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In-Situ Modbus Communication Protocol

for

Level ***TROLL***®, *Baro****TROLL***®,
and *Aqua* ***TROLL***®

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Contents

Revision History

Date	Revision	Author	Description
08/09/2005	Draft	Bill Bonner	Initial draft
08/29/2005	000	Bill Bonner	Initial release
09/29/2005	1.0	Bill Bonner	Added DB-9 pin pinout (Appendix D)
01/30/2006	2.0	Bill Bonner	Added section numbers, added Level TROLL 300 device ID, added RS485 Network Guidelines
3/16/2006	3.0	Bill Bonner	Added Revision History, added Level TROLL 300 & BaroTROLL fast sampling to device register table
4/3/2006	4.0	Bill Bonner	Added Modbus Tutorial
11/16/2006	5.0	Bill Bonner	Updated for the Aqua TROLL
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1 Introduction

The In-Situ Level TROLL 300, Level TROLL 500, Level TROLL 700, BaroTROLL and Aqua TROLL 200 products 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 a Level TROLL, BaroTROLL or Aqua TROLL 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.

2.3.1 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-Z. 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 checksum value uses a different mathematical algorithm.

Computer (Master) Message Format:

Start Packet	Device Address	Function Code	Data Payload	CRC	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.
- CRC: 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	CRC	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.
- CRC: 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 asychronous 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.

2.3.2 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.

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

2.3.3 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.

2.3.4 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.

2.3.4.1 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
Start Register Address	2 Bytes	0 to 0xFFFF	Byte Count	1 Byte	0 to 0xFA
Register Count	2 Bytes	0 to 0x7D	Register Data	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.

2.3.4.2 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
Register Address	2 Bytes	0 to 0xFFFF	Register Address	2 Bytes	0 to 0xFFFF
Register Data	2 Bytes	0 to 0xFFFF	Register Data	2 Bytes	0 to 0xFFFF
CRC	2 Bytes		CRC	2 Bytes	

2.3.4.3 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
Start Register Address	2 Bytes	0 to 0xFFFF	Start Register 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	
Register Data	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.

2.3.4.4 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
Register Address	2 Bytes	0 to 0xFFFF	Register 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.

2.3.4.5 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	Function Code	byte	0x11
1	Byte Count	byte	23
2	Slave Id	byte	0x49 ('I')
3	Run Status Indicator	byte	0x00 = Off, 0xFF = On
Device Specific Info			
4	Slave Id Format Version Id	byte	0x01
Format Version 1 Id Block			
5-6	Manufacturer Id	ushort	0x5349 ('SI')
7-8	Device Id	ushort	
9-10	Application Firmware Version	ushort	Version * 100
11-12	Boot Code Firmware Version	ushort	Version * 100
13-14	Hardware Version	ushort	
15-16	Register Map Template Id	ushort	
17-20	Device Serial Number	ulong	
21-22	Max Message/Response Size (bytes)	ushort	
23-24	Max Baud Rate Id	ushort	
25-26	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

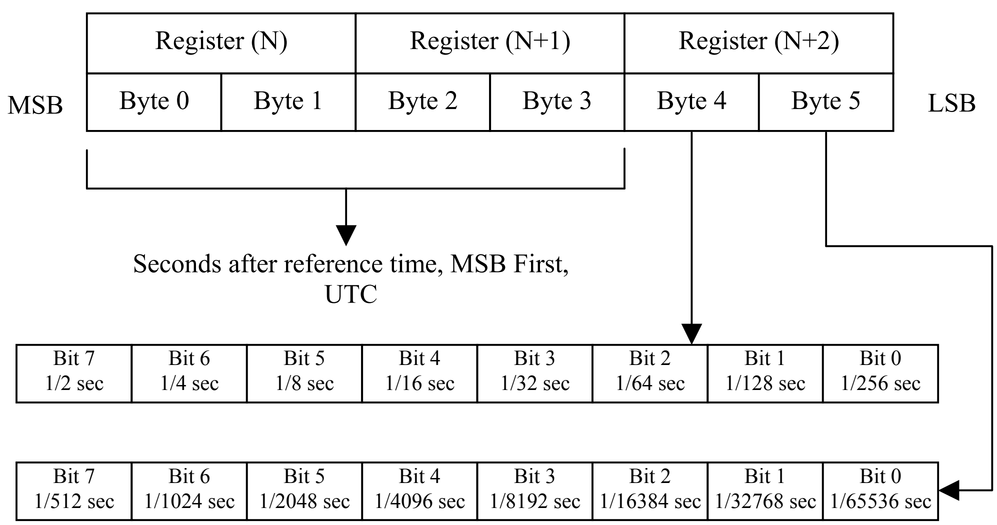
A 2 byte Unicode character contained with a single register data address.

