Innovations in Water Monitoring

In-Situ Modbus Communication Protocol Version 5.10

Level ***TROLL***® 700, 500, 400
*Baro****TROLL***® 500
Aqua ***TROLL***® 100, 200
Rugged ***TROLL***® *200,*
*Rugged Baro****TROLL***®
(Instruments developed with System Spec 1)

RDO® PRO
RDO® PRO-X
RDO® TITAN,
ConTROLL® PRO
Aqua ***TROLL***® 400, 600
(Instruments developed with System Spec 3)

Contents

Revision History

Date	Revision	Description
08/09/2005	Draft	Initial draft
08/29/2005	000	Initial release
09/29/2005	1.0	Added DB-9 pin out (Appendix D)
01/30/2006	2.0	Added section numbers, added Level TROLL 300 device ID, added RS485 Network Guidelines
3/16/2006	3.0	Added Revision History, added Level TROLL 300 & BaroTROLL fast sampling to device register table
4/3/2006	4.0	Added Modbus Tutorial
11/16/2006	5.0	Updated for the Aqua TROLL 200
8/25/2008	5.1	Updated for the LevelTROLL 100
10/8/2008	5.2	Corrected RDO partial pressure parameter id. Added Aqua TROLL 100. Added Level TROLL 200.
11/05/2008	5.3	Added unit conversions for pressure
06/17/2009	5.4	Added sensor connection registers, SIS3 logging and analog configuration registers, ConTROLL PRO
10/16/2009	5.5	Added clarification for register map designation 4XXXX
05/07/2010	5.6	Updated for Rugged TROLL product line
02/15/2011	5.7	Updated Slave-Id format to include device address.
01/03/2011	5.8	Updated for RDO TITAN.
09/10/2013	5.9	Updated for RDO PRO-X
07/02/2015	5.10	Updated Data Quality IDs, common registers 0005 and 0008 to show the differences between Sys. 1 and Sys 3 instruments. Removed references to obsolete products.

1 Introduction

The In-Situ Rugged TROLL 200 and Rugged BaroTROLL support Modbus with their direct connect cable accessory. All other instruments referenced in this document support Modbus as their primary communication protocol.

Section 2 of this document is an In-Situ generated Modbus protocol tutorial intended to accelerate the learning curve for someone new to the protocol.

The remaining sections of this document provide the information required to program a PLC/DCS and/or SCADA system to poll data from an In-Situ Modbus device. The user is expected to have a working knowledge of Modbus (or refer to Section 2 below).

This document is not an official protocol document. More information about Modbus, including protocol specifications, can be downloaded from www.modbus.org.

2 Modbus Tutorial

2.1 Modbus Description

Modbus is a lightweight communication protocol developed in the late 1970's by Modicon as a digital communication protocol for its PLC's. The protocol requires very little code space and processing power to implement and has become a worldwide favorite for embedded devices. Modbus is royalty free and the specifications and standards can be downloaded from the web.

Modbus is a transport protocol. What this means is that Modbus does not have any protocol features that indicate what types of data are being transported in a message packet. This is similar to TCP/IP, the internet protocol standard. If we use TCP/IP as an example, consider that when a person connects to a web site, the primary data content being moved via TCP/IP is HTML. When a person downloads an instrument manual from an FTP site, typically the data content being moved is an Adobe PDF file. In both cases, TCP/IP is used as the protocol. The TCP/IP protocol simply ensures all the bytes (whatever they represent) are transferred from point A to point B correctly. Modbus is similar in concept. It provides a transport mechanism to move data safely over a communication link from a device to a computer.

Modbus can be used on a wide variety of communication links. In most applications, the protocol is used over an RS485 or RS232 link. This is because these types of communication links are inexpensive and efficient, perfectly suited for communication with embedded devices. Modbus can also be used over wireless radios, satellites, TCP/IP (Ethernet, token ring, etc.) and any other protocol-independent communication link.

Modbus is designed to be a Master/Slave protocol. This means that the protocol assumes that a single Master computer will initiate control and commands to the slave devices. The slave devices do not send any data on the communication link unless specifically asked for that data by the Master. This is very different from a typical computer network like Ethernet which is peer-to-peer. In a peer-to-peer network, any device can communicate with any other device. A peer-to-peer network requires that network arbitration takes place so that there is only one device transmitting a message at a time. This requires more costly hardware usually not available in a small device network.

2.2 Modbus Modes

Modbus message packets can be formatted in three ways, RTU, ASCII and IP.

- RTU is the format of choice for hard connected **serial** connections such as RS485 or RS232 because it is the most compact and therefore the most efficient.
- ASCII format is required for any kind of wireless **serial** communications because it eliminates the message timing requirements needed for RTU mode. Message timing can be erratic over a wireless link.
- IP formatted messages can be used when the messages are transported using a secondary transport protocol such as TCP/IP. In this case the secondary transport protocol ensures that all of the packet bytes are transported correctly. Additionally, this format provides for packet sequence numbering because the secondary transport layer eliminates the synchronous Master/Slave nature of the serial RTU/ASCII formats.

In-Situ devices support RTU and ASCII modes.

2.3 Protocol Overview

Modbus provides message structures to read and write data to/from a device. The protocol also provides for the extension of the protocol to permit customization of the message structures. In-Situ adheres to the standard read/write message structures in its implementations. Modbus does not provide as part of the standard, a suitable file transfer message structure. For this function, In-Situ has used a protocol extension to satisfy the downloading of data files from In-Situ devices.

General Message Formats

The general message format consists of a device address, a function code, a data payload and a message validity checksum. For each of the 3 modes (RTU, ASCII and IP), the message format changes as described below.

2.3.1.1 RTU Message Format

The RTU message format allows the transmission of bytes of data encompassing the full range of values per byte 0-255. There are no start or ending characters to indicate the beginning or end of the packet. The end of packet is signaled by a time delay equivalent to a 3 byte transfer time on the communication link without any data transmitted.

Computer (Master) Message Format:

Device Address	Function Code	Data Payload	CRC

- Device Address: 1 byte field with a value ranging from 1 to 247. Broadcast address is 0.
- Function Code: 1 byte field with a value range 1-127 representing the standard or extended function code. The function code tells the device what operation is to take place (i.e. Read/Write).
- Data Payload: 0-N bytes with information required to complete the requested function code operation.
- CRC: 2 bytes with a value computed mathematically from the message bytes. This value can be computed on both sides of the link and verified to ensure that the bits of the message were transmitted and received correctly.

Device (Slave) Response Format:

Device Address	Function Code	Data Payload	CRC

- Device Address: Echo of device address sent in the message to the device. A broadcast message will not generate a response.
- Function Code: Echo of the function code sent to the device in the message packet. If an error occurs, the top bit of the byte is set and the data payload is the 1 byte error code from the device.
- Data Payload: 0-N bytes with response data from the device. For an error response, the payload will be a 1 byte value 1-255.
- CRC: 2 bytes with a value computed mathematically from the message bytes. This value can be computed on both sides of the link and verified to ensure that the bits of the message were transmitted and received correctly.

2.3.1.2 ASCII Message Format

The ASCII formatted message is for the most part identical in content to the RTU formatted message with the addition of the Start Of Packet (SOP) and End Of Packet (EOP) characters. The SOP character is a ‘:’ and the EOP is the combination carriage return <CR> (0x0D) followed by a linefeed <LF> (0x0A).

The contents of the packet are converted to 2 byte hex characters 0-9 and A-F. For example, the 1 byte device address 25 would be two bytes 0x3235 where 0x32 is the ASCII character ‘2’ and 0x35 is the ASCII character ‘5’. This ensures that the message contents never contain SOP or EOP characters.

The check value uses a different mathematical algorithm and is called an LRC.

Computer (Master) Message Format:

Start Packet	Device Address	Function Code	Data Payload	LRC	End Packet

- Start Packet: the ‘:’ character signals the start of an ASCII packet.

- Device Address: 2 byte field containing the device address 1-247 in hex characters.
- Function Code: 2 byte field with a value range 1-127 representing the standard or extended function code in hex characters.
- Data Payload: 0-N bytes with information required to complete the requested function code operation. Each data byte is represented in its two byte hex character format.
- LRC: 2 bytes represented in hex characters with a value computed mathematically from the message bytes. This value can be computed on both sides of the link and verified to ensure that the bits of the message were transmitted and received correctly.
- End Packet: the <CR><LF> characters.

Device (Slave) Response Format:

Start Packet	Device Address	Function Code	Data Payload	LRC	End Packet

- Start Packet: the ':' character signals the start of an ASCII packet.
- Device Address: 2 byte field containing the device address 1-247 in hex characters.
- Function Code: 2 byte field with a value range 1-127 representing the standard or extended function code in hex characters.
- Data Payload: 0-N bytes with response data from the device in hex characters. For an error response, the payload will be a 1 byte value 1-255.
- LRC: 2 bytes represented in hex characters with a value computed mathematically from the message bytes. This value can be computed on both sides of the link and verified to ensure that the bits of the message were transmitted and received correctly.
- End Packet: the <CR><LF> characters.

2.3.1.3 IP Message Format

The IP message format is based on the RTU format but eliminates the CRC because TCP/IP will ensure that the message bytes are transmitted correctly. In-Situ devices do not support this message format.

Additionally, TCP/IP is an asynchronous protocol. The significance is that the device must send its response to the address of the sender (computer). This differs from the serial RTU and ASCII formats where the protocol assumes only a single master device (computer) which does not have an address. For this reason, the IP format has a different header than the RTU serial formatted message.

Computer (Master) Message Format:

Xac Id	Protocol Id	Msg Length	Device Address	Function Code	Data Payload

- Xac Id: 2 byte transaction id to provide for asynchronous messages.
- Protocol Id: 2 byte field – always 0.
- Length: 2 byte field represents number of bytes following.
- Device Address: 1 byte field with a value ranging from 1 to 247. Broadcast address is 0.
- Data Payload: 0-N bytes with information required to complete the requested function code operation.

Device (Slave) Response Format:

Xac Id	Protocol Id	Msg Length	Device Address	Function Code	Data Payload

- Xac Id: transaction id echoed from message.
- Protocol Id: 2 byte field – always 0.
- Length: 2 byte field represents number of bytes following.
- Device Address: Echoed from message. No response for broadcast.
- Data Payload: 0-N bytes with information required to complete the requested function code operation.

Data Addresses (Registers)

As shown in the section pertaining to message formats, the function code from the Master's message tells the Slave device what operation to perform. There are a number of standard function codes defined by Modbus. These functions typically operate on atomic chunks of data historically and generically called registers. A register is quite simply a data address. A Modbus device will always have a published "Register Map" that defines the numerical addresses of data values that can be accessed in the device.

Note: Register Maps typically use 1-based numbering system whereas the protocol requires that the data address/register number passed to a device to be 0-based. In this document, the register maps are 1-based.

Data addresses are associated with two atomic sizes of memory, 1 bit and 2 bytes (word). These are divided into Read-Only Bits, Read/Write Bits, Read-Only Words and Read/Write Words each with their own associated name as follows:

- **Discretes:** Read Only Bits
- **Coils:** Read/Write Bits
- **Input Register:** Read Only Word
- **Holding Register:** Read/Write Word

All In-Situ Registers are Holding Registers.

Function Codes

Function codes in a message packet tell the device what operation to perform. The function code is always in the byte following the device address. Some of the standard function codes are as follows:

01: Read Coil
02: Read Discrete
03: Read Holding Registers
04: Read Input Registers
05: Write Coil
06: Write single Holding Register
15: Write multiple Coils
16: Write multiple Holding Registers
17: Read slave device id
22: Mask write Holding Register

The slave id is an implementation defined response that will vary with manufacturer and/or device.

Function codes from 65 to 72 and 100 to 110 can be used as custom function codes.

Standard Message Formats

In-Situ has implemented a sub-set of the standard function codes in every Modbus product. These message formats are defined in this section.

2.3.1.4 Read Holding Registers

This command reads one or more registers from a device.

