.
If there is no historical data a good starting point for a daily monitoring round is performing a calibration once every week or every other week.

The results of the calibrations will need to be recorded to monitor over time whether the frequency of calibration needs to be increased or decreased relative to the confidence required.

The confidence required will be driven by the site specific / user requirements.

When undertaking the monitoring with an understanding of the history of the gas levels of that site, a calibration check could be triggered if the readings measured are different to what is expected.

✍ Note: For assistance please contact Technical Support at (800) 968-2026 or email landtec_support@qedenv.com

9.3 Calibration gases

User calibration of a gas analyzer will greatly improve the data accuracy in the range of the calibration gases used. This may cause less accurate readings of concentrations outside this calibrated range. Users should select the correct calibration gas for the expected gas levels on their particular application.

- To improve calibration at lower levels requires the use of gas mixtures 1 and 2.
- To improve higher levels use gas mixture 3.
- For standard CO only 100ppm CO gas is needed.
- For CO (H_2 compensated) both CO 100ppm and H_2 1000ppm gases are needed.

The following table indicates the different gas mixture canisters used for calibration:

Calibration gas	**CH_4**	**CO_2**	**O_2**
Mixture 1	5%	5%	6%
Mixture 2	5%	10%	0%
Mixture 3	60%	40%	0%

Calibration targets for gas cells are dependent on the gas/range and type of cell fitted. Contact Technical Support for assistance.

These are for general use but other gas concentrations can be used.

✍ Note: The above gases and most other gas concentrations can be supplied by QED. For further information please contact Sales at (800) 624-2026 or email info@qedenv.com

⚠ **Warning**	Calibration gases can be dangerous. For each gas used the appropriate material safety data sheet must be read and understood before proceeding.

9.4 Calibration set-up

⚠ **Warning**	Do NOT attach the gas supply to the gas analyzer before putting the analyzer into the 'Gas Check' screen. Select 'Check Spans' from the 'Operation Settings' menu.

The regulator supplied with the calibration kit has been configured to deliver a fixed flow.

As the regulator's flow is factory set, it only requires a few turns to open, no adjustment is necessary.

⚠ **Warning**	**Exhaust port** When the gas analyzer is being calibrated, there are two possible exits for the gas, via the usual manner out of the exhaust (yellow) port of the analyzer or in cases of over-pressurisation the 1/16″ port on the red pressure relief valve located on the regulator. It is recommended that both ports have exhaust tubing attached. The exhaust tubing must emerge in a well-ventilated area. Ensure there are no leaks in the tubing and connections. The calibration of the gas analyzer should be carried out in a safe area with all necessary precautions taken when using potentially dangerous, explosive or toxic gases.

✍ Note: There is also potential for gas to expel from the internal flow (blue) port of the gas analyzer (applies to the GA5000 only).

9.5 Calibration equipment

The diagram below displays the regulator and tubing equipment for user calibration:

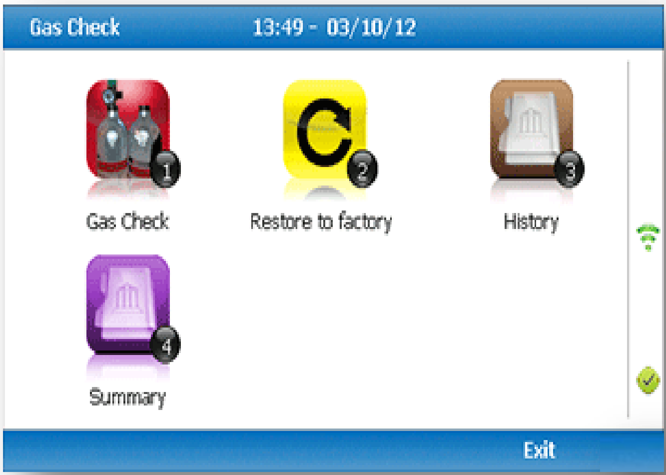
- Certified calibration gas, available in either 29 liter, 34 liter or 58 liter gas canisters are supplied with the Landtec calibration kit. Please refer to the Landtec website www.landtecna.com for further information.

- The regulator supplied with the calibration kit is pre-set for flow and pressure rates that are factory set.

- If you are using a non Landtec supplied regulator, please ensure that it does not supply any greater than 200 mbar pressure.

9.6 Gas analyzer

For the GEM5000 gas analyzer the calibration options can be found by selecting the 'Menu' key followed by soft-key 'Operation Settings'. Select 'Key 2 – Gas Check' then follow the instructions on the analyzer screen by selecting 'Key 2 – Gas Check'.



9.7 Calibration processes – best practice

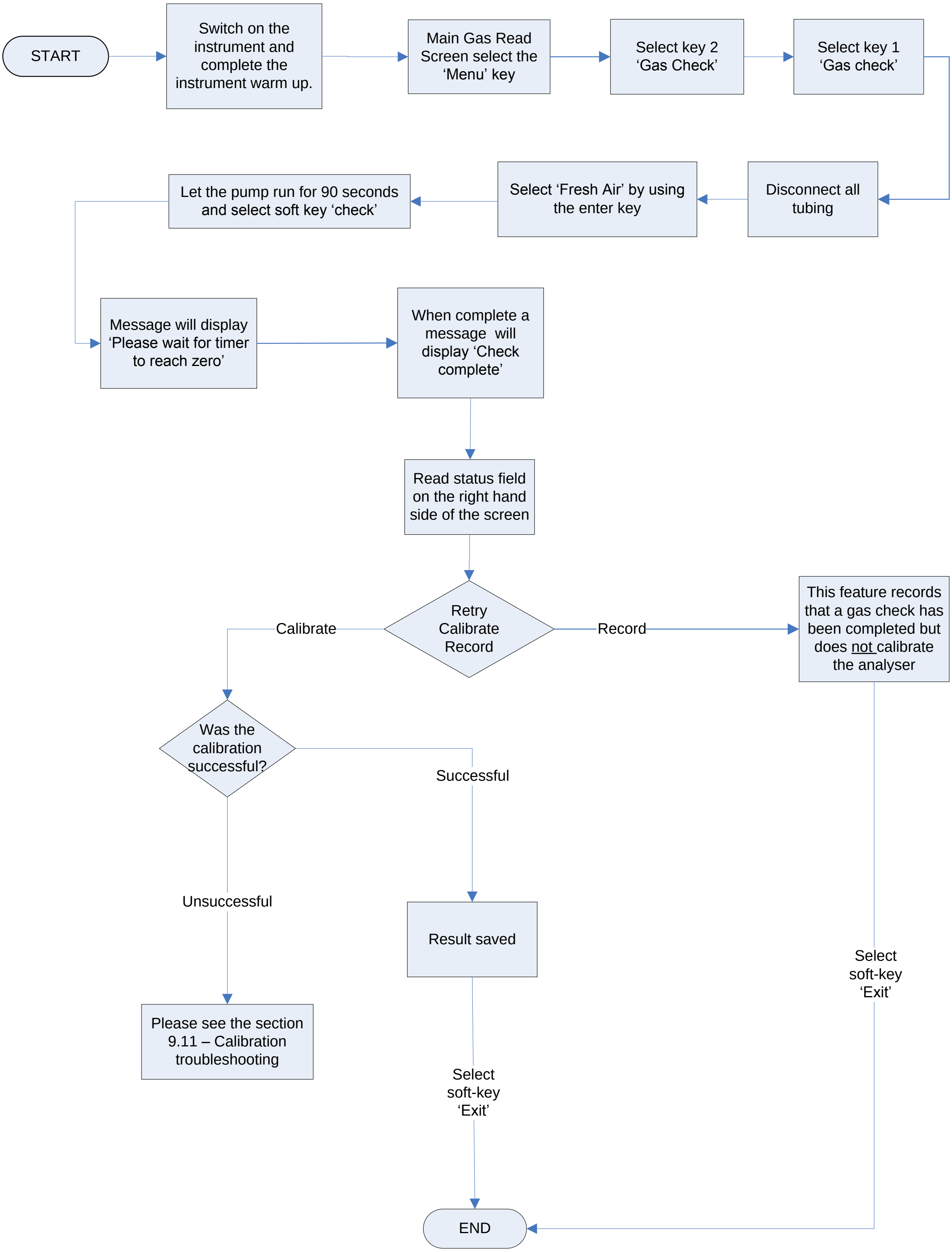
The following process diagrams outline the calibration steps.

- Ensure that you are regulating calibration gas down to below 200 mbar pressure, if you're not using a Landtec regulator. The use of a pressure relief valve is also highly recommended.

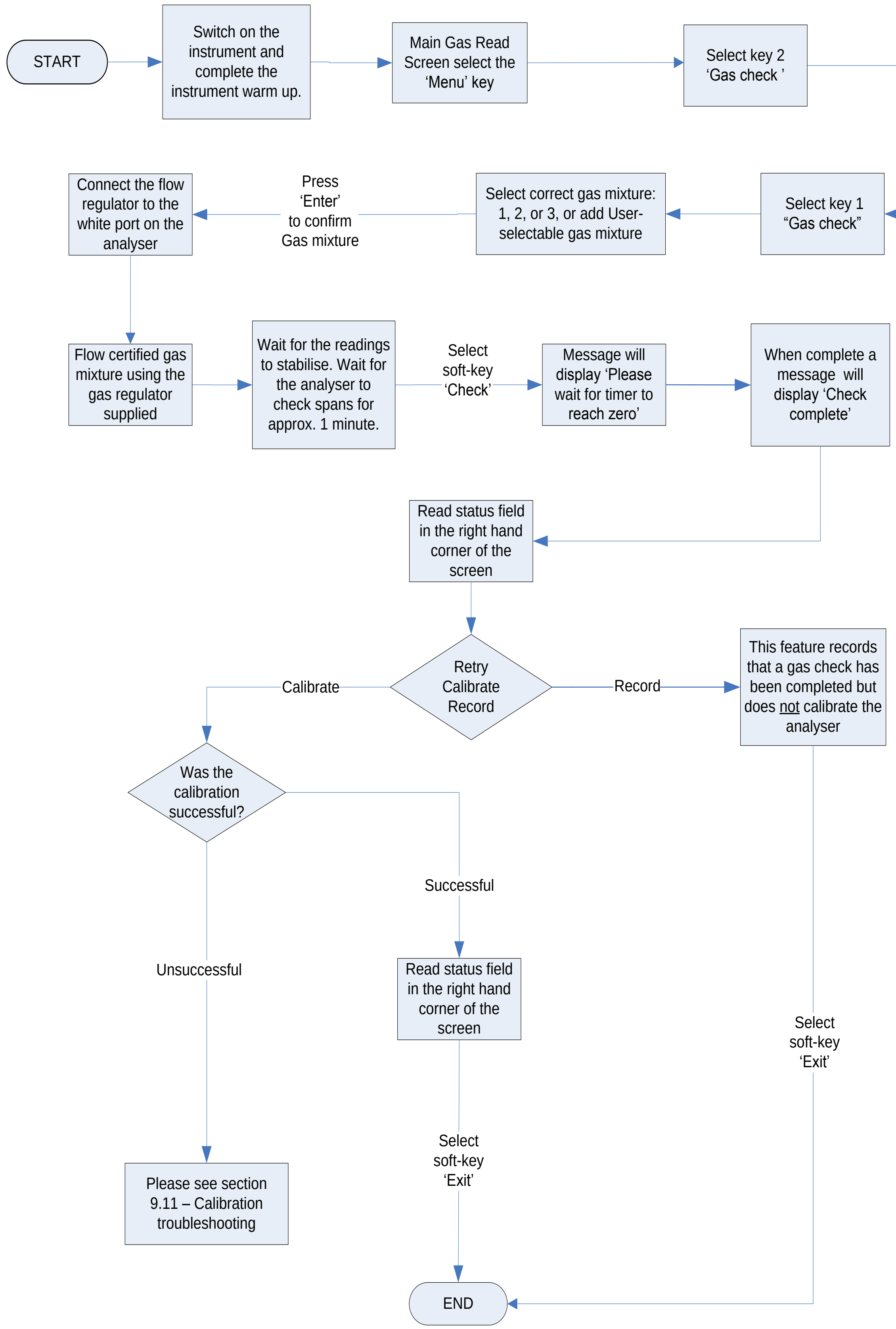
- When calibrating, it is recommended to use a calibration mixture close to the levels you are trying to measure, i.e. if you are trying to measure gas migration on a closed landfill, we'd recommend calibrating with CH4 5%/CO2 5%.

- In regards to frequency, we would recommend that you perform a fresh air calibration before each monitoring session, and a span calibration typical every 4 – 6 weeks.

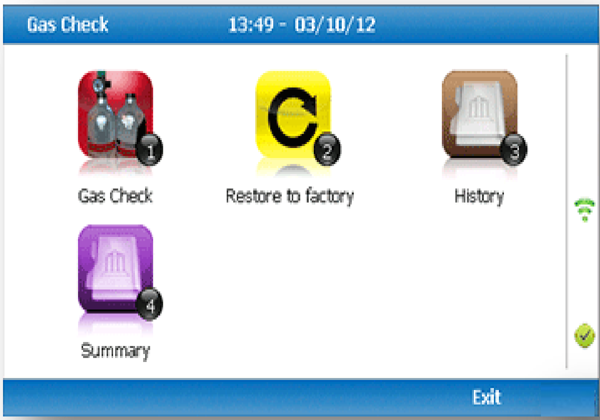
9.7.1 Gas Check in fresh air



9.7.2 Calibration – mixtures 1, 2, & 3



9.8 Restore to factory settings



This option will reset the gas analyzer to all of its factory programmed calibration settings and will clear ALL the user defined calibration points. It will not affect or remove ID's or readings from the analyzer.

1) Select 'Key 2 - Restore to factory' followed by the soft-key 'Confirm' or 'Cancel'.

2) A validation message is displayed 'Reset user calibration?' Press the soft-key 'Confirm' to continue with the factory settings or soft-key 'Cancel' to cancel the operation and return to the Gas Check menu.

9.9 Calibration history

The GEM5000 gas analyzer logs user calibrations in 'History' application. This can be used as an aid to ensuring that gas measurements are valid and accurate. Both good and failed calibration results are recorded for each channel calibrated.

1) Select 'Key 3 – History'.

2) The operator may view the calibration data stored. Use the soft-key 'Filter' to add a sort filter to the history enquiry.

9.10 Calibration summary

The GEM5000 gas analyzer has the facility to log the history of user calibrations.

1) Select 'Key 4 – Summary'.

2) The operator may view the calibration data history stored by ID, technician, timestamp, type and calibration result. Use the soft-key 'Exit' to exit and return to the 'Gas Check' menu.

10.0 Problem Solving

This section outlines various warning and error messages which the operator may receive during general operation of the instrument. For further assistance please contact Technical Support at (800) 968-2026 or email landtec_support@qedenv.com

11.0 Warning and error display

When switched on, the instrument will perform a pre-determined self-test sequence taking approximately 15 seconds. During this time many of the instrument's working parameters and settings are checked.

If any operational parameters are out of specification or the pre-programmed recommended calibration/service date has passed, errors or warnings may be displayed.

Use the 'Scroll up' and 'Scroll down' keys to move through the list if required.

Only three warnings/errors can be displayed at any time.

To ascertain if more errors have occurred use 'Key 8' – Scroll down' and 'Key 2' - Scroll up' through the list.

Warnings displayed:

All warnings displayed will be prefixed by the word WARNING followed by a relevant description.

There are two types of warning that may be displayed:

1. General warnings that may not affect the instrument's function and those where the self-test has detected a function that is outside the usual programmed operating criteria, e.g. battery charge low, memory nearly full.

2. Operational parameters that could affect the performance of the analyzer: Cell out of calibration, CH_4 out of calibration, CO_2 out of calibration.

The most likely reason for the errors is either an incorrect user calibration or sensor failure. If an incorrect user calibration has caused the warning it should be correctable by way of returning the instrument to factory settings, zeroing or carrying out a user calibration as necessary for the relevant function.

12.0 Service

The GEM5000 gas analyzer should be regularly serviced to ensure correct and accurate operation. QED recommends a service and recalibration every **12 months**.

The GEM5000 range is ATEX certified for use in potentially explosive areas. As such it should be serviced only by qualified engineers. Failure to observe this will result in the warranty becoming invalid and could invalidate the ATEX certification.

⚠ **Warning**	If the GEM5000 is serviced by unqualified engineers the ATEX certification may be invalidated and the instrument may be unsafe for use in a potentially explosive atmosphere.

User serviceable parts:

There are no user serviceable parts inside the instrument.

The following parts can be user serviced:

In-line water filter	This should be regularly inspected for obstructions, moisture or damage and changed if needed. The instrument should never be operated without the in-line water filter as this may result in water entering the instrument.
Sample tubing	Always ensure that sample tubes are not contaminated or damaged.
Gas port connectors	Periodically check that the O-rings on the gas port connectors are not damaged. A damaged O-ring can let air into the sample gas and result in incorrect readings. If the O-ring is damaged the complete gas port connector should be replaced.
H_2S filter material	When the filter material changes color to a *light gray* color the filter should be replaced.

13.0 Warranty policy

This instrument is guaranteed, to the original end user purchaser, against defect in materials and workmanship for a period of **3 years** from the date of the shipment to the user.

During this period QED will repair or replace defective parts on an exchange basis.

The decision to repair or replace will be determined by QED.

To maintain this warranty, the purchaser must perform maintenance and calibration as prescribed in the operating manual.

Normal wear and tear, and parts damaged by abuse, misuse, negligence or accidents are specifically excluded from the warranty.

✍ Note: Please contact Technical Support at (800) 968-2026 or email landtec_support@qedenv.com for further information.

14.0 Glossary of terms

5000 series	The 5000 series refers to the GA5000, GEM5000 and the Biogas5000 gas analyzers.
Accu-Flo	A flow device used to aid accurate flow measurement.
Analyzer error messages	Operational errors are prefixed on the analyzer by the word ERROR followed by an error code. Refer to the list of standard error codes for more information.
Analyzer warning	Analyzer warnings are prefixed by the word WARNING followed by a relevant description. There are two types of warning messages displayed; general warnings that may not necessarily affect the instrument's function (for example, battery power low) and operational parameters that could affect the performance of the analyser (for example, CH_4 out of calibration).
Anemometer probe	Device for measuring velocity of gas in the pipe. The GEM5000 analyzer can be set to convert into a flow. See also flow measurement.
ATEX certification	The GEM5000 is ATEX certified to zone 1 & 2 areas above ground not in mines.
Auxiliary channel	This refers to the channels where external devices will be connected or displayed.
Backlight	The analyser has a built-in backlight for low ambient light conditions. This can be toggled on/off using the backlight key.
Barometric pressure	The atmospheric pressure at the given location.
Borehole	Typical location from which a gas sample is obtained.
Calibration	The gas analyzer is carefully calibrated against known standards.
Calibration record	The GEM5000 instrument has the facility to log user calibrations as a validation tool.
CH_4	Methane
Chemical cells	A method of gas detection that works on the basis of a chemical reaction with the target gas.
Clean air purge	Process used to clear out gas from the sample tube and analyser prior to taking a new reading.

CO	Carbon monoxide
CO_2	Carbon dioxide
Data logging	Data logging enables the operator to leave the analyzer unattended to take samples at predetermined intervals for a set period of time
Download	Terminology used for the movement of data from the analyzer to the LSGAM application on the PC.
Dual beam infrared absorption	Method of gas detection by measuring how much infrared is absorbed by the target gas.
Event log	Used as an aid to monitoring the use of the analyser. It can also be used as a diagnostic tool. The event log can be viewed via LSGAM. It cannot be viewed on the analyzer screen.
Exhaust port	The usual manner for the gas to exit the analyzer is via the exhaust port located on the top side of the analyzer. This port should have an exhaust tube attached.
Exhaust tube	Clear plastic tubing used to expel gases from the exhaust port.
Factory settings	Default settings preset at time of manufacture or service.
Firmware	Firmware is the term by which the internal analyzer software is known and is not accessible by the client. This firmware is updated to the latest version when the analyzer is returned for servicing.
Flow measurement	Flow can be measured by either gas velocity m/s or volume flow rate m^3/hr. This measurement of flow relates to the use of the anemometer and not the internal flow measurement technique.
Flow port	For the measurement of gas flow at the sample point.
Landtec Systems Gas Analyser Manager	Also referred to as LSGAM. PC based software which enables the operator to upload and download information to/from the analyser. LSGAM enables operators to maximise the operation of their gas analyzer. It features a simple upload and download facility and is fully compatible with the latest Microsoft™ operating systems. This is optional.

Gas channels	The gases that are analyzed by the instrument.
Gas velocity	The positional rate of change of the gas. Measured using the optional anemometer.
General warnings	Displayed throughout the documentation with a warning symbol. Warning information may affect the safety of operators.
H_2	Hydrogen
H_2S	Hydrogen sulphide
H_2S filter	Filter required for removal of H_2S. When the filter material changes color to a light gray color or if H_2S values are displayed, then the filter should be replaced.
Hydro-carbons	Organic compound consisting of only hydrogen and carbon.
In-line water filter	The component used to help protect the instrument from water ingress.
LCD display	Liquid Crystal Display
LEL	Lower Explosive Limit. Lower explosive limit of methane in air. 5% methane in air is the point at which it becomes explosive. 100% LEL equates to 5% methane.
m/s	Meters per second – measurement of gas velocity.
m^3/hr	Meters cubed per hour – volumetric flow rate measurement.
Main Gas Read Screen	The main analyzer screen for normal operations and all operations are carried out from this screen.
Material data sheet	Document from which information about a certain substance can be obtained.
MCERTS certification	MCERTS is the UK Environment Agency's Monitoring Certification Scheme. The scheme provides a framework within which environmental measurements can be made in accordance with the Agency's quality requirements. The scheme covers a range of monitoring, sampling and inspection activities.
Memory	Location where data and ID information is stored. The analyzer memory should not be used as a permanent storage medium. Stored data should be regularly transferred using the LSGAM download software.

NO_2
Nitrogen dioxide

Operating language
The operator can choose the default operating language for the analyzer. Choices are English, German, Spanish, French and Italian.

PPM
Parts per million

Pump
Used to draw the gas sample from the sample point to the analyzer.

Select the pump key on the analyzer to activate.

ID
The user definable identification tag allocated to a sample point.

Relative pressure
The pressure at the sample point 'relative' to atmospheric (barometric) pressure.

Relative pressure transducer
The internal component used to measure the relative pressure.

Residual N_2
The calculation for the residual N_2 used on the latest version of the GEM5000 platform is as follows:

Residual N_2 = Balance – (O_2% x 3.76)

Where, Balance = 100% - (CH_4% + CO_2% + O_2%) and 3.76 is the ratio of O_2 to N_2 in ambient air (79/21)

Sample tube
The tube used to obtain a sample of gas from the sample point to the analyzer.

Span
The point at which the gas analyzer is calibrated when a known quantity of the target gas is present.

Span multi gas
Term by which the span calibration of the three main gas channels is known. This option must only be used when the calibration gas being used is a combination of CH_4 CO_2 O_2.

Technician ID
An alpha-numeric code tagged to each gas reading. Facility only available via LSGAM. This is an optional feature.

Temperature probe
External device used to measure the gas temperature at the sample point.
This is optional.

Update site data
Enables the operator to answer pre-defined questions relating to the site, environment etc. These questions are defined via LSGAM software.

Upload	Terminology used for the movement of data from the PC via LSGAM software application to the analyzer.
Volume flow rate	The volume of a gas that passes through a given surface per unit of time e.g. m^3/hr
Warm-up self-test	Pre-determined self-test sequence to test the analyser functions which takes place after the analyzer is switched on.
Warranty	The instrument is under guarantee against defect in materials and workmanship for a period of 3 years from the date of shipment to the operator and is subject to the recommended service and recalibration requirements.
Water trap	Device used to protect the instrument from water or moisture ingress.
Zero	The point at which the gas analyzer is calibrated when there is none of the target gas present.
Zero transducers	This option allows the relative pressure transducer to be zeroed.

geotech

Landfill Gas Monitor

Landtec GEM™ 5000 Portable Gas Analyzer

The GEM™ 5000 is designed specifically for use on landfills to monitor Landfill Gas (LFG) collection and control systems. The GEM™ 5000 samples and analyzes the methane, carbon dioxide and oxygen content of landfill gas with options for additional analysis.

FEATURES

- Measures % CH_4, CO_2 and O_2 Volume, static pressure and differential pressure
- Calculates balance gas, flow (SCFM) and calorific value
- High accuracy and fast response time
- Lighter and more compact
- Certified intrinsically safe for landfill use
- Calibrated to ISO/IEC 17025
- CO and H_2S (on Plus models only)
- 3 year warranty
- Annual recommended factory service
- Available with GPS and additional gas detection

BENIFITS

- Designed specifically for use on landfills to monitor landfill gas (LFG) extraction systems, flares, and migration control systems.
- No need to take more than one instrument to site
- Can be used for monitoring subsurface migration probes and for measuring gas composition, pressure and flow in gas extraction systems
- The user is able to set up comments and questions to record information at site and at each sample point
- Ensures consistent collection of data for better analysis
- Streamlined user experience reduces operational times

APPLICATIONS

- Landfill Gas Collection & Control Systems
- Environmental Compliance
- Landfill Gas to Energy
- Subsurface Migration Probes

GEM 5000 MODELS

Model	Meter with AC Charger – No Kit
5000	CH_4, CO_2, 0_2, static and differential pressure
5000+	Adds CO (0-2000 ppm), and H_2S (0-500 ppm)
5000+1	Adds CO (0-2000 ppm), and H_2S (0-1000 ppm)
5000+5	Adds CO (0-2000 ppm), and H_2S (0-5000 ppm)
5000+10	Adds CO (0-2000 ppm), and H_2S (0-10000 ppm)
5000Nav	Adds Built-in GPS
5000Nav+	Adds Built-in GPS, CO (0-2000 ppm), and H_2S (0-500 ppm)
5000Nav+1	Adds Built-in GPS, CO (0-2000 ppm), and H_2S (0-1000 ppm)
5000Nav+5	Adds Built-in GPS, CO (0-2000 ppm), and H_2S (0-5000 ppm)
5000Nav+10	Adds Built-in GPS, CO (0-2000 ppm), and H_2S (0-10000 ppm)
GM5K-Kit	GEM 5000 Kit Includes: Hoses, heavy duty water trap filter, soft case, electronic manual accompanies software, LANDTEC System Gas Analyzer Manager (LSGAM) software, USB download cable and hard-case.

CALL GEOTECH TODAY (800) 833-7958

Geotech Environmental Equipment, Inc.
2650 East 40th Avenue • Denver, Colorado 80205
(303) 320-4764 • FAX (303) 322-7242
email: sales@geotechenv.com • website: www.geotechenv.com

geotech

Landfill Gas Monitor

Landtec GEM™ 5000 Portable Gas Analyzer

SPECIFICATIONS

Gas Ranges

Gases Measured	CH_4	By dual wavelength infrared cell with reference channel
	CO_2	By dual wavelength infrared cell with reference channel
	O_2	By internal electrochemical cell
	CO	By internal electrochemical cell
	H_2S	By internal electrochemical cell
Ranges	CH_4	0-100% (vol)
	CO_2	0-100% (vol)
	O_2	0-25% (vol)
	CO	0-2000 ppm***
	H_2S	0-500 ppm***

Gas Accuracy*	CH_4	0-5% ±0.3% (vol)	0-70% ±0.5% (vol)	70-100% ±1.5% FS
	CO_2	0-5% ±0.3% (vol)	0-60% ±0.5% (vol)	60-100% ±1.5% FS
	O_2	0-25% ±1.0% (vol)		
	CO (H_2)**	0-2000 ppm ±1.0% FS		
	H_2S	0-500 ppm ±2.0% FS		

* Typical accuracy after calibration as recommended in the operations manual.
** Hydrogen compensated Carbon Monoxide measurement.
*** Additional ranges available, call for more information.

Other Parameters

	Unit	Resolution	Comments
Energy	BTU/hr	1000 BTU/hr	Calculated from specific parameters
Static Pressure	in. H_2O	0.1 in. H_2O	Direct Measurement
Differential Pressure	in. H_2O	0.001 in. H_2O	Direct Measurement

Important Note: The information in this document is correct at the time of generation. Specification may change without prior notice as a result of continuing development.

Pump

Flow	Typically 550cc/min.
Flow with 80 in. H_2O vacuum	Approximately 80cc/min.

Environmental Conditions

Operating Temperature Range	14°F–122°F (-10°C–50°C)
Operating Pressure	-100 in. H_2O, +100 in. H_2O (-250 mbar, +250 mbar)
Relative Humidity	0-95% non-condensing
Barometric Pressure	±14.7 in. Hg (±500 mbar) from calibration pressure
Barometric Pressure Accuracy	±1% typically

Power Supply

Battery Life	Typical use 8 hours from fully charged
Charge Time	Approximately 4 hours from complete discharge

Certification Rating

ATEX	II 2G Ex ib IIA T1 Gb (Ta= -10°C to +50°C)
ISO17025	ISO/IEC17025:2005 Accreditation #66916
CSA	Ex ib IIA T1 (Ta= -10°C to +50°C) (Canada), AEx ib IIA T1 (Ta= -10°C to +50°C) USA

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GMP252 Carbon Dioxide Probe

For ppm-level measurements

Features

- Measurement range 0 ... 10 000 ppm CO_2
- Intelligent, stand-alone probe with analog and digital outputs
- Compatible with Indigo transmitters and Insight PC software
- Wide operating temperature range, −40 ... +60 °C (−40 ... +140 °F)
- IP65-classified housing
- Integrated temperature measurement for CO_2 compensation purposes
- Compensations also for pressure, oxygen, and humidity
- Sensor head heated to prevent condensation

Vaisala CARBOCAP® Carbon Dioxide Probe GMP252 is a new intelligent probe for measuring carbon dioxide. This robust, standalone measurement device is designed for use in agriculture, refrigeration, greenhouses, and demanding HVAC applications.

Benefits

- Superior long-term stability
- Reliable and accurate
- Calibration certificate included

GMP252 is suitable for harsh and humid CO_2 measurement environments where stable and accurate ppm-level CO_2 measurements are needed. GMP252 is based on Vaisala's patented, latest-generation CARBOCAP technology that enables exceptional stability. A new type of infrared (IR) light source is used instead of the traditional incandescent light bulb, which extends the lifetime of GMP252.

GMP252 incorporates an internal temperature sensor for compensation of the CO_2 measurement according to ambient temperature. The effects of pressure and background gas can also be compensated for. The measurement range is 0 ... 10 000 ppm CO_2 (measurements up to 30 000 ppm CO_2 are available with reduced accuracy). The operating temperature range of the probe is wide (−40 ... +60 °C (−40 ... +140 °F)), and the probe housing is classified as IP65. Condensation is prevented as the internal sensor head is heated.

GMP252 is resistant to dust and most chemicals, such as, H_2O_2 and alcohol-based cleaning agents.

Ease of use

GMP252 is a compact probe with easy and fast plug-in, plug-out installation. The surface of the probe is smooth, which makes it easy to clean. The probe provides several output options, including analog current and voltage outputs and digital RS-485 output with Modbus® protocol.

GMP252 can be connected to Indigo series transmitters for an extended selection of outputs and configuration options. See www.vaisala.com/indigo.

For easy-to-use access to field calibration, device analytics, and configuration functionality, the probe can be connected to Vaisala Insight PC software. See www.vaisala.com/insight.

Applications

GMP252 is ideal for agriculture, refrigeration, greenhouses, and demanding HVAC applications where stable and accurate ppm-level CO_2 measurements are needed.

A flow-through adapter with gas ports is available as an accessory, enabling tubing for easy and flexible remote measurement with a separate pump. A multiplexer can also be added for sampling gas from several locations. [1)]

1) Third-party pump and multiplexer not provided by Vaisala.

Technical data

Measurement performance

Measurement range	0 ... 10 000 ppm CO_2 (up to 30 000 ppm CO_2 with reduced accuracy)
Accuracy [1]	
0 ... 3000 ppm CO_2	±40 ppm CO_2
3000 ... 10 000 ppm CO_2	±2 % of reading
Up to 30 000 ppm CO_2	±3.5 % of reading
Calibration uncertainty	
at 2000 ppm CO_2	±31 ppm CO_2
at 10 000 ppm CO_2	±105 ppm CO_2
Long-term stability	
0 ... 3000 ppm CO_2	±60 ppm CO_2/year
3000 ... 6000 ppm CO_2	±150 ppm CO_2/year
6000 ... 10 000 ppm CO_2	±300 ppm CO_2/year
Temperature dependence 0 ... 10 000 ppm CO_2	
With compensation, −10 ... +50 °C	±0.05 % of reading/°C
With compensation, −40 ... +60 °C	< ±0.1 % of reading/°C
Without temperature compensation at 2000 ppm CO_2 (typical)	−0.5 % of reading/°C
Pressure dependence	
With compensation at 0 ... 10 000 ppm CO_2, 500 ... 1100 hPa	±0.015 % of reading/hPa
Without compensation (typical)	+0.15 % of reading/hPa
Humidity dependence	
With compensation, 0 ... 10 000 ppm CO_2, 0 ... 100 %RH	±0.7 % of reading (at +25 °C (+77 °F))
Without compensation (typical)	+0.05 % of reading/%RH
O_2 dependence	
With compensation, 0 ... 10 000 ppm $\%CO_2$, 0 ... 90 $\%O_2$	±0.6 % of reading (at +25 °C (+77 °F))
Without compensation (typical)	−0.08 % of reading/$\%O_2$
Start-up, warm-up, and response time	
Start-up time at +25 °C	< 12 s
Warm-up time for full spec.	< 2 min
Response time (T90):	
With standard filter	< 1 min
Flow-through option with > 0.1 l/min	30 s
With spray shield	< 3 min
Flow rate dependence (for flow-through option)	
< 1 l/min flow	no effect
1 ... 10 l/min flow	< 0.6 % of reading l/min

1) *At 25 °C and 1013 hPa (incl. repeatability and non-linearity).*

Inputs and outputs

Analog outputs	• 0 ... 5/10 V (scalable), min. load 10 kΩ • 0/4 ... 20 mA (scalable), max. load 500 Ω
Digital output	Over RS-485: • Modbus • Vaisala Industrial Protocol
Operating voltage	
With digital output in use	12 ... 30 V DC
With voltage output in use	12 ... 30 V DC
With current output in use	20 ... 30 V DC
Power consumption	
Typical (continuous operation)	0.4 W
Maximum	0.5 W

Operating environment

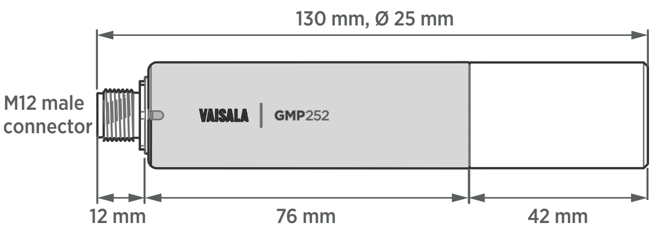
Operating temperature of CO_2 measurement	−40 ... +60 °C (−40 ... +140 °F)
Storage temperature	−40 ... +70 °C (−40 ... +158 °F)
Humidity	0 ... 100 %RH, non-condensing
Condensation prevention	Sensor head heating when power on
IP rating, probe body	IP65
Chemical tolerance (temporary exposure during cleaning)	• H_2O_2 (2000 ppm, non-condensing) • Alcohol-based cleaning agents (for example ethanol and IPA) • Acetone • Acetic acid
Pressure	
Compensated	500 ... 1100 hPa
Operating	< 1.5 bar
Gas flow (for flow-through option)	
Operating range	< 10 l/min
Recommended range	0.1 ... 0.8 l/min

Compliance

EU directives	EMC, RoHS
EMC compatibility	EN 61326-1, basic electromagnetic environment
Compliance marks	CE, RCM, WEEE

Mechanical specifications

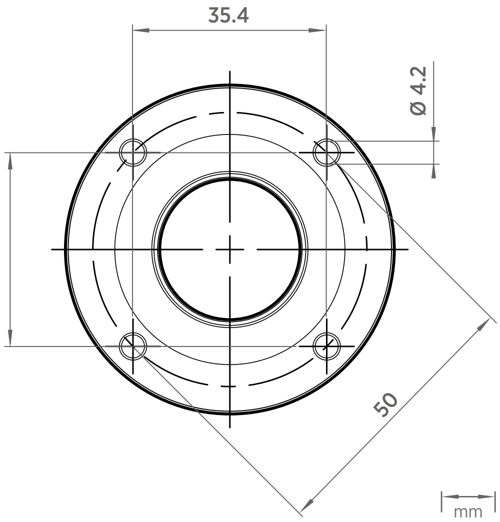
Weight, probe	58 g (2.05 oz)
Connector type	M12 5-pin male
Materials	
Probe housing	PBT polymer
Filter	PTFE
Connector	Nickel plated brass
Dimensions	
Probe diameter	25 mm (0.98 in)
Probe length	130 mm (5.12 in)



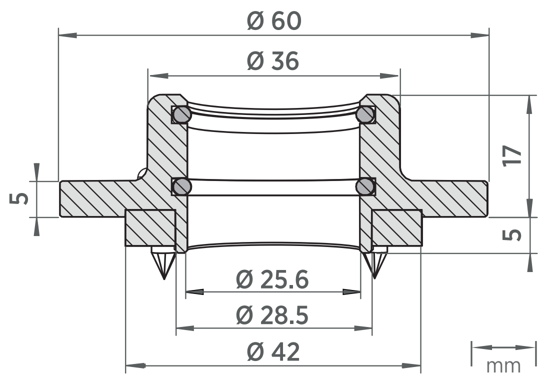
Spare parts and accessories

Porous sintered PTFE filter for GMP252	DRW244221SP
Probe cable with open wires (1.5 m)	223263SP
Probe cable with open wires (1.5 m), shielded	254294SP
Probe cable with open wires (3 m)	26719SP
Probe cable with open wires (10 m)	216546SP
Probe cable with open wires and 90° plug (0.6 m)	244669SP
Probe cable with open wires and 90° plug (1.5 m)	255102
Flow-through adapter with gas ports	ASM212011SP
Indigo USB adapter [1]	USB2
MI70 connection cable for probe	CBL210472
Flat cable for GMP250 probes, M12 5-pin	CBL210493SP
Probe mounting clips (2 pcs)	243257SP
Probe mounting flange	243261SP
Calibration adapter	DRW244827SP
Spray shield	ASM212017SP
Radiation shield DTR250	DTR250
Radiation shield DTR250 with pole mounting kit	DTR250A

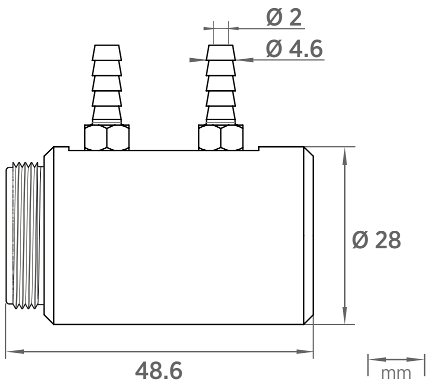
1) *Vaisala Insight software for Windows is available at www.vaisala.com/insight.*



Dimensions of probe mounting flange (243261SP)



Probe mounting flange cross section



Flow-through adapter with gas ports (ASM212011SP).
Suitable for tubes with 4 mm inner diameter.

www.vaisala.com

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Using the LI-870 CO_2/H_2O Analyzer

LI-COR®

Using the LI-870

CO_2/H_2O Analyzer

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Notice

The information in this document is subject to change without notice.

Printing History

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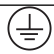
Notes on Safety

This LI-COR product has been designed to be safe when operated in the manner described in this manual. The safety of this product cannot be assured if the product is used in any other way than is specified in this manual. The product is intended to be used by qualified personnel. Read this entire manual before using the product.

Equipment markings:	
	The product is marked with this symbol when it is necessary for you to refer to the manual or accompanying documents in order to protect against injury or damage to the product.
	The product is marked with this symbol when a hazardous voltage may be present.
	The product is marked with this symbol if a Chassis Ground connection is required.
	The product is marked with this symbol to indicate that a direct current (DC) power supply is required.
WARNING	Warnings must be followed carefully to avoid bodily injury.
CAUTION	Cautions must be observed to avoid damage to your equipment.
Manual markings:	
Warning	Warnings must be followed carefully to avoid bodily injury.
Caution	Cautions must be observed to avoid damage to your equipment.
Note	Notes contain important information and useful tips on the operation of your equipment.

CE Marking:

This product is a CE-marked product. For conformity information, contact LI-COR Support at envsupport@licor.com. Outside of the U.S., contact your local sales office or distributor.

California Proposition 65 Warning

WARNING: This product contains chemicals known to the State of California to cause cancer and birth defects or other reproductive harm.

Federal Communications Commission Radio Interference Statement

WARNING: This equipment generates, uses, and can radiate radio frequency energy and if not installed in accordance with the instruction manual, may cause interference to radio communications. It has been tested and found to comply with the limits for a Class A computing device pursuant to Subpart J of Part 15 of FCC rules, which are designed to provide a reasonable protection against such interference when operated in a commercial environment. Operation of this equipment in a residential area is likely to cause interference in which case the user, at his own expense, will be required to take whatever measures may be required to correct the interference.

Waste Electronic and Electrical Equipment (WEEE) Notice

This symbol indicates that the product is to be collected separately from unsorted municipal waste. The following applies to users in European countries: This product is designated for separate collection at an appropriate collection point. Do not dispose of as household waste. For more information, contact your local distributor or the local authorities in charge of waste management.

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Section 1.
Overview of the LI-870

The LI-870 is a CO_2/H_2O Gas Analyzer that is designed for use with the Smart Chamber and LI-8250 Multiplexer in soil gas flux systems. This document provides basic operating instructions for the LI-870. Refer to the Smart Chamber and LI-8250 manuals for additional information.

What's what

If you have just taken delivery of your LI-870, check your packing list to ensure the following items have been included.

LI-870 CO_2/H_2O Analyzer

Part number: 870-01

The LI-870 is a portable gas analyzer designed for use with the Smart Chamber or LI-8250 Multiplexer for soil CO_2 flux measurements.

The LI-870 measures CO_2 in air at concentrations from 0 to 20,000 ppm using non-dispersive infrared gas analysis technology. This technology is well-established in other LI-COR products, including the widely-published LI-8100A Automated Soil CO_2 Flux System, LI-830 and LI-850 CO_2 and CO_2/H_2O Gas Analyzers, and LI-COR eddy covariance analyzers. Water vapor measurements are used in corrections to report CO_2 concentrations with high accuracy. Power to the LI-870 is supplied from the Smart Chamber or LI-8250 Multiplexer. The LI-870, in turn, provides CO_2 data to the Smart Chamber or LI-8250 Multiplexer for storage and processing.

LI-870 cable and tube assembly

Part number: 9982-010

A 1.2 meter cable and tubing assembly is included with the LI-870 to connect the LI-870 with the Smart Chamber or LI-8250 Multiplexer. This assembly includes:

- Sealed USB-A to USB-B cable (part number 392-17654).
- Sealed 2.5 × 5 mm IP68 power cable (part number 9982-008).
- Two lengths 1.2 meter 1/4" Bev-A-Line® tubing (part number 222-01824) with quick-connect fittings (part numbers 300-07124 (male) and 300-07125 (female)).

The assembly components are zip tied in plastic conduit.

Shoulder strap

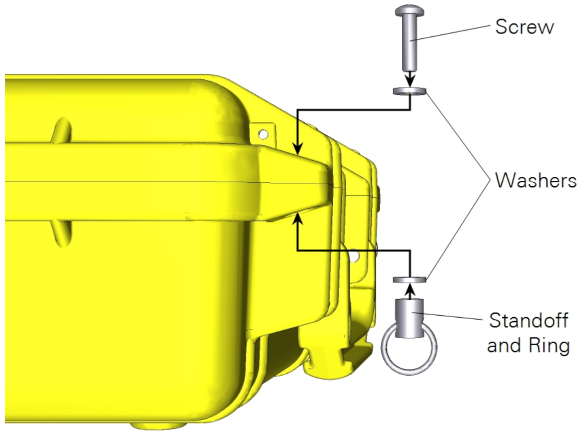
Part number: 604-18146

The shoulder strap is to carry the LI-870.

Split ring assembly

Part number: 9882-019

The LI-870 ships with a split ring and standoff assembled for attaching the shoulder strap. The rings are attached near the clasps of the case. Each assembly consists of a machined standoff (part number 9882-019), screw (part number 122-07715), split ring (part number 610-10353), and two washers (part number 167-00154).



Spares kit

Part number: 9982-020

A spares kit is shipped with the LI-870 and contains the following.

Description	Quantity	Part Number
1/4" Bev-A-Line® IV Plastic Tubing (12 meters)	1	8150-250[a]
1/4" Quick-connect Straight Union	2	300-03123
Quick Connect Plug 0.165 with Hose Barb (Male)	1	300-07124
Quick Connect Plug 0.165 with Hose Barb (Female)	1	300-07125
Optical Bench Cleaning Kit	1	9980-066
USB-A to USB-B, Unsealed, 2 meter	1	392-06652

Software

The LI-870 can be calibrated using the LI-830/LI-850 user interface software, which is available from the LI-COR support site at licor.com/830-850-support. Select software, and find the installer appropriate for your operating system. This software is available for both Windows® and macOS® operating systems and is used to calibrate your LI-870 and view live data.

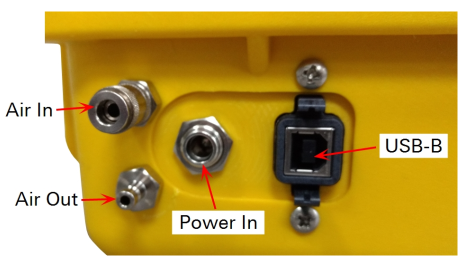
[a]Additional tubing can be repurchased as a 15 meter roll.

Section 2.
Using the LI-870

The basic operation of the LI-870 involves connecting the USB data cable, connecting the tubing, and connecting the power cable between the LI-870 and Smart Chamber or LI-8250 Multiplexer, as described here.

Connecting the cable assembly

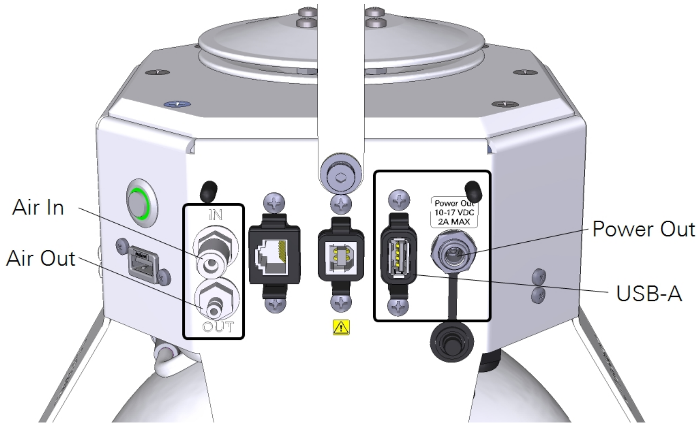
Connecting the LI-870 to the Smart Chamber or LI-8250 Multiplexer is simple, only requiring a few steps.



First, attach each end of the cable assembly to the LI-870. The USB-B end of the USB-A to USB-B cable is attached to the LI-870, while the USB-A end is attached to the Smart Chamber or LI-8250.

Note: Only use the supplied USB-A to USB-B cable from the LI-870 to cable assembly (part number 9982-010).

Next, attach the cable assembly to the Smart Chamber or LI-8250. Connect the steel quick connect fittings for the air tubing, and thread the power cable on to the power-in and power-out connectors on each panel. Tighten snugly to ensure a water-tight seal. Follow the detailed instructions in the Smart Chamber or LI-8250 instruction manual for additional details.



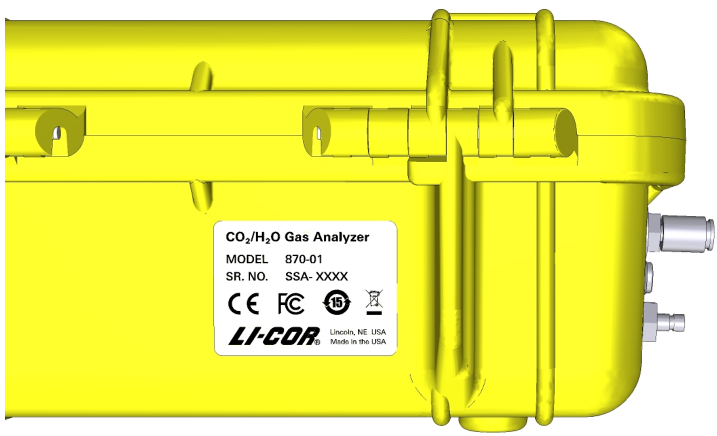
Warning: *The power output is 10-17 VDC with a center positive pin. The output has a 2 amp maximum and is designed to only power the LI-870 CO_2/H_2O Analyzer Accessory. Only use the power cable supplied with the LI-870 cable assembly (P/N 9982-010), and do not attempt to power any other devices with the Smart Chamber or LI-8250. Drawing a current in excess of 2 amps will trip the self-resetting breaker. If you trip the self-resetting breaker, you will need to wait for a few minutes before attempting to re-power the LI-870.*

Powering the analyzer and making measurements

After connecting the power cable, you should power on your Smart Chamber or LI-8250 and launch the user interface software. Power to the LI-870 is supplied directly from the Smart Chamber or LI-8250.

Identifying the LI-870 serial number

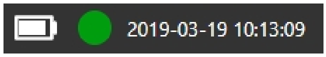
In the **Settings** page of the Smart Chamber or LI-8250 interface, you will need to connect to your LI-870 using the serial number. The label is on the bottom of the case.



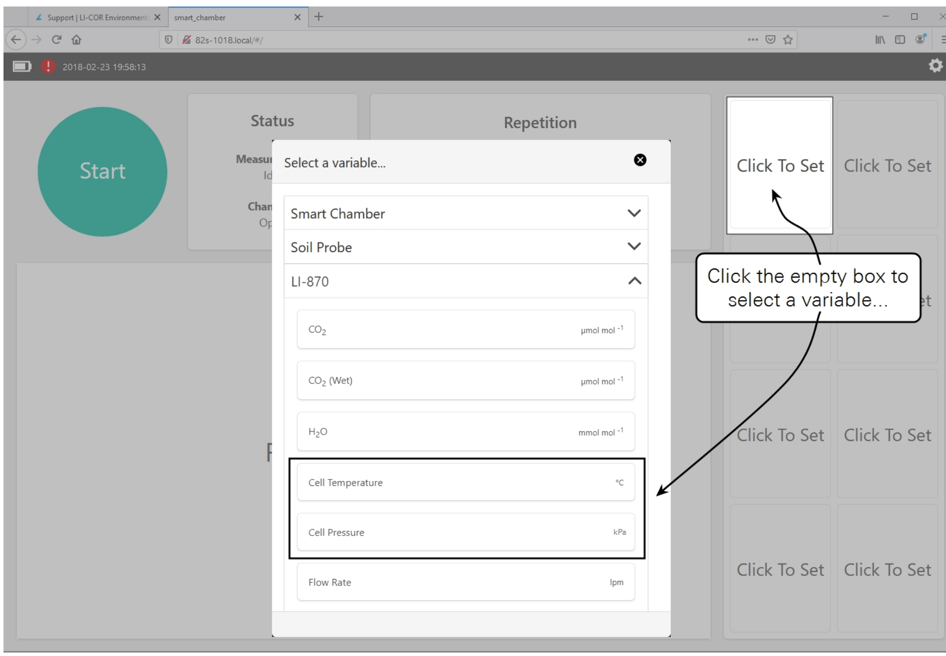
Warm up time

The LI-870 will boot up as soon as power is supplied from the chamber. The optical bench should be allowed to warm up prior to taking measurements. The LI-870 optical bench is temperature- and pressure-controlled, so a sudden influx of ambient air into an optical bench that has not been allowed to warm up and stabilize will likely produce noisy data. For this reason, it is critical that your analyzer is allowed to warm up prior to taking measurements. In most cases, 10 to 15 minutes of warm up time will allow the optical bench to stabilize, but warmup time depends largely on ambient temperature.

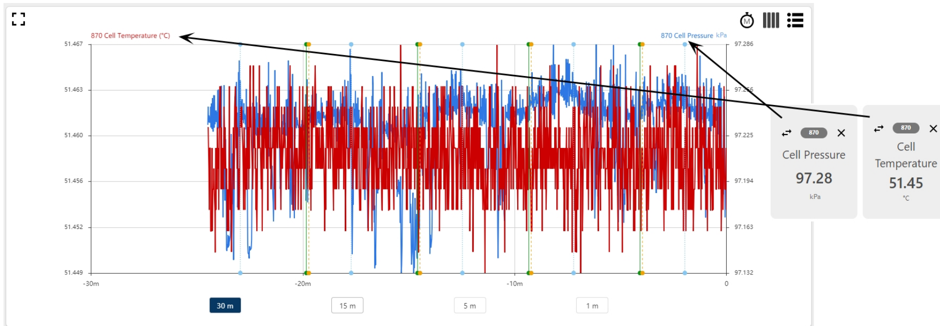
In the Smart Chamber and LI-8250 interface, you can see when your LI-870 optical bench has stabilized when the dot in the upper-left portion of any screen by the time stamp is green. If the bench is not stabilized, this dot will be red.



You can also visualize the optical bench temperature and pressure from the **Home Page** of the Smart Chamber or LI-8250 interface to assess whether they have stabilized. After connecting to the Smart Chamber or LI-8250, from the **Home Page**, select **Click to Set**. In the **Select a variable...** window that opens, open the LI-870 list, and you can select **Cell Temperature** and **Cell Pressure**.



These variables will now be in the grid on the **Home Page**. Click them again to graph the values live.



The axes auto-scale, so pay close attention to the axis labels to assess stability. In the example graph above, the bench temperature, for example, is stabilized within roughly ± 0.1 °C from the median value/middle of the graph. Once the values have stabilized like this, you can begin taking measurements following the instructions in the Smart Chamber or LI-8250 manual.

Storing the LI-870

The post-purge function of the Smart Chamber is designed to allow for ambient air to flush CO_2- and water vapor-rich air from the cable assembly tubing and analyzer after each measurement. When you are performing your last measurement(s) of the season, or when you return to the lab or desk after taking your last measurements, you should perform a measurement or two with the Smart Chamber to allow dry ambient air to flow through your chamber. This will help to remove humidity before storage.

> **Note:** For more information on post-purge, consult the Smart Chamber manual or find resources online at licor.com/env/support.

The LI-870 should be stored in non-condensing conditions. If the instrument is stored in high humidity or moderate humidity for a long time while powered off, some optical components may temporarily become saturated with humidity. If this occurs, the instrument may need to run for several days before readings return to normal. If possible, store the instrument in an air conditioned environment.

Section 3.
Troubleshooting

In this section, we describe how to identify some potential problems with the LI-870 and how to resolve them. If you can't find a solution here, if you need further assistance performing maintenance, or if you have other questions, contact your local distributor or LI-COR technical support for more help.

Smart Chamber or LI-8250 software not recognizing LI-870

Power is supplied from the Smart Chamber or LI-8250, and assuming your connection is completed correctly, the gas analyzer is always powered on when the Smart Chamber or LI-8250 is powered on. The Smart Chamber or LI-8250 will automatically recognize your device with no further steps needed. Simply expand the **LI-870** drop-down in the **Connections** menu of the **Measurement Settings** page of the Smart Chamber or LI-8250 software, select your instrument serial number, and press **Update.**

If you open the drop-down menu and your instrument does not appear,

- Is your power cable fully connected to both devices? Make sure the cable is fully inserted and the threaded nut is snugly fastened.
- Is your USB cable fully connected to both devices? Ensure that the connectors on both sealed cables are clipped to the prongs on each device.

If your cables are fully connected but you still cannot identify your device, you can open your device to see if power is being supplied. Next to the connection panel inside the case, a red LED light will be blinking if power is being supplied.

> **Note:** Do not open the LI-870 enclosure in the field. This can cause the temperature and pressure of the optics to become destabilized. More importantly, this can allow dust and debris into your analyzer. If possible, you should confirm whether your analyzer is working properly and troubleshoot any issues before taking it out to the field.

If your Smart Chamber or LI-8250 is on and your cables are properly connected, the light should be blinking. If it is not blinking, something could be wrong with your power cable, the chamber power-out connector, analyzer power-in connector, or other electronics inside the case. Check for dust and debris in the connectors and for damage to the cable itself. For power-related issues, it is recommended that you call LI-COR technical support for further instructions.

If the light is blinking but you still cannot identify your device through the Smart Chamber or LI-8250 software, check your USB cable for damage. Is there dust or debris in the cable heads or the connectors? Try refreshing the interface software, clearing your browser cache, and rebooting your Smart Chamber or LI-8250. If you still cannot connect, contact LI-COR technical support.

Unable to Zero or Span the Instrument

Is there dirt in the optics? If the optical cell becomes contaminated, the instrument will drift in either the zero or span. See *Cleaning the optical bench* on page 4-1 for details on cleaning your optical bench.

Instrument Reports -50 ppm CO_2 or Measurements Jump Around

If the instrument measures -50 ppm or the measurements are going between negative and positive values, or just simply not making any sense, the optical source may have failed or be in the midst of failure. Contact technical support for additional troubleshooting help.

Section 4.
Maintenance

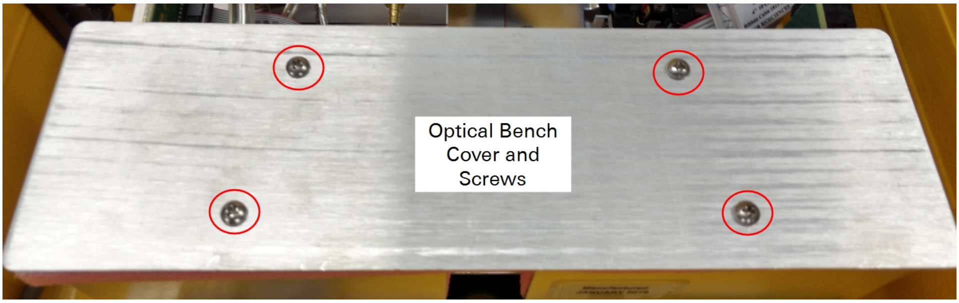
Cleaning the optical bench

The LI-870 optical bench can be removed and cleaned with just a few steps if necessary. Generally speaking, you shouldn't undertake this procedure unless you've ruled out other potential problems. While the process itself is not difficult, you will have to set the instrument zero and span after reassembling the optical bench.

An optical bench cleaning kit (part number 9980-066) is included with your LI-870 spares kit. You will also need a small Phillips screwdriver. Follow these steps to remove and clean your optical bench and replace the O-rings. Note that the images included in this section were taken from a prototype LI-870. The wiring and plumbing in your instrument may appear slightly different.

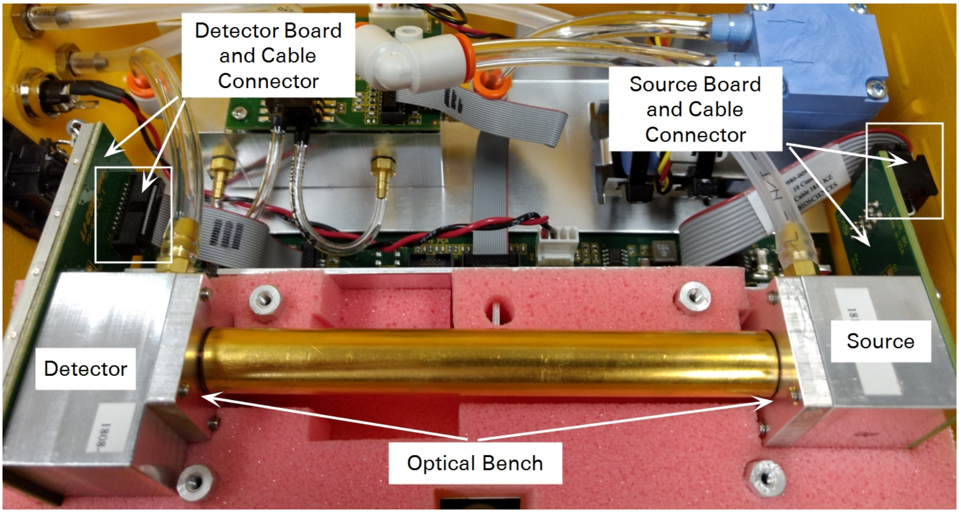
Warning: *Be sure that you are properly grounded to avoid electrostatic discharge that can damage the electronics. Use an anti-static wrist strap, electrostatic discharge grounding mat, or occasionally touch bare metal that has a clear path to ground, such as an unpainted computer case.*

1. Unplug your instrument from the Smart Chamber or LI-8250. If you've been operating the instrument recently, you should allow the optical bench to cool down to room temperature.
2. Open the analyzer and remove the plate covering the optical bench.

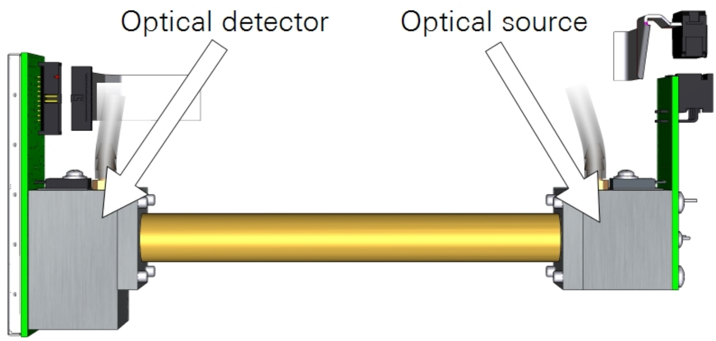


The bench cover is held in place by four screws. Remove these screws, remove the plate and foam, and set aside. The insulated optical bench will now be visible.

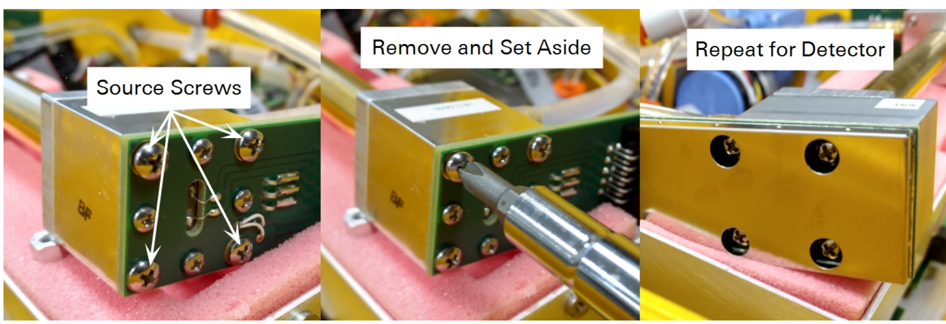
3 Gently lift the optical bench out of the insulating foam and remove the cable connectors from the source and detector circuit boards.



