Innovations in Water Monitoring

AquaTROLL 600

AquaTroll 600

Interface Specification

Revision: 1.33

Conventions

The terminology used for requirements is as follows:

Must/Shall

All requirements containing the words "Must" or "Shall" are mandatory and non-negotiable. These terms signify a requirement that is essential to the inter-operation of the overall architecture.

Should/Recommended

All requirements containing the word "May" "Might" or "Should" are suggestion for standard behavior and design and should be considered a requirement unless specific reasons are presented to ignore or disregard the suggestion. The implications of discarding suggested design requirements should be carefully considered.

Optional

All requirements listed as “Optional” are purely up to the discretion of the designer to implement.

Purpose

This document is the high-level interface specification for the In-Situ AquaTroll 600 Probe (both non-vented and vented versions). It is an extension to the In-Situ System Interface Specification, and defines the device-specific characteristics of the probe.

Overview

The AquaTroll 600 Probe is a multi-parameter water quality probe with data logging. It has integral depth and barometric pressure sensors and supports a variety of plug-in sensors including, but not limited to, RDO, conductivity, temperature, turbidity, pH and ORP. The probe supports the following interface standards.

1. MODBUS RS485. The device shall adhere to the specifications for probes and sensors as described in the In-Situ System Interface specification and the extensions described in this document.

2. MODBUS over Bluetooth. The device shall adhere to the specifications for probes and sensors as described in the In-Situ System Interface specification and the extensions described in this document.

3. SDI-12. The device shall adhere to the Serial Digital Interface Standard for Microprocessor-Based Sensors, Version 1.3 dated September 17, 2002 and the extensions to the specification described in this document.

MODBUS Reserved Registers

The device shall implement the full reserved register set identified in the System Interface Specifications. This section identifies device-specific values returned in the reserved registers.

Register Map Template Version

This register shall return the value 3.

Device Id

The device id shall return 7 for the non-vented version.

The device id shall return 26 for the vented version.

The functionality of the two devices shall be identical except for the barometric pressure measurement methodology.

Hardware Version

The valid range for the device hardware version shall be 0 to 15.

Hardware Version	Firmware Versions
0 – prototypes	0.10 – 0.43
15 – alpha	0.44 – 0.65

Hardware Version	Firmware Versions
1 – beta	0.70 – 0.99
2 – wet-mate connectors	1.00 – 1.XX
3 – battery circuit update	1.20 – 1.XX
4 – new baro & log memory	1.77 – 1.XX

Max Data Logs

The maximum number of data logs supported is 50.

Total Data Log Memory

The total data log memory is 16,384,000 bytes.

Total Battery Ticks

This register shall return 15,000,000, representing the battery capacity in microamp-hours.

Last Battery Change

This register shall return the time of the last detected battery change. The time shall be the internal UTC time with the current time offset correction applied. Batteries will be considered changed under the following conditions.

- The battery compartment is open and a set of alkaline batteries (defined as measuring less than 3.5 volts) measures more than 200 millivolts different than when last measured.
- The battery compartment is open and a set of lithium batteries (defined as measuring greater than 3.5 volts) measures more than 400 millivolts different than when last measured.
- The battery compartment is open and the battery type is changed as indicated by transitioning between the above voltage ranges.

This register shall be read only.

Device Commands

The device-specific commands are specified below.

Id	Name	Access Level	Description
0xD100	Operate Wiper	3	Manual wiper operation. Resets the wiper interval. Exceptions: 0x94 – Wiper port open 0x93 – Wiper not installed (wiper plug) 0x95 – Wiper current overload

Id	Name	Access Level	Description
			0x97 – Wiper operation timeout
0xD104	Initiate radio firmware update	3	Initiate radio firmware update per manufacturer's protocol.

Current Time

The current UTC time is kept to the nearest second. The fractions portion of the current time register shall always return zero.

If the current UTC time is less than the manufacture date, indicating a loss of the time, writing to the time register shall update the internal UTC time and set the offset correction to zero. Otherwise, the internal UTC time shall not be modified by writing to the register. A write shall cause an offset correction to the internal UTC time to be calculated and stored. All subsequent reads and timestamps shall have the offset correction applied to the internal UTC time. The device shall set the internal UTC time to the manufacture time when the manufacture time is written at the factory access level.

Device Status

The device will set bit 15 of the standard device status (physical port open warning) if the wiper port or battery cover is open. The device supports the following device specific status values.

Device Status Bit Values

Bit	Category	Mask	Description	Cleared on Status Reset
16	Warning	0x00010000	Battery cover open	No (note 1)
17	Warning	0x00020000	Wiper port open	No (note 1, 2)
18	Status	0x00040000	Wiper installed	No (note 2)
19	Warning	0x00080000	Wiper operation warning	Yes
20	Status	0x00100000	Reserved	No
21	Status	0x00200000	Reserved	No
22	Status	0x00400000	Reserved	No
23	Status	0x00800000	Reserved	No
24	Status	0x01000000	Reserved	No
25	Status	0x02000000	Reserved	No
26	Status	0x04000000	Reserved	No
27	Status	0x08000000	Reserved	No
28	Status	0x10000000	Reserved	No
29	Status	0x20000000	Reserved	No
30	Status	0x40000000	Reserved	No
31	Status	0x80000000	Reserved	No

Note 1: These bits will also cause the standard port open status bit (bit 15) to be set.

Note 2: These bits are refreshed by reading the sensor connection status register.

Used Battery Ticks

This register shall return the used battery capacity in microamp-hours.

Serial Communication Configuration

The standard communication control registers (9200 to 9209) shall apply to the RS485 interface. Operation of the Bluetooth interface shall not be affected by changes in these registers. The RS485 interface shall support the communication configurations specified in the table below.

Bits	Description
0	Modbus Transmission Mode 0 = RTU (default) 1=ASCII
1,2 & 3	Baud Rate Id 0 = 9600 1 = 19200 (default) 2 = 38400 3 = 57600
4	Data Bits 0 = 7 data bits 1 = 8 data bits (default)
5,6	Parity Bits 0 = Even (default) 1 = Odd 2 = None
7	Stop Bits 0 = 1 Stop Bit (default) 1 = 2 Stop Bits

Note: 7 data bits is not a valid setting for Modbus RTU communication. If an attempt is made to write RTU mode with 7 data bits, the device will return an exception with error code 0x84. All other combinations of communication configurations shall be supported.

Max Allowed Baud Rate Id

This register shall return a value of 3 (57600 baud).

Max Message/Response Size

The device shall have a maximum message and response size of 1024 bytes. Reading this value will return the maximum message size of the RS485 connection.

Device Address

The sonde shall support a broadcast read of its device address register.

Probe Connection Registers

Probe connection registers 9297 through 9299 are not supported since this device is not a controller. Any attempt to access these registers will return an exception response with exception code 2 (illegal data address).

Max Sensor Connections

This register will return a value of 6 to 7 depending on the factory configuration of the instrument.

Sensor Connection Status

Up to seven sensor connections are supported, represented by Bits 0 through 6 in the sensor connection register as defined in the table below. The probe will detect its sensor configuration and respond within 2500 milliseconds.

Bit	Port	Sensor	Description
0	Port 1	Port 1	User installed, bit set when a sensor or plug is installed.
1	Port 2	Port 2	User installed, bit set when a sensor or plug is installed.
2	Port 3	Port 3	User installed, bit set when a sensor or plug is installed.
3	Port 4	Port 4	User installed, bit set when a sensor or plug is installed.
4	Port 5	Internal	Internal parameters, always installed, bit is always set.
5	Port 6	Baro	Always installed, bit is always set.
6	Port 7	Level	Factory installed option, bit set if installed.

Sensor Map Registers

The sensor map registers are allocated per the following table. Attempts to access unused map registers will result in an exception response with exception code 0x02 (illegal data address).

Port	Map Registers	Data Register Offset
Port 1	9303 – 9307	1
Port 2	9308 – 9312	219
Port 3	9313 – 9317	437
Port 4	9318 – 9322	655
Port 5	9323 – 9327	873
Port 6	9328 – 9332	1091
Port 7	9333 – 9337	1309

Sensor Cache Timeout

The default value for this register shall be 10000 milliseconds. The cache timer has a resolution of one second. The cache timeout will be adjusted to be the smallest number of whole seconds not less than the specified value.

Interface Configuration

This register shall return a value of 485 (0x01E5) indicating that SDI-12, Win-Situ logging control, continuous readings, modem information, calibration history file, and RTU over Bluetooth are supported.

A 4-20 mA current loop interface is not supported. Attempting to access current loop configuration registers 9501 through 9507 will result in an exception response with exception code 0x02 (illegal data address).

Internal Parameters Sensor

The internal parameters register is factory installed and always appears as sensor connection 5 (bit 4 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Parameters provided by the internal sensor are considered "preferred." If an internal parameter id is a duplicate of a parameter id provided by other sensors, the internal sensor parameter will provide the preferred representation of that parameter, allowing the other representations of the parameter to be ignored if desired.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 79
1	2	R1	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 400 milliseconds
17	1	R1	ushort	Fast sample rate = 400 milliseconds
18	1	R1	ushort	Number of sensor parameters (N) = 3
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
				Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Parameter 1: Preferred Temperature

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 1 (temperature)
40	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0003 (3)

The preferred temperature presents the most accurate temperature available from the set of sensors plugged into the instrument at the time. If a temperature sensor is not available, or the sensor temperature returns an error, the sonde will substitute its internal temperature sensor value and set the data quality id to a warning.

The sensor warm-up and fast sample rate registers will update to reflect those of the selected temperature sensor.

Sensors with temperature parameters are ranked as follows. A higher number indicates a higher preference, sensors of equal ranking are chosen in port order.

Temperature Sensor (Id 55): 7

Conductivity/Temperature Sensor (Id 56): 5

RWT Sensor (Id 60): 3

CHLA Sensor (Id 62): 3

BGA-PC Sensor (Id 64): 3

BGA-PE Sensor (Id 65): 3

Parameter 2: External Voltage

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value
47	1	R1	ushort	Parameter Id = 32 (external voltage)
48	1	R1/W2	ushort	Units Id 163 = Volts (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Sentinel value (default = 0.0 V)
52	1	R1	16 bits	Available Units = 0x0004 (4)

Parameter 3: Battery Capacity

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
53	2	R1	float	Measured value
55	1	R1	ushort	Parameter Id = 33 (battery capacity)
56	1	R1/W2	ushort	Units Id 241 = % (default)
57	1	R1	ushort	Data Quality Id
58	2	R1/W3	float	Sentinel value (default = 0.0 %)
60	1	R1	16 bits	Available Units = 0x0001 (1)

Barometric Pressure Sensor

The barometric pressure sensor is factory installed and always appears as sensor connection 6 (bit 5 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value. Measuring the barometric sensor does not trigger the wiper.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 59
1	2	R1	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 300 milliseconds
17	1	R1	ushort	Fast sample rate = 300 milliseconds
18	1	R1	ushort	Number of sensor parameters (N) = 1
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Parameter 1: Barometric Pressure

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value, P_B
39	1	R1	ushort	Parameter Id = 16 (barometric pressure)
40	1	R1/W2	ushort	Units Id 17 = PSI 19 = KPa 20 = bar 21 = mbar 22 = mmHg (default) 24 = cmH_2O 25 = in H_2O
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Sentinel value (default = 760.0 mmHg)
44	1	R1	16 bits	Available Units = 0x01FD (509)

The measured barometric pressure (P_B) is calculated as:

$P_B = B_S + B_O$

Where B_S is the factory calibrated barometric pressure and B_O is the user offset calibration, all in the current units.

Pressure is factory calibrated in mbar. Conversion to other units is as follows.

KPa = 6.894757 * PSI

bar = 0.06894757 * PSI

mbar = 68.94757 * PSI

mmHg = 51.71492 * PSI

inHg = 2.036021 * PSI

cmH_2O = 70.30696 * PSI

inH_2O = 27.67990 * PSI

In the non-vented unit, the barometric pressure is only measured when the battery compartment is open. If a measurement is requested when the battery compartment is closed, the most recent measurement taken with the battery compartment open, or written to the probe's live barometric pressure register, is returned instead of a live sensor reading. If a barometric measurement has never been stored or written, the sensor will return the sentinel value with an error data quality.

In the vented unit, barometric pressure can be measured at any time. The value contained in the probe's live barometric pressure register is ignored.

Calibration Registers

Values in the calibration registers determine how sensor parameters are calculated.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Barometric Offset, B_O (default = 0.0)

Calibration Procedure

The procedure to calibrate barometric pressure shall be as follows. The procedure is used to match open air readings to a barometric reference.

1. Write the Calibration On command (0xE000) to the sensor command register. Reading the pressure parameter in the calibration mode shall present the barometric pressure with the current user calibration applied (P_B).
2. For a non-vented unit, instruct the user to open the battery cover.
3. Read the barometric pressure parameter P_B and external barometric pressure reference B_R. If the barometric pressure is read in calibration mode on a non-vented unit with the battery cover closed, the sensor will return the sentinel value with an error data quality.
4. Compute the barometric offset as $B_O = B_R - P_M$ and write the offset to the barometric offset register, all in the current units. Internally, the new offset is added to the old offset. If the resulting offset is greater than +/-10 mbar, the probe will return an exception response with error code 0x97 indicating an invalid calibration. If valid, the calibration is in effect immediately but not yet permanently.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration date, if not zero, to the current date plus the previous next calibration interval. For a non-vented unit, saves the last calibrated reading as the last measurement taken.
6. Optionally, read the last user calibration time, add the next calibration interval, and write the result to the next user calibration time register.

7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Level Sensor

The level sensor is a factory installed option. If installed, it appears as sensor connection 7 (bit 6 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value. Measuring the level sensor does not trigger the wiper unless a dependent parameter requires it.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id 0 = not installed 51 = 30 foot full-scale level, absolute pressure 52 = 100 foot full-scale level, absolute pressure 53 = 250 foot full-scale level, absolute pressure 54 = 650 foot full-scale level, absolute pressure
1	2	R1	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1	time	Last factory calibration
7	3	R1	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 1000 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 1000 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N) = 4
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Sensor Status

Bit 15 of the sensor status register shall be set to indicate that the level parameters provided (Depth, Depth to Water, and Surface Elevation) have fixed parameter ids.

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, and read dependent sensor parameters (temperature, density, barometric pressure).

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up and includes the time necessary to read dependent sensor parameters.