Message (8 bytes):			**Response (5 + N bytes):**		
Address	1 Byte	1-247	Address	1 Byte	1-247
Function Code	1 Byte	0x03	Function Code	1 Byte	0x03
Data Address	2 Bytes	0 to 0xFFFF	Byte Count	1 Byte	0 to 0xFA
Register Count	2 Bytes	0 to 0x7D	Data Payload	N Bytes	
CRC	2 Bytes		CRC	2 Bytes	

- Where Byte Count is the #bytes in the Data Payload (does not include CRC bytes). Byte Count = 2 * Register Count.

2.3.1.5 Write Holding Register

This command sets a **single** register in a device.

Message (8 bytes):			**Response (8 bytes – message echo):**		
Address	1 Byte	1-247	Address	1 Byte	1-247
Function Code	1 Byte	0x06	Function Code	1 Byte	0x06
Data Address	2 Bytes	0 to 0xFFFF	Data Address	2 Bytes	0 to 0xFFFF
Data Payload	2 Bytes	0 to 0xFFFF	Data Payload	2 Bytes	0 to 0xFFFF
CRC	2 Bytes		CRC	2 Bytes	

2.3.1.6 Write Holding Registers

This command sets one or more registers in a device.

Message (9 + N bytes):			Response (8 bytes):		
Address	1 Byte	1-247	Address	1 Byte	1-247
Function Code	1 Byte	0x10	Function Code	1 Byte	0x10
Data Address	2 Bytes	0 to 0xFFFF	Data Address	2 Bytes	0 to 0xFFFF
Register Count	2 Bytes	1 to 0x7B	Register Count	2 Bytes	0 to 0x78
Byte Count	1 Byte	2 to 0xF0	CRC	2 Bytes	
Data Payload	N Bytes				
CRC	2 Bytes				

- Where Byte Count is the #bytes in the Data Payload (does not include CRC bytes). Byte Count = 2*Register Count.
- The register count is limited to a single data format field. If an attempt is made to write a data field with an incorrect register count, the device will return a Modbus exception response with error code 0x80.

2.3.1.7 Mask Write Register

This command will set and/or clear one or more bits in a single register.

Message :			Response:		
Address	1 Byte	1-247	Address	1 Byte	1-247
Function Code	1 Byte	0x16	Function Code	1 Byte	0x16
Data Address	2 Bytes	0 to 0xFFFF	Data Address	2 Bytes	0 to 0xFFFF
And_Mask	2 Bytes	0 to 0xFFFF	And_Mask	2 Bytes	0 to 0xFFFF
Or_Mask	2 Bytes	0 to 0xFFFF	Or_Mask	2 Bytes	0 to 0xFFFF
CRC	2 Bytes		CRC	2 Bytes	

Register = (Register Value AND And_Mask) OR (Or_Mask AND (NOT And_Mask))
And_Mask: 0 = bits to change, 1 = bits to leave unchanged.
Or_Mask: 0 = bits to clear, 1 = bits to set.

Example: - set bit 1 (LSB), clear bit 2, leave remaining bits unchanged

Old Value:	0x007E	0000 0000 0111 1110
And_Mask:	0xFFFC	1111 1111 1111 1100
Or_Mask:	0x0001	0000 0000 0000 0001
New Value:	0x007D	0000 0000 0111 1101

This command is useful in a bit mapped register where the Master wants to set some bits of a register that are mapped to a feature without disturbing the other bits of the register that might be mapped to a different feature.

2.3.1.8 Report Slave Id

This command query's a device for id information.

Message (4 bytes):			**Response (N bytes):**		
Address	1 Byte	1-247	Address	1 Byte	1-247
Function Code	1 Byte	0x11	Function Code	1 Byte	0x11
CRC	2 Bytes		Byte Count	1 Byte	0 to 0xFF
			Slave Id	1 Byte	0 to 0xFF
			Run Status	1 Byte	0 to 0xFF
			Data Payload	N Bytes	
			CRC	2 Bytes	

- The Data Payload layout is defined in the Slave Id Format section.
- The Byte Count field is the number of bytes from the Slave Id field to the end of the Data Payload (excludes the 2 byte CRC).
- Run Status – must be 0x00 or 0xFF.

In-Situ Slave Id Layout Example

Byte Offset	Field Description	Type	Value
0	Device Address	byte	1-247
1	Function Code	byte	0x11
2	Byte Count	byte	23
3	Slave Id	byte	0x49 ('I')
4	Run Status Indicator	byte	0x00 = Off, 0xFF = On
	Device Specific Info		
5	Slave Id Format Version Id	byte	0x01
	Format Version 1 Id Block		
6-7	Manufacturer Id	ushort	0x5349 ('SI')
8-9	Device Id	ushort	
10-11	Application Firmware Version	ushort	Version * 100
12-13	Boot Code Firmware Version	ushort	Version * 100
14-15	Hardware Version	ushort	
16-17	Register Map Template Id	ushort	
18-21	Device Serial Number	ulong	
22-23	Max Message/Response Size (bytes)	ushort	
24-25	Max Baud Rate Id	ushort	
26-27	CRC		

The specific field values such as device id, baud id…etc are documented in the sections that follow.

3 In-Situ Data Types

Modbus defines all I/O in terms of 2 byte blocks called registers. Modbus does not formally define blocks for floating point values or strings. In the In-Situ implementation, these fundamental types and others are handled by combining two or more registers. The In-Situ data type implementations are defined in the following sections.

3.1 Short

A 2 byte signed integer contained in a single register data address. IEEE standard.

MSB	SXXX XXXX	XXXX XXXX	LSB
	Byte 0	Byte 1	

where 'S' = sign bit.

3.2 Unsigned Short

A 2 byte unsigned integer contained in a single register data address. IEEE standard.

MSB	XXXX XXXX	XXXX XXXX	LSB
	Byte 0	Byte 1	

3.3 Long

A 4 byte signed integer contained in two register data address's. IEEE standard.

MSB	SXXX XXXX	XXXX XXXX	XXXX XXXX	XXXX XXXX	LSB
	Byte 0	Byte 1	Byte 2	Byte 3	

where 'S' = sign bit.

3.4 Unsigned Long

A 4 byte unsigned integer contained in two register data address's. IEEE standard.

MSB	XXXX XXXX	XXXX XXXX	XXXX XXXX	XXXX XXXX	LSB
	Byte 0	Byte 1	Byte 2	Byte 3	

3.5 Float

IEEE 4 byte numeric standard – 1 sign bit, 8-bit exponent, 23-bit mantissa.

MSB	SXXX XXXX	XMMM MMMM	MMMM MMMM	MMMM MMMM	LSB
	Byte 0	Byte 1	Byte 2	Byte 3	

where 'S' = sign bit, 'X' = exponent bits and 'M' = mantissa bits.

3.6 Double

IEEE 8 byte numeric standard – 1 sign bit, 11-bit exponent, 64-bit mantissa.

MSB	SXXX XXXX	XXXX MMMM	MMMM MMMM	…	MMMM MMMM	LSB
	Byte 0	Byte 1	Byte 2		Byte 7	

where 'S' = sign bit, 'X' = exponent bits and 'M' = mantissa bits.

3.7 Character

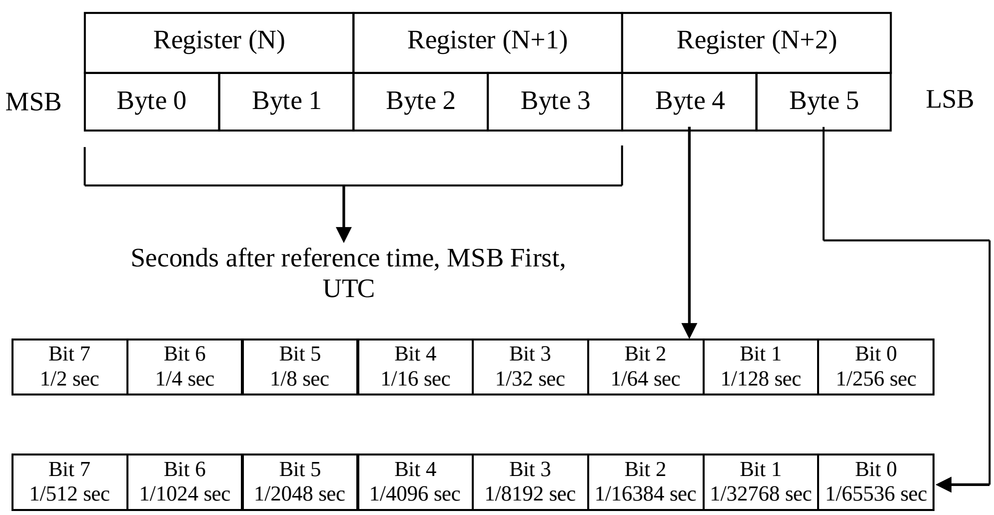
A 2 byte Unicode character contained with a single register data address.

3.8 String

The number of consecutive registers in the register map will represent the maximum string length in Unicode characters excluding any termination characters. For example, a 6 register string can have 6 Unicode characters. When reading/writing a string, all register values must be transmitted. If the string to be written does not require the full defined field length, the extra bytes must be padded with the value 0x0000 to reach full length. A string termination character is not required, all registers may contain a character. Failure of the Master device to transmit or request all registers of a string field will be rejected by the Slave device with the Modbus exception error code 0x80.

3.9 Time

Represented by a 6 byte (3 register) number. The first 4 bytes represent the number of seconds since 00:00:00 January 1, 1970 UTC, MSB first, not adjusted for DST. The 5th and 6th bytes are fractions of a second represented by the bits in powers of 2 starting with the MSB. If a device does not have the ability to support the full fractions of a second resolution available in the time format, unused bits must be set to 0.



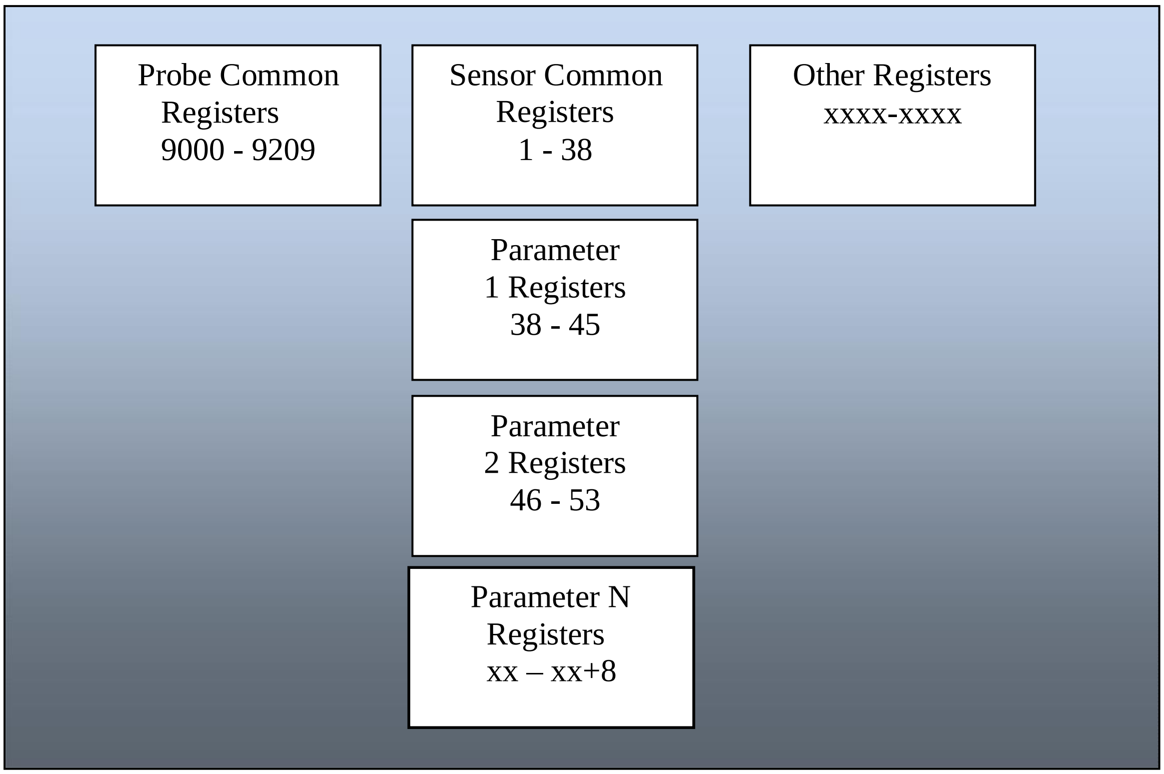
Time Example: For a time value of 0x001A5E00C000, the bytes 0x001A5E00 represent the whole number of seconds from the reference time. The bytes 0xC000 represent the additional fractional number of seconds as shown in the diagram above. In this example, the whole number of seconds represents 20 days and the fractional seconds represents 750ms.