4 Gently grasp the plugs and pull them free.

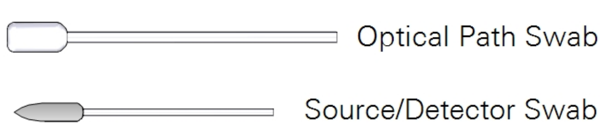


5 Remove the screws that secure the source and detector (4 each), then separate the source and detector housings (with circuit boards attached) from the optical path.



6 Clean the optical bench, source, and detector.

7 Retrieve an optical path swab from the accessories kit.



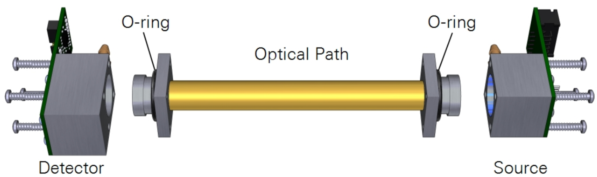
Dip one end into a 50:50 ethanol:water mixture (mild dish washing soap and water will work too) and carefully swab both ends of the optical path. Then, dip a Source/Detector swab into the solution and then swab around the source and detector to remove any residue.

Warning: *Do not use abrasive cleansers. Abrasive cleaners can irreparably damage the gold plating on the optical path, source, or detector.*

8 Inspect the hose barbs and tubing.

If the tubes are dirty or damaged, cut a new length of tubing from the extra tubing included in your spares kit, and replace them. Carefully remove them from the hose barbs. If the tubes are in good condition and clean, you may be able to reuse them. If the hose barbs are dirty, remove them and clean them with rubbing alcohol or soapy water. Use caution and do not scratch the hose barbs because scratches may cause leaks.

9 Inspect the O-Rings.



Four O-rings are included in the Optical Bench Cleaning Kit (part number 9980-066), and additional O-rings can be purchased from LI-COR. Replace them if they are smashed flat or damaged in any way.

10 Let the optical components dry and reassemble the optical bench.

Attach the source and detector. The orientation of the optical path cylinder is unimportant — either end can be inserted into the source and detector housing. Tighten each of the screws snugly.

11 Place the optical bench back into the foam, re-insert the cable connectors to the source and detector, and screw the cover plate back to complete the re-assembly.

12 Perform a zero and span calibration (see *User calibration* on page 4-6 for instructions).

Connecting to LI-870 for calibration

Though the primary interface for the LI-870 is through the Smart Chamber or LI-8250 software, you may also connect your LI-870 to the LI-COR LI-830/850 software to view data and for user calibration.

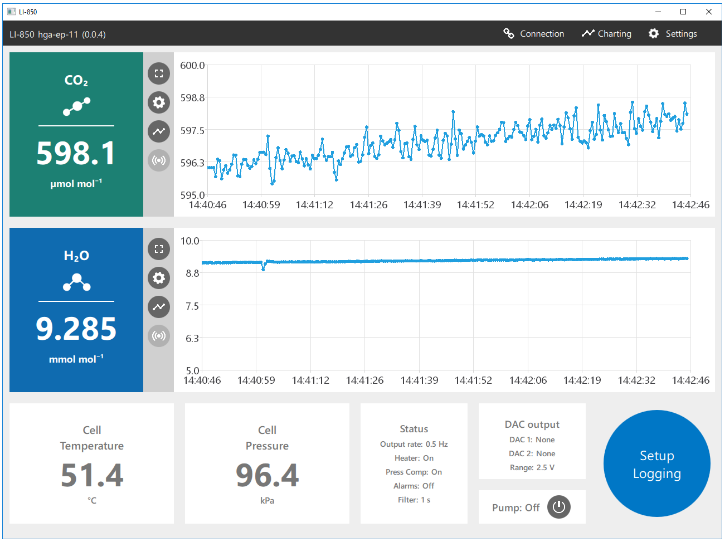
After downloading and installing the software from the LI-COR support site (licor.com/env/support), launch the software. It should display **No Analyzer Connected**.

> **Note:** You must connect the power cable from a powered-on Smart Chamber or LI-8250 to power to analyzer when using the software.

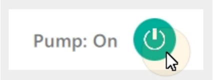
Connect your analyzer to your computer using the USB-B to USB-A cable included with your purchase. You may see a notification that says **Setting up device**, or something similar. After the automatic device setup is complete, go back to the software, and click **Connect**. In the box that opens, expand the **Connect to** drop-down menu, and you will see your device.

> **Important:** The LI-830/850 software will recognize your LI-870 as an LI-850. This is normal. Go ahead and click **Update**, and you will connect to your LI-870.

After connecting, the software presents you with live data and graphs.



Here you can see important diagnostic information like **Cell Temperature** and **Cell Pressure**. You can also turn the pump on by clicking the power button next to **Pump:** in the bottom-right of the software.



The software offers a variety of other features you may choose to explore. A more thorough explanation of the software is available at the LI-COR support site. However, for LI-870 soil applications, you will likely only the use the software for instrument calibration.

User calibration

If the instrument is not measuring as expected, or if you have disassembled the optical bench for any reason, you should check the zero and span settings and set them if necessary. The zero and span are an offset and slope. The zero value ensures that the instrument shows zero when the gas has a zero concentration. A change in the zero will affect every measurement. The span setting ensures a correct measurement at a known non-zero concentration. A change in the span affects higher concentration measurements more than lower ones. The recommended order of operation for user calibration is

1. Set the H_2O zero.
2. Set the CO_2 zero.
3. Set the H_2O span.
4. Set the CO_2 span.

For user calibration, additional tubing (part number 222-01824) and quick connects (part numbers 300-07124 (male) and 300-07125 (female)) are included with your spares kit.

Setting the H_2O zero and spans

The water vapor span can be set with a dew point generator such as the LI-610. The procedure is the same as setting the CO_2 zero and spans, only this uses known concentrations of water vapor rather than CO_2.

> **Caution:** Setting the zero and span incorrectly for either CO_2 or H_2O will adversely impact the performance of your instrument. If you do not have the proper equipment to span the analyzer, it is best to leave it alone.

Setting the CO_2 zero

Always perform the zero first. To set the zero, you'll need either a tank of dry air that is free of CO_2 or a CO_2 scrubbing chemical such as wet soda lime and a desiccant such as Drierite.

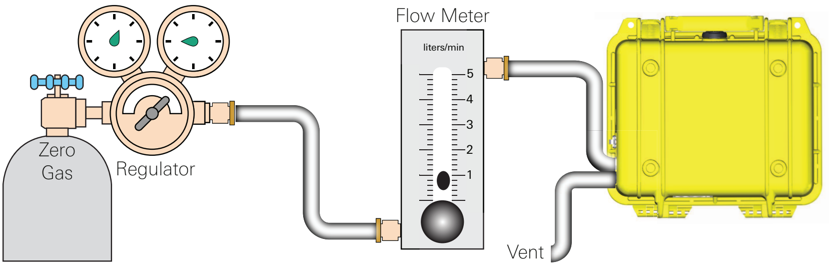
1. Plumb the zero-gas tank or scrubber to the air inlet.

   Be sure to use an air filter to prevent contaminants from entering the optical path.

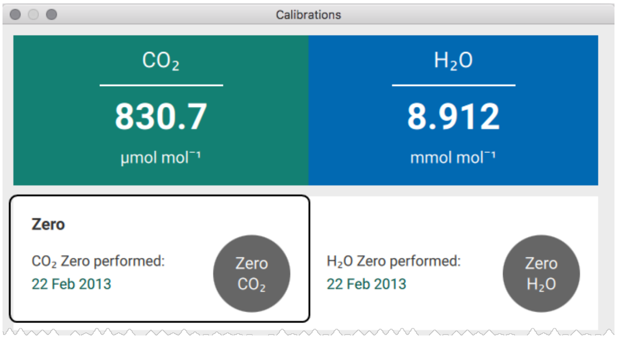
- If using tank air, the pressure of the tank is sufficient to flow the gas through the analyzer. Allow at least 0.75 liters per minute to flow through the cell (no more than 1.0 lpm).
- If using a scrubbing chemical, use a pump to draw air through the analyzer.

2 Install a 10 to 20 cm length of tubing to the air outlet.

This vent prevents ambient air from diffusing upstream into the optical cell.



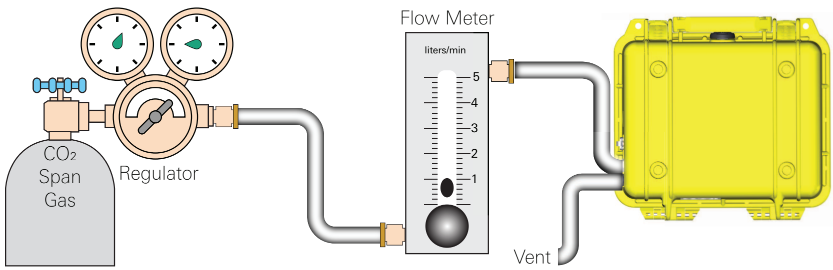
3 When the CO_2 concentration has stabilized, click the **Zero CO_2** button.



Setting the primary CO_2 span

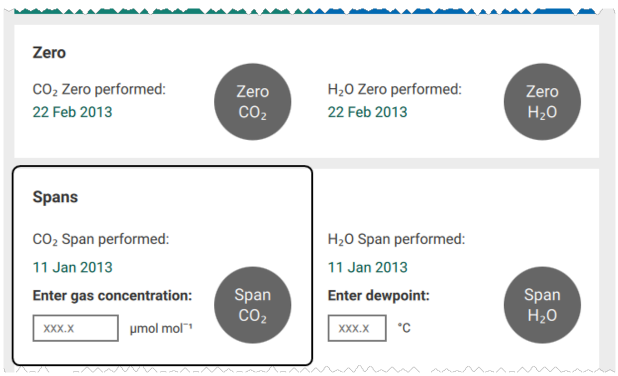
When choosing a span gas, we recommend a gas concentration that is close to - but still slightly above - the upper limit of what you expect to measure. For example, if you are measuring near-ambient levels, choose a span gas that is near 400 ppm CO_2 (as opposed to 18,000 ppm). Similarly, if you are measuring concentrations near 15,000 ppm CO_2, a span gas with 100 ppm would not be ideal.

4 After zeroing, flow a gas with a known CO_2 concentration through the analyzer at a rate of 0.5 liters per minute.



5 Enter the CO_2 concentration of the span gas into the software.

6 When the CO_2 reading has stabilized, click **Span CO_2**.



Setting the secondary CO_2 span

You can set a second span (using a gas that has a CO_2 concentration that is higher or lower than the primary span gas) to improve the precision of the analyzer. The process is exactly the same as setting the primary span, only you'll enter a different concentration and click **Span2 CO_2**.

Recovering from a bad zero or span

If your attempt to zero or span does not go as planned, you can restore the factory default zero and span settings. The information you need is provided on the calibration sheet (included with the instrument or available for download from www.licor.com/env/support/). Under **Settings > Calibrations > Advanced**, enter the factory zero and span values for your instrument.

Appendix A.
Specifications

General

Case dimensions: 28.4 cm L × 27.9 cm W × 12.4 cm H (11.2 in × 11 in × 4.9 in)
Weight: 2.31 kg (5.1 lbs.)
Measurement rate: 1 per second (1 Hz)
Operating temperature range: -20 to 45 °C, without solar loading
Relative humidity range: 0 to 95% RH, non-condensing
Measurement principle: Non-dispersive infrared (NDIR)
Operating pressure range: 50 to 110 kPa
Flow rate (nominal): 0.75 liters min^{-1}
Power Requirements:

- **Input voltage:** 10-17 VDC, 2 A max
- **After warmup (without pump):** 0.33 A @ 12 VDC (4.0 W) average
- **After warmup (with pump):** 0.42 A @ 12 VDC (5.0 W) average
- **Power source**: 8200-01S Smart Chamber or LI-8250 Multiplexer

CO_2 Measurements

Measurement range: 0 to 20,000 ppm
Accuracy: Within 1.5% of reading

H_2O Measurements

Measurement range: 0 to 60 mmol mol^{-1}
Accuracy: Within 1.5% of reading

Appendix B.
Equations summary

The LI-870 computes CO_2 concentrations using an equation of the form

$$c = f(\alpha'')(T + 273.15) \qquad \text{B-1}$$

where c is concentration, $f()$ is the calibration function, α'' is the absorptance, $g(\alpha,P)$ is the pressure correction, $S(\alpha)$ is the span, and T is the temperature (°C) of the gas in the cell, typically 51.5 °C. Absorptance is computed from

$$\alpha'' = \alpha' g(\alpha', P) \qquad \text{B-2}$$

α' is a span corrected absorptance, and $g(\alpha',P)$ is the pressure correction.

$$\alpha' = \alpha S(\alpha) \qquad \text{B-3}$$

$S(\alpha)$ is the span function, and raw absorptance α is computed from

$$\alpha = \left(1 - \frac{V}{V_o} Z\right) \qquad \text{B-4}$$

where V and V_o are the raw detector sample and reference readings, and Z is the zeroing parameter.

Span is a linear function of absorptance.

$$S(\alpha) = S_o + S_1 \alpha \qquad \text{B-5}$$

H_2O Equations

Absorptance α_ω for water vapor is computed from

$$\alpha_w = \left(1 - \frac{V_w}{V_{wo}} Z_w\right) \quad \text{B-6}$$

$$\alpha'_w = \alpha_w S_w(\alpha_w)$$

$$\alpha''_w = \alpha' g_w(\alpha'_w, P)$$

where V_w and V_{wo} are the sample and reference raw detector readings, and Z_w is the zero parameter. The pressure correction for water vapor is an empirical function $g_w()$ of absorptance and pressure P:

$$g_w(\alpha'_w, P) = \frac{P_o}{P\left(1+0.8\alpha'_w\left(\frac{P_o}{P}-1\right)\right)} \quad \text{B-7}$$

The value of P_o is 99 kPa. When the pressure correction is not enabled, $g_w()$ is simply 1.0. Water vapor concentration W (mmol mol^{-1}) is computed from

$$W = f_w(\alpha''_w)(T + 273.15) \quad \text{B-8}$$

where $f_w(x)$ is a third order polynomial whose coefficients are given on the calibration sheet.

$$f_w(x) = a_{w1}x + a_{w2}x^2 + a_{w3}x^3 \quad \text{B-9}$$

CO_2 Equations

The measurement of CO_2 is a bit more complicated than for H_2O because of the influence of water vapor. There is a slight direct cross sensitivity in the CO_2 signal to H_2O. This is measured at the factory and accounted for in the computation of absorptance (equation B-10). There is also a band broadening effect that is accounted for in the computation of concentration (equation B-14).

CO_2 absorptance αc is computed from

$$\alpha_c = \left(1 - \left(\frac{V_c}{V_{co}} + X_{wc}\left(1 - \frac{V_w}{V_{wo}} Z_w\right)\right) Z_c\right) \quad \text{B-10}$$

$$\alpha'_c = \alpha_c S_c(\alpha_w)$$

$$\alpha''_c = \alpha'_c g_c(\alpha'_c, P)$$

where V_c and V_{co} are the raw detector signals for sample and reference, Z_c is the CO_2 zero parameter, and X_{wc} is a cross sensitivity parameter for the effect of water vapor on CO_2. Its value is reported on the calibration sheet as **XS=**.

The empirical pressure correction function $g_c()$ depends on CO_2 absorptance and pressure:

When $P = P_o$, $g_c() = 1$.

When $P < P_o$

$$g_c(\alpha_c, P) = X$$

$$X = \frac{1}{A + B\left(\frac{1}{z - \alpha_c} - \frac{1}{z}\right)} + 1$$

$$A = \frac{1}{a(p-1)} \qquad \text{B-11}$$

$$B = \frac{1}{\frac{1}{b+cp} + d}$$

$$p = \frac{P_0}{P}$$

where $a = 1.10158$, $b = -6.1217E-3$, $c = -0.266278$, $d = 3.69895$, and z is the asymptotic value of absorptance, obtained from the calibration coefficients (equation B-15).

$$z = a_{c1} + a_{c3} \qquad \text{B-12}$$

When $P > P_o$

$$g_c(\alpha_c, P) = \frac{1}{X}$$

$$P = \frac{P}{P_0} \qquad \text{B-13}$$

where X, A, and B are computed as in equation B-11. CO_2 concentration C (µmol mol^{-1}) is computed from

$$C = f_c\left(\frac{\alpha''_c}{\psi(W)}\right)\psi(W)(T + 273.15) \qquad \text{B-14}$$

where $f_c(x)$ is a function whose inverse is a double rectangular hyperbola, and whose coefficients $(a1\ldots a4)$ are given on the calibration sheet.

$$f_c^{-1}(C) = \frac{a_{c1}C}{a_{c2}+C} + \frac{a_{c3}C}{a_{c4}+C} \qquad \text{B-15}$$

Solving equation B-15 for C yields the calibration function

$$f_c\left(x\right) = \frac{\left(a_2a_3+a_1a_4\right)-\left(a_2+a_4\right)x-\sqrt{\left(a_2-a_4\right)^2x^2+Dx+\left(a_2a_3+a_1a_4\right)^2}}{2(x-a_1-a_3)} \qquad \text{B-16}$$

Where

$$D = 2\left(a_2 - a_4\right)\left(a_1a_4 - a_2a_3\right) \qquad \text{B-17}$$

$\psi(W)$ accounts for band broadening by water vapor.

$$\psi(W) = 1 + \left(h(\alpha'_c) - 1\right)\frac{W}{1000} \qquad \text{B-18}$$

The band broadening coefficient $h(\alpha'_c)$ has been determined to be 1.45 for the instrument for CO_2 concentrations near ambient. At higher concentrations, the value decreases. We capture this behavior with an empirical relationship (equation B-19).

$$h(\alpha'_c) = \frac{1}{(0.64b_w - 0.64)e^{-3\left(\frac{z}{\alpha'_c}-1\right)} + \frac{1}{b_w}} \qquad \text{B-19}$$

Where z is from equation B-12, and b_w is the low concentration band broadening coefficient: 1.45. This is the value shown on the calibration sheet as *BB* = 1.45. The typical relationship between $h(\alpha'_c)$ and CO_2 concentration is shown in *Figure B-1* on the facing page. ('Typical' because the exact relationship depends on the relationship between absorptance and CO_2, which is the calibration curve.)

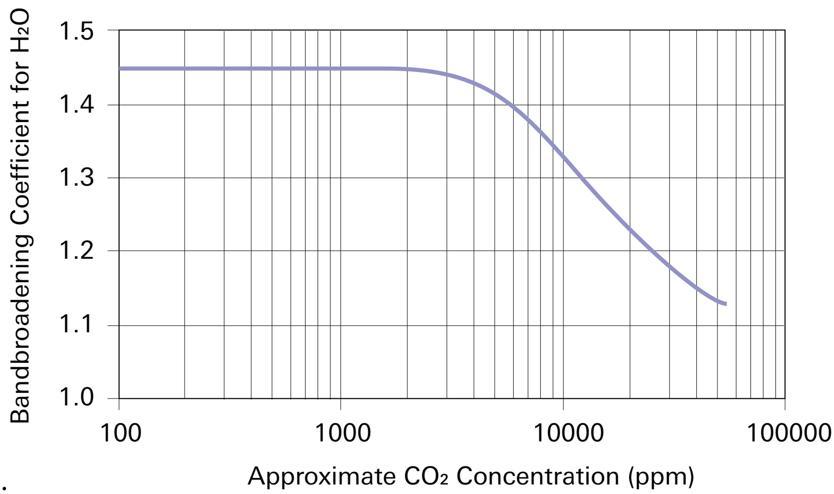


Figure B-1. The typical relationship between h(α'_c) *and CO_2 concentration.*

> **Note:** We formulated equation B-19 with $0.64b_w - 0.64$ instead of the simple equivalent (0.29) because this allows band broadening corrections to be turned off by setting b_w to 1. When $b_w = 1$, $h(\alpha_c) = 1$ everywhere. Also, to avoid computational problems (underflows, overflows, and division by zero) we constrain the argument α_c when computing $h(\alpha_c)$ to be $0.1 < \alpha_c \leq z$. α_c - 0.1 is typically equivalent to about 600 ppm.

Calibration Equations

The following equations describe the implementation of zero and span calibrations.

Zeroing H_2O

When the command for zeroing water is received, the LI-870 computes the water zero from equation B-20, where $\overline{V}_w$ and $\overline{V}_{wo}$ are averaged for 5 seconds.

$$Z_w = \frac{\overline{V}_{wo}}{\overline{V}_w} \qquad \text{B-20}$$

Zeroing CO_2

When the command for zeroing CO_2 is received, the instrument computes the CO_2 zero term from equation B-21, where $\overline{V}_c$, $\overline{V}_{co}$, $\overline{V}_w$, and $\overline{V}_{wo}$ are averaged for 5 seconds.

$$Z_c = \frac{1}{\left(\frac{\overline{V}_c}{\overline{V}_{co}} + X_{wc}\left(1 - \frac{\overline{V}_w}{\overline{V}_{wo}} Z_w\right)\right)} \quad \text{B-21}$$

Spanning H_2O

When the command for setting the span for H_2O is received, along with the target concentration W_T, from the target concentration, the target absoprtance α_T is computed from

$$\alpha_{wT} = f_w^{-1}\left(\frac{W_T}{T+273.15}\right) \quad \text{B-22}$$

LI-870 computes S_{w0} from equation B-23 , where $\overline{\alpha}_w$ is averaged over five seconds.

$$S_{w0} = \frac{\beta_w}{\overline{\alpha}_w} - S_{w1}\overline{\alpha}_w \quad \text{B-23}$$

where

$$\beta_w = \frac{\alpha_{wT}}{g_w(\alpha_{wT}, P)} \quad \text{B-24}$$

The instrument retains the following values, which are used for subsequent secondary spans:

$$\alpha_{w1} = \overline{\alpha}_w \quad \text{B-25}$$

$$\beta_{w1} = \beta_w$$

Secondary Span H_2O

When the secondary span command for H_2O is received, the instrument computes new values for both S_{w0} and S_{w1}. First, it measures a new $\overline{\alpha}_w$ and computes a new β_w from equation B-24. Then, it uses these plus the retained values (α_{w1} and β_{w1} from the previous normal span) to compute

$$S_{w1} = \frac{\frac{\beta_w}{\overline{\alpha}_w} - \frac{\beta_{w1}}{\alpha_{w1}}}{\overline{\alpha}_w - \alpha_{w1}} \qquad \text{B-26}$$

Given the new span slope S_{w1}, it updates the span offset S_{w0} by equation B-23.

Spanning CO_2

When the command for setting the CO_2 span is received, along with the target concentration C_T, the instrument computes S_{c0} from equation B-28, where $\overline{\alpha}_c$ and $\overline{W}$ are averaged for 5 seconds.

$$\alpha_{cT} = f_c^{-1}\left(\frac{C_T}{(T+273.15)\psi(\overline{W})}\right) \qquad \text{B-27}$$

$$S_{c0} = \frac{\beta_c}{\overline{\alpha}_c} - S_{c1}\overline{\alpha}_c \qquad \text{B-28}$$

where

$$\beta_c = \frac{\alpha_{cT}\psi(\overline{W})}{g_c(\alpha_{cT},P)} \qquad \text{B-29}$$

Note that

$$\psi(\overline{W}) = 1 + (h(\alpha_{cT}) - 1)\frac{\overline{W}}{1000}$$

$$= \left(1 + \left(\frac{1}{(0.64b_w - 0.64)e^{-3\left(\frac{z}{\alpha_{cT}}-1\right)} + \frac{1}{b_e}} - 1\right)\frac{\overline{W}}{1000}\right) \qquad \text{B-30}$$

We need αcT to compute $\psi\left(\overline{W}\right)$, but αcT depends on $\psi\left(\overline{W}\right)$. We resolve this by using an approximation (equation B-31) instead when computing equation B-30

$$\alpha_{cT} \approx f_c^{-1}\left(\frac{C_T}{(T+273.15)}\right) \qquad \text{B-31}$$

The instrument retains the following values, which are used for subsequent secondary spans, if necessary:

$$\alpha_{c1} = \overline{\alpha}_c \qquad \text{B-32}$$

$$\beta_{c1} = \beta_c \qquad \text{B-33}$$

Secondary Span CO_2

When the secondary span command for CO_2 is received, the instrument computes new values for both S_{c0} and S_{c1}. First, it measures a new $\overline{\alpha}_c$ and computes a new β_c from equation B-29. Then it uses these, plus the retained values (α_{c1} and β_{c1} from the previous normal span) to compute

$$S_{c1} = \frac{\frac{\beta_c}{\overline{\alpha}_c} - \frac{\beta_{c1}}{\alpha_{c1}}}{\overline{\alpha}_c - \alpha_{c1}} \qquad \text{B-34}$$

Given the new span slope S_{c1}, it updates the span offset S_{c0} by equation B-28.

Appendix C.
Warranty

Each LI-COR, Inc. instrument is warranted by LI-COR, Inc. to be free from defects in material and workmanship; however, LI-COR, Inc.'s sole obligation under this warranty shall be to repair or replace any part of the instrument which LI-COR, Inc.'s examination discloses to have been defective in material or workmanship without charge and only under the following conditions, which are:

1. The defects are called to the attention of LI-COR, Inc. in Lincoln, Nebraska, in writing within one year after the shipping date of the instrument.
2. The instrument has not been maintained, repaired or altered by anyone who was not approved by LI-COR, Inc.
3. The instrument was used in the normal, proper and ordinary manner and has not been abused, altered, misused, neglected, involved in an accident or damaged by act of God or other casualty.
4. The purchaser, whether it is a DISTRIBUTOR or direct customer of LI-COR or a DISTRIBUTOR'S customer, packs and ships or delivers the instrument to LI-COR, Inc. at LI-COR Inc.'s factory in Lincoln, Nebraska, U.S.A. within 30 days after LI-COR, Inc. has received written notice of the defect. Unless other arrangements have been made in writing, transportation to LI-COR, Inc. (by air unless otherwise authorized by LI-COR, Inc.) is at customer expense.
5. No-charge repair parts may be sent at LI-COR, Inc.'s sole discretion to the purchaser for installation by purchaser.
6. LI-COR, Inc.'s liability is limited to repair or replace any part of the instrument without charge if LI-COR, Inc.'s examination disclosed that part to have been defective in material or workmanship.

There are no warranties, express or implied, including but not limited to any implied warranty of merchantability of fitness for a particular purpose on underwater cables or on expendables such as batteries, lamps, thermocouples, and calibrations.

Other than the obligation of LI-COR, Inc. expressly set forth herein, LI-COR, Inc. disclaims all warranties of merchantability or fitness for a particular purpose. The foregoing constitutes LI-COR, Inc.'s sole obligation and liability with respect to damages resulting from the use or performance of the instrument and in no event shall LI-COR, Inc. or its representatives be liable for damages beyond the price paid for the instrument, or for direct, incidental or consequential damages.

The laws of some locations may not allow the exclusion or limitation on implied warranties or on incidental or consequential damaged, so the limitations herein may not apply directly. This warranty gives you specific legal rights, and you may already have other rights which vary from state to state. All warranties that apply, whether included by this contract or by law, are limited to the time period of this warranty which is a twelve-month period commencing from the date the instrument is shipped to a user who is a customer or eighteen months from the date of shipment to LI-COR, Inc.'s authorized distributor, whichever is earlier.

This warranty supersedes all warranties for products purchased prior to June 1, 1984, unless this warranty is later superseded. To the extent not superseded by the terms of any extended warranty, the terms and conditions of LI-COR's Warranty still apply.

DISTRIBUTOR or the DISTRIBUTOR's customers may ship the instruments directly to LI-COR if they are unable to repair the instrument themselves even though the DISTRIBUTOR has been approved for making such repairs and has agreed with the customer to make such repairs as covered by this limited warranty.

Further information concerning this warranty may be obtained by writing or telephoning Warranty manager at LI-COR, Inc.

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APPENDIX E.1-3

LABORATORY STANDARD OPERATING PROCEDURES FOR GROUNDWATER ANALYSIS

Management Approval:
Lenzie Boring Approved on 2/10/2022 9:29:54 AM
Charles Girgin Approved on 2/10/2022 10:05:02 AM
Kenneth Busch Approved on 2/10/2022 1:48:14 PM

1.0 Scope And Application

This standard operating procedure (SOP) describes the laboratory procedure for the analysis of drinking water by Inductively Coupled Plasma Mass Spectrometry (ICP/MS). A Thermo Scientific RQ ICP/MS is used in this procedure.

1.1 Target Analyte List and Limits of Quantitation (LOQ)

The target analytes and the normal LOQ that can be achieved with this procedure are provided in Table 1, Appendix A.

LOQ are established in accordance with Pace policy and SOPs for method validation and for the determination of detection limits (DL) and quantitation limits (LOQ). DL and LOQ are routinely verified and updated when needed. The current LOQ for each target analyte that can be determined by this SOP as of the effective date of this SOP is provided in Table 1, Appendix A.

The reporting limit (RL) is the value to which analytes are reported as detected or not detected in the final report. When the RL is less than the lower limit of quantitation (LLOQ), all detects and non-detects at the RL are qualitative. The LLOQ is the lowest point of the calibration curve used for each target analyte.

DL, LOQ, and RL are always adjusted to account for actual amounts used and for dilution.

2.0 Summary of Method

2.1 A representative sample aliquot is tested for turbidity. If the turbidity is less than 1 NTU, the sample is matrix matched to the calibration standards and analyzed without digestion. If turbidity is greater than 1 NTU the sample is digested using an appropriate procedure. Sample material in solution is introduced by pneumatic nebulization into a radio frequency plasma where energy transfer processes cause desolvation, atomization and ionization. The ions are extracted from the plasma through a differentially pumped vacuum interface and separated on the basis of their mass-to-charge ratio (m/z) by a quadrupole mass spectrometer. The ions transmitted through the quadrupole are detected by an electron multiplier and the ion information processed by a data handling system. Interferences relating to the technique must be recognized and corrected for. Such corrections must include compensation for isobaric elemental interferences and interferences from polyatomic ions derived from the plasma gas, reagents or sample matrix.

2.2 Instrumental drift as well as suppressions or enhancements of instrument response caused by the sample matrix is corrected for by the use of internal standards.

3.0 INTERFERENCES

3.1 Isobaric Elemental Interferences – Isobaric elemental interferences result when isotopes of different elements have the same nominal mass-to-charge ratio and cannot be resolved with the instruments spectrometer. One way to solve this problem is to measure a different isotope for which there is no interference. Alternatively, one can monitor another isotope of the element and subtract an appropriate amount from the element being analyzed, using known isotope ratio information. Corrections for most of the common elemental interferences are programmed into the software.

3.2 Isobaric Polyatomic Interferences – Isobaric polyatomic interferences result when ions containing more than one atom have the same nominal mass-to-charge ratio as an analyte of interest and cannot be resolved by the instrument's spectrometer. Examples include ArCl+ (mass 75), which interferes with As. ClO+ (mass 51), which interferes with V, and must be corrected by measuring ClO+ at mass 53. When possible an interference-free isotope should be chosen for measurement.

3.3 Physical interferences are associated with the sample nebulization and transport processes as well as with ion-transmission efficiencies. Nebulization and transport processes can be affected if a matrix component causes a change in surface tension or viscosity. Changes in matrix composition can cause significant signal suppression or enhancement. Dissolved solids can deposit on the nebulizer tip of a pneumatic nebulizer and on the interface skimmers (reducing the orifice size and the instrument performance). Total solid levels below 0.2% (2,000 mg/L) have been currently recommended to minimize solid deposition. An internal standard can be used to correct for physical interferences, if it is carefully matched to the analyte so that the two elements are similarly affected by matrix changes.

3.4 Memory interferences can occur when there are large concentration differences between samples or standards, which are analyzed sequentially. Sample deposition on the sampler and skimmer cones, spray chamber design, and the type of nebulizer affects the extent of the memory interferences, which are observed. The rinse period between samples must be long enough to eliminate significant memory interference.

3.5 It is important to note that matrix matching acid concentrations between standards, blanks and samples cannot be ignored. ICPMS is more sensitive than ICP in this regard.

3.6 Chromic acid should never be used to clean any container used in ICPMS analysis.

3.7 Standards shall be prepared in class "A" glassware and then stored in clean, plastic containers.

3.8 Interference equations are used to correct for isobaric elemental and polyatomic interferences. All equations can be adjusted if necessary or added if the analyst determines that a particular correction is insufficient or is over correcting the data.

4.0 DEFINITIONS

Refer to the Laboratory Quality Manual for a glossary of common lab terms and definitions.

4.1. Total Recoverable Analyte: The concentration of analyte determined either by "direct analysis" of an unfiltered acid preserved drinking water sample with turbidity of <1 NTU, or by analysis of the solution extract of a solid sample or an unfiltered aqueous sample following digestion by refluxing with hot dilute mineral acid(s) as specified in the method.

4.2. Dissolved Analyte: The concentration of analyte in an aqueous sample that will pass through a 0.45µm membrane filter assembly prior to sample acidification.

4.3. Instrument Detection Limit (IDL): The concentration equivalent to the analyte signal that is equal to the average of the standard deviation of a series of 7 replicate measurements of the calibration blank for 3 non-consecutive days at the selected analytical masses as defined in method SW846-6020B. Method 200.8 defines the IDL as 3 times the standard deviation of 10 replicates run in a single day. We perform these IDL studies as defined by 200.8 because this procedure is more representative of the normal variation of an instrument through a longer period of time than that of 6020B.

4.4. Linear Dynamic Range (LDR): The maximum concentration of the range where the instrument response is linear. The LDR must be determined initially and verified every six months or whenever a significant change in instrument response is observed or expected. The initial demonstration of linearity must use sufficient standards to ensure that the resulting curve is linear. The verification of linearity must use a minimum of a blank and three standards. If any verification data exceeds the initial values by ± 10%, linearity must be reestablished. If any portion of the range is shown to be nonlinear, sufficient standards must be used to clearly define the nonlinear portion. This study will be performed as follows:

4.4.1. A blank and a minimum of three mid-level calibration standards of varied concentrations are plotted on a first order linear curve. The resulting regression coefficient must be ≥ 0.998.

4.4.2. Any additional standards are analyzed using this curve. Their observed concentrations are compared to their known values.

4.4.3. The linear portion of the curve is determined by those standards with observed concentrations that vary by less than 10% from their known values.

4.4.4. Any sample with a concentration over the linear dynamic range must be diluted and reanalyzed until the concentration is within the linear dynamic range.

4.4.5. The linear dynamic range is verified semi-annually by running a multi element standard at the high concentration of the linear range. If the standard recovers within 10% of its true value, it is determined that the element is still linear at that range.

4.5. Autotune/Tune: is a Qtegra software tool that allows the iCAP RQ to be optimized in a consistent, routine manner, giving reproducible levels of performance and saving the operator time and effort. It works by following a pre-defined sequence, optimizing individual instrument parameters in turn. Once the Autotune is completed, an Instrument Setting file is created.

4.6. Instrument calibrations: There are two instrument calibrations that are fundamental for obtaining good quality data on the iCAP RQ: (1) Mass calibration, (2) Detector Cross calibration. Both calibrations may be performed in a single routine, or may be performed separately as needed.

4.7. Mass calibration: Sets the quadrupole scan parameters to give the correct measured mass positions. A mass-calibration must be performed whenever the resolution settings are adjusted, as this will affect the apparent mass position. Mass-calibration must be performed when the Performance Report shows that measured peak positions are >0.1 AMU from their nominal position. Mass-calibrations are best performed using a solution containing as many elements as possible or with every analyte required for analysis at the very least. The solution should contain Li and U as these are used as low and high mass datum points. An appropriate, 1 µg/L, concentration solution should be used and should yield between 100,000-1,500,000 cps for each mass to be calibrated is appropriate.

4.8. Detector Cross Calibration (X-Cal): calculates the correction factor, for each measured mass, between the two detector modes, pulse counting and analogue. These routines can be performed separately, but it is advised to run them simultaneously as described here. The necessary frequency of these calibrations depends upon the amount of signal the detector is exposed to, i.e. how many samples are analyzed, which analytes and what concentrations. This routine must be performed whenever the detector voltages are altered. For most laboratories running a moderate sample load, this procedure may be run weekly. A solution that gives a count rate of between 100,000-1,500,000 cps is appropriate. The default mass used here is indium (m/z 115), so this must be present in the solution for the routine to work. For a iCAP RQ instrument, an appropriate concentration would typically be between 3 and 35 µg/L, depending upon the sensitivity of the system. The solution used must contain all the analytes to be measured as an absolute minimum.

4.9. Tuning Solution: A solution that is used to determine acceptable instrument performance prior to calibration and sample analyses.

4.10. Performance Reports: a PlasmaLab software tool that allows the X Series performance to be checked on a daily basis. The Performance Report can be set-up to give information about instrument sensitivity, stability, background, oxide species, doubly charged species, mass-calibration validity and peak resolution. Like Autotune, the Performance Report is user definable but defaults are provided by the manufacturer during installation.

4.11. Cross Calibration Solution: The cross calibration solution is a standard that allows the ICP-MS to determine the crossover point between the analog and the pulse count detector modes, over the entire mass spectrum. It must contain a large number of isotopes that span the full mass spectrum, at high enough concentrations to trigger the analog detector.

4.12. Interelement Corrections (IEC): Single element standards are prepared and ran at each elements upper linear dynamic range limit. If the standard produces a false positive or negative result for any element other than the target analyte, a correction factor can be calculated and used during calibration and analysis of any samples. However the built-in correction equations in the Qtegra software are usually more accurate than the equations derived from a single analysis run.

4.13. Interference Check Solution (ICSA and ICSAB): A solution of elements that are known as interferants prepared at high concentrations. The results are used to verify the accuracy of the interelement corrections and the absence of interelement spectral interferences.

5.0 HEALTH AND SAFETY

The toxicity or carcinogenicity of each chemical material used in the laboratory has not been fully established. Each chemical should be regarded as a potential health hazard and exposure to these compounds should be as low as reasonably achievable.

The laboratory maintains documentation of hazard assessments and OSHA regulations regarding the safe handling of the chemicals specified in each method. Safety data sheets for all hazardous chemicals are available to all personnel. Employees must abide by the health, safety and environmental (HSE) policies and procedures specified in this SOP and in the Pace Chemical Hygiene / Safety Manual.

Personal protective equipment (PPE) such as safety glasses, gloves, and a laboratory coat must be worn in designated areas and while handling samples and chemical materials to protect against physical contact with samples that contain potentially hazardous chemicals and exposure to chemical materials used in the procedure.

Concentrated corrosives present additional hazards and are damaging to skin and mucus membranes. Use these acids in a fume hood whenever possible with additional PPE designed for handing these materials. If eye or skin contact occurs, flush with large volumes of water. When working with acids, always add acid to water to prevent violent reactions. Any processes that emit large volumes of solvents (evaporation/concentration processes) must be in a hood or apparatus that prevents employee exposure.

Contact your supervisor or local HSE coordinator with questions or concerns regarding safety protocol or safe handling procedures for this procedure.

6.0 Sample Collection, Preservation, Holding Time, And Storage

Samples should be collected in accordance with a sampling plan and procedures appropriate to achieve the regulatory, scientific, and data quality objectives for the project.

The laboratory sometimes performs samples collection for samples to be analyzed by this SOP in accordance with laboratory SOP ENV-SOP-LENE-0107, *Field Manual*. Refer to this SOP for these instructions.

The laboratory will provide containers for the collection of samples upon client request for analytical services. Bottle kits are prepared in accordance with laboratory SOP ENV-SOP-LENE-*Assembly of Sample Container Kits*. .

Requirements for container type, preservation, and field quality control (QC) for the common list of test methods offered by Pace are included in the laboratory's quality manual.

General Requirements

Matrix	Routine Container	Minimum Sample Amount[1]	Preservation	Holding Time
Total Aqueous	Plastic 500mL	150 mL	Thermal: None Chemical: pH<2 with Nitric Acid	Collection to Analysis: 180 days
Dissolved Aqueous (lab filtered)	Plastic 500mL	150 mL	Thermal: None Chemical: no preservation	Collection to Analysis: 180 days

Drinking Water	Pre-cleaned, HDPE, glass or PTFE (500 mL)	50 mL	Thermal: NA Chemical: 1:1 HNO3; pH <2	
solid	Glass 4oz	10g	Thermal: ≤6°C Chemical: None	Collection to Analysis: 180 days

[1]*Minimum amount needed for each discrete analysis.*

Field / Matrix QC

Trip Blank	Equipment Blank	MS/MSD	Field Duplicate
NA	As Needed	1/20	1/20

Thermal preservation is checked and recorded on receipt in the laboratory in accordance with laboratory SOP ENV-SOP-LENE-0021, *Sample Management*. Chemical preservation is checked and recorded at time of receipt or prior to sample preparation.

6.1 Sample pH is measured upon receipt to ensure that the pH is <2. If pH is found to be >2, an additional aliquot of 1:1 nitric acid is added by receiving staff (not to exceed 1% of the container's total volume). A label is attached to container noting the time, and date of the addition.

6.2 The sample must now be held for 24 hours and the pH rechecked by the metals staff before digestion may begin. This section does not apply to samples that are received unpreserved for filtration by the laboratory. Failure to achieve proper preservation must be documented on the final report.

6.3 For dissolved elements, sample must be filtered through a 0.45 micron pore diameter membrane filter at collection.

After receipt, samples are stored at room temperature. Prepared samples (extracts, digestates, distillates, other) are stored at room temperature.

After analysis, unless otherwise specified in the analytical services contract, samples are retained for 30 days from date of final report and then disposed of in accordance with Federal, State, and Local regulations.

7.0 Equipment And Supplies

7.1 Equipment

Table 7.1 Equipment

Supply	Vendor	Model / Version	Comments
ICP-MS	Thermo Scientific	RQ	or equivalent
Autosampler	Elemental Scientific	SC4DX	or equivalent

7.2 Supplies

Table 7.2 Supplies

Supply	Vendor	Model / Version	Comme
Volumetric Flasks	Various	Various; 5- to1000-mL	Class A
Test tubes	17 x 100mm	Mold Pro / MP-120	or equivalent
Pipettors	Eppendorf	Various	

8.0 Reagents And Standards

8.1 Reagents

Table 8.1 Reagents

Reagent/Standard	Concentration/ Description	Requirements/ Vendor/ Item #
Reagent water	ASTM Type II	SOP S-KS-Q-011
Nitric acid	TraceMetal Grade	Fisher / A509-212 (or equivalent)
Hydrochloric acid	TraceMetal Grade	Fisher / A508-212 (or equivalent)

8.2 Standards

Table 8.2 Standards

Reagent/Standard	Concentration/ Description	Requirements/ Vendor/ Item #
Reagent water	ASTM Type II	SOP S-KS-Q-011
Nitric acid	TraceMetal Grade	Fisher / A509-212 (or equivalent)
Hydrochloric acid	TraceMetal Grade	Fisher / A508-212 (or equivalent)
ICP-1A	200 mg/L: As, Ba, Be, Cd, Co, Cr, Cs, Cu, Li, Mn, Ni, Pb, Se, Sr, U, V, Zn 100 mg/L: Ag, Tl	SPEX / XPACEMN-76-500
ICP-2A	200 mg/L: B, Mo, Pd, Pt, Sb, Sn, Ti, Zr	SPEX / XPACEMN-77-500
ICP-3A	1000 mg/L: Al, Ca, K, Mg, Na, S 500 mg/L Fe, P, Si	SPEX / XPACEMN-75-500
ICP-1B	200 mg/L: As, Ba, Be, Cd, Co, Cr, Cs, Li, Mn, Ni, Pb, Se, Sr, U, V, Zn 100 mg/L: Ag, Tl	High Purity Standards / HP7379-500
ICP-2B	200 mg/L: B, Mo, Pd, Pt, Sb, Sn, Ti, Zr	High Purity Standards / HP7376-500
ICP-3B	1000 mg/L: Al, Ca, K, Mg, Na, S 500 mg/L Fe, P, Si	High Purity Standards / HP7375-500
SPK-STD-1B	200 mg/L: As, Ba, Be, Cd, Co, Cr, Cu, Li, Mn, Ni, P, Pb, Se, Sr, Tl, V, Zn	Inorganic Ventures / PA-STD-1B
SPK-STD-2B	1000 mg/L: Si 200 mg/L: B, Mo, Sb, Sn, Ti, Zr 100 mg/L: Ag	Inorganic Ventures / PA-STD-2B
SPK-STD-3B	2000 mg/L: Al, Ca, Fe, K, Mg, Na	Inorganic Ventures / PA-STD-3B
6020 Internal Standard	10 mg/L Bi, Ho, In, Li6 , Rh, Sc, Tb, Y, Ga, I	Inorganic Ventures / 6020ISS
iCAP Q/RQ TUNE solution	1.0 µg/L Ba, Bi, Ce, Co, In, Li, U	Inorganic Ventures / THERMO-4AREV
iCAP Q/Qnova Calibration solution	35 µg/L Be 20 µg/L Zn 15 µg/L Cu, Ni 10 µg/L Al, Ga, Mg 8 µg/L Co, Li, Sc 6 µg/L Ag, Mn 5 µg/L Sr 4 µg/L Ba, Tl 3 µg/L Bi, Ce, Cs, Ho, In, Rh, Ta, Tb, U, Y	Inorganic Ventures / THERMO-5AREV
Single Element Standards	1-10 mg/L; CRDL, ICSB, STK	Ultra Scientific / Various
ICS-ICPMS	10000 mg/L: Cl 2000 mg/L: C 1000 mg/L: Al, Ca, Fe, K, Mg, Na, P, S 20 mg/L: Mo, Ti	High Purity / CLP-INF-1-500

Reagent/Standard	Concentration/ Description	Requirements/ Vendor/ Item #
Uranium	1000 mg/L	SPEX
Uranium	1000 mg/L	Inorganic Ventures
Mercury - Primary	1000 mg/L	SPEX
Mercury - Secondary	1000 mg/L	Inorganic Ventures

8.3 Storage Conditions

Table 8.3 Storage Conditions

Standard Type	Description	Expiration	Storage
Stock Solutions	▪ Concentrated reference solution purchased directly from approved vendor	▪ Manufacturer's recommended expiration date	▪ Store at room temperature unless manufacturer recommends different storage conditions
Intermediate and Working Standard Solutions	▪ Reference solutions prepared by dilutions of the stock solution	▪ 6 months from preparation or the expiration date listed for the stock source, whichever is sooner. ▪ Working solutions must be checked frequently and replaced if degradation or evaporation is suspected.	▪ Store at room temperature unless stock standard manufacturer recommends different storage conditions

8.4 All working solutions are prepared with an acid matrix of 2% nitric acid and 5% hydrochloric acid. If 1:1 nitric acid and 1:1 hydrochloric acid are used in place of concentrated acids, the final solution must contain 2% nitric acid and 5% hydrochloric acid. If Drinking Water analysis is to be performed, the acid concentration is reduced to 1% nitric and 0.5% hydrochloric.

8.5 Prepare calibration standards according to the table below

Table 8.5 – Working Calibration Standards

Working Standard	Stock(s)	Volume Used (mL)	ICPMS Reagent Blank (or drinking water equivalent) (mL)	Final Volume (mL)
CAL0 (Blk Soln/ICB/CCB)	N/A	N/A	1000	1000
CAL4	ICP-1A	0.250	489.5	500
	ICP-2A	0.250		
	ICP-3A	5.00		
	Hg Intermediate - 1	5.00		

Working Standard	Stock(s)	Volume Used (mL)	ICPMS Reagent Blank (or drinking water equivalent) (mL)	Final Volume (mL)
CAL3	CAL4	100.0	100.0	200
CAL2	CAL4	50.0	150.0	200
CAL1	CAL4	10.0	190.0	200
CCV	ICP-1A ICP-2A ICP-3A Hg Intermediate - 1	0.20 0.20 4.00 4.00	991.6	1000
ICV	SPK-STD-1B SPK-STD-2B SPK-STD-3B U intermediate 2 Hg Intermediate - 2	0.05 0.05 1.00 1.0 2.0	195.90	200
ICPMS Spike (waters)	PA-STD-1B PA-STD-2B PA-STD-3B Zn 1000 mg/L U 1000 mg/L	2.0 2.0 5.0 0.6 0.4	190.0	200
ICPMS Mercury Spike	Mercury - Secondary	0.5	99.5	100
U intermediate – 1 (10mg/L) Primary source	U primary stock	1.0	99.0	100
U working - primary Source (0.1 mg/L)	U intermediate-1	1.0	99.0	100
U intermediate -2	U secondary stock	1.0	99.0	100
Uranium Soil Spike 20 mg/L	U primary stock	2.0	98.0	100
Hg Intermediate – 1	Hg Primary	0.05	99.95	100
Hg Intermediate – 2	Hg Secondary	0.05	99.95	100

8.6 Reporting Limit Standard (CRDL): The CRDL is analyzed prior to any samples after the ICB. Additional CRDLs may be analyzed throughout the analytical sequence at the analyst's discretion. The control limits for the CRDL are ±50% of the true value.

8.6.1 The CRDL 1 Stock Standard is prepared from single element standards. Add 500 mL deionized water to a 1-L volumetric, then add all of the single element standards per the Table 8.6 below, except for Sb, Mo, Pd, Pt, Ti, and Sn. Add 1.0 mL nitric acid. Bring to volume and transfer to a labeled, plastic container.

8.6.2 The CRDL 2 Stock Standard is prepared from Sb, Mo, Pd, Pt, Ti and Sn single element standards. Add 500 mL deionized water to a 1-L volumetric, then add the single element standards per the Table 8.6 below. Add 1.0 mL nitric acid. Bring to volume and transfer to a labeled, plastic container.

8.6.3 CRDL Working Standard – In a 100-mL volumetric flask, add 50 mL deionized water, 2.0 mL nitric acid, 5 mL hydrochloric acid (1.0 mL nitric acid, 0.5 mL hydrochloric if performing drinking water analysis), 1.0 mL each of CRDL1 and CRDL 2 Stock Standards. Bring to volume and transfer to a labeled, plastic container.

Table 8.6 – CRDL 1 and CRDL 2 Stock Standards

Component Standard	Element	Stock Standard Concentration (mg/L)	Volume Used (mL)	Final Volume (mL)	CRDL 1,2 Stock Standard Concentration (ug/L)
Single Element Standard	Al	10,000	0.5	1000	5000
Single Element Standard	Sb	1,000	0.1	1000	100
Single Element Standard	As	1,000	0.1	1000	100
Single Element Standard	Ba	1,000	0.1	1000	100
Single Element Standard	Be	1,000	0.05	1000	50
Single Element Standard	Cd	1,000	0.05	1000	50
Single Element Standard	Cr	1,000	0.1	1000	100
Single Element Standard	Co	1,000	0.1	1000	100
Single Element Standard	Cu	1,000	0.1	1000	100
Single Element Standard	Fe	10,000	0.5	1000	5000
Single Element Standard	Pb	1,000	0.1	1000	100
Single Element Standard	Pd	1,000	0.02	1000	100
Single Element Standard	Pt	1,000	0.1	1000	100
Single Element Standard	Mn	1,000	0.1	1000	100
Single Element Standard	Mo	1,000	0.1	1000	100
Single Element Standard	Ni	1,000	0.1	1000	100
Single Element Standard	Se	1,000	0.1	1000	100
Single Element Standard	Ag	1,000	0.05	1000	50
Single Element Standard	Sr	1,000	0.1	1000	100
Single Element Standard	Tl	1,000	0.1	1000	100
Single Element Standard	Sn	1,000	0.5	1000	100
Single Element Standard	Ti	1,000	0.2	1000	200
Single Element Standard	V	1,000	0.1	1000	100
Single Element Standard	Zn	1,000	1.0	1000	1000

8.6 ICS Interference Check Standards (ICSA and ICSAB). The ICSA and ICSAB are analyzed to demonstrate adequate correction for known interferences. The ICSA and ICSAB are analyzed prior to any samples and every 12 hours thereafter, or at a frequency specified by a project QAPP. Chloride in the ICS provides a means to evaluate software corrections for chloride-related interferences such as $^{35}Cl\,^{16}O$ on ^{51}V, and $^{40}Ar\,^{35}Cl$ on $^{75}As^{+}$. Iron is used to demonstrate adequate resolution of the spectrometer for the determination of manganese. Molybdenum serves to indicate oxide effects on cadmium isotopes. The other components are present to evaluate the ability of the measurement system to correct for various polyatomic isobaric interferences. The ICSA(B) recovery limits are ± 20% of the true value or less than 2 times (2X) the RL for non-spiked elements.

8.6.1 The ICSA working standard is prepared by adding 10 mL of ICSA stock and 4.0 mL nitric acid to a 200-mL volumetric half-filled with deionized water. Bring to volume and transfer to a labeled, plastic container.

8.6.2 ICSB-1 Stock Standard – The ICSB stock is prepared from single-element standards. Add 500 mL deionized water to a 1-L volumetric flask, and then add the single elements per the Table 8.7 below. Add 20 mL nitric acid. Bring to volume and transfer to a labeled, plastic container.

Table 8.7 – ICSB-1 Stock Standard

Component Standard	Element	Stock Standard Concentration (mg/L)	Volume Used (mL)	Final Volume (mL)	ICSB Stock Concentration (ug/L)
Single Element Standard	Ag	1000	0.5	1000	500
Single Element Standard	As	1000	1.0	1000	1,000
Single Element Standard	Ba	1000	1.0	1000	1,000
Single Element Standard	Be	1000	0.5	1000	500
Single Element Standard	Cd	1000	0.5	1000	500
Single Element Standard	Cr	1000	1.0	1000	1,000
Single Element Standard	Co	1000	1.0	1000	1,000
Single Element Standard	Cu	1000	1.0	1000	1,000
Single Element Standard	Pb	1000	1.0	1000	1,000
Single Element Standard	Mn	1000	1.0	1000	1,000
Single Element Standard	Ni	1000	1.0	1000	1,000
Single Element Standard	Se	1000	1.0	1000	1,000
Single Element Standard	Sr	1000	1.0	1000	1,000
Single Element Standard	Tl	1000	1.0	1000	1,000
Single Element Standard	V	1000	1.0	1000	1,000
Single Element Standard	Zn	1000	10.0	1000	10,000

8.6.3 ICSB-2 Stock Standard – The ICSB stock is prepared from single-element standards. Add 500 mL deionized water to a 1-L volumetric flask, and then add the single elements per the Table 8.8 below. Add 20 mL nitric acid and 100 mL hydrochloric acid.

Table 8.8 – ICSB-2 Stock Standard

Component Standard	Element	Stock Standard Concentration (mg/L)	Volume Used (mL)	Final Volume (mL)	ICSB Stock Concentration (ug/L)
Single Element Standard	Sb	1000	0.50	1000	500
Single Element Standard	Pd	10,000	0.05	1000	500
Single Element Standard	Pt	1000	0.50	1000	500
Single Element Standard	Sn	1000	0.50	1000	500

8.6.4 The ICSAB standard is prepared by adding 10 mL of ICSA stock, 10 mL ICSB-1, and 10 mL ICSB-2 to a 200-mL volumetric half-filled with deionized water. Add 4.0 mL nitric acid and 10.0 mL hydrochloric acid (2.0 mL nitric, 1.0 mL hydrochloric acid if performing drinking water analysis). Bring to volume and transfer to a labeled, plastic container.

8.7 Carrier Solution - The ESI FAST system autosampler uses a carrier solution since the sample is not continuously pumped to the nebulizer. The Blank Solution is used as the carrier.

8.8 Mass Spectrometer Tuning Standard: A standard containing elements representing all of the mass regions of interest (for example, 10 µg/L of ^{6}Li, ^{115}In and ^{238U} or Pb) must be prepared to verify that the mass resolution and mass calibration of the instrument are within the required specifications. This solution is also used to verify that the instrument has reached thermal stability.

8.8.1 It is preferred to use Tune Standard manufactured by Inorganic Ventured, THERMO-4REV, however, an in-house Tune Standard can be made. See below for instructions.

8.8.2 Stock Tuning Standard (ICPMS Tune Stock) – In a 100-mL volumetric flask, add 1.0 mL nitric acid and 1.0 mL each of the 1,000 mg/L Ba, Bi, Ce, Co, In, Li7, Pb, U single element standards. Bring to volume with deionized water and transfer to a labeled, plastic container.

8.8.3 Working Tuning Standard: In a 1-L volumetric flask, add 500 mL deionized water, 10 mL nitric acid, 5 mL hydrochloric acid, and 0.1 mL ICPMS Tune Stock. Bring to volume and transfer to a labeled, plastic container.

8.9 Cross Calibration Standard (X Cal): contains 50 ug/L of as many elements as possible from ^{6}Li to ^{238}U. This standard is used to calculate the concentration when the detector changes from pulse mode to analog mode. This enables a large linear range while protecting the detector. It is preferred to use a Cross Calibration Standard manufactured by Inorganic Ventures, THERMO-5REV.

8.10 Internal Standards (IS):

8.10.1 Internal standards must be present in all samples, standards and blanks at identical levels. This is achieved by directly adding the internal standard stock by on-line addition prior to nebulization using a second channel of the peristaltic pump and a mixing connector. For full mass range scans, a minimum of six internal standards are suggested. During the analysis, the software uses the ratio of analyte and internal standard intensities to adjust the final concentration values. Ratios are based on the intensities in the sample vs. the calibration blank.

8.10.2 The internal standard should be within 50 amu of the measured mass. The procedure described in this SOP for general applications, details the use of ^{6}Li, ^{45}Sc, ^{71}Ga, ^{89}Y, ^{103}Rh, ^{115}In, ^{159}Tb, ^{165}Ho, ^{193}Ir, and ^{209}Bi. Internal standards may be used per mass, mass range (50 amu) or by interpolation.

8.10.3 The assignment of a particular IS may be dictated by the sample matrix. The concentration of the internal standard should be sufficiently high that good precision is obtained and the possibility of correction errors is minimized if the internal standard is naturally present in the sample. One or more of the internal standards may not be suitable due to matrix interferences. It is up to the analyst to recognize and correct the problem by diluting the sample(s) for reanalysis or selecting an alternative internal standard. The analyst may also enhance the concentration of the IS, however, that procedure requires recalibration with the enhanced IS concentration.

8.10.4 Stock Internal Standard Solution – In a 100-mL volumetric flask, add 10 mL deionized water, 1.0 mL nitric acid, 1.0 mL hydrochloric acid, 3.0 mL 1,000 mg/L ^{209}Bi, 25.0 mL 1,000 mg/L ^{71}Ga, 1.0 mL 1,000 mg/L ^{165}Ho, 3.0 mL 1,000 mg/L ^{115}In, 5.0 mL 1,000 mg/L ^{193}Ir, 5.0 mL 1,000 mg/L ^{6}Li, 1.0 mL 1,000 mg/L ^{103}Rh, 10.0 mL 1,000 mg/L ^{45}Sc, 1.0 mL 1,000 mg/L ^{159}Tb, and 1mL 1,000 mg/L ^{89}Y. Bring to volume and transfer to a labeled, plastic 100-mL container.

8.10.5 Working Internal Standard Solution - In a 1-L volumetric flask, add 500 mL deionized water, 10.0 mL nitric acid, 5.0 mL hydrochloric acid, and 5.0 mL Stock Internal Standard Solution. Bring to volume and transfer to a labeled, plastic 1-L container.

9.0 PROCEDURE

9.1 Equipment Preparation

9.1.1 Verify that the internal standard and carrier lines are in the appropriate containers. Verify that all standards are in the correct positions. Prepare calibration standards, blanks, samples, and QC samples. Build a sequence in the sequence table and apply the repeat run rules to insert the CCV and CCB for every 10 unknowns. Queue the experiment to the Technician queue. Each experiment will require a unique code (e.g. 090511A, 090511B, etc.).

9.1.2 Support Equipment

9.1.3 Instrument

9.1.3.1 Routine Instrument Operating Conditions

Daily – inspect pump tubing, fill internal standard and rinse bottles. Keep immediate area near the instrument clean. As needed based on performance – inspect cones, spray changer and torch. Clean or replace as needed. Quarterly, inspect and clean air filters.

9.2 Initial Calibration

9.2.1 Calibration Design

Calibration consists of a calibration blank and a minimum of three non-zero standards for each mass. The reporting limit is normally the lowest non-blank standard in the calibration curve. The reporting limit may not be less than the lowest non-zero standard in the curve. The ICPMS software uses a linear regression curve fit. Weighting of the curve is allowed. Curve may be forced through zero if acceptance criteria are met. The correlation coefficient must be ≥0.998.

9.2.2 Calibration/Analysis Sequence

1	Instrument Blank
2	CAL0
3	CAL1
4	CAL2
5	CAL3
6	CAL4
7	ICV
8	ICB
9	CRDL
10	ICSA
11	ICSAB
12	CCV
13	CCB
14	10 analytical samples, including QC
15	CCV
16	CCB
17	10 analytical samples, including QC
18	CCV
19	CCB
20	

9.2.3 ICAL Evaluation

Calibration Metric	Parameter / Frequency	Criteria	Comments
Calibration Curve Fit	Performed daily or as needed	Correlation coefficient ≥ 0.998	If not met, determine cause and recalibrate
Initial Calibration Verification Standard (Second Source)	Immediately after each calibration	±10% of true value	Reanalyze ICV once, if ICV is still out, terminate analysis, correct problem, and recalibrate instrument
Calibration Blank (ICB/CCB)	Immediately after the ICV, after each CCV	< PRL or client specified	Samples analyzed with a bracketing CCB that exceeded criteria may be reported if the target analyte(s) in the samples are >10X the amount that was found in the CCB.
CRDL Standard (LLICV/LLCCV)	6020: Immediately after ICB and at the end or as specified per client QAPP 200.8 Immediately after ICB.	Each element tested must be at least between 50-150% of the CRDL value OR As specified per client QAPP	If recoveries are not acceptable, stop analysis for that analyte *Pace Metals 3P Team has determined it is a best practice to use PRL limits of at least 50-150%. Limits may be stricter if required by client.
ICSA	Immediately after the CRDL, or every 12 hours and as specified by client QAPP	Results for non-interference elements = ND ± 2 x CRDL Recovery of interfering elements must be 80-120% of true value	If recoveries are not acceptable, stop analysis for that analyte
ICSAB	Immediately after the CRDL, or every 12 hours and as specified by client QAPP	± 20% of true value	If recoveries are not acceptable, stop analysis for that analyte
Continuing Calibration Verification (CCV)	After the ICSAB, every 10 samples and at the end of analytical sequence	±10% of true value.	If recoveries are not acceptable, stop analysis for that analyte. Samples analyzed with a bracketing CCV that exceeded criteria due to an increase in response may be reported if the target analytes were not detected in the samples.
Internal Standard	Every sample, quality control sample and calibration standard.	6020A: 70-130%. 200.8: 60-125%	If criteria not met, dilute and reanalyze, adjust IS level or select a different internal standard.

9.3 Sample Preparation

9.3.1 Homogenization and Subsampling

Refer to SOP ENV-SOP-LENE-0135

9.4 Drinking Water samples may be tested for turbidity to avoid the digestion step. Samples with turbidity equal to or greater than 1 NTU are digested prior to analysis. Samples with turbidity less than 1 NTU may be analyzed without digestion after matrix matching.