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 as follows:

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.
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.

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5 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 registers are defined in the table below:

Common Register Map

Register	Size (registers)	Mode (R/W)	Data Type	Description
49000	1	R	ushort	Register Map Template Version
49001	1	R/W	ushort	Device Id
49002-003	2	R/W	ulong	Device Serial Number
49004-006	3	R/W	time	Manufacture Date
49007	1	R	ushort	Firmware version * 100
49008	1	R	ushort	Boot Code version * 100
49009	1	R	ushort	Hardware version
49010	1	R	ushort	Max Data Logs
49011-012	2	R	ulong	Total Data Log Memory (bytes)
49013-014	2	R	ulong	Total Battery Ticks
49015-017	3	R/W	time	Last Battery Change
49018	1			Reserved
49019-050	32	R/W	string	Device Name
49051-082	32	R/W	string	Site Name
49083-086	4	R/W	double	Latitude Coordinate (degrees) (negative = east)
49087-090	4	R/W	double	Longitude Coordinate (degrees) (negative = south)
49091-094	4	R/W	double	Altitude Coordinate (meters)
49095-096	2			Reserved
49097-099	3	R/W	time	Current time (GMT)
49100-101	2	R	32 bits	Device Status
49102-103	2	R/W	ulong	Used Battery Ticks
49104-105	2	R	ulong	Used Data Log Memory (bytes)

Communication Control Registers

Register	Size (registers)	Mode (R/W)	Data Type	Description
49200	1	R/W	ushort	Device Address (1-247, default = 1)
49201	1	R/W	ushort	Serial Communication Configuration
49202	1	R/W	ushort	EOM timeout (1000-15000 msec, default = 1000)
49203	1	R/W	ushort	EOS timeout (5000-60000 msec, default = 5000)
49204	1	R	ushort	Max allowed baud rate id (0-7)
49205	1	R	ushort	Max Message/Response size (bytes)
49206-207	2	R/W	ulong	Good message counter
49208	1	R/W	ushort	Bad message counter
49209	1	R/W	ushort	Exception response counter

Note: Registers 49097 (current time) thru 49105 (used data log memory) are grouped together to permit optimized reading of the registers that will change frequently in the device.

5.1 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.

5.2 Device Id

This is the id number for the device. Each device in the system will receive a unique id number. The current id numbers are as follows:

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

5.3 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.

5.4 Manufacture Date

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

5.5 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.

5.6 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.

5.7 Total Data Log Memory

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

5.8 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.

5.9 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.

5.10 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).

5.11 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).

5.12 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).

5.13 Current Time

This represents the time in the device in GMT.

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5.14 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.

5.15 Used Battery Ticks

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

5.16 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 comm configuration register.

5.16.1 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).

5.16.2 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).

5.16.3 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

5.17 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.

5.18 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.

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6 Level TROLL / BaroTROLL Registers

The device specific registers are as follows:

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
40001	1	R1	ushort	Sensor Id (see pressure sensor slot registers)
40002	2	R1	ulong	Sensor serial number
40004	1	R1	16 bits	Sensor status (see pressure sensor slot registers)
40005	3	R1	time	Last factory calibration
40008	3	R1	time	Next factory calibration (0 = none required)
40011	3	R1	time	Last user calibration
40014	3	R1/W2	time	Next user calibration (0 = none required)
40017	1	R1	ushort	Warm-up time in milliseconds = 100
40018	1	R1	ushort	Fast sample rate in milliseconds Level TROLL 300 = 1000 msec Level TROLL 500 = 500 msec Level TROLL 700 = 250 msec BaroTROLL 500 = 500 msec
40019	1	R1	ushort	Number of sensor parameters = 3
40020	1	R1/W3	ushort	Alarm and warning parameter number (1 – 3, default = 1)
40021	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
40022	2	R1/W3	float	High alarm set value (default = 0.0)
40024	2	R1/W3	float	High alarm clear value (default = 0.0)
40026	2	R1/W3	float	High warning set value (default = 0.0)
40028	2	R1/W3	float	High warning clear value (default = 0.0)
40030	2	R1/W3	float	Low warning clear value (default = 0.0)
40032	2	R1/W3	float	Low warning set value (default = 0.0)
40034	2	R1/W3	float	Low alarm clear value (default = 0.0)
40036	2	R1/W3	float	Low alarm set value (default = 0.0)
Parameter # 1 - Pressure				
40038	2	R1	float	Measured value
40040	1	R1	ushort	Parameter Id = 2 (pressure)
40041	1	R1/W2	ushort	Units Id 17 = PSI (default) 19 = KPa
40042	1	R1	ushort	Data Quality Id
40043	2	R1/W3	float	Off line sentinel value (default = 0.0)
40045	1	R1	16 bits	Available Units = 0x0005