4 Exception Codes

In-Situ supports the standard modbus exception codes but also provides additional exception codes to assist with troubleshooting problems. The exception codes are listed in Appendix A.

5 Probe Register Map Layout

Each probe and sensor will follow a common layout pattern which provides consistency and improves code reuse between platforms. **All In-Situ registers are Holding Registers**. The common probe register map layout is as follows:



All registers in this document are 1-based. This means the actual packets sent to the devices must have a data address 1 less than what the register number is in this document.

6 Probe Common Registers

The new In-Situ communication system implemented by the Level TROLL and BaroTROLL provides for a set of data fields that are to be at the same register address for all devices. These common holding registers are defined in the table below:

Common Register Map

Register XXXX	Size (registers)	Mode (R/W)	Data Type	Description
9000	1	R	ushort	Register Map Template Version (SIS Level)
9001	1	R/W	ushort	Device Id
9002-003	2	R/W	ulong	Device Serial Number
9004-006	3	R/W	time	Manufacture Date
9007	1	R	ushort	Firmware version * 100
9008	1	R	ushort	Boot Code version * 100
9009	1	R	ushort	Hardware version
9010	1	R	ushort	Max Data Logs
9011-012	2	R	ulong	Total Data Log Memory (bytes)
9013-014	2	R	ulong	Total Battery Ticks
9015-017	3	R/W	time	Last Battery Change
9018	1			Reserved
9019-050	32	R/W	string	Device Name
9051-082	32	R/W	string	Site Name
9083-086	4	R/W	double	Latitude Coordinate (degrees) (negative = east)
9087-090	4	R/W	double	Longitude Coordinate (degrees) (negative = south)
9091-094	4	R/W	double	Altitude Coordinate (meters)
9095-096	2			Reserved
9097-099	3	R/W	time	Current time (UTC)
9100-101	2	R	32 bits	Device Status
9102-103	2	R/W	ulong	Used Battery Ticks
9104-105	2	R	ulong	Used Data Log Memory (bytes)

Communication Control Registers

Register XXXX	Size (registers)	Mode (R/W)	Data Type	Description
9200	1	R/W	ushort	Device Address (1-247, default = 1)
9201	1	R/W	ushort	Serial Communication Configuration
9202	1	R/W	ushort	EOM timeout (1000-15000 ms, default = 1000)
9203	1	R/W	ushort	EOS timeout (5000-60000 ms, default = 5000)
9204	1	R	ushort	Max allowed baud rate id (0-7)
9205	1	R	ushort	Max Message/Response size (bytes)
9206-207	2	R/W	ulong	Good message counter
9208	1	R/W	ushort	Bad message counter
9209	1	R/W	ushort	Exception response counter

Probe Connection Registers

Register XXXX	Size (registers)	Mode (R/W)	Data Type	Description
9297	1	R1	ushort	Max Probe Connections (1-32)
9298-299	2	R1	32 bits	Probe Connection Status

Sensor Connection Registers

Register XXXX	Size (registers)	Mode (R/W)	Data Type	Description
9300	1	R1	ushort	Max Sensor Connections (1-32)
9301-302	2	R1	32 bits	Sensor Connection Status
Sensor Map Registers				
9303	1	R1	ushort	Connection 1 sensor id
9304	1	R1	16 bits	Connection 1 sensor status
9305	1	R1/W2	ushort	Connection 1 sensor command
9306	1	R1	ushort	Connection 1 sensor data register map version
9307	1	R1	ushort	Connection 1 sensor data register offset
9308-462	5 x 31			Connections 2-32 patterned after connection 1
9463	1	R1/W3	ushort	Sensor Data Cache Timeout (0-60000 msec)

Current Loop Configuration Registers (Register Map Version 3+)

Register XXXX	Size (registers)	Mode (R/W)	Data Type	Description
9501	1	R1/W3	ushort	Current loop sensor number
9502	1	R1/W3	ushort	Current loop parameter number
9503-504	2	R1/W3	float	Current loop 20 mA setpoint (I_{20})
9505-506	2	R1/W3	float	Current loop 4 mA setpoint (I_4)
9507	1	R1/W3	ushort	Current loop enable (0 = off, 1 = on)

Logged Record Registers (Register Map Version 3+)

Register XXXX	Size (registers)	Mode (R/W)	Data Type	Description
9600-601	2	R1	ulong	Number of logged records
9602-603	2	R1/W3	ulong	Requested log record number
9604-606	3	R1	time	Time stamp for record
9607-608	2	R1	float	Parameter 1 measured value
9609	1	R1	ushort	Parameter 1 data quality id
96010-696	29 x 3	R1	---	Parameters 2 – 30 (30 is max allowed #log parameters)

6.1 Register Map Template Id

This is a number that represents the version of the reserved register map supported by the device. This provides for the modification of the reserved register map at a future date and detection of this difference by the Master. This register is commonly referred to as the System Interface Specification Level or (SIS Level).

6.2 Device Id

This is the id number for the device. Each device in the system will receive a unique id number. See Appendix B for device ids.

6.3 Device Serial Number

This is a 6 digit serial number for the device. Serial numbers for devices in this system will range from 000001 to 999999.

6.4 Manufacture Date

This is the date and time of manufacture in the In-Situ time format.

6.5 Firmware, Boot Code, Hardware Versions

The firmware and boot code versions will be the floating point version multiplied by 100 to create an integer. For example, version 1.32 will be stored as 132. The hardware version will be a non-scaled integer that represents the circuit board version. The hardware version will be calculated by the firmware based on parameters determined from the circuit board components.

6.6 Max Data Logs

This register indicates the maximum number of data logs that can be stored in the device. If data logs are not supported by the device, this register will be zero.

6.7 Total Data Log Memory

This represents the total amount of data log memory in bytes.

6.8 Total Battery Ticks

This represents the total battery capacity in “ticks”. A tick represents approximately 1 microamp-hour. For more see section below on Battery Status.

6.9 Last Battery Change

This represents the date and time of the last internal battery change. For Level TROLL and BaroTROLL products, the internal battery is sealed and cannot be replaced. For these products, this value will not change after manufacture.

6.10 Device Name

This is a general-purpose 32 character string representing a user-defined device name or identifier.

- If an attempt is made to change the device name while logging, the device will return an exception response with error code 0xA0 (Illegal write with running log).

6.11 Site Name

This is a 32 character string that represents the location where the instrument is recording data.

- If an attempt is made to change the site while logging, the device will return an exception response with error code 0xA0 (Illegal write with running log).

6.12 Coordinates

These registers are used by the computer to store the coordinates of a device when taking measurements. The device expects coordinates in meters and degrees.

- A negative latitude value represents south, a negative longitude value represents east.
- If an attempt is made to change the coordinates while logging, the device will return an exception response with error code 0xA0 (Illegal write with running log).

6.13 Current Time

This represents the time in the device in UTC.

6.14 Device Status

The device status register holds general status information. Each set bit represents a status value. There are a limited number of standardized predefined status values that all devices will support. These predefined status values are contained in the lower register. The upper register is reserved for device specific status values.

Device Status Bit Values

Bit	Category	Description
0	Alarm	Sensor high alarm
1	Warning	Sensor high warning
2	Warning	Sensor low warning
3	Alarm	Sensor low alarm
4	Warning	Sensor calibration warning
5	Alarm	Sensor malfunction
6-7	N/A	Reserved
8	Status	Power management disabled.
9	Status	Device off line
10	Alarm	Device hardware reset occurred
11	Alarm	Device malfunction
12	Status	No external power.
13	Warning	Low battery – battery capacity < 5%
14	Warning	Low memory – data log memory capacity < 5%
15	N/A	Reserved
16-31	N/A	Available for device-specific status

Bits 0-7 of the device status register are reserved for sensor status. These bits are the logical OR of bits 0-7 of the sensor status register in each sensor connection.

Bits 8-15 of the device status register are reserved for common device status. Any bit in this range that is not applicable to a device will be set to zero.

Bits 16-31 of the device status register are available for device-specific status. Any bit in this range that is not utilized by a device will be set to zero.

6.15 Used Battery Ticks

This represents the approximate number of microamp-hours that have been used by the device.

6.16 Serial Communication Configuration

The 16 bits in this register are mapped to the communication parameters. The bits are mapped as follows:

Bits	Description
0	Modbus Transmission Mode 0 = RTU (default) 1=ASCII
1,2 & 3	Baud Rate Id 0 = 9600 (mandatory) 1 = 19200 (default) 2 = 38400 3 = 57600 4 = 115200 5 = 128000 6 = 230400 7 = 256000
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
8-15	Unassigned

When the communication configuration register is changed, the Modbus response will be sent to the Master at the current configuration (mode, baud, parity, data bits…etc). After the response has been sent to the Master, the device will switch to the new settings.

The Master software must switch communications to the new settings **after** receiving a positive Modbus response to the write message. The Master software should confirm the new settings by reading back the device address and communication configuration register.

Baud Rates

All devices will support 9600 and 19200 baud rates. A device will support all baud rates from 9600 up to and including the maximum baud rate as specified by the Max Baud Rate Id register.

- If the Master attempts to set the baud rate of a device to a non-supported value, the device will respond with a Modbus exception error code 3 (Illegal Data Value).
- Baud rates will be referenced in this document by the id 0-7.
- The Level TROLL and BaroTROLL support baud rates up to 3 (57600).

RTU Settings

Every device supporting serial communications will implement Modbus RTU. The device will at a minimum support the standard settings defined below.

- 1 Start Bit
- 8 Data Bits
- 1 Parity Bit
- 1 Stop Bit
- Even Parity

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 (Write Illegal Value).

ASCII Settings

When implementing Modbus ASCII, the device will at a minimum support the standard settings defined below.

- 1 Start Bit
- 7 Data Bits
- 1 Parity Bit
- 1 Stop Bit
- Even Parity

6.17 Max Message/Response Size

This register indicates to the Master the largest message or response the device can accept. This may vary based on the hardware configuration of the device.

6.18 Message Counters

The message counter registers are to provide diagnostic information for troubleshooting communication problems. The counters will not roll over and can only be cleared using Win-Situ.

There are 3 message counter registers allocated as follows:

- Good Message Counter – count of number of properly formatted messages received that are addressed to this device
- Bad Message Counter – count of number of improperly formatted messages received (i.e. bad CRC). Bad messages might not be associated with this device because it is impossible to determine if a bad message was addressed to the device or not.
- Exception Response Counter – count of the number of messages received that were rejected with a Modbus exception response.

6.19 Probe Connection Registers

Max Probe Connections

Each controller can have attached to it up to 32 probes. For the attached probes, the controller acts as a gateway, passing thru messages to the connected probes. The controller maps unique addresses to each connected probe starting at the next higher modbus address than the controller (if controller is at address 5, first probe is at address 6). Messages sent to the controller for a probe will be remapped to the protocol and address of the attached probe. Responses from a probe to the Modbus master are protocol and address converted before being sent back to the master.

Probe Connection Status

Each bit when set indicates that the controller is actively connected to a probe on the corresponding connection/port. The bit position 0-31 is used to determine the modbus device address offset (from the controller) of the attached probe. For example, if bit 5 is set and the controller is at address 5, then the probe on the 6^{th} port is at address 11.