9.5 Digestion Procedure – Applies only to 200.8 Drinking Water samples. All other soils and waters must follow the digestion procedures laid out in ENV-SOP-LENE-0094 and ENV-SOP-LENE-0089 respectively. The digestion is a modified EPA 200.8 procedure as follows:

9.5.1 Shake each sample well and pour 50 mL of sample into a 50-mL digestion tube. LCS, MS and MSD's are spiked with 1.0 mL of ICPMS Spike solution using DI water to bring to volume. Method blanks are not spiked.

9.5.2 Add 1.0 mL of (1:1) HNO_3 and 0.5 mL of (1:1) HCl to the sample. This will be a 1% HNO_3 – 0.5% HCl digestion matrix.

9.5.3 Place the samples in the hot block and cover with a watch glass for 4 hours at 90-95 ºC. Remove from the block and allow to cool.

9.5.4 Bring to volume with reagent water. If digestates are turbid, filter all samples and QC.

9.5.5 Cap and shake each sample as they are diluted, and place them back into the racks while continuing to maintain order.

9.6 Direct Analysis – Allowed for 200.8 Drinking Water analysis only. Add (1:1) HCl to the sample to match standards at 0.5% HCl.

9.6.1 LCS- Spike an aliquot of the CAL0 (Blank).

Method Blank – Use an aliquot of the CAL0 (Blank)

MS/MSD – Spike an aliquot of the matrix-matched sample.

9.7 Aqueous samples – Follow digestion procedure in ENV-SOP-LENE-0089. If samples are turbid, filter all samples and QC.

9.8 Soil samples – Follow the digestion procedure for soils in ENV-SOP-LENE-0094. Dilute digestates 10-fold prior to analysis using a 2% nitric acid solution.

9.9 Instrument Startup:

9.9.1 Verify argon supply and pressure (approx. 85 psi).

9.9.2 Turn on water chiller and verify that the exhaust fan is on.

9.9.3 Ensure that the internal standard solution bottle is filled.

9.9.4 Verify that the auto sampler rinse container is filled.

9.9.5 Empty the waste reservoir if needed.

9.9.6 Ignite the plasma and allow at least 25 minutes of warm-up time while scanning the mass analyzer. Insure that all peristaltic pump tubes are in good condition and correctly clamped onto the peristaltic pumps. Verify that the flow of sample, carrier and internal standard solutions through the uptake lines and into the nebulizer. Verify that the system is free of pulsations by introducing a bubble into each line and observing its progress.

9.9.7 System Operating Conditions

Power	1400W
Pump speed	14 rpm
Uptake time (example)	35 sec
Washout time (example)	15 sec
Carrier pump tubing	Black-black
IS pump tubing	orange-green

9.9.8 Acquisition Parameters

Points per Mass	1
Number of Replicates	3
Integration Time	100 ms (As, Se) 10 ms (all others)
Resolution	Standard

9.10 Performance Reports

9.10.1 A Performance report is run prior to the calibration of the ICPMS.

9.10.1.1 The Standard Mode Performance Report verifies the mass calibration, sensitivity, peak widths, oxides and doubly charged ions and is required to analyze any drinking water samples. If the Standard Mode Performance Report fails, a mass tune may be required.

9.10.1.2 The KED Mode Performance Report verifies the mass calibration, sensitivity, peak widths, oxides and doubly charged ions while utilizing the collision cell and is required to analyze all samples other than drinking water samples. If the KED Mode Performance Report fails, a mass tune may be required.

9.10.1.3 Print and file performance reports with the raw data.

9.10.2 KED Mode: Verify that the instrument is in KED mode indicated by the picklist in the tool bar menu in Instrument Control. Aspirate the tuning solution (place both the carrier and the internal standard lines in the tune solution) and run the Standard Mode performance

9.10.2.1 Mass Resolution (35 Sweeps, 5 Reps)

- Acquisition Parameter: Peak width measured at 10% of peak maximum
- Dwell Time (msec): 1.0
- Point Spacing: 0.05 amu
- Mass Limits: 0.65-0.85 amu (Max error 0.10 amu)

9.10.2.2 Sensitivity (50 Sweeps, 5 Reps)

Element	Limits
$^{4.5}$Bkg	<10 CPS
$^{220.7}$Bkg	<10 CPS
^{59}Co/^{35}Cl.^{16}O	>18.0
^{59}Co	>30,000 CPS
^{238}U	>85,000 CPS
^{209}Bi	>42,500 CPS
^{140}Ce.^{16}O/^{140}Ce	<0.03
^{115}In	>35,000 CPS

9.10.2.3 Stability

Element	%RSD Limit
^{59}Co	2.0
^{238}U	2.0
^{209}Bi	2.0
^{115}In	2.0

9.10.2.4 Mass Resolution (50 Sweeps, 5 Reps)

- Acquisition Parameter: Peak width measured at 10% of peak maximum
- Dwell Time (msec): 0.04
- Point Spacing: 0.02 amu
- Mass Limits: 0.65-0.85 amu (Max error 0.10 amu)

9.10.3 Standard Mode: Verify that the instrument is in standard mode indicated by the picklist in the tool bar menu in Instrument Control. Aspirate the tuning solution (place both the carrier and the internal standard lines in the tune solution) and run the Standard Mode performance report.

9.10.3.1 Mass Resolution (35 Sweeps, 5 Reps)

- Acquisition Parameter: Peak width measured at 10% of peak maximum
- Dwell Time (msec): 1.0
- Point Spacing: 0.05 amu
- Mass Limits: 0.65-0.85 amu (Max error 0.10 amu)

9.10.3.2 Sensitivity (35 Sweeps, 5 Reps)

Element	Limits
$^{4.5}$Bkg	<5.0 CPS
$^{220.7}$Bkg	<5.0 CPS
^{59}Co	>50,000 CPS
^{238}U	>200,000 CPS
^{209}Bi	>42,500 CPS
^{140}Ce.^{16}O/^{140}Ce	<0.03
^{137}Ba++/^{137}Ba	<0.03
^{115}In	>175,000 CPS

9.10.3.3 Stability

Element	%RSD Limit
^{59}Co	2.0
^{238}U	2.0
^{209}Bi	2.0
^{115}In	2.0

9.11 Mass Tuning (if needed): Allow the instrument to achieve thermal stability. Aspirate the 1 ug/L Tuning Solution, inserting both the carrier and internal standard delivery lines into the tune solution so as not to dilute the tune solution. Run the appropriate tune as needed. Tuning events should be logged in the maintenance logbook.

9.11.1 Tune Procedure Summary (Use this order of events, some adjustments may be required after an auto tune)

9.11.1.1 Autotune – Source Tune High Matrix 14.0rpm 3% Oxides

9.11.1.2 Mass Calibration

9.12 Cross-Calibration (Xcal)

9.12.1 The Xcal solution does not need to be run unless a deviation between the pulse counting and analog counting methods is observed in the spectra. The analog counting will appear to sit above the pulse baseline in an observed spectra and indicates that the cross calibration needs to be performed. Also, an indication of when the Xcal needs to be reset is when the calibration loses its linearity (this will likely occur first with High Resolution Mineral elements like Na and K). Aspirate the Xcal solution in Standard Mode, with both the sample delivery and internal standard lines (so as to not dilute the Xcal solution)

9.12.1.1 Cross Calibration Only. This is done when the deviation between the pulse and analog counting methods is observed (from spectra or from linearity observations) and the minimum counts per second listed in the tuning section are achievable. Run the Detector Set-Up wizard in Qtegra when deviation of the analog spectra is observed. The detector cross calibration is selected by default in the wizard. This will reset the detector-gating plateau such that the analog spectra (dashed line in the spectra) will sit directly on top of the pulse baseline (solid line in the spectra).

9.12.1.2 Internal or Labbook Cross Calibration: This can be done during analysis to prevent stopping the current analysis. If, during a run sequence, it is evident that the calibration between pulse and analog is not optimal, the Internal Cross Calibration function can be used. Click the icon in the labbook menu to utilize this functionality. This function uses data within the current labbook to perform and optimize the cross calibration.

9.12.1.3 Detector Setup and Cross Calibration. This is done when the minimum counts per second listed in the tune section are not achievable. Thus, the detector dynode value will be adjusted and a new cross calibration will be performed with the new detector voltage setting. Launch the Instrument Calibration wizard in Qtegra and select detector set up. The detector cross calibration will be checked by default, also select the detector set up portion in the wizard. The voltage applied to the detector will be set first to achieve acceptable sensitivity followed by a detector cross calibration with the new detector setting.

9.13 Analysis

9.13.1 Example Analytical Sequence

See 9.2.2 above.

10.0 Data Analysis And Calculations

10.1 Qualitative Identification

10.2 Quantitative Identification

10.3 Calculations

See the Laboratory Quality Assurance Manual for equations for common calculations.

Manual Calculation of Element Concentrations

Aqueous Samples

$$\text{Concentration } (\mu g/L) = \frac{(A)(V2)(DF)}{(V1)}$$

Solid Samples

$$\text{Concentration } (mg/kg) = \frac{(A)(V2)(DF)}{(W) \times 1000}$$

where:

A = Analyzed concentration of element, ug/L.

V1 = Volume of sample, mL.

V2 = Final digestate volume, mL.

DF = Dilution factor.

W = Weight of sample, g

11.0 Quality Control and Method Performance

11.1 Quality Control

The following QC samples are prepared and analyzed with each batch of samples. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency
Method Blank (MB)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Laboratory Control Sample (LCS)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Internal Standard	Every sample, QC sample and Cal Std.
Matrix Spike (MS)	One per 10 samples
Matrix Spike Duplicate (MSD)	One per batch (20 samples or less)
Sample Duplicate	One per batch of 20 samples or less (Not Required if MSD done.
CRDL Standard (LLICV/LLCCV)	Immediately after ICB and at the end or as specified per client QAP

11.2 Instrument QC

The following Instrument QC checks are performed. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency
Initial Calibration	Daily or as needed
Initial Calibration Verification	Immediately after each calibration
Initial Calibration Blank	Immediately after the ICV, after each CCV
Continuing Calibration Verification	Immediately after ICSAB, every 10 samples and at the end of the analytical sequence
Continuing Calibration Blank	Immediately after the ICV after each CCV
ICSA	Immediately after the CRDL, or every 12 hours and as specified by client QAP
ICSAB	Immediately after the CRDL, or every 12 hours and as specified by client QAP
Internal Standard	Every sample, QC sample and Cal Std.

11.3 Method Performance

11.3.1 Method Validation

11.3.1.1 Detection Limits

Detection limits (DL) and limits of quantitation (LOQ) are established at initial method setup and verified on an on-going basis thereafter. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 Method Validation.

11.4 Analyst Qualifications and Training

Employees that perform any step of this procedure must have a completed Read and Acknowledgment Statement for this version of the SOP in their training record. In addition, prior to unsupervised (independent) work on any client sample, analysts that prepare or analyze samples must have successful initial demonstration of capability (IDOC) and must successfully demonstrate on-going proficiency on an annual basis. Successful means the initial and on-going DOC met criteria, documentation of the DOC is complete, and the DOC record is in the employee's training file. Refer to laboratory SOP ENV-SOP-LENE-0110, *Training Procedures* for more information.

12.0 Data Review And Corrective Action

12.1 Data Review

Pace's data review process includes a series of checks performed at different stages of the analytical process by different people to ensure that SOPs were followed, the analytical record is complete and properly documented, proper corrective actions were taken for QC failure and other nonconformance(s), and that test results are reported with proper qualification.

The review steps and checks that occur as employee's complete tasks and review their own work is called primary review.

All data and results are also reviewed by an experienced peer or supervisor. Secondary review is performed to verify SOPs were followed, that calibration, instrument performance, and QC criteria were met and/or proper corrective actions were taken, qualitative ID and quantitative measurement is accurate, all manual integrations are justified and documented in accordance with the Pace ENV's SOP for manual integration, calculations are correct, the analytical record is complete and traceable, and that results are properly qualified.

A third-level review, called a completeness check, is performed by reporting or project management staff to verify the data report is not missing information and project specifications were met.

Refer to laboratory SOP ENV-SOP-LENE-0088, *Data Reduction, Review and Reporting* for specific instructions and requirements for each step of the data review process.

12.2 Corrective Action

Corrective action is expected any time QC or sample results are not within acceptance criteria. If corrective action is not taken or was not successful, the decision/outcome must be documented in the analytical record. The primary analyst has primary responsibility for taking corrective action when QA/QC criteria are not met. Secondary data reviewers must verify that appropriate action was taken and/or that results reported with QC failure are properly qualified.

Corrective action is also required when carryover is suspected and when results are over range.

Samples analyzed after a high concentration sample must be checked for carryover and reanalyzed if carryover is suspected. Carryover is usually indicated by low concentration detects of the analyte in successive samples analyzed after the high concentration sample.

Sample results at concentrations above the upper limit of quantitation must be diluted and reanalyzed. The result in the diluted samples should be within the upper half of the calibration range. Results less than the mid-range of the calibration indicate the sample was over diluted and analysis should be repeated with a lower level of dilution. If dilution is not performed, any result reported above the upper range is considered a qualitative measurement and must be qualified as an estimated value.

Refer to Appendix B for a complete summary of QC, acceptance criteria, and recommended corrective actions for QC associated with this test method.

13.0 Pollution Prevention And Waste Management

Pace proactively seeks ways to minimize waste generated during our work processes. Some examples of pollution prevention include but are not limited to: reduced solvent extraction, solvent capture, use of reusable cycletainers for solvent management, and real-time purchasing.

The EPA requires that laboratory waste management practice to be conducted consistent with all applicable federal and state laws and regulations. Excess reagents, samples and method process wastes must be characterized and disposed of in an acceptable manner in accordance with Pace's Chemical Hygiene Plan / Safety Manual.

14.0 Modifications

A modification is a change to a reference test method made by the laboratory. For example, changes in stoichiometry, technology, quantitation ions, reagent or solvent volumes, reducing digestion or extraction times, instrument runtimes, etc. are all examples of modifications. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 *Method Validation and Instrument Verification* for the conditions under which the procedures in test method SOPs may be modified and for the procedure and document requirements.

The aqueous digestion procedure is a modification of that found in Method 200.8. Samples are digested for a period of four hours, regardless of volume reduction. Sample volume is reduced to 50 mL and acid volumes are reduced to match the method.

15.0 Responsibilities

Pace ENV employees that perform any part this procedure in their work activities must have a signed Read and Acknowledgement Statement in their training file for this version of the SOP. The employee is responsible for following the procedures in this SOP and handling temporary departures from this SOP in accordance with Pace's policy for temporary departure.

Pace supervisors/managers are responsible for training employees on the procedures in this SOP and monitoring the implementation of this SOP in their work area.

16.0 ATTACHMENTS

Attachment 1 -- Internal Standard Assignments

Attachment 2 – Internal Standards

Attachment 3 – Tuning Solution

Attachment 4 – Recommended Elemental Interference Equations

Attachment 5 – Standard True Values

Appendix A – Target Analyte List and Routine

Appendix B – QC Summary

17.0 REFERENCES

17.1. Pace Quality Assurance Manual - most current version.

17.2. National Environmental Laboratory Accreditation Conference (NELAC), Chapter 5, "Quality Systems"- most current version.

17.3. The NELAC Institute (TNI); Volume 1, Module 2, "Quality Systems"- most current version.

17.4. Methods for the Determination of Metals in Environmental Samples, Supplement 1 (EPA/600/R-94/111), Method 200.8, Revision 5.4, 1994.

18.0 REVISION HISTORY

This Version: ENV-SOP-LENE-0024, V03

Section	Description of Change
All	combined all ICPMS SOPs and added 6020B

This document supersedes the following document(s):

Document Number	Title	Version
ENV-SOP-LENE-0024	Metals in Drinking Water by EPA 200.8	02

Appendix A: Target Analyte List and Routine LOQ

Table 1: Routine Analyte List and Limits of Quantitation (LOQ)[1]

Element	CAS Number	LOQ (ug/L)		Element	CAS Number	LOQ (ug/L)
Aluminum	7429-90-5	50		Manganese	7439-96-5	1.0
Antimony	7440-36-0	1.0		Molybdenum	7439-98-7	1.0
Arsenic	7440-38-2	1.0		Nickel	7440-02-0	1.0
Barium	7440-39-3	1.0		Selenium	7782-49-2	1.0
Beryllium	7440-41-7	0.5		Silver	7440-22-4	0.5
Cadmium	7440-43-9	0.5		Thallium	7440-28-0	1.0
Chromium	7440-47-3	1.0		Vanadium	7440-62-2	1.0
Cobalt	7440-48-4	1.0		Zinc	7440-66-6	10
Copper	7440-50-8	1.0				
Iron	7439-89-6	50				
Lead	7439-92-1	1.0				

[1] *Values in place as of effective date of this SOP. LOQ are subject to change. For the most up to date LOQ, refer to the LIMS or contact the laboratory.*

Appendix B: QC Summary QC Item	Frequency	Acceptance Criteria	Corrective Action	Qualification
Internal Standards	Added to all client and QC samples.	200.8: 60-125% 6020: 70-130%	If criteria not met, dilute and reanalyze, adjust IS level or select a different internal standard.	Qualify as needed
ICAL	At instrument set up, daily or after CCV failure	Must meet one of curve fit options presented in Section 9.0. Curve must also pass RSE test at the low and midpoint calibration standard.	Identify and correct source of problem, repeat	None. Do not proceed with analysis
ICV	After Each ICAL	All analytes must be within ± 10% of the true value (%R) or < MDL	Identify source of problem, re-analyze. If repeat failure, repeat ICAL. Analysis may proceed if it can be demonstrated that the ICV exceedance has no impact on analytical measurements. For example, the ICV %R is high, CCV is within criteria, and the analyte is not detected in sample(s).	Qualify analytes with ICV out of criteria.
ICB/CCB	Immediately after the ICV, and after each CCV	< PQL or <10% of the analyte level of associated samples	Samples analyzed with a bracketing CCB that exceeded criteria may be reported if the target analyte(s) in the samples are >10X the amount that was found in the CCB.	Rerun or qualify
CRDL	Immediately after ICB and at the end or as specified per client QAPP	Each element tested must be at least between 50-150% of the CRDL value OR As specified per client QAP	If recoveries are not acceptable, stop analysis for that analyte *Pace Metals 3P Team has determined it is a best practice to use PRL limits of at least 50-150%. Limits may be stricter if required by client.	Rerun
CCV	Daily, before sample analysis, after every 10, and at end of analytical window.	Opening CCV: All analytes within ± 10 %D Ending CCV: All analytes within ± 10 %D	See Section 12 for required corrective actions based on circumstance.	If recoveries are not acceptable, stop analysis for that analyte. Samples analyzed with a bracketing CCV that exceeded criteria due to an increase in response may be reported if the target

Appendix B: QC Summary **QC Item**	**Frequency**	**Acceptance Criteria**	**Corrective Action**	**Qualification**
				analytes were not detected in the samples
Method Blank	One per batch of up to 20 samples	Target analytes must be less than one-half the RL.	1)Re-analyze blank to confirm failure.	Qualify results and / or re-digest associated samples. Exceptions: 1)If sample is less than the MDL, report sample qualification 2) If sample result >10x MB detects, report sample with appropriate qualifier indicating blank contamination. 3) If sample result <10x MB detects, re-digest and reanalyze affected samples. If sample cannot be redigested, report sample with appropriate qualifier to indicate an estimated value.
LCS	One per batch of up to 20 samples	85-115%	1) Reanalyze the LCS to verify failure 2) If problem persists, check spike solution 3) Re-digest affected samples where possible	Exception: If LCS recovery > QC limits and target analytes are non-detect in the associated samples, the sample data may be reported with appropriate data qualifiers.
MS/MSD	One per batch of 20 or less samples	70-130%, RPD: Lab-Generated	Perform post digestion spike if required by client	Qualify is outside limits
Dilution Test	1:5 dilution of un-spiked sample digest	PDS failure upon client request; or To verify matrix interference	±10% of undiluted result	Matrix effects are confirmed. Follow client specified actions. NOTE: This test is NOT valid if the original sample is not greater than 50 times the RL.
Post Digestion Spike	Sample spiked with a known amount of standard usually at 1-2 times the amount in the sample	MS/MSD failure upon client request.	80-120%	Follow client specified criteria and /or perform serial dilution test.
Linear Dynamic Range	Whenever a change in instrument hardware or operating conditions or once every 6 months	Upper LDR not more than 10% below the level extrapolated	NA	NA

ATTACHMENT 1 – DEFAULT INTERNAL STANDARD ASSIGNMENTS

ISTD	Analytes
^{45}Sc, Li 6	Be, Al
^{71}Ga, ^{89}Y	As - Sr
^{89}Y, ^{103}Rh	Mo
^{103} Rh, ^{115}In	Ag - Cd
^{115}In, ^{159}Tb, ^{165}Ho	Sn -Ba
^{159}Tb, ^{165}Ho, ^{193} Ir, ^{209}Bi	Tl - Pb

ATTACHMENT 2 – INTERNAL STANDARDS

Mass	ug/L
^{45}Sc	500
^{71}Ga	1250
^{89}Y	50
^{103}Rh	50
^{115}In	150
^{159}Tb	50
^{165}Ho	50
^{193}Ir, Li 6	250
^{209}Bi	150

ATTACHMENT 3 – TUNING SOLUTION

Mass	ug/L
^{7}Li	1
Ba	1
Bi	1
Ce	1
Co	1
In	1
Pb	1
U	1

ATTACHMENT 4 – RECOMMENDED ELEMENTAL INTERFERENCE EQUATIONS

Analyte	Equation
^{43}Ca (1)	-0.00125 * ^{88}Sr
^{45}Sc-KED	-0.06099* ^{31}P
^{51}V (2)	-0.0995 * ^{53}ClO
^{53}ClO	-0.11400 * ^{52}Cr
^{52}Cr (2)	-0.00032 * ^{35}Cl
^{55}Mn	-0.00125 * ^{54}Fe
^{54}Fe	-0.02841 * ^{52}Cr
^{60}Ni	-0.00020 * ^{43}Ca
^{78}Se	-0.03065 * ^{83}Kr
^{111}Cd	-0.00055 * ^{95}Mo
^{115}In	-0.01416 * ^{118}Sn
^{201}Hg	-0.00055 * ^{184}W
^{208}Pb	1.00000 * ^{206}Pb + 1.00000 * ^{207}Pb

(1) Both the ICSAB and the LCS sample are used in the evaluation of this equation. Ca is affected by doubly charged strontium and can vary from day to day plasma conditions. The ICSAB will not fully identify doubly charged conditions based on the ratio of Ca to Sr, whereas the LCS sample for waters and soils have sufficiently large Sr concentrations compared to Ca and will assist in identification of adjustment requirements for the Ca interference equation.

(2) The equation may require periodic adjustment based on the tuning parameters. The mean value in counts per second (cps) for the calibration blank MUST be > 0 cps (ideally, all replicates should be > 0 cps). The normal operating range in cps is 0-1000cps for the calibration blank and must be inspected by the analyst.

ATTACHMENT 5 – STANDARD TRUE VALUES (µG/L)

Mass	ICV	CRDL	CCV	LCS/MS	ICSA	ICSAB
^{9}Be	50	0.5	40	40	0	25
^{27}Al	5000	50	4,000	4,000	50,000	50,000
^{47}Ti	50	2.0	40	40	1,000	1,000
^{51}V	50	1.0	40	40	0	50
^{52}Cr	50	1.0	40	40	0	50
^{54}Fe	2500	50	2,000	2,000	50,000	50,000
^{55}Mn	50	1.0	40	40	0	50
^{89}Co	50	1.0	40	40	0	50
^{60}Ni	50	1.0	40	40	0	50
^{65}Cu	50	1.0	40	40	0	50
^{66}Zn	50	10	40	40	0	500
^{75}As	50	1.0	40	40	0	50
^{78}Se	50	1.0	40	40	0	50
^{88}Sr	50	1.0	40	40	0	50
^{95}Mo	50	1.0	40	40	1,000	1,000
^{105}Pd	50	1.0	40	20	0	50
^{107}Ag	25	0.5	20	20	0	25
^{111}Cd	50	0.5	40	40	0	25
^{118}Sn	50	5.0	40	40	0	50
^{121}Sb	50	1.0	40	40	0	50
^{137}Ba	50	1.0	40	40	0	50
^{195}Pt	50	1.0	40	20	0	50
^{205}Tl	25	1.0	20	20	0	50
^{208}Pb	50	1.0	40	40	0	50
^{238}U	50	0.02	40	40	0	50

Management Approval:
Lenzie Boring Approved on 1/14/2022 4:09:17 PM
Charles Girgin Approved on 2/3/2022 4:27:55 PM
Kenneth Busch Approved on 2/4/2022 1:28:27 PM

1.0 Scope And Application

This standard operating procedure (SOP) describes the laboratory procedure for the determination of metals by inductively coupled plasma atomic emissions spectroscopy in water/soil/wipe samples.

1.1 Target Analyte List and Limits of Quantitation (LOQ)

The target analytes and the normal LOQ that can be achieved with this procedure are provided in Table 1, Appendix A.

LOQ are established in accordance with Pace policy and SOPs for method validation and for the determination of detection limits (DL) and quantitation limits (LOQ). DL and LOQ are routinely verified and updated when needed. The current LOQ for each target analyte that can be determined by this SOP as of the effective date of this SOP is provided in Table 1, Appendix A.

The reporting limit (RL) is the value to which analytes are reported as detected or not detected in the final report. When the RL is less than the lower limit of quantitation (LLOQ), all detects and non-detects at the RL are qualitative. The LLOQ is the lowest point of the calibration curve used for each target analyte.

DL, LOQ, and RL are always adjusted to account for actual amounts used and for dilution.

2.0 Summary of Method

2.1 This method describes the sequential or simultaneous multi-elemental determination of elements by ICP.

2.2 Samples are digested prior to analysis using appropriate sample preparation methods as found in the Metals Prep SOPs (ENV-SOP-LENE-0089(SW-846 3010), ENV-SOP-LENE-0094(SW-846 3050), and ENV-SOP-LENE-0124(wipes).

2.3 Sample digestates are nebulized and the resulting aerosol is transported to the plasma torch. Element-specific atomic-line emission spectra are produced by an inductively-coupled plasma.

2.4 The spectra are dispersed by a grating spectrometer and the intensity of each line is monitored by Charge-Inductive-Device Detector.

3.0 Interferences

3.1 Spectral Interferences

3.1.1 Overlap of a spectral line from another element.

3.1.2 Unresolved overlap of molecular band spectra.

3.1.3 Background contribution from continuous or recombination phenomena.

3.1.4 Stray light from the line emission of high-concentration elements. Spectral overlap can be compensated for by computer-correcting the raw data after monitoring and measuring the interfering element. Unresolved overlap requires selection of an alternate wavelength. Background contribution and stray light can usually be compensated for by a background correction adjacent to the analyte line. Interelement correction factors are used with the iCAP 6500.

3.2 Physical Interferences

3.2.1 These are effects associated with the sample nebulization and transport processes. Changes in viscosity and surface tension can cause significant inaccuracies, especially in samples containing high levels of dissolved solids or high acid concentrations. Physical interferences may be reduced by diluting the sample.

3.2.2 Salt buildup at the tip of the nebulizer can occur when analyzing samples with high dissolved solids, such as soils. Such buildup can affect the aspiration flow rate, resulting in instrument drift. The effects from the aspiration of samples containing high dissolved solids may be controlled by wetting the argon prior to nebulization or diluting the sample.

4.0 DEFINITIONS

Refer to the Laboratory Quality Manual for a glossary of common lab terms and definitions.

5.0 HEALTH AND SAFETY

The toxicity or carcinogenicity of each chemical material used in the laboratory has not been fully established. Each chemical should be regarded as a potential health hazard and exposure to these compounds should be as low as reasonably achievable.

The laboratory maintains documentation of hazard assessments and OSHA regulations regarding the safe handling of the chemicals specified in each method. Safety data sheets for all hazardous chemicals are available to all personnel. Employees must abide by the health, safety and environmental (HSE) policies and procedures specified in this SOP and in the Pace Chemical Hygiene / Safety Manual.

Personal protective equipment (PPE) such as safety glasses, gloves, and a laboratory coat must be worn in designated areas and while handling samples and chemical materials to protect against physical contact with samples that contain potentially hazardous chemicals and exposure to chemical materials used in the procedure.

Concentrated corrosives present additional hazards and are damaging to skin and mucus membranes. Use these acids in a fume hood whenever possible with additional PPE designed for handing these materials. If eye or skin contact occurs, flush with large volumes of water. When working with acids, always add acid to water to prevent violent reactions. Any processes that emit large volumes of solvents (evaporation/concentration processes) must be in a hood or apparatus that prevents employee exposure.

Contact your supervisor or local HSE coordinator with questions or concerns regarding safety protocol or safe handling procedures for this procedure.

6.0 Sample Collection, Preservation, Holding Time, And Storage

Samples should be collected in accordance with a sampling plan and procedures appropriate to achieve the regulatory, scientific, and data quality objectives for the project.

The laboratory does not perform sample collection or field measurements for this test method. To assure sample collection and field checks and treatment are performed in accordance with applicable regulations Pace project managers will inform the client of these requirements at the time of request for analytical services when the request for testing is received prior to sample collection. If samples were already collected, the laboratory will record any nonconformance to these requirements in the laboratory's sample receipt record when sufficient information about sample collection is provided with the samples.

The laboratory will provide containers for the collection of samples upon client request for analytical services. Bottle kits are prepared in accordance with laboratory SOP ENV-SOP-LENE-0025, *Assembly of Sample Container Kits*. The bottle kits provided by the laboratory should include field test kits and treatment reagent.

Requirements for container type, preservation, and field quality control (QC) for the common list of test methods offered by Pace are included in the laboratory's quality manual.

General Requirements

Sample type	Collection per sample	Preservation	Storage	Hold time
Aqueous	250-1L HDPE	Acidified with 1:1 Nitric to pH<2	Room Temperature	Must be analyzed within 180 days of collection.
Aqueous (Pb&Cu)	1L HDPE	Acidified with 1:1 Nitric to pH<2	Room Temperature	Must be analyzed within 180 days of collection.
Soil/Solid	4oz glass jar, or HDPE plastic container	None	0-6°C	Must be analyzed within 180 days of collection.

Field / Matrix QC

Trip Blank	Equipment Blank	MS/MSD	Field Duplicate
N/A	Per QAPP	1 in 20	Per QAPP

Thermal preservation is checked and recorded on receipt in the laboratory in accordance with laboratory SOP ENV-SOP-LENE-0021, *Sample Management*. Chemical preservation is checked and recorded at time of receipt or prior to sample preparation.

After receipt, samples are stored at ≤6°C until sample preparation. Prepared samples (extracts, digestates, distillates, other) are stored at ≤6°C until sample analysis.

After analysis, unless otherwise specified in the analytical services contract, samples are retained for 30 days from date of final report and then disposed of in accordance with Federal, State, and Local regulations.

7.0 Equipment And Supplies

7.1 Equipment

Equipment	Vendor	Model / Version	Description / Comments
Spectrophotometer	Thermo Scientific	iCAP 6500	60ICP03 w/ Iteva or Qtegra Software
Spectrophotometer	Thermo Scientific	iCAP PRO	60ICP06 and 60ICP07 w/ Qtegra Software
Autosampler	Elemental Scientific	SC-FAST	none

7.2 Supplies

Glassware

Glassware	Description	Vendor / Item # / Description
Volumetric Flasks	5-, 10-, 50-, 100-, 500-mL, 1-L	Class A
Test tubes	17 x 100mm	Mold Pro

Miscellaneous

Item	Description	Vendor / Item # / Description
Pipetters	N/A	Eppendorf / various
Kimwipes	Delicate task wipes	Fisher / 06-666A
Filters	Filter-mate screw on filters	Environmental Express / various

8.0 Reagents And Standards

All reagents and standards must be logged into the Epic Pro Standards log and assigned a unique number by the system. See the Standards and Reagents SOP for additional information and requirements pertaining to all standards and reagents. Equivalent materials may be used without violating this SOP. All reagents and stock standards are stored at room temperature.

8.1 The reagents listed below are those currently in use. Other sources or grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

Table 8.1 – Standard Storage Conditions

Standard Type	Description	Expiration	Storage
Stock Standards	Concentrated reference solution purchased directly from approved vendor	Manufacturer's recommended expiration date	Manufacturer's recommended storage conditions
Intermediate and Working Standards	Reference solutions prepared by dilutions of the stock solution	Intermediate and working standards – The earliest of six months from the date of preparation or the expiration date of any component standard.	Manufacturer's recommended storage conditions for stock source solution.

Table 8.2 – Reagents and Standards

Standard	Concentration/ Description	Requirements/ Vendor / Item #
ICP-1A	200 mg/L: As, Ba, Be, Cd, Co, Cr, Cs, Cu, Li, Mn, Ni, Pb, Se, Sr, U, V, Zn 100 mg/L: Ag, Tl	SPEX / XPACEMN-76-500
ICP-2A	200 mg/L: B, Mo, Pd, Pt, Sb, Sn, Ti, Zr	SPEX / XPACEMN-77-500
ICP-3A	1000 mg/L: Al, Ca, K, Mg, Na, S 500 mg/L Fe, P, Si	SPEX / XPACEMN-75-500
ICP-1B	200 mg/L: As, Ba, Be, Cd, Co, Cr, Cs, Cu, Li, Mn, Ni, Pb, Se, Sr, U, V, Zn 100 mg/L: Ag, Tl	High Purity Standards / HP7379-500
ICP-2B	200 mg/L: B, Mo, Pd, Pt, Sb, Sn, Ti, Zr	High Purity Standards / HP7376-500
ICP-3B	1000 mg/L: Al, Ca, K, Mg, Na, S 500 mg/L Fe, P, Si	High Purity Standards / HP7375-500
SPK-STD-1B	200 mg/L: As, Ba, Be, Cd, Co, Cr, Cu, Li, Mn, Ni, P, Pb, Se, Sr, Tl, V, Zn	Inorganic Ventures / PA-STD-1B
SPK-STD-2B	1000 mg/L: Si 200 mg/L: B, Mo, Sb, Sn, Ti, Zr	Inorganic Ventures / PA-STD-2B

Standard	Concentration/ Description	Requirements/ Vendor / Item #
	100 mg/L: Ag	
SPK-STD-3B	2000 mg/L: Al, Ca, Fe, K, Mg, Na	Inorganic Ventures / PA-STD-3B
Hydrochloric acid	Baker Instra-Analyzed® Reagent	J.T. Baker / 9530-33
ICSA or Interference Check Standard 1	5000 mg/L: Al, Ca, Mg 2000 mg/L: Fe	High Purity / CLP-INF-1-500
Single Element Standards	1-10 mg/L; CRDL; ICSB	Inorganic Ventures / Various
Yttrium Standard	1000 mg/L	SPEX / PLY2-2X
Reagent water	ASTM Type II	SOP S-KS-Q-011 (latest revision)

8.2 ICP Reagent Blank Solution - Prepare as follows: Add 5000 mL of reagent water to a 20-L carboy. Add 1000 mL of HCl and 400 mL of HNO_3. Bring to volume with reagent water.

8.3 Blank Solution (CAL0) - is a zero standard consisting of 5% HCl and 2% HNO_3. ICP Reagent Blank Solution.

8.4 CAL 5 – Add approximately 100 mL of ICP Reagent Blank Solution to a 1000-mL volumetric flask. Add 4.0 mL ICP-1A, 10.0 mL ICP-2A, and 20.0 mL ICP-3A to the 1000-mL volumetric flask and dilute to volume with ICP Reagent Blank Solution.

8.5 CAL 4 – Add approximately 100 mL of ICP Reagent Blank Solution to a 500-mL volumetric flask. Add 200.0 mL of the CAL 5 solution to the 500-mL volumetric flask and dilute to volume with ICP Reagent Blank Solution.

8.6 CAL 3 – Add approximately 100 mL of ICP Reagent Blank Solution to a 500-mL volumetric flask. Add 50.0 mL of the CAL 5 solution to the 500-mL volumetric flask and dilute to volume with ICP Reagent Blank Solution.

8.7 CAL2 – Add approximately 100 mL of ICP Reagent Blank Solution to a 500-mL volumetric flask. Add 10.0 mL of the CAL 5 solution to the 500-mL volumetric flask and dilute to volume with ICP Reagent Blank Solution.

8.8 CAL 1 - Add approximately 100 mL of ICP Reagent Blank Solution to a 500-mL volumetric flask. Add 5.0 mL of the CAL 5 solution to the 500-mL volumetric flask and dilute to volume with ICP Reagent Blank Solution.

Table 8.3 CAL Standards

Element	CAL 0	CAL 1 (ug/L)	CAL 2 (ug/L)	CAL 3 (ug/L)	CAL 4 (ug/L)	CAL 5 (ug/L)
Ag	Not spiked	5	10	50	200	500
Al	Not spiked	200	400	2000	8000	20000
As	Not spiked	10	20	100	400	1000
B	Not spiked	20	40	200	800	2000
Ba	Not spiked	10	20	100	400	1000
Be	Not spiked	10	20	100	400	1000
Ca	Not spiked	200	400	2000	8000	20000
Cd	Not spiked	10	20	100	400	1000
Co	Not spiked	10	20	100	400	1000
Cr	Not spiked	10	20	100	400	1000
Cs	Not spiked	10	20	100	400	1000
Cu	Not spiked	10	20	100	400	1000
Fe	Not spiked	100	200	1000	4000	10000
K	Not spiked	200	400	2000	8000	20000
Li	Not spiked	10	20	100	400	1000
Mg	Not spiked	200	400	2000	8000	20000
Mn	Not spiked	10	20	100	400	1000
Mo	Not spiked	20	40	200	800	2000
Na	Not spiked	200	400	2000	8000	20000
Ni	Not spiked	10	20	100	400	1000
P	Not spiked	100	200	1000	4000	10000
Pb	Not spiked	10	20	100	400	1000
Pd	Not spiked	20	40	200	800	2000
Pt	Not spiked	20	40	200	800	2000
S	Not spiked	100	200	1000	4000	10000
Sb	Not spiked	20	40	200	800	2000
Se	Not spiked	10	20	100	400	1000
Si	Not spiked	100	200	1000	4000	10000
Sn	Not spiked	20	40	200	800	2000
Sr	Not spiked	10	20	100	400	1000

Element	CAL 0	CAL 1 (ug/L)	CAL 2 (ug/L)	CAL 3 (ug/L)	CAL 4 (ug/L)	CAL 5 (ug/L)
Ti	Not spiked	20	40	200	800	2000
Tl	Not spiked	5	10	50	200	500
U	Not spiked	10	20	100	400	1000
V	Not spiked	10	20	100	400	1000
Zn	Not spiked	10	20	100	400	1000
Zr	Not spiked	20	40	200	800	2000

8.9 Internal Standard - Add approximately 500 mL of ICP Reagent Blank Solution to a 1000-mL volumetric flask. Add 5.0 mL of Yttrium Standard to the 1000-mL volumetric flask and dilute to volume with ICP Reagent Blank Solution.

8.10 Interference Check Sample - The ICS consists of two solutions: Solution A (ICSA) and Solution AB (ICSAB). ICSA consists of the interferents and ICSAB consists of the other target analytes mixed with the interferents.

8.10.1 ICSA - Add approximately ten mL of ICP Reagent Blank Solution to a 400-mL volumetric flask. Add 40.0 mL of ICS1 to the 400-mL volumetric flask and dilute to volume with ICP Reagent Blank Solution. The ICSA contains Al, Ca, Mg at 500 mg/L and Fe at 200 mg/L. These elements should recover within ± 20% of the true value and all other elements should be zero ± 2 x PRL. Due to linear range limitations, it is recommended that this standard be ran at a 10x dilution when analyzed on the iCAP PRO.

8.10.2 ICSB stock - The ICSB stock solution is prepared from single-element standards. In a 1-L volumetric flask add 500 mL of deionized water and 5 mL of concentrated nitric acid. Add the single elements per the table below and bring to volume with deionized water.

Table 8.4 – ICSB Stock Standard

Pace Standard #	Element Components	Single-Element Standard Concentration (µg/mL)	Volume Used (mL)	Final Volume (mL)	ICSB Stock Concentration (µg/L)
Single-Element Standard	Ag	1000	0.50	1000	500
Single-Element Standard	As	1000	1.0	1000	1000
Single-Element Standard	B	1000	5.0	1000	5000
Single-Element Standard	Ba	1000	1.0	1000	1000
Single-Element Standard	Be	1000	0.5	1000	500
Single-Element Standard	Cd	1000	1.0	1000	1000
Single-Element Standard	Co	1000	1.0	1000	1000
Single-Element Standard	Cr	1000	1.0	1000	1000
Single-Element Standard	Cu	1000	1.0	1000	1000
Single-Element Standard	K	10000	5.0	1000	50000
Single-Element Standard	Mn	1000	1.0	1000	1000
Single-Element Standard	Mo	1000	1.0	1000	1000
Single-Element Standard	Na	10000	5.0	1000	50000
Single-Element Standard	Ni	1000	1.0	1000	1000
Single-Element Standard	P	1000	5.0	1000	5000
Single-Element Standard	Pb	1000	1.0	1000	1000
Single-Element Standard	Sb	1000	1.0	1000	1000
Single-Element Standard	Se	1000	1.0	1000	1000
Single-Element Standard	Si	1000	10.0	1000	10000
Single-Element Standard	Sn	1000	1.0	1000	1000
Single-Element Standard	Sr	1000	1.0	1000	1000
Single-Element Standard	Ti	1000	1.0	1000	1000
Single-Element Standard	Tl	1000	1.0	1000	1000
Single-Element Standard	V	1000	1.0	1000	1000
Single-Element Standard	Zn	1000	1.0	1000	1000
Single-Element Standard	Li	1000	1.0	1000	1000
Single-Element Standard	Zr	1000	1.0	1000	1000

8.10.3 ICSAB - Add approximately 100 mL of ICP Reagent Blank Solution to a 400-mL volumetric flask. Add 40.0 mL of ICSA and 40.0 mL of ICSB Stock to the volumetric flask and dilute to volume with ICP Reagent Blank Solution. Results for the ICSAB must recover within the control limit of ±20% of the true value. If analyzing on the iCAP PRO add 4.0 mL of ICSA and 40.0 mL of ICSB Stock solutions.

Table 8.5 ICSAB Concentrations

Element	Concentration (ug/L)
Ag	50
Al	500000
As	100
B	100
Ba	100
Be	50
Ca	500000
Cd	100
Co	100
Cr	100
Cu	100
Fe	200000
K	5000
Mg	500000
Mn	100
Mo	100
Na	5000
Ni	100
P	500
Pb	100
Sb	100
Se	100
Si	1000
Sn	100
Sr	100
Ti	100

Element	Concentration (ug/L)
Tl	100
V	100
Zn	100
Li	100
Zr	100

8.11 Initial Calibration Verification Standard (ICV)

8.11.1 The ICV is a standard from a NIST-traceable, second (independent) source, which contains the same elements that are in the calibration standard. The concentrations are at a level near or equal to the midpoint of the calibration curve. Add approximately 100 mL of ICP Reagent Blank Solution to a 400-mL volumetric flask. Add 1.00 mL ICP-1B, 2.00 mL ICP-2B, and 10.00 mL ICP-3B to the 400-mL volumetric flask and dilute to volume with ICP Reagent Blank Solution.

Table 8.6 ICV Concentrations

Element	Concentration (ug/L)
Ag	250
Al	25000
As	500
B	1000
Ba	500
Be	500
Ca	25000
Cd	500
Co	500
Cr	500
Cu	500
Fe	12500
K	25000
Li	500
Mg	25000
Mn	500
Mo	1000

Element	Concentration (ug/L)
Na	25000
Ni	500
P	12500
Pb	500
Sb	1000
Se	500
Si	12500
Sn	1000
Sr	500
Ti	500
Tl	250
V	500
Zn	500
Zr	1000

8.12 Continuing Calibration Verification Standard (CCV)

8.12.1 The CCV is a standard prepared from the same stock as the calibration standard. Add approximately 100 mL of ICP Reagent Blank Solution to a clean, acid-rinsed 400-mL volumetric flask. Add 1.0 mL ICP-1A, 2.0 mL ICP-2A, and 10.0 mL ICP-3A to the 400-mL volumetric flask and dilute to volume with ICP Reagent Blank Solution.

Table 8.7 CCV Concentrations

Element	Concentration (ug/L)
Ag	250
Al	25000
As	500
B	1000
Ba	500
Be	500
Ca	25000
Cd	500
Co	500
Cr	500

Element	Concentration (ug/L)
Cu	500
Fe	12500
K	25000
Li	500
Mg	25000
Mn	500
Mo	1000
Na	25000
Ni	500
P	12500
Pb	500
Sb	1000
Se	500
Si	12500
Sn	1000
Sr	500
Ti	500
Tl	250
V	500
Zn	500
Zr	1000

8.13 CRDL Stock Standard

8.13.1 The CRDL Stock Solution is prepared from single-element standards and ICP Reagent Blank Solution, in a 1000-mL volumetric flask at the concentrations listed below.

Table 8.8 CRDL Stock Standard

Element	Concentration (ug/L)
Ag	140
Al	1500
As	200
B	2000

Element	Concentration (ug/L)
Ba	100
Be	20
Ca	4000
Cd	100
Co	100
Cr	100
Cu	200
Fe	1000
K	10000
Li	200
Mg	1000
Mn	100
Mo	400
Na	10000
Ni	100
P	2000
Pb	200
Sb	200
Se	300
Si	20000
Sn	1000
Sr	200
Ti	200
Tl	400
V	200
Zn	1000
Zr	200

8.14 CRDL Working Standard

8.14.1 The CRDL Working Standard is prepared from the CRDL Stock solution. In a 400-mL volumetric flask add 100 mL ICP Reagent Blank Solution, 20.0 mL of CRDL Stock Solution and bring to volume with ICP Reagent Blank Solution.

8.15 LCS/MS/MSD Spike True Values

8.15.1 The LCS, MS, and MSD spiking solutions are prepared in accordance with the Metals Preparation SOPs: ENV-SOP-LENE-0089(SW-846 3010), ENV-SOP-LENE-0094(SW-846 3050), and ENV-SOP-LENE-0124(wipes). This solution is made by adding approximately 50 mL DI water to a 400 mL volumetric flask then add 100 mL of each SPK-ICP-1B, SPK-ICP-2B, and SPK-ICP-3B solution, then add 10 mL of Uranium single element standard and fill to the mark with ICP reagent blank.

Table 8.9 – LCS/MS True Values

Element	Concentration (ug/L)
Ag	500
Al	10000
As	1000
B	1000
Ba	1000
Be	1000
Ca	10000
Cd	1000
Co	1000
Cr	1000
Cu	1000
Fe	10000
K	10000
Li	1000
Mg	10000
Mn	1000
Mo	1000
Na	10000
Ni	1000
P	1000
Pb	1000

Element	Concentration (ug/L)
Sb	1000
Se	1000
Si	5000
Sn	1000
Sr	1000
Ti	1000
Tl	1000
V	1000
Zn	1000

9.0 PROCEDURE

9.1 Equipment Preparation

9.1.1 Support Equipment

All support equipment used must be calibrated or verified prior to use according to SOP ENV-SOP-LENE-0030; Support Equipment current revision.

9.1.2 Instrument

9.1.1 Qtegra Methodology and Operation

9.1.1.1 Before startup of the instrument inspect the pump tubing for breakage or uneven wear and replace if necessary. Rotate the pump tubing between thumb and forefinger at the point of contact with the peristaltic pump rollers. Replace any tubing that has a feel of flat spots and does not roll evenly. Replace any tubing that shows any sign of leakage. The peristaltic pump is equipped with a four- position roller assembly, which uses 2-stop pump tubing. Sample delivery tubing coded orange-white. Drain removal tubing is white-white. Internal standard delivery tubing is orange/blue.

9.1.1.2 Check gas supplies. Argon pressure should be regulated to ~90 psi; Check chiller; temperature set point should be at approx.. 20ºC.

9.1.1.3 Turn computer on and log into the network according to instructions given by the IT staff. Confirm main power switch is in the on position.

9.1.1.4 To open the instrument software double-click on the Qtegra icon. In the Dashboard click the "Get Ready" button at the top and center to ignite the plasma. Allow the instrument to warm up for at least 10 minutes however, it is preferable to allow the warm up time to exceed 30 minutes.

9.1.1.5 Create a new labbook from a previous labbook or reference a pre-made template.

9.1.1.6 In the menu option "Sample List" confirm the sample sequence is made in accordance with the quality control requirements of the method and QAAP of the client samples. Type, scan, or copy in any samples needed for analysis.

9.2 **Initial Calibration**

To perform quantitative measurements, an initial calibration must be established before the analysis of samples. An initial calibration is an evaluation of the relationship between response of the instrument (or process) and the concentration of the target analytes.

9.2.1 The ICP must be calibrated each time it is set up for analysis according to the manufacturer's instructions. Calibration requires analysis of a Calibration Blank and at least one level of calibration solution. Instrument standardization date and time must be recorded in the raw data.

9.2.2 Calibration Design

The standards are prepared according to Section 8.2 and analyzed like samples according to Section 9.3. Final volumes/concentrations of calibration standards may be adjusted as long as there are a minimum of one calibration point and the CRDL/LLOQ must be at or lower than the current reporting limit (LOQ). See Appendix C for concentrations of working standards.

9.2.3 Calibration Sequence

Analyze calibration standards 0 and 1 followed by the ICB, ICV, CRDL, ICSA, and ICSAB, CCV and CCB.

Sequence	Name

1	CAL0
2	CAL1
3	ICB
4	ICV
5	CRDL
6	ICSA
7	ICSAB
8	CCV
9	CCB

9.2.4 ICAL Evaluation

9.2.4.1 Curve Fit

A single point calibration is performed for this method using an instrument zero and one calibration standard.

9.2.4.2 Relative Standard Error (RSE)

For calibrations evaluated using correlation coefficient, the lab evaluates relative error by measurement of the Relative Standard Error (RSE). This calculation shall be performed for 2 calibration levels: the standard at or near the mid-point of the initial calibration and the standard at the lowest level.

Refer to Appendix B for complete RSE acceptance criteria and recommended corrective actions associated with this test method.

9.2.5 Initial Calibration Verification (ICV) / Second Source

9.2.5.1 In addition to meeting the linearity criteria, any new calibration curve must be assessed for accuracy in the values generated. Accuracy is a function of both the "fit" of the curve to the points used and the accuracy of the standards used to generate the calibration points. By meeting the fit criteria, the accuracy relative to the goodness of fit is addressed. However, because all calibration points are from the same source, it is possible that the calibration points may meet linearity criteria but not be accurately made in terms of their true value.

9.2.5.2 Therefore, to assess the accuracy relative to the purity of the standards, a single standard from a secondary source must be analyzed and the results obtained must be assessed relative to the known true value. This step is referred to as *Secondary Source Verification* or, alternatively as *Initial Calibration Verification*. This secondary source must be from an alternative vendor or, in the event an alternative vendor is not available, from a different lot from the same vendor. This standard must be analyzed immediately after the calibration and before any batch QC or client samples. The accuracy of the standard is assessed as a percent difference from the true value according to the following equation:

% Difference = [ResultICV –TrueValueICV] / TrueValueICV * 100

9.2.6 PRL Standard Verification

9.2.6.1 With every ICAL, a standard corresponding to the practical reporting limit (PRL) must also be analyzed and meet established acceptance criteria in Table 9.2.

9.2.7 ICSA (Interference Check Standard) Verification

9.2.7.1 With every ICAL, the inter-element check solution standard must be run to verify the inter-element correction factors. At a minimum, the ICSA standard must be analyzed at the beginning of the run, following the initial calibration, and evaluated against the criteria in Table 9.2. If client-specific requirements dictate that the ICSA must be analyzed at both the beginning and end of the analysis, the ICSA may be analyzed immediately after the completion of those specific samples and is not required to be placed at the very end of the sequence. The ICSAB must be analyzed immediately following the ICSA and meet the criteria in Table 9.2.

9.2.8 Continuing Calibration Verification (CCV)

9.2.8.1 As part of the analytical process, the instrumentation must be checked periodically to determine if the response has changed significantly since the initial calibration was established. This verification process is known as Continuing Calibration Verification. The validity of the initial calibration is checked after every 10 samples and at the end of an analytical sequence by analyzing a midpoint calibration standard (CCV).

9.2.8.2 The values obtained from the analysis of the CCV are compared to the true values. The percent difference must meet the method specified criteria in Table 9.2 for the analysis to proceed.

Table 9.2 – Calibration Acceptance and Verification Criteria

Calibration Metric	Parameter / Frequency	Criteria	Comments
Calibration Curve Fit	Linear Regression for elements requiring multiple calibration levels	Correlation coefficient ≥ 0.995	If not met, remake standards and recalibrate
Initial Calibration Verification Standard (Second Source)	Immediately after each initial calibration	6010B: ≤±10% of true value 200.7: ≤±5% of true value The % RSD between replicate integrations of an ICV std must be <5% (min of 2 integrations).	If 4 or more replicates are used for analysis the RSD must be ≤ 3%
Initial Calibration Verification Standard Low (ICVA)	Immediately after each initial calibration (if required by client- or project-specific QAPP).	≤±10% of true value The % RSD between replicate integrations of an ICV std must be <5% (min of 2 integrations).	If 4 or more replicates are used for analysis the RSD must be ≤ 3%
Calibration Blank	Immediately after each initial calibration (ICB), every 10 samples (CCB), and at the end of the analytical sequence	< PRL	If recoveries are not acceptable, stop analysis and follow corrective actions.
ICSA	Once per ICAL, immediately after verification	Results for non-interference elements = ND ± 2 x PRL Recovery of interfering elements must be 80-120% of true value	If recoveries are not acceptable, stop analysis and follow corrective actions.
ICSAB	Once per ICAL, immediately after ICSA (if required by client- or project-specific QAPP; see Attachments I – IV)	Results = True Value ± 20% (or ± 2 x PRL, whichever is greater).	If recoveries are not acceptable, stop analysis and follow corrective actions.
Continuing Calibration Verification	After every 10 samples and at the end of analytical sequence	≤±10% of true value. The % RSD between replicate integrations of a CCV std must be <5% (min of 2 integrations).	If criteria not met, follow corrective actions.
CRDL	Daily prior to sample analysis (as-needed basis per client- or project-specific QAPP; see Attachments I – IV)	±50% of true value.	If criteria not met, follow corrective actions.
Internal Standard	Every sample, quality control sample and calibration standard.	±30% of true value	If criteria not met, dilute, and reanalyze. Alternatively, Indium may be used if Yttrium is present in the samples.

9.3 Calibration Corrective Actions

9.3.1 Reanalyze the original standard to determine instrument consistency.

9.3.2 Prepare and analyze a new standard to determine preparation consistency / standard integrity.

9.3.3 Perform instrument maintenance, document in instrument maintenance log book.

9.3.4 Recalibrate instrument

9.3.5 Reanalyze any samples affected by unacceptable standard analysis.

9.3.6 If samples were analyzed in spite of verification failures, note the following exceptions for addressing those results. Deviations from this requirement must be noted on the run log with a thorough explanation for the deviation from policy.

Exceptions:

Samples analyzed with a bracketing CCV that exceeded criteria due to an increase in response may be reported if the target analytes were not detected in the samples.

Samples analyzed with a bracketing CCB that exceeded criteria may be reported if the target analyte(s) in the samples are >10x the amount that was found in the CCB.

9.4 Sample Preparation

9.4.1 Follow ICP digestion SOPs (ENV-SOP-LENE-0089(SW-846 3010), ENV-SOP-LENE-0094(SW-846 3050), and ENV-SOP-LENE-0124(wipes) for the sample prep of the samples before analysis.

9.5 Analysis

9.5.1 Example Analytical Sequence

Run No.	Sample ID
1	ICV
3	ICB
4	CRDL
5	ICSA
6	ICSAB
7	CCV1
8	CCB1
9	Sample 1
10	Sample 2
11	Sample 3
12	Sample 4
13	Sample 5
14	Sample 6

Run No.	Sample ID
15	Sample 7
16	Sample 8
17	Sample 9
18	Sample 10
19	CCV2
20	CCB2
21	Sample 11
22	Sample 12
23	Sample 13
24	Sample 14
25	Sample 15
26	Sample 16
27	Sample 17
28	Sample 18
29	CCV3
30	CCB3

10.0 DATA ANALYSIS AND CALCULATIONS

10.1 Calculations

See the Laboratory Quality Assurance Manual for equations for common calculations.

10.2 **Water, TCLP and SPLP leachate:**

$$\text{Concentration}\ (\text{ug/L}) = \frac{(A)(V2)(DF)}{V1}$$

10.3 **Soil:**

$$\text{Concentration}\ (\text{mg/kg}) = \frac{(A)(V2)(DF)}{(W \times 1000)}$$

10.4 Wipe:

$$\text{Concentration (ug/wipe)} = \frac{(A)(V2)(DF)}{1000}$$

10.5 Paint:

$$\text{Concentration (\%)} = \frac{(A)(V2)(DF)}{(W \times 1E6)}$$

where:
A = Analyzed concentration of element, ug/L.
V1 = Volume of sample, mL.
V2 = Final digestate volume, mL.
DF = Dilution factor.
W = Weight of sample, g.

10.6 Hardness Calculation

mg equivalent $CaCO_3$/L = $2.497\,[\text{Ca, mg/L}] + 4.118\,[\text{Mg,mg/L}]$

11.0 Quality Control and Method Performance

11.1 Quality Control

The following QC samples are prepared and analyzed with each batch of samples. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency
Method Blank (MB)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Laboratory Control Sample (LCS)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Laboratory Control Sample Duplicate (LCSD)	As needed
Matrix Spike (MS)	6010B - One per batch of up to 20 samples. 200.7 - One per 10 samples.
Matrix Spike Duplicate (MSD)	6010B - One per batch of up to 20 samples. 200.7 – if required by QAPP.
Sample Duplicate	200.7 – One Duplicate per batch of up to 20 samples
Post-Digestion Spike (PDS)	QAPP requirements upon MS/MSD failure
Dilution test	QAPP requirements upon PDS failure

11.2 Instrument QC

The following Instrument QC checks are performed. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency
Initial Calibration	Performed daily
Initial Calibration Verification	After each ICB
Initial Calibration Blank	After each ICAL

QC Item	Frequency
Lower Limit of Quantitation Check/Contract Required Detection Limit	After each ICV
Interference Check Standard A	After each CRDL
Interference Check Standard B	After each ICSA, if required by QAPP
Continuing Calibration Verification	Daily, before sample analysis, after every 10 samples, and at end of an analytical run
Continuing Calibration Blank	After each CCV

11.3 Method Performance

11.3.1 Method Validation

11.3.1.1 Detection Limits

Detection limits (DL) and limits of quantitation (LOQ) are established at initial method setup and verified on an on-going basis thereafter. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 Method Validation and Instrument Verification.

11.3.1.2 Interfering Element Corrections (IECs)

IECs are checked each quarter for at least the four major interferences, Ca, Mg, Fe, and Al. There is usually not sufficient concentration of the minor interferences to cause a deviation, but once a year, and any time there is a request for other analytes on a sample with a very high concentration of one of the following elements, interferences are updated for Cr, Cu, Mn, Ni, Zn, Mo, V and Co.

Inter-element interferences occur when elements in the sample emit radiation at wavelengths so close to that of the analyte that they contribute to the intensity of the light striking the analyte pixels. If such conditions exist, the calculation will yield an inaccurate concentration for the analyte. Applying inter-element corrections removes the effects of these non-analyte emissions.

Refer to Attachment I for detailed instructions on determining and applying IECs.

11.3.1.3 Linear Dynamic Range (LDR)

The LDR study must be run when the instrument is initially set up and after significant instrument maintenance is performed (i.e. replacing the instrument optics) and at least once annually. The range is determined by running multiple standards (at least 3) approaching the expected range. The highest standard run ±10% of the true value (%R) determines the linear range. The usable range is 90% of that highest standard's true value.

The LDR is verified every 6 months by analyzing a standard at the last established linear range for each analyte, and each analyte must pass ±20% of the true value (%R).

For example, if the current LDR for an analyte is 90,000µg/L, this means that a 100,000µg/L standard previously ran and passed ±10%. To verify that the LDR has not changed, run standards at 80,000µg/L, 90,000µg/L, and 100,000µg/L (or other similar concentrations approaching the previously established range). Use

90% of the true value of the highest standard that passes within ±10% as the new LDR.

Make each standard by adding the appropriate amount of single element stock standard to a 50 mL volumetric, and then bring to volume with matrix blank.

11.4 Analyst Qualifications and Training

Employees that perform any step of this procedure must have a completed Read and Acknowledgment Statement for this version of the SOP in their training record. In addition, prior to unsupervised (independent) work on any client sample, analysts that prepare or analyze samples must have successful initial demonstration of capability (IDOC) and must successfully demonstrate on-going proficiency on an annual basis. Successful means the initial and on-going DOC met criteria, documentation of the DOC is complete, and the DOC record is in the employee's training file. Refer to laboratory SOP ENV-SOP-LENE-0110, *Training Procedures*, for more information.

12.0 Data Review And Corrective Action

12.1 Data Review

Pace's data review process includes a series of checks performed at different stages of the analytical process by different people to ensure that SOPs were followed, the analytical record is complete and properly documented, proper corrective actions were taken for QC failure and other nonconformance(s), and that test results are reported with proper qualification.

The review steps and checks that occur as employee's complete tasks and review their own work is called primary review.

All data and results are also reviewed by an experienced peer or supervisor. Secondary review is performed to verify SOPs were followed, that calibration, instrument performance, and QC criteria were met and/or proper corrective actions were taken, qualitative ID and quantitative measurement is accurate, all manual integrations are justified and documented in accordance with the Pace ENV's SOP for manual integration, calculations are correct, the analytical record is complete and traceable, and that results are properly qualified.

A third-level review, called a completeness check, is performed by reporting or project management staff to verify the data report is not missing information and project specifications were met.

Refer to laboratory SOP ENV-SOP-LENE-088, *Data Reduction, Review and Reporting*, for specific instructions and requirements for each step of the data review process.

12.2 Corrective Action

Corrective action is expected any time QC or sample results are not within acceptance criteria. If corrective action is not taken or was not successful, the decision/outcome must be documented in the analytical record. The primary analyst has primary responsibility for taking corrective action when QA/QC criteria are not met. Secondary data reviewers must verify that appropriate action was taken and/or that results reported with QC failure are properly qualified.

Corrective action is also required when carryover is suspected and when results are over range.

Samples analyzed after a high concentration sample must be checked for carryover and reanalyzed if carryover is suspected. Carryover is usually indicated by low concentration detects of the analyte in successive samples analyzed after the high concentration sample.

Sample results at concentrations above the upper limit of quantitation must be diluted and reanalyzed. The result in the diluted samples should be within the upper half of the calibration range. Results less than the mid-range of the calibration indicate the sample was over diluted and analysis should be repeated with a lower level of dilution. If dilution is not performed, any result reported above the upper range is considered a qualitative measurement and must be qualified as an estimated value.

Refer to Appendix B for a complete summary of QC, acceptance criteria, and recommended corrective actions for QC associated with this test method.