Parameter 1: Pressure

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value, P
39	1	R1	ushort	Parameter Id = 2 (pressure)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
40	1	R1/W2	ushort	Units Id 17 = PSI (default) 19 = KPa 20 = bar 21 = mbar 22 = mmHg 24 = cmH_2O 25 = in H_2O
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x01FD (509)

Pressure is factory calibrated in PSI. Conversion to other units is as follows.

KPa = 6.894757 * PSI

bar = 0.06894757 * PSI

mbar = 68.94757 * PSI

mmHg = 51.71492 * PSI

inHg = 2.036021 * PSI

cmH_2O = 70.30696 * PSI

inH_2O = 27.67990 * PSI

The calculation of pressure requires temperature. If a temperature sensor is not available, the probe's internal temperature will be used and the data quality will be a warning.

Parameter 2: Depth

The depth parameter is calculated from the pressure parameter using settings contained in the sensor configuration registers.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value, D
47	1	R1/W2	ushort	Parameter Id = 3 (depth)
48	1	R1/W2	ushort	Units Id

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
				33 = millimeters 34 = centimeters 35 = meters 37 = inches 38 = feet (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0037 (55)

Depth is initially calculated in meters. Conversion to other units is as follows.

Millimeters = 1000 * meters

Centimeters = 100 * meters

Inches = 39.37008 * meters

Feet = 3.280840 * meters

Note that the units for depth, depth to water, and surface elevation are synchronized; changing the units id for one will change the units id for all three.

Parameter 3: Depth to Water

The DTW parameter is calculated from the pressure parameter using settings contained in the sensor configuration registers.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
53	2	R1	float	Measured value, DTW
55	1	R1/W2	ushort	Parameter Id = 4 (DTW)
56	1	R1/W2	ushort	Units Id, same options as depth
57	1	R1	ushort	Data Quality Id
58	2	R1/W3	float	Sentinel value (default = 0.0)
60	1	R1	16 bits	Available Units = 0x0037 (55)

DTW is initially calculated in meters. Conversion to other units is the same as depth. Note that the units for depth, depth to water, and surface elevation are synchronized; changing the units id for one will change the units id for all three.

Parameter 4: Surface Elevation

The surface elevation parameter is calculated from the pressure parameter using settings contained in the sensor configuration registers.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
61	2	R1	float	Measured value, L
63	1	R1/W2	ushort	Parameter Id = 5 (level, elevation)
64	1	R1/W2	ushort	Units Id, same options as depth
65	1	R1	ushort	Data Quality Id
66	2	R1/W3	float	Sentinel value (default = 0.0)
68	1	R1	16 bits	Available Units = 0x0037 (55)

Surface elevation is initially calculated in meters. Conversion to other units is the same as depth. Note that the units for depth, depth to water, and surface elevation are synchronized; changing the units id for one will change the units id for all three.

Calibration Registers

Values in the calibration registers determine how sensor parameters are calculated.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Automatic barometric correction enable Default = 0.0 for non-vented unit Default = 1.0 for vented unit
119	2	R1/W3	float	Automatic density correction enable (default = 0.0)
121	2	R1/W3	float	Specific Gravity, SG (default = 1.0)
123	2	R1/W3	float	Depth correction enable (default = 1.0)
125	2	R1/W3	float	Pressure Offset, P_O (default = 0.0)
127	2	R1/W3	float	Level Reference, L_R (default = 0.0)
129	2	R1/W3	float	Pressure Reference, P_R (default = 0.0)

Automatic Barometric Correction

Set this register to zero to disable automatic barometric correction. Set to one to enable automatic correction. If disabled, the measured pressure reading (P_M) is simply the pressure reading of the sensor (P_S).

$P_M = P_S$

If automatic barometric correction is enabled, the probe's barometric pressure value (P_B) is subtracted from the sensor pressure (P_S) to generate the measured pressure reading.

$P_M = P_S - P_B$

If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

Automatic Density Correction

Set this register to zero to disable automatic density correction. Set to one to enable automatic correction. If disabled, pressures (PSI) are converted to depth (meters) accounting for the specific gravity (SG) of the fluid according to the following equation. Values shall be in the range 0.1 to 10.0 inclusive.

If automatic density correction is enabled, pressures (PSI) are converted to depth (meters) accounting for the measured fluid density (ρ) according to the following equation. The value contained in the specific gravity register is ignored.

$D(P) = (P * 0.70307) / \rho$

If density is not available from a sensor on the probe, the specific gravity will be used instead, and measurements will be flagged with a warning data quality. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

Specific Gravity

Values for specific gravity are allowed in the range 0.1 to 10.0 inclusive. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

Depth Correction

Set this register to zero to disable depth correction. Set to one to enable depth correction. If enabled, the depth parameter is adjusted to present depth at the face of the sensors instead of the pressure sensor. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

The equation to adjust the depth is:

Offset = $L \sin \Theta$, where $\Theta = \tan^{-1}(G)$ and $G = g_x / \mathrm{sqrt}(g_y^2 + g_z^2)$

g_x, g_y, and g_z are accelerometer outputs, L = 0.1916684 m (7.546 in)

Using trigonometric identities the offset can also be calculated as:

Offset = L (G / sqrt(1 + G^2)), where G is defined above.

Pressure Offset

The pressure offset (P_O) is subtracted from the measured pressure reading (P_M) to correct for offset errors in the pressure sensor. This register shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off. Master software must ensure that the pressure offset is written in the currently selected units. This value shall be converted to the appropriate units when the Pressure Units Id register is written. The measured pressure is presented as:

$P = P_M - P_O$

Level Reference

This value is used to reference a DTW or surface elevation reading to an independently established value. This register shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off. Master software must ensure that the level value is written in the currently selected depth/level units. When this register is written, the device shall record the current pressure reading P as the reference pressure P_R in the currently selected pressure units. The following equations shall be used to calculate level based on the level parameter id selection.

Pressure Calibration Procedure

The procedure to calibrate the pressure parameter shall be as follows. The procedure can be used to zero the pressure reading, or to match open air readings to a barometric reference (either internal or external).

1. Write the Calibration On command (0xE000) to the sensor command register. Reading the pressure parameter in the calibration mode shall present the measured pressure reading (P_M) applying barometric compensation if enable, but without applying the pressure offset.
2. Instruct the user to place the pressure sensor in open air.
3. Read the pressure parameter P_S and pressure reference P_R. P_R can be assumed to be zero, or can be the internal or an external barometric reference.
4. Compute the pressure offset as $P_O = P_S - P_R$ and write it to the pressure offset register.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration date, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

DTW, Level Reference Procedure

The procedure to reference the DTW or level parameter shall be as follows.

1. Write the Calibration On command (0xE000) to the sensor command register. Reading the depth parameter in the calibration mode shall present depth using the active pressure calibration and depth configuration settings to assist the user in properly deploying the device.
2. Instruct the user to deploy the probe and to independently determine the reference DTW or level (L_R).
3. Write the new value of L_R to the Level Reference register.
4. The sensor stores the current pressure P as P_R.
5. Optionally, the master device can overwrite the pressure reference register with a calculated value.
6. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration date, if not zero, to the current date plus the previous next calibration interval.
7. Optionally, read the last user calibration time, add the next calibration interval, and write the result to the next user calibration time register.
8. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Port Plug

A port plug is a user installed option and can appear in any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value. A port plug does not support parameters. Any attempt to access parameter registers will return an exception response with exception code 2 (illegal data address).

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1	ushort	Sensor Id = 20
1	2	R1	ulong	Sensor serial number = 0
3	1	R1	16 bits	Sensor status = 0
4	3	R1	time	Last factory calibration = 0
7	3	R1	time	Next factory calibration = 0
10	3	R1	time	Last user calibration = 0
13	3	R1	time	Next user calibration = 0
16	1	R1	ushort	Warm-up time = 0 milliseconds
17	1	R1	ushort	Fast sample rate = 0 milliseconds
18	1	R1	ushort	Number of sensor parameters (N) = 0
19	1	R1	ushort	Alarm/warning parameter number (1 – N,

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
				default = 1)
20	1	R1	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1	float	High alarm set value (default = 0.0)
23	2	R1	float	High alarm clear value (default = 0.0)
25	2	R1	float	High warning set value (default = 0.0)
27	2	R1	float	High warning clear value (default = 0.0)
29	2	R1	float	Low warning clear value (default = 0.0)
31	2	R1	float	Low warning set value (default = 0.0)
33	2	R1	float	Low alarm clear value (default = 0.0)
35	2	R1	float	Low alarm set value (default = 0.0)

Writing to the next user calibration register will return an exception response with exception code 0x94 (sensor missing). Because a port plug provides no parameters, writing to the alarm/warning parameter number registers will return an exception response with exception code 0x84 (illegal field value). Alarm and warning set points can be read and written; however, their values have no affect.

Temperature Sensor

The temperature sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1	ushort	Sensor Id = 55
1	2	R1	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 1100 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 1100 milliseconds
18	1	R1	ushort	Number of sensor parameters (N) = 1
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state and perform a wipe cycle.

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up and a wipe cycle is not required.

Parameter 1: Temperature

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 1 (temperature)
40	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0003 (3)

Temperature is factory calibrated in °C. The measured temperature in °C (T_M) is calculated as:

$T_M = T_o + T_f$

Where T_f is the factory calibrated temperature in °C and T_o is the user offset calibration.

Conversion to other units is as follows.

°F = 1.8 * °C + 32

If the sensor temperature measurement returns an error, the sonde will substitute its internal temperature sensor value and set the data quality id to a warning. If the sonde temperature measurement also generates an error, the sonde will use the sentinel value and set the data quality id to an error.

Calibration Registers

Values in the calibration registers determine how sensor parameters are calculated.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Temperature Offset To in °C (default = 0.0)
155	2	R1	float	Factory Thermistor2 Temperature
157	2	R1/W4	float	Factory Register Index (default = 326)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
159	2	R1/W4	float	Factory Register Value (default = 0)

Temperature Calibration Procedure

The procedure to calibrate the temperature parameter shall be as follows.

1. Write the Calibration On command (0xE000) to the sensor command register. Reading the temperature parameter in the calibration mode shall present the temperature with the current user calibration applied (T_M).
2. Instruct the user to place the temperature sensor in a water bath.
3. Read the temperature parameter T_M and the external temperature reference T_R.
4. Calculate the temperature offset as $T_O = T_M - T_R$ and write the offset to the temperature offset register, all in the current units. Internally, the new offset is added to the old offset. If the resulting offset is greater than +/- 1°C, the probe will return an exception response with error code 0x97 indicating an invalid calibration. If valid, the calibration is in effect immediately but not yet permanently.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Conductivity Sensor

The conductivity sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1	ushort	Sensor Id = 56
1	2	R1	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1	time	Last factory calibration

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1/W4	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 1100 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 1100 milliseconds
18	1	R1	ushort	Number of sensor parameters (N) = 7
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, and correctly position the wiper.

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up and the wiper is correctly positioned.

Parameter 1: Temperature

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 1 (temperature)
40	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0003 (3)

Temperature is factory calibrated in °C. The measured temperature in °C (T_M) is calculated as:

$T_M = T_o + T_f$

Where T_f is the factory calibrated temperature in °C and T_o is the user offset calibration.

Conversion to other units is as follows.

°F = 1.8 * °C + 32

If the sensor temperature measurement returns an error, the sonde will substitute its internal temperature sensor value and set the data quality id to a warning. If the sonde temperature measurement also generates an error, the sonde will use the sentinel value and set the data quality id to an error.

Parameter 2: Actual Conductivity

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value, AC
47	1	R1	ushort	Parameter Id = 9 (actual conductivity)
48	1	R1/W2	ushort	Units Id 65 = microsiemens per centimeter (default) 66 = millisiemens per centimeter

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0003 (3)

Actual conductivity is factory calibrated in uS/cm. Conversion to other units is as follows.

mS/cm = uS/cm / 1000

Parameter 3: Specific Conductivity

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
53	2	R1	float	Measured value, SC
55	1	R1	ushort	Parameter Id = 10 (specific conductivity)
56	1	R1/W2	ushort	Units Id 65 = microsiemens per centimeter (default) 66 = millisiemens per centimeter
57	1	R1	ushort	Data Quality Id
58	2	R1/W3	float	Off line sentinel value (default = 0.0)
60	1	R1	16 bits	Available Units = 0x0003 (3)

The default units for specific conductivity are uS/cm. Conversion to other units is as follows.

mS/cm = uS/cm / 1000

Specific conductivity is calculated from actual conductivity and temperature using the following equation.

$SC = AC * (b_0 + b_1T + b_2T^2 + \ldots + b_7T^7) / (1 + a (T-T_{ref}))$

Where T_{ref}, a, and b_{0-7} are specified in the sensor calibration registers. The factory default coefficients shall calculate specific conductivity per Standard Methods 2510B.

Parameter 4: Salinity

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
61	2	R1	float	Measured value, S
63	1	R1	ushort	Parameter Id = 12 (salinity)
64	1	R1/W2	ushort	Units Id 97 = Practical Salinity Units PSU (default) 98 = ppt
65	1	R1	ushort	Data Quality Id
66	2	R1/W3	float	Off line sentinel value (default = 0.0)
68	1	R1	16 bits	Available Units = 0x0003 (3)

The default units for salinity are PSU. Conversion to other units is as follows.

ppt = PSU

Salinity is calculated from actual conductivity and temperature using the following equations as defined by Standard Methods 2520A with extensions for operation from 0 to 42 PSU. If the calculated value exceeds 2500 PSU, the sentinel value is substituted with an error data quality.

$S = a_0 + a_1R_t^{1/2} + a_2R_t + a_3R_t^{3/2} + a_4R_t^2 + a_5R_t^{5/2}$

$+ f(T)(b_0 + b_1R_t^{1/2} + b_2R_t + b_3R_t^{3/2} + b_4R_t^2 + b_5R_t^{5/2})$

$-a_0 / (1 + 1.5X + X^2)$

$-b_0 f(T) / (1 + Y^{1/2} + Y^{3/2})$

Where:

$R_t = AC / (r_0 + r_1T + r_2T^2 + r_3T^3)$

$X = 400 R_t$

$Y = 100 R_t$

$f(T) = (T – 15) / (1 + 0.0162 (T – 15))$

The following table defines the constants for the equations.