Controller/Probe Addressing

Since controllers will map virtual device addresses to the connected probes, the controller's modbus address range must be less than the max 247 by the number of allowed probes. For example, if a controller supports two probes, the max allows address for the controller is 245 where address 246 is mapped to the first probe and address 247 is mapped to the second probe.

6.20 Sensor Connection Registers

Max Sensor Connections

Each probe or controller can present up to 32 sensor images to the outside world. These sensors may be real sensors plugged into physical ports, sensors on the internal PCB or it may be virtual sensors created from derived information. This register tells how many sensor images are being presented by the probe or controller at the time it is read.

Sensor Connection Status

Each bit when set indicates that the probe or controller is actively presenting a sensor image on the corresponding port. The bit position 0-31 is used to determine the sensor map register group to use to control the sensor or access its data block.

6.21 Sensor Map Registers

Sensor Id Registers

These registers duplicate the sensor id register provided in each sensor's Sensor Data Header Register block (refer to the Sensors section). If a sensor connection is open, the probe shall return a zero. If an attempt is made to access a sensor id register that is not mapped to a sensor (one that exceeds the maximum number of sensors supported by the probe), the probe will return an exception response with error code 0x02 (illegal data address).

Sensor Status Register

These registers duplicate the sensor status register provided in each sensor's Sensor Data Header Block (refer to the Sensors section). If a sensor connection is open, the probe shall return a zero. If an attempt is made to access a sensor status register that is not mapped to a sensor (one that exceeds the maximum number of sensors supported by the probe), the probe will return an exception response with error code 0x02 (illegal data address).

Sensor Command Register

These registers are used to send commands to a sensor. The behavior of the sensor command register and the commands available is different from SIS-1&2 and SIS-3. The sensor command register is primarily used to calibrate the sensor. Failure of the command is returned in the response exception.

If an attempt is made to access a sensor command register that is not mapped to a sensor (one that exceeds the maximum number of sensors supported by the probe), the probe will return an exception response with error code 0x02 (illegal data address).

Sensor Commands for SIS-3

Id	Name	Description
0xE000	Calibration Mode On	Put sensor in the calibration mode.
0xE001	Calibration Update	Commit new calibration to memory.
0xE002	Calibration Mode Off	Put sensor in the normal operating mode.
0xE003	Restore Cal Defaults	Restore factory default calibration for sensor only
0xE004	Restore sensor defaults	Restore factory defaults for calibration, parameters and units, sentinel values…etc for sensor only

Sensor Data Register Map Version Registers

These registers specify the version of the sensor data register map pointed to by the Sensor Data Register Offset registers. If a sensor connection is open, the probe shall return a zero. If an attempt is made to access a sensor map version register that is not mapped to a sensor (one that exceeds the maximum number of sensors supported by the probe), the probe will return an exception response with error code 0x02 (illegal data address).

Sensor Data Register Map Offsets

These registers specify the register number of the first register in each sensor's Sensor Data Header Block (refer to the Sensors section). These registers assume the 4x (holding register) reference id and therefore will not contain the reference id as part of the value (i.e. 40001 will be stored as 1).

If an attempt is made to access a sensor status register that is not mapped to a sensor (one that exceeds the maximum number of sensors supported by the probe), the probe will return an exception response with error code 0x02 (illegal data address).

If a sensor connection is open (the sensor is not plugged in or is not part of the current configuration) the probe shall return 0. This permits a valid block read of the mapped sensor status registers regardless of the current configuration of the probe and sensors.

If an attempt is made to access a sensor connection register that is not mapped to a sensor (one that exceeds the maximum number of sensors supported by the probe), the probe will return an exception response with error code 0x02 (illegal data address).

Sensor Data Cache Timeout (SIS-3 Only)

Sensors shall measure all of their parameters whenever a parameter value register is read. The parameters are recorded in a data cache and a cache timeout is started. If any subsequent parameter value from the sensor is read within the specified cache timeout, the device shall return the value recorded in the cache instead of making a new measurement. The default value of the cache timeout is device specific. If the cache timeout value is set to 0 milliseconds, each Modbus message to read one or more parameters will cause a new sensor reading to be taken. Logs running on a probe will also populate the data cache when a measurement is taken.

The end of session timeout supersedes the cache timeout – if an end of session timeout occurs, the cache for all sensors shall be cleared.

6.22 Current Loop Configuration (SIS-3 Only)

This set of registers applies to probes that support a single analog output such as the Level TROLL or Aqua TROLL. This feature is only available on SIS-3 and newer probes.

Current Loop Sensor Number
This is the sensor connection number 1-32 assigned to the analog output signal.

Current Loop Parameter Number
This is the parameter number 1-16 on the sensor that is assigned to the analog output signal.

Current Loop 20mA/4mA set point
These registers are used to assign the value that scales the analog output signal over a range of values.

Current Loop Enable
This register can be used to enable or disable the analog output.

Current Loop Calculations
The required 4-20 mA current loop output shall be calculated as follows:

$$I = 4 + 16(\text{Parameter} - I_4) / (I_{20} - I_4)$$

Where Parameter is the sensor parameter value determined by the Current Loop Sensor Number and Current Loop Parameter Number registers. The device shall not allow the Current Loop 20 mA Setpoint (I_{20}) and Current Loop 4 mA Setpoint (I_4) registers to be set equal to one another.

6.23 Logged Record Registers (SIS-3 Only)

This group of registers allows the Master to perform a single Read Registers command to obtain the last logged record data for the most recent or currently active log. If logging is not supported by the device, attempting to read these registers shall return a Modbus exception with error code 0x02 (invalid address).

Number of Logged Records

This represents the number of records in the active or most recent log file. If there are no log files on the device, this will be 0.

Requested Log Record Number

This value can be written to tell the device to retrieve a specific log record from the most recent log file. If the user writes a number greater than the value in the Number of Logged Records register, the device will return an exception code 0x03 (illegal data value).

Record Time Stamp

This represents the time and date of the current log record in the record cache.

Parameter Measured Value and Data Quality

Each group of 3 registers represents the logged value and its quality id. The quality ids are defined in Appendix F.

- Attempting to read a parameter register beyond the number of parameters specified in the active log configuration shall return a Modbus exception with error code 0x02.

- There are a maximum of 30 parameters allowed per log.

7 Sensor Common Registers

All sensors expose a common set of registers to support basic information and common settings such as alarming, calibration dates…etc. The sensor common register set precedes the device specific measurement holding registers and is always located in the same block as described in the following table:

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0001	1	R1	ushort	Sensor Id (see pressure sensor slot registers)
0002	2	R1	ulong	Sensor serial number
0004	1	R1	16 bits	Sensor status (see pressure sensor slot registers)
0005	3	R1	time	Last factory calibration (Level TROLL, Aqua TROLL 100, 200, BaroTROLL, Rugged TROLL, Rugged BaroTROLL) RDO cap start date/time (RDO PRO, RDO PRO-X, RDO Titan, Aqua TROLL 400, 600 ConTROLL PRO)
0008	3	R1	time	Next factory calibration; 0 = none required (Level TROLL, Aqua TROLL 100, 200, BaroTROLL, Rugged TROLL, Rugged BaroTROLL) RDO cap end of usable life date/time; 0 = cap missing (RDO PRO, RDO PRO-X, RDO Titan, Aqua TROLL 400, 600, ConTROLL PRO)
0011	3	R1	time	Last user calibration
0014	3	R1/W2	time	Next user calibration (0 = none required)
0017	1	R1	ushort	Warm-up time in milliseconds = 100
0018	1	R1	ushort	Fast sample rate in milliseconds Level TROLL 400 = 500 msec Level TROLL 500 = 500 msec Level TROLL 700 = 250 msec BaroTROLL 500 = 500 msec
0019	1	R1	ushort	Number of sensor parameters = 3
0020	1	R1/W3	ushort	Alarm and warning parameter number (1 – 3, default = 1)
0021	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
0022	2	R1/W3	float	High alarm set value (default = 0.0)
0024	2	R1/W3	float	High alarm clear value (default = 0.0)
0026	2	R1/W3	float	High warning set value (default = 0.0)
0028	2	R1/W3	float	High warning clear value (default = 0.0)
0030	2	R1/W3	float	Low warning clear value (default = 0.0)
0032	2	R1/W3	float	Low warning set value (default = 0.0)
0034	2	R1/W3	float	Low alarm clear value (default = 0.0)
0036	2	R1/W3	float	Low alarm set value (default = 0.0)
First Parameter Block				
0038	2	R1	float	Measured value
0040	1	R1	ushort	Parameter Id
0041	1	R1/W2	ushort	Units Id

0042	1	R1	ushort	Data Quality Id
0043	2	R1/W3	float	Off line sentinel value
0045	1	R1	16 bits	Available Units
Parameter Block 2-N				

7.1 Sensor Id Register

The devices can be factory-configured to a variety of full-scale pressure ranges in both gauge and absolute pressure formats. See Appendix C for Sensor Ids.

7.2 Sensor Status Register

Bits in this register signal the status of sensor operation. The lower 8 bits of each sensor status register represent a common set of status bits and are to be logically OR'ed together and placed in the lower 8 bits of the device status register.

Bit	Description
0	Sensor high alarm
1	Sensor high warning
2	Sensor low warning
3	Sensor low alarm
4	Sensor calibration warning
5	Sensor malfunction
6-7	Reserved for future standard OR'ed sensor status bits (always return 0)
8, 9	Sensor mode (00 = Disabled, 01 = Enabled, 10 = Enabled-Continuous, 11 = Cal-Continuous)
10-15	Reserved for sensor-specific status (always return 0)

7.3 Calibration Times

These represent the expiration dates of the calibrations of the sensor. Data collected after these dates will have its quality id marked as Out-Of-Calibration. If the calibration time is zero, it is ignored.

7.4 Warm-up Time

Time required to prepare a sensor for a measurement. Some sensors require a significant warm up and this needs to be accounted for when computing the best possible sample rate.

7.5 Fast Sample Rate

Fastest measurement rate of the sensor after warm-up has completed.

7.6 Alarm Parameter Number

This is the parameter number associated with the alarm setpoints. The value can be 1-3 for the Level TROLL.

7.7 Alarm Enable Bits

This register provides for the capability to enable and disable Hi/Lo alarms and warning values. The set points are defined in the registers following this one.

7.8 Alarm Set Points

Alarms and Warnings have trigger points called the "set value" and reset points called the "clear value".

- High clear set points cannot exceed their respective trigger set points (i.e., the High Alarm clear value cannot be larger than the High Alarm set point).
- Low clear set points cannot be lower than their respective trigger set points.
- No restrictions exist on the relationships between the high/low alarm/warning set points.

7.9 Parameter Blocks

After the sensor header register set, a series of one or more parameter blocks will contain the register set pertaining to each parameter. The parameter block fields are as follows:

Measured Value – the value of the sensor parameter in the units specified in the parameters Units Id register. The measured value might be cached for sensors that require a long cycle time for a measurement.

Parameter Id – the id that is associated with the measured parameter from Appendix A. This is not to be confused with the parameter number which represents the order of parameters within the sensor block. The ability to write to the Parameter Id register is device and parameter dependent.

Units Id – the id of the units used to represent the measured value. The entire range of available units for a parameter do not have to be supported by a sensor. The ability to write to the Units Id register is device and parameter dependent. If writing to the Units Id register is supported, the device will convert the values in the Sentinel Value register and Alarm Set Point registers (if the parameter is specified for alarm) to the specified units.

Data Quality Id – a value that contains additional information about the measured value. For example, if the sensor is out of calibration, the quality value will indicate that the measured value cannot be trusted. Quality ids are defined in Appendix C. Quality ids cannot be OR'd together. The Quality value will represent only one possible quality state.

Sentinel Value – if the sensor is offline (i.e. for maintenance or calibration purposes) the sensor will return the sentinel values for its parameters. These values can be defined by the user such that they can be recognized as illegal values for the customers application. The sentinel value allows the sensor and probe to continue to respond to requests for data from a PLC or SCADA system while the sensor is offline which helps eliminate numerous problems associated with reporting and alarming.