13.0 Pollution Prevention And Waste Management

Pace proactively seeks ways to minimize waste generated during our work processes. Some examples of pollution prevention include but are not limited to: reduced solvent extraction, solvent capture, use of reusable cycletainers for solvent management, and real-time purchasing.

The EPA requires that laboratory waste management practice to be conducted consistent with all applicable federal and state laws and regulations. Excess reagents, samples and method process wastes must be characterized and disposed of in an acceptable manner in accordance with Pace's Chemical Hygiene Plan / Safety Manual.

14.0 Modifications

A modification is a change to a reference test method made by the laboratory. For example, changes in stoichiometry, technology, quantitation ions, reagent or solvent volumes, reducing digestion or extraction times, instrument runtimes, etc. are all examples of modifications. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 *Method Validation and Instrument Verification* for the conditions under which the procedures in test method SOPs may be modified and for the procedure and document requirements.

15.0 Responsibilities

Pace ENV employees that perform any part this procedure in their work activities must have a signed Read and Acknowledgement Statement in their training file for this version of the SOP. The employee is responsible for following the procedures in this SOP and handling temporary departures from this SOP in accordance with Pace's policy for temporary departure.

Pace supervisors/managers are responsible for training employees on the procedures in this SOP and monitoring the implementation of this SOP in their work area.

16.0 Attachments

16.1 Appendix A: Target Analyte List and Routine LOQ

16.2 Appendix B: QC Summary

17.0 REFERENCES

17.1 Pace Quality Assurance Manual – most current version

17.2 National Environmental Laboratory Accreditation Conference (NELAC), Chapter 5, "Quality Systems"- most current version.

17.3 The NELAC Institute (TNI); Volume 1, Module 2, "Quality Systems"- most current version.

17.4 Methods for Determination of Metals in Environmental Samples, Supplement I, EPA-600/R-94/111, May 1994, Method 200.7, revision 4.4.

17.5 Test Methods for Evaluating Solid Wastes, Physical/Chemical Methods (SW-846), Third Edition, Method 6010B, revision 2, December 1996.

17.6 ENV-SOP-LENE-0089(SW-846 3010)

17.7 ENV-SOP-LENE-0094(SW-846 3050)

17.8 ENV-SOP-LENE-0124(wipes)

18.0 REVISION HISTORY

This Version: ENV-SOP-LENE-0026, REV. 03

Section	Description of Change
ALL	NEW CORPORATE SOP FORMAT
7.0	NEW ICP INSTRUMENTS ADDED

This document supersedes the following document(s):

Document Number	Reason for Change	Date
S-KS-M-005-rev.9	Section 6 – Changed SOP review frequency Section 9 – Changed instrument make/model. Section 10 – Removed S2 standard and revised procedures for new instrument. Section 11 – Added ICVA and ICSAB standards, changed CRDL to PRL. Section 12 – Revised procedures for new instrument. Section 13 – Updated 200.7 MS requirement and IS recovery limits. Section 14 – Removed 20% nitric acid rinse modification. Section 17 – Added ICSAB table.	August 25, 2009
S-KS-M-005-rev.10	Section 7 – Added Environmental Quality Director. Changed SOP review frequency to annual. Section 15 – Revised SOP reference. Section 16 – Revised method references. Section 17 – Added PRL table.	November 29, 2010

Document Number	Reason for Change	Date
S-KS-M-005-rev.11	SOP - Remove references to Thermo 61E Trace ICP. Section 8 – Removed 24-hour hold period after lab filtration. Table 10.2 – Removed Lithium standard Section 10 – Removed Trace ICP Internal Standard. Revised ICSA prep. Change RDL to CRDL and CRDL to CRDL 2. Table 11.1 – Added Indium as alternative to Yttrium. Section 12 - Added 60ICP04 operating conditions, data storage, and ESI SC-FAST operating conditions. Section 16 – Revised method references.	March 10, 2011
S-KS-M-005-rev.12	General – Converted SOP to new format Table 9.1 – Added Iteva Software Table 13.1 – Added Post Spike and Dilution Test Table 10.1 – Added "or equivalent". Table 11.1 – ICVA/CRDL/CRDL2 if required by client- or project-specific QAPP. Section 18 – Removed Internal Standards and Dilution Test. Redundant info that is now in tables 11.1 and 13.1 Section 20.3 – Added equipment safety Table 24.7 – Updated Si and Ag Solid RLs	July 11, 2012
S-KS-M-005-rev.13	SOP - Updated to latest prescribed format. Adjusted HCl conc in standards. Section 5 – Revised Pb in Soil LOQ from 0.5mg/Kg to 1.0 mg/Kg Section 12 – Eliminated CRDL2 standard. Added Cetac ASXpress operating table. Section 18 – Added MDL verification. Attachments 1-3: Added client-specific criteria.	February 1, 2013
S-KS-M-005-rev.14	Section 1 – Added note that only water samples are analyzed via 200.7 Section 4 – Added note that only water samples are analyzed via 200.7	April 2, 2013
S-KS-M-005-rev.15	Section 10.1 – Increased amount of HCl from 400mL to 1000mL Section 10.2 – Increased concentration of HCl from 2% to 5% Table 11.1 – Added 200.7 ICV criteria Table 12.3 – Updated probe in sample time from 7s to 8s	February 4, 2014
S-KS-M-005-rev.16	Attachment IV - Added client-specific criteria	June 18, 2014
S-KS-M-005-rev.17	SOP - Updated to latest prescribed format. Added sections for Instrument/Equipment Maintenance and Troubleshooting. Section 3.2 Added Hardness to Scope and Application Section 10 – Added equivalency statement. Table 10.1– Updated reagent sources/item #'s Section 14.5 Added formula for Hardness calculation.	April 17, 2015
S-KS-M-005-rev.18	Table 5.1 – Added Li Soil LOQ Table 10.1 – Modified Intermediate and Working Std. Expiration Table 13.1- MSD limits revised to those of MS and RPD of 20.	November 12, 2015
S-KS-M-005-rev.19	Table 9.1 – Updated CETAC model number. Table 12.1 – Revised coolant flow, nebulizer flow, pump speed Table 12.2 – Revised coolant flow, nebulizer flow. Section 12.1.8 – Revised local storage for 60ICP03. Table 13.1 – Added criteria for sample replicates.	June 22, 2016
S-KS-M-005-rev.20	Revised cover to Pace LLC.	September 1, 2017
ENV-SOP-LENE-0026-01	SOP – Removed cover page, TOC and Headers. Tables 10.3 through 10.8 – Added Zirconium Section 18.1 – Revised SOP reference Section 23.1 – Revised SOP reference	January 7, 2018

Document Number	Reason for Change	Date
ENV-SOP-LENE-0026-02	Section 18.3 – Revised SOP reference Section 19 – Added a method modification for 200.7 Table 5.1 – Added TCLP PRLs Sections 10.3 and 10.4 – Revised Table 10.7 — Revised CRDL for some metals Section 12.1.8 – Added file storage instructions	July 18, 2019

Appendix A: Target Analyte List and Routine LOQ

Table 1: Routine Analyte List and Limits of Quantitation (LOQ)[1]

Element	CAS Number	LOQ (ug/L)	LOQ (mg/kg)	TCLP (mg/L)	Element	CAS Number	LOQ (ug/L)	LOQ (mg/kg)	TCLP (mg/L)
Aluminum	7429-90-5	75	7.5	2	Molybdenum	7439-98-7	20	2	0.5
Antimony	7440-36-0	15	1.5	0.3	Nickel	7440-02-0	5	0.5	0.1
Arsenic	7440-38-2	10	1	0.5	Phosphorus	7723-14-0	100	10	10
Barium	7440-39-3	5	0.5	2.5	Potassium	7440-09-7	500	50	50
Beryllium	7440-41-7	1	0.1	0.05	Selenium	7782-49-2	15	1.5	0.5
Boron	7440-42-8	100	10	1	Silicon	7440-21-3	500	50	5
Cadmium	7440-43-9	5	0.5	0.05	Silver	7440-22-4	7	0.7	0.1
Calcium	7440-70-2	200	20	50	Sodium	7440-23-5	500	50	50
Chromium	7440-47-3	5	0.5	0.1	Strontium	7440-26-6	10	1	0.1
Cobalt	7440-48-4	5	0.5	0.1	Thallium	7440-28-0	20	2	0.5
Copper	7440-50-8	10	1	0.2	Tin	7440-31-5	50	5	0.5
Iron	7439-89-6	50	5	1	Titanium	7440-32-6	10	1	0.1
Lead	7439-92-1	10	1	0.5	Vanadium	7440-62-2	10	1	0.1
Lithium	7439-93-2	10	1	0.5	Zinc	7440-66-6	50	10	2.5
Magnesium	7439-95-4	50	5	50	Zirconium	7440-67-7	10	1	0.1
Manganese	7439-96-5	5	0.5	0.1					

[1] Values in place as of effective date of this SOP. LOQ are subject to change. For the most up to date LOQ, refer to the LIMS or contact the laboratory.

Appendix B: QC Summary

QC Item	Frequency	Acceptance Criteria	Corrective Action	Qualification
ICAL	Calibration is done on a daily basis.	Single point calibration	Remake standards, perform maintenance, recalibrate, and verify before sample analysis.	None. Do not proceed with analysis
Lower Limit of Quantitation Check/Contract Required Detection Limit (LLOQ/CRDL)	After each ICV	All analytes must be within ± 50% of the true value. (%R)	Identify source of problem, re-analyze. If repeat failure, repeat ICAL. ***Exceptions:*** Analysis may proceed if it can be demonstrated that the CRDL exceedance has no impact on analytical measurements. If the CRDL %R is high, and the analyte is not detected in sample(s). If the CRDL %R is low, and the analyte is 50x the LOQ.	None.
ICV	After each ICB	**200.7**: All analytes must be within ± 5% of the true value. (%R) **6010B:** All analytes must be within ± 10% of the true value. (%R) with <5% (%RSD) from a minimum of 2 replicate integration	Identify source of problem, re-analyze. If repeat failure, repeat ICAL. ***Exceptions:*** Analysis may proceed if it can be demonstrated that the ICV exceedance has no impact on analytical measurements. If the ICV %R is high, CCV is within criteria, and the analyte is not detected in sample(s).	Qualify analytes with ICV out of criteria.
ICB	After each ICAL	All analytes must be below the LOQ.	Identify source of problem, re-analyze. If repeat failure, repeat ICAL. ***Exceptions:*** Analysis may proceed if it can be demonstrated that the ICB exceedance has no impact on analytical measurements. If the ICB is above the LOQ, and the analyte is not detected in sample(s).	None.
CCV	Daily, before sample analysis, after every 10 samples, and at end of the analytical run.	All analytes within ± 10% of the true value (%R) with <5% (%RSD) from a minimum of 2 replicate integration.	Identify source of problem, re-analyze. If repeat failure, rerun the affected analytes. ***Exceptions:*** Analysis may proceed if it can be demonstrated that the CCV exceedance has no impact on analytical measurements.	Qualify analytes with CCV out of criteria.

QC Item	Frequency	Acceptance Criteria	Corrective Action	Qualification
			If the CCV %R is high and the analyte is not detected in sample(s).	
CCB	After Each CCV	All analytes must be below the LOQ.	Identify source of problem, re-analyze. If repeat failure, repeat the affected analytical sequence or repeat ICAL. ***Exceptions:*** Analysis may proceed if it can be demonstrated that the CCB exceedance has no impact on analytical measurements. If the CCB is above the LOQ, and the analyte is not detected in sample(s) or the analyte is ≥10x the concentration in the blank, report the samples without qualification.	None.
ICSA	Once per calibration	Al, Ca, Fe, and Mg must be within ± 20% of the true value (%R) All other analytes must be below the LOQ	Identify source of problem, re-analyze or adjust the inter-element corrections. Re-analyze until acceptance criteria are met.	None.
ICSAB	Once per calibration if required by QAPP	All analytes must be within ± 20% of the true value (%R)	Identify source of problem, re-analyze or adjust the inter-element corrections. Re-analyze until acceptance criteria are met.	None.
Internal Standards	Every sample, standard and QC sample	Must be within ± 30% of the IS reading for the CAL0 standard.	Associated samples must be diluted and reanalyzed.	Qualify if reanalysis is not possible.
Method Blank	1 per batch of 20 or fewer samples.	All analytes must be below the LOQ.	Identify source of problem, re-analyze. If repeat failure, reanalyze the associated samples. ***Exceptions:*** Analysis may proceed if it can be demonstrated that the MB exceedance has no impact on analytical measurements. If the MB is above the LOQ, and the analyte is not detected in sample(s) or the analyte is ≥10x the concentration in the blank, report the samples without qualification.	Report analytes without qualification and qualify MB for being out of criteria.
LCS	1 per batch of 20 or fewer samples.	**200.7**: All analytes must be within ± 15% of the true value. (%R) **6010B:**	Identify source of problem, re-analyze. If repeat failure, all samples with affected analytes must be removed from the batch, redigested, and reanalyzed. ***Exceptions:***	Report analytes without qualification and qualify LCS for being out of criteria.

QC Item	Frequency	Acceptance Criteria	Corrective Action	Qualification
		All analytes must be within ± 20% of the true value. (%R)	Analysis may proceed if it can be demonstrated that the LCS exceedance has no impact on analytical measurements. If the LCS %R is high, and the analyte is not detected in sample(s).. If samples cannot be redigested (wipes, paint chips, limited volume).	
MS	**200.7:** 1 per batch of 10 or fewer samples. If greater than 10 samples, another MS is required. **6010B:** 1 per batch of 20 or fewer samples.	**200.7**: All analytes must be within ± 30% of the true value. (%R) **6010B:** All analytes must be within ± 25% of the true value. (%R) **Alternative:** In compliance with lab generated limits.	None.	Qualify analytes with MS out of criteria.
MSD	**200.7:** 1 per batch of 10 or fewer samples. If greater than 10 samples, another MSD is required. **6010B:** 1 per batch of 20 or fewer samples.	All analytes must be within ± 20% of the MS. (%RPD) **Alternative:** In compliance with lab generated limits.	None.	Qualify analytes with MSD out of criteria.
Dilution test	6010B Only - Per client request or at analyst discretion. Dilution of samples with analytes 10x the LOQ. Dilution of sample at a 5x or 10x dilution to demonstrate that the analytes are not affected by spectral interference.	All analytes must be within 10% of the initial, undiluted analysis. (%R)	Analyze additional dilutions of the sample digestate until at least two results are within 10% (%R). **Exceptions:** The analyte is less than 10x of the LOQ.	Report from that dilution for the samples in the batch unless they are lower than the LOQ when diluted.

Management Approval:
Lenzie Boring Approved on 1/20/2022 10:52:36 AM
Charles Girgin Approved on 2/3/2022 4:23:47 PM
Kenneth Busch Approved on 2/4/2022 1:33:36 PM

1.0 Scope And Application

This standard operating procedure (SOP) describes the laboratory procedure for the determination of metals by aqueous digestion.

1.1 Target Analyte List and Limits of Quantitation (LOQ)

The target analytes and the normal LOQ that can be achieved with this procedure are provided in the determinative SOP.

LOQ are established in accordance with Pace policy and SOPs for method validation and for the determination of detection limits (DL) and quantitation limits (LOQ). DL and LOQ are routinely verified and updated when needed. The current LOQ for each target analyte that can be determined by this SOP as of the effective date of this SOP is provided in Table 1, Appendix A.

The reporting limit (RL) is the value to which analytes are reported as detected or not detected in the final report. When the RL is less than the lower limit of quantitation (LLOQ), all detects and non-detects at the RL are qualitative. The LLOQ is the lowest point of the calibration curve used for each target analyte.

DL, LOQ, and RL are always adjusted to account for actual amounts used and for dilution.

2.0 Summary of Method

2.1 Sample aliquots are digested for the analysis of metals by heating for an extended period of time in the presence of nitric acid and hydrochloric acid.

3.0 Interferences

3.1 See the analytical SOPs ENV-SOP-LENE-0026 and ENV-SOP-LENE-0024 (or their equivalent revisions or replacements).

4.0 Definitions

Refer to the Laboratory Quality Manual for a glossary of common lab terms and definitions.

5.0 Health and Safety

The toxicity or carcinogenicity of each chemical material used in the laboratory has not been fully established. Each chemical should be regarded as a potential health hazard and exposure to these compounds should be as low as reasonably achievable.

The laboratory maintains documentation of hazard assessments and OSHA regulations regarding the safe handling of the chemicals specified in each method. Safety data sheets for all hazardous chemicals are available to all personnel. Employees must abide by the health, safety and environmental (HSE) policies and procedures specified in this SOP and in the Pace Chemical Hygiene / Safety Manual.

Personal protective equipment (PPE) such as safety glasses, gloves, and a laboratory coat must be worn in designated areas and while handling samples and chemical materials to protect against physical contact with samples that contain potentially hazardous chemicals and exposure to chemical materials used in the procedure.

Concentrated corrosives present additional hazards and are damaging to skin and mucus membranes. Use these acids in a fume hood whenever possible with additional PPE designed for handing these materials. If eye or skin contact occurs, flush with large volumes of water. When working with acids, always add acid to water to prevent violent reactions. Any processes that emit large volumes of solvents (evaporation/concentration processes) must be in a hood or apparatus that prevents employee exposure.

Contact your supervisor or local HSE coordinator with questions or concerns regarding safety protocol or safe handling procedures for this procedure.

6.0 Sample Collection, Preservation, Holding Time, and Storage

Samples should be collected in accordance with a sampling plan and procedures appropriate to achieve the regulatory, scientific, and data quality objectives for the project.

The laboratory does not perform sample collection or field measurements for this test method. To assure sample collection and field checks and treatment are performed in accordance with applicable regulations Pace project managers will inform the client of these requirements at the time of request for analytical services when the request for testing is received prior to sample collection. If samples were already collected, the laboratory will record any nonconformance to these requirements in the laboratory's sample receipt record when sufficient information about sample collection is provided with the samples.

The laboratory will provide containers for the collection of samples upon client request for analytical services. Bottle kits are prepared in accordance with laboratory SOP ENV-SOP-LENE-0025, *Assembly of Sample Container Kits*.

Requirements for container type, preservation, and field quality control (QC) for the common list of test methods offered by Pace are included in the laboratory's quality manual.

General Requirements

Matrix	Routine Container	Minimum Sample Amount[1]	Preservation	Holding Time
Aqueous	Plastic or Glass	50mL	Thermal: Ambient temp or <6°C Chemical: 1:1 HNO3; pH<2	180 days

[1]*Minimum amount needed for each discrete analysis.*

Field / Matrix QC

Trip Blank	Equipment Blank	MS/MSD	Field Duplicate
NA	NA	1/20	1/20

Thermal preservation is checked and recorded on receipt in the laboratory in accordance with laboratory SOP ENV-SOP-LENE-0021, *Sample Management*. Chemical preservation is checked and recorded at time of receipt or prior to sample preparation.

After receipt, samples are stored at ambient temperature until sample preparation. Prepared samples (extracts, digestates, distillates, other) are stored ambient until sample analysis.

After analysis, unless otherwise specified in the analytical services contract, samples are retained for 30 days from date of final report and then disposed of in accordance with Federal, State, and Local regulations.

7.0 Equipment And Supplies

7.1 Equipment and Supplies

Supply	Description	Vendor/ Item # / Description
Analytical balance		Mettler-Toledo / PB3002-S (Or equivalent)
Boiling stones	PTFE	Fisher / 09-191-20 (Or equivalent)
Digestion tubes	50mL, Graduated	Environmental Express / SC475 (Or equivalent)
Filter paper	Whatman #41	Fisher / 09-850-D (Or equivalent)
Filtermate™	2.0 micron	Environmental Express / SC0401 (Or equivalent)
Graduated cylinders	Various sizes	Fisher / 03-007-40 / 03-007-41 (Or equivalent)
Hotblock	Multi-position	Environmental Express / SC154 (Or equivalent)
Pipettors	Various sizes	Eppendorf (Or equivalent)
Watch glasses	Plastic Disposable	Environmental Express / SC505 (Or equivalent)

8.0 Reagents And Standards

8.1 Reagents and Standards

The reagents listed below are those currently in use. Other sources or grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

Table 8.1 – Standard Storage Conditions

Standard Type	Description	Expiration	Storage
Stock Solutions	▪ Concentrated reference solution purchased directly from approved vendor	▪ Manufacturer's recommended expiration date	▪ Manufacturer's recommended storage conditions
Intermediate and Working Standard Solutions	▪ Reference solutions prepared by dilutions of the stock solution	▪ Six months from preparation or the expiration date listed for the stock source, whichever is sooner.	▪ Manufacturer's recommended storage conditions for stock source solution.

Standard Type	Description	Expiration	Storage
		▪ Working solutions must be checked frequently and replaced if degradation or evaporation is suspected.	

Table 8.2 – Reagents and Standards

Reagent/Standard	Concentration/ Description	Vendor/ Item #
Hydrochloric acid	Baker Instra-Analyzed®	J.T. Baker / 9530-33
Hydrogen peroxide	ACS Reagent grade	Macron Fine Chemicals / 5240-05
Nitric acid	Baker Instra-Analyzed®	J.T. Baker / 9598-34
PA-STD-1B (Custom)	200 mg/L: As, Ba, Be, Cd, Co, Cr, Mn, Ni, P, Pb, Se, Sr, Tl, V, Zn	Inorganic Ventures / PA-STD-1B
PA-STD-2B (Custom)	1000 mg/L: Si 200 mg/L: B, Mo, Sb, Sn, Ti, Zr 100 mg/L: Ag	Inorganic Ventures / PA-STD-2B
PA-STD-3B (Custom)	2000 mg/L: Al, Ca, Fe, K, Mg, Na	Inorganic Ventures / PA-STD-3B
Reagent water	ASTM Type II	SOP S-KS-Q-011

Table 8.3 – Working Spike Standards

Working Standard	Stock(s)	Volume Used (mL)	Nitric acid (mL)	Final Volume (mL)
ICP-AES Spike	PA-STD-1B PA-STD-2B PA-STD-3B	50 50 50	**NA**	**200**
ICP-MS Spike	PA-STD-1B PA-STD-2B PA-STD-3B	2.0 2.0 5.0	**2.0**	**200**

8.2 Spike Standard Verification

8.2.1 **Dilute ICP Spiking Standard fifty-fold and analyze according to ENV-SOP-LENE-0026, ENV-SOP-LENE-0018, *Metals Determination by ICP-AES* or SOP ENV-SOP-LENE-009, ENV-SOP-LENE-0060 *Metals Determination by ICP-MS* (or their equivalent revisions or replacements). Spike true values are noted in Attachment I.**

8.2.2 **Spiking Solutions may be used for sample analysis if all element concentrations are ± 15% of the true value.**

9.0 PROCEDURE

9.1 Equipment Preparation

9.1.1 Support Equipment

See SOP ENV-SOP-LENE-0030, Support Equipment (or its equivalent revision or replacement) for the calibration of the support equipment used in this procedure

9.1.2 Instrument

9.1.2.1 Routine Instrument Operating Conditions

Not applicable to this SOP

9.2 Initial Calibration

9.2.1 Calibration Design

Not applicable

9.2.2 Calibration Sequence

Not applicable

9.2.3 ICAL Evaluation

9.2.3.1 Curve Fit

Not applicable

9.2.3.2 Relative Standard Error (RSE)

Not applicable

9.2.3.3 Initial Calibration Verification

Not applicable

9.2.4 Continuing Calibration Verification

Not applicable

9.3 Sample Preparation

9.3.1 Homogenization and Subsampling

Not applicable

9.4 Analysis

9.4.1 Filtration of samples for dissolved metals analysis

9.4.1.1 Samples for dissolved metals analysis are normally filtered in the field. In certain instances, the samples are filtered in the laboratory. An aliquot of unpreserved sample is filtered through a 0.45-um, cellulose nitrate filter and preserved with nitric acid.

9.4.1.2 The filtration procedure is as follows:

9.4.1.3 Rinse the filtration apparatus (Erlenmeyer flask, filtration top and bottom) with 20% nitric acid, followed by five rinses with deionized water.

9.4.1.4 A 0.45-um filter is placed on the filtration support with a forceps

9.4.1.5 The filtration top is attached and the pump tubing is attached to the flask

9.4.1.6 150 mL of deionized water is added to the filtration apparatus and the pump is started.

9.4.1.7 After the deionized water has passed through the filter, turn the pump off and disconnect the tubing from the pump. Remove the filter support and pour the filtered aliquot into a pre-certified, HNO_3-preserved, 250-mL sample bottle (obtain from Bottle Prep Department).

9.4.1.8 This aliquot of deionized water serves as the method blank for the batch.

9.4.1.9 Label the bottle with the date, analyst's initials and attach a sample identification label.

9.4.1.10 Repeat steps 1 through 6 for up to twenty samples (substituting the sample for deionized water in Step 4).

9.4.1.11 Record the filter lot number on the filtration batch sheet with the analyst initials and date. Place the batch in the filtration binder.

9.4.1.12 Alternatively, the Flip-mate filters may be used with the filtration manifold to filter multiple samples at once. This system utilizes the 50 mL digestion vessels.

9.4.1.12.1 Fill a digestion tube with 50 mL of sample and screw the flip-mate filter to the tube

9.4.1.12.2 Attach an empty 50 mL digestion tube to the other side of the flip-mate filter.

9.4.1.12.3 Invert the tubes so the sample side is up. Attach the flip-mate filter to the manifold by pressing the male end of the valve to the female end of the flip-mate filter.

9.4.1.12.4 Ensure the pump hose is attached to the manifold. Turn the pump on and open the valve to all ports of the manifold where filters have been attached.

9.4.1.12.5 Allow the sample enough time to filter from the top tube to lower tube.

9.4.1.12.6 Check the volume to ensure no loss of sample.

9.4.1.13 The samples are now ready for digestion. The filtered blank is carried through the digestion process and is the method blank.

9.4.2 Batch samples according to EPIC procedures. Using batch worklist, mark the digestion tube with the sample ID.

9.4.3 Transfer information into Workbench system according to IT staff instructions. Transfer the same information into the prep logbook along with the project number, batch code, QC samples, and spike solution used for the LCS, MS, and MSD.

9.5 Hotblock Digestion

9.5.1 Prepare the Prep Blank and the LCS by measuring out 50 mL of reagent water into an appropriately labeled 50-mL digestion tubes.

9.5.2 Transfer a 50-mL aliquot of a well-mixed sample into a labeled 50-mL digestion tube. For the QC samples (MS/MSD) transfer additional 50-mL aliquots of the same sample into labeled 50-mL digestion tubes.

9.5.3 Spike the LCS, MS and MSD samples with 1.0 mL of the ICP Spiking Standard or 1.0 mL of ICPMS spiking standard.

9.5.4 For analysis by ICP or ICPMS add 2.0 mL of 1:1 HNO_3, 5.0 mL of 1:1 HCl, and place in hotblock maintained at 90-95 °C (do not boil).

9.5.5 Place watch-glasses on the digestion tubes and heat until sample volume has reduced to approximately 10% of the initial sample volume or a minimum of 4 hours.

9.5.6 Remove from heat and allow sample to cool. Wash down sides of digestion tube with reagent water and adjust the final volume to 50 mL with reagent water. Filter only if necessary to remove silicates and other insoluble material.

9.5.7 Complete the digestion logbook page.

10.0 Data Analysis And Calculations

10.1 Qualitative Identification

Not applicable

10.2 Quantitative Identification

Not applicable

10.3 Calculations

See the Laboratory Quality Assurance Manual for equations for common calculations.

11.0 Quality Control and Method Performance

11.1 Quality Control

The following QC samples are prepared and analyzed with each batch of samples. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency

Method Blank (MB)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Laboratory Control Sample (LCS)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Matrix Spike (MS) / Matrix Spike Duplicates (MSD)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.

11.2 Instrument QC

Not applicable. Refer to the determinative SOP.

11.3 Method Performance

11.3.1 Method Validation

11.3.1.1 Detection Limits

Detection limits (DL) and limits of quantitation (LOQ) are established at initial method setup and verified on an on-going basis thereafter. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 Method Validation and Instrument Verification.

11.4 Analyst Qualifications and Training

Employees that perform any step of this procedure must have a completed Read and Acknowledgment Statement for this version of the SOP in their training record. In addition, prior to unsupervised (independent) work on any client sample, analysts that prepare or analyze samples must have successful initial demonstration of capability (IDOC) and must successfully demonstrate on-going proficiency on an annual basis. Successful means the initial and on-going DOC met criteria, documentation of the DOC is complete, and the DOC record is in the employee's training file. Refer to laboratory SOP ENV-SOP-LENE-0110, *Training Procedures*, for more information.

12.0 DATA REVIEW AND CORRECTIVE ACTION

12.1 Data Review

Pace's data review process includes a series of checks performed at different stages of the analytical process by different people to ensure that SOPs were followed, the analytical record is complete and properly documented, proper corrective actions were taken for QC failure and other nonconformance(s), and that test results are reported with proper qualification.

The review steps and checks that occur as employee's complete tasks and review their own work is called primary review.

All data and results are also reviewed by an experienced peer or supervisor. Secondary review is performed to verify SOPs were followed, that calibration, instrument performance, and QC criteria were met and/or proper corrective actions were taken, qualitative ID and quantitative measurement is accurate, all manual integrations are justified and documented in accordance with the Pace ENV's SOP for manual integration, calculations are correct, the analytical record is complete and traceable, and that results are properly qualified.

A third-level review, called a completeness check, is performed by reporting or project management staff to verify the data report is not missing information and project specifications were met.

Refer to laboratory SOP ENV-SOP-LENE-088, *Data Reduction, Review and Reporting*, for specific instructions and requirements for each step of the data review process.

12.2 Corrective Action

Corrective action is expected any time QC or sample results are not within acceptance criteria. If corrective action is not taken or was not successful, the decision/outcome must be documented in the analytical record. The primary analyst has primary responsibility for taking corrective action when QA/QC criteria are not met. Secondary data reviewers must verify that appropriate action was taken and/or that results reported with QC failure are properly qualified.

Corrective action is also required when carryover is suspected and when results are over range.

Samples analyzed after a high concentration sample must be checked for carryover and reanalyzed if carryover is suspected. Carryover is usually indicated by low concentration detects of the analyte in successive samples analyzed after the high concentration sample.

Sample results at concentrations above the upper limit of quantitation must be diluted and reanalyzed. The result in the diluted samples should be within the upper half of the calibration range. Results less than the mid-range of the calibration indicate the sample was over diluted and analysis should be repeated with a lower level of dilution. If dilution is not performed, any result reported above the upper range is considered a qualitative measurement and must be qualified as an estimated value.

Refer to Appendix B for a complete summary of QC, acceptance criteria, and recommended corrective actions for QC associated with this test method.

13.0 Pollution Prevention And Waste Management

Pace proactively seeks ways to minimize waste generated during our work processes. Some examples of pollution prevention include but are not limited to: reduced solvent extraction, solvent capture, use of reusable cycletainers for solvent management, and real-time purchasing.

The EPA requires that laboratory waste management practice to be conducted consistent with all applicable federal and state laws and regulations. Excess reagents, samples and method process wastes must be characterized and disposed of in an acceptable manner in accordance with Pace's Chemical Hygiene Plan / Safety Manual.

14.0 Modifications

A modification is a change to a reference test method made by the laboratory. For example, changes in stoichiometry, technology, quantitation ions, reagent or solvent volumes, reducing digestion or extraction times, instrument runtimes, etc. are all examples of modifications. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 *Method Validation and Instrument Verification* for the conditions under which the procedures in test method SOPs may be modified and for the procedure and document requirements.

14.1 Method 3010A has been modified to utilize plastic digestion tubes rather than glass Griffin beakers, and acid strengths have been modified. It has been found that the amount of time needed to evaporate samples to method specified volumes exceeds an 8 hour work shift. Therefore, samples are digested until volume is reduced to 10% of the initial sample volume or for a minimum of 4 hours. After which, the samples are considered to be completely digested. Performance Testing (PT) studies support that these modifications do not adversely affect the quality of the analytical data produced by this digestion procedure. (See Attachment II for initial validation data.) Additionally, the method deviates by adding 2 mL Nitric acid per 50 mL final volume instead of the 3 mL Nitric acid per 50 mL.

14.2 Method 200.7, Rev. 4.4 specifies using 1 mL 1:1 HNO_3 and 0.5 mL HCl (when reduced to a 50 mL sample volume). Instead Pace is using 2 mL 1:1 HNO_3 and 5 mL 1:1 HCl, the same ratios used for method 3010A in this SOP.

14.3 Method 200.8 for Total Recoverable metals specifies using 2 mL (1+1) Nitric acid and 1.0 mL of (1+1) HCl to a 100 mL sample. Pace is adding 2 mL of (1+1) Nitric acid and 0.5 mL of (1+1) HCl to a 50 mL sample. The change in HCl concentration is recommended by the Instrument engineers.

15.0 RESPONSIBILITIES

Pace ENV employees that perform any part this procedure in their work activities must have a signed Read and Acknowledgement Statement in their training file for this version of the SOP. The employee is responsible for following the procedures in this SOP and handling temporary departures from this SOP in accordance with Pace's policy for temporary departure.

Pace supervisors/managers are responsible for training employees on the procedures in this SOP and monitoring the implementation of this SOP in their work area.

16.0 ATTACHMENTS

16.1 Attachment I: Spike True Values

16.2 Attachment II: Initial Validation Data

17.0 REFERENCES

17.1 Pace Quality Assurance Manual - most current version.

17.2 National Environmental Laboratory Accreditation Conference (NELAC), Chapter 5, "Quality Systems"- most current version.

17.3 The NELAC Institute (TNI); Volume 1, Module 2, "Quality Systems"- most current version.

17.4 "Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act; Analysis and Sampling Procedures; Final Rule" Federal Register Doc. No: 2012-10210.

17.5 EPA Test Methods for Evaluating Solid Waste. SW-846, Third Edition, Update I, Method 3010A, Revision 1, July 1992.

17.6 Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, Method 200.7, Revision 4.4, 1994.

18.0 REVISION HISTORY

This Version: ENV-SOP-LENE-0089, v02

Section	Description of Change
All	This is a new SOP format

This document supersedes the following document(s):

Document Number	Title	Version
ENV-SOP-LENE-0089	Acid Digestion of aqueous samples	01

Attachment I: Spike True Values (50-mL digestate)

ICP-AES Spike True Values

Element	Concentration (ug/L)	Element	Concentration (ug/L)
Ag	500	Mo	1000
Al	10000	Na	10000
As	1000	Ni	1000
B	1000	P	1000
Ba	1000	Pb	1000
Be	1000	Sb	1000
Ca	10000	Se	1000
Cd	1000	Si	5000
Co	1000	Sn	1000
Cr	1000	Sr	1000
Cu	1000	Ti	1000
Fe	10000	Tl	1000
K	10000	V	1000
Li	1000	Zn	1000
Mg	10000		
Mn	1000		

ICP-MS Spike True Values

Element	Concentration (ug/L)	Element	Concentration (ug/L)
^{9}Be	40	^{105}Pd	20
^{27}Al	4,000	^{107}Ag	20
^{47}Ti	40	^{111}Cd	40
^{51}V	40	^{118}Sn	40
^{52}Cr	40	^{121}Sb	40
^{54}Fe	2,000	^{137}Ba	40
^{55}Mn	40	^{195}Pt	20
^{89}Co	40	^{205}Tl	20
^{60}Ni	40	^{208}Pb	40
^{65}Cu	40	^{238}U	40
^{66}Zn	40	Tin	40
^{75}As	40		
^{78}Se	40		
^{88}Sr	40		
^{95}Mo	40		

Attachment II: Initial Validation Data

	Analytical Results Obtained (ug/L) Date: 2/4/13		ERA WasteWatR Trace Metals (Lot No. P208-500)	
Parameter	(ICP-AES) Instrument ID: 60ICP04	(ICP-MS) Instrument ID: 60ICPM1	Certified Value (ug/L)	Acceptance Range (ug/L)
Aluminum	467	453.1	456	350-564
Antimony	399	397.4	401	277-484
Arsenic	371	376.5	376	314-441
Barium	1750	1959	1880	1630-2120
Beryllium	539	541.7	544	462-614
Boron	868	Not Evaluated	930	769-1080
Cadmium	672	652	671	573-762
Chromium	796	810.8	779	679-880
Cobalt	289	282.5	276	242-310
Copper	241	240.8	238	214-264
Iron	1026	984.4	1070	946-1210
Lead	321	320.9	305	262-346
Manganese	820	800	767	688-852
Molybdenum	207	208.3	202	168-234
Nickel	813	772	765	688-855
Selenium	631	581.7	652	517-755
Silver	263	264.5	257	220-294
Strontium	213	218.9	217	188-246
Thallium	543	508.9	513	412-616
Vanadium	1462	Not Evaluated	1420	1240-1590
Zinc	255	242.7	253	216-295

Management Approval:
Lenzie Boring Approved on 9/12/2022 3:13:41 PM
Charles Girgin Approved on 9/13/2022 12:55:27 PM
Kenneth Busch Approved on 9/13/2022 2:59:17 PM

1.0 SCOPE AND APPLICATION

This standard operating procedure (SOP) describes the laboratory procedure for the determination of Anions by Ion Chromatography by EPA 300.0 rev 2.1 and SW-846 9056A.

1.1 Target Analyte List and Limits of Quantitation (LOQ)

The target analytes and the normal LOQ that can be achieved with this procedure are provided in Table 1.1.

Table 1.1 – Limits of Quantitation

Anion	Water, mg/L	Soil, mg/kg
Fluoride (F)	0.2	2.0
Chloride (Cl)	1.0	10
Nitrite-N (NO_{2}-N)	0.1	1.0
Bromide (Br)	1.0	10
Nitrate-N (NO_3-N)	0.1	1.0
Sulfate (SO_4)	1.0	10

LOQ are established in accordance with Pace policy and SOPs for method validation and for the determination of detection limits (DL) and quantitation limits (LOQ). DL and LOQ are routinely verified and updated when needed. The current LOQ for each target analyte that can be determined by this SOP as of the effective date of this SOP is provided in Table 1, Appendix A.

The reporting limit (RL) is the value to which analytes are reported as detected or not detected in the final report. When the RL is less than the lower limit of quantitation (LLOQ), all detects and non-detects at the RL are qualitative. The LLOQ is the lowest point of the calibration curve used for each target analyte.

DL, LOQ, and RL are always adjusted to account for actual amounts used and for dilution.

2.0 SUMMARY OF METHOD

A water sample or a deionized water extract for soil samples are injected into a stream of carbonate-bicarbonate eluent and passed through a series of ion exchangers. The anions of interest are separated on the basis of their relative affinities for a low capacity, strongly basic anion exchanger (guard and separator columns). The separated anions are directed onto a micromembrane suppressor. In the suppressor, the separated anions are converted to their highly conductive acid forms and the carbonate-bicarbonate eluent is converted to a weakly conductive carbonic acid. The separated anions are measured by conductivity. They are identified on the basis of retention time as compared to standards. Quantitation is by measurement of peak area compared to an external standard calibration curve. Nitrite and nitrate are calculated as nitrogen as N+N.

3.0 INTERFERENCES

- Interferences can be caused by substances with retention times that are like and overlap those of the anion of interest. Large concentrations of one anion can interfere with the peak resolution of an adjacent anion. An initial conductivity reading is recommended prior to analysis, to determine adequate dilution factors. Sample dilution can be used to solve most interference problems.
- Method interferences may be caused by contaminants in the deionized water, reagents, glassware, and other sample processing apparatus that led to discrete artifacts or to elevated baselines in ion chromatograms.
- Any anion that is not retained by the column or only slightly retained will elute in the area of fluoride and interfere. Known co-elution is caused by carbonate, acetate, formate, and other small organic anions.
- The retention times of anions may differ when large amounts of acetate are present. Therefore, this method is not recommended for leachates of solid samples where acetate is used for pH adjustment.
- Samples that contain particulate matter require filtration to prevent damage to instrument columns and flow systems.

4.0 DEFINITIONS

Refer to the Laboratory Quality Manual for a glossary of common lab terms and definitions.

5.0 HEALTH AND SAFETY

Contact your supervisor or local safety coordinator with questions or concerns regarding safety protocol or safe handling procedures for this procedure

The following sections provide general health and safety information about chemicals and materials that may be present in the laboratory.

- The toxicity or carcinogenicity of each chemical material used in the laboratory has not been fully established. Each chemical should be regarded as a potential health hazard and exposure to these compounds should be as low as reasonably achievable.
- The laboratory maintains documentation of hazard assessments and OSHA regulations regarding the safe handling of the chemicals specified in each method. Safety data sheets for all hazardous chemicals are available to all personnel. Employees must abide by the health, safety and environmental (EHS) policies and procedures specified in this SOP and in the Pace® Chemical Hygiene / Safety Manual (COR-MAN-0001)

- Personal protective equipment (PPE) such as safety glasses, gloves, and a laboratory coat must be worn in designated areas and while handling samples and chemical materials to protect against physical contact with samples that contain potentially hazardous chemicals and exposure to chemical materials used in the procedure.
- Concentrated corrosives present additional hazards and are damaging to skin and mucus membranes. For procedures that require use of acids, use acids in a fume hood whenever possible with PPE designed for handing these materials. If eye or skin contact occurs, flush with large volumes of water. When working with acids, always add acid to water to prevent violent reactions. For procedures that that emit large volumes of solvents (evaporation/concentration processes), these activities must be performed in a fume hood or apparatus that reduces exposure.

6.0 Sample Collection, Preservation, Holding Time, and Storage

Samples should be collected in accordance with a sampling plan and procedures appropriate to achieve the regulatory, scientific, and data quality objectives for the project.

The laboratory does not always perform sample collection or field measurements for this test method. To assure sample collection and field checks and treatment are performed in accordance with applicable regulations Pace project managers will inform the client of these requirements at the time of request for analytical services when the request for testing is received prior to sample collection. If samples were already collected, the laboratory will record any nonconformance to these requirements in the laboratory's sample receipt record when sufficient information about sample collection is provided with the samples.

The laboratory performs sample collection for samples to be analyzed by this SOP in accordance with laboratory SOP ENV-SOP-LENE-0107. Refer to this SOP for these instructions.

The laboratory will provide containers for the collection of samples upon client request for analytical services. Bottle kits are prepared in accordance with laboratory SOP ENV-SOP-LENE-0025.

Requirements for container type, preservation, and field quality control (QC) for the common list of test methods offered by Pace are included in the laboratory's quality manual.

General Requirements

Matrix	Routine Container	Minimum Sample Amount[1]	Preservation	Holding Time
Aqueous	Plastic; 250mL	10mL	Thermal: ≤6ºC Chemical: None	28 days from Collection (F, Cl, Br, & SO4) 48 hours from Collection (NO2 & NO3)
Solid	Glass; 4oz	10g	Thermal: ≤6ºC Chemical: None	28 days from Collection (F, Cl, Br, & SO4) 48 hours from Extraction (NO2 & NO3)

[1]*Minimum amount needed for each discrete analysis.*

Thermal preservation is checked and recorded on receipt in the laboratory in accordance with laboratory SOP ENV-SOP-LENE-0021.

After receipt, samples are stored at ≤6°C until sample preparation.

After analysis, unless otherwise specified in the analytical services contract, samples are retained for 30 days from date of final report and then disposed of in accordance with Federal, State, and Local regulations.

7.0 Equipment And Supplies

7.1 Equipment and Supplies

Table 7.1 – Instrumentation

Equipment	Vendor	Model / Version	Comments
Adjustable pipettor	Eppendorf	Various	
Analytical Balance	Mettler-Toledo	AE-200	
Volumetric(s)	Fisher	various	Class A
Autosampler	Dionex	AS-40, AS-DV	
50 mL Graduated Cylinder	Fisher		Class A
Data Acquisition Software	Dionex	Chromeleon 7.3	
Detector	Dionex	CDM-II	Conductivity
Detector	Dionex	DS6 Heated Cell	Conductivity
Electrolytic pH Modifier	Dionex	063175	
Ion Chromatograph	Dionex	ICS-1600, ICS-2000, ICS-1500, Aquion	
Suppressor	Dionex	AERS 500, 4mm	Or equivalent

Table 7.2 – Chromatographic Supplies

Item	Vendor	Model / ID	Catalog #	Description
Analytical Column	Dionex	Ion Pac AS 22	064141	7 µm, 250 mm x 4 mm
Guard Column	Dionex	Ion Pac AG 22	064139	10 µm, 50 mm x 4 mm
Fast Analytical Column	Thermo	Ion Pac AG 22	079936	150mm x 4 mm

Table 7.3 – General Supplies

Item	Description	Vendor / Item # / Description
Volumetric Flasks	Various sizes	Class A
Centrifuge tubes	50-mL	Fisher
Sample vials	5-mL w/filtering cap	Environmental Express / K1250
Nitrate test strips	For quick dilution testing	Hach/Fisher / 27454-25

Item	Description	Vendor / Item # / Description
Chloride test strips	For quick dilution testing	Hach/Fisher / 27513-40
Filters (0.45 um)	For Luer Lok Syringe	Environmental Express / SF045E
10 mL syringe	Luer Lok	Fisher / 302995

NOTE: All glassware must be rinsed several times with deionized water prior to use. It is recommended that the volumetric flasks be segregated from other use and filled with deionized water during storage.

8.0 REAGENTS AND STANDARDS

8.1 Reagents and Standards

Table 8.1 – Stock Reagents

Reagent	Concentration/ Description	Vendor/ Item #
Deionized water	ASTM Type II	
Sodium carbonate (Na_2CO_3)	ACS Reagent grade	Fisher / S263-500
Sodium bicarbonate ($NaHCO_3$)	ACS Reagent grade	Fisher / S631-3

Table 8.2 – Intermediate Reagents

Reagent	Description
Eluent Stock	Dissolve 5.88g sodium bicarbonate and 23.845g sodium carbonate into a 1-L volumetric flask containing approximately 600 mL deionized water. Dilute to the mark and invert several times to mix. Prepare monthly.

Table 8.3 – Working Reagents

Reagent	Description
Working Eluent	Add 40 mL of Concentrated Eluent into a 2-L volumetric flask. Dilute to the mark with deionized water and invert several times to mix. Prepare daily.

Table 8.4 – Standard Storage Conditions

Standard Type	Description	Expiration	Storage
Stock Solutions	Concentrated reference solution purchased directly from approved vendor	Manufacturer's recommended expiration date	Manufacturer's recommended storage conditions
Working Standard Solutions	Reference solutions prepared by dilutions of the stock solution	▪ One week from preparation or the expiration date listed for the stock source, whichever is sooner.	

Standard Type	Description	Expiration	Storage
		▪ Nitrite working standards are prepared daily	

Table 8.5 – Stock Standards

Standard	Concentration	Vendor / Item #
Primary Stock Standard	25 mg/L: , Nitrate-N, Nitrite-N 50 mg/L: Fluoride 100 mg/L: Bromide, Sulfate, Chloride,	Inorganic Ventures / PACEKS-2016
Secondary Stock Standard	250 mg/L: Bromide, Chloride, Sulfate 125mg/L: Fluoride 100 mg/L: Nitrate-N, Nitrite-N	SPEX / VPCLKS-6-250
Soil Spike Standard	400 mg/L Nitrate-N, Nitrite-N 500 mg/L Fluoride 1000 mg/L: Bromide, Sulfate, Chloride	SPEX / VPCLKS-7
MDL Spike Solution	100 mg/L Bromide, Chloride, Sulfate 20 mg/L Fluoride 10 mg/L Nitrate-N, Nitrite-N	SPEX/VPCLKS-5-250

Table 8.6 – Preparation of Calibration, High, Low and CCV Standards

Standard	Stock Standard	Standard Amount	Solvent	Final Total Volume	Calibration Notes R2 value = ≥0.995
CAL0	N/A	0	DI Water	5mL	
CAL1	CAL7	0.05 mL	DI Water	5mL	50% of true value for Fluoride on QAP samples
CAL2	CAL 7	0.1 mL	DI Water	5mL	50% of true value for Fluoride, Nitrate, and Nitrite.
CAL3	CAL7	0.25 mL	DI Water	5mL	50% of true value for Chloride, Bromide, and Sulfate
CAL4CCVB	CAL 7 /Primary	0.625 mL / 2.50mL	DI Water	5mL /50mL	

Standard	Stock Standard	Standard Amount	Solvent	Final Total Volume	Calibration Notes R2 value = ≥0.995
CAL5/CCV	CAL7 / Primary	1.25 mL / 5.00mL	DI Water	5 mL / 50mL	
CCVA	Primary	7.50mL	DI Water	50mL	
CAL6	CAL7	2.5 mL	DI Water	5mL	10% of true value for midpoint of the curve.
CAL7	Primary	10.0 mL	DI Water	50mL	

Table 8.7 – Initial Calibrations Concentrations (mg/L)

Anion	CAL0	CAL1	CAL2	CAL3	CAL4	CAL5	CAL6	CAL7
Fluoride (F)	0	0.1	0.2	0.5	1.25	2.5	5.0	10.0
Chloride (Cl)	0	—	0.4	1.0	2.5	5.0	10.0	20.0
Nitrite-N (NO_2-N)	0	-	0.1	0.25	0.625	1.25	2.5	5.0
Bromide (Br)	0	—	0.4	1.0	2.5	5.0	10.0	20.0
Nitrate-N (NO_3-N)	0	-	0.1	0.25	0.625	1.25	2.5	5.0
Sulfate (SO_4)	0	—	0.4	1.0	2.5	5.0	10.0	20.0

Table 8.8 – ICV/LCS Concentrations

Anion	Stock Concentration (mg/L)	Final Concentration (mg/L)
Fluoride (F)	125.0	2.5
Chloride (Cl)	250.0	5.0
Nitrite-N (NO_2-N)	100.0	2.0
Bromide (Br)	250.0	5.0
Nitrate-N (NO_3-N)	100.0	2.0
Sulfate (SO_4)	250.0	5.0

***prepare ICV/LCS standard by pipetting 2mL of the secondary source into a 100mL volumetric flask. Prepare daily**

Table 8.9 – CCVB CHK Concentrations, 50% true value

Anion	CAL7 Concentration (mg/L)	Final Concentration (mg/L)
Fluoride (F)	50.0	2.5

Anion	CAL7 Concentration (mg/L)	Final Concentration (mg/L)
Chloride (Cl)	100.0	5.0
Nitrite-N (NO_2-N)	25.0	1.25
Bromide (Br)	100.0	5.0
Nitrate-N (NO_3-N)	25.0	1.25
Sulfate (SO_4)	100.0	5.0

***prepare CCVB by pipetting 2.5mL of the primary source into a 50mL volumetric flask. Prepare daily.**

Table 8.10 – CCVA CHK Concentrations, 10% true value

Anion	Stock Concentration (mg/L)	Final Concentration (mg/L)
Fluoride (F)	50.0	7.5
Chloride (Cl)	100.0	15
Nitrite-N (NO_2-N)	25.0	3.75
Bromide (Br)	100.0	15
Nitrate-N (NO_3-N)	25.0	3.75
Sulfate (SO_4)	100.0	15

prepare CCVA by pipetting 7.5mL of the primary source into a 50mL volumetric flask. Prepare daily.

9.0 PROCEDURE

9.1 Equipment Preparation

9.1.1 Support Equipment

Refer to Pace Analytical Services – Kansas SOP ENV-SOP-LENE-0030, Support Equipment, or equivalent replacement, for additional information on calibration requirements for support equipment that may be used in this procedure.

Balances are checked prior to use on each working day with NIST traceable references in the expected range of use, and the results are recorded in the logbook assigned to the balance.

9.1.2 Instrument setup

9.1.2.1 Turn on the PC, suppressor, and pump.

If the instrument is starting from the “off” status, priming the instrument should take place to eliminate air bubbles from the tubing.

To do this, press “Prime” under the pump settings.

Next, follow the instructions on the screen.

Turn the pump head a quarter of a turn (eluent will come out of the hole in the front)

Press "OK" and let instrument prime for 5-10 minutes.

9.1.2.2 Allow the instrument to stabilize for a minimum of 30 minutes before starting the analytical sequence.

9.1.2.3 Enter the sample identifications into Chromeleon.

9.1.2.4 Analyze samples according to specific instrument instructions.

9.1.3 Instrument Operating Conditions (approximate)

9.1.3.1 Eluent flow rate: 1.0 mL/min

9.1.3.2 Suppressor current: 31mA

9.1.3.3 Sample loop: 25 µl

9.1.3.4 Total run time per sample is 7-15 minutes (depending on the type of analytical column) with approximately 2 minutes for loading and injection.

Table 9.1 – Approximate Retention Times

Anion	AS22 Column (Min)
Fluoride (F)	2.72
Chloride (Cl)	4.08
Nitrite-N (NO_2-N)	4.97
Bromide (Br)	5.98
Nitrate-N (NO_3-N)	6.82
Sulfate (SO_4)	10.90

9.2 Initial Calibration

9.2.1 Calibration Design

9.2.1.1 An initial calibration curve using a minimum of five levels and a blank is analyzed prior to the analysis of any client samples. The lowest concentration standard of the initial calibration curve must be at or below the reporting limit, a level below which all reported results must be qualified as estimated values.

9.2.1.2 Allow the instrument to stabilize for a minimum of 30 minutes. Analyze calibration standards 0-7 followed by the ICVand ICB. Process the CAL7 standard and optimize the integration parameters and retention times. Once the integration parameters and retention times are set, reprocess the entire curve, and save.

9.2.1.3 Once the system software's integration parameters (including retention times) have been optimized and saved, they are not to be adjusted unless the following procedure is completed. Further adjustments to the integration parameters must be approved by the Quality Manager and the Inorganics Manager (or their designees). If approved, the adjustments need to be applied to the original curve and all analytical sequences to which they apply. This includes all QC/samples. The revised curve and all QC data must be evaluated and reviewed.

9.2.2 Calibration Sequence

Table 9.2 – Example Sequence Beginning with Initial Calibration

Injection	Name
1	CAL0
2	CAL1
3	CAL2
4	CAL3
5	CAL4
6	CAL5
7	CAL6
8	CAL7
10	ICV
11	ICB
12	MB
13	LCS
14	SAMPLE A
15	SAMPLE A MS
16	SAMPLE A MSD
17	SAMPLE B
18	SAMPLE C
19	SAMPLE D
20	SAMPLE E
21	SAMPLE E MS
22	CCV
23	CCB

9.2.3 ICAL Evaluation

9.2.3.1 Curve Fit

Linear Regression – The linear regression calibration curve is derived from a least square's regression analysis of the calibration points. A calibration curve based on this technique will have the format of y=ax+b where "a" is the slope of the line and "b" is the y-intercept. The linear regression is not forced through the origin; therefore, there is a possibility that very low levels of contaminants below the response of the lowest calibration point may generate erroneous reportable results. A calculation of the correlation coefficient “r” is used to determine the acceptability of a linear regressed curve (see Appendix B).

9.2.3.2 Calibration Linearity Problems

The lowest and/or highest-level calibration standards may be removed from the calibration if the remaining number of concentration levels meets the minimum 5 calibration point requirement. For multi-parameter methods, this may be done on an individual analyte basis. The reporting limit must be adjusted to the lowest concentration remaining in the calibration curve and the upper limit of quantitation must be adjusted to the highest concentration remaining in the calibration curve.

If a calibration point is removed, indicate on the analytical checklist, at the time of calibration, the reason for removing the point. If the removal of a calibration point requires the use of an alternative high daily check standard, document this on the daily run log.

If the calibration problem requires maintenance and recalibration, document the items in the maintenance logbook and recalibrate.

9.2.3.3 Relative Standard Error (RSE)

For any calibration model other than average response, the laboratory shall evaluate Relative Error. This evaluation shall be done on a mid-level calibration point and the lowest calibration point. Refer to Appendix B for acceptance criteria.

Refer to Pace Analytical Services – Corporate POL ENV-POL-CORQ-0005, Acceptable Calibration Practices for Instrument Testing, or equivalent replacement, for additional information and calculations.

9.2.3.4 Initial Calibration Verification

In addition to meeting the linearity criteria, any new calibration curve must be assessed for accuracy in the values generated. Accuracy is a function of both the “fit” of the curve to the points used and the accuracy of the standards used to generate the calibration points. By meeting the fit criteria, the accuracy relative to the goodness of fit is addressed. However, because all calibration points are from the same source, it is possible that the calibration points may meet linearity criteria, but not be accurately made in terms of their true value.

Therefore, to assess the accuracy relative to the purity of the standards, a single standard from a secondary source must be analyzed and the results obtained must be assessed relative to the known true value. This step is referred to as Secondary Source Verification or, alternatively as Initial Calibration Verification. This secondary source must be from an alternative vendor or, in the event an alternative vendor is not available, from a different lot from the same vendor. The accuracy of the standard is assessed as a percent difference from the true value according to the following equation:

$$\%\text{Drift} = \frac{\left(\text{Result}_{\text{ICV}} - \text{True Value}_{\text{ICV}}\right)}{\text{True Value}_{\text{ICV}}} \times 100$$

9.2.4 Continuing Calibration Verification

9.2.4.1 Continuing Calibration Verification (CCV)

As part of the analytical process, the instrumentation must be checked periodically to determine if the response has changed significantly since the initial calibration was established. This verification process is known as Continuing Calibration Verification (CCV). The validity of the initial calibration is checked after every ten samples and at the end of the analytical sequence by analyzing a midpoint calibration standard. The accuracy of the standard is assessed as a percent difference from the true value according to the following equation:

$$\%\text{Drift} = \frac{(\text{Result}_{\text{CCV}} - \text{True Value}_{\text{CCV}})}{\text{True Value}_{\text{CCV}}} \times 100$$

9.2.4.2 CCVA and CCVB Standards

If an ICAL is not analyzed the day of analysis, then the validity of the initial calibration is checked by the analysis of both a CCVA check standard and a CCVB check standard. The accuracy of the standard is assessed as a percent difference from the true value according to the following equation:

$$\%\text{Drift} = \frac{(\text{Result}_{\text{CHK}} - \text{True Value}_{\text{CHK}})}{\text{True Value}_{\text{CHK}}} \times 100$$

Table 9.3 – Example Sequence NOT Beginning with Initial Calibration

Injection	Name
1	CCVA
2	CCVB
3	CCB
4	MB
5	LCS
6	Sample A
7	Sample A MS
8	Sample A MSD
9	Sample B
10	Sample C
11	Sample D
12	Sample D MS
13	Sample E
14	CCV
15	CCB

9.2.5 Continuing Verification Problems

9.2.5.1 Reanalyze the original CCV standard to determine instrument consistency.

9.2.5.2 Prepare and analyze a new CCV standard to determine preparation consistency / standard integrity.

9.2.5.3 Perform and document instrument maintenance

9.2.5.4 Reanalyze CCV standard to determine if maintenance was effective in restoring performance.

9.2.5.5 Complete recalibration of instrument.

9.2.5.6 If samples were analyzed despite verification failures, note the exception below for addressing those results. Deviations from this requirement must be noted on the injection log with a thorough explanation for the deviation from policy.

9.2.5.7 Exception: If the calibration verification is above the upper control limit for an analyte, non-detect results may be reported without reanalysis.

9.2.6 Retention Time Windows

9.2.6.1 New retention time windows must be established whenever a new IC column is installed.

9.2.6.2 Before establishing retention time windows make sure that the chromatographic system is operating reliably and that the system conditions have been optimized for the anions in the sample matrix to be analyzed.

9.2.6.3 The following process may be used to identify retention times. Make three injections of a standard over the course of a 24-hour period. Serial injections or injections over a period of less than 24 hours may result in retention time windows that are too tight. Record the retention time for each anion to three decimal places (e.g., 0.007). The width of the retention time window for each anion is defined as ± 3 times the standard deviation of the retention times established during the 24-hour period.

9.2.6.4 The width of the retention time windows used to make identifications will be ±10% of the absolute retention time of the CAL6 standard in the initial calibration. However, the experience of the analyst should weigh heavily in the interpretation of chromatograms.

9.3 Sample Preparation

9.3.1 Homogenization & Subsampling

Refer to Pace Analytical Services – Kansas SOP ENV-SOP-LENE-0135, Sample Homogenization and Sub-Sampling, or equivalent replacement, for information regarding the handling, homogenization, and splitting of samples in order to ensure that a representative aliquot is used for analysis.

9.3.2 **Water samples**: Preparation is not normally needed with “clean” aqueous samples. Turbid aqueous sample may require pre-filtration before they are placed in the autosampler. If any of the samples are pre-filtered, then the MB and the LCS must also be pre-filtered as well. Make sure the sample has been shaken well to mix the sample.

9.3.3 Soil

- Make sure to mix the sample in the jar
- Weigh 5 g of the sample into a 50-mL centrifuge tube and add 50 mL of deionized water. Record the soil weight, in grams, in the preplog.
- Place the centrifuge tubes on a shaker table and shake for 30 minutes.
- Remove tubes from shaker and centrifuge for 10 minutes.
- The supernatant liquid is now ready for analysis.
- Dilute ten-fold prior to sample analysis unless a lower reporting limit is requested for sludges (503). Ex) biosolids, 503 sludges, TWAS etc

9.4 Analysis

9.4.1 Follow the instructions given in Section 9.2 above to calibrate the IC, or to verify the current calibration of the IC.

9.4.2 High conductivities are generally due to chloride or sulfate concentrations. Historical results will also be useful in determining appropriate dilutions. Appropriate dilutions are selected such that the instrument result will fall in the upper half of the calibration curve.

Create a bench sheet (example below) to show the sample number, dilution, and analyte(s) needed. The bench sheet creates an "equation" that pulls in information into LimsLink correctly and efficiently.

CCVA	INSTRUMENT		60WTAU	DATE	9/1/2022		CCVA x	batch worklist notes
CCVB	ANALYST		RKA				CCVB x	
CCB	Q BATCH		90958 / 799254	TEST/METHOD	300.0/9056		CCB x	
BLANK	BLANK						BLANK x	
LCS	LCS			RR 90963			LCS x	
60408911005	CLIENT	200	CL F SO BR				60408911005 x200	
60408951003	CLIENT	500	CL				60408951003 x500	
60408963004	CLIENT	10	SO				60408963004 x10	
60408990001	CLIENT	200	SO				60408990001 x200	
60408990002	CLIENT	200	SO				60408990002 x200	
60408990003	CLIENT	200	SO				60408990003 x200	
60409011001	CLIENT	10	CL SO				60409011001 x10	
60409011001	CLIENT	1000	CL SO				60409011001 x1000	
CCV							CCV x	
CCB							CCB x	
60409032001	CLIENT	200	SO				60409032001 x200	
60409032002	CLIENT	200	SO (CL F BR)				60409032002 x200	
3204858	MS	200	CL F SO BR				3204858 x200	
60409097003	CLIENT	50	SO				60409097003 x50	
60409103001	CLIENT	5000	CL				60409103001 x5000	
60409103002	CLIENT	2000	CL				60409103002 x2000	
60409103003	CLIENT	1000	CL				60409103003 x1000	
60409103004	CLIENT	4000	CL				60409103004 x4000	
60409103005	CLIENT	5000	CL				60409103005 x5000	
60409123001	CLIENT	20	CL				60409123001 x20	
CCV							CCV x	
CCB							CCB x	

9.4.3 Aliquot a portion of the sample into the autosampler cups for analysis.

9.4.4 If the liquid is turbid or has suspended sediment, filter a portion of the liquid into the autosampler cup using a 0.45um syringe filter.