Constant	Value	Constant	Value	Constant	Value
a_0	0.0080	b_0	0.0005	r_0	29752.63
a_1	-0.1692	b_1	-0.0056	r_1	830.5102
a_2	25.3851	b_2	-0.0066	r_2	3.429338
a_3	14.0941	b_3	-0.0375	r_3	-0.02193934
a_4	-7.0261	b_4	0.0636		
a_5	2.7081	b_5	-0.0144		

Parameter 5: Total Dissolved Solids

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
69	2	R1	float	Measured value, TDS
71	1	R1	ushort	Parameter Id = 13 (TDS)
72	1	R1/W2	ushort	Units Id 113 = parts per million 114 = parts per thousand (default)
73	1	R1	ushort	Data Quality Id
74	2	R1/W3	float	Off line sentinel value (default = 0.0)
76	1	R1	16 bits	Available Units = 0x0003 (3)

The default units for TDS are ppt. Conversion to other units is as follows.

ppm = ppt * 1000

TDS is calculated from specific conductivity using the following equation.

$TDS = CF_{TDS} * SC$

Where CF_{TDS} is the TDS conversion factor in ppm units as specified in the sensor calibration registers.

Parameter 6: Resistivity

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
77	2	R1	float	Measured value, R
79	1	R1	ushort	Parameter Id = 11 (resistivity)
80	1	R1/W2	ushort	Units Id 81 = ohm-cm (default)
81	1	R1	ushort	Data Quality Id
82	2	R1/W3	float	Off line sentinel value (default = 0.0)
84	1	R1	16 bits	Available Units = 0x0001 (1)

Resistivity is calculated from actual conductivity using the following equation.

R (ohm-cm) = 10^6 / AC (uS/cm)

If the actual conductivity is zero, R shall be reported as 10,000,000 ohm-cm.

Parameter 7: Density of Water

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
85	2	R1	float	Measured value, p
87	1	R1	ushort	Parameter Id = 14 (density of water)
88	1	R1/W2	ushort	Units Id 129 = g/cm^3 (default)
89	1	R1	ushort	Data Quality Id
90	2	R1/W3	float	Off line sentinel value (default = 0.0)
92	1	R1	16 bits	Available Units = 0x0001 (1)

Density of water is calculated from salinity (S) and temperature (T) using the following equations.

$\rho(g/cm^3) = (\rho 0 + aS + bS^{3/2} + cS^2) / 1000$

Where:

$\rho 0 = 999.842594 + 0.06793952T - 0.00909529T^2 + 1.001685e\text{-}4T^3$

$- 1.120083e\text{-}6T^4 + 6.536332e\text{-}9T^5$

$a = 0.824493 - 0.004089T + 7.6438e\text{-}5T^2 - 8.2467e\text{-}7T^3 + 5.3875e\text{-}9T^4$

$b = -0.00572466 + 1.0227e\text{-}4T - 1.6546e\text{-}6T^2$

$c = 0.000483140$

Calibration Registers

Values in the calibration registers determine how sensor parameters are calculated.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Reference Temperature T_{ref} in °C (default = 25)
119	2	R1/W3	float	Alpha Coefficient a (default = 0.0191)
121	2	R1/W3	float	Beta Coefficient b_0 (default = 1.0)
123	2	R1/W3	float	Beta Coefficient b_1 (default = 0.0)
125	2	R1/W3	float	Beta Coefficient b_2 (default = 0.0)
127	2	R1/W3	float	Beta Coefficient b_3 (default = 0.0)
129	2	R1/W3	float	Beta Coefficient b_4 (default = 0.0)
131	2	R1/W3	float	Beta Coefficient b_5 (default = 0.0)
133	2	R1/W3	float	Beta Coefficient b_6 (default = 0.0)
135	2	R1/W3	float	Beta Coefficient b_7 (default = 0.0)
137	2	R1/W3	float	TDS Conversion Factor CF_{TDS} in ppm (default = 0.65)
139	2	R1/W3	float	Cell Constant, K (default = 1.0)
141	2	R1/W3	float	Cell Offset, K0 (default = 0.0)
143	2	R1/W3	float	Temperature Offset To in °C (default = 0.0)
155	2	R1	float	Factory Conductivity Ratio (default = 1.0)
157	2	R1/W4	float	Factory Register Index (default = 0)
159	2	R1/W4	float	Factory Register Value (default = 0)

Cell Offset and Cell Constant – These values are used to calibrate conductivity to user standards. These registers shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off.

Actual conductivity (AC) is calculated as follows.

$AC = K_0 + K * AC_f$

Where AC_f is the actual conductivity value computed using the factory calibrated cell constant. For a single point calibration, K_0 is set to zero.

Conductivity Calibration Procedure

The procedure to calibrate the actual conductivity parameter shall be as follows.

1. Write the Calibration Mode On command (0xE000) to the sensor command register. Reading the actual conductivity parameter in calibration mode shall present actual conductivity as AC_f (the current cell offset and cell constant shall not be applied).
2. Instruct the user to place the conductivity sensor into one or more conductivity standards.
3. Read the actual conductivity and temperature parameters at each conductivity standard.
4. Calculate new values for the cell constant K and cell offset K_0 and write these values to their corresponding registers.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Temperature Calibration Procedure

The procedure to calibrate the temperature parameter shall be as follows.

1. Write the Calibration On command (0xE000) to the sensor command register. Reading the temperature parameter in the calibration mode shall present the temperature with the current user calibration applied (T_M).
2. Instruct the user to place the temperature sensor in a water bath.
3. Read the temperature parameter T_M and the external temperature reference T_R.
4. Calculate the temperature offset as $T_O = T_M – T_R$ and write the offset to the temperature offset register, all in the current units. Internally, the new offset is added to the old offset. If the sum of the new offset and the old offset is greater than +/- 1°C, the probe will return an exception response with error code 0x97 indicating an invalid calibration. If valid, the calibration is in effect immediately but not yet permanently.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration date to zero (none required).
6. Optionally, read the last user calibration time, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

RDO Sensor

The RDO sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Sensor Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1	ushort	Sensor Id = 57
1	2	R1	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration (cap start time, 0 = no cap)
7	3	R1/W4	time	Next factory calibration (cap expiration time, 0 = no cap)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 2400 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 1400 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N) = 3
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Sensor Serial Number

This field shall return the serial number of the sensor, not of the installed sensor cap. The serial number of the sensor cap is available in the calibration register set.

Sensor Status

Bit 9 of the sensor status register shall be set to indicate that the sensor cap is not installed.

Last Factory Calibration

This field shall return the start time of the installed sensor cap. If the cap has not been used, the cap manufactured time shall be returned. The probe shall return zero if the sensor cap is not installed.

Next Factory Calibration

This field shall return the expiration time of the installed sensor cap. The probe shall return zero if the sensor cap is not installed. The expiration calculation varies with the supported cap type:

- Classic Cap, Id 17: The value shall be the lesser of the cap manufactured time plus 24 months, or the cap start time plus 12 months. The cap wear algorithm shall be applied.

- Fast Cap, Id 1: The value shall be the lesser of the cap manufactured time plus 36 months, or the cap start time plus 15 months. The cap wear algorithm shall not be applied.

- Test Cap, Id 65535: The value shall be calculated in the same manner as a fast cap.

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, correctly position the wiper, read calibration data from a new cap, and read dependent sensor parameters (temperature, salinity, barometric pressure).

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up. The measurement time shall include the time necessary to reposition the wiper if needed, and to read dependent sensor parameters.

Parameter 1: DO Concentration

DO concentration is calculated from the oxygen partial pressure and temperature using settings contained in the sensor calibration registers.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value, C_0
39	1	R1	ushort	Parameter Id = 20
40	1	R1/W2	ushort	Units Id 117 = mg/L (default) 118 = µg/L
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0030 (48)

If the parameter value is read when the sensor cap is not installed, it shall return the sentinel value and a data quality id of 7 (sensor communication error).

DO concentration is internally calculated in mg/L. Conversion to other units is as follows.

µg/L = 1000 * mg/L

Oxygen concentration C_0 (mg/L) shall be calculated as follows:

$$C_0 = 31.9988 \times 1E6 \times \frac{\rho \, P_0}{k_0 M}(1-\theta_0) \times S_C$$

Where:

P_0 is the partial pressure of O2 in atmospheres.

$$P_{torr} = 759.999876 \times P_{atm}$$

Salinity correction:

ln Sc = S(B0 + B1Ts + B2Ts^2 + B3Ts^3) + C0S^2

B0 = -6.246090E-003

B1 = -7.423444E-003

B2 = -1.048635E-002

B3 = -7.987907E-003

C0 = -4.679983E-007

Ts is the scaled temperature (t is the temperature in °C):

$$Ts = \ln [(298.15 - t) / (273.15 + t)]$$

S is the salinity in psu

Henry's constant:

$$\ln k_0 = 3.71814 + (5596.17/T) - (1{,}049{,}668/T^2)$$

T is temperature in degrees Kelvin.

Negative of the second pressure coefficient.

$$\theta_0 = 0.000975 - (1.426 \times 10^{-5}t) + (6.436 \times 10^{-8}t^2).$$

t is temperature in degrees C.

Density of Water:

$$\ln \rho = -0.589581 + (326.785/T) - (45{,}284.1/T^2)$$

T is in Kelvin

Molar mass of water.

$$M = 18.0152$$

References:

Benson and Krause, Jr.

The concentration and isotopic fractionation of gases dissolved in freshwater in equilibrium with the atmosphere.

Limnol, Oceanogr, 25(4), 1980, 662-671

Gordon and Garcia

Oxygen Solubility in Seawater: Better Fitting Equations

Limnol, Oceaongr, 37(6), 1992, 1307-1312

Parameter 2: DO Saturation

The saturation parameter is calculated from DO concentration and settings contained in the sensor calibration registers.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value
47	1	R1/W2	ushort	Parameter Id = 21
48	1	R1/W2	ushort	Units Id 177 = percent saturation (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0001 (1)

If the parameter value is read when the sensor cap is not installed, it shall return the sentinel value and a data quality id of 7 (sensor communication error).

RDO Saturation Equations:

$$O_2\%Sat = \frac{O_2\text{Reading}}{O_2 100\%Sat}$$

Where:

O_2 Reading is the mg/l reading from the RDO sensor.

O_2 100% Sat is the theoretical saturation value in mg/l and is derived as:

$$O_2 100\% Sat = 31.9988 \times 10^6 \times \frac{\rho \left[0.20946 \times \left(P - P_{wv}\right)\right]}{k_0 M} (1 - \theta_0 P) \times S_C$$

Where:

ρ is the density of water in g/cm^3:

$$\ln \rho = -0.589581 + (326.785/T) - (45{,}284.1/T^2)$$

T is the temperature in Kelvin degrees.

P is the atmospheric pressure in atm.

Parameter 3: Oxygen Partial Pressure

Oxygen partial pressure is calculated using calibration information stored in the sensor cap.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
53	2	R1	float	Measured value
55	1	R1	ushort	Parameter Id = 30 (oxygen partial pressure)
56	1	R1/W2	ushort	Units Id 26 = torr (default)
57	1	R1	ushort	Data Quality Id
58	2	R1/W3	float	Off line sentinel value (default = 0.0)
60	1	R1	16 bits	Available Units = 0x0200 (512)

If the parameter value is read when the sensor cap is not installed, it shall return the sentinel value and a data quality id of 7 (sensor communication error).

Calibration Registers

Values in the calibration registers determine how sensor parameters are calculated.

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1	float	Installed cap type (0 = not installed)
119	2	R1	float	Installed cap serial number (0 = not installed)
121	2	R1/W3	float	Automatic salinity correction (default = 1)
123	2	R1/W3	float	Default salinity value (PSU, default = 0.0)
125	2	R1/W3	float	100% saturation calibration reading (mg/L)
127	2	R1/W3	float	100% saturation temperature reading (°C)
129	2	R1/W3	float	100% saturation salinity value (PSU)
131	2	R1/W3	float	100% saturation barometric pressure (mbar)
133	2	R1/W3	float	0% saturation calibration reading (mg/L)
135	2	R1/W3	float	0% saturation temperature reading (°C)
137	2	R1/W3	float	Calibration slope (default = 1.0)
139	2	R1/W3	float	Calibration offset, mg/L (default = 0.0)
157	2	R1/W4	float	Factory Register Index (default = 0)
159	2	R1/W4	float	Factory Register Value (default = 0)

Automatic Salinity Correction

Set this register to zero to disable automatic salinity correction. Set to one to enable automatic correction. If disabled, the default salinity value is used to correct the oxygen concentration value for salinity. If enabled, the salinity value is obtained from the conductivity sensor. The valid range for salinity is 0 to 2500 PSU. If the salinity provided by the conductivity sensors exceeds 2500 PSU, the default salinity value is substituted and a warning data quality is given.

Default Salinity Value

The default salinity value is used to correct the oxygen concentration value for salinity when automatic salinity correction is disabled. The allowed range of salinity is 0 to 42 PSU. If automatic salinity correction is enabled, the salinity value is obtained from the conductivity sensor. If a conductivity sensor is not available, or a measurement error occurs, the default salinity will be used and the measurement data quality will be reduced to a warning.

100% Saturation Calibration Values

These values represent the sensor conditions while the probe is in a 100% saturation calibration environment. These are not measured values, they are written by the controller during the calibration process.

Writes to these registers are only accepted if the probe is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off.

0% Saturation Calibration Values

These values represent the sensor conditions while the probe is in a 0% saturation calibration environment. These are not measured values, they are written by the controller during the calibration process.

Writes to these registers are only accepted if the probe is in the calibration mode. The probe will return exception 0x92 (invalid sensor) if an attempt is made to write these registers when the calibration mode is off.

Calibration Slope and Offset

These values represent the slope and offset that will be applied to the raw concentration reading from the sensor to generate the final values reported by the sensor parameters. Writes to these registers are only accepted if the probe is in the calibration mode. The probe will return exception 0x92 (invalid sensor) if an attempt is made to write these registers when the calibration mode is off. These registers may be written independently of the normal internal calibration procedure.

RDO Calibration Procedure

The RDO sensor is calibrated using the following procedure.

1. Write the Calibration Mode On command (0xE000) to the sensor command register.

2. If automatic barometric correction is enabled, prompt the user to “burp” the battery pack cover to update the barometric pressure.

3. Prompt the user to place the probe in a 100% saturation environment.

4. Read the oxygen concentration and temperature parameters. When these values have reached equilibrium, record them in their respective 100% saturation calibration registers. Write the current salinity and barometric pressure readings to their respective calibration registers.