Available Units – Unit Ids are grouped in blocks of 16 with each block corresponding to a measurement type. Each bit in the Available Units register corresponds to a unit id, with bit 0 corresponding to the first unit id in the measurement block assigned to the Parameter Id (see Appendix B). For example, if the Parameter Id is 5 (Level), bit 0 corresponds to unit id 33 (mm) and bit 15 corresponds to unit id 48. Each bit that is set indicates that the corresponding unit id is available to be written to the parameter's Units Id register.

8 Level TROLL / BaroTROLL Registers

The device specific measurement holding registers are as follows:

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
Parameter # 1 - Pressure				
0038	2	R1	float	Measured value
0040	1	R1	ushort	Parameter Id = 2 (pressure)
0041	1	R1/W2	ushort	Units Id 17 = PSI (default) 19 = KPa 20 = bar 21 = mbar 22 = mmHg
0042	1	R1	ushort	Data Quality Id
0043	2	R1/W3	float	Off line sentinel value (default = 0.0)
0045	1	R1	16 bits	Available Units = 0x0005
Parameter # 2 - Temperature				
0046	2	R1	float	Measured value
0048	1	R1	ushort	Parameter Id = 1 (temperature)
0049	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
0050	1	R1	ushort	Data Quality Id
0051	2	R1/W3	float	Off line sentinel value (default = 0.0)
0053	1	R1	16 bits	Available Units = 0x0003
Parameter # 3 – Level (Level TROLL only)				
0054	2	R1	float	Measured value, L_m
0056	1	R1/W2	ushort	Parameter Id 3 = level, depth (default) 4 = level, top of casing 5 = level, elevation
0057	1	R1/W2	ushort	Units Id 33 = millimeters 34 = centimeters 35 = meters 37 = inches 38 = feet (default)
0058	1	R1	ushort	Data Quality Id
0059	2	R1/W3	float	Off line sentinel value (default = 0.0)
0061	1	R1	16 bits	Available Units = 0x0037

8.1 Pressure Units Id

This register can be changed only when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

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

8.2 Temperature Units Id

This register can be changed only when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

Temperature is factory calibrated in °C. Conversion to other units is as follows.

°F = 1.8 * °C + 32

8.3 Level Parameter Id

This register can be changed only when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

8.4 Level Units Id

This register can be changed only when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

Millimeters = 1000 * meters
Centimeters = 100 * meters
Inches = 39.37008 * meters
Feet = 3.280840 * meters

8.5 Sensor Calibration Registers

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

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description

0100	2	R1/W3	float	Specific Gravity (default = 1.0)
0102	2	R1/W3	float	Pressure Offset, P_o (default = 0.0)
0104	2	R1/W3	float	Level Reference, L_r (default = 0.0)
0106	2	R1/W3	Float	Pressure Reference (default = 0.0)

Specific Gravity

Pressures (PSI) are converted to level (meters) accounting for the specific gravity (SG) of the fluid according to the following equation. Values will be in the range 0.1 to 10.0 inclusive. This register can be changed only when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

$$L(P) = (P * 0.70307) / SG$$

Pressure Offset

The pressure offset is subtracted from the pressure reading (P) to correct for offset errors in the pressure sensor. This register can be changed only by using the WinSitu software or 3rd party software using the In-Situ Software Development Kit (SDK). The measured pressure is presented as:

$$P_m = P - P_o$$

Level Reference

This value is used to reference a level reading to an independently established value. Master software must ensure that the level value is written in the currently selected units. When this register is written, the device will measure and record the current pressure reading P_m as reference pressure P_r in the currently selected pressure units. This value will be converted to the appropriate units when the Level Units Id register is written. The following equations are used to calculate level based on the level parameter id selection.

Parameter Id	Description	Equation
3	Level, depth	$L_m = L(P_m)$
4	Level, top of casing	$L_m = L_r - L(P_m – P_r)$
5	Level, elevation	$L_m = L_r + L(P_m – P_r)$

8.6 Other Level TROLL Registers

Level TROLL 300, 500, 700 and BaroTROLL 500 only

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0108	1	R1	ushort	Probe Register Map Template Version (1)
0109	1	R1	ushort	External Power Voltage (millivolts)
0110	1	R1	ushort	Internal Battery Voltage (millivolts)
0111	2	R1	ulong	Total Measurements Counter
0113	2	R1	ulong	Battery Measurements Counter

Level TROLL/Rugged TROLL 200 and Rugged BaroTROLL only

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
7000	1	R1	ushort	Probe Register Map Template Version (1)
7002	1	R1	ushort	Internal Battery Voltage (millivolts)
7003	2	R1	ulong	Total Measurements Counter
7005	2	R1	ulong	Battery Measurements Counter
7007	1	R1/W3	ushort	Parameter buffer timeout (milliseconds), 0-5000, default = 1000

Total Measurements Counter

The device counts the total number of sensor measurements made. The count is incremented whenever a sensor measurement is made by reading a sensor parameter register, or when a sensor parameter is read for a data log.

Battery Measurements Counter

The device counts the number of sensor measurements made while operating from the internal battery. The count is incremented whenever a sensor measurement is made by reading a sensor parameter register, or when a sensor parameter is read for a data log. The count is not incremented if the device is operating from external power.

Analog Control Registers

Level TROLL 300, 400, 500 and 700 and BaroTROLL 500 only – there is no analog output on a Rugged TROLL 200 or Rugged BaroTROLL.

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0115	1	R1/W3	ushort	Current loop parameter number (1-3, default = 1)
0116	2	R1/W3	float	20 mA setpoint (I_{20}, default = full scale pressure)
0118	2	R1/W3	float	4 mA setpoint (I_4, default = 0)

9 Aqua TROLL 200 Registers

The device specific measurement registers for the Aqua TROLL 200 are as follows:

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
Parameter # 1 - Pressure				
0038	2	R1	float	Measured value
0040	1	R1	ushort	Parameter Id = 2 (pressure)
0041	1	R1/W2	ushort	Units Id 17 = PSI (default) 19 = KPa 20 = bar 21 = mbar 22 = mmHg
0042	1	R1	ushort	Data Quality Id
0043	2	R1/W3	float	Off line sentinel value (default = 0.0)
0045	1	R1	16 bits	Available Units = 0x0005
Parameter # 2 - Temperature				
0046	2	R1	float	Measured value
0048	1	R1	ushort	Parameter Id = 1 (temperature)
0049	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
0050	1	R1	ushort	Data Quality Id
0051	2	R1/W3	float	Off line sentinel value (default = 0.0)
0053	1	R1	16 bits	Available Units = 0x0003
Parameter # 3 – Level				
0054	2	R1	float	Measured value, L_m
0056	1	R1/W2	ushort	Parameter Id 3 = level, depth (default) 4 = level, top of casing 5 = level, elevation
0057	1	R1/W2	ushort	Units Id 33 = millimeters 34 = centimeters 35 = meters 37 = inches 38 = feet (default)
0058	1	R1	ushort	Data Quality Id
0059	2	R1/W3	float	Off line sentinel value (default = 0.0)
0061	1	R1	16 bits	Available Units = 0x0037

Parameter # 4 – Actual Conductivity				
0062	2	R1	float	Measured value, AC
0064	1	R1	ushort	Parameter Id = 9 (actual conductivity)
0065	1	R1/W2	ushort	Units Id 65 = microsiemens per centimeter (default) 66 = millisiemens per centimeter
0066	1	R1	ushort	Data Quality Id
0067	2	R1/W3	float	Off line sentinel value (default = 0.0)
0069	1	R1	16 bits	Available Units = 0x0003 (3)
Parameter # 5 – Specific Conductivity				
0070	2	R1	float	Measured value, SC
0072	1	R1	ushort	Parameter Id = 10 (specific conductivity)
0073	1	R1/W2	ushort	Units Id 65 = microsiemens per centimeter (default) 66 = millisiemens per centimeter
0074	1	R1	ushort	Data Quality Id
0075	2	R1/W3	float	Off line sentinel value (default = 0.0)
0077	1	R1	16 bits	Available Units = 0x0003 (3)
Parameter # 6 – Salinity				
0078	2	R1	float	Measured value, S
0080	1	R1	ushort	Parameter Id = 12 (salinity)
0081	1	R1/W2	ushort	Units Id 97 = Practical Salinity Units PSU (default)
0082	1	R1	ushort	Data Quality Id
0083	2	R1/W3	float	Off line sentinel value (default = 0.0)
0085	1	R1	16 bits	Available Units = 0x0001 (1)
Parameter # 7 – Total Dissolved Solids				
0086	2	R1	float	Measured value, TDS
0088	1	R1	ushort	Parameter Id = 13 (TDS)
0089	1	R1/W2	ushort	Units Id 113 = parts per million 114 = parts per thousand (default)
0090	1	R1	ushort	Data Quality Id
0091	2	R1/W3	float	Off line sentinel value (default = 0.0)
0093	1	R1	16 bits	Available Units = 0x0003 (3)
Parameter # 8 – Resistivity				
0094	2	R1	float	Measured value, R
0096	1	R1	ushort	Parameter Id = 11 (resistivity)
0097	1	R1/W2	ushort	Units Id 81 = ohm-cm (default)
0098	1	R1	ushort	Data Quality Id
0099	2	R1/W3	float	Off line sentinel value (default = 0.0)
0101	1	R1	16 bits	Available Units = 0x0001 (1)

Parameter # 9 – Density of Water				
0102	2	R1	float	Measured value, p
0104	1	R1	ushort	Parameter Id = 14 (density of water)
0105	1	R1/W2	ushort	Units Id 129 = g/cm^3 (default)
0106	1	R1	ushort	Data Quality Id
0107	2	R1/W3	float	Off line sentinel value (default = 0.0)
0109	1	R1	16 bits	Available Units = 0x0001 (1)

9.1 Pressure Units Id

This register can be changed only when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

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

KPa = 6.894757 * PSI

9.2 Temperature Units Id

This register can be changed only when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

Temperature is factory calibrated in °C. Conversion to other units is as follows.

°F = 1.8 * °C + 32

9.3 Level Parameter Id

This register can be changed only when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

9.4 Level Units Id

This register can be changed only when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

9.5 Sensor Calibration Registers

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

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0118	1	R1	ushort	Sensor data register map version
0119	1	R1	ushort	Sensor firmware version * 100
0120	2	R1/W3	float	Pressure Offset, P_o (default = 0.0)
0122	2	R1/W3	float	Specific Gravity (default = 1.0)
0124	2	R1/W3	float	Level Reference, L_r (default = 0.0)
0126	2	R1/W3	float	Pressure Reference, P_r (default = 0.0)
0128	2	R1/W3	float	Cell Offset, K_0 (default = 0.0)
0130	2	R1/W3	float	Cell Constant, K (default = 1.0)
0132	2	R1/W3	float	Reference Temperature, T_{ref} in °C (default = 25)
0134	2	R1/W3	float	Alpha Coefficient α_0 (default = 1.0)
0136	2	R1/W3	float	Alpha Coefficient α_1 (default = -0.0191)
0138	2	R1/W3	float	Alpha Coefficient α_2 (default = 0.0)
0140	2	R1/W3	float	Alpha Coefficient α_3 (default = 0.0)
0142	2	R1/W3	float	Alpha Coefficient α_4 (default = 0.0)
0144	2	R1/W3	float	Alpha Coefficient α_5 (default = 0.0)
0146	2	R1/W3	float	Alpha Coefficient α_6 (default = 0.0)
0148	2	R1/W3	float	Alpha Coefficient α_7 (default = 0.0)
0150	2	R1/W3	float	Beta Coefficient β (default = 1.0)
0152	2	R1/W3	float	TDS Conversion Factor CF_{TDS} in ppt (default = 0.65)
0154	2	R1/W3	float	Local gravity constant (pg) for density corrected level calculations (default = 0.0 for no correction)

Specific Gravity

Pressures (PSI) are converted to level (meters) accounting for the specific gravity (SG) of the fluid according to the following equation. Values will be in the range 0.1 to 10.0 inclusive. This register can be changed only when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0.

$$L(P) = (P * 0.70307) / SG$$

Pressure Offset

The pressure offset is subtracted from the pressure reading (P) to correct for offset errors in the pressure sensor. This register can be changed only by using the WinSitu software or 3rd party software using the In-Situ Software Development Kit (SDK). The measured pressure is presented as:

$$P_m = P - P_o$$

Level Reference

This value is used to reference a level reading to an independently established value. Master software must ensure that the level value is written in the currently selected units. When this register is written, the device will measure and record the current pressure reading P_m as reference pressure P_r in the currently selected pressure units. This value will be converted to the appropriate units when the Level Units Id register is written. The following equations are used to calculate level based on the level parameter id selection.