NOTE: If sample filtration is performed, then the quality control samples (MB, LCS, MS/MSD, Sample and Duplicate) must also undergo filtration. Document each filtration on the Batch Worklist; include the lot number of the syringe filters used.

9.4.5 Arrange the autosampler cups on the autosampler tray in the order listed on the benchsheet.

9.4.6 Sample concentrations greater than the highest standard (CAL7) require dilution and reanalysis. Re-analyzed result should be in the upper three-quarters of the curve.

9.5 Example Analytical Sequence - See Tables 9.1 and 9.2

10.0 DATA ANALYSIS AND CALCULATIONS

10.1 Qualitative Identification

10.1.1 Manual Integration

Manual changes to automated integration are called manual integration. Manual integration is sometimes necessary to correct inaccurate automated integrations but must never be used to meet QC criteria or to substitute for proper instrument maintenance and/or method set-up. To assure that all manual integrations are performed consistently and are ethically justified, all manual integrations must be performed, reviewed, and recorded in accordance with corporate SOP ENV-SOP-CORQ-0006, *Manual Integration.*

10.2 Quantitative Identification

10.2.1 When reviewing sample chromatography, the analyst must: note the retention time of the analytes in relation to the retention time windows, identify samples that are greater than the high standard and review peak integrations.

10.2.2 Manual changes to automated integration are called manual integrations. Manual integration is sometimes necessary to correct inaccurate automated integrations but must never be used to meet QC criteria or to substitute for proper instrument maintenance and/or method set-up. To assure that all manual integrations are performed consistently and are ethically justified, all manual integrations must be performed, reviewed, and recorded in accordance with Pace Analytical Services – Corporate SOP ENV-SOP-CORQ-0006, Manual Integration, or equivalent replacement.

10.2.3 Once the system software's integration parameters have been set, they cannot be adjusted unless the adjustments are being made during the processing/review of the initial calibration to optimize the system. After the initial calibration's processing and review is complete, the integration parameters must not be adjusted. Further adjustments to the integration parameters after the initial calibration requires prior approval from the Quality Manager and the Inorganics Manager (or their designees). If approved, then the adjustments need to be applied to the original curve. Then all QC/samples in the analytical sequence need to be processed with both the updated calibration curve as well as the updated integration parameters.

10.3 EPIC Posting:

10.3.1 Aqueous Samples

- Aqueous samples have one step acodes.
- LIMSLINK is to be utilized for data review and posting to EPIC PRO.
- Post the sample values for each of the anions in mg/L and any applied dilution factor.

10.3.2 Soil/Solid Samples

- Soil/Solid samples have two step acodes.
- Post the actual extracted sample amount in g for the Initial Weight (default is 5 g) and the actual final volume in mL for the Final Volume (default is 50 mL). This information will be autoposted from the prep log in the “leachate soil template”.
- LIMSLINK is to be utilized for data review and posting to EPIC PRO.
- Post the sample value for each of the anions in mg/L and any applied dilution factor.

10.4 Calculations

See the Laboratory Quality Assurance Manual for equations for common calculations.

11.0 QUALITY CONTROL AND METHOD PERFORMANCE

11.1 Quality Control

The following QC samples are prepared and analyzed with each batch of samples. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency
Method Blank (MB)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Laboratory Control Sample (LCS)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Matrix Spike (MS)	1 per batch of 10 or fewer samples. If batch exceeds, 10 samples, every 10.
Matrix Spike Duplicate (MSD) or Duplicate	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.

11.2 Instrument QC

The following Instrument QC checks are performed. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency
Initial Calibration (ICAL)	Quarterly or as needed
Initial Calibration Verification (ICV)	Immediately following ICAL
Continuing Calibration Verification High (CCVA)	Once per analytical run, at the beginning of the run
Reporting Limit Verification Standard/Low (CRDL/CCVB)	Once per analytical run, at the beginning of the run and not to exceed 24 hours
Continuing Calibration Verification (CCV)	After every 10 samples and at end of the sequence.
Continuing Calibration Blank (CCB)	Immediately following each CCV
RT Window (RTW)	Check with ICAL point 7 and with daily CCV

11.3 Method Performance

11.3.1 Method Validation

11.3.1.1 Detection Limits

Detection limits (DL) and limits of quantitation (LOQ) are established at initial method setup and verified on an on-going basis thereafter. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 Method Validation and Instrument Verification.

11.4 Analyst Qualifications and Training

Employees that perform any step of this procedure must have a completed Read and Acknowledgment Statement for this version of the SOP in their training record. In addition, prior to unsupervised (independent) work on any client sample, analysts that prepare or analyze samples must have successful initial demonstration of capability (IDOC) and must successfully demonstrate on-going proficiency on an annual basis. Successful means the initial and on-going DOC met criteria, documentation of the DOC is complete, and the DOC record is in the employee's training file. Refer to laboratory SOP ENV-SOP-LENE-0110, *Training Procedures*, for more information.

12.0 DATA REVIEW AND CORRECTIVE ACTION

12.1 Data Review

The data review process of Pace® Analytical Services includes a series of checks performed at different stages of the process by different people to ensure that SOPs were followed, the analytical record is complete, and properly documented, QC criteria were met, proper corrective actions were taken for QC failure and other nonconformance(s), and test results are reported with proper qualification, when necessary.

The review and checks that are performed by the employee performing the task is called primary review.

All data and test results are also peer reviewed.

This process, known as secondary review is performed to verify SOPs were followed, that calibration, instrument performance, and QC criteria were met and/or proper corrective actions were taken, qualitative ID and quantitative measurement is accurate, all manual integrations are justified and documented, and approved in accordance with the Pace® Analytical Services SOP for manual integration, calculations are correct, the analytical record is complete and traceable, and that results are properly qualified.

Lastly, a third-level review, called a completeness check, is performed by reporting or project management staff to verify the test report is complete.

Refer to laboratory SOP ENV-SOP-LENE-0088 for specific instructions and requirements for each step of the data review process.

12.2 Corrective Action

Corrective action is required when QC or sample results are not within acceptance criteria.

Refer to Appendix B for a complete summary of QC, acceptance criteria, and recommended corrective actions for QC associated with this test method.

If corrective action is not taken or was not successful, the decision/outcome must be documented in the analytical record. The primary analyst has primary responsibility for taking corrective action when QA/QC criteria are not met. Secondary data reviewers must verify that appropriate action was taken and/or that results reported with QC failure are properly qualified.

Corrective action is also required when carryover is suspected and when results are over range.

Samples analyzed after a high concentration sample must be checked for carryover and reanalyzed if carryover is suspected. Carryover is usually indicated by low concentration detects of the analyte in successive samples analyzed after the high concentration sample.

Sample results at concentrations above the upper limit of quantitation must be diluted and reanalyzed. The result in the diluted samples should be within the upper half of the calibration range. Results less than the mid-range of the calibration indicate the sample was over diluted and analysis should be repeated with a lower level of dilution. If dilution is not performed, any result reported above the upper range is considered a qualitative measurement and must be qualified as an estimated value.

13.0 POLLUTION PREVENTION AND WASTE MANAGEMENT

Pace® proactively seeks ways to minimize waste generated during work processes. Some examples of pollution prevention include but are not limited to reduced solvent extraction, solvent capture, use of reusable cycletainers for solvent management, and real-time purchasing.

The EPA requires that laboratory waste management practices comply with all applicable federal and state laws and regulations. Excess reagents, samples, and method process wastes are characterized and disposed of in an acceptable manner in accordance with the Pace® Chemical Hygiene Plan / Safety Manual. Refer to this manual for these procedures.

14.0 MODIFICATIONS

The procedures in this SOP have been modified from the reference test method as follows:

Modification	Test Method Procedure	Justification for Modification

LCR is equal to the top point of calibration curve.	Any sample above the calibration curve.	Any sample above the calibration is being diluted and equals doing an LCS every six months.

When applicable, comparability and/or equivalency studies necessary to validate the modification as required per corporate SOP ENV-SOP-CORQ-0011 are retained by local quality personnel for historical reference.

15.0 RESPONSIBILITIES

- All employees of Pace® Analytical Services that perform any part this procedure in their work activities must have a signed Read and Acknowledgement Statement (R&A) in their training file for the version(s) of the SOP that were in effect during the time the employee performed the activity.
- Local quality personnel are responsible for tracking the currency of the R&A on this SOP for employees at the locations they are assigned to and for notifying the General Manager (GM), however named, when R&A are overdue or outstanding. The GM and the employee's direct supervisor are responsible for ensuring the employee completes the R&A assignments as required.
- The supervisors and managers of Pace® Analytical Services, however named, are responsible for training employees on the procedures in this SOP, implementing the SOP in the work area, and monitoring on-going adherence to the SOP the work area(s) they oversee.
- All employees of Pace® Analytical Services are responsible for following the procedures in this SOP. Unauthorized deviations or departures from this SOP are not allowed except with documented approval from the local Quality Manager and only when those deviations do not violate the Pace® Code of Ethics or Professional Conduct (COR-POL-0004) or associated policy and procedure(s). Hand-edits or manual change to the SOP are not permitted. If a change is desired or necessary, Pace® employees must follow the procedures for document revision specified in corporate SOPs ENV-SOP-CORQ-0015 *Document Managemen*t and ENV-SOP-CORQ-0016 *SOP for Creation of SOP and SWI*.
- Local quality personnel are responsible for monitoring conformity to this SOP during routine internal audits of work areas that utilize this SOP and for communicating gaps and deviations found during monitoring to the work area supervisor, who is responsible for correction of the situation.

16.0 ATTACHMENTS

Attachment 1: Method Flow Diagram

Appendix B: QC summary

17.0 REFERENCES

- ENV-SOP-CORQ-0006, *Manual Integration*, current version.
- ENV-SOP-CORQ-0011, *Method Validation*, current version.
- ENV-SOP-CORQ-0015, *Document Management*, current version.

- ENV-SOP-CORQ-0016, *SOP for SOP and SWI,* current version.
- ENV-TMP-CORQ-0007, *Quality Manual Template*, current version.
- COR-POL-0004, *Code of Ethics and Professional Conduct*, current version.
- COR-MAN-001, *Pace® Safety Manua*l, current version.
- EPA Test Methods for Evaluating Solid Waste. SW-846, Third Edition, Final Update IV, Method 9056A, February 2007.
- EPA Methods for Chemical Analysis of Water and Wastes, Revision 2.1 August 1993, Method 300.0

18.0 REVISION HISTORY

Authorship

Primary Author[1]	Job Title	Date Complete
Lenzie Boring	Inorganics Manager	09/12/2022

[1]The primary author is the individual / role responsible for the content of this SOP. Send questions or suggestions for content to the primary author. See the Quality Manager for questions or concerns related to implementation of this SOP.

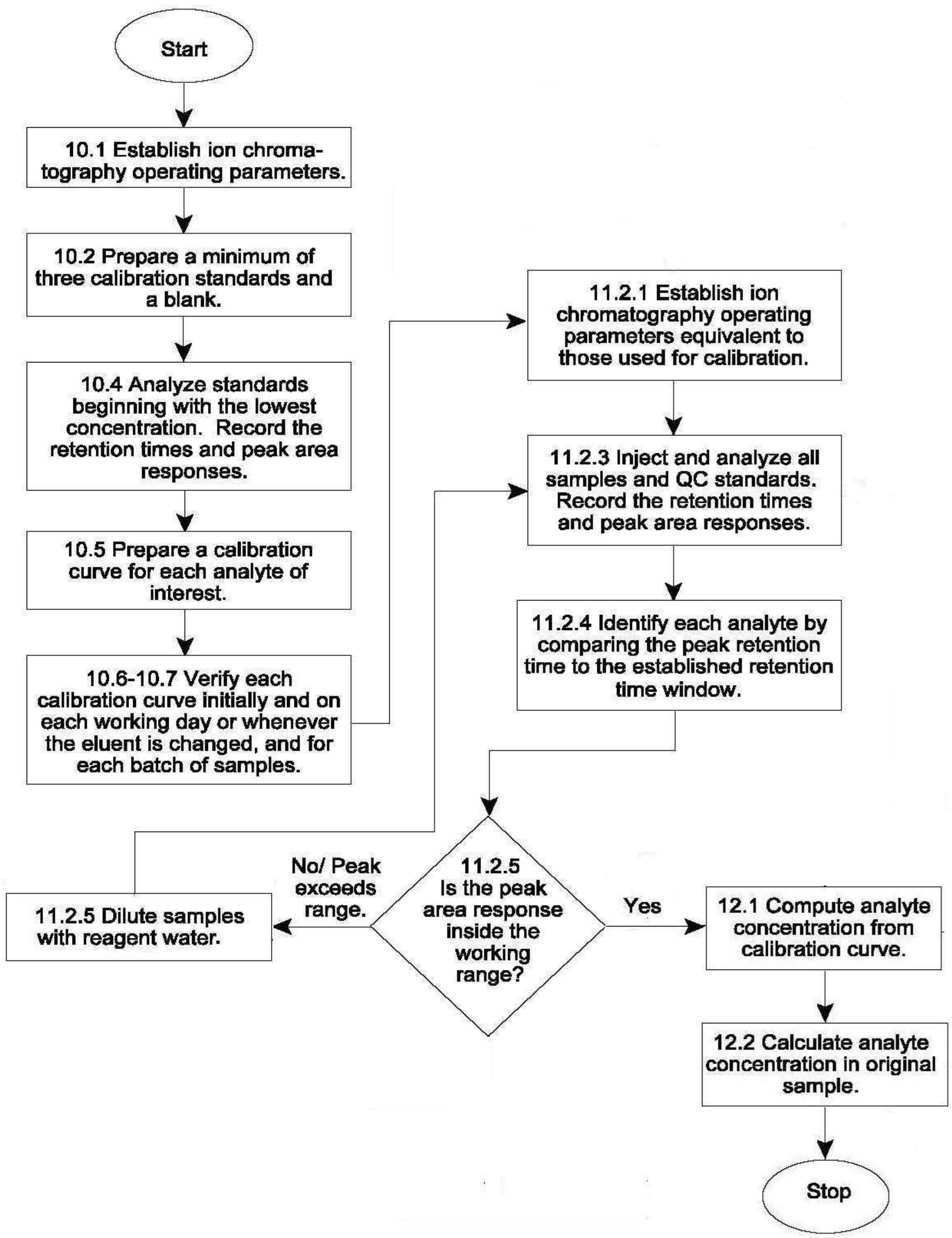
Revisions Made from Prior Version

Section	Description of Change
Various	Updated sections due to SOP template language changing
8.0 & 9.0	Added CAL 7 to SOP
8.0	Updated reagent to ISO 17034 certified

Document Succession: This version replaces the following documents:

Document Number & Version	Document Title	Effective Date:
ENV-SOP-LENE-0075 v0	Anions by Ion Chromatography	09/03/2019

Attachment 1: Method Flow Diagram



Appendix B: QC Summary

Calibration Acceptance and Verification Criteria

Calibration Metric	Parameter / Frequency	Criteria	Comments/Corrective Actions
Calibration Curve Fit	Linear Regression	r ≥ 0.995	If not met, remake standards and recalibrate. Instrument maintenance may be required if problem persists.
CCVA and CCVB Standards	If ICAL is not done on the day of analysis, then these check standards must be analyzed before the samples.	%Drift ±10 % RT ± 10% that of the ICAL 6 standard	Either standard may be reanalyzed once. A second failure confirms and requires corrective action (e.g. re-preparation and/or recalibration).
Initial Calibration Verification Standard (ICV)	Immediately after each initial calibration	%Drift ±10 %	May be reanalyzed once. A second failure confirms and requires re-preparation of standard and/or recalibration. If problem persists an alternative source standards may need to be obtained.
Initial Calibration Verification Blank (ICB)	Immediately after each Initial Calibration Verification Standard	Result should be less than the reporting limit or client QAPP. If results are reported to MDL, the ICB must be evaluated to the MDL.	May be reanalyzed once. A second failure confirms and requires corrective action (e.g. re-preparation of standard(s) and/or recalibration) **<u>Exceptions:</u>** If sample results are reported to MDL and ICB is <RL but >MDL, then corrective action is not necessary other than appropriately qualifying the sample results. Unless the customer's QAPP or technical specification instruct to do otherwise. Samples that are <RL may be reported without qualification. (Not applicable to samples reporting down to MDL) Samples >10x ICB may be reported with appropriate qualification.
Continuing Calibration Verification (CCV)	Immediately after the ICV, prior to the analysis of any samples. Also daily, after every 10 samples and at the end of a run.	%Drift ±10 %	May be reanalyzed once. A second failure confirms and requires corrective action (e.g. re-preparation and/or recalibration). **<u>Exception:</u>** If CCV fails high, then sample(s) that are <RL may be reported with appropriate qualification.
Continuing Calibration Blank (CCB)	Immediately after each Continuing Calibration Verification Standard	Result should be less than the reporting limit or client QAPP.	May be reanalyzed once. A second failure confirms and requires corrective action **<u>Exceptions:</u>** If sample results are reported to MDL and CCB is <RL but >MDL, then corrective action is not necessary other than appropriately qualifying

Calibration Metric	Parameter / Frequency	Criteria	Comments/Corrective Actions
		If results are reported to MDL, the ICB must be evaluated to the MDL.	the sample results. Unless the customer's QAPP or technical specification instruct to do otherwise. Samples that are <RL may be reported without qualification. (Not applicable to samples reporting down to MDL) Samples >10x CCB may be reported with appropriate qualification.

Batch Quality Control Criteria

QC Sample	Components	Frequency	Acceptance Criteria	Corrective Action
Method Blank (MB)	Matrix-specific; reagent water or glass beads for soils.	One per batch of up to 20 samples	Result should be less than the reporting limit. If results are reported to MDL, the MB must be evaluated to the MDL.	Re-analyze blank to confirm failure. Qualify results and / or re-analyze associated samples. **Exceptions:** If sample ND, report sample without qualification. If sample result >10x MB report sample with appropriate qualifier indicating blank contamination. If sample result <10x MB and sample cannot be reanalyzed report sample with appropriate qualifier to indicate an estimated value. Client should be alerted of this condition. If sample results are reported to MDL and MB is <RL but >MDL, then corrective action is not necessary other than appropriately qualifying the sample results. Unless the customer's QAPP or technical specification instruct to do otherwise.
Laboratory Control Sample (LCS)	Matrix-specific; reagent water or glass beads for soils spiked with standard	One per batch of up to 20 samples	EPA 300.0: 90-110% EPA 9056A: 80-120%	Reanalyze the LCS to confirm failure Re-prep and reanalyze associated samples. If problem persists, check spike solution **Exceptions:** If LCS > QC limits and these compounds are non-detect in the associated samples, the sample data may be reported with appropriate data qualifiers. If LCS < QC limits and sample cannot be reanalyzed report sample with appropriate qualifier to indicate an estimated value. Client should be alerted to this condition.
Matrix Spike (MS)	Spike standard in client sample(s)	One per 10 samples or 10% per batch of up to 20 samples.	EPA 9056A: 80-120% EPA 300.0: 90-110%	1) No corrective actions necessary. If LCS recovery is in range, the system is considered valid and the out-of-control MS/MSDs are footnoted appropriately by the analyst.
Duplicate	MS Duplicate *OR (alternative)* Sample Dup	One per batch of up to 20 samples.	Max RPD: 15%	1) No corrective actions necessary. Report outliers with comment.

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ENVIRONMENTAL SCIENCES

Document Information

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Document Title: Inorganic Anions by Ion Chromatography

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Document Notes:

All Dates and Times are listed in: Central Time Zone

Signature Manifest

Document Number: ENV-SOP-SAL1-0013 **Revision:** 03

Title: Inorganic Anions by Ion Chromatography

All dates and times are in Central Time Zone.

ENV-SOP-SAL1-0013 Inorganic Anions by Ion Chromatography

QM Approval

Name/Signature	Title	Date	Meaning/Reason
Kenneth Busch (991414)	Manager - Quality	11 Jun 2021, 09:59:48 AM	Approved

Management Approval

Name/Signature	Title	Date	Meaning/Reason
Charles Girgin (002243)	General Manager 2	14 Jun 2021, 02:19:13 PM	Approved
Melissa Lundgrin (005033)	Supervisor	22 Jun 2021, 08:49:50 AM	Approved

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TEST METHOD STANDARD OPERATING PROCEDURE
TITLE: Inorganic Anions by Ion Chromatography
TEST METHOD EPA 300.0 and EPA 9056A
ISSUER: Pace ENV – Lenexa Quality – LENE

1.0 SCOPE AND APPLICATION

This standard operating procedure (SOP) describes the laboratory procedure for the determination of Fluoride, Chloride, Nitrite, Nitrate, Bromide and Sulfate by Ion Chromatography.

1.1 Target Analyte List and Limits of Quantitation (LOQ)

The target analytes and the normal LOQ that can be achieved with this procedure are provided in Table 1, Appendix A.

LOQ are established in accordance with Pace policy and SOPs for method validation and for the determination of detection limits (DL) and quantitation limits (LOQ). DL and LOQ are routinely verified and updated when needed. The current LOQ for each target analyte that can be determined by this SOP as of the effective date of this SOP is provided in Table 1, Appendix A.

The reporting limit (RL) is the value to which analytes are reported as detected or not detected in the final report. When the RL is less than the lower limit of quantitation (LLOQ), all detects and non-detects at the RL are qualitative. The LLOQ is the lowest point of the calibration curve used for each target analyte.

DL, LOQ, and RL are always adjusted to account for actual amounts used and for dilution.

2.0 SUMMARY OF METHOD

2.1. A water sample is injected into a stream of carbonate-bicarbonate eluent and passed through a series of ion exchangers. The anions of interest are separated based on their relative affinities for a low capacity, strongly basic anion exchanger (guard and separator columns). The separated anions are directed onto a micro membrane suppressor. In the suppressor, the separated anions are converted to their highly conductive acid forms and the carbonate-bicarbonate eluent is converted to a weakly conductive carbonic acid. The separated anions are measured by conductivity. They are identified on the basis of retention time as compared to standards. Quantitation is by measurement of peak area compared to an external standard calibration curve. Nitrite and nitrate are calculated as nitrogen.

3.0 INTERFERENCES

3.1 Interferences can be caused by substances with retention times that are similar to and overlap those of the anion of interest. Large concentrations of one anion can interfere with the peak resolution of an adjacent anion. An initial conductivity reading is recommended prior to analysis, to determine adequate dilution factors. Sample dilution can be used to solve most interference problems.

3.2 Method interferences may be caused by contaminants in the deionized water, reagents, glassware, and other sample processing apparatus that lead to discrete artifacts or to elevated baselines in ion chromatograms.

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3.3 Any anion that is not retained by the column or only slightly retained will elute in the area of fluoride and interfere. Known co-elution is caused by carbonate, acetate, format, and other small organic anions.

3.4 The retention times of anions may differ when large amounts of acetate are present. Therefore, this method is not recommended for leachates of solid samples where acetate is used for pH adjustment.

3.5 Samples that contain particulate matter require filtration to prevent damage to instrument columns and flow systems.

4.0 DEFINITIONS

Refer to the Laboratory Quality Manual for a glossary of common lab terms and definitions.

5.0 HEALTH AND SAFETY

The toxicity or carcinogenicity of each chemical material used in the laboratory has not been fully established. Each chemical should be regarded as a potential health hazard and exposure to these compounds should be as low as reasonably achievable.

The laboratory maintains documentation of hazard assessments and OSHA regulations regarding the safe handling of the chemicals specified in each method. Safety data sheets for all hazardous chemicals are available to all personnel. Employees must abide by the health, safety and environmental (HSE) policies and procedures specified in this SOP and in the Pace Chemical Hygiene / Safety Manual.

Personal protective equipment (PPE) such as safety glasses, gloves, and a laboratory coat must be worn in designated areas and while handling samples and chemical materials to protect against physical contact with samples that contain potentially hazardous chemicals and exposure to chemical materials used in the procedure.

Concentrated corrosives present additional hazards and are damaging to skin and mucus membranes. Use these acids in a fume hood whenever possible with additional PPE designed for handing these materials. If eye or skin contact occurs, flush with large volumes of water. When working with acids, always add acid to water to prevent violent reactions. Any processes that emit large volumes of solvents (evaporation/concentration processes) must be in a hood or apparatus that prevents employee exposure.

Contact your supervisor or local HSE coordinator with questions or concerns regarding safety protocol or safe handling procedures for this procedure.

6.0 SAMPLE COLLECTION, PRESERVATION, HOLDING TIME, AND STORAGE

Samples should be collected in accordance with a sampling plan and procedures appropriate to achieve the regulatory, scientific, and data quality objectives for the project.

The laboratory does not perform sample collection or field measurements for this test method. To assure sample collection and field checks and treatment are performed in accordance with applicable

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regulations Pace project managers will inform the client of these requirements at the time of request for analytical services when the request for testing is received prior to sample collection. If samples were already collected, the laboratory will record any nonconformance to these requirements in the laboratory's sample receipt record when sufficient information about sample collection is provided with the samples.

The laboratory will provide containers for the collection of samples upon client request for analytical services. Bottle kits are prepared in accordance with laboratory SOP ENV-SOP-LENE-0025, *Assembly of Sample Container Kits.*

Requirements for container type, preservation, and field quality control (QC) for the common list of test methods offered by Pace are included in the laboratory's quality manual.

General Requirements

Matrix	Routine Container	Minimum Sample Amount[1]	Preservation	Holding Time
Aqueous	Plastic, 120 or 250 or 500 ml	5 ml	Thermal: ≤6ºC Chemical: None	28 days from collection for fluoride, chloride, bromide, and sulfate. 48 hours from collection for nitrate, and nitrite.

[1]*Minimum amount needed for each discrete analysis.*

Field / Matrix QC

Trip Blank	Equipment Blank	MS/MSD	Field Duplicate
NA	NA	1/20	1/20

Thermal preservation is checked and recorded on receipt in the laboratory in accordance with laboratory SOP ENV-SOP-LENE-0021, *Sample Management*. Chemical preservation is checked and recorded at time of receipt or prior to sample preparation.

After receipt, samples are stored at ≤6°C until sample preparation. Prepared samples (extracts, digestates, distillates, other) are stored at ≤6°C until sample analysis.

After analysis, unless otherwise specified in the analytical services contract, samples are retained for 30 days from date of final report and then disposed of in accordance with Federal, State, and Local regulations.

7.0 EQUIPMENT AND SUPPLIES

7.1 Equipment

Equipment	Vendor	Model / Version	Comments
Adjustable pipettor	Eppendorf	Various	
Analytical Balance	Mettler-Toledo	XS205	
Volumetric(s)	Fisher	various	

Autosampler	Dionex	AS-DV	
50 mL Graduated Cylinder	Fisher		Class A
Conductivity electrode	Fisher	09-327-1	
Conductivity meter	Fisher	09-328	Or equivalent
Data Acquisition Software	Dionex	Chromeleon® 6.80	
Detector	Dionex	CDM-II	Conductivity
Detector	Dionex	DS6 Heated Cell	Conductivity
Electrolytic pH Modifier	Dionex	063175	
Ion Chromatograph	Dionex	ICS-1600	
Suppressor	Dionex	AERS 500, 4mm	Or equivalent

7.2 Supplies

Item	Vendor	Model / ID	Catalog #	Description
Analytical Column	Dionex	Ion Pac AS14A	NC9314210	7 µm, 250 mm x 4 mm
Guard Column	Dionex	Ion Pac AG	056897	7µm, 50 mm x 4 mm
Volumetric Flasks		Various sizes		Class A
Sample Vials	Environmental Express	5 mL vials w/ filtering cap	K1250	
Centrifuge Tubes	Fisher	50 mL and 15 mL	22-170-199/ 22-170-194	

NOTE: All glassware must be rinsed several times with deionized water prior to use. It is recommended that the volumetric flasks be segregated from other use and filled with deionized water during storage.

8.0 Reagents And Standards

8.1 Reagents

Reagent	Concentration/ Description	Vendor/ Item #
Deionized water	ASTM Type II	ENV-SOP-SAL1-0027 (current revision)
Sodium carbonate (Na_2CO_3)	ACS Reagent grade	Fisher / S263-500
Sodium bicarbonate ($NaHCO_3$)	ACS Reagent grade	Fisher / S631-3
Hydrochloric acid (HCl)	ACS Reagent grade	Fisher / A508-212
Intermediate Reagent: Eluent Stock	Dissolve 8.4g sodium bicarbonate and 84.8g sodium carbonate into a 1-L volumetric flask containing approximately 600 mL deionized	

	water. Dilute to the mark and invert several times to mix. Prepare as needed or every 6 months.	
Working Eluent	Add 20 mL of Concentrated Eluent into a 2-L volumetric flask. Dilute to the mark with deionized water and invert several times to mix. Prepare as needed.	

8.2 Standard Storage Conditions

Standard Type	Description	Expiration	Storage
Stock Solutions	▪ Concentrated reference solution purchased directly from approved vendor	▪ Manufacturer's recommended expiration date	▪ Manufacturer's recommended storage conditions
Working Standard Solutions	▪ Reference solutions prepared by dilutions of the stock solution	▪ One week from preparation or the expiration date listed for the stock source, whichever is sooner	

8.3 Stock Standards

Standard	Concentration	Vendor / Item #
Primary Stock Standard	25 mg/L: , Nitrate-N, Nitrite-N 50 mg/L: Fluoride 100 mg/L: Bromide, Sulfate, Chloride,	Inorganic Ventures / PACEKS-2016
Secondary Stock Standard	250 mg/L: Bromide, Chloride, Sulfate 125mg/L: Fluoride 100 mg/L: Nitrate-N, Nitrite-N	SPEX / VPCLKS-6-250
MDL Spike Solution	100 mg/L Bromide, Chloride, Sulfate 20 mg/L Fluoride 10 mg/L Nitrate-N, Nitrite-N	SPEX/VPCLKS-5-250

8.4 Preparation of Calibration, High, Low and CCV Standards

Standard	Stock Standard	Standard Amount	Solvent	Final Total Volume
CAL0	N/A	0	DI Water	50mL
CAL1	Primary	1 mL	DI Water	500mL
CAL2	Primary	2 mL	DI Water	500mL
CAL3	Primary	5 mL	DI Water	500mL
CAL4/Low check	Primary	5 mL	DI Water	100mL

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CAL5/CCV	Primary	5.00mL	DI Water	50mL
CAL6	Primary	10.0mL	DI Water	50mL
High check	Primary	15.0mL	DI Water	100mL

8.5 ICV Concentrations

Anion	Stock Concentration (mg/L)	Final Concentration (mg/L)
Fluoride (F)	125.0	2.5
Chloride (Cl)	250.0	5.0
Nitrite-N (NO_2-N)	100.0	2.0
Bromide (Br)	250.0	5.0
Nitrate-N (NO_3-N)	100.0	2.0
Sulfate (SO_4)	250.0	5.0

8.6 Low Check Standard Concentrations

Anion	Stock Concentration (mg/L)	Final Concentration (mg/L)
Fluoride (F)	50.0	2.5
Chloride (Cl)	100.0	5.0
Nitrite-N (NO_2-N)	25.0	1.25
Bromide (Br)	100.0	5.0
Nitrate-N (NO_3-N)	25.0	1.25
Sulfate (SO_4)	100.0	5.0

8.7 High Check Standard Concentrations

Anion	Stock Concentration (mg/L)	Final Concentration (mg/L)
Fluoride (F)	50.0	7.5
Chloride (Cl)	100.0	15
Nitrite-N (NO_2-N)	25.0	3.75
Bromide (Br)	100.0	15
Nitrate-N (NO_3-N)	25.0	3.75
Sulfate (SO_4)	100.0	15

8.8 CCV Concentrations

Anion	Stock Concentration (mg/L)	Final Concentration (mg/L)
Fluoride (F)	50.0	5
Chloride (Cl)	100.0	10
Nitrite-N (NO_2-N)	25.0	2.5
Bromide (Br)	100.0	10
Nitrate-N (NO_3-N)	25.0	2.5
Sulfate (SO_4)	100.0	10

9.0 PROCEDURE

9.1 Equipment Preparation

9.1.1 Support Equipment

9.1.2 Instrument

9.1.2.1 Routine Instrument Operating Conditions

9.1.2.1.1 Allow the instrument to stabilize for a minimum of 30 minutes. Analyze calibration standards 0-6 followed by the ICV, ICB, CCV and ICB. Process the CAL6 standard and optimize the integration parameters and retention times. Once the integration parameters and retention times are set, reprocess the entire curve and save.

9.1.2.1.2 Once the system software's integration parameters (including retention times) have been optimized and saved, they are not to be adjusted unless the following procedure is completed. Further adjustments to the integration parameters must be approved by the Quality Manager and the Inorganics Manager (or their designees). If approved, the adjustments need to be applied to the original curve and all analytical sequences to which they apply. This includes all QC/samples. The revised curve and all QC data must be evaluated and reviewed

9.2 Initial Calibration

9.2.1 Calibration Design

Linear Regression – The linear regression calibration curve is derived from a least squares regression analysis of the calibration points. A calibration curve based on this technique will have the format of y = ax + b where "a" is the slope of the line and "b" is the y-intercept. The linear regression is not forced through the origin; therefore, there is a possibility that very low levels of contaminants below the response of the lowest calibration point may generate erroneous reportable results. A calculation of the correlation coefficient "r" is used to determine the acceptability of a linear regressed curve.

An initial calibration curve using a minimum of five levels and a blank is analyzed prior to the analysis of any client samples. The lowest concentration standard of the initial calibration curve must be at or below the reporting limit, a level below which all reported results must be qualified as estimated values.

9.2.2 Calibration Sequence

Anion	S0	S1	S2	S3	S4	S5	S6	Stock
Fluoride (F)	0	0.1	0.2	0.5	2.5	5	10	50
Chloride (Cl)	0	—	0.4	1.0	5.0	10	20	100
Nitrite-N (NO_2-N)	0	-	0.1	0.25	1.25	2.5	5	25
Bromide (Br)	0	—	0.4	1.0	5.0	10	20	100
Nitrate-N (NO_3-N)	0	-	0.1	0.25	1.25	2.5	5	25
Sulfate (SO_4)	0	—	0.4	1.0	5.0	10	20	100

9.2.3 ICAL Evaluation

9.2.3.1 Curve Fit

The correlation coefficient must be >0.995. If the curve passes, print the data and continue with the run. If the curve fails, determine the problem and recalibrate.

9.2.3.2 Relative Standard Error (RSE)

Initial calibrations using linear regression must be evaluated for their relative error using the following equation:

$$\%\ \text{Relative Error} = \frac{\text{Calculated Value} - \text{True Value}}{\text{True Value}} \times 100$$

9.2.3.3 The procedure used is to quantitate calibration standards against the curve. All except the low standard must recover within 90-110% and the low-level stand must recover at 50-150%.

9.2.3.4 Initial Calibration Verification

In addition to meeting the linearity criteria, any new calibration curve must be assessed for accuracy in the values generated. Accuracy is a function of both the “fit” of the curve to the points used and the accuracy of the standards used to generate the calibration points. By meeting the fit criteria, the accuracy relative to the goodness of fit is addressed. However, because all calibration points are from the same source, it is possible that the calibration points may meet linearity criteria, but not be accurately made in terms of their true value.

Therefore, to assess the accuracy relative to the purity of the standards, a single standard from a secondary source must be analyzed and the results obtained must be assessed relative to the known true value. This step is referred to as Secondary Source Verification or, alternatively as Initial Calibration Verification. This secondary source must be from an alternative vendor or, in the event an alternative vendor is not available, from a different lot from the same vendor. The accuracy of the standard is assessed as a percent difference from the true value according to the following equation:

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$$\%\text{Drift} = \frac{(\text{Result}_{\text{ICV}} - \text{True Value}_{\text{ICV}})}{\text{True Value}_{\text{ICV}}} \times 100$$

9.2.4 Continuing Calibration Verification

As part of the analytical process, the instrumentation must be checked periodically to determine if the response has changed significantly since the initial calibration was established. This verification process is known as Continuing Calibration Verification (CCV). The validity of the initial calibration is checked after every ten samples and at the end of the analytical sequence by analyzing a midpoint calibration standard. The accuracy of the standard is assessed as a percent difference from the true value according to the following equation:

$$\%\text{Drift} = \frac{(\text{Result}_{\text{CCV}} - \text{True Value}_{\text{CCV}})}{\text{True Value}_{\text{CCV}}} \times 100$$

9.3 Sample Preparation

9.3.1 Homogenization and Subsampling

Refer to the SOP ENV-SOP-LENE-0135, Sample Homogenization and Sub-Sampling.

9.4 Analysis

9.4.1 Example Analytical Sequence Beginning with an Initial Calibration

Injection	Name
1	CAL0
2	CAL1
3	CAL2
4	CAL3
5	CAL4
6	CAL5
7	CAL6
8	ICV
9	ICB
10	CCV
11	CCB
12	MB
13	LCS
14	Sample A
15	Sample B
16	Sample B MS
17	Sample B MSD
18	Sample C

Injection	Name
19	Sample D
20	Sample E
21	Sample E MS
22	CCV
23	CCB

9.4.2 Example Sequence NOT Beginning with Initial Calibration

Injection	Name
1	CCVA (High Check)
2	CCVB (Low Check)
3	CCB
4	MB
5	LCS
6	Sample A
7	Sample A MS
8	Sample A MSD
9	Sample B
10	Sample C
11	Sample D
12	Sample D MS
13	Sample D MSD
14	CCV
15	CCB

10.0 DATA ANALYSIS AND CALCULATIONS

10.1 Qualitative Identification

10.1.1 Manual Integration

Manual changes to automated integration is called manual integration. Manual integration is sometimes necessary to correct inaccurate automated integrations but must never be used to meet QC criteria or to substitute for proper instrument maintenance and/or method set-up. To assure that all manual integrations are performed consistently and are ethically justified, all manual integrations must be performed, reviewed, and recorded in accordance with corporate SOP ENV-SOP-CORQ-0006, *Manual Integration.*

10.2 Quantitative Identification

The curve is used to quantitate the concentration of an unknown based on its response and this known relationship.

10.3 Calculations

See the Laboratory Quality Assurance Manual for equations for common calculations.

11.0 QUALITY CONTROL AND METHOD PERFORMANCE

11.1 Quality Control

The following QC samples are prepared and analyzed with each batch of samples. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency
Method Blank (MB)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Laboratory Control Sample (LCS)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Matrix Spike (MS)	2per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20
Matrix Spike Duplicate (MSD)	2 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20

11.2 Instrument QC

The following Instrument QC checks are performed. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency
Initial Calibration	As needed
Initial Calibration Verification (ICV)	Immediately following an Initial Calibration
Initial Calibration Blank (ICB)	Immediately following the ICV
Continuing Calibration Verification (CCV)	Immediately after the ICB, prior to the analysis of any samples. Also, daily, after every 10 samples and at the end of a run.
Continuing Calibration Blank (CCB)	Immediately after each Continuing Calibration Verification Standard

11.3 Method Performance

11.3.1 Method Validation

11.3.1.1 Detection Limits

Detection limits (DL) and limits of quantitation (LOQ) are established at initial method setup and verified on an on-going basis thereafter. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 Method Validation and Instrument Verification.

11.4 Analyst Qualifications and Training

Employees that perform any step of this procedure must have a completed Read and Acknowledgment Statement for this version of the SOP in their training record. In addition, prior to unsupervised (independent) work on any client sample, analysts that prepare or analyze samples must have successful initial demonstration of capability (IDOC) and must successfully demonstrate on-going proficiency on an annual basis. Successful means the initial and on-going DOC met criteria, documentation of the DOC is complete, and the DOC record is in the employee's training file. Refer to laboratory SOP ENV-SOP-LENE-0110, *Training Procedures*, for more information.

12.0 Data Review and Corrective Action

12.1 Data Review

Pace's data review process includes a series of checks performed at different stages of the analytical process by different people to ensure that SOPs were followed, the analytical record is complete and properly documented, proper corrective actions were taken for QC failure and other nonconformance(s), and that test results are reported with proper qualification.

The review steps and checks that occur as employee's complete tasks and review their own work is called primary review.

All data and results are also reviewed by an experienced peer or supervisor. Secondary review is performed to verify SOPs were followed, that calibration, instrument performance, and QC criteria were met and/or proper corrective actions were taken, qualitative ID and quantitative measurement is accurate, all manual integrations are justified and documented in accordance with the Pace ENV's SOP for manual integration, calculations are correct, the analytical record is complete and traceable, and that results are properly qualified.

A third-level review, called a completeness check, is performed by reporting or project management staff to verify the data report is not missing information and project specifications were met.

Refer to laboratory SOP ENV-SOP-LENE-088, *Data Reduction, Review and Reporting*, for specific instructions and requirements for each step of the data review process.

12.2 Corrective Action

Corrective action is expected any time QC or sample results are not within acceptance criteria. If corrective action is not taken or was not successful, the decision/outcome must be documented in the analytical record. The primary analyst has primary responsibility for taking corrective action when QA/QC criteria are not met. Secondary data reviewers must verify that appropriate action was taken and/or that results reported with QC failure are properly qualified.

Corrective action is also required when carryover is suspected and when results are over range.

Samples analyzed after a high concentration sample must be checked for carryover and reanalyzed if carryover is suspected. Carryover is usually indicated by low concentration detects of the analyte in successive samples analyzed after the high concentration sample.

Sample results at concentrations above the upper limit of quantitation must be diluted and reanalyzed. The result in the diluted samples should be within the upper half of the calibration range. Results less than the mid-range of the calibration indicate the sample was over diluted and analysis should be repeated with a lower level of dilution. If dilution is not performed, any result reported above the upper range is considered a qualitative measurement and must be qualified as an estimated value.

Refer to Appendix B for a complete summary of QC, acceptance criteria, and recommended corrective actions for QC associated with this test method.

13.0 Pollution Prevention And Waste Management

Pace proactively seeks ways to minimize waste generated during our work processes. Some examples of pollution prevention include but are not limited to: reduced solvent extraction, solvent capture, use of reusable cycletainers for solvent management, and real-time purchasing.

The EPA requires all laboratory waste management practice to be conducted consistent with all applicable federal and state laws and regulations. Excess reagents, samples and method process wastes must be characterized and disposed of in an acceptable manner in accordance with Pace's Chemical Hygiene Plan / Safety Manual.

14.0 Modifications

A modification is a change to a reference test method made by the laboratory. For example, changes in stoichiometry, technology, quantitation ions, reagent or solvent volumes, reducing digestion or extraction times, instrument runtimes, etc. are all examples of modifications. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 *Method Validation and Instrument Verification* for the conditions under which the procedures in test method SOPs may be modified and for the procedure and document requirements.

15.0 Responsibilities

Pace ENV employees that perform any part this procedure in their work activities must have a signed Read and Acknowledgement Statement in their training file for this version of the SOP. The employee is responsible for following the procedures in this SOP and handling temporary departures from this SOP in accordance with Pace's policy for temporary departure.

Pace supervisors/managers are responsible for training employees on the procedures in this SOP and monitoring the implementation of this SOP in their work area.

16.0 Attachments

Attachment 1: Method Flow Diagram

17.0 References

17.1 Pace Quality Assurance Manual- most current version.

17.2 National Environmental Laboratory Accreditation Conference (NELAC), Chapter 5, "Quality Systems"- most current version.

17.3 The NELAC Institute (TNI); Volume 1, Module 2, "Quality Systems"- most current version.

17.4 EPA Test Methods for Evaluating Solid Waste. SW-846, Third Edition, Final Update IV, Method 9056A, February 2007.

17.5 EPA Methods for Chemical Analysis of Water and Wastes, Revision 2.1 August 1993, Method 300.0

18.0 REVISION HISTORY

This Version:

Section	Description of Change
All	This is and SOP reformat

This document supersedes the following document(s):

Document Number	Title	Version
ENV-SOP-SAL1-0013	Inorganic Anions by Ion Chromatography	02

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TEST METHOD STANDARD OPERATING PROCEDURE

TITLE:	Inorganic Anions by Ion Chromatography
TEST METHOD	EPA 300.0 and EPA 9056A
ISSUER:	Pace ENV – Lenexa Quality – LENE

Appendix A: Target Analyte List and Routine LOQ

Table 1: Routine Analyte List and Limits of Quantitation (LOQ)[1]

Analyte	Aqueous (mg/L)
Fluoride (F)	0.1
Chloride (Cl)	1.0
Nitrite-N (NO_2-N)	0.1
Bromide (Br)	0.5
Nitrate-N (NO_3-N)	0.1
Sulfate (SO_4)	1.0

[1] Values in place as of effective date of this SOP. LOQ are subject to change. For the most up to date LOQ, refer to the LIMS or contact the laboratory.

TEST METHOD STANDARD OPERATING PROCEDURE
TITLE: Inorganic Anions by Ion Chromatography
TEST METHOD EPA 300.0 and EPA 9056A
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Appendix B: QC Summary

QC Item	Frequency	Acceptance Criteria	Corrective Action	Qualification
ICAL	At instrument set up, after CCV failure	Must meet one of curve fit options presented in Section 9.0. For any curve fit other than Average RF (RSD), curve must also pass RSE test at the low and midpoint calibration standard.	Identify and correct source of problem, repeat	None. Do not proceed with analysis
ICV	After Each ICAL	All analytes must be within ± 10% of the true value. (%R)	Identify source of problem, re-analyze. If repeat failure, repeat ICAL. Analysis may proceed if it can be demonstrated that the ICV exceedance has no impact on analytical measurements. For example, the ICV %R is high, CCV is within criteria, and the analyte is not detected in sample(s).	Qualify analytes with ICV out of criteria.
RT Window Study	At method set-up and after major instrument maintenance	Window is ±10% of the absolute retention time of the Ccalib6	NA	NA
CCV	Daily, before sample analysis, after every 10, and at end of analytical window.	Opening CCV: All analytes within ± 10 %D Ending CCV: All analytes within ± 10 %D RT ± 10% that of the ICAL 6 standard	See Section 12 for required corrective actions based on circumstance.	Qualify analytes with CCV out of criteria.
Method Blank	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20	Result should be less than the reporting limit. If results are reported to MDL, the MB must be evaluated to the MDL.	1) Re-analyze blank to confirm failure. 2) Qualify results and / or re-analyze associated samples.	1) If sample ND, report sample without qualification. 2) If sample result >10x MB report sample with appropriate qualifier indicating blank contamination. 3) If sample result <10x MB and sample cannot be reanalyzed report sample with appropriate qualifier to indicate an estimated value.

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				Client should be alerted of this condition. 4) If sample results are reported to MDL and MB is <RL but >MDL, then corrective action is not necessary other than appropriately qualifying the sample results. Unless the customer's QAPP or technical specification instruct to do otherwise.
LCS	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20	EPA 300.0: 90-110% EPA 9056A: 80-120%	1) Reanalyze the LCS to confirm failure 2) Re-prep and reanalyze associated samples. 3) If problem persists, check spike solution	1) If LCS > QC limits and these compounds are non-detect in the associated samples, the sample data may be reported with appropriate data qualifiers. 2) If LCS < QC limits and sample cannot be reanalyzed report sample with appropriate qualifier to indicate an estimated value. Client should be alerted to this condition.
MS/MSD	2 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20	EPA 9056A: 80-120% EPA 300.0: 80-120%	1) No corrective actions necessary. If LCS recovery is in range, the system is considered valid and the out-of-control MS/MSDs are footnoted appropriately by the analyst.	
Sample Duplicate	1 per batch of 20 or fewer samples if no MSD. If batch exceeds, 20 samples, every 20	Max RPD: 15%	1) No corrective actions necessary. Report outliers with comment.	
LLCCV		%Drift ±10 % RT ± 10% that of the ICAL 6 standard	Either standard may be reanalyzed once. A second failure confirms and requires corrective action (e.g. re-preparation and/or recalibration).	

TEST METHOD STANDARD OPERATING PROCEDURE
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ICB	Immediately after each Initial Calibration Verification Standard	Result should be less than the reporting limit or client QAPP. If results are reported to MDL, the ICB must be evaluated to the MDL.	May be reanalyzed once. A second failure confirms and requires corrective action (e.g. re-preparation of standard(s) and/or recalibration)	If sample results are reported to MDL and ICB is <RL but >MDL, then corrective action is not necessary other than appropriately qualifying the sample results. Unless the customer's QAPP or technical specification instruct to do otherwise. Samples that are <RL may be reported without qualification. (Not applicable to samples reporting down to MDL) Samples >10x ICB may be reported with appropriate qualification.
CCB	Immediately after each Continuing Calibration Verification Standard	Result should be less than the reporting limit or client QAPP. If results are reported to MDL, the ICB must be evaluated to the MDL.	May be reanalyzed once. A second failure confirms and requires corrective action	If sample results are reported to MDL and CCB is <RL but >MDL, then corrective action is not necessary other than appropriately qualifying the sample results. Unless the customer's QAPP or technical specification instruct to do otherwise. Samples that are <RL may be reported without qualification. (Not applicable to samples reporting down to MDL) Samples >10x CCB may be reported with appropriate qualification.

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ENVIRONMENTAL SCIENCES

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QM Approval

Name/Signature	Title	Date	Meaning/Reason
Kenneth Busch (991414)	Manager - Quality	07 Apr 2021, 11:37:11 AM	Approved

Management Approval

Name/Signature	Title	Date	Meaning/Reason
Kenneth Busch (991414)	Manager - Quality	07 Apr 2021, 11:37:22 AM	Approved
Charles Girgin (002243)	General Manager 2	07 Apr 2021, 12:58:55 PM	Approved
Joshua Cunningham (003261)	Manager	20 Apr 2021, 12:27:16 PM	Approved

1.0 SCOPE AND APPLICATION

This standard operating procedure (SOP) describes the laboratory procedure for the determination of Alkalinity by an automated Titration.

1.1 Target Analyte List and Limits of Quantitation (LOQ)

The target analytes and the normal LOQ that can be achieved with this procedure are 20 mg/L for water and 200 mg/kg for solid alkalinity samples.

LOQ are established in accordance with Pace policy and SOPs for method validation and for the determination of detection limits (DL) and quantitation limits (LOQ). DL and LOQ are routinely verified and updated when needed. The current LOQ for each target analyte that can be determined by this SOP as of the effective date of this SOP is provided in Table 1, Appendix A.

The reporting limit (RL) is the value to which analytes are reported as detected or not detected in the final report. When the RL is less than the lower limit of quantitation (LLOQ), all detects and non-detects at the RL are qualitative. The LLOQ is the lowest point of the calibration curve used for each target analyte.

DL, LOQ, and RL are always adjusted to account for actual amounts used and for dilution.

2.0 SUMMARY OF METHOD

An unpreserved sample is titrated with a standardized sulfuric acid solution to an endpoint that is determined electrometrically. The endpoint for total alkalinity is pH 4.5, with extrapolation to pH 4.2 if alkalinity is low. The endpoint for phenolphthalein alkalinity is pH 8.3. The results obtained from the phenolphthalein and total alkalinity determinations offer a means for classification of bicarbonate, carbonate, hydroxide, and total alkalinity.

This method is applicable to most water and solid samples, regardless of moisture content. Common matrices are ground and surface water, wastewater, aqueous sludge, sediment, soils, and other solid samples.

The method is not applicable for alkalinity in samples that contain a significant amount of oils, greases, and petroleum products.

3.0 INTERFERENCES

3.1 Substances, such as salts of weak organic and inorganic acids present in large amounts, may cause interference in the electrometric pH measurements.

3.2 Soaps, oily matter, suspended solids, or precipitates may coat the glass electrode and cause a sluggish response. Allow additional time between titrant additions to let electrode come to equilibrium or clean the electrodes occasionally. Do not filter, dilute, concentrate, or alter sample.

4.0 DEFINITIONS

Refer to the Laboratory Quality Manual for a glossary of common lab terms and definitions.

5.0 HEALTH AND SAFETY

The toxicity or carcinogenicity of each chemical material used in the laboratory has not been fully established. Each chemical should be regarded as a potential health hazard and exposure to these compounds should be as low as reasonably achievable.

The laboratory maintains documentation of hazard assessments and OSHA regulations regarding the safe handling of the chemicals specified in each method. Safety data sheets for all hazardous chemicals are available to all personnel. Employees must abide by the health, safety and environmental (HSE) policies and procedures specified in this SOP and in the Pace Chemical Hygiene / Safety Manual.

Personal protective equipment (PPE) such as safety glasses, gloves, and a laboratory coat must be worn in designated areas and while handling samples and chemical materials to protect against physical contact with samples that contain potentially hazardous chemicals and exposure to chemical materials used in the procedure.

Concentrated corrosives present additional hazards and are damaging to skin and mucus membranes. Use these acids in a fume hood whenever possible with additional PPE designed for handing these materials. If eye or skin contact occurs, flush with large volumes of water. When working with acids, always add acid to water to prevent violent reactions. Any processes that emit large volumes of solvents (evaporation/concentration processes) must be in a hood or apparatus that prevents employee exposure.

Contact your supervisor or local HSE coordinator with questions or concerns regarding safety protocol or safe handling procedures for this procedure.

6.0 SAMPLE COLLECTION, PRESERVATION, HOLDING TIME, AND STORAGE

Samples should be collected in accordance with a sampling plan and procedures appropriate to achieve the regulatory, scientific, and data quality objectives for the project.

The laboratory does not perform sample collection or field measurements for this test method. To assure sample collection and field checks and treatment are performed in accordance with applicable regulations Pace project managers will inform the client of these requirements at the time of request for analytical services when the request for testing is received prior to sample collection. If samples were already collected, the laboratory will record any nonconformance to these requirements in the laboratory's sample receipt record when sufficient information about sample collection is provided with the samples.

The laboratory will provide containers for the collection of samples upon client request for analytical services. Bottle kits are prepared in accordance with laboratory SOP ENV-SOP-LENE-0025, *Assembly of Sample Container Kits*. For this test method, immediately after sample collection, samples should be checked for X and X and field treated. The bottle kits provided by the laboratory should include field test kits and treatment reagent.

Requirements for container type, preservation, and field quality control (QC) for the common list of test methods offered by Pace are included in the laboratory's quality manual.

General Requirements

Matrix	Routine Container	Minimum Sample Amount[1]	Preservation	Holding Time
Aqueous	Plastic or Glass 1L	60mL	Thermal: ≤6°C, but not freezing Chemical: None	14 days
Solid	4oz glass jar	10g	Thermal: ≤6°C, but not freezing Chemical: None:	14 days

[1]*Minimum amount needed for each discrete analysis.*

Field / Matrix QC

Trip Blank	Equipment Blank	MS/MSD	Field Duplicate
NA	NA	1 per 20	Per client request

Thermal preservation is checked and recorded on receipt in the laboratory in accordance with laboratory SOP ENV-SOP-LENE-0021, *Sample Management*. Chemical preservation is checked and recorded at time of receipt or prior to sample preparation.

After receipt, samples are stored at ≤6°C until sample preparation. Prepared samples (extracts, digestates, distillates, other) are stored at ≤6°C until sample analysis.

After analysis, unless otherwise specified in the analytical services contract, samples are retained for 30 days from date of final report and then disposed of in accordance with Federal, State, and Local regulations.

7.0 EQUIPMENT AND SUPPLIES

7.1 Equipment and Supplies

Table 7.1 – Equipment and Supplies

Supply	Vendor	Model / Version	Comments
Autosampler	Mantech	PC-1000-681	AutoMax73 Beaker Sampler
Rinse Pump	Mantech	PC-1000-475	
Titration Module	Mantech	PC-1040-00	QC-Titrate™
Analytical balance	Mettler-Toledo	AE200	or equivalent capable of weighing
Volumetric Flasks	Various	Class A	2-L, 1-L, and 500-mL.
Graduated cylinder	Fisher	08-561A	50-mL, Class A, TD

8.0 Reagents And Standards

8.1 Reagents and Standards

Table 8.1 – Standard Storage Conditions

Standard Type	Description	Expiration	Storage
Stock Solutions	▪ Concentrated reference solution purchased directly from approved vendor	▪ Manufacturer's recommended expiration date	▪ Manufacturer's recommended storage conditions
Working Standard Solutions	▪ Reference solutions prepared by dilutions of the stock solution	▪ Working Alkalinity standards are stored for no more than a week.	▪ Ambient temperature or manufacturer's recommended storage conditions for stock source solution.

Table 8.2 – Reagents and Standards

Reagent/Standard	Concentration/ Description	Vendor/ Item #
Reagent water	ASTM Type II	SOP S-KS-Q-011
Sodium carbonate, anhydrous	ACS reagent grade	Fisher / S263
Ampulated Alkalinity Standard	25,000 mg/L	Fisher / NC9308291
Sulfuric acid, concentrated	Fisher TraceMetal grade	Fisher / A510
Buffer Solution, pH 4.00	Color-coded Red	Fisher / SB-101
Buffer Solution, pH 7.00	Color-coded Yellow	Fisher / SB-107
Buffer Solution, pH 10.00	Color-coded Blue	Fisher / SB-115
0.02N Sulfuric acid	0.02N Sulfuric acid	Fisher/AA35649K7

8.2 H_2SO_4 (1.0N): Measure 28 mL concentrated H_2SO_4 into a 1-L volumetric flask containing approximately 700 mL of reagent water, dilute to the mark and invert several times to mix.

8.3 H_2SO_4 (0.02N): Measure 40 mL of the 1.0 N H_2SO_4 solution into a 2-L volumetric flask containing approximately 1500 mL of reagent water, dilute to the mark and invert several times to mix. Depending on concentration of sample alkalinity, higher concentration of titrant may be necessary.

8.4 ICV/LCS Solution: Add the contents of one Alkalinity Standard ampoule to a 500mL volumetric flask containing approximately 350mL of reagent water, dilute to the mark and invert several times to mix. This will yield a concentration of 500 mg/L. Do not store for more than one week. (Alternatively, the contents of two Alkalinity Standard ampoules can be diluted to a final volume of 1000mL using a 1-L volumetric flask if additional available volume is needed.)

8.5 CCV: Dry approximately 1 g of sodium carbonate at 180ºC for 4 hours in an oven and cool in a desiccator. Weigh out 0.5 g (to the nearest mg) of the dried sodium carbonate, Na_2CO_3, and place into a 1-L volumetric flask containing approximately 500 mL of reagent water, invert several times to dissolve and dilute to the mark with reagent water. Do not store for more than a week.

9.0 PROCEDURE

9.1 Sample Analysis Set-up

9.1.1 Return to the Main Menu. Select the “prism: button, then “OK”. Select load template. Enter the sample ID’s using the following convention: 60121234001_x1.

9.1.2 The x1 denotes the dilution based on 30 mL of sample.

9.1.3 Save the template using today’s date. Click the “start” button to begin the run. NEVER use the “STOP” button. It will erase all run data.

9.1.4 To add samples or dilutions to the run, select “Priority” and add at the end of the sample list.

9.1.5 The data file will be saved automatically to the G: drive on the network. When the run is complete a dialog box will appear. The raw data will print when exiting this dialog box.

9.2 Reporting Data

9.2.1 Use Limslink create a runlog. Include the LCS, CCV,ICV, titrant and pH ID’s on the runlog. The runlog should match the dilutions on the raw data. Also indicate on the runlog if any data is not being reported. Save the runlog to G:/WET/RUNLOGS/ALK/. Print the runlog and include with the raw data.

9.2.2 Import data to EPIC Pro. Submit the data for peer review.

9.3 Calibration

9.3.1 Calibration must be performed daily prior to sample analysis or Titrant Standardization.

9.3.2 Load freshly poured, 30-mL aliquots of the 4.0, 7.0, and 10.0 pH buffers into autosampler positions one through three, respectively. Fill the titrant bottle and the rinse bottle as needed. Verify that the waste bottle is empty. pH Buffers should be replaced daily.

9.3.3 Verify that the power is active to all QC-Titrate components. Click on the QC-Titrate icon. This will bring you to the main menu. Select the pH cal button. Click start. The unit will calibrate and print a report automatically. Record the pH buffer ID’s on the calibration report or add to the run log.

9.3.4 Calibration Criteria

	Minimum	Maximum
Slope	-65	-53
Intercept	-100	100
Correlation Coeff.	0.990	1.00

9.4 Standardization of the Alkalinity Titrant (if needed)

9.4.1 Standardize the titrant each time a new batch is prepared, if purchased 0.02N sulfuric acid is not used. Section 11.2 is not needed when purchased 0.02N sulfuric is used.

9.4.2 Quantitatively measure two 30-mL aliquots of the Normality check solution (ICV/LCS) into separate cups.

9.4.3 At the Main Menu. Select the “prism: button, then “OK”. Select load template. Load the ALK NORM CHECK. Autotitrate the two aliquots with the (0.02 N) H_2SO_4 solution to pH 4.2.

9.4.4 Print and submit the titrant standardization for peer review.

9.4.5 Determine the normality of acid by use of the following equation:

$$\text{Normality (N)} = \frac{A \times B}{53.00 \times C}$$

where:

A = grams of Na_2CO_3 weighed in to 1-L flask

B = mL of Na_2CO_3 solution taken for titration

C = average of the two titrant volumes in mL.

9.4.6 Update the H_2SO_4 normality in the Alkalinity templates.

9.5 Initial Calibration Verification (ICV) and LCS: Measure 30 mL of the ICV/LCS Solution into a 100-mL cup. The final concentration of the ICV is 500 mg $CaCO_3$/L. An ICV sample must be analyzed at the beginning of the tray. ICV acceptability is ± 10%. An LCS is included for every batch and the acceptability is ±10%. (Note: Since there is no separate preparation step for aqueous samples in this procedure, the ICV can also be used for the aqueous LCS for the first analytical batch of samples.)

9.6 Continuing Calibration Verification (CCV): Measure 30 mL of the sodium carbonate solution from Section 10.4 into a 100-mL cup. Prepare a sufficient number of CCVs to be analyzed every 10 titrations and at the end of the tray. CCV acceptability is ± 10%.

9.7 Calibration Blanks (ICB/CCB): Measure 30 mL of reagent water into a 100-mL cup. Prepare a sufficient number of CCBs to be analyzed after every ICV and CCV. Calibration blanks must not contain any alkalinity above the reporting limit. (Note: Since there is no separate preparation step for aqueous samples in this procedure, the ICB can also be used for the aqueous MB for the first analytical batch of samples.)

9.8 Sample Preparation

9.8.1 Homogenization and Subsampling

Samples: Measure 30 mL of a water sample or 5 g of a soil sample plus 30 mL reagent water into a 100-mL cup (mix soil and water to form a slurry). Any sample that requires greater than 30 mL titrant must be analyzed using stronger titrant. Batch QC and verification standards may also need to be made at higher concentration to better represent the concentration of the samples and to increase the likelihood of passing QC.