5. Prompt the user to place the probe in a 0% saturation environment. When these registers have reached equilibrium, record them in their respective 0% saturation calibration registers. If a zero calibration is not to be performed, these registers should be set to zero.

6. Write the Calibration Update command (0xE001) to the sensor command register. The sensor will calculate a new slope and offset, will write the current time to the last user calibration time register, and set the next user calibration time register, if not zero, to the current date plus the previous next calibration interval. If the concentrations at 100% and 0% saturation are equal the probe will return an exception response with code 0x97 (invalid calibration) and not attempt to compute a new slope and offset due to possible division by zero. If the slope does not calculate between 0.85 and 1.20 inclusive, or the offset does not calculate between -0.2 and +0.2 inclusive, the probe will return an exception response with code 0x97 (invalid calibration). The slope and offset will be available for read but will not be committed to flash.

7. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.

8. Write the Calibration Mode Off command (0xE002) to the sensor command register to place the sensor in normal operation. If the calibration mode is turned off without a calibration update command, or the calibration command returned an exception, the previous calibration shall be restored.

pH/ORP Sensor

The pH/ORP sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 58
1	2	R1/W4	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 900 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 900 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N = 3)
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, correctly position the wiper, and read dependent sensor parameters (temperature).

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up. The measurement time shall include the time necessary to reposition the wiper if needed, and to read dependent sensor parameters.

Parameter 1: pH

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 17 (pH)
40	1	R1/W2	ushort	Units Id 145 = pH (default)
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0001 (1)

Parameter 2: pH mV

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
47	1	R1	ushort	Parameter Id = 18 (pH mV)
48	1	R1/W2	ushort	Units Id 162 = mV (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0002 (2)

Parameter 3: ORP mV

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
53	2	R1	float	Measured value
55	1	R1	ushort	Parameter Id = 19 (ORP)
56	1	R1/W2	ushort	Units Id 162 = mV (default)
57	1	R1	ushort	Data Quality Id
58	2	R1/W3	float	Off line sentinel value (default = 0.0)
60	1	R1	16 bits	Available Units = 0x0002 (2)

Calibration Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Number of pH calibration points 1, 2, or 3 (default = 1)
119	2	R1/W3	float	pH value of solution 1 (default = 0)
121	2	R1/W3	float	mV response in solution 1 (default = 0)
123	2	R1/W3	float	Temperature of solution 1, T_1 in °C (default = 25)
125	2	R1/W3	float	pH value of solution 2 (default = 0)
127	2	R1/W3	float	mV response in solution 2, mV_2 (default = 0)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
129	2	R1/W3	float	Temperature of solution 2, T_2 in °C (default = 25)
131	2	R1/W3	float	pH value of solution 3 (default = 0)
133	2	R1/W3	float	mV response in solution 3 (default = 0)
134	2	R1/W3	float	Temperature of solution 3, T_3 in °C (default = 25)
137	2	R1/W3	float	Slope, m_1 in pH/mV (default = -0.016903313)
139	2	R1/W3	float	Offset, b_1 in pH (default = 7.0)
141	2	R1/W3	float	Slope, m_2 in pH/mV (default = -0.016903313)
143	2	R1/W3	float	Offset, b_2 in pH (default = 7.0)
145	2	R1/W3	float	ORP solution type (default = 0)
147	2	R1/W3	float	mV value of solution (default = 0)
149	2	R1/W3	float	mV response in solution (default = 0)
151	2	R1/W3	float	Temperature of solution, T_{orp} in °C (default = 25)
153	2	R1/W3	float	Slope, m_{orp} in mV/mV (default = 1.0)
155	2	R1/W3	float	Offset, b_{orp} in mV (default = 0.0)
157	2	R1/W4	float	Factory Register Index (default = 0)
159	2	R1/W4	float	Factory Register Value (default = 0)

These registers shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off. pH solution data must be written into the registers in order of increasing pH.

pH Calculation

The measured value is derived from either one line (one or two point calibration) segment or two line segments (three point calibration).

For one line segment:

$pH = (T_{1K} / T_K) \times m_1 \times mV + b_1$

For two line segments:

$mV > mV_2$: $pH = (T_{1K} / T_K) \times m_1 \times mV + b_1$

$mV <= mV_2$: $pH = (T_{2K} / T_K) \times m_2 \times mV + b_2$

Where:

mV is the measured sensor millivolts

T_K is the measured temperature in °K

T_{1K} is the calibration temperature converted to °K. ($T_{1K} = T_1 + 273.15$)

T_{2K} is the calibration temperature converted to °K. ($T_{2K} = T_2 + 273.15$)

m_1 and b_1 are slope and offset for segment one respectively

m_2 and b_2 are slope and offset for segment two respectively

pH is the calculated result

Calibration Slopes and Offsets

One point calibration:

$$m_1 = \frac{T_{kdef}}{T_{k1}} \times m_{def}$$

$$b_1 = pH_1 - m_1 \times mV_1$$

Two point calibration:

$$m_1 = \frac{pH_2 - pH_1}{\frac{T_{k1}}{T_{k2}} \times mV_2 - mV_1}$$

$$b_1 = pH_1 - m_1 \times mV_1 b_1 = pH_1 - m_1 \times mV_1$$

Three point calibration:

Line segment 1:

$$m_1 = \frac{pH_2 - pH_1}{\frac{T_{k1}}{T_{k2}} \times mV_2 - mV_1}$$

$$b_1 = pH_1 - m_1 \times mV_1 b_1 = pH_1 - m_1 \times mV_1$$

Line segment 2:

$$m_2 = \frac{pH_3 - pH_2}{\frac{T_{k2}}{T_{k3}} \times mV_3 - mV_2}$$

$$b_2 = pH_2 - m_2 \times mV_2 b_2 = pH_2 - m_2 \times mV_2$$

Where:

T_{kdef} is the default temperature in °K (25 + 273.15 = 298.15 °K)

m_{def} is the default slope in pH/mV (-0.016903313 pH/mV)

T_{1K} is the calibration temperature in pH solution 1 converted to °K. ($T_{1K} = T_1$(°C) + 273.15)

T_{2K} is the calibration temperature in pH solution 2 converted to °K. ($T_{2K} = T_2$(°C) + 273.15)

T_{3K} is the calibration temperature in pH solution 3 converted to °K. ($T_{3K} = T_3(°C) + 273.15$)

mV_1 is the measured sensor millivolts in pH solution 1

mV_2 is the measured sensor millivolts in pH solution 2

mV_3 is the measured sensor millivolts in pH solution 3

pH_1 is the pH value of solution 1 corrected for temperature per standard specifications.

pH_2 is the pH value of solution 2 corrected for temperature per standard specifications.

pH_3 is the pH value of solution 3 corrected for temperature per standard specifications.

m_1 and b_1 are slope and offset for segment one respectively

m_2 and b_2 are slope and offset for segment two respectively

ORP Measured Value

The measured value is derived as follows:

$$ORP = m_{orp} \times mV + b_{orp}$$

Where:

mV is the measured sensor millivolts

m_{orp} and b_{orp} are slope and offset respectively

ORP is the calculated value

ORP Calibration Procedure

The procedure to calibrate the ORP parameter shall be as follows.

1. Write the Calibration Mode On command (0xE000) to the sensor command register.
2. Instruct the user to place the ORP sensor into a standard.
3. Read the ORP mV and temperature parameters of the standard. Reading the ORP parameter in the calibration will return raw ORP millivolts, without the current calibration applied.
4. Calculate new ORP calibration values and write these values to their corresponding registers.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Turbidity Sensor

The turbidity sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 50
1	2	R1/W4	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 800 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 800 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N = 2)
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, and correctly position the wiper.

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up and the wiper is correctly positioned.

Parameter 1: Turbidity

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 25 (turbidity)
40	1	R1/W2	ushort	Units Id 193 = FNU 194 = NTU (default)
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0003 (3)

Turbidity is internally calculated in NTU. The default units are NTU. Conversion to other units is as follows:

FNU = NTU

Parameter 2: Total Suspended Solids

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value
47	1	R1	ushort	Parameter Id = 31 (TSS)
48	1	R1/W2	ushort	Units Id 114 = parts per thousand 117 = mg/L (default)
49	1	R1	ushort	Data Quality Id

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0012 (18)

The default units for TSS are mg/L. Conversion to other units is as follows.

ppt = 0.001 * mg/L

TSS is calculated from turbidity using the follow equation.

$TSS = CF_{TSS} * NTU$

Calibration Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	TSS Conversion Factor CFT_{SS} in mg/L (default = 0.0)
119	2	R1/W3	float	User calibration slope, m (default = 1.0)
121	2	R1/W3	float	User calibration offset, b (default = 0.0)
155	2	R1	float	Factory Ratio = Sig/Ref
157	2	R1/W3	float	Factory Register Index (default = 300)
159	2	R1/W3	float	Factory Register Value

User Calibration Slope and Offset – These values are used to calibrate turbidity to user standards. These registers shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off.

Turbidity is calculated as follows.

$NTU = b + m * NTU_f$

Where NTU_f is the factory calibrated turbidity value.

Turbidity Calibration Procedure

The procedure to calibrate the turbidity parameter shall be as follows.

1. Write the Calibration Mode On command (0xE000) to the sensor command register. Reading the turbidity parameter in calibration mode shall present turbidity as NTU_f (the current user slope and offset shall not be applied).
2. Instruct the user to place the turbidity sensor into one or more turbidity standards.
3. Read the turbidity parameter at each turbidity standard.
4. Calculate new values for the user slope and offset, and write these values to their corresponding registers.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Nitrate ISE Sensor

The Nitrate Ion Selective Electrode (ISE) sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 70
1	2	R1/W4	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 900 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 900 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N = 2)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, correctly position the wiper, and read dependent sensor parameters (temperature).

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up. The measurement time shall include the time necessary to reposition the wiper if needed, and to read dependent sensor parameters.

Parameter 1: Nitrate Concentration

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 37 (Nitrate as Nitrogen)
40	1	R1/W2	ushort	Units Id 113 = ppm 117 = mg/L (default)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0011 (17)

It is recommended to do at least a user two-point calibration. A single point user calibration can however be made that only determines an offset and assumes a default sensitivity of -56 millivolt (mV) per decade of concentration change. For a single point user calibration, the user concentration should be written into the first look up table (LUT) point, C_1. The associated mV reading gets written into the first mV table point, V_1. The remaining register table values C_2, V_2 and C_3 and V_3 are all set to zero.

For a two-point user calibration, the values C_3 and V_3 are set to zero.

Any sensor mV reading outside of the minimum or maximum mV value(s) from the LUT will use linear extrapolation for estimating concentration.

Table concentrations must go from low to high concentrations, where the lowest concentration is written into the C_1 register. A successful multipoint calibration requires that the mV readings are monotonic down, meaning the numbers must always be decreasing (ie Nitrate ISE has a negative mV/decade slope).

The concentration of Nitrate as Nitrogen is computed as:

For one line segment (single point or two-point calibration):

$C = 10\text{^}(m_1 * (V * (T_{1K} / T_K) – b_1))$

For two line segments (three-point calibration):

$V > V_2$: $C = 10\text{^}(m_1 * (V * (T_{1K} / T_K) – b_1))$

$V <= V_2$: $C = 10\text{^}(m_2 * (V * (T_{2K} / T_K) – b_2))$

where:

C is the concentration of Nitrate as Nitrogen in mg/L

V is the measured sensor millivolts

m_1 and b_1 are slope and offset for segment one respectively

m_2 and b_2 are slope and offset for segment one respectively

T_K is the measured temperature in Kelvin (K)

T_{1K} is the calibration temperature converted to K. ($T_{1K} = T_1 + 273.15$)

T_{2K} is the calibration temperature converted to K. ($T_{2K} = T_2 + 273.15$)

If the Nitrate as Nitrogen is computed to be outside of the range [0, 50e3] mg/L the measured value is set to 0mg/L or 50e3 mg/L and the data quality ID is shown to be an error.

The slopes and offsets for a given segment are computed as:

$m = (\log_{10}(C_i) – \log_{10}(C_{i+1}))/ (V_i\text{-}V_{i+1})$, with units of pNO3-/mV

$b = V_i - \log_{10}(C_i)/m$, with units of mV

where:

C_i and C_{i+1} are the two concentrations of Nitrate as Nitrogen, in mg/L.

V_i and V_{i+1} are the two associated millivolt readings

Parameter 2: Nitrate mV

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value
47	1	R1	ushort	Parameter Id = 38 (Nitrate mV)
48	1	R1/W2	ushort	Units Id 162 = mV (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0002 (2)

Calibration Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Number of user cal. points 1-3 (default = 2)
119	2	R1/W3	float	Nitrate as N value, C_1 (default = 1 mg/L)
121	2	R1/W3	float	mV response, V_1 (default = 160 mV)
123	2	R1/W3	float	Temperature of solution 1, T_1 in °C (default = 25)
125	2	R1/W3	float	Nitrate as N value, C_2 (default = 100 mg/L)
127	2	R1/W3	float	mV response, V_2 (default = 48 mV)
129	2	R1/W3	float	Temperature of solution 2, T_2 in °C (default = 25)
131	2	R1/W3	float	Nitrate as N value, C_3 (default = 0 mg/L)
133	2	R1/W3	float	mV response, V_3 (default = 0 mV)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
135	2	R1/W3	float	Temperature of solution 3, T_3 in °C (default = 25)
137	2	R1/W3	float	Slope, m_1 in pNO3/mV (default =-0.01785714 = -1/56)
139	2	R1/W3	float	Offset, b_1 in mV (default = 160)
141	2	R1/W3	float	Slope, m_2 in pNO3/mV (default = 0)
143	2	R1/W3	float	Offset, b_2 in mV (default = 0)
157	2	R1/W4	float	Factory Register Index (default = 0)
159	2	R1/W4	float	Factory Register Value (default = 0)

These registers shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off.

Nitrate Calibration Procedure

The procedure to calibrate the Nitrate as N concentration parameter shall be as follows.

1. Write the Calibration Mode On command (0xE000) to the sensor command register.
2. Instruct the user to place the Nitrate sensor into one or more Nitrate standards.
3. Read the Nitrate mV and temperature parameters at each Nitrate standard.
4. Load Nitrate as N concentration Standards, mV readings and temperature readings as well as the calculated Slopes and Offsets into the correct calibration register locations.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Ammonium ISE Sensor

The Ammonium Ion Selective Electrode (ISE) sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 71
1	2	R1/W4	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 900 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 900 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N = 4)
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, correctly position the wiper, and read dependent sensor parameters (temperature).