Parameter Id	Description	Equation
3	Level, depth	$L_m = L(P_m)$
4	Level, top of casing	$L_m = L_r - L(P_m - P_r)$
5	Level, elevation	$L_m = L_r + L(P_m - P_r)$

Cell Offset and Cell Constant

These values are used to calibrate conductivity to user standards. These registers can only be written when the sensor is in the cal-continuous mode. When either of these registers are written, the device will set the last user calibration time to the current time and set the next user calibration time to zero. 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.

Local Gravity Constant

If the local gravity constant is non-zero, pressures (PSI) are converted to level (meters) accounting for the measured fluid density (p) and the local gravity constant (pg) according to the following equation. Values for pg shall be in the range 0.9 to 1.1 inclusive. This register shall only be able to be written when the device is not logging. If an attempt is made to change this register while logging, the device will return an exception response with error code 0xA0. The value contained in the specific gravity register is ignored.

$$L(P) = (P * 0.70307) / (p * pg)$$

9.6 Other Aqua TROLL 200 Registers

Register XXXX	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	ulong	Total Measurements Counter
7005	2	R1	ulong	Battery Measurements Counter
7007	1	R1/W3	ushort	Parameter buffer timeout (milliseconds), 0-5000, default = 1750

Total Measurements Counter

The device counts the total number of sensor measurements made. The count is incremented whenever a sensor measurement is made by reading a sensor parameter register, or when a sensor parameter is read for a data log.

Battery Measurements Counter

The device counts the number of sensor measurements made while operating from the internal battery. The count is incremented whenever a sensor measurement is made by reading a sensor parameter register, or when a sensor parameter is read for a data log. The count is not incremented if the device is operating from external power.

Parameter Buffer Timeout

The device measures all parameters when a measured parameter value register is read, records the values in a parameter buffer, then starts the parameter buffer timer. If any parameter is read again within the specified buffer timeout, the device will return parameter values from the parameter buffer instead of making a new measurement.

Analog Control Registers

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
9501	1	R1/W3	ushort	Current loop sensor number (can only be 1)
9502	1	R1/W3	ushort	Current loop parameter number (1-N, default = 1)
9503	2	R1/W3	float	20 mA setpoint (I_{20}, default = 100)
9505	2	R1/W3	float	4 mA setpoint (I_4, default = 0)
9507	1	R1/W3	ushort	Current loop enable (0 = off, 1 = on, default = 0)

10 Aqua TROLL 100 Registers

The Aqua TROLL 100 does not support the pressure and level parameters. Its device specific measurement registers are arranged as follows:

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
Parameter # 1 – Actual Conductivity				
0038	2	R1	float	Measured value, AC
0040	1	R1	ushort	Parameter Id = 9 (actual conductivity)
0041	1	R1/W2	ushort	Units Id 65 = microsiemens per centimeter (default) 66 = millisiemens per centimeter
0042	1	R1	ushort	Data Quality Id
0043	2	R1/W3	float	Off line sentinel value (default = 0.0)
0045	1	R1	16 bits	Available Units = 0x0003 (3)
Parameter # 2 - Temperature				
0046	2	R1	float	Measured value
0048	1	R1	ushort	Parameter Id = 1 (temperature)
0049	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
0050	1	R1	ushort	Data Quality Id
0051	2	R1/W3	float	Off line sentinel value (default = 0.0)
0053	1	R1	16 bits	Available Units = 0x0003
Parameter # 3 – Specific Conductivity				
0054	2	R1	float	Measured value, SC
0056	1	R1	ushort	Parameter Id = 10 (specific conductivity)
0057	1	R1/W2	ushort	Units Id 65 = microsiemens per centimeter (default) 66 = millisiemens per centimeter
0058	1	R1	ushort	Data Quality Id
0059	2	R1/W3	float	Off line sentinel value (default = 0.0)
0061	1	R1	16 bits	Available Units = 0x0003 (3)

Parameter # 4 – Salinity				
0062	2	R1	float	Measured value, S
0064	1	R1	ushort	Parameter Id = 12 (salinity)
0065	1	R1/W2	ushort	Units Id 97 = Practical Salinity Units PSU (default)
0066	1	R1	ushort	Data Quality Id
0067	2	R1/W3	float	Off line sentinel value (default = 0.0)
0069	1	R1	16 bits	Available Units = 0x0001 (1)
Parameter # 5 – Total Dissolved Solids				
0070	2	R1	float	Measured value, TDS
0072	1	R1	ushort	Parameter Id = 13 (TDS)
0073	1	R1/W2	ushort	Units Id 113 = parts per million 114 = parts per thousand (default)
0074	1	R1	ushort	Data Quality Id
0075	2	R1/W3	float	Off line sentinel value (default = 0.0)
0077	1	R1	16 bits	Available Units = 0x0003 (3)
Parameter # 6 – Resistivity				
0078	2	R1	float	Measured value, R
0080	1	R1	ushort	Parameter Id = 11 (resistivity)
0081	1	R1/W2	ushort	Units Id 81 = ohm-cm (default)
0082	1	R1	ushort	Data Quality Id
0083	2	R1/W3	float	Off line sentinel value (default = 0.0)
0085	1	R1	16 bits	Available Units = 0x0001 (1)
Parameter # 7 – Density of Water				
0086	2	R1	float	Measured value, p
0088	1	R1	ushort	Parameter Id = 14 (density of water)
0089	1	R1/W2	ushort	Units Id 129 = g/cm^3 (default)
0090	1	R1	ushort	Data Quality Id
0091	2	R1/W3	float	Off line sentinel value (default = 0.0)
0093	1	R1	16 bits	Available Units = 0x0001 (1)

10.1 Sensor Calibration Registers

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

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0118	1	R1	ushort	Sensor data register map version
0119	1	R1	ushort	Sensor firmware version * 100
0128	2	R1/W3	float	Cell Offset, K_0 (default = 0.0)
0130	2	R1/W3	float	Cell Constant, K (default = 1.0)
0132	2	R1/W3	float	Reference Temperature, T_{ref} in °C (default = 25)
0134	2	R1/W3	float	Alpha Coefficient α (default = 0.0191)
0136	2	R1/W3	float	Beta Coefficient β_0 (default = 1.0)
0138	2	R1/W3	float	Beta Coefficient β_1 (default = 0.0)
0140	2	R1/W3	float	Beta Coefficient β_2 (default = 0.0)
0142	2	R1/W3	float	Beta Coefficient β_3 (default = 0.0)
0144	2	R1/W3	float	Beta Coefficient β_4 (default = 0.0)
0146	2	R1/W3	float	Beta Coefficient β_5 (default = 0.0)
0148	2	R1/W3	float	Beta Coefficient β_6 (default = 0.0)
0150	2	R1/W3	float	Beta Coefficient β_7 (default = 0.0)
0152	2	R1/W3	float	TDS Conversion Factor CF_{TDS} in ppt (software limited range 0.001 to 10.000, default = 0.65, resolution 0.001)

10.2 Other Aqua TROLL 100 Registers

Register XXXX	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	ulong	Total Measurements Counter
7005	2	R1	ulong	Battery Measurements Counter
7007	1	R1/W3	ushort	Parameter buffer timeout (milliseconds), 0-5000, default = 1750

Total Measurements Counter

The device shall count the total number of sensor measurements made. The count shall be incremented whenever a sensor measurement is made by reading a sensor parameter register, or when a sensor parameter is read for a data log.

Battery Measurements Counter

The device shall count the number of sensor measurements made while operating from the internal battery. The count shall be incremented whenever a sensor measurement is made by reading a sensor parameter register, or when a sensor parameter is read for a data log. The count shall not be incremented if the device is operating from external power.

Parameter Buffer Timeout

The device measures all parameters when a measured parameter value register is read, records the values in a parameter buffer, then starts the parameter buffer timer. If any parameter is read again within the specified buffer timeout, the device shall return parameter values from the parameter buffer instead of making a new measurement.

Analog Control Registers

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
9501	1	R1/W3	ushort	Current loop sensor number (can only be 1)
9502	1	R1/W3	ushort	Current loop parameter number (1-N, default = 1)
9503	2	R1/W3	float	20 mA setpoint (I_{20}, default = 100)
9505	2	R1/W3	float	4 mA setpoint (I_4, default = 0)
9507	1	R1/W3	ushort	Current loop enable (0 = off, 1 = on, default = 0)

11 Aqua TROLL 400 and 600 Registers

See the instrument manuals for device specific registers.

12 RDO PRO / RDO PRO-X / RDO TITAN Registers

The device specific measurement registers are as follows:

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
Dissolved Oxygen Concentration				
0038	2	R1	float	Measured value, C_0
0040	1	R1	ushort	Parameter Id = 20
0041	1	R1/W2	ushort	Units Id 117 = mg/L (default) 118 = µg/L
0042	1	R1	ushort	Data Quality Id (See Sensor Health Table in the instrument Operator's manuals)
0043	2	R1/W3	float	Off line sentinel value (default = 0.0)
0045	1	R1	16 bits	Available Units = 0x0030 (48)
Temperature				
0046	2	R1	float	Measured value
0048	1	R1	ushort	Parameter Id = 1
0049	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
0050	1	R1	ushort	Data Quality Id
0051	2	R1/W3	float	Off line sentinel value (default = 0.0)
0053	1	R1	16 bits	Available Units = 0x0003 (3)
Dissolved Oxygen %Saturation				
0054	2	R1	float	Measured value
0056	1	R1/W2	ushort	Parameter Id = 21
0057	1	R1/W2	ushort	Units Id 177 = percent saturation (default)
0058	1	R1	ushort	Data Quality Id
0059	2	R1/W3	float	Off line sentinel value (default = 0.0)
0061	1	R1	16 bits	Available Units = 0x0001 (1)
Oxygen Partial Pressure				
0062	2	R1	float	Measured value
0064	1	R1	ushort	Parameter Id = 30 (pressure)
0065	1	R1/W2	ushort	Units Id 26 = torr (default)
0066	1	R1	ushort	Data Quality Id
0067	2	R1/W3	float	Off line sentinel value (default = 0.0)
0069	1	R1	16 bits	Available Units = 0x0200 (512)

12.1 RDO PRO / RDO PRO-X Calibration Registers.

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
0118	2	R1/W3	float	Live salinity value (PSU)
0120	2	R1/W3	float	Default salinity value (PSU, default = 0.0)
0122	2	R1/W3	float	Live barometric pressure (mbar)
0124	2	R1/W3	float	Default barometric pressure (mbar, default = 1013.25)
0126	2	R1/W3	float	100% saturation calibration reading (mg/L)
0128	2	R1/W3	float	100% saturation temperature reading (°C)
0130	2	R1/W3	float	100% saturation salinity value (PSU)
0132	2	R1/W3	float	100% saturation barometric pressure (mbar)
0134	2	R1/W3	float	0% saturation calibration reading (mg/L)
0136	2	R1/W3	float	0% saturation temperature reading (°C)
0138	2	R1/W3	float	Calibration slope (default = 1.0)
0140	2	R1/W3	float	Calibration offset (default = 0.0)

Live Salinity Value

The live salinity value is used to correct the oxygen concentration value for salinity. Values must be written in Practical Salinity Units (PSU) in the range 0 to 42 PSU. This is not a measured parameter.