9.9 Analysis

9.9.1 Example Analytical Sequence

Run Number	Sample Description
1	ICAL Standard 1
2	ICAL Standard 2
3	ICAL Standard 3
4	ICAL Standard 4
5	ICAL Standard 5
6	ICAL Standard 6
7	ICAL Standard 7
8	ICV Standard
9	ICB
10	CCV
11	MB
12	LCS
13	Sample 1
14	Sample 2
15	Sample 3
16	Sample 3 Matrix Spike
17	Sample 3 Duplicate
18	Sample 4
19	Sample 5
20	Sample 6
21	CCV
22	CCB
23	Sample 7
24	Sample 8
25	Sample 9
26	CCV
27	CCB

10.0 DATA ANALYSIS AND CALCULATIONS

10.1 Aqueous sample:

$$\text{Alkalinity (mg CaCO}_3\text{/L)} = \frac{A \times N \times 50000}{\text{mL of sample}}$$

10.2 Soil/ Solid sample:

$$\text{Alkalinity (mg CaCO}_3\text{/kg)} = \frac{A \times N \times 50000}{\text{g of sample}}$$

Where:
A = mL of standard acid.
N = Normality of standard acid.

10.3 Alkalinity Relationships

10.3.1 The results obtained from the phenolphthalein and total alkalinity determinations offer a means for stoichiometric classification of the three principal forms of alkalinity present in many waters.

10.3.2 The classification ascribes the entire alkalinity to bicarbonate, carbonate, and hydroxide, and assumes the absence of other (weak) inorganic or organic acids, such as silicic, phosphoric, and boric acids. It further presupposes the incompatibility of hydroxide and bicarbonate alkalinities.

10.3.3 Because the calculations are made on a stoichiometric basis, ion concentrations in the strictest sense are not represented in the results, which may differ significantly from actual concentrations especially at pH>10. According to this scheme:

- Carbonate ($CO3^{2-}$) alkalinity is present when phenolphthalein alkalinity is not zero, but is less than total alkalinity.
- Hydroxide (OH^-) alkalinity is present if phenolphthalein alkalinity is more than half the total alkalinity.
- Bicarbonate ($HCO3^-$) alkalinity is present if phenolphthalein alkalinity is less than half the total alkalinity.

Table 10.1 – Alkalinity Relationships*

Result of Titration	Hydroxide Alkalinity (as $CaCO_3$)	Carbonate Alkalinity (as $CaCO_3$)	Bicarbonate Alkalinity (as $CaCO_3$)
P = 0	0	0	T
P < ½T	0	2P	T-2P
P = ½T	0	2P	0
P > ½T	2P-T	2(T-P)	0
P = T	T	0	0

*P=phenolphthalein alkalinity (pH 8.3 endpoint); T= total alkalinity (pH 4.5 endpoint).

10.4 Calculations

See the Laboratory Quality Assurance Manual for equations for common calculations.

11.0 Quality Control and Method Performance

11.1 Quality Control

The following QC samples are prepared and analyzed with each batch of samples. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency
Method Blank (MB)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Laboratory Control Sample (LCS)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Matrix Spike (MS)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Matrix Spike Duplicate (MSD)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.

11.2 Instrument QC

The following Instrument QC checks are performed. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Frequency
Initial Calibration	Run every batch
Initial Calibration Verification	Run after Calibration
Initial Calibration Blank	Run after ICV
Continuing Calibration Verification	Run after every 10 samples
Continuing Calibration Blank	Run after CCV

11.3 Method Performance

11.3.1 Method Validation

11.3.1.1 Detection Limits

Detection limits (DL) and limits of quantitation (LOQ) are established at initial method setup and verified on an on-going basis thereafter. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 Method Validation and Instrument Verification.

11.4 Analyst Qualifications and Training

Employees that perform any step of this procedure must have a completed Read and Acknowledgment Statement for this version of the SOP in their training record. In addition, prior to unsupervised (independent) work on any client sample, analysts that prepare or analyze samples must have successful initial demonstration of capability (IDOC) and must successfully demonstrate on-going proficiency on an annual basis. Successful means the initial and on-going DOC met criteria, documentation of the DOC is complete, and the DOC record is in the employee's training file. Refer to laboratory SOP ENV-SOP-LENE-0110, *Training Procedures*, for more information.

12.0 DATA REVIEW AND CORRECTIVE ACTION

12.1 Data Review

Pace's data review process includes a series of checks performed at different stages of the analytical process by different people to ensure that SOPs were followed, the analytical record is complete and properly documented, proper corrective actions were taken for QC failure and other nonconformance(s), and that test results are reported with proper qualification.

The review steps and checks that occur as employee's complete tasks and review their own work is called primary review.

All data and results are also reviewed by an experienced peer or supervisor. Secondary review is performed to verify SOPs were followed, that calibration, instrument performance, and QC criteria were met and/or proper corrective actions were taken, qualitative ID and quantitative measurement is accurate, all manual integrations are justified and documented in accordance with the Pace ENV's SOP for manual integration, calculations are correct, the analytical record is complete and traceable, and that results are properly qualified.

A third-level review, called a completeness check, is performed by reporting or project management staff to verify the data report is not missing information and project specifications were met.

Refer to laboratory SOP ENV-SOP-LENE-088, *Data Reduction, Review and Reporting*, for specific instructions and requirements for each step of the data review process.

12.2 Corrective Action

Corrective action is expected any time QC or sample results are not within acceptance criteria. If corrective action is not taken or was not successful, the decision/outcome must be documented in the analytical record. The primary analyst has primary responsibility for taking corrective action when QA/QC criteria are not met. Secondary data reviewers must verify that appropriate action was taken and/or that results reported with QC failure are properly qualified.

Corrective action is also required when carryover is suspected and when results are over range.

Samples analyzed after a high concentration sample must be checked for carryover and reanalyzed if carryover is suspected. Carryover is usually indicated by low concentration detects of the analyte in successive samples analyzed after the high concentration sample.

Sample results at concentrations above the upper limit of quantitation must be diluted and reanalyzed. The result in the diluted samples should be within the upper half of the calibration range. Results less than the mid-range of the calibration indicate the sample was over diluted and analysis should be repeated with a lower level of dilution. If dilution is not performed, any result reported above the upper range is considered a qualitative measurement and must be qualified as an estimated value.

Refer to Appendix B for a complete summary of QC, acceptance criteria, and recommended corrective actions for QC associated with this test method.

13.0 Pollution Prevention And Waste Management

Pace proactively seeks ways to minimize waste generated during our work processes. Some examples of pollution prevention include but are not limited to: reduced solvent extraction, solvent capture, use of reusable cycletainers for solvent management, and real-time purchasing.

The EPA requires that laboratory waste management practice to be conducted consistent with all applicable federal and state laws and regulations. Excess reagents, samples and method process wastes must be characterized and disposed of in an acceptable manner in accordance with Pace's Chemical Hygiene Plan / Safety Manual.

14.0 Modifications

A modification is a change to a reference test method made by the laboratory. For example, changes in stoichiometry, technology, quantitation ions, reagent or solvent volumes, reducing digestion or extraction times, instrument runtimes, etc. are all examples of modifications. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 *Method Validation and Instrument Verification* for the conditions under which the procedures in test method SOPs may be modified and for the procedure and document requirements.

14.1 Method 2320B has been modified to analyze soils by performing a DI Leach and analyzing the

15.0 Responsibilities

Pace ENV employees that perform any part this procedure in their work activities must have a signed Read and Acknowledgement Statement in their training file for this version of the SOP. The employee is responsible for following the procedures in this SOP and handling temporary departures from this SOP in accordance with Pace's policy for temporary departure.

Pace supervisors/managers are responsible for training employees on the procedures in this SOP and monitoring the implementation of this SOP in their work area.

16.0 Attachments

Attachment 1: Batch and Instrument QC summary

17.0 References

17.1 Pace Quality Assurance Manual - most current version.

17.2 National Environmental Laboratory Accreditation Conference (NELAC), Chapter 5, "Quality Systems"- most current version.

17.3 The NELAC Institute (TNI); Volume 1, Module 2, "Quality Systems"- most current version.

17.4 Standard Methods for the Examination of Water and Wastewater, Online Edition, Method 2320B (1997).

18.0 REVISION HISTORY

This Version:

Section	Description of Change
17	Added attachment for QC summaries

This document supersedes the following document(s):

Document Number	Reason for Change	Date
S-KS-I-050-rev.0	New Procedure	January 10, 2013
S-KS-I-050-rev.1	Table 10.1 – Added Section 10.3 – Reworded ICV/LCS prep so that either one or two ampoules can be used. Sections 11.3 and 11.5 – Added note about ICV/ICB can also be used as LCS/MB Table 11.1 – Reworded for clarity Table 13.1 – Reworded for clarity	August 7, 2013
S-KS-I-050-rev.2	SOP – Updated to latest prescribed format. Added sections for Instrument/Equipment Maintenance and Troubleshooting. Section 12 – Added path for runlog and additional information for sample IDs.	November 18, 2014
S-KS-I-050-rev.3	Table 10.2 – Added 0.02N Sulfuric Acid Section 11.2 – Modified to include purchased 0.02N Sulfuric Acid	December 29, 2015
S-KS-I-050-rev.4	SOP – Minor grammatical changes. Section 12.1 – Soils are mixed before titration.	April 10, 2017
S-KS-I-050-rev.5	SOP – Revised date and minor formatting changes	June 20, 2018
ENV-SOP-LENE-0014	Published to Master Control, no changes	October 8, 2018
ENV-SOP-LENE-0014-02	Section 12.1 – Revised to add using a stronger titrant if needed. Dilution of a sample is not allowed.	March 1, 2019
ENV-SOP-LENE-0014-03	NEW SOP format	March 23, 2021
ENV-SOP-LENE-0014-04	Addition of QC limits chart Attachment 1	April 7, 2021

Attachment 1: Batch and Instrument QC summary

QA Sample	Components	Frequency	Acceptance Criteria	Corrective Action
Method Blank (MB)	Matrix-specific; reagent water or glass beads for soils.	One per batch of up to 20 samples	Result should be less than the reporting limit. If results are reported to MDL, the MB must be evaluated to the MDL.	1) Re-analyze blank to confirm failure. 2) Qualify results and / or reanalyze associated samples. ***Exceptions:*** 1) If sample ND, report sample without qualification 2) If sample result >10x MB report sample with appropriate qualifier indicating blank contamination. 3) If sample result <10x MB and sample cannot be reanalyzed report sample with appropriate qualifier to indicate an estimated value. Client should be alerted of this condition.
Laboratory Control Sample (LCS)	Matrix-specific; reagent water or glass beads for soils spiked with standard	One per batch of up to 20 samples	90-110%	1) Reanalyze the LCS to confirm failure 2) Re-prep and reanalyze associated samples. 3) If problem persists, check spike solution ***Exceptions:*** 1) If LCS > QC limits and these compounds are non-detect in the associated samples, the sample data may be reported with appropriate data qualifiers. 2) If LCS < QC limits and sample cannot be reanalyzed report sample with appropriate qualifier to indicate an estimated value. Client should be alerted to this condition.
Duplicate	Sample Dup	One per every 10 samples (10%)	Water Max RPD: 10% Soil Max RPD: 20%	1) No corrective actions necessary. Report outliers with comment.

Calibration Metric	Parameter / Frequency	Criteria	Comments
Initial Calibration Verification	Daily, prior to sample analysis.	90-110%	May be reanalyzed once. A second failure confirms and requires re-preparation of standard and/or recalibration. If problem persists an alternative source standards may need to be obtained.

Calibration Metric	Parameter / Frequency	Criteria	Comments
Initial Calibration Verification Blank	Immediately after each Initial Calibration Verification	Result should be less than the reporting limit. If sample results are reported to MDL, the ICB must be evaluated to the MDL.	May be reanalyzed once. A second failure confirms and requires corrective action (e.g. re-preparation of standard(s) and/or recalibration) **Exceptions:** If sample results are reported to MDL and ICB is <RL but >MDL, then corrective action is not necessary other than appropriately qualifying the sample results. Unless the customer's QAPP or technical specification instruct to do otherwise. Samples that are <RL may be reported without qualification. (Not applicable to samples reporting down to MDL) Samples >10x ICB may be reported with appropriate qualification.
Continuing Calibration Verification	Every 10 titrations thereafter and at the end of the analytical sequence. Samples need to be bracketed with an acceptable CCV standard	90-110%	May be reanalyzed once. A second failure confirms and requires corrective action (e.g. re-preparation and/or recalibration). **Exception:** If CCV fails high, then sample(s) that are <RL may be reported with appropriate qualification.
Continuing Calibration Blank	Immediately after each Continuing Calibration Verification. Samples need to be bracketed with an acceptable CCB standard	Result should be less than the reporting limit. If sample results are reported to MDL, the ICB must be evaluated to the MDL.	May be reanalyzed once. A second failure confirms and requires corrective action **Exceptions:** If sample results are reported to MDL and ICB is <RL but >MDL, then corrective action is not necessary other than appropriately qualifying the sample results. Unless the customer's QAPP or technical specification instruct to do otherwise. Samples that are <RL may be reported without qualification. (Not applicable to samples reporting down to MDL) Samples >10x CCB may be reported with appropriate qualification.

Management Approval:
Charles Girgin Approved on 11/23/2022 1:27:07 PM
Kenneth Busch Approved on 11/29/2022 1:50:23 PM

1.0 SCOPE AND APPLICATION

This standard operating procedure (SOP) describes the laboratory procedure for the determination of Total Dissolved Solids (TDS) by gravimetry by SM 2540 C 1997 and 2015. Applicable matrices are aqueous samples which include drinking water, surface waters and saline waters as well as domestic and industrial wastes.

1.1 Target Analyte List and Limits of Quantitation (LOQ)

The target analytes that can be determined by this SOP and the associated LOQ is provided in Table 1, Appendix A.

2.0 SUMMARY OF METHOD

A well-mixed sample is filtered through a standard glass fiber filter. The filtrate is then evaporated and dried to constant weight at 180°C.

3.0 INTERFERENCES

Highly mineralized waters containing significant concentrations of calcium, magnesium, chloride, and/or sulfate may be hygroscopic and will require prolonged drying, desiccation and rapid weighing.

Samples containing high concentrations of bicarbonate will require careful and prolonged drying at 180°C to ensure that all the bicarbonate is converted to carbonate.

Too much residue in the evaporating dish will crust over and entrap water that will not be driven off during drying. Total residue must be limited to less than 200 mg. . Sample results with residue greater than 200 mg must be reanalyzed using less sample volume. Any results reported with residue greater than 200 mg must be noted as such.

4.0 DEFINITIONS

Refer to the Laboratory Quality Manual for a glossary of common lab terms and definitions.

5.0 HEALTH AND SAFETY

Contact your supervisor or local safety coordinator with questions or concerns regarding safety protocol or safe handling procedures for this procedure

The following sections provide general health and safety information about chemicals and materials that may be present in the laboratory.

- The toxicity or carcinogenicity of each chemical material used in the laboratory has not been fully established. Each chemical should be regarded as a potential health hazard and exposure to these compounds should be as low as achievable.

- The laboratory maintains documentation of hazard assessments and OSHA regulations regarding the safe handling of the chemicals specified in each method. Safety data sheets for all hazardous chemicals are available to all personnel. Employees must abide by the health, safety and environmental (EHS) policies and procedures specified in this SOP and in the Pace® Chemical Hygiene / Safety Manual (COR-MAN-0001)
- Personal protective equipment (PPE) such as safety glasses, gloves, and a laboratory coat must be worn in designated areas and while handling samples and chemical materials to protect against physical contact with samples that contain potentially hazardous chemicals and exposure to chemical materials used in the procedure.
- Concentrated corrosives present additional hazards and are damaging to skin and mucus membranes. For procedures that require use of acids, use acids in a fume hood whenever possible with PPE designed for handing these materials. If eye or skin contact occurs, flush with large volumes of water. When working with acids, always add acid to water to prevent violent reactions. For procedures that emit large volumes of solvents (evaporation/concentration processes), these activities must be performed in a fume hood or apparatus that reduces exposure.

6.0 SAMPLE COLLECTION, PRESERVATION, HOLDING TIME & STORAGE

The laboratory provides containers for the collection of samples upon client request. Refer to laboratory SOP ENV-SOP-LENE-0107 for procedures related to preparation of bottle kits for the test method(s) associated with this SOP.

The laboratory performs samples collection for samples to be analyzed by this SOP in accordance with laboratory SOP ENV-SOP-LENE-0025. Refer to this SOP for these instructions.

Container Type, Minimum Sample Amount, Preservation, and Holding Time Requirements:

Matrix	Container Size & Type	Required Sample Amount[1]	Preservation	Holding Time
Aqueous	Plastic or Glass: 500mL	200mL	Thermal: ≤6°C, but not frozen Chemical: N/A	Collection to Analysis: 7 days

[1] *Amount of sample required for each discrete test.*

Thermal preservation is checked and recorded on receipt in accordance with laboratory SOP ENV-SOP-LENE-0021. Chemical preservation is checked and recorded at time of receipt or prior to sample preparation.

After receipt, samples are stored at ≤6°C until sample preparation. Prepared samples (extracts, digestates, distillates, other) are stored at ≤6C until sample analysis.

After analysis, samples are retained as stated in the Pace® standard terms and conditions, unless otherwise specified in the analytical services contract. Samples are then disposed of in accordance with Federal, State, and Local regulations.

7.0 EQUIPMENT & SUPPLIES

7.1 Equipment

- Analytical Balance by Mettler-Toledo, Model AE-240 or equivalent
- Stable Weigh Station by Environmental Express, Model TDS600F; 6 Place filtration system

7.2 Supplies

- Graduated cylinders: 10, 25, 50, 100, 250-mL, Class A, To Deliver (TD): Catalog #'s Fisher / 07-250 (-067, -068, -069)
- Volumetric flask: 1-liter, Class A: Catalog #'s Fisher / 10-209H
- TDS Vessels: TDS Pre-weighed bags and filters: Catalog #'s Env. Exp. / TDS111
- Drying Oven Maintains 180 ± 2°C , 104 ± 1°C Fisher / 15-103-0520
- Desiccator Cabinet Four-shelf, acrylic Fisher / 08-642-23C
- Desiccant Drierite, non-indicating, 8 mesh Fisher / 07-577-3B
- Desiccant Drierite, indicating, 10-20 mesh Fisher / 07-578-4B
- Vacuum pump Edwards Amazon
- Tubing PVC, 5/16" ID Fisher / 14-169-7F

8.0 REAGENTS & STANDARDS

8.1 Reagents

- Reagent water that is ASTM Type II, refer to SOP ENV-SOP-LENE-0131

8.2 Standards

- Potassium chloride (KCl): ACS Reagent Grade; crystalline: Catalog #'s: Fisher / P-217

8.3 Formulations

- LCS Working Standard – Add 1.00g of potassium chloride to a 1-liter volumetric flask containing approximately 400 mL of reagent water. Bring to volume and invert several times to mix. Assign a three-month expiration date from the preparation date (not to extend beyond the expiration dates of the source reagents). Store at ambient temperature.

9.0 PROCEDURE

9.1 Equipment Preparation

9.1.1 Support Equipment

Refer to Pace Analytical Services – SOP ENV-SOP-LENE-0030, Support Equipment, or equivalent replacement, for additional information on calibration requirements for support equipment that may be used in this procedure.

Balances are checked prior to use on each working day with NIST traceable references in the expected range of use, and the results are recorded in the logbook assigned to the balance.

9.1.2 **Instrument Set Up**

9.1.2.1 Balance

Check balance calibration daily before use. The balance must be clean and level (level indicator bubble in circle) before use. The balance is calibrated and serviced annually by a qualified technician.

9.1.2.2 Desiccators

Check the desiccant to determine if re-drying or replacing desiccant is needed (pink color).

9.1.2.3 Ovens

Check the oven temperatures each day of use. Perform corrective action if oven temperature acceptance criteria are not met.

9.1.2.4 Vacuum Filtration Device and Filter Maintenance

Periodically inspect the vacuum filtration device for leaks. Maintain the oil level in the vacuum pump and periodically change the oil. Change the Whatman Vacu-guard Filter on the vacuum line when necessary. Soak filter funnels in soap and water weekly. Clean or change the tubing as needed.

9.2 Sample Preparation

9.2.1 **Homogenization & Subsampling**

Refer to Pace Analytical Services – ENV-SOP-LENE-0135, Sample Homogenization and Sub-Sampling, or equivalent replacement, for information regarding the handling, homogenization, and splitting of samples in order to ensure that a representative aliquot is used for analysis.

9.3 Sample Batch Creation

9.3.1 Create a batch (per 20 samples) in Epic-Pro for each TDS test code required. Each batch must include 1 LCS, 1MB, and 2 DUP (or 1 DUP per ten samples).

9.3.2 Print the batch worklist report and use this to search the scannable locations of samples. Once all samples have been found scan them out to your location or cart.

9.3.3 Open prep log 2540C | TDS (Stable Weigh) template. NOTE: If beakers are use 2540C | TDS template

9.3.4 Under “Search by Batch” on the workbench, enter the HBN of the TDS batch (this can be found in the upper left-hand corner of the batch worklist) and use this workbench to record the sample volumes filtered below.

9.3.5 Populate the Standard Sequence IDs for the TDS Stable Weigh vessels and TDS filters used under the corresponding column.

9.3.6 TDS Stable Weigh vessels have a scannable barcode allowing simultaneous population of vessel traceability under the “ID” column and “Beaker Wt. 1 (g)” fields.

9.3.7 Note: The run date/time is automatically entered into the electronic log when the vessel barcode is scanned. This time needs to be changed to the “Oven temp 1 date/time” (the time that the samples are placed into the drying oven).

9.3.8 All samples require a specific conductance measurement to be determined and recorded.

9.3.9 After the specific conductance measurements have been recorded, return to data software, and transcribe them into the appropriate fields.

9.3.10 The volume to be filtered is dependent upon the range of the conductivity (see table below).

Conductance (μmho/cm)	Filtration Volume (mL)
0-500	200
500-1000	100
1000-1500	75
1500-2000	50
2000-2500	25
2500-3500	15
3500-4500	10
4500-5500	8
5500-6500	7
6500-7500	6
7500-9000	5
9000-11000	4
11000-13000	3
13000-16000	2
16000-20000	1
>20000	0.5-1

Note: If you have insufficient sample, change the volume in the column to the amount used. This must be done to allow the sample to be calculated correctly. If the conductivity is greater than 8,000, then you will need to use less sample by performing stepwise dilutions.

9.4 Sample Vessel Weight Determination/Verification (Initial)

9.4.1 Tare the balance.

9.4.2 Place an empty Stable Weigh vessel on the balance using the weighing bracket and close the door.

9.4.3 While the balance is equilibrating, confirm the Stable Weigh vessel trace number in column labeled "ID."

9.4.4 Record or confirm the weight of the TDS vessel/pre-weighed vessel in the data software

9.4.5 Place the vessels on their aluminum tray. This will allow for a much faster process from this point forward.

9.4.6 Resave the electronic log (recommended to save often).

9.4.7 If beakers are used record ID and weigh of the empty beaker into appropriate columns, beakers must have been previously dry at 180 ± 2°C for a minimum of one hour.

9.5 Sample Filtration

9.5.1 Assemble the 6-Place filling station.

9.5.2 Thoroughly mix the sample by vigorous hand shaking (or stirring).

9.5.3 Using the conductivity measurement determined in Section 9.3.8, transfer the specified sample volume to the filtration apparatus. Use a graduated cylinder for volumes of 10 mL or greater, and a pipette for volumes less than 10mL.

9.5.4 Place the filter on the apparatus with the wrinkled side facing up. Wash the filter with 3 successive volumes of ≥10 mL of DI water. Allow complete drainage between washings and continue suction until all traces of water are removed.

9.5.5 Collect the sample and washings into the appropriate beaker/vessel and place beakers/vessels on trays to be placed into the drying oven.

9.5.6 DI water is filtered for the MB, and a potassium chloride solution is used for the LCS.

9.6 Sample Vessel Weight Determination/Verification (Final)

9.6.1 Place the vessel into the 104 ± 1°C oven, until the liquid has evaporated to dryness from all vessels (usually overnight). Record time in/time out and temperature reading in the TDS worksheet for each drying cycle. This will complete the drying process and convert all bicarbonates to carbonates.

9.6.2 Once the samples have evaporated, place them into the 180 degree oven for 1 hour.

9.6.3 Remove the trays and vessels from the 180 ± 2°C oven and let cool on the counter for about 2 minutes, until they will not melt the plastic desiccator shelves. Do not allow samples to cool to room temperature! The residue will absorb water from the air, requiring an additional drying cycle for removal.

9.6.4 Place the vessels into the desiccator while maintaining the order to allow them to finish cooling without absorbing any humidity.

9.6.5 Tare the balance.

9.6.6 Place beaker/vessel on balance and record weight on the data software.

9.6.7 Repeat the drying (at 180 ± 2°C) and weighing process for all the samples until the weight change between successive measurements is <0.5 mg of the previous weight.

9.6.8 Evaluate the data and identify any samples that do not meet the QC objectives outlined in Section 11.1.

9.6.9 When finished, save the electronic log template**.**

Pace **Prep Log Report**

Batch Information: WET TDS 105492 **Template Version: F-KANS-I-011-Rev.01 (17Oct2021)**

Analysis Method	SM 2540C	Analyzed By	JDS	Instrument	60BL12	Oven ID	60OV03
Acceptance Range	178-182 C	Oven Correction Factor (C)	-2.7	Oven Temp In1 (C) | Corr | Date/Time | Init	182.7 | 180.0 | 02/14/2022 15:26 | JDS	Oven Temp Out1 (C) | Corr | Date/Time | Init	182.7 | 180.0 | 02/15/2022 08:11 | JDS
Desic. In 1 ID | Date/Time | Init	02/15/2022 08:11:28:007 | 02/15/2022 08:11 | JDS	Desic. Out 1 Date/Time | Init	02/15/2022 09:14 | JDS	Oven Temp In2 (C) | Corr | Date/Time | Init	182.7 | 180.0 | 02/15/2022 09:25 | JDS	Oven Temp Out2 (C) | Corr | Date/Time | Init	182.7 | 180.0 | 02/15/2022 10:25 | JDS
Desic. In 2 ID | Date/Time | Init	02/15/2022 10:25:14:732 | 02/15/2022 10:25 | JDS	Desic. Out 2 Date/Time | Init	02/15/2022 13:17 | JDS	Oven Temp In3 (C) | Corr | Date/Time | Init		Reviewed By	BLA
Reviewed By Date	02/15/2022 14:48	Batch Notes					

Sample Information:

QC Rule	Sample Type	Lab Sample ID	Select	ID	Conductivity (uS/cm)	TDS Residue (g)	TDS Posted (mg/L)	TDS Final (mg/L)	Run Date/Time	Cont. Wt 1 (g)	Cont. Use 1	Initial Volume (mL)	Oven Wt 1 (g)	Oven Use 1
2540C W	BLANK	**3078772**	Y	B0391913		0.0000	0.0000	0.0000	02/14/2022 14:40:57	3.9137	M	200	3.9138	N
2540C W	LCS	**3078773**	Y	B0391914		0.1000	500.00	1000.0	02/14/2022 14:41:03	3.7326	M	100	3.8328	N
2540C W	PS	**60392305002**	Y	B0391915	1037	0.0781	390.50	1041.3	02/14/2022 14:41:09	3.7003	M	75	3.7784	N
2540C W	DUP	**3078774**	Y	B0391916	1037	0.0799	399.50	1065.3	02/14/2022 14:41:15	3.8062	M	75	3.8856	N
2540C W	PS	**60392461001**	Y	B0391917	108.3	0.0136	68.000	68.000	02/14/2022 14:41:21	3.6884	M	200	3.7025	N
2540C W	PS	**60392291003**	Y	B0391918	4000	0.0502	251.00	5020.0	02/14/2022 14:41:27	3.9781	M	10	4.0284	N
2540C W	PS	**60392293001**	Y	B0391919	7010	0.0477	238.50	7950.0	02/14/2022 14:41:35	3.7935	M	6	3.8407	N
2540C W	PS	**60392331001**	Y	B0391920	1149	0.0888	444.00	1184.0	02/14/2022 14:41:42	3.8674	M	75	3.956	N
2540C W	PS	**60392331002**	Y	B0391921	659	0.0621	310.50	621.00	02/14/2022 14:41:48	3.8395	M	100	3.9013	N
2540C W	PS	**60392331003**	Y	B0391922	869	0.0452	226.00	452.00	02/14/2022 14:41:55	3.7056	M	100	3.7503	N
2540C W	PS	**60392331004**	Y	B0391923	665	0.2405	1202.5	2405.0	02/14/2022 14:42:01	3.6879	M	100	3.9283	N
2540C W	PS	**60392331005**	Y	B0391924	1567	0.0909	454.50	1818.0	02/14/2022 14:42:08	3.7056	M	50	3.7963	N
2540C W	PS	**60392331006**	Y	B0391925	1337	0.1100	550.00	1466.7	02/14/2022 14:42:15	3.7879	M	75	3.8975	N
2540C W	PS	**60392331007**	Y	B0391926	1481	0.1207	603.50	1609.3	02/14/2022 14:42:22	3.8346	M	75	3.9553	N
2540C W	DUP	**3078775**	Y	B0391927	1481	0.1297	648.50	1729.3	02/14/2022 14:42:28	3.9209	M	75	4.0503	N

Tue, 1 Mar 2022 16:32:38 -0600

10.0 DATA ANALYSIS & CALCULATIONS

10.1 Calculations

Refer to the Laboratory Quality Assurance Manual, Lab Calculations, or equivalent replacement, for equations used to perform common calculations.

10.1.1 **Total Dissolved Solids (TDS)**

Total Dissolved Solids (mg/L) = ((A-B) ×1,000)/C

Where:

A (grams) = Weight of vessel + residue

B (grams) = Weight of vessel

C (mL) = Volume of sample filtered

11.0 QUALITY CONTROL & METHOD PERFORMANCE

11.1 Quality Control

Prepare the following QC samples with each batch of samples. Refer to Appendix B for acceptance criteria and required corrective action(s).

QC Check	Acronym	Frequency
Method Blank	MB	1 per batch of 20 or fewer samples. If batch exceeds 20 samples, every 20 samples.
Laboratory Control Sample	LCS	1 per batch of 20 or fewer samples. If batch exceeds 20 samples, every 20 samples.
LCS Duplicate	LCSD	As Required.
Sample Duplicate	SD	1 per 10 or fewer samples

11.2 Method Performance

11.2.1 Method Validation

Refer to corporate SOP ENV-SOP-CORQ-0011 for general requirements and procedures for method validation.

Establish detection limits (DL) and limits of quantitation (LOQ) at initial method set up and verify the DL and LOQ on an on-going basis thereafter. Refer to corporate policy and/or SOP for DL and LOQ requirements and procedures.

12.0 DATA REVIEW & CORRECTIVE ACTION

12.1 Data Review

The data review process of Pace® Analytical Services includes a series of checks performed at various stages of the process by different people to ensure that SOPs were followed, the analytical record is complete, and properly documented, QC criteria were met, proper corrective actions were taken for QC failure and other nonconformance(s), and test results are reported with proper qualification, when necessary.

The review and checks that are performed by the employee performing the task is called primary review.

All data and test results are also peer reviewed.

This process, known as secondary review is performed to verify SOPs were followed, that calibration, instrument performance, and QC criteria were met and/or proper corrective actions were taken, qualitative ID and quantitative measurement is accurate, all manual integrations are justified and documented, and approved in accordance with the Pace® Analytical Services SOP for manual integration, calculations are correct, the analytical record is complete and traceable, and that results are properly qualified.

Lastly, a third-level review, called a completeness check, is performed by reporting or project management staff to verify the test report is complete.

Refer to laboratory SOP ENV-SOP-LENE-0088 for specific instructions and requirements for each step of the data review process.

12.2 Corrective Action

Corrective action is required when QC or sample results are not within acceptance criteria.

Refer to Appendix B for a complete summary of QC, acceptance criteria, and recommended corrective actions for QC associated with this test method.

If corrective action is not taken or was not successful, the decision/outcome must be documented in the analytical record. The primary analyst has primary responsibility for taking corrective action when QA/QC criteria are not met. Secondary data reviewers must verify that appropriate action was taken and/or that results reported with QC failure are properly qualified.

Corrective action is also required when carryover is suspected and when results are over range.

Samples analyzed after a high concentration sample must be checked for carryover and reanalyzed if carryover is suspected. Carryover is usually indicated by low concentration detects of the analyte in successive samples analyzed after the high concentration sample.

Sample results at concentrations above the upper limit of quantitation must be diluted and reanalyzed. The result in the diluted samples should be within the upper half of the calibration range. Results less than the mid-range of the calibration indicate the sample was over diluted and analysis should be repeated with a lower level of dilution. If dilution is not performed, any result reported above the upper range is considered a qualitative measurement and must be qualified as an estimated value.

13.0 Pollution Prevention & Waste Management

Pace® proactively seeks ways to minimize waste generated during work processes. Some examples of pollution prevention include but are not limited to reduced solvent extraction, solvent capture, use of reusable cycletainers for solvent management, and real-time purchasing.

The EPA requires that laboratory waste management practices comply with all applicable federal and state laws and regulations. Excess reagents, samples, and method process wastes are characterized and disposed of in an acceptable manner in accordance with the Pace® Chemical Hygiene Plan / Safety Manual. Refer to this manual for these procedures.

14.0 Modifications

The procedures in this SOP have not been modified from the reference test method(s) cited.

When applicable, comparability and/or equivalency studies necessary to validate the modification as required per corporate SOP ENV-SOP-CORQ-0011 are retained by local quality personnel for historical reference.

15.0 RESPONSIBILITIES

- All employees of Pace® Analytical Services that perform any part this procedure in their work activities must have a signed Read and Acknowledgement Statement (R&A) in their training file for the version(s) of the SOP that were in effect during the time the employee performed the activity.
- Local quality personnel are responsible for tracking the currency of the R&A on this SOP for employees at the locations they are assigned to and for notifying the General Manager (GM), however named, when R&A are overdue or outstanding. The GM and the employee's direct supervisor are responsible for ensuring the employee completes the R&A assignments as required.
- The supervisors and managers of Pace® Analytical Services, however named, are responsible for training employees on the procedures in this SOP, implementing the SOP in the work area, and monitoring on-going adherence to the SOP the work area(s) they oversee.
- All employees of Pace® Analytical Services are responsible for following the procedures in this SOP. Unauthorized deviations or departures from this SOP are not allowed except with documented approval from the local Quality Manager and only when those deviations do not violate the Pace® Code of Ethics or Professional Conduct (COR-POL-0004) or associated policy and procedure(s). Hand-edits or manual change to the SOP are not permitted. If a change is desired or necessary, Pace® employees must follow the procedures for document revision specified in corporate SOPs ENV-SOP-CORQ-0015 *Document Management* and ENV-SOP-CORQ-0016 *SOP for Creation of SOP and SWI*.
- Local quality personnel are responsible for monitoring conformity to this SOP during routine internal audits of work areas that utilize this SOP and for communicating gaps and deviations found during monitoring to the work area supervisor, who is responsible for correction of the situation.

16.0 ATTACHMENTS

- Appendix A: Routine Analyte List and LOQ
- Appendix B: QC Summary & Corrective Action Table

17.0 REFERENCES

- ENV-SOP-CORQ-0006, *Manual Integration*, current version.
- ENV-SOP-CORQ-0011, *Method Validation*, current version.
- ENV-SOP-CORQ-0015, *Document Management*, current version.
- ENV-SOP-CORQ-0016, *SOP for SOP and SWI,* current version.
- ENV-TMP-CORQ-0007, *Quality Manual Template*, current version.
- COR-POL-0004, *Code of Ethics and Professional Conduct*, current version.
- COR-MAN-001, *Pace® Safety Manual*, current version.
- Standard Methods 2540 C – 1997 and 2015 published editions

18.0 REVISION HISTORY

Authorship

Primary Author[1]	Job Title	Date Complete
Lenzie Boring	Inorganics Manager	11/22/2022

[1]The primary author is the individual / role responsible for the content of this SOP. Send questions or suggestions for content to the primary author. See the Quality Manager for questions or concerns related to implementation of this SOP.

Revisions Made from Prior Version

Section	Description of Change
Various	Updated to SOP Template language
9.5.4	Added language as to which way the filter should face on the filtering apparatus
9.6.1	Updated procedure to add drying the sample to dryness before placing in 180 oven.

Document Succession: This version replaces the following documents:

Document Number & Version	Document Title	Effective Date:
ENV-SOP-LENE-0036 v03	Total Dissolved Solids (TDS)	04/11/2022

Appendix A: Target Analyte List and LOQ

Table 1: Routine Analyte List and Limits of Quantitation (LOQ)[1]

Analyte	Water (mg/L)
Total Dissolved Solids	5

[1]Values in place as of effective date of this SOP. LOQ are subject to change. For the most up to date LOQ, refer to the LIMS or contact the laboratory.

Appendix B: QC Summary and Corrective Action Table

QC Item	Frequency	Acceptance Criteria	Corrective Action	Qualification
Constant Weight Check	All QC and samples	Weight change of less than 0.5 mg.	Put the samples back in the oven for an additional hour and reweigh. If constant weight cannot be achieved, samples must be reanalyzed. If constant weight cannot be achieved due to the sample matrix, the sample must be qualified as estimated.	Reportable Comment "Constant weight could not be obtained. The reported result should be considered an estimated value."
Method Blank (MB)	1 per batch of 20 or fewer samples.	TDS < RL	Reanalyze batch with associated MB and/or re-prepare batch of samples with a new MB, unless the original result meets the exceptions stated below: **Exceptions:** 1) If sample is ND or > 10x MB result, report sample without qualifier. 2) If sample result <10x MB result and the samples cannot be reanalyzed, report the associated samples with appropriate qualifier.	Qualify samples with MB out of criteria. Refer to Footnotes in EPIC.
Laboratory Control Sample (LCS)	1 per batch of 20 or fewer samples.	TDS must be within ± 10% of the true value. (%R)	Reanalyze batch with associated LCS and/or re-prepare batch of samples with a new LCS, unless the original result meets the exception stated below: **Exceptions:** If LCS recovery is > QC limits, and the associated samples are ND, then the sample data may be reported with the appropriate data qualifier.	Qualify samples with LCS out of criteria. Refer to Footnotes in EPIC.
Sample Duplicate (DUP)	1 per 10 or fewer samples	TDS must have RPD ≤ 10% (%D)	Qualify duplicated sample.	Qualify sample with DUP out of criteria. Refer to Footnotes in EPIC.
Maximum Dried Residue Yield	All samples	Max. Residue < 200 mg	If there is an excess of residue, or filtration time exceeds 10 minutes, the sample must be prepared at a reduced initial volume. Identify any sample that yields >200 mg of dried residue, and if necessary, report the value the appropriate qualifier.	Refer to Section 9.6 Reportable Comment "Result estimated. Sample residue is greater than 200 mg at a volume of X mL."
Minimum Dried Residue Yield	All samples	Min. Residue > 2.5 mg	Identify any sample that yields <2.5 mg **of dried residue** and report the value and qualify accordingly.	Refer to Section 9.6

Management Approval:
Lenzie Boring Approved on 2/10/2022 9:05:49 AM
Charles Girgin Approved on 2/10/2022 10:06:05 AM
Kenneth Busch Approved on 2/10/2022 1:50:27 PM

1. SCOPE AND APPLICATION

This standard operating procedure (SOP) describes the laboratory procedure for the determination of Mercury by CVAA

1.1. Target Analyte List and Limits of Quantitation (LOQ)

The target analytes and the normal LOQ that can be achieved with this procedure:

Analyte	LOQ
MERCURY (AQUEOUS)	**0.2 ug/L**
MERCURY (NON-AQUEOUS)	**0.5 mg/Kg**

LOQ are established in accordance with Pace policy and SOPs for method validation and for the determination of detection limits (DL) and quantitation limits (LOQ). DL and LOQ are routinely verified and updated when needed. The current LOQ for each target analyte that can be determined by this SOP as of the effective date of this SOP is provided in Table 1, Appendix A.

The reporting limit (RL) is the value to which analytes are reported as detected or not detected in the final report. When the RL is less than the lower limit of quantitation (LLOQ), all detects and non-detects at the RL are qualitative. The LLOQ is the lowest point of the calibration curve used for each target analyte.

DL, LOQ, and RL are always adjusted to account for actual amounts used and for dilution.

2. SUMMARY OF METHOD

2.1. Aqueous - A sample aliquot is digested in diluted potassium permanganate, potassium persulfate, sulfuric acid, and nitric acid and oxidized for 2 hours at 95 ± 3°C. The mercury is then reduced with stannous chloride to elemental mercury and measured by automated cold vapor atomic absorption technique at a wavelength of 253.7 nm.

2.2. Solid - A weighed portion of sample is digested in nitric and hydrochloric acids for 2 minutes at 95 ± 3°C. The sample is diluted, and potassium permanganate solution added. The sediment sample is then oxidized for 30 minutes at 95 ± 3°C. The mercury is reduced with stannous chloride to elemental mercury, aerated from solution in a closed system, and measured by automated cold vapor atomic absorption technique at a wavelength of 253.7 nm.

3. INTERFERENCES

3.1. Potassium permanganate is added to eliminate possible interference from sulfide. Concentrations as high as 20 mg/L of sulfide as sodium sulfide do not interfere with the recovery of added inorganic mercury from reagent water.

3.2. Copper has also been reported to interfere; however, copper concentrations as high as 10 mg/L had no effect on recovery of mercury from spiked samples.

3.3. Seawaters, brines, and industrial effluents high in chlorides require additional permanganate because during the oxidation step, chlorides are converted to free chlorine, which also absorbs radiation at 253.7 nm. Care must therefore be taken to ensure that free chlorine is absent before the mercury is reduced and swept into the spectrometer.

3.4. Certain volatile organic materials that absorb at this wavelength may also cause interference. Letting the samples vent before analysis can help to reduce this interference.

4. DEFINITIONS

Refer to the Laboratory Quality Manual for a glossary of common lab terms and definitions.

5. HEALTH AND SAFETY

The toxicity or carcinogenicity of each chemical material used in the laboratory has not been fully established. Each chemical should be regarded as a potential health hazard and exposure to these compounds should be as low as reasonably achievable.

The laboratory maintains documentation of hazard assessments and OSHA regulations regarding the safe handling of the chemicals specified in each method. Safety data sheets for all hazardous chemicals are available to all personnel. Employees must abide by the health, safety and environmental (HSE) policies and procedures specified in this SOP and in the Pace Chemical Hygiene / Safety Manual.

Personal protective equipment (PPE) such as safety glasses, gloves, and a laboratory coat must be worn in designated areas and while handling samples and chemical materials to protect against physical contact with samples that contain potentially hazardous chemicals and exposure to chemical materials used in the procedure.

Concentrated corrosives present additional hazards and are damaging to skin and mucus membranes. Use these acids in a fume hood whenever possible with additional PPE designed for handing these materials. If eye or skin contact occurs, flush with large volumes of water. When working with acids, always add acid to water to prevent violent reactions. Any processes that emit large volumes of solvents (evaporation/concentration processes) must be in a hood or apparatus that prevents employee exposure.

Caution: Mercury compounds are highly toxic if swallowed, inhaled, or absorbed through the skin. All analyses should be conducted under an exhaust hood. Safety glasses and chemical resistant gloves should always be worn when handling concentrated mercury standards.

Contact your supervisor or local HSE coordinator with questions or concerns regarding safety protocol or safe handling procedures for this procedure.

6. SAMPLE COLLECTION, PRESERVATION, HOLDING TIME, AND STORAGE

Samples should be collected in accordance with a sampling plan and procedures appropriate to achieve the regulatory, scientific, and data quality objectives for the project.

The laboratory performs samples collection for samples to be analyzed by this SOP in accordance with laboratory SOP ENV-SOP-LENE-0107, *Field Manual*. Refer to this SOP for these instructions.

The laboratory will provide containers for the collection of samples upon client request for analytical services. Bottle kits are prepared in accordance with laboratory SOP ENV-SOP-LENE-0025, *Assembly of Sample Container Kits*. The bottle kits provided by the laboratory should include field test kits and treatment reagent.

Requirements for container type, preservation, and field quality control (QC) for the common list of test methods offered by Pace are included in the laboratory's quality manual.

General Requirements

Matrix	Routine Container	Minimum Sample Amount[1]	Preservation	Holding Time
Aqueous	Plastic or glass (500-mL).	90mL	Thermal: N/A Chemical: HNO3; pH<2	Collection to Analysis: 28 Days.
Solid	Wide-mouth glass jar (4-oz).	1 g	Thermal: ≤6°C Chemical: HNO3; pH<2	Collection to Analysis: 28 Days.
Wipe	One Ghost Wipe™ per digestion tube or glass vial w/PTFE-lined septum.	1 wipe	Thermal: N/A Chemical: HNO3; pH<2	Collection to Analysis: 28 Days.
Leachate	Plastic or glass (500-mL).	90mL	Thermal: N/A Chemical: HNO3; pH<2	Filtration to Analysis: 28 Days.

[1]*Minimum amount needed for each discrete analysis.*

Field / Matrix QC

Trip Blank	Equipment Blank	MS/MSD	Field Duplicate
If client requested	If client requested	1/20 (or MS per 10 for 245.1)	If requested

Thermal preservation is checked and recorded on receipt in the laboratory in accordance with laboratory SOP ENV-SOP-LENE-0021, *Sample Management*. Chemical preservation is checked and recorded at time of receipt or prior to sample preparation.

After receipt, samples are stored at ≤6°C until sample preparation. Prepared samples (extracts, digestates, distillates, other) are stored at ≤6°C until sample analysis.

After analysis, unless otherwise specified in the analytical services contract, samples are retained for 30 days from date of final report and then disposed of in accordance with Federal, State, and Local regulations.

7. Equipment And Supplies

Table 7.1 Equipment and Supplies

Supply	Vendor	Model / Version	Comments
Boiling Stones	Fisher	09-191-20	PTFE
Cellulose Nitrate Filters	Fisher	09-905-17	Whatman, 47 um x 47mm
Digestion Tubes	Environmental Express	SC475/SC415	68-mL, graduated to 50-mL, 15mL
Ghost Wipes™	Environmental Express	SC4200	15 x 15 cm
HDPE Sample bottles, 250-m	Fisher	NC9095184	Preserved with 2.5 mL 20% HNO_3.
Hotblock	Environmental Express	SC154/196	54-or 96 position
Mercury Analyzer	Perkin-Elmer	FIMS-400	or equivalent
Mercury Analyzer	Cetac	QuickTrace™ M-76	or equivalent
Pipettor	Fisher	05-403-121	Eppendorf

8. Reagents And Standards

8.1. The reagents listed below are those currently in use. Other sources or grades may be used, provided it is first ascertained that the reagent is of sufficiently high purity to permit its use without lessening the accuracy of the determination.

Table 8.1 – Standard Storage Conditions

Standard Type	Description	Expiration	Storage
Stock Standards	▪ Concentrated reference solution purchased directly from approved vendor	▪ Manufacturer's recommended expiration date	▪ Manufacturer's recommended storage conditions
Intermediate and Working Standards	▪ Reference solutions prepared by dilutions of the stock solution	▪ Intermediate standards – two weeks from preparation or the expiration date listed for the stock source, whichever is sooner. ▪ Working Standards – Prepared directly at the time of use.	▪ Manufacturer's recommended storage conditions for stock source solution.

Table 8.2 – Stock Reagents and Standards

Reagent/Standard	Concentration/ Description	Vendor/ Item #
1000 ppm Mercury	Primary Standard, ISO 17034 certified	Spex, PLHG4-2Y
1000 ppm Mercury (2nd Source)	Secondary Standard, ISO 17034 certified	Inorganic Ventures CGHC1-500mL
Hydrochloric acid	Baker Instra-Analyzed®	J.T. Baker / 9530-33
Hydroxylamine HCl	ACS Reagent Grade	J.T. Baker / 2196-01

Reagent/Standard	Concentration/ Description	Vendor/ Item #
Nitric acid	Baker Instra-Analyzed®	J.T. Baker / 9598-34
Potassium permanganate	ACS Reagent Grade	J.T. Baker / 3227-01
Potassium persulfate	Baker Instra-Analyzed®	J.T. Baker / 3239-01
Reagent water	ASTM Type II	
Stannous chloride dihydrate	ACS Reagent Grade	J.T. Baker / 3980-01
Sulfuric acid	Baker Instra-Analyzed®	J.T. Baker / 9673-33

Table 8.3 – Intermediate Standards

Standard	Source Standard	Standard Amount (mL)	Solvent	Final Total Volume (mL)	Final Concentration (ug/L)
Primary Intermediate (Working) Standard (ICAL Spike Solution)	Primary Stock Standard	0.075	Water	500	150
Secondary Intermediate (Working) Standard (ICV Spike Solution)	Secondary Stock Standard	0.075	Water	500	150

8.2. Intermediate preparation: Add 5 mL of concentrated HNO_3 to a 500-mL volumetric flask containing ~250 mL of reagent water, followed by 0.075 mL of the 1000 ppm Mercury primary standard or secondary standard. Dilute to the mark with reagent water and invert the flask to mix the standard. Assign a fourteen day expiration date.

8.3. Since some programs require the verification of the spike solutions prior to use, the intermediates are prepared weekly and overlap so that the solutions can be verified prior to use. After weekly intermediate preparation, dilute as a CCV or ICV respectively. Analyze as a sample. The recovery must be 90-110%. Note the verification date in the Mercury standards logbook.

Table 8.4 – Working Standards for Aqueous Calibration Curve

Standard	Source Standard	Standard Amount (mL)	Solvent	Final Total Volume (mL)	Final Concentration (ug/L)
CAL0 Standard 1/ICB/CCB*	NA	N/A	Water	30	0
CAL1 Standard 2/Low CHK	ICAL Spike Solution	0.040	Water	30	0.20
CAL2 Standard 3	ICAL Spike Solution	0.20	Water	30	1.0
CAL3 Standard 4	ICAL Spike Solution	0.40	Water	30	2.0
CAL4 Standard 5/CCV	ICAL Spike Solution	1.0	Water	30	5.0
CAL5 Standard 6	ICAL Spike Solution	2.0	Water	30	10
ICV Standard	ICV Spike Solution	1.0	Water	30	5.0

*Reagent water only.

Note: The working standards for the aqueous calibration curve get the same amounts of reagents added to them just like the samples (see section 9.6 below). For EPA method 245.1, the calibration standards skip the heating step. When preparing EPA method 7470A, the calibration standards are heated like the samples.

Table 8.5 – Working Standards for Soil/Wipe Calibration Curve

Standard	Source Standard	Standard Amount (mL)	Solvent	Starting Volume (mL)	Final Concentration (ug/L)
ICAL0 Standard 1/ICB/CCB*	NA	N/A	Water	10	0
CAL1 Standard 2/Low CHK	ICAL Spike Solution	0.10	Water	10	0.50
CAL2 Standard 3	ICAL Spike Solution	0.20	Water	10	1.0
CAL3 Standard 4	ICAL Spike Solution	0.40	Water	10	2.0
CAL4 Standard 5/CCV	ICAL Spike Solution	1.0	Water	10	5.0
CAL5 Standard 6	ICAL Spike Solution	2.0	Water	10	10
ICV Standard	ICV Spike Solution	1.0	Water	10	5.0

*Reagent water only.

Note: The working standards for the soil/wipe calibration curve undergo the same digestion procedures as the samples (see section 9.5 below).

Table 8.6 – Working Reagents

Working Reagent	Description
Hydroxylamine Hydrochloride Solution	Dissolve 120 g of hydroxylamine hydrochloride in a 1-L volumetric flask containing about 500mL of reagent water. Dilute to the mark with reagent water and invert several times to mix.
Potassium Permanganate Solution	Dissolve 50 g of potassium permanganate in a 1-L volumetric flask containing about 500mL of reagent water. Dilute to the mark with reagent water and invert several times to mix.
Potassium Persulfate Solution	Dissolve 50 g of potassium persulfate in a 1-L volumetric flask containing about 500mL of reagent water. Dilute to the mark with reagent water and invert several times to mix.
Stannous Chloride Solution	Add 60 mL of concentrated HCl to a 2-L volumetric flask containing 500-1000 mL reagent water. Add 22.2 g of stannous chloride and dissolve. Dilute to the mark with reagent water and invert several times to mix. Store in refrigerator at ≤6°C, but not freezing.
Hg Carrier Solution	In a 2-L volumetric flask, add 500 mL of reagent water and 60 mL of concentrated HCl. Dilute to the mark with reagent water and invert several times to mix.
QuickTrace Rinse Solution	Add 1000 mL of reagent water to the 2-L rinse bottle, followed by 100 mL concentrated HCl and 40 mL concentrated HNO_3. Dilute to the mark with reagent water and invert several times to mix.

9. PROCEDURE

9.1. Equipment Preparation

9.1.1. Support Equipment

All support equipment (balances, pipettors, thermometers, etc.) must be calibrated or verified prior to use according to SOP ENV-SOP-LENE-0030, *Support Equipment*, current revision or replacement.

9.1.2. **Instrument**

9.1.2.1 **Routine Instrument Operating Conditions**

1.1.1.1.1 Refer to instrument manual (manufacturer recommendations).

- *Gas Flow (mL/min): 100*
- *Sample Uptake (s): 40*
- *Rinse (s): 95*
- *Read Delay (s): 51 (adjusted as needed at start of each day)*
- *Replicates (s): 4*
- *Replicate Time (s): 1.5*
- *Pump Speed (%): 50*
- *Wavelength (nm): 253.7*

1.1.1.1.2 Allow the instrument to warmup for a minimum of 30 minutes for the lamp and pump to stabilize. See the manufacturer's instruction manual for maintenance and troubleshooting.

9.1.2.2 **Maintenance**

- Replace the Hg lamp every 6 months or when a noticeable loss in stability is observed.
- Replace the Perma Pure® Dryer Cartridge every 3-6 months or when the mercury absorbance for a given standard drops to 50% or more of its original value.
- Inspect the block digestors on a daily basis and report any problems to the supervisor. Send digestors back to manufacturer if repairs are needed.
- On a daily basis check the LED on the DI water still and ensure that it reads no less than 10 MΩ. Let the Department Manager know if the reading falls below 10 MΩ.
- Periodically clean the GLS and replace the drain tube.
- Change tubing on the peristaltic pump regularly.
- Recalibrate the thermometers in the Hotblocks annually.
- All maintenance is recorded in the Maintenance Log for the Teledyne Leeman Labs QuickTrace® M-7600 Mercury Analyzer.

9.2. **Initial Calibration**

To perform quantitative measurements, an initial calibration must be established before the analysis of samples. An initial calibration is an evaluation of the relationship between response of the instrument (or process) and the concentration of the target analytes.

All samples, where applicable, must be associated with an acceptable initial calibration. In general, if an initial calibration is not acceptable, corrective actions must be performed and all associated samples re-analyzed. If the sample re-analysis is not possible, data associated with an unacceptable initial calibration must be reported with appropriate data qualifiers.

See the Pace *Acceptable Calibration Practices for Instrument Testing* Policy, ENV-POL-CORQ-0005, current revision or equivalent, for additional information regarding acceptable calibration practices.

9.2.1. **Calibration Design**

An initial calibration curve using five calibration standards and a blank (method requirement is a blank and three calibration standards) is prepared and analyzed each working day (24 hour clock) or when CCVs do not meet acceptance criteria. The lowest concentration standard of the initial calibration curve must be at or below the reporting limit, a level below which all reported results must be qualified as estimated values.

9.2.2. **Calibration Sequence**

Run Number	Sample Description
1	HG-CAL0
2	HG -CAL1
3	HG -CAL2
4	HG -CAL3
5	HG -CAL4
6	HG -CAL5
7	ICV Standard (from 2nd source)
8	CRDL
9	CCV (as required by EPA 245.1)
10	ICB

9.2.3. **ICAL Evaluation**

9.2.3.1 **Curve Fit**

The calibration curve is a representation of the relationship of the instrument response and analyte concentration. The curve is used to quantitate the concentration of an unknown based on its response and this known relationship. A linear calibration curve is produced by this method.

Linear Regression – The linear regression calibration curve is derived from a least square's regression analysis of the calibration points. A calibration curve based on this technique will have the format of y= ax+b where "a" is the slope of the line and "b" is the y-intercept. The linear regression is not forced through the origin; therefore, there is a possibility that very low levels of contaminants below the response of the lowest calibration point may generate erroneous reportable results. A calculation of the correlation coefficient "r" is used to determine the acceptability of a linear regressed curve.

9.2.3.2 **Relative Standard Error (RSE)**

Initial calibrations using linear regression must be evaluated for Relative Error. Relative error can be calculated and evaluated by either of two options. The Mercury curve is evaluated using Relative Standard Error (%RSE). %RSE is analogous to %RSD. In fact, both SW-846 8000 and 40CFR Part 136 allow %RSE to be used in place of correlation coefficient (R) or coefficient of determination (r^2) for the acceptability determination of the curve.

The Mercury curve is evaluated using the following equation for Relative Standard Error (%RSE):

$$\% RSE = 100 \times \sqrt{\sum_{i=1}^{n} \left[\frac{x'i - xi}{xi}\right] \Big/ (n-p)}$$

xi = True Value of the Calibration Standard

x'i = Measured Concentration of the Calibration Standard

p = Number of terms in fitting equation

n = number of calibration points.

The % RSE is calculated by the instrument software and can be found on the results printout. In the absence of method defined criteria, the %RSE must be ≤ 20%.

When criteria for relative standard error are not met, the calibration is not acceptable for use. The source of the problem must be determined and corrected, or recalibration is required. If recalibration does not meet acceptance criteria, notify the department manager and Quality Manager to determine how to proceed.

9.2.3.3 **Initial Calibration Verification**

Because all calibration points are from the same source, it is possible that the calibration points may meet linearity criteria but not be accurately made in terms of their true value.

To assess the accuracy relative to the purity of the standards, a single standard from a secondary source must be analyzed and the results obtained must be assessed relative to the known true value. This verification process is performed using the standard referred to as the Initial Calibration Verification Standard (ICV). This secondary source must be from an alternative manufacturer or, in the event an alternative manufacturer is not available, from a different lot prepared independently by the same manufacturer. Prepare the ICV as specified in Section 8.2.9 and analyze immediately after the last initial calibration standard. The accuracy of the standard is assessed as a percent difference from the true value according to the following equation:

$$\% \, Difference = \frac{Result\ ICV - True\ Value\ ICV}{True\ Value\ ICV} \times 100$$

The ICV must be within ± 10% of its true value. ICV failure indicates that the working standards used for initial calibration or verification may not have been prepared correctly or are no longer adequate for use. When criteria are not met, investigation and corrective action is expected regardless of whether the ICV fails high or low.

If the ICV does not meet acceptance criteria, examine the data to determine the cause for failure:

Inspect the calibration and ICV standard preparation records to verify the parent materials used were not expired and/or have not degraded and verify the standard(s) were made properly in accordance with the test method SOP.

If no problems are found, remake and reanalyze the ICV. If the second ICV fails, remake the calibration standards and recalibrate the instrument.

Notify the department manager and Quality Manager if the additional calibration curve does not meet acceptance criteria.

Decisions to proceed with use of the calibration without resolution of the ICV failure, whether the failure is high or low, must be documented in the technical record by the individual making the decision with the rationale for which the decision was made.

Any test result reported for an analyte that did not meet ICV criteria must be qualified in the final test report to alert the end user of the data of the nonconformance.

Primary, secondary and tertiary data reviewers must confirm that any results reported for analyte(s) that did not meet ICV acceptance criteria are qualified in the final test report, regardless of level of type or level of report.

An Initial Calibration Blank (ICB) must be run after the ICV to verify the instrument is working correctly (i.e., there is no drift). The ICB should meet acceptance criteria of < ½ the Reporting Limit (RL/LOQ) for methods EPA 7470A/7471B and < the MDL for method EPA 245.1.

9.2.4. **Continuing Calibration Verification**

As part of the analytical process, the instrumentation must be checked daily to determine if the response has changed significantly since the initial calibration was established. The Continuing Calibration Verification Standard (CCV) is analyzed to check the validity of the initial calibration. The CCV is run prior to the analysis of any sample, after every ten samples, and at the end of the analytical sequence by analyzing a midpoint calibration standard. EPA 245.1 also requires a CCV to be run following the calibration curve. The accuracy of the standard is assessed as percent difference from the true value according to the following equation:

$$\% \, Difference = \frac{Result\ ICV - True\ Value\ ICV}{True\ Value\ ICV} \times 100$$

For EPA 245.1, a CCV must be run immediately following the calibration curve and must be within ± 5% of the true value. Subsequent CCVs must be within ± 10% of the true value. EPA 7470A and 7471B require CCVs to be within ± 10% of the true value. If the CCV does not meet acceptance criteria, examine the data to determine the cause for failure and impact to results.

If the identified cause of failure is known and affects only the CCV standard (such as improper standard preparation), then document corrective action and proceed if reanalysis of the CCV passes.

If the cause of the failure is unknown, then all samples analyzed prior to the failing CCV must be re-analyzed following corrective action and a passing CCV. If the source of the problem cannot be determined and corrected, recalibration is required.

See the Pace *Acceptable Calibration Practices for Instrument Testing* Policy, ENV-POL-CORQ-0005, current revision or equivalent, for additional information regarding continuing calibration verification corrective action.

A Continuing Calibration Blank (CCB) must be run after every CCV. The CCB should meet acceptance criteria of < ½ the Reporting Limit (RL/LOQ) for methods EPA 7470A/7471B and < the MDL for method EPA 245.1.

9.2.5. **Reporting Limit Verification Sample**

During daily sample analysis, a reporting limit verification standard (CRDL) must be run prior to running any samples.

The CRDL should be within ± 50% of the true value. If the CRDL does not meet acceptance criteria, it may be re-prepared and re-analyzed to determine if improper standard preparation occurred. If it still fails acceptance criteria, see the Department Manager and Quality Manager.

9.2.6. **Initial and Daily Calibration Acceptance Criteria**

The calibration criteria listed below must be met for each calibration curve/batch or additional actions must be performed.

Calibration Acceptance and Verification Criteria

Calibration Metric	Parameter / Frequency	Criteria	Comments/Corrective Actions
Calibration Curve Fit	Linear Regression	r ≥ 0.995	If not met, remake standards and recalibrate. Instrument maintenance may be required if problem persists.
Initial Calibration Verification Standard (ICV) **[Known as QCS in 245.1]**	Immediately after each initial calibration	7470/7471: 90-110% 245.1: 95-105%	May be reanalyzed once. A second failure confirms and requires re-preparation of standard and/or recalibration. If problem persists an alternative source standard may need to be obtained.
Low Level Check Standard (CRDL or RL)	Immediately after each initial calibration	50-150%	May be reanalyzed once. A second failure confirms and requires re-preparation of standard and/or recalibration
Initial Calibration Verification Blank (ICB)	Immediately after each Initial Calibration Verification Standard	Result should be less than the reporting limit. If results are reported to MDL, the ICB must be evaluated to the MDL.	May be reanalyzed once. A second failure confirms and requires corrective action (e.g., re-preparation of standard(s) and/or recalibration) **Exceptions:** If sample results are reported to MDL and ICB is <RL but >MDL, then corrective action is not necessarily other than appropriately qualifying the sample results. Unless the customer's QAPP or technical specification instruct to do otherwise. Samples that are <RL may be reported without qualification. (Not applicable to samples reporting down to MDL) Samples >10x ICB may be reported with appropriate qualification.
Continuing Calibration Verification (CCV)	Prior to the analysis of any samples and every 10 samples thereafter. Samples need to be bracketed with CCVs	7470/7471: 80-120% 245.1: 90-110%	May be reanalyzed once. A second failure confirms and requires corrective action (e.g. re-preparation and/or recalibration). **Exception:** If CCV fails high, then sample(s) that are <RL may be reported with appropriate qualification.