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up. The measurement time shall include the time necessary to reposition the wiper if needed, and to read dependent sensor parameters.

Parameter 1: Ammonium Concentration

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 39 (Ammonium as Nitrogen)
40	1	R1/W2	ushort	Units Id 113 = ppm 117 = mg/L (default)
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0011 (17)

It is recommended to do at least a user two-point calibration. A single point user calibration can however be made that only determines an offset and assumes a default sensitivity of -56 millivolt (mV) per decade of concentration change. For a single point user calibration, the user concentration should be written into the first look up table (LUT) point, C_1. The associated mV reading gets written into the first mV table point, V_1. The remaining register table values C_2, V_2 and C_3 and V_3 are all set to zero.

For a two-point user calibration, the values C_3 and V_3 are set to zero.

Any sensor mV reading outside of the minimum or maximum mV value(s) from the LUT will use linear extrapolation for estimating concentration.

Table concentrations must go from low to high concentrations, where the lowest concentration is written into the C_1 register. A successful multipoint calibration requires that the mV readings are monotonic up, meaning the numbers must always be increasing (ie Ammonium ISE has a positive mV/decade slope).

The concentration of Ammonium as Nitrogen is computed as:

For one line segment (single point or two-point calibration):

$C = 10\text{^}(m_1*(V*(T_{1K} / T_K) – b_1))$

For two line segments (three-point calibration):

$V < V_2$: $C = 10\text{^}(m_1*(V*(T_{1K} / T_K) - b_1))$

$V >= V_2$: $C = 10\text{^}(m_2*(V*(T_{2K} / T_K) - b_2))$

where:

C is the concentration of Nitrate as Nitrogen in mg/L

V is the measured sensor millivolts

m_1 and b_1 are slope and offset for segment one respectively

m_2 and b_2 are slope and offset for segment one respectively

T_K is the measured temperature in Kelvin (K)

T_{1K} is the calibration temperature converted to K. ($T_{1K} = T_1 + 273.15$)

T_{2K} is the calibration temperature converted to K. ($T_{2K} = T_2 + 273.15$)

If the Ammonium as Nitrogen is computed to be outside of the range [0, 15e3] mg/L the measured value is set to 0 mg/L or 15e3 mg/L and the data quality ID is shown to be an error.

The slopes and offsets for a given segment are computed as:

$m = (\log_{10}(C_i) - \log_{10}(C_{i+1}))/ (V_i-V_{i+1})$, with units of $pNH^+{}_4$/mV

$b = V_i - \log_{10}(C_i)/m$, with units of mV

where:

C_i and C_{i+1} are the two concentrations of Ammonium as Nitrogen, in mg/L.

V_i and V_{i+1} are the two associated millivolt readings

Parameter 2: Ammonium mV

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value
47	1	R1	ushort	Parameter Id = 40 (Ammonium mV)
48	1	R1/W2	ushort	Units Id 162 = mV (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0002 (2)

Parameter 3: Ammonia Concentration

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
53	2	R1	float	Measured value
55	1	R1	ushort	Parameter Id = 41 (Ammonia as Nitrogen)
56	1	R1/W2	ushort	Units Id 113 = ppm 117 = mg/L (default)
57	1	R1	ushort	Data Quality Id
58	2	R1/W3	float	Off line sentinel value (default = 0.0)
60	1	R1	16 bits	Available Units = 0x0011 (17)

The dissolved Ammonia gas concentration as Nitrogen is calculated from the Ammonium as Nitrogen concentration, pH, temperature, and salinity as follows. If any dependent parameter is missing, the sentinel value will be returned with a data quality of 7 (sensor missing).

B = C * 10^(pH - pK_a(T,S))

Where:

B is the dissolved Ammonia as Nitrogen concentration in mg/L.

C is the Ammonium as Nitrogen concentration in mg/L.

T is temperature in Celcius.

S is the Salinity, in ppt (parts per thousand).

pH is the acidity or negative log of the Hydronium ion concentration.

pK_a(T,S) is the Ammonia dissociation constant

= 10.0423 -0.0315536*T + 0.003071*S

References:

T. G. Bell, M. T. Johnson, T. D. Jickells, P. S. Liss
Ammonia/ammonium dissociation coefficient in seawater: a significant numerical correction
Environ. Chem. 2007, 4, 183–186.

T. G. Bell, M. T. Johnson, T. D. Jickells, P. S. Liss
Ammonia/ammonium dissociation coefficient in seawater: a significant numerical correction
Environ. Chem. 2008, 5, 258.

Parameter 4: Total Ammonia

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
61	2	R1	float	Measured value
63	1	R1	ushort	Parameter Id = 42 (Total Ammonia as Nitrogen)
64	1	R1/W2	ushort	Units Id 113 = ppm 117 = mg/L (default)
65	1	R1	ushort	Data Quality Id
66	2	R1/W3	float	Off line sentinel value (default = 0.0)
68	1	R1	16 bits	Available Units = 0x0011 (17)

Total Ammonia as Nitrogen is calculated as the sum of the Ammonium concentration as Nitrogen and the Ammonia concentration as Nitrogen. The data quality will be the same as Ammonia concentration as Nitrogen.

Calibration Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Number of user cal. points 1-3 (default = 2)
119	2	R1/W3	float	Ammonium as N value, C_1 (default = 1 mg/L)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
121	2	R1/W3	float	mV response, V_1 (default = 0 mV)
123	2	R1/W3	float	Temperature of solution 1, T_1 in °C (default = 25)
125	2	R1/W3	float	Ammonium as N value, C_2 (default = 100 mg/L)
127	2	R1/W3	float	mV response, V_2 (default = 112 mV)
129	2	R1/W3	float	Temperature of solution 2, T_2 in °C (default = 25)
131	2	R1/W3	float	Ammonium as N value, C_3 (default = 0 mg/L)
133	2	R1/W3	float	mV response, V_3 (default = 0 mV)
135	2	R1/W3	float	Temperature of solution 3, T_3 in °C (default = 25)
137	2	R1/W3	float	Slope, m_1 in pNH4/mV (default = 0.01785714 = 1/56)
139	2	R1/W3	float	Offset, b_1 in mV (default = 0)
141	2	R1/W3	float	Slope, m_2 in pNH4/mV (default = 0)
143	2	R1/W3	float	Offset, b_2 in mV (default = 0)
157	2	R1/W4	float	Factory Register Index (default = 0)
159	2	R1/W4	float	Factory Register Value (default = 0)

These registers shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off.

Ammonium Calibration Procedure

The procedure to calibrate the Ammonium concentration parameter shall be as follows.

1. Write the Calibration Mode On command (0xE000) to the sensor command register.
2. Instruct the user to place the Ammonium sensor into one or more Ammonium as Nitrogen standards.
3. Read the Ammonium mV and temperature parameters at each Ammonium as Nitrogen standard.
4. Load Ammonium as Nitrogen concentration Standards, mV readings and temperature readings as well as the calculated Slopes and Offsets into the correct calibration register locations.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.

6. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Chloride ISE Sensor

The Chloride Ion Selective Electrode (ISE) sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 72
1	2	R1/W4	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 900 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 900 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N = 2)
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, correctly position the wiper, and read dependent sensor parameters (temperature).

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up. The measurement time shall include the time necessary to reposition the wiper if needed, and to read dependent sensor parameters.

Parameter 1: Chloride Concentration

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 24 (Chloride Cl^-)
40	1	R1/W2	ushort	Units Id 113 = ppm 117 = mg/L (default)
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0011 (17)

It is recommended to do at least a user two-point calibration. A single point user calibration can however be made that only determines an offset and assumes a default sensitivity of -56 millivolt (mV) per decade of concentration change. For a single point user calibration, the user concentration should be written into the first look up table (LUT) point, C_1. The associated mV reading gets written into the first mV table point, V_1. The remaining register table values C_2, V_2 and C_3 and V_3 are all set to zero.

For a two-point user calibration, the values C_3 and V_3 are set to zero.

Any sensor mV reading outside of the minimum or maximum mV value(s) from the LUT will use linear extrapolation for estimating concentration.

Table concentrations must go from low to high concentrations, where the lowest concentration is written into the C_1 register. A successful multipoint calibration requires that the mV readings are monotonic down, meaning the numbers must always be decreasing (ie Chloride ISE has a negative mV/decade slope).

The concentration of Chloride is computed as:

For one line segment (single point or two-point calibration):

$C = 10\text{^}(m_1 * (V * (T_{1K} / T_K) – b_1))$

For two line segments (three-point calibration):

$V > V_2$: $C = 10\text{^}(m_1 * (V * (T_{1K} / T_K) – b_1))$

$V <= V_2$: $C = 10\text{^}(m_2 * (V * (T_{2K} / T_K) – b_2))$

where:

C is the concentration of Nitrate as Nitrogen in mg/L

V is the measured sensor millivolts

m_1 and b_1 are slope and offset for segment one respectively

m_2 and b_2 are slope and offset for segment one respectively

T_K is the measured temperature in Kelvin (K)

T_{1K} is the calibration temperature converted to K. ($T_{1K} = T_1 + 273.15$)

T_{2K} is the calibration temperature converted to K. ($T_{2K} = T_2 + 273.15$)

If the Chloride is computed to be outside of the range [0, 190e3] mg/L the measured value is set to 0mg/L or 190e3 mg/L and the data quality ID is shown to be an error.

The slopes and offsets for a given segment are computed as:

$m = (\log_{10}(C_i) – \log_{10}(C_{i+1})) / (V_i - V_{i+1})$, with units of pCl^-/mV

$b = V_i - \log_{10}(C_i)/m$, with units of mV

where:

C_i and C_{i+1} are the two concentrations of Chloride, in mg/L.

V_i and V_{i+1} are the two associated millivolt readings

Parameter 2: Chloride mV

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value
47	1	R1	ushort	Parameter Id = 36 (Chloride mV)
48	1	R1/W2	ushort	Units Id 162 = mV (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0002 (2)

Calibration Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Number of user cal. points 1-3 (default = 2)
119	2	R1/W3	float	Chloride value, C_1 (default = 10 mg/L)
121	2	R1/W3	float	mV response, V_1 (default = 230 mV)
123	2	R1/W3	float	Temperature of solution 1, T_1 in °C (default = 25)
125	2	R1/W3	float	Chloride value, C_2 (default = 1000 mg/L)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
127	2	R1/W3	float	mV response, V_2 (default = 118 mV)
129	2	R1/W3	float	Temperature of solution 2, T_2 in °C (default = 25)
131	2	R1/W3	float	Chloride value, C_3 (default = 0 mg/L)
133	2	R1/W3	float	mV response, V_3 (default = 0 mV)
135	2	R1/W3	float	Temperature of solution 3, T_3 in °C (default = 25)
137	2	R1/W3	float	Slope, m_1 in pCl/mV (default = -0.01785714 = -1/56)
139	2	R1/W3	float	Offset, b_1 in mV (default = 286)
141	2	R1/W3	float	Slope, m_2 in pCl-/mV (default = 0)
143	2	R1/W3	float	Offset, b_2 in mV (default = 0)
157	2	R1/W4	float	Factory Register Index (default = 0)
159	2	R1/W4	float	Factory Register Value (default = 0)

These registers shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off.

Chloride Calibration Procedure

The procedure to calibrate the Chloride concentration parameter shall be as follows.

1. Write the Calibration Mode On command (0xE000) to the sensor command register.
2. Instruct the user to place the Chloride sensor into one or more Chloride standards.
3. Read the Chloride mV and temperature parameters at each Chloride standard.
4. Load Chloride concentration Standards, mV readings and temperature readings as well as the calculated Slopes and Offsets into the correct calibration register locations.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Rhodamine WT Sensor

The Rhodamine WT (Water Tracer) or RWT sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 60
1	2	R1/W4	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 1000 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 1000 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N = 3)
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, and correctly position the wiper.

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up and the wiper is correctly positioned.

Parameter 1: Temperature

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 1 (temperature)
40	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0003 (3)

Temperature is factory calibrated in °C. The measured temperature in °C (T_M) is calculated as:

$T_M = T_o + T_f$

Where T_f is the factory calibrated temperature in °C and T_o is the user offset calibration.

Conversion to other units is as follows.

°F = 1.8 * °C + 32

The temperature measurement inside the fluorescence sensor has a slow thermal response time. When a faster temperature sensor is installed on the sonde, the sonde will use those temperature measurements for compensating the fluorophore concentration estimate.

If the sensor temperature measurement returns an error, the sonde will substitute its internal temperature sensor value and set the data quality id to a warning. If the sonde temperature measurement also generates an error, the sonde will use the sentinel value and set the data quality id to an error.

Parameter 2: Rhodamine WT Fluorescence Intensity

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value
47	1	R1	ushort	Parameter Id = 35 (RWT Fluorescence Intensity)
48	1	R1/W2	ushort	Units Id 257 = RFU (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0001 (1)

The default units for RWT fluorescence intensity is RFU (Relative Fluorescence Units). The Ratio (signal/reference) is passed as input to a Look up table (LUT) to linearize the RFU at high concentrations. The output of the LUT is the non-temperature compensated concentration. The RFU parameter being a relative parameter, its relationship to the concentration is user programmable. The default relationship sets the RFU value at 0.1 of the concentration such that 1000 µg/L RWT nominally equals 100 RFU. This relationship can however be adjusted by the user during user calibrations.

$X = LUT(Ratio)$

$Y = X * 0.1$

$Z = m_1*Y + b_1$

$RFU = m_2*Z + b_2$

Where:

Ratio is equal to the AC signal amplitude divided AC reference amplitude.

X is the non-temperature compensated concentration of RWT as calculated from

the LUT (Look Up Table).

Y is a measure of RFU with default slope adjustment.

Z is a measure of RFU after factory calibration

m_1 and b_1 are the factory defined slope and offset.

m_2 and b_2 are the user defined slope and offset.

Parameter 3: Rhodamine WT Concentration

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
53	2	R1	float	Measured value
55	1	R1	ushort	Parameter Id = 34 (RWT concentration)
56	1	R1/W2	ushort	Units Id 118 = µg/L (default) 121 = ppb
57	1	R1	ushort	Data Quality Id
58	2	R1/W3	float	Off line sentinel value (default = 0.0)
60	1	R1	16 bits	Available Units = 0x0120 (288)

The Rhodamine WT (RWT) concentration is calculated from the measured Ratio (signal/reference) value input to a Look up table (LUT). The RWT concentration is also temperature compensated because the fluorophore has a significant temperature coefficient. The temperature compensation was developed from Smart and Laidlaw, 1977 (see Reference below). The coefficient T_{co} has a default setting of -2.7%/^{o}C consistent with literature values from Smart and Laidlaw.