Default Salinity Value

The default salinity value is loaded into the live salinity value register when power is first applied to the probe. The default salinity value is used in calculations until a live salinity value is written. This is not a measured parameter.

Live Barometric Pressure

The live barometric pressure is used in the calculation of percent saturation and to determine the theoretical saturation point during calibration. Values must be written in millibars in the range 506.625 to 1114.675 mbar. This is not a measured parameter.

Default Barometric Pressure

The default barometric pressure is loaded into the live barometric pressure register when power is applied to the probe. The default barometric pressure is used in calculations until a live barometric pressure is written. This is not a measured parameter.

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 0x85 (invalid device command sequence) 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 0x85 (invalid device command sequence) 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. These registers may be written independently of the normal internal calibration procedure.

Calibration Procedure

The probe is calibrated using the following procedure.

1. Write the Calibration Mode On command (0xE000) to the sensor command register 49305.

2. Update the live salinity and barometric pressure registers if necessary.

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 live 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 can be set to zero or left at their previous values.

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 to zero (disabled). 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.

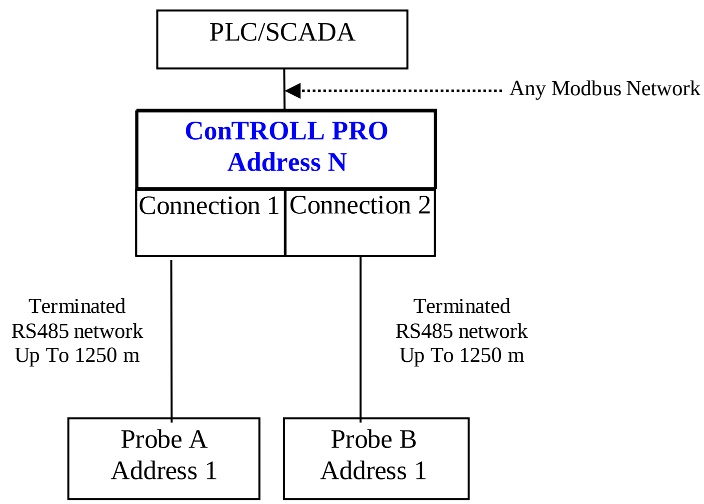
7. Optional: read the last user calibration time register, add the next calibration interval, and write the result to the next user calibration time register.

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.

13 ConTROLL PRO

This series of devices act as both controllers and modbus gateways to the attached probes. The controllers are vented and have an internal virtual sensor that supports Barometer and Temperature parameters. The controller can support up to two attached probes at factory default communication settings. A diagram of the physical configuration is shown below:

Physical Layout



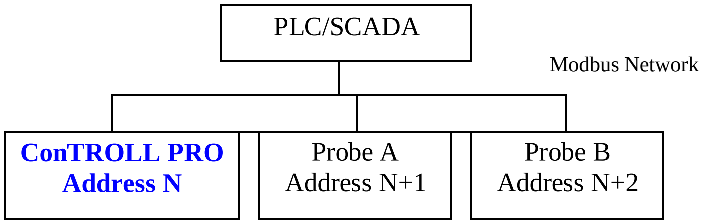
The Controller will have a contiguous address block associated with it that begins at the controller's assigned device address and ends at the controller's device address plus the maximum number of connections supported by the controller. The Controller will always occupy the same number of contiguous addresses regardless of the number of probes actually connected.

For example, a controller that supports two probes and is set to address 5 will occupy three network addresses assigned as follows:

Network Address	Addressed Device
5	Controller.
6	Probe connection 1.
7	Probe connection 2.

The logical or network representation from a SCADA perspective is as shown below:

Physical Layout



The Controller will pass through any messages sent between the SCADA/PLC and Probe A or B. The Controller must also poll the probes for measured values to control the analog outputs, relays and internal log as well as the local display. When the Controller is polling the probes for measured values, the SCADA/PLC will get a modbus exception 0x06 (slave device busy).

13.1 Probe Measurement Cache

The ConTROLL PRO will cache and expose modbus registers for the PLC/SCADA to read up to 30 parameter values of the attached probes and itself at the ConTROLL device address. The maximum number of parameters cached from each probe is limited to 14. If a probe does not have 14 parameters, the cached values are packed into consecutive registers. The Probe A values are first, followed by Probe B and the ConTROLL PRO parameters last. The first register of the cache is 47100.

Example 1 – single RDO PRO attached to Probe A port:

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
7100	2	R1	float	Probe A: RDO PRO DO Concentration
7102	2	R1	float	Probe A: RDO PRO Temperature
7104	2	R1	float	Probe A: RDO PRO DO % Saturation
7106	2	R1	float	Probe A: RDO PRO Oxygen Partial Pressure
7108	2	R1	float	ConTROLL PRO: Baro Pressure
7110	2	R1	float	ConTROLL PRO: Temperature
7112-158	2	R1	float	Cached parameter 7 – 30 NOT USED

Example 2 – two RDO PRO's attached to Probe A and B ports:

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
7100	2	R1	float	Probe A: RDO PRO DO Concentration
7102	2	R1	float	Probe A: RDO PRO Temperature
7104	2	R1	float	Probe A: RDO PRO DO % Saturation
7106	2	R1	float	Probe A: RDO PRO Oxygen Partial Pressure
7108	2	R1	float	Probe B: RDO PRO DO Concentration
7110	2	R1	float	Probe B: RDO PRO Temperature
7112	2	R1	float	Probe B: RDO PRO DO % Saturation
7114	2	R1	float	Probe B: RDO PRO Oxygen Partial Pressure
7116	2	R1	float	ConTROLL PRO: Baro Pressure
7118	2	R1	float	ConTROLL PRO: Temperature
7120-158	2	R1	float	NOT USED

Example 3 – RDO PRO on Probe A port, Aqua TROLL on Probe B port:

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
7100	2	R1	float	Probe A: RDO PRO DO Concentration
7102	2	R1	float	Probe A: RDO PRO Temperature
7104	2	R1	float	Probe A: RDO PRO DO % Saturation
7106	2	R1	float	Probe A: RDO PRO Oxygen Partial Pressure
7108	2	R1	float	Probe B: AquaTROLL Pressure
7110	2	R1	float	Probe B: AquaTROLL Temperature
7112	2	R1	float	Probe B: AquaTROLL Level
7114	2	R1	float	Probe B: AquaTROLL Actual Conductivity
7116	2	R1	float	Probe B: AquaTROLL Specific Conductivity
7118	2	R1	float	Probe B: AquaTROLL Salinity
7120	2	R1	float	Probe B: AquaTROLL Total Dissolved Solids
7122	2	R1	float	Probe B: AquaTROLL Resistivity
7124	2	R1	float	Probe B: AquaTROLL Density of Water
7126	2	R1	float	ConTROLL PRO: Baro Pressure
7128	2	R1	float	ConTROLL PRO: Temperature
7130-158	2	R1	float	NOT USED

13.2 Control PRO Measurement Registers

The device specific measurement registers are as follows:

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
Parameter # 1 - Pressure				
0038	2	R1	float	Measured value
0040	1	R1	ushort	Parameter Id = 2 (pressure)
0041	1	R1/W2	ushort	Units Id 17 = PSI (default) 19 = KPa 20 = bar 21 = mbar 22 = mmHg
0042	1	R1	ushort	Data Quality Id
0043	2	R1/W3	float	Off line sentinel value (default = 0.0)
0045	1	R1	16 bits	Available Units = 0x0005
Parameter # 2 - Temperature				
0046	2	R1	float	Measured value
0048	1	R1	ushort	Parameter Id = 1 (temperature)
0049	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
0050	1	R1	ushort	Data Quality Id
0051	2	R1/W3	float	Off line sentinel value (default = 0.0)
0053	1	R1	16 bits	Available Units = 0x0003

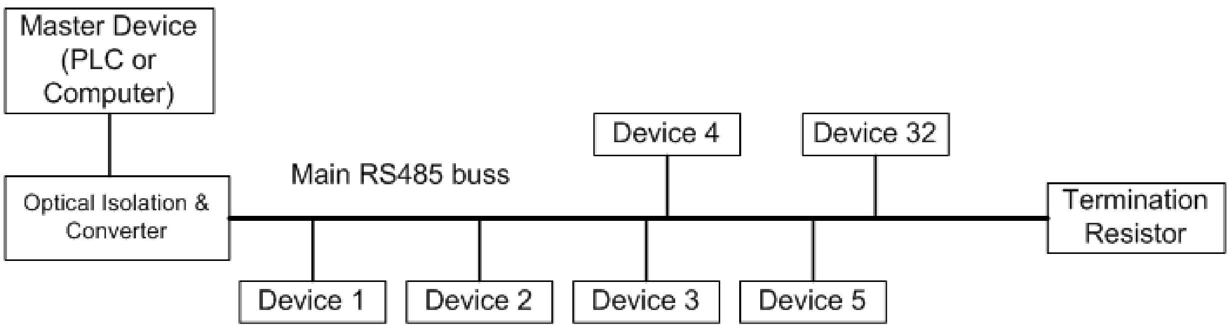
13.3 Other Registers

Register XXXX	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
7001	1	R1	ushort	External Power Voltage (millivolts)

14 RS485 Network Guidelines

In-Situ uses RS485 as its main digital communications link. RS485/422 is often used in an industrial setting as a small device network. There are some installation guidelines to follow when configuring an RS485 network with implications to use with the Level TROLL or Aqua TROLL.

RS485 Rule#1:
RS485 is a bus network. It does not work when configured in a star network topology. This means that a user can have a network that looks like 1 long wire (up to 4000 ft) with short stubs hanging off the main branch with a device. Each stub must be less than 1 meter in length. See picture below:



RS485 Rule#2
There should only be a 100 ohm terminating resistor at the end of the network. The bus is terminated on the long main bus wire at the opposite end from the Master.

RS485 Rule#3
This rule is not really specific to RS485; rather it applies to any situation where you have long wires running across the ground or in the ground connected back to a computer. Always add an optical isolator to the link between the main bus wire and the Master device. This reduces the chance that a nearby lightning strike will damage the Master device.

RS485 Rule#4
Only 32 devices per network, including the Master.

Implications to Level TROLL / Aqua TROLL users are as follows:
These devices are typically deployed on a cable of much greater length than the 1 meter stub supported by RS485. The above documented Rule#1 requires that only two devices are on an individual RS485 link, the PLC and the TROLL. Many PLC's support multiple RS485 networks which can be used to connect multiple TROLLs to a single PLC.