9.3. **Sample Preparation**

9.3.1. **Homogenization and Subsampling**

Refer to the current SOP ENV-SOP-LENE-0135, Sample Homogenization and Sub-sampling.

9.3.2. **Sample Batch Preparation**

1. Before beginning the digestion, obtain a batch number and fill in the electronic logbook for each set of samples of a similar matrix and analytical requirements using the assigned HBN number.
2. The electronic logbook for the scheduled batch is examined prior to beginning the digestion process to ensure that no more than 20 samples are scheduled for the batch and that all samples require the scheduled digestion. If an error is detected in the scheduled batch, the error is fixed before proceeding with the digestion. The scheduled samples are batched in Epic and all digestion data (sample volumes, spiking information, etc.) is entered directly into the electronic logbook.
3. Obtain all the samples from their respective places on the storage shelves. Log them out from the EPIC using the barcode reader.
4. Set out the number of digestion cups required for the sample batch. All samples in the batch must be digested in the same type of digestion cup.
5. Labels printed from Epic Pro are attached on the upper side of each digestion cup. Also label digestion cups to be used for QC samples and calibration standards (if first digestion batch of the day). Make sure the labels match the corresponding sample or QC.

9.4. **Filtration for dissolved metals analysis (Total mercury samples are not filtered for EPA Method 245.1, Rev. 3.0).**

9.4.1. Dissolved samples are normally filtered in the field; however, samples are filtered in the laboratory in certain instances. The dissolved sample is prepared by filtering an aliquot of unpreserved sample through a 0.45-um, cellulose nitrate filter and preserving with nitric acid.

9.4.1.1 Rinse the filtration apparatus (Erlenmeyer flask, filtration top and bottom) with 20% nitric acid, followed by five rinses with reagent water.

9.4.1.2 A 0.45-um filter is placed on the filtration support with a forceps

9.4.1.3 The filtration top is attached, and the pump tubing is attached to the flask

9.4.1.4 Add 150 mL of reagent water to the filtration apparatus and start the pump.

9.4.1.5 After the reagent water has passed through the filter, turn the pump off and disconnect the tubing from the pump. Remove the filter support and pour the filtered aliquot into a pre-certified, HNO_3-preserved, 250-mL sample bottle (obtain from Bottle Prep Department).

9.4.1.6 This aliquot of reagent water serves as the method blank for the batch.

9.4.1.7 Label the bottle with the date, analyst's initials and attach a sample identification label.

9.4.1.8 Repeat steps 1 through 6 for up to twenty samples (substituting the sample for reagent water in Step 4).

9.4.1.9 Record the filter lot number in the digestion logbook.

9.4.1.10 The samples are now ready for digestion. The filtered blank is carried through the digestion process and takes the place of the method blank.

9.5. **Soil Digestion**

9.5.1. Begin by preparing the working standards as outlined in Table 10.5 above.

9.5.2. Method Blank: Add 0.3-0.4 g of boiling stones to a digestion tube. Bring volume to 10 mL with reagent water.

9.5.3. LCS: Add 0.3-0.4 g of boiling stones to a digestion tube, and spike with 1.0 mL of the Working Calibration Standard. After the spike has been added, bring volume to 10 mL with reagent water.

9.5.4. MS/MSD: Weigh into a digestion tube 0.3-0.4 g (soil) of a well homogenized portion of the selected sample. (Homogenization procedures can be found in S-KS-Q-046-rev.1, Sample Homogenization and Sub-Sampling, or its equivalent revision or replacement.) Spike with 1.0 mL of the Working Calibration Standard. After the spike has been added, bring volume to 10 mL with reagent water.

9.5.5. Client samples: Weigh into a digestion tube 0.3-0.4 g (soil) of a well homogenized portion of the selected sample. (Homogenization procedures can be found in S-KS-Q-046, Sample Homogenization and Sub-Sampling, or its equivalent revision or replacement.) Bring volume to 10 mL with reagent water.

9.5.5.1 Sludge samples: use 1 to 2 g.

9.5.6. Add 1.25 mL HNO_3 and 3.75 mL HCl to all digestion tubes including calibration curve, ICV/CCV, Method Blank, LCS, MS/MSD, and Client Samples. CAUTION: Perform this step inside a fume hood.

9.5.7. Heat all the digestion tubes in a hot block at 90-95°C for 2 minutes.

9.5.8. Remove the tubes from the hot block and allow them to cool to room temperature.

9.5.9. Bring volume of each tube to 25mL with reagent water. Add 5.0 mL of potassium permanganate solution to each tube and allow them to stand at least 15 minutes. Note: If the samples do not maintain their purple color at this step, add an additional 5.0mL of the $KMnO_4$ solution and wait an additional 15 minutes. If the purple color is still not maintained, use less sample volume and repeat this process. Also notify the department supervisor about this situation.

- Note: If additional $KMnO_4$ is added to a sample, then additional $KMnO_4$ also needs to be added to the Method Blank and the LCS. In this event, it is imperative to maintain the same final volume for all tubes processed together.

9.5.10. Place each tube back into the 90-95°C hot block, cover with watch glass, and allow them to digest for at least 30 minutes.

9.5.11. Remove the tubes and allow them to cool to room temperature.

9.5.12. Verify that the volume of each tube is 30mL and bring volume up to 30mL with reagent water if needed.

9.5.13. Add 1.8 mL of hydroxylamine hydrochloride solution to remove the excess permanganate. Note: Perform this step in a fume hood, as chlorine gas may evolve.

9.5.14. The samples are then ready for analysis. Note: A basis of 30mL is used to calculate the final results of the samples.

9.6. **Digestion of Water, TCLP and SPLP Leachates**

9.6.1. Begin by preparing the working standards as outlined in Table 10.4 above.

9.6.2. Method Blank: Measure 30 mL of reagent water into a digestion tube. Note: For TCLP use 10 mL of the leachate blank and 20 mL of reagent water. For SPLP use 30 mL of leachate blank.

9.6.3. LCS: Measure approximately 10 mL of reagent water into a digestion tube. Add 1.0 mL of the Working Calibration Standard to the digestion tube and dilute to 30 mL with reagent water. Note: For TCLP use 10 mL of the leachate blank and 19 mL of reagent water. Extra permanganate is necessary to reduce positive chloride interference from TCLP fluid.

9.6.4. MS/MSD: Measure 30 mL of the selected water sample or SPLP leachate into each of two digestion tubes. Add 1.0 mL of the Working Calibration Standard to each digestion tube. Note: For TCLP use 10 mL of the sample leachate and 20 mL of reagent water.

9.6.5. Client samples: Measure 30 mL of the water sample or SPLP leachate into a digestion tube. Note: For TCLP use 10 mL of the sample leachate and 20 mL of reagent water.

9.6.6. Add 1.5 mL of concentrated H_2SO_4 and 0.75 mL of concentrated HNO_3 to each digestion tube.

9.6.7. Add 5.0 mL of $KMnO_4$ solution to each of the digestion tubes and allow them to stand at least 15 minutes. Note: If the samples do not maintain their purple color at this step, add an additional 5.0mL of the $KMnO_4$ solution and wait an additional 15 minutes. If the purple color is still not maintained, use less sample volume and repeat this process. Also notify the department supervisor about this situation.

- Note: If additional $KMnO_4$ is added to a sample, then additional $KMnO_4$ also needs to be added to the Method Blank and the LCS. In this event, it is imperative to maintain the same final volume for all tubes processed together.

9.6.8. Add 2.5 mL of potassium persulfate solution to each digestion tube.

9.6.9. Heat the tubes for 2 hours in a 90-95°C hot block. (Note: Calibration standards used for EPA 245.1 skip this heated step. This includes the ICV, CCV, and RL standards. Calibration standards used for 7470A are heated just like the samples.)

9.6.10. Remove the tubes from the hot block and allow them to cool to room temperature.

9.6.11. Verify that the volume of each tube is 40mL and bring volume up to 40mL with reagent water if needed.

9.6.12. Add 1.8 mL of hydroxylamine hydrochloride solution to remove the excess permanganate. NOTE: Perform this step in a fume hood, as chlorine gas may evolve.

9.6.13. The samples are now ready for analysis. Note: A basis of 30mL is used to calculate the final results of the samples.

9.7. **Optional reduced volume digestion**

9.7.1. Pour 10 mL of sample (or 3.3 mL of a TCLP leachate) into a 15-mL digestion tube.

9.7.2. Add 0.5 mL of sulfuric acid and 0.3 mL of nitric acid to each digestion tube.

9.7.3. Add 1.7 mL of potassium permanganate solution to each of the digestion tubes and allow them to stand at least 15 minutes. Note: If the samples do not maintain their purple color at this step, add an additional 1.0mL of the $KMnO_4$ solution and wait an additional 15 minutes. If the purple color is still not maintained, use less sample volume and repeat this process. Also notify the department supervisor about this situation.

- Note: If additional $KMnO_4$ is added to a sample, then additional $KMnO_4$ also needs to be added to the Method Blank and the LCS. In this event, it is imperative to maintain the same final volume for all tubes processed together.

9.7.4. Add 0.8 mL of potassium persulfate to each digestion tube.

9.7.5. Cap and place digestion tubes in the hot block for 2 hours at 90-95°C.

9.7.6. Remove the tubes from the hot block and allow them to cool to room temperature

9.7.7. Add 0.6 mL of hydroxylamine hydrochloride solution to remove the excess permanganate. NOTE: Perform this step in a fume hood, as chlorine gas may evolve.

9.8. **Ghost Wipe™ Digestion**

9.8.1. Begin by preparing the working standards as outlined in Table 10.5 above.

9.8.2. Method Blank: Place one unused Ghost Wipe™ in a digestion tube.

9.8.3. LCS: Place one unused Ghost Wipe™ in a digestion tube and spike with 1.0 mL of the Working Calibration Standard.

9.8.4. Add 5 mL of reagent water to all digestion tubes including calibration curve, ICV/CCV, Method Blank, LCS, MS/MSD, and Client Samples.

9.8.5. Add 5 mL of concentrated HNO_3 to all digestion tubes and place them into a hot block at 90-95 °C for a minimum of 15 minutes. NOTE: It is necessary to continue heating until the Ghost Wipes™ have completely dissolved.

9.8.6. Remove the tubes from the hot block and allow them to cool to room temperature.

9.8.7. Add 5 mL of 1:1 HCl, 10 mL of reagent water and 5 mL of potassium permanganate solution to each tube and cover with cap. Place each tube back into the 90-95 °C hot block and allow them to digest for 15 minutes.

9.8.8. Remove the tubes and allow them to cool to room temperature.

9.8.9. Add 1.8 mL of hydroxylamine hydrochloride solution to remove the excess permanganate. NOTE: Perform this step in a fume hood, as chlorine gas may evolve.

9.8.10. The samples are then ready for analysis.

9.9. **Analysis by Perkins Elmer FIMS 400**

9.9.1. Before startup of the instrument, inspect the pump tubing for signs of wear and replace if necessary.

9.9.2. Check gas supply. Argon pressure should be regulated to 50 psi.

9.9.3. Turn computer on and log in according to instructions given by the IT staff. Confirm FIMS main power switch is in the on position. After confirmation of the switch setting, double click on the WinLab icon to initialize the instrument setup routine. After routine is complete go to toolbar at the top of the screen and double click on the Method window. Select the correct operating method (See the supervisor) and double click to load the method.

9.9.4. Allow the instrument to warm up for at least one hour. This allows the instrument to stabilize before analysis begins and will eliminate instrument drift as analysis occurs.

9.9.5. Place the standards in the autosampler cups in the following sequence: Calibration Blank-Position 1, RL(0.2 for Waters, 0.5 for Soils)-Position 2, 1.0 ug/L-Position 3, 2.0 ug/L-Position 4, 5.0 ug/L-Position 5, 10.0 ug/L-Position 6, Low Level CHK-Position 7 and ICV/CCV-Position 8.

9.9.6. Place the Reductant line into the Stannous Chloride solution and the Carrier line into the Hg Carrier solution prior to analysis. The Reductant line has a red connector and uses the red-red pump tubing while the Carrier line uses the yellow-blue tubing. Verify that these lines are properly connected according to the diagram on the instrument manifold.

9.9.7. The autosampler table is set up as follows. At one of the computer workstations, double click on the Limslink icon. Follow the instructions for creating a Lims autosampler for the FIMS. Close and exit the Lims spreadsheet. Return to the FIMS WinLab menu. Locate the File menu on the toolbar and click. Go to Open Autosampler and double-click. Locate the autosampler table created and identified in the Lims method. Double click. Autosampler table is now loaded into the FIMS autosampler method.

9.9.8. Load samples in the positions indicated on the autosampler menu. Return to FIMS WinLab menu. Locate Auto icon on the toolbar. Click and the automated analysis window opens. Double click on gray SET UP tab and click on correct method, hit ok. Double click on the Results Data Set. Type in the date of the analysis and hit enter. This saves the data to this results file.

9.9.9. Click on the Analyze tab on the automated analysis window. Click the Analyze All button. The instrument will now perform the automated analysis in the sequence indicated by Table 4.

9.10. **Analysis by Cetac M-7500/M7600 QuickTrace Mercury Analyzer**

9.10.1. Open Quicktrace software and turn on the lamp. Allow 30 minutes for the unit to stabilize. Verify that the gas pressure is between 110 and 120 psi. Empty drain bottle if needed. Fill the reagent bottle with stannous chloride and verify that the rinse bottle is filled adequately..

9.10.2. Click on Instrument tab in the toolbar, set the carrier gas to 100mL/min. Inspect pump tubing, replace any worn tubing and then lock into place. Place rinse tubing and recirculator into rinse bottle and stannous line into the reagent bottle. Do not lock shoe clamps on the pump tubing at this time.

9.10.3. In the Instrument tab click on the auto-sampler button, turn on the rinse pumps and lower sipper into rinse station. Verify that the vents are open on the waste container.

9.10.4. Open the method template appropriate to the run by clicking on File-Open-QuickTrace-Templates-Pace Templates.

9.10.5. Lock down shoe clamps, click on the analyzer button. Set pump speed to 35% and start pumps. Verify a smooth flow in both the auto-sampler line and the stannous line.

9.10.6. Open the optical cabinet door by loosening the thumbscrew on the front of the instrument. Verify sample flowing over the center post in the Gas Liquid Separator (GLS). Place Chemwipe™ by exhaust port on top of GLS. Increase gas to 350 mL/min and pump speed to 100%, pinch drain tubing allowing several bubbles to rise up the center post to wet it fully. Center post should change from a frosted look to clear. Remove Chemwipe™ and allow GLS to drain fully. Reduce carrier gas back to 100mL/min as well as setting pump speed to 35%.

9.10.7. Attach the naphyion to the exhaust port at the top of the GLS and close the optical cabinet door. Allow several minutes to stabilize and click on the lamp status button located in the analyzer tab and record the lamp current in the logbook.

9.10.8. Click on the Sequence button in the toolbar and enter the sample information into the table. Place the standards in the appropriate slot on the auto-sampler; 0=S:1, RL(0.2 for Waters, 0.5 for Soils)=S:2, 1.0=S:3, 2.0=S:4, 5.0=S:5, 10.0=S:6, ICV/CCV=S:7. Pour samples and place in appropriate slots on the auto-sampler. Then go to File→Save As MMDDYYMethod(i.e.-040112S for Soil run on 04/01/16). Save file to QuickTrace\Data.

9.10.9. Click the GO button in the toolbar to begin analysis. The QuickTrace will perform an autozero and a calibration designated by the method selected, followed by an analysis of the samples entered into the sequence table. Record the absorbance of the 10 ug/L standard in the log book.

9.10.10. Upon completion of analysis place the stannous tubing in a 10% Nitric acid solution and allow to rinse for 10 minutes. Disconnect the GLS exhaust tubing from the top. Increase carrier gas to 350mL/min and pump speed to 100%. Place Chemwipe by exhaust port and pinch drain tubing. Allow solution to bubble up over the center post and drain out completely to clean the GLS. Repeat 2-3 times to ensure full cleaning of the post. If pumps stop due to overflow sensor just restart and continue.

9.10.11. Place stannous line in reagent water to rinse and remove rinse tubing from rinse bottle and place in plastic bag, leave recirculator tubing in the rinse bottle.

9.10.12. Allow autosampler rinse station to dry fully and no more rinse should be seen in the recirculator tubing. Remove the stannous line from reagent water and raise the sipper. Remove recirculator line from rinse bottle and place in bag with the rest of the rinse tubing. Allow all lines to run dry, when nothing can be seen moving through the waste line close the vents on the waste container.

9.10.13. Click Instrument Tab, Analyzer. Stop pumps and release shoe clamps. Loosen the tubing to prevent further wear. Set carrier gas to 0 mL/min, close gas off at regulator as well, and turn off the lamp.

9.10.14. Software should be closed if the unit will not be used for an extended period of time (>1day).

9.11. **Example Analytical Sequence**

Typical Sequence with Continuing Calibration

Run Number	Sample Description
1	CRDL
2	CCV
3	CCB
4	Method Blank
5	LCS
6	Sample 1
7	Sample 1-MS (or MS1; 245.1 only)*
8	Sample 1-MSD (7470A and 7471B)
9	Post Digestion Spike
10	Sample 2
11	Sample 3
12	Sample 4
13	Sample 5 (or Sample 4 Dup if requested)
14	CCV
15	CCB
16	Sample 6
17	Sample 7
18	Sample 8
19	Sample 9
20	Sample 10
21	Sample 11
22	Sample 12 (or Sample 11 MS2; 245.1 only)*
23	Sample 13
24	Sample 14
25	Sample 15
26	CCV
27	CCB
28-32	Sample 16-20
33	CCV
34	CCB

*MS required for 10% of samples for 245.1

10. DATA ANALYSIS AND CALCULATIONS

10.1. Quantitative Identification

10.1.1. The instrument software automatically calculates the Mercury concentration of the sample from a comparison of the sample absorbance reading and the calibration curve.

10.2. Calculations

See the Laboratory Quality Assurance Manual for equations for common calculations.

Quantitative results are calculated as shown in Equation 10-1, -2, and -3:

Equation 10-1:

$$\text{Mercury aqueous}\left(\frac{\mu g}{L}\right) = \frac{\boldsymbol{ppb\ Hg\ x\ 60\ mL}}{\boldsymbol{40\ mL}} \times \mathbf{D}$$

where: 60 mL is the final volume of the sample

40 mL is the initial sample volume.

D is any dilution factor required.

Equation 10-2:

$$\text{Mercury TCLP}\left(\frac{\mu g}{L}\right) = \frac{\boldsymbol{ppb\ Hg\ x\ 60\ mL}}{\boldsymbol{6\ mL}} \times \mathbf{D}$$

where: 60 mL is the final volume of the sample

6 mL is the initial sample volume.

D is any dilution factor required.

Equation 10-3:

$$\text{Mercury solid}\left(\frac{\mu g}{kg}\right) = \frac{\boldsymbol{ppb\ Hg\ x\ Vf}}{\boldsymbol{weight\ of\ sample}} \times \mathbf{D}$$

where: Vf is the final volume of the sample

D is any dilution factor required.

10.3. Epic Pro Reporting

Digestion prep data is recorded in the electronic logbook and saved as the batch ID and analysis. The analyst must document any sample or batch information determined to be outside normal procedure in either the Sample Notes or Batch Notes (including adding additional Potassium Permanganate if needed).

Review all digestion data for data entry errors and Save the finished data in the logbook. Send batch for secondary review. Clone the MPRP batch to create an analytical batch for the instrument analyst. Post data from the Electronic logbook into Epic Pro.

Go to Epic Pro and open the batch to check the validation report. Check for data entry errors and quality control issues before exiting the screen. Submit batch paperwork for secondary review Quality Control and Method Performance

11.0 QUALITY CONTROL AND METHOD PERFORMANCE

11.1 Batch QC

The following QC samples are prepared and analyzed with each batch of samples. Refer to Appendix A for acceptance criteria and required corrective action.

QC Item	Frequency per batch
Method Blank (MB)	1 per batch of 20 or fewer samples.
Laboratory Control Sample (LCS)	1 per batch of 20 or fewer samples.
Matrix Spike/Duplicate (MS/MSD)	1 MS/MSD pair per batch of 20 or fewer samples for EPA 7470A and EPA 7471B. 1 MS per 10 samples for EPA 245.1.
Sample Duplicate	Sample/Sample Dup run if requested by a client or for verification purposes.

11.2 Instrument QC

The following Instrument QC checks are performed. Refer to Appendix A for acceptance criteria and required corrective action.

QC Item	Frequency
Initial Calibration	Every 24 hours.
Initial Calibration Verification (ICV)	Immediately after each Initial Calibration.
Initial Calibration Blank (ICB)	Immediately after each Initial Calibration Verification (ICV) Standard.
Continuing Calibration Verification (CCV)	After the ICV as part of the Initial Calibration (required for EPA 245.1). (Referred to as the IPC solution in the EPA 245.1 method.) Prior to the analysis of any samples, after every 10 samples, and at the end of a run.
Continuing Calibration Blank (CCB)	Prior to the analysis of any samples, after every 10 samples, and at the end of a run. Immediately following each Continuing Calibration Verification Standard.
Reporting Limit Verification/Lower Limit of Quantitation Check/Contract Reporting Detection Limit (CRDL)	At the beginning of the batch, before any samples including QC are run.

11.3 Method Performance

11.3.1 Method Validation

11.3.1.1 Detection Limits

Detection limits (DL) and limits of quantitation (LOQ) are established at initial method setup and verified on an on-going basis thereafter. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 Method Validation.

11.4 Analyst Qualifications and Training

Employees that perform any step of this procedure must have a completed Read and Acknowledgment Statement for this version of the SOP in their training record. In addition, prior to unsupervised (independent) work on any client sample, analysts that prepare or analyze samples must have successful initial demonstration of capability (IDOC) and must successfully demonstrate on-going proficiency on an annual basis. Successful means the initial and on-going DOC met criteria, documentation of the DOC is complete, and the DOC record is in the employee's training file. Refer to laboratory SOP ENV-SOP-LENE-0110, *Training Procedures* for more information.

12. DATA REVIEW AND CORRECTIVE ACTION

12.1. Data Review

Pace's data review process includes a series of checks performed at different stages of the analytical process by different people to ensure that SOPs were followed, the analytical record is complete and properly documented, proper corrective actions were taken for QC failure and other nonconformance(s), and that test results are reported with proper qualification.

The review steps and checks that occur as employee's complete tasks and review their own work is called primary review.

All data and results are also reviewed by an experienced peer or supervisor. Secondary review is performed to verify SOPs were followed, that calibration, instrument performance, and QC criteria were met and/or proper corrective actions were taken, qualitative ID and quantitative measurement is accurate, all manual integrations are justified and documented in accordance with the Pace ENV's SOP for manual integration, calculations are correct, the analytical record is complete and traceable, and that results are properly qualified.

A third-level review, called a completeness check, is performed by reporting or project management staff to verify the data report is not missing information and project specifications were met.

Refer to laboratory SOP ENV-SOP-LENE-088, *Data Reduction, Review and Reporting*, for specific instructions and requirements for each step of the data review process.

12.2. Corrective Action

Corrective action is expected any time QC or sample results are not within acceptance criteria. If corrective action is not taken or was not successful, the decision/outcome must be documented in the analytical record. The primary analyst has primary responsibility for taking corrective action when QA/QC criteria are not met. Secondary data reviewers must verify that appropriate action was taken and/or that results reported with QC failure are properly qualified.

Corrective action is also required when carryover is suspected and when results are over range.

Samples analyzed after a high concentration sample must be checked for carryover and reanalyzed if carryover is suspected. Carryover is usually indicated by low concentration detects of the analyte in successive samples analyzed after the high concentration sample.

Sample results at concentrations above the upper limit of quantitation must be diluted and reanalyzed. The result in the diluted samples should be within the upper half of the calibration range. Results less than the mid-range of the calibration indicate the sample was over diluted and analysis should be repeated with a lower level of dilution. If dilution is not performed, any result reported above the upper range is considered a qualitative measurement and must be qualified as an estimated value.

Refer to Appendix B for a complete summary of QC, acceptance criteria, and recommended corrective actions for QC associated with this test method.

13. Pollution Prevention And Waste Management

Pace proactively seeks ways to minimize waste generated during our work processes. Some examples of pollution prevention include but are not limited to: reduced solvent extraction, solvent capture, use of reusable cycletainers for solvent management, and real-time purchasing.

The EPA requires that laboratory waste management practice to be conducted consistent with all applicable federal and state laws and regulations. Excess reagents, samples and method process wastes must be characterized and disposed of in an acceptable manner in accordance with Pace's Chemical Hygiene Plan / Safety Manual.

14. Modifications

A modification is a change to a reference test method made by the laboratory. For example, changes in stoichiometry, technology, quantitation ions, reagent or solvent volumes, reducing digestion or extraction times, instrument runtimes, etc. are all examples of modifications. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 *Method Validation and Instrument Verification* for the conditions under which the procedures in test method SOPs may be modified and for the procedure and document requirements.

14.1. Hydrochloric acid is used in place of sulfuric acid in making the stannous chloride solution. This modification is used to keep the stannous chloride from precipitating out. This precipitation would cause the instrument lines to clog and force the instrument to be inoperable. Using the HCl eliminates this and ensures longer stability of the stannous chloride solution.

14.2. For solid samples, well homogenized portions are weighed as per 7471B. Triplicate portions of solid samples are not taken as per 7471A.

15. Responsibilities

Pace ENV employees that perform any part this procedure in their work activities must have a signed Read and Acknowledgement Statement in their training file for this version of the SOP. The employee is responsible for following the procedures in this SOP and handling temporary departures from this SOP in accordance with Pace's policy for temporary departure.

Pace supervisors/managers are responsible for training employees on the procedures in this SOP and monitoring the implementation of this SOP in their work area.

16. ATTACHMENTS

None.

17. REFERENCES

17.1. Methods for the Determination of Metals in Environmental Samples, Supplement 1 (EPA/600/R-94/111), Revision 3.0, Method 245.1.

17.2. EPA Test Methods for Evaluating Solid Waste. SW-846, Third Edition, Update IV, 2/2007, Methods 7000B and 7471B.

17.3. EPA Test Methods for Evaluating Solid Waste. SW-846, Third Edition, Update II, 9/1994, Methods 7470A and 7471A.

17.4. EPA Test Methods for Evaluating Solid Waste. SW-846, Third Edition, Update I, 7/1992, Method 7000A.

17.5. Federal Register, Volume 72, Page 11200, Method Update Rule.

17.6. Pace Quality Assurance Manual - most current version.

17.7. National Environmental Laboratory Accreditation Conference (NELAC), Chapter 5, "Quality Systems"- most current version.

18. REVISION HISTORY

This Version: ENV-SOP-LENE-0059_V2

Section	Description of Change
All	New SOP template

This document supersedes the following document(s):

Document Number	*Reason for Change*	*Date*
S-KS-M-006-rev.11	Section 10 – Converted standard and reagent prep into table format Table 10.2 – Added standard expiration and storage Section 10.4.1 – Added note about water ICAL prep. 245.1 no heat and 7470 w/ heat Section 10.5.1 – Added note about soil ICAL prep. Same as samples Section 11 – Reworded and added general descriptions Section 12.2.9 – Revised add 10mL of DI to bring volume to 25mL with DI. Revised note to add additional KMnO4 solution instead of adding neat crystals. Section 12.2.12 – Added verify 30mL volume and bring to 30mL if necessary before the hydroxylamine addition. The 30mL final volume was after the hydroxylamine addition in previous revision. Section 12.2.14 – Added note about 30mL basis Section 12.3.7 – Revised note to add additional KMnO4 solution instead of adding neat crystals. Section 12.3.9 – Revised note. 245.1 ICAL no heat and 7470 ICAL w/ heat Section 12.3.11 – Added 40mL volume verification, and bring to 40mL if necessary Section 12.3.13 – Added note about 30mL basis Section 12.4.3 – Added 15min wait to see if purple color sticks Table 13.1 – Reworded and removed Replicate Table 13.2 – Added sample QC table for Replicate Section 14 – Added note about 30mL final volume basis used to calc results Section 17 – Removed 7470 mod about no heat ICAL Attachments II, III, and IV - Added	February 3, 2014
S-KS-M-006-rev.12	SOP - Updated to latest prescribed format. Added sections for Instrument/Equipment Maintenance and Troubleshooting. Section 10 – Added equivalency statement. Table 10.1– Updated reagent sources/item #'s Section 12.7.9 – Removed Autozero step and replaced with following section.	February 23, 2015
S-KS-M-006-rev.13	Section 12.2.4-Corrected reference to Sample Homogenization SOP Section 10.2, 10.3 – Intermediate (Working) Spike Solution verification added.	September 18, 2015
S-KS-M-006-rev.14	Table 13.1, Error correction; "Phosphorus" removed as the element spiked.	October 5, 2015

Document Number	*Reason for Change*	*Date*
S-KS-M-006-rev.15	SOP – Revised formatting and Pace Inc. to Pace LLC Section 2.0 – Removed reference to FIMS, sentences restructured. Table 7.1 – Added Method 245.1 samples held for 24 hours after preservation and before prep begins. Section 12.1 – Added not filtering Method 245.1 samples for Total Mercury. Section 12.2.2 – Weight range of boiling stones changed. Section 12.2.5.1 – Added Section 12.2.9 – Added to maintain same final volumes for all tubes processed. Section 12.3.7 – Added to maintain same final volumes for all tubes processed. Section 12.7.7 – Added clarification to exhaust line connections.	December 20, 2016
S-KS-M-006-rev.16	SOP – Revised cover. Table 13.1 – Revised for MS/MSD recovery using 7471B is 80-120%. Section 12.7 – Revised instrument pump speed from 50% to 35%.	September 5, 2017
S-KS-M-006-rev.17	Table 13.1—Added RSD criteria.	January 5, 2018
S-KS-M-006-rev.18	SOP – Revised cover to 2018 dates Section 11.1.2 and 11.1.3 from rev. 17 removed (Not Applicable Calibration techniques) Section 18.3.2 – Changed RSD criteria to 20%.	July 18, 2018
SOP-LENE-0059-01	Master Control Published	October 8, 2018
ENV-SOP-LENE-0059-02	Table 10.4 and Table 10.5 – Revised for terminology Section 12.3.3 – Revised LCS instructions Section 12.3.4 – Revised MS/MSD instructions	September 4, 2019

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ENVIRONMENTAL SCIENCES

Document Information

Document Number: ENV-SOP-LENE-0023 **Revision:** 02

Document Title: Conductivity

Department(s): Wet Chemistry

Date Information

Effective Date: 31 Aug 2021

Notes

Document Notes:

All Dates and Times are listed in: Central Time Zone

Signature Manifest

Document Number: ENV-SOP-LENE-0023 **Revision:** 02

Title: Conductivity

All dates and times are in Central Time Zone.

ENV-SOP-LENE-0023 (Conductivity & Salinty)

QM Approval

Name/Signature	Title	Date	Meaning/Reason
Kenneth Busch (991414)	Manager - Quality	23 Aug 2021, 10:51:08 AM	Approved

Management Approval

Name/Signature	Title	Date	Meaning/Reason
Kenneth Busch (991414)	Manager - Quality	23 Aug 2021, 10:51:20 AM	Approved
Joshua Cunningham (003261)	Manager	23 Aug 2021, 11:09:09 AM	Approved
Charles Girgin (002243)	General Manager 2	25 Aug 2021, 11:05:10 AM	Approved

TEST METHOD STANDARD OPERATING PROCEDURE
TITLE: Specific Conductivity and Salinity
TEST METHOD SM 2510B and SM 2520B
ISSUER: Pace ENV – Lenexa Quality – LENE

1.0 Scope And Application

This standard operating procedure (SOP) describes the laboratory procedure for the determination of Conductivity and Salinity by electrode meter.

1.1 Target Analyte List and Limits of Quantitation (LOQ)

The target analytes and the normal LOQ that can be achieved with this procedure are provided in achieved with this procedure is 1.0 µmhos/cm for Conductivity and 1.0 ppth (part per thousand). MDLs are not applicable to this procedure.

LOQ are established in accordance with Pace policy and SOPs for method validation and for the determination of detection limits (DL) and quantitation limits (LOQ). DL and LOQ are routinely verified and updated when needed. The current LOQ for each target analyte that can be determined by this SOP as of the effective date of this SOP is provided in Table 1, Appendix A.

The reporting limit (RL) is the value to which analytes are reported as detected or not detected in the final report. When the RL is less than the lower limit of quantitation (LLOQ), all detects and non-detects at the RL are qualitative. The LLOQ is the lowest point of the calibration curve used for each target analyte.

DL, LOQ, and RL are always adjusted to account for actual amounts used and for dilution.

2.0 Summary of Method

2.1 The specific conductance or salinity of a sample is measured using a self-contained conductivity meter, Wheatstone Bridge type, or equivalent.

2.2 Samples are preferably analyzed at 25°C. If not, the instrument will apply a Temperature Compensation factor of 2% per ºC

3.0 Interferences

3.1 Coatings of oily material or particulate matter can impair electrode response. The electrode should be thoroughly rinsed and cleaned between samples.

4.0 Definitions

Refer to the Laboratory Quality Manual for a glossary of common lab terms and definitions.

5.0 Health and Safety

The toxicity or carcinogenicity of each chemical material used in the laboratory has not been fully established. Each chemical should be regarded as a potential health hazard and exposure to these compounds should be as low as reasonably achievable.

The laboratory maintains documentation of hazard assessments and OSHA regulations regarding the safe handling of the chemicals specified in each method. Safety data sheets for all hazardous

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chemicals are available to all personnel. Employees must abide by the health, safety and environmental (HSE) policies and procedures specified in this SOP and in the Pace Chemical Hygiene / Safety Manual.

Personal protective equipment (PPE) such as safety glasses, gloves, and a laboratory coat must be worn in designated areas and while handling samples and chemical materials to protect against physical contact with samples that contain potentially hazardous chemicals and exposure to chemical materials used in the procedure.

Concentrated corrosives present additional hazards and are damaging to skin and mucus membranes. Use these acids in a fume hood whenever possible with additional PPE designed for handing these materials. If eye or skin contact occurs, flush with large volumes of water. When working with acids, always add acid to water to prevent violent reactions. Any processes that emit large volumes of solvents (evaporation/concentration processes) must be in a hood or apparatus that prevents employee exposure.

Contact your supervisor or local HSE coordinator with questions or concerns regarding safety protocol or safe handling procedures for this procedure.

6.0 Sample Collection, Preservation, Holding Time, and Storage

Samples should be collected in accordance with a sampling plan and procedures appropriate to achieve the regulatory, scientific, and data quality objectives for the project.

The laboratory performs samples collection for samples to be analyzed by this SOP in accordance with laboratory SOP ENV-SOP-LENE-0107, *Field Manual*. Refer to this SOP for these instructions.

The laboratory will provide containers for the collection of samples upon client request for analytical services. Bottle kits are prepared in accordance with laboratory SOP ENV-SOP-LENE-0025, *Assembly of Sample Container Kits*.

Requirements for container type, preservation, and field quality control (QC) for the common list of test methods offered by Pace are included in the laboratory's quality manual.

General Requirements

Matrix	Routine Container	Minimum Sample Amount[1]	Preservation	Holding Time
Aqueous	Plastic or glass, 250 or 500 mL	50 mL	Thermal: ≤6°C (not frozen) Chemical: None	28 days
Soil	2 or 4 oz. glass jar	20 g	Thermal: ≤6°C (not frozen) Chemical: None	Collection to Prep:28 days Prep to Analysis: Same Day

[1]*Minimum amount needed for each discrete analysis.*

Field / Matrix QC

Trip Blank	Equipment Blank	MS/MSD	Field Duplicate
NA	NA	NA	As Needed

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Thermal preservation is checked and recorded on receipt in the laboratory in accordance with laboratory SOP ENV-SOP-LENE-0021, *Sample Management*. Chemical preservation is checked and recorded at time of receipt or prior to sample preparation.

After receipt, samples are stored at ≤6°C until sample preparation. Prepared samples (extracts, digestates, distillates, other) are stored at ≤6°C until sample analysis.

After analysis, unless otherwise specified in the analytical services contract, samples are retained for 30 days from date of final report and then disposed of in accordance with Federal, State, and Local regulations.

7.0 EQUIPMENT AND SUPPLIES

7.1 Equipment

Supply	Vendor	Model / Version	Comments
Conductivity meter	Thermo-Fisher	Orion Star A212	With automatic temperature compensation
Analytical balance	Mettler-Toledo	AE240	Or equivalent
Magnetic stirrer	Fisher	Various	

7.2 Supplies

Supply	Vendor	Model / Versior	Comments
Disposable cups, 100-mL	Fisher	N/A	N/A
Stirbars	Fisher	14-513-94	8x25mm
Wash bottle	Fisher	03-409-11E	Nalgene®
Graduated cylinders	Fisher	08-553B	100-mL, Class A
Volumetric flask	Fisher	10-209H	1-L, Class A
Laboratory wipe tissues	Fisher	06666A	Kimwipes

8.0 REAGENTS AND STANDARDS

8.1 Reagents

Reagent/Standard	Concentration/ Description	Vendor/ Item #
Reagent water	ASTM Type II	SOP ENV-SOP-LENE-0131 (latest revision)
Probe storage solution	Redi-Stor® Probe Storage Solution	Fisher / 09-330-1

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8.2 Standards

Reagent/Standard	Concentration/ Description	Vendor/ Item #
Primary standard (high)	30,100 µmho/cm; Ricca Chemical	Fisher / 2247.30-32
Primary standard (mid)	4,500 µmho/cm; Ricca Chemical	Fisher / R5888420-1A
Primary standard (mid)	1409 µmho/cm; Ricca Chemical	Fisher / 589532
Primary standard (mid)	718 µmho/cm; Ricca Chemical	Fisher / 58877232
Primary standard (low)	15 µmho/cm; Ricca Chemical	Fisher / 22360316
Secondary check standard	447 µmho/cm; Cole-Parmer	Fisher / 13-300-117

9.0 PROCEDURE

9.1 Initial Calibration

9.1.1 Turn the conductivity meter on and let it warm up for 10 minutes. Ensure that all standards are at room temperature.

9.1.2 Fill a disposable cup with approximately 50 mL of each primary standard.

9.1.3 Press the “Cal” button. Immerse the conductivity probe into the 15 µmho/cm solution up to the immersion level.

9.1.4 While stirring, select the “Start” button. Allow sufficient time for conductivity value to stabilize.

9.1.5 If the displayed concentration differs from the actual concentration press the “Edit” button and adjust the value. Once entered, press the “done” button to establish the value then the “next” button to move to the next standard.

9.1.6 Repeat steps 9.2.4 – 9.2.5 for each remaining primary standard.

9.1.7 Once the last standard is read select the “cal done” button followed by the “measure” button to return to the main screen.

9.2 Measure the 5 primary standards to verify proper operation over the entire range. Note: This is equivalent to performing the cell constant (K). The cell constant is determined by dividing the measured value by the true value of the reference standard.

9.3 Results must be within ±10% of the solution true values to begin analysis.

9.4 Recalibrate when any of the calibration check standards, ICV or CCV’s are verified outside of the control limits.

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9.4.1 Calibration Standard Concentrations

Standard Concentration (µmho/cm)	Standard Type	Lower Control Limit	Upper Control Limit
15	Primary	13.5	16.5
718	Primary	646	790
1408	Primary	1267	1549
4500	Primary	4050	4950
30100	Primary	27090	33110

9.4.2 ICAL Evaluation

9.4.2.1 Curve Fit

The instrument response to the standards is checked to verify the response is accurate. No external curve is produced.

9.4.2.2 Relative Standard Error (RSE)

Not applicable to this procedure.

9.4.2.3 Initial Calibration Verification

9.4.2.4 Initial Calibration Verification (ICV) must be performed using the secondary check standard (447 µmho/cm).

9.4.2.5 The values obtained from the analysis of the ICV are compared to the true values and a percent difference calculated. The percent difference must meet the method specified criteria for the analysis to proceed for an additional 20 samples.

9.4.3 Continuing Calibration Verification

9.4.3.1 The values obtained from the analysis of the CCV are compared to the true values and a percent difference calculated. The percent difference must meet the method specified criteria for the analysis to proceed for an additional 20 samples.

9.5 Sample Preparation

9.5.1 Homogenization and Subsampling

Refer to the SOP ENV-SOP-LENE-0135, *Sample Homogenization and Sub-Sampling*.

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9.6 Analysis

A daily calibration check is performed prior to analysis. Read each of the standards listed in Calibration Concentrations table and record the values in the electronic logbook. If all are in control, proceed with sample analysis. If any are out of control, recalibrate.

9.7 Sample Analysis

9.7.1 Allow samples to warm to room temperature prior to analysis.

9.7.2 Water Samples: Fill the disposable cup with about 50 mL of sample. Verify that the probe is fully immersed.

9.7.3 Soil Samples: Weigh 20 g of sample into a centrifuge tube, add 20 mL reagent water and cap. Place the centrifuge tube on a shaker and shake for about 15 minutes. Centrifuge the mixture for about 10 minutes. Decant the supernatant into a disposable cup.

9.7.4 Rinse the probe with reagent water and immerse the probe into the sample, up to the immersion level. Press the “measure” button. Stir and allow reading to stabilize.

9.7.5 Rinse the probe with reagent water and return to step 12.1.4.

9.7.6 Record all results in the Conductivity or Salinity Workbench template.

9.7.7 If performing Salinity analysis, perform daily QC checks in the same manner as conductivity analysis. Once instrument performance is verified, change the measured units from mS/cm to psu. The acceptable range is 2 to 42 psu. If greater than 42 psu, the result must be qualified as estimated.

9.7.8 Example Analytical Sequence

Lab Sample ID	Sample Type
CAL0	CAL 0
CAL1	CAL 1
CAL2	CAL 2
CAL3	CAL 3
CAL4	CAL 4
CAL5	CAL 5
ICV	Calibration Verification
Method blank	Blank
Sample	PS
Sample Duplicate	DUP
Sample	PS
Sample	PS
Sample	PS
Sample	PS
Sample	PS

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Lab Sample ID	Sample Type
Sample	PS
Sample	PS
CCVA	CCVA
Repeat cycle of Samples alternating CCVA and CCVB	

10.0 Data Analysis And Calculations

10.1 Quantitative Identification

Results are read directly from the instrument.

10.2 Calculations

See the Laboratory Quality Assurance Manual for equations for common calculations.

11.0 Quality Control and Method Performance

11.1 Quality Control

The following QC samples are prepared and analyzed with each batch of samples. Refer to Appendix A for acceptance criteria and required corrective action.

QC Item	Frequency
Method Blank (MB)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Sample Duplicate	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Laboratory Control Sample (Salinity only)	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.

11.2 Instrument QC

The following Instrument QC checks are performed. Refer to Appendix A for acceptance criteria and required corrective action.

QC Item	Frequency
Initial Calibration	Every 6 months or if daily calibration verification fails. Whichever is sooner.
Initial Calibration Verification	After calibration prior to the analysis of samples.
Initial Calibration Blank	With each calibration
Continuing Calibration Verification	Every 10 samples or QC

11.3 Method Performance

11.3.1 Method Validation

11.3.1.1 Detection Limits

Detection limits (DL) and limits of quantitation (LOQ) are established at initial method setup and verified on an on-going basis thereafter. The Method Detection Limit procedure does not apply to this test. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 Method Validation and Instrument Verification and to the laboratory's SOP ENV-SOP-LENE-0117, *Limit of Detection*, for these procedures.

11.4 Analyst Qualifications and Training

Employees that perform any step of this procedure must have a completed Read and Acknowledgment Statement for this version of the SOP in their training record. In addition, prior to unsupervised (independent) work on any client sample, analysts that prepare or analyze samples must have successful initial demonstration of capability (IDOC) and must successfully demonstrate on-going proficiency on an annual basis. Successful means the initial and on-going DOC met criteria, documentation of the DOC is complete, and the DOC record is in the employee's training file. Refer to laboratory SOP ENV-SOP-LENE-010, *Training Procedures*, for more information.

12.0 Data Review And Corrective Action

12.1 Data Review

Pace's data review process includes a series of checks performed at different stages of the analytical process by different people to ensure that SOPs were followed, the analytical record is complete and properly documented, proper corrective actions were taken for QC failure and other nonconformance(s), and that test results are reported with proper qualification.

The review steps and checks that occur as employee's complete tasks and review their own work is called primary review.

All data and results are also reviewed by an experienced peer or supervisor. Secondary review is performed to verify SOPs were followed, that calibration, instrument performance, and QC criteria were met and/or proper corrective actions were taken, qualitative ID and quantitative measurement is accurate, all manual integrations are justified and documented in accordance with the Pace ENV's SOP for manual integration, calculations are correct, the analytical record is complete and traceable, and that results are properly qualified.

A third-level review, called a completeness check, is performed by reporting or project management staff to verify the data report is not missing information and project specifications were met.

Refer to laboratory SOP ENV-SOP-LENE-088, *Data Reduction, Review and Reporting*, for specific instructions and requirements for each step of the data review process.

12.2 Corrective Action

Corrective action is expected any time QC or sample results are not within acceptance criteria. If corrective action is not taken or was not successful, the decision/outcome must be documented in the analytical record. The primary analyst has primary responsibility for taking corrective action when QA/QC criteria are not met. Secondary data reviewers must verify that appropriate action was taken and/or that results reported with QC failure are properly qualified.

Corrective action is also required when carryover is suspected and when results are over range.

Samples analyzed after a high concentration sample must be checked for carryover and reanalyzed if carryover is suspected. Carryover is usually indicated by low concentration detects of the analyte in successive samples analyzed after the high concentration sample.

Sample results at concentrations above the upper limit of quantitation must be diluted and reanalyzed. The result in the diluted samples should be within the upper half of the calibration range. Results less than the mid-range of the calibration indicate the sample was over diluted and analysis should be repeated with a lower level of dilution. If dilution is not performed, any result reported above the upper range is considered a qualitative measurement and must be qualified as an estimated value.

Refer to Appendix B for a complete summary of QC, acceptance criteria, and recommended corrective actions for QC associated with this test method.

13.0 Pollution Prevention And Waste Management

Pace proactively seeks ways to minimize waste generated during our work processes. Some examples of pollution prevention include but are not limited to: reduced solvent extraction, solvent capture, use of reusable cycletainers for solvent management, and real-time purchasing.

The EPA requires that laboratory waste management practice to be conducted consistent with all applicable federal and state laws and regulations. Excess reagents, samples and method process wastes must be characterized and disposed of in an acceptable manner in accordance with Pace's Chemical Hygiene Plan / Safety Manual.

14.0 Modifications

A modification is a change to a reference test method made by the laboratory. For example, changes in stoichiometry, technology, quantitation ions, reagent, or solvent volumes, reducing digestion or extraction times, instrument runtimes, etc. are all examples of modifications. Refer to Pace ENV corporate SOP ENV-SOP-CORQ-0011 *Method Validation and Instrument Verification* for the conditions under which the procedures in test method SOPs may be modified and for the procedure and document requirements.

15.0 Responsibilities

Pace ENV employees that perform any part this procedure in their work activities must have a signed Read and Acknowledgement Statement in their training file for this version of the SOP. The employee is responsible for following the procedures in this SOP and handling temporary departures from this SOP in accordance with Pace's policy for temporary departure.

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Pace supervisors/managers are responsible for training employees on the procedures in this SOP and monitoring the implementation of this SOP in their work area.

16.0 ATTACHMENTS

Attachment 1: Electronic Logbook example for Conductivity

17.0 REFERENCES

17.1 Pace Quality Assurance Manual - most current version.

17.2 National Environmental Laboratory Accreditation Conference (NELAC), Chapter 5, “Quality Systems”- most current version.

17.3 The NELAC Institute (TNI); Volume 1, Module 2, “Quality Systems”- most current version.

17.4 Guidelines Establishing Test Procedures for the Analysis of Pollutants Under the Clean Water Act; Analysis and Sampling Procedures, Federal Register Doc. No: 2012-10210.

17.5 Methods for the Chemical Analysis of Water and Wastes, EPA/600/4-79/020, Method 120.1, Revised 1982.

17.6 Standard Methods for the Examination of Water and Wastewater, Method 2510 B – 2011 and 2520 B – 2011.

17.7 Test Methods for Evaluating Solid Waste; SW-846, Method 9050A, Revision 1, December 1996.

18.0 REVISION HISTORY

This Version: ENV-SOP-LENE-0023, Rev 02

Section	Description of Change
All	New SOP format and added salinity 2520.

This document supersedes the following document(s):

Document Number	Reason for Change	Date
KS-I-2340-E	Grammatical/Removal of outdated information.	June 4, 2001
KS-I-2340-F	Grammatical/Removal of outdated information.	February 11, 2003

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Document Number	Reason for Change	Date
KS-I-025-rev.6	Section 9.1 – Changed definition of deionized water. Section 9.2 – Changed upper range of conductivity meter. Added catalog number. Section 9.3 – Added probe description, catalog number and strorage instructions. Section 10 – Changed 10.2 umho to ~10 umho*. Section 11 – Deleted reference to sample screening. Changed 10.2 umho to ~10 umho. Section 11.11 – Changed Range switch setting for reading 447 standard. Section 12.2.1 – Changed 30 grams and 30 mL to 20 grams and 20 mL. Section 12.2.2 – Added 'approximately'. Section 12.2.3 – Added 'approximately'. Section 13 – Deleted references to ½ PRL, LCS and MS/MSD. Section 14 – Deleted references to MDL studies. Added cell constant determination.	11May2006
KS-I-025-rev.7	Title Page – Added Standard Method method number. Section 9.2 – Removed duplicate supplies. Table 10.1 – Updated table with current order #'s. Table 10.2 – Updated table with current order #'s. Section 11 – Changed thought to throughout. Table 11.1 – Updated table to include secondary standards. Table 12.1 – Updated table to include instrument Pace ID# and levels of conductivity meter. Section 13.4.3 – Corrected equation used to determine cell constant.	30September2008
S-KS-I-025-rev.8	Section 6 – Added unit definitions. Section 7 – Revised SOP review frequency, official version and added Environmental Quality Director. Section 10 – Changed standard sources and values.	November 30, 2010
S-KS-I-025-rev.9	SOP – Deleted Responsibilities and Distribution section. Section 10 – Revised Calibration Verification Section 14 – Revised SOP reference. Section 15 – Added MUR reference.	January 11, 2012

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Document Number	Reason for Change	Date
S-KS-I-025-rev.10	SOP - Updated to latest prescribed format. Table 9.1 – Added new instrument. Section 11 – Revised for new instrument. Section 12 – Revised for new instrument. Section 23 – Revised references. Attachment 1 – Added client-specific criteria.	March 5, 2013
S-KS-I-025-rev.11	Revised standard concentration. Added 12.1.5.4	June 11, 2014
S-KS-I-025-rev.12	SOP – Updated to latest prescribed format. Table 10-- Revised primary standard conc. Section 11.1-- Revised wording and added a warning. Section 11.5.2 -- Revised CCV corrective actions Section 12.1.5 – Revised to dilute the sample if reading is high (overload at high setting).	June 23, 2015
S-KS-I-025-rev.13	Section 11.2 – Revised to specify the secondary standard as an "ICV". Section 11.4 – Initial Calibration Verification (ICV) must be the secondary check standard. Section 12.1.5.4 – Results should be from the minimum dilution needed.	May 6, 2016
S-KS-I-025-rev.14	SOP – Updated cover page to Pace LLC Table 9.1 – Updated with new instrument.t Table 10.1 – Two new high standards added. Section 11.0 – Revised calibration instructions. Section 11.2 – Added cell constant reference. Table 11.1 – Revised to add high standards. Section 12.0 – Removed selecting the range of sample measurement. Table 13.1 – Added Table 13.1 header. Section 14.0 – Removed cell constant. Added reference to Section 11 tables. Section 16.0 – Changed to reference Table 11.2.	May 31, 2017
ENV-SOP-0023, Rev 01	New SOP format	September 03, 2019

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Attachment 1: Electronic logbook example for Conductivity

Prep Log Report

Batch Information: WET COND/RESIST 101083 101084 **Template Version: F-KANS-I-003-Rev.00 (25Apr2019)**

Analysis Method	EPA 9050	Instrument	60WETM	Balance ID	60BAL11	Analyzed By	BLA
Reviewed By	LDB	Reviewed By Date	08/03/2021 13:08	Batch Notes			

Sample Information:

QC Rule	Sample Type	Lab Sample ID	Select	Run Date/Time	Meter Specific Conductance	Units	Sample Temp (C)	Posted Specific Conductance	Units	Resistivity (ohms-cm)	Final Resistivity (ohms-cm)	Matrix	Sample Weight (g)	Sample Notes
WET COND_Q	CAL1	**CAL1**	Y	08/02/2021 10:32:28	14.13	uS/cm	18.6	14.13	uS/cm			Water		
WET COND_Q	CAL2	**CAL2**	Y	08/02/2021 10:33:07	694.8	uS/cm	18.6	694.8	uS/cm			Water		
WET COND_Q	CAL3	**CAL3**	Y	08/02/2021 10:33:25	1368	uS/cm	18.6	1368	uS/cm			Water		
WET COND_Q	CAL4	**CAL4**	Y	08/02/2021 10:36:24	4350	uS/cm	18.6	4350	uS/cm			Water		
WET COND_Q	CAL5	**CAL5**	Y	08/02/2021 10:36:52	28940	uS/cm	18.6	28940	uS/cm			Water		
WET COND_Q	ICV	**ICV**	Y	08/02/2021 10:37:19	432.5	uS/cm	18.6	432.5	uS/cm			Water		
9050 S	BLANK	**2950511**	Y	08/02/2021 10:37:43	0.496	uS/cm	18.6	0.496	uS/cm			Solid		
9050 S	PS	**60375467001**	Y	08/02/2021 10:38:16	231.9	uS/cm	18.6	231.9	uS/cm			Solid	20.09	
9050 S	DUP	**2950512**	Y	08/02/2021 10:38:19	231.9	uS/cm	18.6	231.9	uS/cm			Solid	20.09	
9050 S	PS	**60375467003**	Y	08/02/2021 10:38:53	175.8	uS/cm	18.6	175.8	uS/cm			Solid	20.24	
9050 S	PS	**60375467005**	Y	08/02/2021 10:39:25	27.27	uS/cm	18.6	27.27	uS/cm			Solid	20.29	
9050 S	PS	**60375467007**	Y	08/02/2021 10:39:56	28.71	uS/cm	18.6	28.71	uS/cm			Solid	20.36	
RESIST	PS	**40230596001**	Y	08/02/2021 10:40:30	168.3	uS/cm	18.6	168.3	uS/cm	5942	5942	Solid	19.95	
RESIST	PS	**60375831001**	Y	08/02/2021 10:40:59	897.5	uS/cm	18.6	897.5	uS/cm	1114	1114	Solid	20.28	
WET COND_Q	CCVA	**CCVA**	Y	08/02/2021 10:41:30	14.09	uS/cm	18.6	14.09	uS/cm			Water		

Prep Log Report

QC Rule	Sample Type	Lab Sample ID	CAL-STD
WET COND_Q	CAL1	**CAL1**	42458 (1)
WET COND_Q	CAL2	**CAL2**	42459 (1)
WET COND_Q	CAL3	**CAL3**	42464 (1)
WET COND_Q	CAL4	**CAL4**	42460 (1)
WET COND_Q	CAL5	**CAL5**	42461 (1)
WET COND_Q	ICV	**ICV**	42462 (1)
9050 S	BLANK	**2950511**	
9050 S	PS	**60375467001**	
9050 S	DUP	**2950512**	
9050 S	PS	**60375467003**	
9050 S	PS	**60375467005**	
9050 S	PS	**60375467007**	
RESIST	PS	**40230596001**	
RESIST	PS	**60375831001**	
WET COND_Q	CCVA	**CCVA**	42458 (1)

Standard Notes:

42458: WET Specific Conductivity 15 uS/cm
42462: WET Specific Conductivity ICV 447 uS/cm
42459: WET Specific Conductivity 718 uS/cm
42464: WET Specific Conductivity 1409 uS/cm
42460: WET Specific Conductivity 4500 uS/cm
42461: WET Specific Conductivity 30,100 uS/cm

Management Approval:
Lenzie Boring Approved on 10/27/2022 12:30:52 PM
Charles Girgin Approved on 10/31/2022 4:23:43 PM
Kenneth Busch Approved on 10/31/2022 5:01:24 PM

1.0 SCOPE AND APPLICATION

This standard operating procedure (SOP) describes the laboratory procedure for the determination of sulfide in water samples by colorimetry by SM 4500 S2 D - 2000.

1.1 Target Analyte List and Limits of Quantitation (LOQ)

The target analytes and the normal LOQ that can be achieved with this procedure is 0.05 mg/L.

2.0 SUMMARY OF METHOD

Sulfide reacts with N,N-dimethyl-p-phenylenediamine in the presence of ferric chloride to produce methylene blue, a dye whose absorbance is measured at wavelength maximum of 664 nm using a spectrophotometer.

3.0 INTERFERENCES

The sample must be collected with minimum aeration. Sulfide may be volatilized by aeration and any oxygen inadvertently added to the sample may convert the sulfide to an immeasurable form. Dissolved oxygen should not be present in any water used to dilute standards.

Color and turbidity may interfere with the observation of color or with the photometric readings.

Strong reducing agents interfere by preventing the formation of the blue color. Thiosulfate at concentrations of about 10 mg/L may retard color formation or completely prevent it. Sulfide itself prevents the reaction if its concentration is very high, in the range of several hundred milligrams per liter.

Ferrocyanide can interfere by producing a blue color similar to that of methylene blue.

4.0 DEFINITIONS

Refer to the Laboratory Quality Manual for a glossary of common lab terms and definitions.

5.0 HEALTH AND SAFETY

Contact your supervisor or local safety coordinator with questions or concerns regarding safety protocol or safe handling procedures for this procedure

The following sections provide general health and safety information about chemicals and materials that may be present in the laboratory.

- The toxicity or carcinogenicity of each chemical material used in the laboratory has not been fully established. Each chemical should be regarded as a potential health hazard and exposure to these compounds should be as low as reasonably achievable.

- The laboratory maintains documentation of hazard assessments and OSHA regulations regarding the safe handling of the chemicals specified in each method. Safety data sheets for all hazardous chemicals are available to all personnel. Employees must abide by the health, safety and environmental (EHS) policies and procedures specified in this SOP and in the Pace® Chemical Hygiene / Safety Manual (COR-MAN-0001)
- Personal protective equipment (PPE) such as safety glasses, gloves, and a laboratory coat must be worn in designated areas and while handling samples and chemical materials to protect against physical contact with samples that contain potentially hazardous chemicals and exposure to chemical materials used in the procedure.
- Concentrated corrosives present additional hazards and are damaging to skin and mucus membranes. For procedures that require use of acids, use acids in a fume hood whenever possible with PPE designed for handing these materials. If eye or skin contact occurs, flush with large volumes of water. When working with acids, always add acid to water to prevent violent reactions. For procedures that that emit large volumes of solvents (evaporation/concentration processes), these activities must be performed in a fume hood or apparatus that reduces exposure.

6.0 SAMPLE COLLECTION, PRESERVATION, HOLDING TIME, AND STORAGE

The laboratory provides containers for the collection of samples upon client request. Refer to laboratory SOP ENV-SOP-LENE-0107 for procedures related to preparation of bottle kits for the test method(s) associated with this SOP.

The laboratory performs samples collection for samples to be analyzed by this SOP in accordance with laboratory SOP ENV-SOP-LENE-0025. Refer to this SOP for these instructions.

General Requirements

Matrix	Routine Container	Minimum Sample Amount[1]	Preservation	Holding Time
Aqueous	Plastic or glass (250 or 500-mL)	10 mL	Thermal: ≤6°C Chemical: 1 mL 1N zinc acetate solution and 0.5 mL 50% NaOH.	Collection to Prep: 7 days Prep to Analysis: Immediate
Aqueous Dissolved*	Plastic or glass (250 or 500-mL)	10 mL	Thermal: ≤6°C Chemical: If containing Suspended Matter: Treat with AlCl3 in a 100 ml glass bottle add 0.2 ml of 6 N NaOH. Add 0.2 ml AlCl3. Stopper, mix and allow to flocculate. Let Settle and draw clear supernatant off. Preserve supernatant as above for Aqueous	Collection to Prep: 7 days Prep to Analysis: Immediate

[1]*Minimum amount needed for each discrete analysis.*

**Must be treated in the field.*

Thermal preservation is checked and recorded on receipt in accordance with laboratory SOP ENV-SOP-LENE-0021. Chemical preservation is checked and recorded at time of receipt or prior to sample preparation.

After receipt, samples are stored at ≤6°C until sample preparation. Prepared samples (extracts, digestates, distillates, other) are stored at ≤6C until sample analysis.

After analysis, samples are retained as stated in the Pace® standard terms and conditions, unless otherwise specified in the analytical services contract. Samples are then disposed of in accordance with Federal, State, and Local regulations.

7.0 Equipment And Supplies

7.1 Equipment

Equipment	Vendor	Model/Version	Description
UV-Visible spectrophotometer	Shimadzu	UV-1800	capable of reading absorbance at 664 nm
Centrifuge	International Equipment	0644319	or equivalent
Adjustable Pipettor	Eppendorf	various	or equivalent
Volumetric Flasks	10, 50,100-mL class A	Fisher	
Graduated Cylinder	10-mL, TD	Fisher / 08-553B/ Class A	
Magnetic Stirrer	N/A	Fisher / 14-259-265	or equivalent

7.2 Supplies

Item	Description	Vendor / Item # / Description
Stirbars	6 x 25mm, PTFE-coated	Fisher / 14-513-94
Centrifuge tubes	50-mL, graduated	Fisher / 06-443-19

8.0 Reagents And Standards

8.1 Reagents

Table 8.1

Reagent	Concentration/ Description	Requirements/ Vendor/ Item #
Reagent water	ASTM Type II	SOP ENV-SOP-LENE-0131 (latest revision)
6N NaOH	6N / 4L RICCA	Fisher / 7466-1

8.2 Standards

Table 8.2

Reagent	Concentration/ Description	Requirements/ Vendor/ Item #
Sulfide Reagent Set	Contains Sulfide Reagents #1 & #2	Hach / 2244500
Sulfide Standard Primary	Ampule 1000 mg/L	Absolute Standards / 54139
Sulfide Standard Secondary	Crystalline Reagent / Strem Chem.	Fisher / 50-901-13904

All reagents are stored in manufacturer recommended conditions. Hach Sulfide reagents used are USEPA approved for reporting wastewater analysis, equivalent to Standard Method 4500-S2-D.

8.3 Intermediate Sulfide Standards (Calibration)

Add 0.5 mL of Sulfide Standard to a 50-mL volumetric flask containing reagent water, dilute to the mark, and invert three times to mix. These standards are unstable and made daily.