The RWT concentration in µg/L is calculated as follows.

X = LUT(Ratio)

$Y = m_1 * X + b_1$

$[RWT]_f = Y / (e\text{^}(T_{co}/100*(T – 25)))$

$[RWT] = m_2 * [RWT]_f + b_2$

Where:

Ratio is equal to the AC signal amplitude divided AC reference amplitude.

X is the non-temperature compensated concentration of RWT as calculated from the LUT (Look Up Table).

m_1 and b_1 are the factory defined slope and offset.

Y is the factory calibrated non-temperature compensated concentration of RWT.

$[RWT]_f$ is the factory calibrated temperature compensated concentration of RWT

m_2 and b_2 are the user defined slope and offset.

[RWT] is the user calibrated temp. compensated RWT concentration in µg/L.

T_{co} is the temperature coefficient of RWT in $\%/^oC$

"e" is the natural number equal to about 2.7183.

T is the temperature in Celsius.

Reference: P.L. Smart, I.M.S. Laidlaw, An evaluation of some fluorescent dyes for water tracing. Water Resources Research, Vol. 13, No. 1 Feb. 1977.

Calibration Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Cal. Type for Concentration (default = 0)
119	2	R1/W3	float	Number of Cal. Points for Concentration (default = 0, Range = 0,1,2)
121	2	R1/W3	float	Concentration of Standard 1 (default = 0)
123	2	R1/W3	float	Temperature of Standard 1 (default = 25C)
125	2	R1/W3	float	Concentration Standard 2 (default = 500 ug/L)
127	2	R1/W3	float	Temperature of Standard 2 (default = 25C)
129	2	R1/W3	float	User calibration Concentration slope, m (default = 1)
131	2	R1/W3	float	User calibration Concentration offset, b (default = 0)
133	2	R1/W3	float	Fluorophore Temperature Coefficient T_{co}, -2.7% $/^oC$

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
135	2	R1/W3	float	Cal. Type for Fluorescence Intensity (default = 0)
137	2	R1/W3	float	Number of Cal. Points for Fluorescence Intensity (default = 0, Range = 0,1,2)
139	2	R1/W3	float	Fluorescence Intensity of Standard 1 (default = 0)
141	2	R1/W3	float	Temperature of Fluorescence Intensity Standard 1 (default = 25)
143	2	R1/W3	float	Fluorescence Intensity Standard 2 (default = 50)
145	2	R1/W3	float	Temperature of Fluorescence Intensity Standard 2 (default = 25)
147	2	R1/W3	float	User Cal. Fluorescence Intensity slope, m (default = 1)
149	2	R1/W3	float	User Cal. Fluorescence Intensity offset, b (default = 0)
151	2	R1/W3	float	Temperature Offset T_o in °C (default = 0.0)
155	2	R1	float	Factory Ratio = Sig/Ref
157	2	R1/W3	float	Factory Register Index (default = 342)
159	2	R1/W3	float	Factory Register Value

User Calibration Slope and Offset – These values are used to calibrate Rhodamine WT concentration and fluorescence intensity (RFU) to user standards. These registers shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off.

Fluorophore concentration is calculated as follows.

[RWT] = m * x + b

Where x is the factory calibrated concentration in µg/L or ppb and m and b are the slope and offset respectively for the calibration.

Fluorophore fluorescence intensity is calculated as follows.

RFU = m * x + b

Where x is the factory calibrated fluorescence intensity, in RFU and m and b are the slope and offset respectively for the calibration.

Rhodamine WT Calibration Procedure

The procedure to calibrate the fluorescence intensity and concentration parameters shall be as follows.

1. Write the Calibration Mode On command (0xE000) to the sensor command register. Reading the Rhodamine WT (RWT) Fluorescence Intensity parameter then the RWT concentration in calibration mode shall present the factory fluorescence intensity and concentration readings respectively (the current user slopes and offsets shall not be applied).
2. Instruct the user to place the RWT sensor into one or more RWT standards.
3. Read the RWT parameters at each RWT standard.
4. Calculate new values for the user slope and offset and write these values to their corresponding registers.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Calibration calculations:

The slope and offset calculations for concentration are given below. The equation for a single point slope calibration is:

m = y/x

where:

x is the concentration reading.

y is the user input concentration.

m is the user slope

The equations for two-point calibrations are:

$m = (y_1 – y_2) / (x_1 – x_2)$

$b = y_1 - m^*x_1$

where:

x_1 is the concentration reading in sample 1.

x_2 is the concentration reading in sample 2.

y_1 is the concentration standard value 1 based on User input.

y_2 is the concentration standard value 2 based on User input.

m is the user slope.

b is the user offset.

Fluorescence Intensity readings given in units of RFU are not temperature compensated (as described above). During Fluorescence Intensity calibrations the RFU standard value specified by the user, is assumed to be at 25C. Operationally the RFU value will go up at lower temperatures and down at higher temperatures. In order to make calibrations more consistent across temperature, an RFU standard estimate is made based on the User input RFU standard value at 25C and the water sample temperature. The calculations are as follows.

$RFU(T_c) = RFU(25C) * e^{\wedge}(TempCo/100*(Tc-25))$

where:

e = natural number, approximately 2.71828182

TempCo is the fluorescence Temperature Coefficient (default = -2.7)

T_c = Water sample Temperature in Celsius

RFU(25C) = User Input RFU Standard at 25C

After calculating the standard value(s) at the sample temperature(s), the RFU(Tc) is used in computing the slope and offset from the equation RFU = m*x + b.

The equation for a single point Fluorescence Intensity slope calibration is:

$m = y/x$

where:

x is the RFU reading.

y is the RFU standard value based on User input and Temperature.

m is the user slope

The equations for two-point Fluorescence Intensity calibrations are:

$m = (y_1 – y_2) / (x_1 – x_2)$

$b = y_1 - m*x_1$

where:

x_1 is the RFU reading in sample 1.

x_2 is the RFU reading in sample 2.

y_1 is the RFU standard value 1 based on User input 1 and measured temperature 1.

y_2 is the RFU standard value 2 based on User input 2 and measured temperature 2.

m is the user slope.

b is the user offset.

Chlorophyll-a Sensor

The Chlorophyll-a sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 62
1	2	R1/W4	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 1000 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 1000 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N = 3)
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
				Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, and correctly position the wiper.

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up and the wiper is correctly positioned.

Parameter 1: Temperature

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 1 (temperature)
40	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0003 (3)

Temperature is factory calibrated in °C. The measured temperature in °C (T_M) is calculated as:

$T_M = T_o + T_f$

Where T_f is the factory calibrated temperature in °C and T_o is the user offset calibration.

Conversion to other units is as follows.

°F = 1.8 * °C + 32

The temperature measurement inside the fluorescence sensor has a slow thermal response time. When a faster temperature sensor is installed on the Sonde, the Sonde will use those temperature measurements for compensating the fluorophore concentration estimate.

If the sensor temperature measurement returns an error, the sonde will substitute its internal temperature sensor value and set the data quality id to a warning. If the sonde temperature measurement also generates an error, the sonde will use the sentinel value and set the data quality id to an error.

Parameter 2: Chlorophyll-a Fluorescence Intensity

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value
47	1	R1	ushort	Parameter Id = 51 (Chlorophyll-a Fluorescence Intensity)
48	1	R1/W2	ushort	Units Id 257 = RFU (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0001 (1)

The default units for Chlorophyll-a (CHLA) fluorescence intensity is RFU (relative fluorescence units). The Ratio (signal/reference) is passed as input to a Look up table (LUT) to linearize the RFU at high concentrations. The output of the LUT is the non-temperature compensated concentration. The RFU parameter being a relative parameter, its relationship to the concentration is user programmable. The default relationship sets the RFU value at 0.1 of the concentration such that 1000 µg/L CHLA nominally equals 100 RFU. This relationship can however be adjusted by the user during user calibrations.

X = LUT(Ratio)

Y = X * 0.1

$Z = m_1 * Y + b_1$

$RFU = m_2 * Z + b_2$

Where:

Ratio is equal to the AC signal amplitude divided AC reference amplitude.

X is the non-temperature compensated concentration of RWT as calculated from the LUT (Look Up Table).

Y is a measure of RFU with default slope adjustment.

Z is a measure of RFU after factory calibration

m_1 and b_1 are the factory defined slope and offset.

m_2 and b_2 are the user defined slope and offset.

Parameter 3: Chlorophyll-a Concentration

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
53	2	R1	float	Measured value
55	1	R1	ushort	Parameter Id = 50 (Chlorophyll-a concentration)
56	1	R1/W2	ushort	Units Id 118 = µg/L (default) 121 = ppb
57	1	R1	ushort	Data Quality Id
58	2	R1/W3	float	Off line sentinel value (default = 0.0)
60	1	R1	16 bits	Available Units = 0x0120 (288)

The Chlorophyll-a (CHLA) concentration is calculated from the measured ratio value (signal/reference) and a Look up table (LUT). The sensor is factory calibrated to Chlorophyll-a in MeOH (Methanol). It is not however recommended to use MeOH for doing calibrations because of its toxicity. The Chlorophyll-a can be temperature compensated however its default temperature coefficient is set to 0% /^{o}C.

The Chlorophyll-a concentration [CHLA] in µg/L is calculated as follows.

$X = LUT(Ratio)$

$Y = m_1 * X + b_1$

$[CHLA]_f = Y / (1 + T_{co} * (T - 25) / 100)$

$[CHLA] = m_2 * [CHLA]_f + b_2$

Where:

Ratio is equal to the AC signal amplitude divided AC reference amplitude.

X is the non-temperature compensated concentration of chlorophyll-a as calculated from the LUT (Look Up Table).

m_1 and b_1 are the factory defined slope and offset.

Y is the factory calibrated non-temperature compensated concentration of chlorophyll-a.

$[CHLA]_f$ is the factory calibrated temperature compensated concentration of chlorophyll-a.

m_2 and b_2 are the user defined slope and offset.

[CHL] is the user calibrated temperature compensated chlorophyll-a concentration in µg/L.

T_{co} is the temperature coefficient of CHL-a in %/^{o}C

T is the temperature in Celsius.

Calibration Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Cal. Type for Concentration (default = 0)
119	2	R1/W3	float	Number of Cal. Points for Concentration (default = 0, Range= 0,1,2)
121	2	R1/W3	float	Concentration of Standard 1 (default = 0)
123	2	R1/W3	float	Temperature of Standard 1 (default = 25C)
125	2	R1/W3	float	Concentration Standard 2 (default = 5000 ug/L)
127	2	R1/W3	float	Temperature of Standard 2 (default = 25C)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
129	2	R1/W3	float	User calibration Concentration slope, m (default = 1)
131	2	R1/W3	float	User calibration Concentration offset, b (default = 0)
133	2	R1/W3	float	Fluorophore Temperature Coefficient T_{co}, 0% /^{o}C
135	2	R1/W3	float	Cal. Type for Fluorescence Intensity (default = 0)
137	2	R1/W3	float	Number of Cal. Points for Fluorescence Intensity (default =0, Range= 0,1,2)
139	2	R1/W3	float	Fluorescence Intensity of Standard 1 (default = 0)
141	2	R1/W3	float	Temperature of Fluorescence Intensity Standard 1 (default = 25)
143	2	R1/W3	float	Fluorescence Intensity Standard 2 (default = 50)
145	2	R1/W3	float	Temperature of Fluorescence Intensity Standard 2 (default = 25)
147	2	R1/W3	float	User Cal. Fluorescence Intensity slope, m (default = 1)
149	2	R1/W3	float	User Cal. Fluorescence Intensity offset, b (default = 0)
151	2	R1/W3	float	Temperature Offset T_o in °C (default = 0.0)
155	2	R1	float	Factory Ratio = Sig/Ref
157	2	R1/W3	float	Factory Register Index (default = 342)
159	2	R1/W3	float	Factory Register Value

User Calibration Slope and Offset – These values are used to calibrate Chlorophyll-A concentration and fluorescence intensity (RFU) to user standards. These registers shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off.

Fluorophore concentration is calculated as follows.

[CHLA] = m * x + b

Where x is the factory calibrated concentration in µg/L or ppb and m and b are the slope and offset respectively for the calibration.

Fluorophore fluorescence intensity is calculated as follows.

$RFU = m * x + b$

Where x is the factory calibrated fluorescence intensity, in RFU and m and b are the slope and offset respectively for the calibration.

Chlorophyll-a Calibration Procedure

The procedure to calibrate the concentration parameter shall be as follows.

1. Write the Calibration Mode On command (0xE000) to the sensor command register. Reading the Chlorophyll-a (CHLA) Fluorescence Intensity parameter then the CHLA concentration in calibration mode shall present the factory fluorescence intensity and concentration readings respectively (the current user slopes and offsets shall not be applied).
2. Instruct the user to place the CHLA sensor into one or more CHLA standards.
3. Read the CHLA parameter at each CHLA standard.
4. Calculate new values for the user slope and offset and write these values to their corresponding registers.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Calibration calculations:

The slope and offset calculations for concentration are given below. The equation for a single point slope calibration is:

$m = y/x$

where:

x is the concentration reading.

y is the user input concentration.

m is the user slope

The equations for two-point calibrations are:

$m = (y_1 - y_2) / (x_1 - x_2)$

$b = y_1 - m^*x_1$

where:

x_1 is the concentration reading in sample 1.

x_2 is the concentration reading in sample 2.

y_1 is the concentration standard value 1 based on User input.

y_2 is the concentration standard value 2 based on User input.

m is the user slope.

b is the user offset.

Fluorescence Intensity readings given in units of RFU are not temperature compensated (as described above). Operationally the RFU value will normally go up at lower temperatures and down at higher temperatures but is highly dependent on the algal species and temperature range.

The equation for a single point Fluorescence Intensity slope calibration is:

$m = y/x$

where:

x is the RFU reading.

y is the RFU standard value based on User input and Temperature.

m is the user slope

The equations for two-point Fluorescence Intensity calibrations are:

$m = (y_1 - y_2) / (x_1 - x_2)$

$b = y_1 - m^*x_1$

where:

x_1 is the RFU reading in sample 1.

x_2 is the RFU reading in sample 2.

y_1 is the RFU standard value 1 based on User input 1 and measured temperature 1.

y_2 is the RFU standard value 2 based on User input 2 and measured temperature 2.

m is the user slope.

b is the user offset.