Appendix A: Exception Codes

Standard Modbus Exception Codes

Code	Name	Description
1	Illegal Function	The function code received in the query is not an allowable action for the slave. If a Poll Program Complete command was issued, this code indicates that no program function preceded it.
2	Illegal Data Address	The data address received in the query is not an allowable address for the slave.
3	Illegal Data Value	A value contained in the query data field is not an allowable value for the slave.
4	Slave Device Failure	An unrecoverable error occurred while the slave was attempting to perform the requested action.
5	Acknowledge	The slave has accepted the request and is processing it, but a long duration of time will be required to do so. This response is returned to prevent a timeout error from occurring in the master. The master can next issue a Poll Program Complete message to determine if processing is completed. **This exception code may not be supported by the devices**
6	Slave Device Busy	The slave is engaged in processing a long–duration program command. The master should retransmit the message later when the slave is free. **This exception code may not be supported by the devices**
8	Memory Parity Error	Specialized use in conjunction with function codes 20 and 21 and reference type 6, to indicate that the extended file area failed to pass a consistency check. The server (or slave) attempted to read record file, but detected a parity error in the memory. The client (or master) can retry the request, but service may be required on the server (or slave) device. **This exception code may not be supported by the devices**
0x0A	Gateway Path Unavailable	Specialized use in conjunction with gateways, indicates that the gateway was unable to allocate an internal communication path from the input port to the output port for processing the request. Usually means that the gateway is misconfigured or overloaded. **This exception code may not be supported by the devices.**
0x0B	Gateway Target Device Failed To Respond	Specialized use in conjunction with gateways, indicates that no response was obtained from the target device. Usually means that the device is not present on the network. **This exception code may be used by controllers, but is not used by probes.**

Extended Modbus Exception Codes

Code	Name	Description
0x80	Field Mismatch	Mismatch between register number, count and field size.
0x81	Write Only Register	Attempting to read a Write Only register.
0x82	Read Only Register	Attempting to write a Read Only register.
0x83	Access Level	Attempting to Read/Write a register with invalid access level.
0x84	Write Value	Attempting to write an illegal field value.
0x85	Command Sequence	Invalid device command register sequence.
0x86	File Sequence	Invalid file command register sequence.
0x87	File Command	Invalid file command.
0x88	File Number	Invalid file number.
0x89	File Size	Invalid file size.
0x8A	File Data	The file data block transferred to device is invalid.
0x8B	File Interval	Invalid file interval.
0x90	Gateway Error	Invalid probe command on controller gateway.
0x91	Sensor Sequence	Invalid sensor command register sequence.
0x92	Sensor Mode	Invalid change to sensor mode, or attempting to read/write with an invalid sensor mode set.
0x93	Sensor Config	Attempting a sensor operation on a sensor port that is not part of the current configuration.
0x94	Sensor Missing	Attempting a sensor operation on a sensor port with no sensor connected.
0x95	Sensor Invalid	Attempting a sensor operation on a sensor port that has a sensor that is not compatible with the sensor that was originally configured.
0x96	Sensor Firmware	Attempting a sensor operation on a sensor with no application code.
0xA0	Data Log Register	Attempting to write a register that is read-only during logging.
0xA1	Data Log Memory	Data log memory is full.
0xA2	Data Log Directory	Data log directory is full.
0xA3	Data Log Edit	Log configuration cannot be edited.
0xA4	Data Log Sequence	Invalid data log command sequence.

Appendix B: Device Ids

Device Ids

Device Id	Description
1-32767	**Reserved for probes**
1	Level TROLL® 500
2	Level TROLL® 700
3	BaroTROLL® 500
4	Level TROLL® 300
5	Aqua TROLL® 200
7	Aqua TROLL® 600
10	Aqua TROLL® 100
11	Flow TROLL® 500
12	RDO® PRO
16	Rugged TROLL® 200
17	Rugged BaroTROLL®
18	Aqua TROLL® 400
19	RDO® TITAN
21	smarTROLL
26	Aqua TROLL® 600 Vented
30	Level TROLL® 400
31	RDO® PRO-X
33	Aqua TROLL® 500
34	Aqua TROLL® 500 Vented
32768-65534	**Reserved for controllers**
32768	Con TROLL PRO ACL
32769	Con TROLL PRO AC
32770	Con TROLL PRO DCL
32771	Wireless TROLL Com/smarTROLL Power Pack/Wireless Rugged TROLL Com
65535	**Reserved for factory use**

Appendix C: Sensor Ids

Sensor Ids

Sensor Id	Description
1	Temperature
2	5 PSI full-scale gauge pressure with level and temperature (3.5m/11.5ft)
3	15 PSI full-scale gauge pressure with level and temperature (11m/35ft)
4	30 PSI full-scale gauge pressure with level and temperature (21m/69ft)
5	100 PSI full-scale gauge pressure with level and temperature (70m/231ft)
6	300 PSI full-scale gauge pressure with level and temperature (211m/692ft)
7	500 PSI full-scale gauge pressure with level and temperature (351m/1153ft)
8	1000 PSI full-scale absolute pressure with level and temperature (703m/2306.4 ft)
9	30 PSI full-scale absolute pressure with level and temperature (10.9m/35.8ft)
10	100 PSI full-scale absolute pressure with level and temperature (60.1m/197.3ft)
11	300 PSI full-scale absolute pressure with level and temperature (200.7m/658.7ft)
12	500 PSI full-scale absolute pressure with level and temperature (341.3m/1120ft)
13	30 PSI full-scale absolute pressure with temperature (barometric)
14	5 PSI full-scale gauge pressure with level, temperature, and conductivity (3.5m/11.5ft)
15	15 PSI full-scale gauge pressure with level, temperature, and conductivity (11m/35ft)
16	30 PSI full-scale gauge pressure with level, temperature, and conductivity (21m/69ft)
17	100 PSI full-scale gauge pressure with level, temperature, and conductivity (70m/231ft)
18	300 PSI full-scale gauge pressure with level, temperature, and conductivity (211m/692ft)
19	500 PSI full-scale gauge pressure with level, temperature, and conductivity (351m/1153ft)
20	Not Used
21	30 PSI full-scale absolute pressure with level, temperature, and conductivity (10.9m/35.8ft)
22	100 PSI full-scale absolute pressure with level, temperature, and conductivity (60.1m/197.3ft)
23	300 PSI full-scale absolute pressure with level, temperature, and conductivity (200.7m/658.7ft)
24	500 PSI full-scale absolute pressure with level, temperature, and conductivity (341.3m/1120ft)
25	16.5 PSI full-scale absolute pressure (barometric)
26	pH analog sensor
27	pH/ORP analog sensor
28	Dissolved Oxygen Clark Cell analog sensor
29	Nitrate (NO3-) analog sensor
30	Ammonium (NH4+) analog sensor
31	Chloride (Cl-) analog sensor
32	100 foot full-scale level with absolute pressure and temperature (30m/100ft)
33	250 foot full-scale level with absolute pressure and temperature (90m/250ft)
34	30 foot full-scale level with absolute pressure and temperature (9m/30ft)
35	Conductivity and temperature
36	5 PSI full-scale gauge pressure with temperature, head, and flow.
37	15 PSI full-scale gauge pressure with temperature, head, and flow.
38	30 PSI full-scale gauge pressure with temperature, head, and flow.
39	100 PSI full-scale gauge pressure with temperature, head, and flow.
40	300 PSI full-scale gauge pressure with temperature, head, and flow.
41	500 PSI full-scale gauge pressure with temperature, head, and flow.
42	Optical dissolved oxygen with temperature.
43	1 Bar (15 PSI) full-scale gauge pressure with level and temperature (11m/35ft)
44	2 Bar (30 PSI) full-scale gauge pressure with level and temperature (21m/70ft)
45	5 Bar (75 PSI) full-scale gauge pressure with level and temperature (52m/173ft)

Appendix D: Parameter Ids

Parameter Ids

Id	Parameters
1	Temperature
2	Pressure
3	Depth
4	Level, Depth to Water
5	Level, Surface Elevation
6	Latitude
7	Longitude
8	Elevation
9	Actual Conductivity
10	Specific Conductivity
11	Resistivity
12	Salinity
13	Total Dissolved Solids
14	Density of Water
15	Specific Gravity
16	Barometric Pressure
17	pH
18	pH mV
19	ORP
20	Dissolved Oxygen concentration
21	Dissolved Oxygen % saturation
22	Nitrate (NO3-)
23	Ammonium (NH4+)
24	Chloride (Cl-)
25	Turbidity
26	Battery Voltage
27	Head
28	Flow
29	Total Flow
30	Oxygen Partial Pressure

Appendix E: Unit Ids

Unit Ids

Id	Abbreviation	Units
0		None
		Temperature (1-16)
1	C	Celsius
2	F	Fahrenheit
3	K	Kelvin
		Pressure, Barometric Pressure (17-32)
17	PSI	Pounds per square inch
18	Pa	Pascals
19	kPa	Kilopascals
20	Bar	bars
21	mBar	millibars
22	mmHg	Millimeters of Mercury (0°C)
23	inHg	Inches of Mercury (0°C)
24	cmH_2O	Centimeters of water (4°C)
25	inH_2O	Inches of water (4°C)
26	Torr	Torr
		Distance/Length (33-48)
33	mm	millimeters
34	cm	Centimeters
35	m	Meters
36	km	Kilometer
37	in	Inches
38	ft	Feet
		Coordinates (49-64)
49	deg	Degrees
50	min	Minutes
51	sec	Seconds
		Conductivity (65-80)
65	uS/cm	Microsiemens per centimeter
66	mS/cm	Millisiemens per centimeter
		Resistivity (81-96)
81	ohm-cm	Ohm-centimeters
		Salinity (97-112)
97	PSU	Practical Salinity Units
		Concentration (113-128)
113	ppm	Parts per million
114	ppt	Parts per thousand
115	ppm N	Parts per million Nitrogen
116	ppm Cl	Parts per million Chloride
117	mg/L	milligrams per liter
118	µg/L	micrograms per liter
119	µM/L	micromoles per liter
		Density (129-144)
129	g/cm^3	Grams per cubic centimeter
		pH (145-160)
145	pH	pH

Id	Abbreviation	Units
		Voltage (161-176)
161	µV	micro Volts
162	mV	milli Volts
163	V	Volts
		Dissolved Oxygen (DO) % Saturation (177-192)
177	% sat	Percent saturation
		Turbidity (193-208)
193	FNU	formazin nephelometric units
194	NTU	nephelometric turbidity units
195	FTU	formazin turbidity units
		Flow (209-224)
209	ft^3/s	Cubic feet per second
210	ft^3/min	Cubic feet per minute
211	ft^3/hr	Cubic feet per hour
212	ft^3/day	Cubic feet per day
213	gal/s	Gallons per second
214	gal/min	Gallons per minute
215	gal/hr	Gallons per hour
216	MGD	Millions of gallons per day
217	m^3/sec	Cubic meters per second
218	m^3/min	Cubic meters per minute
219	m^3/hr	Cubic meters per hour
220	m^3/day	Cubic meters per day
221	l/s	Liters per second
222	acre-ft/day	Acre feet per day
		Volume (225-240)
225	ft^3	Cubic feet
226	gal	Gallons
227	mgal	Millions of gallons
228	m^3	Cubic meters
229	l	Liters
230	acre-ft	Acre feet

Appendix F: Data Quality Ids

Instruments developed using System Spec. 1

Level **TROLL**® 700, 500, 400
Baro**TROLL**® 500
Aqua **TROLL**® 100, 200
Rugged **TROLL**® 200
Rugged Baro**TROLL**®

Data Quality Ids

Id	Name	Description
0	Normal	Parameter measured without errors using a current calibration.
1	User Uncal	Parameter measured without errors using an expired user calibration.
2	Factory Uncal	Parameter measured without errors using an expired factory calibration.
3	Error	Parameter measured with error, sentinel value supplied.
4	Warm-up	Sensor is warming up, sentinel value supplied.
5	Disabled	Sensor is disabled, sentinel value supplied.
6	Calibrating	Sensor is calibrating, calibration value supplied.
7	Off Line	Device is off line, sentinel value supplied.
8	Warning	Parameter measured without errors but does not meet normal quality criteria.

Instruments developed using System Spec. 3

RDO® PRO
RDO® PRO-X
RDO® TITAN,
ConTROLL® PRO
Aqua **TROLL**® 400, 600

Data Quality Ids

Id	Name	Description
0	Normal	Parameter measured without errors using a current calibration.
1	User Cal Expired	Parameter measured without errors using an expired user calibration.
2	Factory Cal Expired	Parameter measured without errors using an expired factory calibration.
3	Error	Parameter measured with error, sentinel value supplied.
4	Warm-up	Sensor is warming up, sentinel value supplied.
5	Sensor Warning	Parameter measured but does not meet normal quality criteria. Either the sensor has sustained moderate damage, or the recommended lifespan has been reached.
6	Calibrating	Sensor is calibrating, calibration value supplied.
7	Off Line	Sensor communication failed, sentinel value supplied. Make sure the sensor cap is installed and properly seated.

Appendix G: DB-9 pin Pinout

Pin	Signal Name	
1	Carrier Detector	DCD
2	Receive Data	RXD
3	Transmit Data	TXD
4	Data Terminal Ready	DTR
5	Signal Ground/Common	GND
6	Data Set Ready	DSR
7	Request to Send	RTS
8	Clear to Send	CTS
9	Ring Indicator	RI