8.4 Intermediate Sulfide Standards (Secondary Verification, Daily Linearity, Continuing Calibration)

Create a 1.25N NaOH solution by adding 10.41 mL 6N NaOH to 25 mL DI water in a 50mL volumetric flask and filling to the mark with DI. Dissolve 3.5g Sulfide Crystals in the NaOH solution. Transfer this solution to a 500 mL flask containing ~100 mL DI water. Fill to the mark and invert several times. This will yield a 10 ppm intermediate standard. Store in 2 mL amber vials with no headspace. Standard expires after 6 months or when daily linearity checks fail.

8.5 Working Sulfide Standards

Add varied aliquots of the intermediate calibration Sulfide Standard (see Table 10.2 below) to 10-mL volumetric flasks containing reagent water, dilute to the mark, invert three times to mix and transfer to individual centrifuge tubes. Working standards are made daily.

Table 8.3 – Working Calibration Standard Preparation

Standard	Intermediate Standard Amount (mL)	Final Solvent	Final Volume (mL)	Final Concentration (mg/L)
CAL0 / ICB / CCB	0	Water	10	0
CAL1	0.05	Water	10	0.05
CAL2	0.2	Water	10	0.2

Standard	Intermediate Standard Amount (mL)	Final Solvent	Final Volume (mL)	Final Concentration (mg/L)
CAL3 CCVB / CCV / LCS	0.5	Water	10	0.5
CAL4	.75	Water	10	0.8
CAL5 / CCVA	1.0	Water	10	1.0
ICV	0.5	Water	10	0.5

Add 0.5 mL of Sulfide Reagent #1 to each working standard, swirl to mix.

Add 0.5 mL of Sulfide Reagent #2 to each working standard. Cap the centrifuge tube and immediately invert to mix. The solution will turn pink initially and then turn blue if sulfide is present.

Wait five minutes and proceed to calibrate the instrument.

8.6 Second Source Verification (SSV/ICV/CCVA/CCVB/CCV) Standard

Add 0.5 mL of the working ICV sulfide standard to a 10-mL volumetric flask containing reagent water, dilute to the mark, invert three times to mix, and transfer to a centrifuge tube.

Add 0.5 mL of Sulfide Reagent #1 and swirl to mix.

Add 0.5 mL of Sulfide Reagent #2. Cap the centrifuge tube and immediately invert to mix. The solution will turn pink initially and then turn blue if sulfide is present.

Wait five minutes and proceed to verify the initial calibration.

9.0 PROCEDURE

9.1 Equipment Preparation

9.1.1 Support Equipment

Refer to Pace Analytical Services – Kansas SOP ENV-SOP-LENE-0030, Support Equipment, or equivalent replacement, for additional information on calibration requirements for support equipment that may be used in this procedure.

Balances are checked prior to use on each working day with NIST traceable references in the expected range of use, and the results are recorded in the logbook assigned to the balance.

9.1.2 Instrument

9.1.2.1 Routine Instrument Operating Conditions

Turn on the spectrophotometer. The spectrophotometer should be on at least one hour before analyzing standards or samples.

Open the Sulfide method on the UV-Visible spectrophotometer. Ensure the wavelength is set to 664 nm.

9.2 Initial Calibration

The calibration curve is prepared at approximate six month intervals or as needed. The curve is verified immediately by an ICV and ICB. Daily confirmation is provided by the analysis of a CCVA, CCVB, CCV's and CCB's.

Pour the 0 mg/L standard into two cuvettes, place them into the reference and sample cells and zero the baseline.

Individually read the remaining calibration standards in the sample cell, leaving the 0 mg/L standard in the reference cell, to establish the curve plotting absorbance versus concentration.

The correlation coefficient must be >0.995. Read back of the calibration standards is required. Using the curve parameters, enter the absorbance for each standard, calculate the observed concentration and record on the raw data.

Save the method as Sulfide mmddyy.

9.2.1 Calibration Sequence

Order	Sample ID	Concentration mg/L
1	CAL0	0.000
2	CAL1	0.050
3	CAL2	0.200
4	CAL3	0.500
5	CAL4	0.750
6	CAL5	1.000
7	ICV	0.500
8	ICB	0.00

9.2.2 ICAL Evaluation

9.2.2.1 Curve Fit

Calibration Curve Fit – The calibration curve is a representation of the relationship of the instrument response and analyte concentration. The curve is used to quantitate the concentration of an unknown based on its response and this known relationship.

Linear Regression – The linear regression calibration curve is derived from a least squares regression analysis of the calibration points. A calibration curve based on this technique will have the format of y = ax + b where "a" is the slope of the line and "b" is the y-intercept. Linear regression is not forced through the origin; therefore, there is a possibility that very low levels of contaminants below the response of the lowest calibration point may generate erroneous reportable results. A calculation of the correlation coefficient "r" is used to determine the acceptability of a linear regressed curve.

9.2.2.2 Relative Standard Error (RSE)

Initial calibrations using linear regression must be evaluated for their relative error using the following equation:

$$\% \text{ Relative Error } = \frac{\text{Calculated Value} - \text{True Value}}{\text{True Value}} \times 100$$

Back calculate the concentration of each calibration point in the calibration curve. The back-calculated and true concentrations should agree within ±10%. At the lower limit of the operational range, acceptance criteria are ±50%.

9.2.2.3 Initial Calibration Verification

In addition to meeting the linearity criteria, any new calibration curve must be assessed for accuracy in the values generated. This verification process is known as *Second Source Verification and it is performed using the standard referred to as the LCS*. Accuracy is a function of both the "fit" of the curve to the points used and the accuracy of the standards used to generate the calibration points. By meeting the fit criteria, the accuracy relative to the goodness of fit is addressed. However, because all calibration points are from the same source, it is possible that the calibration points may meet linearity criteria but not be accurately made in terms of their true value.

Prepare and analyze the ICV as specified in Section 8 immediately after the initial calibration.

To assess the accuracy relative to the purity of the standards, a single standard from a secondary source must be analyzed and the results obtained must be assessed relative to the known true value. This secondary source must be from an alternative vendor or, in the event an alternative vendor is not available, from a different lot from the same vendor. The accuracy of the standard is assessed as a percent difference from the true value according to the following equation:

$$\%\text{Difference} = \frac{(\text{Result}_{ICV} - \text{True Value}_{ICV})}{\text{True Value}_{ICV}}$$

9.2.3 Continuing Calibration Verification

As part of the analytical process, the instrumentation must be checked periodically to determine if the response has changed significantly since the initial calibration was established. This verification process is known as Continuing Calibration Verification (CCV). The validity of the initial calibration is checked after every ten samples and at the end of the analytical sequence by analyzing a midpoint calibration standard. The accuracy of the standard is assessed as percent drift from the true value according to the following equation:

$$\%\text{Drift} = \frac{(\text{Result}_{CCV} - \text{True Value}_{CCV})}{\text{True Value}_{CCV}}$$

9.2.4 High (CCVA) and Low (CCVB) Check Standards

If an ICAL is not analyzed the day of analysis, then the validity of the initial calibration should be checked by the analysis of both a high check standard and a low check standard.

The accuracy of the standard is assessed as percent drift from the true value according to the following equation:

$$\%Drift = \frac{(Result_{CHK} - True\ Value_{CHK})}{True\ Value_{CHK}}$$

9.3 Sample Preparation

9.3.1 Homogenization and Subsampling

Refer to SOP ENV-SOP-LENE-0135, Sample Homogenization and Sub-sampling as needed for complex samples.

9.4 Analysis

9.4.1 Example Analytical Sequence

Sample	Cup No.
CCVA	1
CCVB	2
CCB	3
MB (Method Blank)	4
LCS (Laboratory Control Sample)	5
MS	6
DUP (Sample Duplicate)	7
Client Sample ID	8
Client Sample ID	9
Client Sample ID	10
Client Sample ID	11
Client Sample ID	12
Client Sample ID	13
CCV	14
CCB	15
Client Sample ID	16
CCV1	17
CCB1	18
Repeat Sequence as needed with CCV/CCB every 10 samples	

9.5 Procedure

Ensure that the proper method is loaded in the spectrophotometer software.

Method Blank (MB) – Measure 10.0 mL of reagent water into a 50-mL centrifuge tube.

Laboratory Control Sample (LCS) - Measure 9.5 mL of reagent water into a 50-mL centrifuge tube and spike with 0.5 mL of the IntermediateSulfide Standard. This will yield a 0.5 mg/L concentration.

Matrix Spike (MS) - Randomly select a sample from the analytical batch for matrix spiking. Measure 10.0 mL of the selected sample into a 50-mL centrifuge tube and spike with 0.5 mL of the Stock Sulfide Standard. This will yield a 0.5 mg/L spike concentration.

Client Samples - Measure 10.0 mL of sample into a 50-mL centrifuge tube. The sample aliquot may be diluted first if the expected sulfide content is high. If the sample is high in sediment, do a dilution to prove the sample is not overloaded with sulfide.

Add 0.5 mL of Sulfide Reagent #1 to each QC and client sample, swirl to mix.

Add 0.5 mL of Sulfide Reagent #2 to each QC and client sample. Cap the centrifuge tube and immediately invert to mix. The solution will turn pink initially and then turn blue if sulfide is present.

Wait five minutes and proceed to analyze.

Dissolved sample procedure

Pour 20 mls of sample into a 50 ml centrifuge tube and centrifuge for 30 minutes.

Decant and volumetrically place 10 mls of sample into a centrifuge tube.

9.6 Data handling

Transfer the data file to S:WETCHEM/WETDATA/SULFIDE. Open Limslink and select the UV VIS SPEC method. After reviewing the data, post the data to EPIC PRO.

10.0 DATA ANALYSIS AND CALCULATIONS

10.1 Quantitative Identification

This is a direct colorimetric procedure. See the Interferences section.

10.2 Calculations

See the Laboratory Quality Assurance Manual for equations for common calculations.

11.0 QUALITY CONTROL AND METHOD PERFORMANCE

11.1 Quality Control

The following QC samples are prepared and analyzed with each batch of samples. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Acronym	Frequency
Method Blank	MB	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Laboratory Control Sample	LCS	1 per batch of 20 or fewer samples. If batch exceeds, 20 samples, every 20.
Laboratory Control Sample Duplicate	LCSD	as requested by client
Matrix Spike	MS	1 per batch of 20 or fewer sample. If batch exceeds 20 samples, every 20
Sample Duplicate	SD	1 per batch of up to 20 samples

11.2 Instrument QC

The following Instrument QC checks are performed. Refer to Appendix B for acceptance criteria and required corrective action.

QC Item	Acronym	Frequency
Initial Calibration	ICAL	Approximately every 6 months or as needed
Initial Calibration Verification (Second Source)	ICV	Immediately after each initial calibration
Initial Calibration Blank	ICB	After each ICV, Low check or CCV
Continuing Calibration Verification	CCV	Every 10 samples and at the end of the sequence
Continuing Calibration Blank	CCB	Every 10 samples and at the end of the sequence
High Cal Check	CCVA	Daily prior to sample sunless initial calibration is run that day
Low Cal Check	CCVB	Daily prior to samples unless initial calibration is run that day

11.3 Method Performance

11.3.1 Method Validation

Refer to corporate SOP ENV-SOP-CORQ-0011 for general requirements and procedures for method validation.

Establish detection limits (DL) and limits of quantitation (LOQ) at initial method set up and verify the DL and LOQ on an on-going basis thereafter. Refer to corporate policy and/or SOP for DL and LOQ requirements and procedures.

12.0 DATA REVIEW AND CORRECTIVE ACTION

12.1 Data Review

The data review process of Pace® Analytical Services includes a series of checks performed at different stages of the process by different people to ensure that SOPs were followed, the analytical record is complete, and properly documented, QC criteria were met, proper corrective actions were taken for QC failure and other nonconformance(s), and test results are reported with proper qualification, when necessary.

The review and checks that are performed by the employee performing the task is called primary review.

All data and test results are also peer reviewed.

This process, known as secondary review is performed to verify SOPs were followed, that calibration, instrument performance, and QC criteria were met and/or proper corrective actions were taken, qualitative ID and quantitative measurement is accurate, all manual integrations are justified and documented, and approved in accordance with the Pace® Analytical Services SOP for manual integration, calculations are correct, the analytical record is complete and traceable, and that results are properly qualified.

Lastly, a third-level review, called a completeness check, is performed by reporting or project management staff to verify the test report is complete.

Refer to laboratory SOP ENV-SOP-LENE-0088 for specific instructions and requirements for each step of the data review process.

12.2 Corrective Action

Corrective action is required when QC or sample results are not within acceptance criteria.

Refer to Appendix B for a complete summary of QC, acceptance criteria, and recommended corrective actions for QC associated with this test method.

If corrective action is not taken or was not successful, the decision/outcome must be documented in the analytical record. The primary analyst has primary responsibility for taking corrective action when QA/QC criteria are not met. Secondary data reviewers must verify that appropriate action was taken and/or that results reported with QC failure are properly qualified.

Corrective action is also required when carryover is suspected and when results are over range.

Samples analyzed after a high concentration sample must be checked for carryover and reanalyzed if carryover is suspected. Carryover is usually indicated by low concentration detects of the analyte in successive samples analyzed after the high concentration sample.

Sample results at concentrations above the upper limit of quantitation must be diluted and reanalyzed. The result in the diluted samples should be within the upper half of the calibration range. Results less than the mid-range of the calibration indicate the sample was over diluted and analysis should be repeated with a lower level of dilution. If dilution is not performed, any result reported above the upper range is considered a qualitative measurement and must be qualified as an estimated value.

13.0 POLLUTION PREVENTION AND WASTE MANAGEMENT

Pace® proactively seeks ways to minimize waste generated during work processes. Some examples of pollution prevention include but are not limited to reduced solvent extraction, solvent capture, use of reusable cycletainers for solvent management, and real-time purchasing.

The EPA requires that laboratory waste management practices comply with all applicable federal and state laws and regulations. Excess reagents, samples, and method process wastes are characterized and disposed of in an acceptable manner in accordance with the Pace® Chemical Hygiene Plan / Safety Manual. Refer to this manual for these procedures.

14.0 MODIFICATIONS

The procedures in this SOP have been modified from the reference test method as follows:

Modification	Test Method Procedure	Justification for Modification
The dissolved procedure in Section 9.14 above is a modified procedure used only when the client wants Dissolved Sulfide and does not flocculate in the field.		

When applicable, comparability and/or equivalency studies necessary to validate the modification as required per corporate SOP ENV-SOP-CORQ-0011 are retained by local quality personnel for historical reference.

15.0 RESPONSIBILITIES

- All PAS employees that perform any part this procedure in their work activities must have a signed Read and Acknowledgement Statement (R&A) in their training file.
- PAS supervisors and managers are responsible for training employees on the procedures in this SOP, implementing the SOP in the work area, and monitoring on-going adherence to the SOP the work area(s) they oversee.
- Local quality personnel are responsible for tracking the currency of the R&A on this SOP for employees at the locations they are assigned to and for notifying the department leaders of overdue assignments.
- All employees of PAS are responsible for following the procedures in this SOP. Unauthorized deviations or departures from this SOP are not allowed except with documented approval from the local Quality Manager and only when those deviations do not violate the Pace® Code of Ethics or Professional Conduct (COR-POL-0004) or associated policy and procedure(s). Hand-edits or manual change to the SOP are not permitted. If a change is desired or necessary, employees must follow the procedures for document revision specified in corporate SOPs ENV-SOP-CORQ-0015, *Document Management* and ENV-SOP-CORQ-0016, *SOP for Creation of SOP and SWI*.
- Local quality personnel are responsible for monitoring conformity to this SOP during routine internal audits of work areas that utilize this SOP and for communicating gaps and deviations found during monitoring to the work area supervisor, who is responsible for correction of the situation.

16.0 ATTACHMENTS

- Appendix B: QC Summary & Corrective Action Table

17.0 REFERENCES

- ENV-SOP-CORQ-0006, *Manual Integration*, current version.
- ENV-SOP-CORQ-0011, *Method Validation*, current version.

- ENV-SOP-CORQ-0015, *Document Management*, current version.
- ENV-SOP-CORQ-0016, *SOP for SOP and SWI,* current version.
- ENV-TMP-CORQ-0007, *Quality Manual Template*, current version.
- COR-POL-0004, *Code of Ethics and Professional Conduct*, current version.
- COR-MAN-001, *Pace® Safety Manua*l, current version.
- Standard Methods for the Examination of Water and Wastewater, Method 4500-S^{2-} D (2000).
- Methylene Blue Method 8131, Edition 5, February 2008, DOC316.53.01136, Hach Company.

18.0 REVISION HISTORY

Authorship

Primary Author[1]	Job Title	Date Complete
Lenzie Boring	Inorganic Manager	10/18/2022

[1]The primary author is the individual / role responsible for the content of this SOP. Send questions or suggestions for content to the primary author. See the Quality Manager for questions or concerns related to implementation of this SOP.

Revisions Made from Prior Version

Section	Description of Change
Various	Updated to new SOP template language
8.2	Updated standard to be ISO 17034

Document Succession: This version replaces the following documents:

Document Number & Version	Document Title	Effective Date:
ENV-SOP-LENE-0109, v01	Sulfide by Methylene Blue	12/26/2019

Appendix B: QC Summary

QC Item	Frequency	Acceptance Criteria	Corrective Action	Qualification
ICAL	At instrument set up, after CCV failure	Must meet one of curve fit options presented in Section 9.0. Curve must also pass RSE test at the low and midpoint calibration standard. ± 10% of the true value. (%R). Low curve point must be within ± 50% of the true value. (%R)	Identify and correct source of problem, repeat	None. Do not proceed with analysis
ICV	After Each ICAL	All analytes must be within ± 10% of the true value. (%R)	Identify source of problem, re-analyze. If repeat failure, repeat ICAL. Analysis may proceed if it can be demonstrated that the ICV exceedance has no impact on analytical measurements. For example, the ICV %R is high, CCV is within criteria, and the analyte is not detected in sample(s).	Qualify analytes with ICV out of criteria if results are not affected (high bias ICV and ND results)
CCV	Daily, before sample analysis, after every 10, and at end of analytical window.	Opening CCV: All analytes within ± 10 %D Ending CCV: ± 10 D	If the requirements for continuing calibration are not met, corrective actions must be taken prior to reanalysis of standards. Only two analyses of the same standard are permitted back to back.	Qualify analytes with CCV out of of criteria.
Method Blank	Reagent water, 1 per batch of up to 20 samples	≤ RL	1) Re-analyze blank to confirm failure. 2) Qualify results and / or re-analyze associated samples. ***Exceptions:*** If sample ND, report sample without qualification	Qualify results and / or re-analyze associated samples
LCS	Reagent water spiked with sulfide standard, 1 per batch of up to 20 samples	80-120% Recovery	1) Reanalyze the LCS to verify failure 2) If problem persists, check spike solution ***Exceptions:*** 1) If LCS rec > QC limits and these compounds are non-detect in the associated samples, the sample data may be reported with appropriate data qualifiers.	If LCS rec > QC limits and these compounds are non-detect in the associated samples, the sample data may be reported with appropriate data qualifiers.

QC Item	Frequency	Acceptance Criteria	Corrective Action	Qualification
MS/MSD	1 per batch of up to 20 samples	75-125% Recovery	Report with Qualifier on the sample failing	As required
Sample Duplicate	1 per batch of up to 20 samples	20% RPD	Report with Qualifier on the sample failing	As required
Equipment Blank	Used if treated in the field	< RL	Report with Qualifier on the sample failing	As required
Low CCV, High CCV	Daily prior to samples unless initial calibration is run that day	90-110%	If not met, remake standard and recalibrate as needed	None
ICB	After each ICV	< RL	1) Re-analyze blank to confirm failure. 2) Qualify results and / or re-analyze associated samples. ***Exceptions:*** If sample ND, report sample without qualification	Qualify results and / or re-analyze associated samples
CCB	After each Low/High check or CCV	<RL	3) Re-analyze blank to confirm failure. 4) Qualify results and / or re-analyze associated samples. ***Exceptions:*** If sample ND, report sample without qualification	Qualify results and / or re-analyze associated samples

eurofins Environment Testing America

Title: ANALYSIS OF DISSOLVED GASES IN GROUNDWATER

[Method: Method RSK-175]

Approvals (Signature/Date):

Technology Specialist Olguita Colon	Date 09/08/22	Health & Safety Coordinator Raymond Austin Wayt IV	Date 08/23/22
Quality Assurance Manager Mark J. Loeb	Date 09/08/22	Technical Director Lucas Grossman	Date 08/31/22

This SOP was previously identified as SOP NC-GC-032, Rev 12, dated 07/27/20

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1. SCOPE AND APPLICATION

1.1. This document describes a procedure for the determination of dissolved gases in water. The method is applicable to the preparation of water samples by introducing headspace, and the analysis of the resultant headspace to quantify part-per-billion (ppb) levels of dissolved gases (acetylene, ethane, ethylene, methane, propane butane, 1-butene, propene, pentane and 2-methyl propane). See Tables 1 and 2 for List 1 and List 2 compounds with their associated molecular weights.

1.2. This document accurately reflects current laboratory Standard Operating Procedures (SOP) as of the date above. All facility SOPs are maintained and updated as necessary.

2. SUMMARY OF METHOD

2.1. A water sample is collected in the field in a 43-mL VOA vial with no headspace. Headspace is generated using ultra high purity (UHP) helium, fortified with a surrogate compound. The sample is loaded onto the headspace autosampler and analyzed by a Gas Chromatograph (GC) equipped with a Flame Ionization Detector (FID)

3. DEFINITIONS

3.1. Refer to the glossary in the Eurofins Canton QA Manual, current version.

4. INTERFERENCES

4.1. Method interferences may be caused by contaminants in solvents, reagents, glassware, and other processing apparatus that lead to discrete artifacts. All of these materials must be routinely demonstrated to be free from interferences under conditions of the analysis by running laboratory method blanks as described in the Quality Control section. Specific selection of reagents may be required to avoid introduction of contaminants.

5. SAFETY

5.1. Employees must abide by the policies and procedures in the NDSC EH&S Manual, the Facility Addendum to the NDSC EH&S Manual, and this document.

5.2. The following is a list of the materials used in this method, which have a serious or significant hazard rating. NOTE: This list does not include all materials used in the method. The table contains a summary of the primary hazards listed in the Safety Data Sheet (SDS) for each of the materials listed in the table. A complete list of materials used in the method can be found in the Reagents and Standards section. Employees must review the information in the SDS for each material before using it for the first time or when there are major changes to the SDS.

Material	Hazards	Exposure Limit (1)	Signs and symptoms of exposure
Hydrochloric Acid	Corrosive Poison	5 ppm-Ceiling	Inhalation of vapors can cause coughing, choking, inflammation of the nose, throat, and upper respiratory tract, and in severe cases, pulmonary edema, circulatory failure, and death. Can cause redness, pain, and severe skin burns. Vapors are irritating and may cause damage to the eyes. Contact may cause severe burns and permanent eye damage.
Note: Always add acid to water to prevent violent reactions.			
1 – Exposure limit refers to the OSHA regulatory exposure limit.			

5.1. Eye protection that protects against splash, laboratory coat, and appropriate gloves must be worn while samples, standards, solvents, and reagents are being handled. Cut-resistant gloves must be worn when opening vials and any other task that presents a strong possibility of getting cut. Disposable gloves that have been contaminated will be removed and discarded; other gloves will be cleaned immediately.

5.2. It is recommended that analysts break up work tasks to avoid repetitive motion tasks, such as opening a large number of vials or containers in one time period.

5.3. Exposure to chemicals must be maintained **as low as reasonably achievable.** All samples with a sticker that reads "Caution/Use Hood!" **must** be opened in the hood. Contact the EH&S Coordinator if this is not possible. Solvent and waste containers will be kept closed unless transfers are being made.

5.4. All work must be stopped in the event of a known or potential compromise to the health and safety of a laboratory associate. The situation must be reported **immediately** to the EH&S Coordinator and to a Laboratory Supervisor.

6. EQUIPMENT AND SUPPLIES

6.1. Sample Containers:

6.1.1. Pre-preserved 43 mL VOA vials containing reagent grade or equivalent HCl

6.1.2. 43 mL VOA Vials

6.2. Instrumentation

6.2.1. Agilent 6890 Gas Chromatograph (GC) equipped with a Flame Ionization Detector (FID) or equivalent

6.2.2. Column - FID - Agilent PLOT-Q; 30m, 0.53mm ID or equivalent

6.2.3. Autosampler - EST LGX-50 or equivalent

6.3. Syringes: 10µL - 25.0-mL gas tight syringes with 22 gauge side port needles

6.4. Relief needles: 18 gauge with side port for use in relieving pressure created during headspace formation.

6.5. Data System - Agilent Chemstation or equivalent

6.6. Shaker table or equivalent

7. REAGENTS AND STANDARDS

7.1. UHP helium is used to create headspace in initial calibration vials.

7.2. Calibration Standards: The primary standard is purchased through AirGas . The calibration standard is comprised of two cylinders--one composed of nominally 0.1% (mole basis) methane, ethane, ethylene, acetylene, propane, butane, 1-butene, propene, pentane and 2-methyl propane; and the second composed of nominally 1% methane, ethane, ethylene, acetylene, propane, butane, 1-butene, propene, pentane and 2-methyl propane. The second source standard is a 1% mix of all of the above-listed compounds, provided by Scott Specialty Gases. See the LIMS for further details.

7.3. Surrogate Calibration Standard: The surrogate calibration standard is a purchased standard that contains 5% 1,1,1-trifluoroethane in UHP helium. See the LIMS for further details.

7.4. Surrogate fortified helium: The surrogate mixture is a purchased mixture. The standard contains UHP helium fortified with 0.325% 1,1,1-trifluoroethane. The surrogate mixture is used to create headspace in all samples and standards other than the initial calibration. See the LIMS for further details.

7.5. Reagent Water: High purity water that meets the requirements for a method blank when analyzed. Reagent water may be purchased as commercial distilled water and prepared by purging with an inert gas overnight.

7.6. Calibration levels are achieved by using a syringe to inject different amounts of the standards into 43 mL vials of reagent water. Helium is used to create the balance of the final volume of 20 mL headspace in each vial (see Table 10.1).

8. SAMPLE COLLECTION, PRESERVATION, AND STORAGE

8.1. Samples are collected in the field in 43-mL screw cap VOA vials. The samples are preserved with 1:1 HCl to a pH of less than 2. Care should be taken that no headspace is present when capping the vials. A minimum of three vials per analysis is required. Double the volume is collected for a sample with a matrix spike/matrix spike duplicate (MS/MSD).

8.2. Samples are maintained at a temperature of 4°C ± 2°C and should be analyzed within 14 days of collection. Unpreserved samples must be analyzed within 7 days of collection.

9. QUALITY CONTROL

9.1. Batch Definition

9.1.1. A batch is a group of no greater than 20 samples excluding QC samples (LCS, Method Blank, MS, and MSD), which are processed with the same lots of reagents, the same processes, and by the same personnel. All sample analyses must be initiated within a 24-hour period from the initial preparation and without interruption of the process.

9.2. Method Blank (MB)

9.2.1. One MB must be processed with each preparation batch. The MB consists of reagent water, and all other reagents specific to the method and is carried through the entire analytical procedure, including preparation, and analysis, with the sample batch. The MB is used to identify any system and process interferences or contamination of the analytical system that may lead to the reporting of elevated analyte concentrations or false positive data. The MB should not contain any analyte of interest at or above the reporting limit (RL).

Note: Some clients may request reporting down to the Method Detection Limit (MDL). For those clients, detections above the MDL will be flagged.

9.2.2. Corrective Action for MB

9.2.2.1. If the analyte level in the MB exceeds the reporting limit for the analytes of interest in the sample, all associated samples are re-prepared and reanalyzed. If this is not possible due to limited sample quantity or other considerations, the corresponding sample data **must be addressed in the project narrative.**

9.2.2.2. If there is no analyte greater than the RL in the samples associated with an impacted MB, or the impacted analyte(s) in the sample are 10X the concentration found in the MB, the data may be reported with qualifiers. **Such action must be addressed in the project narrative.**

9.3. Laboratory Control Sample (LCS) / Laboratory Control Sample Duplicate (LCSD)

9.3.1. At least one LCS must be processed with each preparation batch. The LCS is fortified to the concentration of a standard near the midpoint of the calibration curve. The LCS must be carried through the entire analytical procedure with the samples and MB. The LCS is used to monitor the accuracy of the analytical process. On-going monitoring of the LCS results provides evidence that the laboratory is performing the method within acceptable accuracy and precision guidelines. (see also Section 17.2 modifications to the reference method)

9.3.2. Acceptance criteria for the LCS can be found in the laboratory information management system (LIMS).

9.3.3. Corrective Action for LCS

9.3.3.1. If any analyte is outside established control limits, the system is out of control and corrective action must occur.

9.3.3.2. The only exception is if the LCS/LCSD recoveries are biased high and the associated sample is non-detect (ND) at the RL for the analyte(s) of interest, the batch is acceptable. **This must be addressed in the project narrative.**

9.3.3.3. Corrective action will be re-preparation and re-analysis of the batch unless the client agrees that other corrective action is acceptable.

9.4. Matrix Spike/Matrix Spike Duplicate (MS/MSD)

9.4.1. One MS/MSD pair is processed for each batch. An MS is a field sample to which known concentrations of target analytes have been added. An MSD is a second aliquot of the same sample (spiked identically as the MS) prepared and analyzed along with the sample and MS. Some client-specific data quality objectives (DQOs) may require the use of sample duplicates in place of or in addition to MS/MSDs. The MS/MSD results are used to determine the effect of a matrix on the precision and accuracy of the analytical process. Due to the potential variability of the matrix of each sample, these results may have immediate bearing only on the specific sample spiked. Samples identified as field blanks cannot be used for MS/MSD analysis.

9.4.2. Corrective action for MS/MSDs

9.4.2.1. If the analyte recovery falls outside of the acceptance range, the results should be evaluated to determine the cause of the error.

9.4.2.2. If laboratory error is suspected, consultation with the PM and the client is necessary to determine the impact on data usability. Re-preparation and/or re-analysis may be necessary.

9.4.2.3. If matrix interference is suspected, the recovery of that analyte must be in control for the LCS. If the LCS recovery is within limits, then the laboratory operation is in control and the results may be accepted.

9.4.2.4. If the native analyte concentration in the MS/MSD exceeds 4 times the spike level for that analyte, the recovery data is reported and flagged with a “4” in the LIMS.

9.4.2.5. If client program requirements specify to confirm matrix interference's, re-preparation and reanalysis of the MS/MSD may be necessary.

9.5. Surrogate

9.5.1. 1,1,1-Trifluoroethane is the surrogate for RSK analytes.

9.5.2. Corrective Action for Surrogate

9.5.2.1. If the surrogate is outside established control limits in the samples or QC, the system is out of control and corrective action must occur.

9.5.2.2. If the surrogate fails in the MB and/or LCS, corrective action will be re-preparation and re-analysis of the batch unless the client agrees that other corrective action is acceptable.

9.5.2.3. For client sample surrogate outliers, it may be necessary to re-prep and re-analyze. When there is an obvious interference causing the surrogate outlier that the analyst knows a corrective action would not resolve the issue, flag the data with a qualifier indicating matrix interference.

9.5.2.4. For instrument QC (ICV and CCV), re-prep and re-analyze the CCV and/or ICV solution. Samples bracketed by an ICV and/or CCV that fails surrogate criteria must be re-analyzed. The exception to this is noted in section 9.5.2.5.

9.5.2.5. The only exception is if the surrogate recoveries are biased high and the associated sample(s) is ND for the analyte(s) of interest, the batch is acceptable. This must be addressed in the project narrative.

9.6. Control Limits

9.6.1. Control limits are established by the laboratory as described in SOP NC-QA-018.

9.6.2. Unless method specified, laboratory control limits are internally generated and updated periodically. Control limits are accessible via the LIMs

9.7. Method Detection Limits (MDLs) and MDL Checks

9.7.1. MDLs and MDL Checks are established by the laboratory as described in NDSC Document No. CA-Q-S-006.

9.7.2. MDLs are accessible via the LIMs

9.8. Nonconformance and Corrective Action

9.8.1. Any deviations from QC procedures must be documented as a nonconformance with applicable cause and corrective action.

10. CALIBRATION AND STANDARDIZATION

10.1. Initial Calibration – Establish an initial calibration curve using the concentrations noted in LIMS.

10.1.1. Preparation of Initial Calibration Standards

10.1.1.1. Fill a 43-ml VOA vial with purged reagent water and cap leaving no headspace in the vial.

10.1.1.2. Withdraw UHP helium from a cylinder using a gastight syringe. Place a relief needle into the headspace vial and inject the helium while keeping the vial inverted. The helium will displace water through the relief needle. Calibration gas can now be added to the still-inverted headspace vial.

10.1.1.3. Once pressure equilibrium has been reached (no more water is escaping), the relief needle is removed. The vials are then placed septa down on a tray. Move the vials and place them horizontally on the shaker table for approximately 5 minutes. After five minutes, the vials can be placed in the autosampler. Program the autosampler to start.

10.1.2. For each analyte, calculate the mean calibration factor (CF) from analyses of the calibration solutions.

10.1.3. Calculate the standard deviation (SD) and relative standard deviation (RSD) from each mean.

10.1.4. For average calibration fit, the percent RSD average of each List 1 analyte must be ≤ 20%, and the List 2 analytes and the surrogate RSD average must be ≤ 30%.

10.1.5. For linear calibration fit, r^2 must be > 0.995.

10.1.6. Removal or replacement of levels from the middle of a calibration (i.e., levels other than the highest or lowest) is not permitted unless an injection or instrument problem confined to that point can be clearly documented as described below.

10.1.7. If the analyst can document that a level is not valid because of an injection or instrument problem confined to that run, the level may be excluded if the curve still has sufficient levels, or if needed, the same run may be repeated once only. If removing a level or replacing a level with a rerun, the whole level (all compounds) must be removed or replaced. The curve is evaluated with the level removed or replaced. This must be documented. If the curve still fails to meet criteria, then corrective action must be taken and the whole curve re-analyzed. Corrective action may include, but is not limited to, instrument maintenance and/or re-preparation of standards.

10.1.8. One of the following conditions must be satisfied to allow removal or replacement of a level.

- The data file is corrupted and unusable or the run is interrupted before completion.
- The analyst observes and documents a problem such as leaking of a purge vessel.
- For external standard methods, the average amount of analyte recovered is less than 70% or greater than 130% of the expected value.

10.1.9. The reason for replacing the level **must** be documented in the run log. The fact that the curve passes criteria with the level removed is **not** alone sufficient evidence to document an injection or instrument problem confined to the level.

10.1.10. Removal of the highest or lowest levels is permitted, but the calibration range must be adjusted accordingly. If the lowest level is removed, then the reporting limit is raised to be equivalent to the lowest level used in the calibration curve. In any event, the number of levels remaining in the calibration must be at least 5 non-zero points, and the calibration range upper or lower limit for the affected compound(s) must be adjusted accordingly. This must be documented.

10.2. Removal of the highest or lowest point is permitted on a compound specific basis. This may be necessary when strongly responding and poorly responding analytes are included in the same standard mix at the same level. Each compound must have at least 5 non-zero points, and the calibration range upper or lower limit for the affected compound(s) must be adjusted accordingly. This must be documented. Calibration range upper or lower limit for the affected compound(s) must be adjusted accordingly

10.3. Continuing Calibration Verification (CCV)

10.3.1. Mid-Range CCV

10.3.1.1. A mid-range CCV is analyzed at the beginning of each run, after every 15 samples (including batch QC samples), and at the end of each run.

10.3.1.2. Withdraw 19 mL surrogate fortified helium from a cylinder using a gastight syringe. Place a relief needle into the headspace vial and inject the helium while keeping the vial inverted. The helium will displace water through the relief needle. Calibration gas mixture can now be added to the still-inverted headspace vial.

10.3.1.3. Add 1 mL of standard to the inverted vial. Once pressure equilibrium has been reached, the relief needle is removed. The vial can be placed on the shaker table and shaken for approximately 5 minutes, then placed on the autosampler.

10.3.1.4. The percent difference / percent drift (%D) between the CCV calibration factor (CF) and the ICAL average CF for each analyte must be ≤ 20% for List 1 compounds and ≤ 30% for List 2 compounds.

10.3.1.5. CCV Resolution: Resolution, or degree of overlap, for ethane /ethane and other close eluting analyte pairs must be at least 50%. Resolution of the compounds from the surrogate must be at least 80%.

10.3.2. Low Level and High Level CCVs

10.3.2.1. One Low Level CCV and one High Level CCV must be analyzed on a monthly basis.

10.3.2.2. The CCV (low) should be spiked at a concentration equivalent to the RL for each compound.

10.3.2.3. Criteria for the CCV (low) and the CCV (high) is as follows:

CCV / Compounds	**Low**	**High**
CCV (low) List 1	60	140
CCV (low) List 2	60	140
CCV (high) List 1	80	120
CCV (high) List 2	70	130

10.4. Initial Calibration Verification - An ICV must be analyzed following the acquisition of the initial calibration.

10.5. The percent difference / percent drift (%D) between the ICV calibration factor (CF) and the ICAL average CF for each analyte must be ≤ 20% for List 1 compounds and ≤ 30% for List 2 compounds.

10.6. The ICV is prepared using 1 mL of the second source standard.

10.7. Corrective Action for ICV/CCV

10.7.1. If the ICV/CCV fails to meet criteria, re-preparation and re-analysis of the ICV is required. Re-calibration may be necessary for re-analysis of the ICV fails to meet criteria. The exception to this is described below.

10.7.2. If the ICV/CCV recoveries are biased high and the associated sample(s) is ND at the RL for the analyte(s) of interest, the data are acceptable. This must be addressed in the project narrative.

11. PROCEDURE

11.1. One-time procedural variations are allowed only if deemed necessary in the professional judgment of QA, operations supervisor, or designee to accommodate variation in sample matrix, chemistry, sample size, or other parameters. Any variation in procedure shall be completely documented using a Nonconformance Memo.

11.2. Any unauthorized deviations from this procedure must also be documented as a nonconformance with a cause and corrective action described.

11.3. Equipment, supplies, reagents and standards, and/or spiking amounts detailed in this SOP are subject to change without notice.

11.4. **Note:** Various states and/or programs may have different requirements. It is the responsibility of the analyst to reference the proper work instructions for the needed requirements.

11.5. Sample Analysis

11.5.1. Sample Analysis - Remove the samples from the refrigerator. Allow the vial to come to room temperature. This will take at least one hour. Insert an 18 gauge relief needle into the septum. Using a 25 mL gastight syringe, inject 20 mL of surrogate-fortified helium into the sample. The helium forces out an equal amount of sample through the relief needle to create a headspace volume of 20 mL. Withdraw the needle and syringe from the vial, then the vials are placed septa down on a tray. Move the vials and place them horizontally on the shaker table for approximately 5 minutes. Load the sample onto the headspace autosampler. 1mL of the sample headspace is injected directly onto the GC column where the target compounds, if present, are detected by FID. Acquire the data and process on Chrom. The recommended instrument operating conditions are outlined in Appendix 1 at the end of this document. .

11.5.2. QC sample prep.

11.5.2.1. The MB is prepared as a sample (see Section 9.2).

11.5.2.2. LCS (and LCSD if needed) is prepared using 1 mL secondary source standard after 19 mL of headspace has been created with surrogate fortified helium (see Sections 9.3 and 17.2).

11.5.2.3. A MS/MSD pair is prepared as a regular sample, but 1 mL of primary source standard is injected after 19 mL of headspace has been created with surrogate-fortified helium (see Section 9.4).

11.6. Analytical Documentation

11.6.1. Record all analytical information in the LIMS, including any corrective actions or modifications to the method.

11.6.2. Record all standards and reagents in the LIMS Reagents module. All standards and reagents are assigned a unique number for identification.

11.6.3. Documentation such as all associated instrument printouts (final runs, screens, reruns, QC samples, etc.) and daily calibration data corresponding to all final runs is stored and available for each data file.

11.6.4. Record all sample results and associated QC in the LIMS. Level I and Level II reviews are performed in the LIMS.

12. DATA ANALYSIS AND CALCULATIONS

12.1. Calibration Factor for GC-FID

$$\mathbf{CF = A/C}$$

Where:

CF = Calibration factor of an analyte
A = Instrument response (peak area or height)
C = Concentration of an analyte in sample

12.2. Percent Difference for Calibration Factors

$$\mathbf{\%\ D = (Avg_{CF} - CF / Avg_{CF}) \times 100}$$

Where:

Avg_{CF} = Average CF for an analyte from the initial calibration
CF = CF for an analyte from standard

12.3. Relative Standard Deviation

$$\mathbf{\%RSD = (SD / Avg_{CF}) \times 100}$$

Where:

Avg_{cf} = Average CF for an analyte from the initial calibration
SD = Standard Deviation of CFs for a compound

12.4. Weighted Linear

$$y = \frac{1}{SD^2} \times (ax + b)$$

Where y = Instrument response
a = Slope of the line
x = Concentration of the calibration standard
b = The intercept
SD = Standard deviation from 12.3

12.5. Sample Concentration in water

$$\mathbf{C = (A/Avg_{CF}) \times DF}$$

Where:
C = Concentration of target analyte in sample
A = Instrument response (peak area or height)
Avg_{CF} = Average CF for an analyte from the calibration
DF = Dilution factor

12.6. Additional constants, equations, and calculations are listed in Section 17.1, Tables 1 and 2, and the following SOPs:

12.6.1. Calibration Curves and the Selection of Calibration Points, NDSC Document No. CA-Q-P-003.

12.6.2. See also section 17.2 Modifications to the reference method.

13. METHOD PERFORMANCE

13.1. Each analyst must have initial demonstration of performance data on file. Each laboratory must have corresponding method detection limit (MDL) study files.

13.2. Training Qualifications

13.2.1. The Group/Team Leader has the responsibility to ensure this procedure is performed by an associate who has been properly trained in its use and has the required experience.

13.2.2. Method validation information (where applicable) in the form of analyst demonstrations of capabilities is maintained for this method in the laboratory training files.

14. POLLUTION PREVENTION

14.1. It is Eurofins' policy to evaluate each method and look for opportunities to minimize waste generate (i.e., examine recycling options, ordering chemicals based on quantity needed, preparation of reagents based on anticipated usage, and reagent stability). Employees must abide by the policies in Section 13 of the NDSC EH&S Manual Document No. CW-E-M-001for "Waste Management and Pollution Prevention".

15. WASTE MANAGEMENT

15.1. All waste will be disposed of in accordance with Federal, State and Local regulations. Where reasonably feasible, technological changes have been implemented to minimize the potential for pollution of the environment. Employees will abide by this method and the policies in Section 13 of the NDSC EH&S Manual Document No. CW-E-M-001for "Waste Management and Pollution Prevention."

15.2. Waste Streams Produced by the Method

15.2.1. All sample vials are collected in boxes and removed from the lab to storage. The Waste Coordinator handles crushing the vials and proper disposal

15.3. Laboratory personnel assigned to perform hazardous waste disposal procedures must have a working knowledge of the established procedures and practices of the laboratory. They must have training on the hazardous waste disposal practices upon initial assignment to these tasks followed by annual refresher training.

16. REFERENCES

16.1. References

16.1.1. RSK SOP-175, Revision 0, August 11, 1994

16.1.2. Minimum requirements for Dissolved Gas Analysis by methods RSK-175 R2-5, RSK-194 R3-4, EPA Region 1 NATATTEN Rev 1.

16.1.3. Some criteria are derived from PA-DEP3686 R1 and ASTM D8028 when the primary references don't address an area.

16.1.4. Best Practices for Dissolved Gas Analysis by methods RSK-175 R2-5, RSK-194 R3-4, EPA Region 1 NATATTEN Rev 1. Work Instruction No. CA-T-WI-017, dated 06 Jan 2020.

16.1.5. Eurofins Canton QA Manual, current version

16.1.6. Quality Management Plan (QMP), current version

16.1.7. NDSC EH&S Manual Document No. CW-E-M-001and Eurofins Canton Facility Addendum and Contingency Plan, current version

16.1.8. NDSC Document No. CA-T-P-005, Rev 0, Policy for Determining RT Windows for GC/ECD Tests

16.1.9. Revision History

Historical File:		Revision 6: 04/03/14		
Revision 0: 05/13/02		Revision 7: 11/19/15		
Revision 1: 11/16/04		Revision 8: 11/08/17		
Revision 2: 02/01/07		Revision 9: 03/12/18		
Revision 3: 03/21/08		Revision 10: 10/22/18		
Revision 4: 05/06/10		Revision 11: 06/29/20		
Revision 5: 04/29/13		Revision 12: 07/27/20		

**4/9/19: Changed logo and copyright information. No changes made to revision number or effective date.*

16.1. Associated SOPs, Work Instructions, and Policies, current version

16.1.1. QA Policy, QA-003

16.1.2. Glassware Washing, NC-QA-014

16.1.3. Statistical Evaluation of Data and Development of Control Charts, NC-QA-018

16.1.4. Detections and Quantitation Limits, NDSC Document No. CA-Q-S-006

16.1.5. Standards and Reagents, NC-QA-017

16.1.6. Manual Integrations CA-Q-S-002

16.1.7. Calibration Curves and the Selection of Calibration Points, NDSC Document No. CA-Q-P-003

17. MISCELLANEOUS (TABLES, APPENDICES, ETC.)

17.1. Reporting limits

17.1.1. The most current reporting limits can be accessed via the LIMS.

17.1.2. If samples require dilution or smaller volumes than specified in this method, the RL will be elevated.

17.2. Modifications from Reference Method

17.2.1. A surrogate, not required by the RSK SOP, has been added to the analytical process

17.2.2. Laboratory control samples are prepared directly in 43 mL VOA vials with screw caps. Headspace is generated using UHP helium fortified with surrogate compounds.

17.2.3. UHP helium fortified with surrogate compounds is injected into every field and QC sample such that a consistent 20 mL of sample is displaced to create headspace. This process normalizes the way samples are processed such that the gas measured in the headspace is reflective of the total amount of gas injected; thus eliminating the need to apply the Henry's Law constant in the result calculation.

17.3. Tables and Appendices

Table 1
List 1 Compounds

Compound	**Molecular Weight (g)**
Methane	16
Ethane	30
Ethene	28
Propane	44

Table 2
List 2 Compounds

Compound	**Molecular Weight (g)**
Acetylene	26
1 Butene	56.1
n-Butane	58.1
Pentane	72.1
2-Methyl Propane	58.1
Propene	42.1

Appendix 1

EXAMPLE CALCULATION
(based on 17 mL of water and 4 mL of headspace)

(Calculations Based on 22°C at 754 mmHg – Molar Equivalent .04099)

2,000 ul of 10,000 ppmv – 17 mL H_20

$$\frac{10{,}000\ \text{ul } CH_4}{\text{L He}} \times \frac{1\ \text{L } CH_4}{1{,}000{,}000\ \text{ul } CH_4} \times \frac{.04099\ \text{moles } CH_4}{1\ \text{L}CH_4} \times \frac{16\ \text{g } CH_4}{1\ \text{mole } CH_4} \times \frac{.002\ \text{L He}}{.017\ \text{L}H_2 0} \times$$

$$\frac{1{,}000{,}000\ \text{ug } CH_4}{1\ \text{g } CH_4} = \frac{13.1168}{.017} = \frac{771.57\text{ug } CH_4}{\text{L}H_2 0}$$

EXPLANATION OF TERMS:

$\frac{10{,}000\ \text{ul Methane}}{\text{L Helium}}$ = Puts PPMV methane into volumetric ratio per liter helium. (Helium is the gas used to generate head space in the sample vial.)

$\frac{1\ \text{L Methane}}{1{,}000{,}000\ \text{ul Methane}}$ = Simple units conversion.

$\frac{.04099\ \text{moles Methane}}{\text{L Methane}}$ = Molar equipment of methane at standard temperature and pressure per ideal gas law.

$\frac{16\ \text{g Methane}}{1\ \text{mole Methane}}$ = Molar weight of methane.

$\frac{.002\ \text{L Helium}}{.017\ \text{L}H_2 0}$ = Amount of helium in calibration standard distributed over 17 ml of reagent water in sample vial.

$\frac{1{,}000{,}000\ \text{ug Methane}}{1\ \text{g Methane}}$ = Units conversion from grams to µg of methane to arrive at µg/L concentration of methane.

$\frac{13.1168}{.017}$ = Collection of terms.

771.57µg L^{-1} Methane = Final concentration of methane in calibration

Appendix 2:

Recommended Instrument Operating Conditions

Recommended GC Conditions

9 psi constant flow
Oven Program: 45 for 1 minute
16°C/min to 180°C hold 1.06 min
GC Inlet Temp: 250ºC

Recommended FID Conditions

FID Temp:	250°C	Hydrogen Flow: 40 mL/min
Air Flow:	450 mL/min	
Helium Makeup:	45 mL/min	

Recommended Headspace Auto Sampler Conditions

Screen Mode

Blank Water Volume (mL)	0
Syringe Prime Time (sec)	3
Syringe/Rinse Needle (mL)	20
Rinse Cycles	OFF
Sample Temperature (ºC)	Off / room temperature
Stir	ON (Med)
Sample Equil. Time (min)	10
Vial Pressurization Time (sec)	5
Loop Fill Time (sec)	5
Loop Equil. Time (sec)	5
Injection Time (sec)	0
Valve Temperature (ºC)	65
GC Line Temperature (ºC)	100
GC Cycle Time (min)	14
Rinse Water Temperature (ºC)	65

APPENDIX E.1-4

LABORATORY STANDARD OPERATING PROCEDURES FOR SOIL GAS/SURFACE AIR ANALYSIS

Gas Chromatographic Analysis of Gases

Equipment

Shimadzu 2010 (complete/full GC) Gas Chromatograph. This GC system is equipped with both thermal conductivity (TCD) and flame ionization (FID) detectors but quantification of fixed gases is done using only the TCD. Data processing is done on GC solutions software and a personal computer.

A. Analysis of hydrocarbons

Shimadzu 2010 Gas Chromatograph. This (partial) GC system is equipped with both thermal conductivity (TCD) and flame ionization (FID) detectors. Data processing is done on GC solutions software and a personal computer.

Method/Procedure The sample loop on the GC is evacuated between each sample. Samples are injected into the evacuated sample loop and adjusted to atmospheric pressure. Sample identification is entered into the GC solutions software and the run is initiated.

The Shimadzu 2010 and 2014 utilizes several different packed columns and valve switching to separate the various components. Instrument configuration was designed by Shimadzu specifically to meet the requirements of Isotech. Helium is used as the carrier gas. All valve switching during the analysis is computer-controlled. The resulting component peak areas are then quantified by the software (given raw percent values) by comparing them to previously run standards. The lab technician checks the raw total for each analysis to ensure that all components have been detected. The raw total can vary from day to day depending on atmospheric pressure, with acceptable raw totals of 96% to 104%. The lab technician also checks all baselines for accuracy from the chromatograms shown on the computer screen. This raw computer record is maintained for each sample corresponding to its individual lab number. The raw percentage values for each sample are downloaded into the main sample database, and are normalized to 100% when the Analysis Report is generated.

B. Analysis of fixed gases

Method/Procedure The procedure for analysis of fixed gases is identical to that for analysis of hydrocarbons, with one exception, for separation of oxygen and argon, an external column on is used. This column operates at -78°C; therefore a dewar of dry ice/isopropyl alcohol is placed on the column before each run. The lab technician checks all baselines to verify peak integration.

Calibration/Standardization Multiple reference gases are used for standardization of the Shimadzu gas chromatographs. All standards are analyzed on the same day during a new standardization to minimize the effects of barometric pressure variations. The minimum and maximum concentration used for calibration cover the range of the majority of natural gases submitted for analysis. At least four points are used for each component. For each new standardization, the peak area of each concentration for each compound is inserted into a table within the GC

Solutions software. This table is then accessed by the software, which uses point-to-point interpolation, to determine component concentrations for gas samples during analysis.

Reference Samples The reference sample used as the 1st run of each day and every tenth sample thereafter is representative of the majority of natural gas samples received for analysis. Data obtained for reference samples and expected results based on previous analyses can be provided as part of a QA/QC report.

Replication Every tenth analysis is a replicate. This replicate analysis is done approximately five samples following the check sample, thus a system check is performed at least every five analyses.

Isotope Analysis

A. $\delta^{13}C$ and δD (Carbon and Hydrogen Isotope Analysis) for Hydrocarbon Gases, Offline Prep Systems (Tradition Method)

Equipment and Supplies

3 SRI 8610C Gas chromatographs
Evacuated transfer system
Copper oxide combustion furnace
Dry ice
Isopropyl alcohol
Liquid nitrogen
Electronic manometer
Electronic vacuum gauge
Helium
Oxygen
Gas-oxygen torch

Method/Procedure The determination of carbon and hydrogen isotopic ratios for hydrocarbons in gas mixtures (e.g. natural gas) requires a sample preparation system capable of first separating the individual hydrocarbons and then quantitatively converting them into carbon dioxide (CO_2) and water for mass-spectrometric analysis. There are 2 systems utilized for processing natural gases. The systems employed are helium purged flow systems consisting of two major units.

The first unit consists of sample injection syringes, SRI 8610C gas chromatographs, a personal computer, and several flow-control valves. This configuration separates the hydrocarbon of interest from the sample and channels it into the combustion-collection unit. The second unit is the combined combustion-collection unit which includes quartz combustion tubes filled with cupric oxide (CuO), and vacuum lines. This system converts the hydrocarbon of interest into CO_2 and water, which are then collected and purified for isotopic analysis.

The water of combustion is transferred into a length of Pyrex tubing that has been sealed at one end and contains a weighed quantity of zinc turnings. The sample tube is sealed off for later mass spectrometric analysis. Similarly, the CO_2 is then transferred into Pyrex tubing and sealed off for later mass spectrometric analysis (see next section-section C).

Reference Samples The system is tested by analyzing a reference sample every tenth analysis performed.

Replication A duplicate analysis of one of the samples is performed approximately every tenth analysis. This duplicate analysis is performed approximately five analyses after the reference sample analysis is performed. Therefore, a test of the system operation is performed every five analyses.

B. Dual Inlet Mass Spectrometric Analysis

1. Measurement of $^{13}C/^{12}C$ and $^{18}O/^{16}O$ in CO_2

Equipment Finnigan MAT Delta S Isotope Ratio Mass Spectrometer

Method/Procedure Because $^{13}C/^{12}C$ and $^{18}O/^{16}O$ analyses are performed simultaneously, the procedure described here generates both measurements. A mass spectrometric analysis involves comparisons of a sample to a reference standard; in this case the comparisons are measurements of mass 44, 45, and 46, giving the both the oxygen and carbon isotopic compositions. This is accomplished by a dual inlet system where the sample and the reference standard are measured alternately. At the beginning of each day, a reference standard is introduced into the standard side of the inlet system, and this gas is generally used for the entire session. There are two different reference standards in aluminum cylinders which are permanently mounted on the MS inlet system. The sample to be analyzed against the standard is introduced into the system via an evacuated inlet system and tube-cracker. With the inlet system fully evacuated, the sample (which is sealed into ¼" Pyrex tubing) is introduced by breaking the glass sample tube and allowing the sample to fill a variable volume bellows. Once the sample has been introduced into the MS, the actual analysis is computer controlled using equipment obtained from the manufacturer. Each analysis is given a specific reference name and/or number, utilizing the lab number as the primary reference. Final results are calculated by the manufacturer's software, and are stored on the hard drive of the computer, recorded in a bound lab notebook, and stored as the computer generated printout.

Calibration/Standardization The first analysis of each session is a zero enrichment, where the working standard is analyzed against itself to check machine stability. Isotope ratio determination involves multiple direct comparisons of the sample to a reference standard (generally at least 6 comparisons). Stable carbon and oxygen isotope compositions are always reported as the difference between the ratios of the two isotopes of interest in the sample and the ratio in a primary reference standard. That is,

$$\delta X_{(sample)} = [(R_{sample} - R_{standard})/ R_{standard}] \times 1000$$

Where X represents the isotope of interest, ^{13}C or ^{18}O, and R represents the ratio of $^{13}C/^{12}C$, or $^{18}O/^{16}O$. The δ value is expressed in terms of per mil (‰), or parts per thousand.

In practice, the difference between the sample and an internal reference standard is measured and then the value relative to the primary standard is calculated by the instrument manufacturer's software. Two internal reference standards are used at Isotech, both of which have been calibrated multiple times relative to several standards (graphite, oil, carbonates, waters, etc.) available from the International Atomic Energy Agency and the National Institute of Standards and Technology.

<u>Replication</u> Because of replicate sample preparations, at least 10% of all analyses are replicates.

<u>Reference Samples</u> Because 10% of all samples prepared for stable isotope analysis are check samples or reference samples which have been previously analyzed, these samples also serve as check samples for the mass spectrometer.

2. Measurement of $^2H/^1H$ (Deuterium/Hydrogen) in H_2

<u>Equipment</u>

Finnigan Delta Plus XL isotope ratio mass spectrometer
Aluminum heating block
Personal computer

<u>Method/Procedure</u> The H_3 factor, which is the portion of the mass 3 signal attributable to ^1H-^1H-^1H (instead of ^2H-^2H), is determined before each run early in the day and periodically throughout the day based on machine performance (if the values start drifting, a new H_3 factor is determined). The reference standard must be replenished at least once during an 8 hour period.

Water samples for deuterium/hydrogen analysis are sealed into ¼" Pyrex tubing as H_2O, along with a measured quantity of zinc. Each sample tube is labeled and reacted in a heating block at 500°C for 35 minutes to generate hydrogen gas. Once the sample has been reacted, it is introduced into the sample side of the MS inlet system and analyzed against the working standard. Each analysis is given a unique label, using the lab number as the primary reference. Once the sample has been introduced into the MS, the analysis is computer controlled. The raw result is calculated by the manufacturer's software and recorded into a bound lab notebook, as well as being stored on computer hard disk and computer generated printout of results.

<u>Calibration/Standardization</u> The first run each day is a zero-enrichment where the standard is run against itself to check machine stability. Stable hydrogen isotope compositions are always reported as the difference between the ratios of the two isotopes of interest in the sample and the ratio in a primary reference standard. That is,

$$\delta D_{(sample)} = [(^2H/^1H_{\ sample} - {}^2H/^1H_{\ standard})/\ {}^2H/^1H_{\ standard}] \times 1000$$

The δ value is expressed in terms of per mil (‰), or parts per thousand.

In practice, the difference between the sample and an internal reference standard is measured and then the value relative to the primary standard is calculated by the instrument manufacturer's software. Two internal reference standards are used at Isotech which have been calibrated relative to several water standards available from the International Atomic Energy Agency and the National Institute of Standards and Technology.

Replication Because of replicate preparation of samples, at least 10% of all analyses are replicates.

Reference Samples Because 10% of all samples prepared for stable isotope analysis are check samples or reference samples which have been previously analyzed, these samples also serve as check samples for the mass spectrometer.

General Statement of ^{14}C Procedures at the National Ocean Sciences AMS Facility

This statement applies only to samples analyzed as solid graphite produced at the National Ocean Sciences AMS (NOSAMS) facility. It does not apply to samples analyzed on the gas-accepting AMS system.

All laboratory preparations for AMS radiocarbon analyses of submitted samples occur in the National Ocean Sciences AMS (NOSAMS) Facility except for collagen extraction from bones which carried out by a specialist at Harvard University and returned to NOSAMS for further analysis. Procedures appropriate to the raw material being analyzed are described on our web pages in the Methods section. Pure CO_2, whether submitted directly or generated at the NOSAMS Facility, is reacted with Fe catalyst to form graphite. Graphite is pressed into targets, which are analyzed by accelerator mass spectrometry along with primary and secondary standards and process blanks.

An AMS measurement determines the ratio of ^{14}C to ^{12}C in an unknown sample relative to the ratio of the concurrently measured standard samples. At NOSAMS, the primary standard for ^{14}C measurements is NBS Oxalic Acid I (NIST-SRM-4990). Every group of samples processed includes an appropriate blank, and a secondary standard analyzed concurrently with the group. Process blank materials typically include but are not limited to IAEA C-1 Carrara marble and TIRI F Icelandic Doublespar (Third International Radiocarbon Intercomparison) for inorganic carbon and gas samples; acetanilide (CE Elantech) or KHP (Sigma Aldrich) for organic carbon samples; a ^{14}C-free groundwater for dissolved inorganic carbon samples; and a glycine (Sigma Aldrich) dissolved in DOC-free water for dissolved organic carbon samples.

Fraction modern (F_m) is a measurement of the deviation of a sample's radiocarbon content from that of the modern standard. Modern is defined as 95% of the radiocarbon concentration (in AD 1950) of NBS Oxalic Acid I, normalized to $\delta^{13}C_{VPDB} = -19‰$ (Olsson, 1970). A correction is made to normalize the sample result to a $\delta^{13}C_{VPDB}$ value of -25‰, assuming a quadratic mass fractionation dependency. This correction is made using simultaneously measured $^{13}C/^{12}C$ ratios on the AMS system. These $^{13}C/^{12}C$ ratios are not reported. Post-analysis stable isotopic corrections are neither necessary nor appropriate for reported results. All $\delta^{13}C$ results reported are measured on a split of sample CO_2 by IRMS when requested.

Radiocarbon ages are calculated using the Libby half-life of 5568 years according to the convention outlined by Stuiver and Polach (1977) and Stuiver (1980). We do not report ages with reservoir corrections applied or ages calibrated to calendar year. If a sample collection date is specified on the submittal form, the $\Delta^{14}C$ activity normalized to 1950 is also reported, i.e. the activity or $\Delta^{14}C$ of the sample is corrected to account for the decay between collection (or death) and the time of measurement.

The ^{14}C atoms contained in a sample are directly counted using the AMS method. Accordingly, we calculate an internal statistical error using the total number of ^{14}C counts measured for each target (internal error = $\frac{1}{\sqrt{n}}$, where n is the number of ^{14}C counts). An external error is calculated from the repeatability of multiple measurements of a given cathode over the course of a run (external error = $\sigma/\sqrt{N}$ where $\sigma = sqrt[\,\Sigma\,(Xi - \mu)2\,/\,N\,]$, or standard deviation of the mean and N is the number of determinations). The final reported error is the larger of the internal or external error, propagated with errors from the normalizing standards and process blank corrections.

It should be noted that the reported error is an estimate of the precision (repeatability) of measurement for a single sample. Due to variability in sample homogeneity, sample collection, and sample processing, the variability of replicate samples (reproducibility) may be greater than the reported error for a single sample.

When publishing results of samples analyzed at the NOSAMS facility, we ask that an accession number (i.e. the reported OS-#####) be listed with the result along with any subsequently made corrections. Published results should acknowledge support from NSF by including the NSF Cooperative Agreement number, OCE-1755125. We encourage you to email references to your publications to nosams@whoi.edu for inclusion in our web-accessible database of NOSAMS research related publications (http://nosamsresearch.whoi.edu/). Any sample material not consumed during sample preparation or AMS radiocarbon analysis, and not requiring refrigeration, is archived for two years at the NOSAMS Facility unless other arrangements are made by the submitter.

REFERENCES

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