Blue Green Algae - Phycocyanin Sensor

The Blue Green Algae - Phycocyanin (BGA-PC) sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). Phycocyanin is a fluorescent pigment-protein complex found in cyanobacteria also called Blue Green Algae. The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 64
1	2	R1/W4	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 1000 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 1000 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N = 3)
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, and correctly position the wiper.

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up and the wiper is correctly positioned.

Parameter 1: Temperature

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 1 (temperature)
40	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0003 (3)

Temperature is factory calibrated in °C. The measured temperature in °C (T_M) is calculated as:

$T_M = T_o + T_f$

Where T_f is the factory calibrated temperature in °C and T_o is the user offset calibration.

Conversion to other units is as follows.

°F = 1.8 * °C + 32

The temperature measurement inside the fluorescence sensor has a slow thermal response time. When a faster temperature sensor is installed on the Sonde, the Sonde will use those temperature measurements for compensating the fluorophore concentration estimate.

If the sensor temperature measurement returns an error, the sonde will substitute its internal temperature sensor value and set the data quality id to a warning. If the sonde temperature measurement also generates an error, the sonde will use the sentinel value and set the data quality id to an error.

Parameter 2: Blue Green Algae-PC Fluorescence Intensity

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value
47	1	R1	ushort	Parameter Id = 55 (BGA-PC Fluorescence Intensity)
48	1	R1/W2	ushort	Units Id 257 = RFU (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0001 (1)

The default units for BGA-PC fluorescence intensity is RFU (Relative Fluorescence Units). The Ratio = sig/ref is passed as input to a Look up table (LUT) to linearize the RFU at high concentrations. The output of the LUT is the non-temperature compensated concentration. The RFU parameter being a relative parameter, its relationship to the concentration is user programmable. The default relationship sets the RFU value at 0.1 of the concentration such that 1000 µg/L BGA-PC nominally equals 100 RFU. This relationship can however be adjusted by the user during user calibrations.

X = LUT(Ratio)

Y = X *0.1

$Z = m_1*Y + b_1$

$RFU = m_2*Z + b_2$

Where:

Ratio is equal to the signal amplitude divided reference amplitude.

X is the non-temperature compensated concentration of BGA-PC as calculated

from the LUT (Look Up Table).

Y is a measure of RFU with default slope adjustment.

Z is a measure of RFU after factory calibration

m_1 and b_1 are the factory defined slope and offset.

m_2 and b_2 are the user defined slope and offset.

Parameter 3: Blue Green Algae–PC Concentration

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
53	2	R1	float	Measured value
55	1	R1	ushort	Parameter Id = 54 (BGA-PC concentration)
56	1	R1/W2	ushort	Units Id 118 = µg/L (default) 121 = ppb
57	1	R1	ushort	Data Quality Id
58	2	R1/W3	float	Off line sentinel value (default = 0.0)
60	1	R1	16 bits	Available Units = 0x0120 (288)

The BGA-PC concentration is calculated from the measured Ratio (signal/reference) value input to a Look up table (LUT). The BGA-PC concentration can be temperature compensated however its default temperature coefficient is set to 0% /^{o}C.

The BGA-PC concentration in µg/L is calculated as follows.

X = LUT(Ratio)

$Y = m_1 * X + b_1$

$[BGA\text{-}PC]_f = Y / (1 + T_{co} * (T - 25) / 100)$

$[BGA\text{-}PC] = m_2 * [BGA\text{-}PC]_f + b_2$

Where:

Ratio is equal to the signal amplitude divided by the reference amplitude.

X is the non-temperature compensated concentration of BGA-PC as calculated from the LUT (Look Up Table).

m_1 and b_1 are the factory defined slope and offset.

Y is the factory calibrated non-temperature compensated concentration of BGA-PC.

$[BGA\text{-}PC]_f$ is the factory calibrated temperature compensated concentration of BGA-PC.

m_2 and b_2 are the user defined slope and offset.

[BGA-PC] is the user calibrated temperature compensated BGA-PC concentration in µg/L.

T_{co} is the temperature coefficient of BGA-PC in %/^{o}C

T is the temperature in Celsius.

Calibration Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Cal. Type for Concentration (default = 0)
119	2	R1/W3	float	Number of Cal. Points for Concentration (default = 0, Range= 0,1,2)
121	2	R1/W3	float	Concentration of Standard 1 (default = 0)
123	2	R1/W3	float	Temperature of Standard 1 (default = 25C)
125	2	R1/W3	float	Concentration Standard 2 (default = 500 ug/L)
127	2	R1/W3	float	Temperature of Standard 2 (default = 25C)
129	2	R1/W3	float	User calibration Concentration slope, m (default = 1)
131	2	R1/W3	float	User calibration Concentration offset, b

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
				(default = 0)
133	2	R1/W3	float	Fluorophore Temperature Coefficient T_{co}, 0% /^{o}C
135	2	R1/W3	float	Cal. Type for Fluorescence Intensity (default = 0)
137	2	R1/W3	float	Number of Cal. Points for Fluorescence Intensity (default = 0, Range=0,1,2)
139	2	R1/W3	float	Fluorescence Intensity of Standard 1 (default = 0)
141	2	R1/W3	float	Temperature of Fluorescence Intensity Standard 1 (default = 25)
143	2	R1/W3	float	Fluorescence Intensity Standard 2 (default = 50)
145	2	R1/W3	float	Temperature of Fluorescence Intensity Standard 2 (default = 25)
147	2	R1/W3	float	User Cal. Fluorescence Intensity slope, m (default = 1)
149	2	R1/W3	float	User Cal. Fluorescence Intensity offset, b (default = 0)
151	2	R1/W3	float	Temperature Offset T_o in °C (default = 0.0)
155	2	R1	float	Factory Ratio = Sig/Ref
157	2	R1/W3	float	Factory Register Index (default = 342)
159	2	R1/W3	float	Factory Register Value

User Calibration Slope and Offset – These values are used to calibrate BGA-PC concentration and fluorescence intensity (RFU) to user standards. These registers shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off.

Fluorophore concentration is calculated as follows.

[BGA-PC] = m * x + b

Where x is the factory calibrated concentration in µg/L or ppb and m and b are the slope and offset respectively for the calibration.

Fluorophore fluorescence intensity is calculated as follows.

RFU = m * x + b

Where x is the factory calibrated fluorescence intensity, in RFU and m and b are the slope and offset respectively for the calibration.

Blue Green Algae-PC Calibration Procedure

The procedure to calibrate the concentration parameter shall be as follows.

1. Write the Calibration Mode On command (0xE000) to the sensor command register. Reading the Blue Green Algae (BGA-PC) Fluorescence Intensity parameter then the BGA-PC concentration in calibration mode shall present the factory fluorescence intensity and concentration readings respectively (the current user slopes and offsets shall not be applied).
2. Instruct the user to place the BGA-PC sensor into one or more BGA-PC standards.
3. Read the BGA-PC parameter at each BGA-PC standard.
4. Calculate new values for the user slope and offset and write these values to their corresponding registers.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Calibration calculations:

The slope and offset calculations for concentration are given below. The equation for a single point slope calibration is:

m = y/x

where:

x is the concentration reading.

y is the user input concentration.

m is the user slope

The equations for two-point calibrations are:

$m = (y_1 - y_2) / (x_1 - x_2)$

$b = y_1 - m*x_1$

where:

x_1 is the concentration reading in sample 1.

x_2 is the concentration reading in sample 2.

y_1 is the concentration standard value 1 based on User input.

y_2 is the concentration standard value 2 based on User input.

m is the user slope.

b is the user offset.

Fluorescence Intensity readings given in units of RFU are not temperature compensated (as described above). Operationally the RFU value will normally go up at lower temperatures and down at higher temperatures but is highly dependent on the algal species and temperature range.

The equation for a single point Fluorescence Intensity slope calibration is:

$m = y/x$

where:

x is the RFU reading.

y is the RFU standard value based on User input and Temperature.

m is the user slope

The equations for two-point Fluorescence Intensity calibrations are:

$m = (y_1 – y_2) / (x_1 – x_2)$

$b = y_1 - m*x_1$

where:

x_1 is the RFU reading in sample 1.

x_2 is the RFU reading in sample 2.

y_1 is the RFU standard value 1 based on User input 1 and measured temperature 1.

y_2 is the RFU standard value 2 based on User input 2 and measured temperature 2.

m is the user slope.

b is the user offset.

Blue Green Algae - Phycoerythrin Sensor

The Blue Green Algae - Phycoerythrin (BGA-PE) sensor is a user installed option and can appear as any sensor connection from 1 to 4 (bits 0 to 3 in the sensor connection status register). Phycoerythrin is a fluorescent pigment-protein complex found cyanobacteria also called Blue Green Algae. The corresponding sensor data offset register points to the first register in the sensor data header block. All register values in this section are offsets from that base value.

Header Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	1	R1/W4	ushort	Sensor Id = 65
1	2	R1/W4	ulong	Sensor serial number
3	1	R1	16 bits	Sensor status
4	3	R1/W4	time	Last factory calibration
7	3	R1/W4	time	Next factory calibration (0 = none required)
10	3	R1	time	Last user calibration
13	3	R1/W2	time	Next user calibration (0 = none required)
16	1	R1	ushort	Warm-up time = 1000 milliseconds + dependencies
17	1	R1	ushort	Fast sample rate = 1000 milliseconds + dependencies
18	1	R1	ushort	Number of sensor parameters (N = 3)
19	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
20	1	R1/W3	16 bits	Alarm and warning enable bits (default = 0) Bit 0 = High alarm enabled Bit 1 = High warning enabled Bit 2 = Low warning enabled Bit 3 = Low alarm enabled Bit 4 = Sensor calibration warning
21	2	R1/W3	float	High alarm set value (default = 0.0)
23	2	R1/W3	float	High alarm clear value (default = 0.0)
25	2	R1/W3	float	High warning set value (default = 0.0)
27	2	R1/W3	float	High warning clear value (default = 0.0)
29	2	R1/W3	float	Low warning clear value (default = 0.0)
31	2	R1/W3	float	Low warning set value (default = 0.0)
33	2	R1/W3	float	Low alarm clear value (default = 0.0)
35	2	R1/W3	float	Low alarm set value (default = 0.0)

Warm-up Time

The warm-up time is the measurement time including the time necessary to power up the sensors from their power off state, perform a wipe cycle, and correctly position the wiper.

Fast Sample Rate

The fast sample rate is the measurement time when the sensors are already powered up and the wiper is correctly positioned.

Parameter 1: Temperature

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
37	2	R1	float	Measured value
39	1	R1	ushort	Parameter Id = 1 (temperature)
40	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
41	1	R1	ushort	Data Quality Id
42	2	R1/W3	float	Off line sentinel value (default = 0.0)
44	1	R1	16 bits	Available Units = 0x0003 (3)

Temperature is factory calibrated in °C. The measured temperature in °C (T_M) is calculated as:

$T_M = T_o + T_f$

Where T_f is the factory calibrated temperature in °C and T_o is the user offset calibration.

Conversion to other units is as follows.

°F = 1.8 * °C + 32

The temperature measurement inside the fluorescence sensor has a slow thermal response time. When a faster temperature sensor is installed on the Sonde, the Sonde will use those temperature measurements for compensating the fluorophore concentration estimate.

If the sensor temperature measurement returns an error, the sonde will substitute its internal temperature sensor value and set the data quality id to a warning. If the sonde temperature measurement also generates an error, the sonde will use the sentinel value and set the data quality id to an error.

Parameter 2: Blue Green Algae-PE Fluorescence Intensity

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
45	2	R1	float	Measured value
47	1	R1	ushort	Parameter Id = 59 (BGA-PE Fluorescence Intensity)
48	1	R1/W2	ushort	Units Id 257 = RFU (default)
49	1	R1	ushort	Data Quality Id
50	2	R1/W3	float	Off line sentinel value (default = 0.0)
52	1	R1	16 bits	Available Units = 0x0001 (1)

The default units for BGA-PE fluorescence intensity is RFU (relative fluorescence units). The Ratio = sig/ref is passed as input to a Look up table (LUT) to linearize the RFU at high concentrations. The output of the LUT is the non-temperature compensated concentration. The RFU parameter being a relative parameter, its relationship to the concentration is user programmable. The default relationship sets the RFU value at 0.1 of the concentration such that 1000 µg/L BGA-PE nominally equals 100 RFU. This relationship can however be adjusted by the user during user calibrations.

X = LUT(Ratio)

Y = X *0.1

$Z = m_1 * Y + b_1$

$RFU = m_2 * Z + b_2$

Where:

Ratio is equal to the AC signal amplitude divided AC reference amplitude.

X is the non-temperature compensated concentration of BGA-PE as calculated

from the LUT (Look Up Table).

Y is a measure of RFU with default slope adjustment.

Z is a measure of RFU after factory calibration

m_1 and b_1 are the factory defined slope and offset.

m_2 and b_2 are the user defined slope and offset.

Parameter 3: Blue Green Algae–PE Concentration

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
53	2	R1	float	Measured value
55	1	R1	ushort	Parameter Id = 58 (BGA-PE concentration)
56	1	R1/W2	ushort	Units Id 118 = µg/L (default) 121 = ppb
57	1	R1	ushort	Data Quality Id
58	2	R1/W3	float	Off line sentinel value (default = 0.0)
60	1	R1	16 bits	Available Units = 0x0120 (288)

The BGA-PE concentration is calculated from the measured Ratio (signal/reference) value input to a Look up table (LUT). The BGA-PE concentration can be temperature compensated however the default temperature coefficient is set to 0% /^{o}C.

The BGA-PE concentration in µg/L is calculated as follows.

X = LUT(Ratio)

$Y = m_1 * X + b_1$

$[BGA\text{-}PE]_f = Y / (1 + T_{co} * (T - 25) / 100)$

$[BGA\text{-}PE] = m_2 * [BGA\text{-}PE]_f + b_2$

Where:

Ratio is equal to the signal amplitude divided by the reference amplitude.

X is the non-temperature compensated concentration of BGA-PE as calculated

from the LUT (Look Up Table).

m_1 and b_1 are the factory defined slope and offset.

Y is the factory calibrated non-temperature compensated concentration of BGA-PE.

$[BGA\text{-}PE]_f$ is the factory calibrated temperature compensated concentration of BGA-PE.

m_2 and b_2 are the user defined slope and offset.

[BGA-PE] is the user calibrated temperature compensated BGA-PE concentration in µg/L.

T_{co} is the temperature coefficient of BGA-PE in %/^oC

T is the temperature in Celsius.

Calibration Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
117	2	R1/W3	float	Cal. Type for Concentration (default = 0)
119	2	R1/W3	float	Number of Cal. Points for Concentration (default = 0, Range =0,1,2)
121	2	R1/W3	float	Concentration of Standard 1 (default = 0)
123	2	R1/W3	float	Temperature of Standard 1 (default = 25C)
125	2	R1/W3	float	Concentration Standard 2 (default = 500 ug/L)
127	2	R1/W3	float	Temperature of Standard 2 (default = 25C)
129	2	R1/W3	float	User calibration Concentration slope, m (default = 1)
131	2	R1/W3	float	User calibration Concentration offset, b (default = 0)
133	2	R1/W3	float	Fluorophore Temperature Coefficient T_{co}, 0% /^oC
135	2	R1/W3	float	Cal. Type for Fluorescence Intensity (default = 0)
137	2	R1/W3	float	Number of Cal. Points for Fluorescence Intensity (default = 0, Range = 0,1,2)
139	2	R1/W3	float	Fluorescence Intensity of Standard 1 (default = 0)

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
141	2	R1/W3	float	Temperature of Fluorescence Intensity Standard 1 (default = 25)
143	2	R1/W3	float	Fluorescence Intensity Standard 2 (default = 50)
145	2	R1/W3	float	Temperature of Fluorescence Intensity Standard 2 (default = 25)
147	2	R1/W3	float	User Cal. Fluorescence Intensity slope, m (default = 1)
149	2	R1/W3	float	User Cal. Fluorescence Intensity offset, b (default = 0)
151	2	R1/W3	float	Temperature Offset T_o in °C (default = 0.0)
155	2	R1	float	Factory Ratio = Sig/Ref
157	2	R1/W3	float	Factory Register Index (default = 342)
159	2	R1/W3	float	Factory Register Value

User Calibration Slope and Offset – These values are used to calibrate BGA-PE concentration and fluorescence intensity (RFU) to user standards. These registers shall only be able to be written when the sensor is in the calibration mode. The probe will return exception 0x92 (invalid sensor mode) if an attempt is made to write these registers when the calibration mode is off.

Fluorophore concentration is calculated as follows.

[BGA-PE] = m * x + b

Where x is the factory calibrated concentration in µg/L or ppb and m and b are the slope and offset respectively for the calibration.

Fluorophore fluorescence intensity is calculated as follows.

RFU = m * x + b

Where x is the factory calibrated fluorescence intensity, in RFU and m and b are the slope and offset respectively for the calibration.

Blue Green Algae-PC Calibration Procedure

The procedure to calibrate the concentration parameter shall be as follows.

1. Write the Calibration Mode On command (0xE000) to the sensor command register. Reading the Blue Green Algae (BGA-PE) Fluorescence Intensity parameter then the BGA-PE concentration in calibration mode shall present the factory fluorescence intensity and concentration readings respectively (the current user slopes and offsets shall not be applied).
2. Instruct the user to place the BGA-PE sensor into one or more BGA-PE standards.
3. Read the BGA-PE parameter at each BGA-PE standard.
4. Calculate new values for the user slope and offset and write these values to their corresponding registers.
5. Write the Calibration Update command (0xE001) to the sensor command register. The sensor sets the last user calibration date to the current date and sets the next user calibration, if not zero, to the current date plus the previous next calibration interval.
6. Optionally, read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.
7. Write the Calibration Off command (0xE002) to the sensor command register to place the sensor in normal operation.

Calibration calculations:

The slope and offset calculations for concentration are given below. The equation for a single point slope calibration is:

$m = y/x$

where:

x is the concentration reading.

y is the user input concentration.

m is the user slope

The equations for two-point calibrations are:

$m = (y_1 – y_2) / (x_1 – x_2)$

$b = y_1 - m*x_1$

where:

x_1 is the concentration reading in sample 1.

x_2 is the concentration reading in sample 2.

y_1 is the concentration standard value 1 based on User input.

y_2 is the concentration standard value 2 based on User input.

m is the user slope.

b is the user offset.

Fluorescence Intensity readings given in units of RFU are not temperature compensated (as described above). Operationally the RFU value will normally go up at lower temperatures and down at higher temperatures but is highly dependent on the algal species and temperature range.

The equation for a single point Fluorescence Intensity slope calibration is:

$m = y/x$

where:

x is the RFU reading.

y is the RFU standard value based on User input and Temperature.

m is the user slope

The equations for two-point Fluorescence Intensity calibrations are:

$m = (y_1 - y_2) / (x_1 - x_2)$

$b = y_1 - m*x_1$

where:

x_1 is the RFU reading in sample 1.

x_2 is the RFU reading in sample 2.

y_1 is the RFU standard value 1 based on User input 1 and measured temperature 1.

y_2 is the RFU standard value 2 based on User input 2 and measured temperature 2.

m is the user slope.

b is the user offset.

Probe Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
7000	1	R1	ushort	Probe Register Map Template Version (1)
7001	1	R1	ushort	External Power Voltage (millivolts)
7002	1	R1	ushort	Internal Battery Voltage (millivolts)
7003	2	R1/W3	ulong	Wiper Interval, 15 to 86400 seconds (default = 3600)
7005	2	R1/W3	float	Live Barometric Pressure (mbar)

Wiper Interval

This register determines shortest time interval (in seconds) that the wiper will be allowed to operate. If the sample rate is faster than this value, whether by logging or live readings, the wiper will only wipe at this interval. If the sample rate is longer than this interval, the wiper will wipe at the sample rate. If a log or live reading is requested within 15 seconds of the wiper interval, a wiper cycle will be triggered.

A wiper cycle consists of one complete revolution. Each revolution of the wiper will be in the opposite direction. A clockwise revolution will be followed by a counterclockwise revolution, etc.

Live Barometric Pressure

The live barometric pressure register allows an external controller to provide live barometric pressure readings to a non-vented instrument. Value must be written in millibars in the range 506.625 to 1114.675 mbar.

Reading this register returns the most recently written external value or internal value measured with the battery compartment open.

The value contained in this register has no effect on the operation of a vented instrument.

Data Log Limitations

A deleted data log can be restored a maximum of one time. Subsequent attempts to restore a data log will result in a Modbus exception with error code 0x88 (invalid file number).

Supported Log Types

The device shall support the log types specified in the table below.

Type Id	Name	Version
1	Simple Linear	1
2	Linear Average	2
6	Linear Event	2

After a log configuration file is written, sensors may be exchanged with sensors of the same type, and do not need to stay in their original port.

Log Sample Rates

For a device loaded with the standard sensor suite of conductivity/temperature, pH/ORP, turbidity, RDO, barometric pressure, and level, the fastest sample rates are as follows.

With no wiper: 10 seconds

With wiper: 15 seconds

Modbus PLC Interface

The standard Modbus interface described in the previous sections, dynamically maps sensor parameter registers based on their physical port position in the Sonde. The standard interface is very flexible and adapts easily to a wide variety of sensor configurations; however, it has the adverse effect of causing parameter registers to move within the register map if the sensor configuration changes. There are many features in the standard interface that enable a Modbus master device to discover the parameter register locations.

The Modbus PLC Interface places parameter registers at fixed register locations based on the parameter id. This interface reduces programming complexity and removes the dependency on the sensor configuration. There are some system limitations when using this interface.

- Only one sensor of any sensor model should be used in the sonde (for example, only one turbidity sensor should be plugged in).
- If a parameter is provided by more than one of the installed sensors, the parameter can only be read from the first sensor in the port order.
- Only parameter measurement registers are supported. Configuration and calibration registers are not accessible using this interface (the standard interface must be used instead).

Parameter Discovery

The first register read in a PLC measurement sequence should be a 14-register block read beginning with register number 6984. The read of these registers triggers the sonde to scan its sensor ports and update its sensor map. This guarantees that the sonde has properly registered any changes to the sensor configuration that a user may have made since the last measurement sequence. The bitwise contents of these registers indicate which parameter ids (1 to 219) are currently available from the sonde according to the table below. Refer to the sensor parameter sections for a description of the parameter ids.

Parameter Id Map					
	Bit				
Register	15	14	13…2	1	0
6984	16	15	14…3	2	1
6985	32	31	30…19	18	17
6986	48	47	46…35	34	33
6987	64	63	62…51	50	49
6988	80	79	78…67	66	65
6989	96	95	94…83	82	81
6990	112	111	110…99	98	97
6991	128	127	126…115	114	113
6992	144	143	142…131	130	129
6993	160	159	158…147	146	145
6994	176	175	174…163	162	161
6995	192	191	190…179	178	177

Parameter Id Map					
6996	208	207	206…195	194	193
6997	0	0	219…211	210	209

Reading Parameters

To determine the starting register number for a given parameter register block, first determine its parameter id by looking in the sensor's parameter tables. Then calculate the starting register number of the parameter block using the following equation.

Starting Register = (Parameter Id – 1) x 7 + 5451

For example, for the Conductivity Sensor, the parameter id for specific conductivity is 10 (bit 9 will be set in register 6984 if it is available). The starting register number for the specific conductivity register block is thus (10 – 1) x 7 + 5451 = 5514.

The starting register for each parameter points to a block of 7 registers that contain the following information.

Register Offset	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0	2	R1	float	Measured value
2	1	R1	ushort	Data Quality Id
3	1	R1/W2	ushort	Units Id
4	1	R1	ushort	Parameter Id
5	2	R1/W3	float	Off line sentinel value

Continuing with the above example, to measure and read specific conductivity, read the two-register floating point value at register 5514 (starting register 5514 + offset 0 = register 5514). To read the corresponding data quality id, read register 5516 (starting register 5514 + offset 2 = register 5516). Block reads within the parameter block are allowed. The specific conductivity can be measured and read along with its data quality id by reading the 3 registers starting at register 5514, then extracting the measured float value and the data quality id.

Registers within the block that are marked as read/write, can be written as well as read. Refer to the sensor-specific parameter information for valid values.

SDI-12 Interface

The device shall adhere to the Serial-Digital Interface Standard for Microprocessor-Based Sensors, Version 1.3 dated September 17, 2002, and the extensions to the specification identified in this document. This section identifies the device-specific implementation of the standard.

Configuration File

The device shall adhere to the specifications for writing and reading an SDI-12 configuration file as identified in the In-Situ System Interface Specification.

After the configuration file is written, sensors may be exchanged with sensors of the same type, and do not need to stay in their original port.

Power Management

When the device display turns off with external power connected, it enters a slightly higher sleep power state that permits faster wake times. This can compensate for SDI-12 data recorders that may not meet the 100 ms wake delay required by the SDI-12 specification. If the display turns off with no external power connected, the device enters its normal sleep mode for maximum battery life.

Basic Command Implementation

The following table lists each basic SDI-12 command, its format, and the format of each response.

Name	Command	Response
Address Query	?!	a<CR><LF> The wildcard address '?' character is only supported for the Address Query command. It shall be ignored as an invalid address for all other commands.
Acknowledge Active	a!	a<CR><LF> The device supports the basic address characters in the range '0' to '9' and the extended address characters in the ranges 'A' to 'Z' and 'a' to 'z'. All other characters are ignored as an invalid address. The default address is '0'.
Change Address	aAb!	b<CR><LF> The device supports software changeable addresses.
Send Identification	aI!	a13IN-SITU AT600 vvv xxxxxx<CR><LF> or a13IN-SITU AT600Vvvv xxxxxx<CR><LF> vvv = device firmware version * 100 (120 = 1.20) xxx = 6-digit device serial number with leading zeroes
Start Verification	aV!	a0033<CR><LF> Three values are available for reading by the Send Data command within 3 seconds.

Name	Command	Response
		A service request (a<CR><LF>) will be sent when the values are ready.
Send Data	aD0!	a+n+u+s<CR><LF> n = lower 16 bits (0-65535) of the device status u = upper 16 bits (0-65535) of the device status s = lower 16 bits (0-65535) of the sensor connection status register
Additional Data	aD1! … aD9!	a<CR><LF> No values are returned after an additional data command.
Start Measurement Start Measurement CRC	aM! aMC!	a015n<CR><LF> n parameters (1 to 9) will be available for reading by the Send Data command within 15 seconds. A service request (a<CR><LF>) will be sent when the parameters are ready. The number of parameters returned and their order is determined by the SDI-12 configuration file. If the device is configured to output more than 9 parameters, only the first 9 parameters can be measured by this command.
Send Data	aD0!	a<values><CR><LF> or a<values><CRC><CR><LF> At most 3 parameters are returned in a send data command. If more than 3 parameters are available, they are returned using the additional data command. A value of -99999 indicates that an expected sensor was missing.

Name	Command	Response
Additional Data	aD1! .. aD9!	a<values><CR><LF> or a<values><CRC><CR><LF> At most 3 parameters are returned per additional data request.
Additional Measurements Additional with CRC Send Data Additional Data	aM1! … aM9! aMC1! … aMC9! aD0! aD1! … aD9!	a0000<CR><LF> or a015n<CR><LF> If the device is configured to output more than 9 parameters, each additional measurement command provides up to an addition 9 parameters. a<values><CR><LF> or a<values><CRC><CR><LF> At most 3 parameters are returned per additional data request.

Extended Command Implementation

The device shall support the following extended SDI-12 commands.

Name	Command	Response
Auto Configure Send Data	aXAC! aD0!	a0051<CR><LF> One result is available within 5 seconds for reading by the Send Data command. Automatically creates an SDI-12 configuration file consisting of all parameters of all sensors beginning with port 1, up to a maximum of 30 parameters. A service request will be sent when the results are ready. a+p<CR><LF> p = number of parameters configured, 0 = command failed.
Set Factory Defaults	aXFD!	a0901<CR><LF> One result is available within 90 seconds for reading by the Send Data command. Restores all settings and calibration values to their factory defaults. A service request

Name	Command	Response
Send Data	aD0!	will be sent when the result is ready. a+s<CR><LF> s = command status, 1 = command successful, 0 = command failed.
Communication Diagnostics	aXCD!	a0012<CR><LF> Two results are available within 1 second for reading by the Send Data command. A service request will be sent when the results are ready.
Send Data	aD0!	a+A+C<CR><LF> A = contents of Modbus device address register 49200, C = contents of Modbus serial communication configuration register 49201.