Parameter # 2 - Temperature				
40046	2	R1	float	Measured value
40048	1	R1	ushort	Parameter Id = 1 (temperature)
40049	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
40050	1	R1	ushort	Data Quality Id
40051	2	R1/W3	float	Off line sentinel value (default = 0.0)
40053	1	R1	16 bits	Available Units = 0x0003
Parameter # 3 – Level (Level TROLL only)				
40054	2	R1	float	Measured value, L_m
40056	1	R1/W2	ushort	Parameter Id 3 = level, depth (default) 4 = level, top of casing 5 = level, elevation
40057	1	R1/W2	ushort	Units Id 33 = millimeters 34 = centimeters 35 = meters 37 = inches 38 = feet (default)
40058	1	R1	ushort	Data Quality Id
40059	2	R1/W3	float	Off line sentinel value (default = 0.0)
40061	1	R1	16 bits	Available Units = 0x0037

6.1 Sensor Id Register

The devices can be factory-configured to a variety of full-scale pressure ranges in both gauge and absolute pressure formats. The device will present a sensor id that matches the factory configured pressure sensor according to the table below.

Sensor Id	Description
1	Temperature
2	5 PSI full-scale gauge pressure with level and temperature
3	15 PSI full-scale gauge pressure with level and temperature
4	30 PSI full-scale gauge pressure with level and temperature
5	100 PSI full-scale gauge pressure with level and temperature
6	300 PSI full-scale gauge pressure with level and temperature
7	500 PSI full-scale gauge pressure with level and temperature
8	15 PSI full-scale absolute pressure with level and temperature
9	30 PSI full-scale absolute pressure with level and temperature
10	100 PSI full-scale absolute pressure with level and temperature
11	300 PSI full-scale absolute pressure with level and temperature
12	500 PSI full-scale absolute pressure with level and temperature
13	30 PSI full-scale absolute pressure with temperature (barometric)

6.2 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)

6.3 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.

6.4 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.

6.5 Fast Sample Rate

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

6.6 Alarm Parameter Number

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

6.7 Alarm Enable Bits

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

6.8 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.

6.9 Sensor Blocks

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.

6.10 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

6.11 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

6.12 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.

6.13 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.

6.14 Sensor Calibration Registers

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

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
40100	2	R1/W3	float	Specific Gravity (default = 1.0)
40102	2	R1/W3	float	Pressure Offset, P_o (default = 0.0)
40104	2	R1/W3	float	Level Reference, L_r (default = 0.0)

6.14.1 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.

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

6.14.2 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:

$$P_m = P - P_o$$

6.14.3 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	$L_m = L_r + L(P_m – P_r)$

6.15 Other Level TROLL Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
40108	1	R1	ushort	Probe Register Map Template Version (1)
40109	1	R1	ushort	External Power Voltage (millivolts)
40110	1	R1	ushort	Internal Battery Voltage (millivolts)
40111	2	R1	ulong	Total Measurements Counter
40113	2	R1	ulong	Battery Measurements Counter

6.15.1 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.

6.15.2 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.

6.15.3 Analog Control Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
40115	1	R1/W3	ushort	Current loop parameter number (1-3, default = 1)
40116	2	R1/W3	float	20 mA setpoint (I_{20}, default = full scale pressure)
40118	2	R1/W3	float	4 mA setpoint (I_4, default = 0)

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7 Aqua TROLL Registers

The device specific registers are as follows:

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
40001	1	R1	ushort	Sensor Id (see pressure sensor slot registers)
40002	2	R1	ulong	Sensor serial number
40004	1	R1	16 bits	Sensor status (see pressure sensor slot registers)
40005	3	R1	time	Last factory calibration
40008	3	R1	time	Next factory calibration (0 = none required)
40011	3	R1	time	Last user calibration
40014	3	R1/W2	time	Next user calibration (0 = none required)
40017	1	R1	ushort	Warm-up time in milliseconds = 1000
40018	1	R1	ushort	Fast sample rate = 1000 milliseconds
40019	1	R1	ushort	Number of sensor parameters (N) = 8
40020	1	R1/W3	ushort	Alarm/warning parameter number (1 – N, default = 1)
40021	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
40022	2	R1/W3	float	High alarm set value (default = 0.0)
40024	2	R1/W3	float	High alarm clear value (default = 0.0)
40026	2	R1/W3	float	High warning set value (default = 0.0)
40028	2	R1/W3	float	High warning clear value (default = 0.0)
40030	2	R1/W3	float	Low warning clear value (default = 0.0)
40032	2	R1/W3	float	Low warning set value (default = 0.0)
40034	2	R1/W3	float	Low alarm clear value (default = 0.0)
40036	2	R1/W3	float	Low alarm set value (default = 0.0)
Parameter # 1 - Pressure				
40038	2	R1	float	Measured value
40040	1	R1	ushort	Parameter Id = 2 (pressure)
40041	1	R1/W2	ushort	Units Id 17 = PSI (default) 19 = KPa
40042	1	R1	ushort	Data Quality Id
40043	2	R1/W3	float	Off line sentinel value (default = 0.0)
40045	1	R1	16 bits	Available Units = 0x0005

Parameter # 2 - Temperature				
40046	2	R1	float	Measured value
40048	1	R1	ushort	Parameter Id = 1 (temperature)
40049	1	R1/W2	ushort	Units Id 1 = °C (default) 2 = °F
40050	1	R1	ushort	Data Quality Id
40051	2	R1/W3	float	Off line sentinel value (default = 0.0)
40053	1	R1	16 bits	Available Units = 0x0003
Parameter # 3 – Level				
40054	2	R1	float	Measured value, L_m
40056	1	R1/W2	ushort	Parameter Id 3 = level, depth (default) 4 = level, top of casing 5 = level, elevation
40057	1	R1/W2	ushort	Units Id 33 = millimeters 34 = centimeters 35 = meters 37 = inches 38 = feet (default)
40058	1	R1	ushort	Data Quality Id
40059	2	R1/W3	float	Off line sentinel value (default = 0.0)
40061	1	R1	16 bits	Available Units = 0x0037
Parameter # 4 – Actual Conductivity				
40062	2	R1	float	Measured value, AC
40064	1	R1	ushort	Parameter Id = 9 (actual conductivity)
40065	1	R1/W2	ushort	Units Id 65 = microsiemens per centimeter (default) 66 = millisiemens per centimeter
40066	1	R1	ushort	Data Quality Id
40067	2	R1/W3	float	Off line sentinel value (default = 0.0)
40069	1	R1	16 bits	Available Units = 0x0003 (3)
Parameter # 5 – Specific Conductivity				
40070	2	R1	float	Measured value, SC
40072	1	R1	ushort	Parameter Id = 10 (specific conductivity)
40073	1	R1/W2	ushort	Units Id 65 = microsiemens per centimeter (default) 66 = millisiemens per centimeter
40074	1	R1	ushort	Data Quality Id
40075	2	R1/W3	float	Off line sentinel value (default = 0.0)
40077	1	R1	16 bits	Available Units = 0x0003 (3)

Parameter # 6 – Salinity				
40078	2	R1	float	Measured value, S
40080	1	R1	ushort	Parameter Id = 12 (salinity)
40081	1	R1/W2	ushort	Units Id 97 = Practical Salinity Units PSU (default)
40082	1	R1	ushort	Data Quality Id
40083	2	R1/W3	float	Off line sentinel value (default = 0.0)
40085	1	R1	16 bits	Available Units = 0x0001 (1)
Parameter # 7 – Total Dissolved Solids				
40086	2	R1	float	Measured value, TDS
40088	1	R1	ushort	Parameter Id = 13 (TDS)
40089	1	R1/W2	ushort	Units Id 113 = parts per million 114 = parts per thousand (default)
40090	1	R1	ushort	Data Quality Id
40091	2	R1/W3	float	Off line sentinel value (default = 0.0)
40093	1	R1	16 bits	Available Units = 0x0003 (3)
Parameter # 8 – Resistivity				
40094	2	R1	float	Measured value, R
40096	1	R1	ushort	Parameter Id = 11 (resistivity)
40097	1	R1/W2	ushort	Units Id 81 = ohm-cm (default)
40098	1	R1	ushort	Data Quality Id
40099	2	R1/W3	float	Off line sentinel value (default = 0.0)
40101	1	R1	16 bits	Available Units = 0x0001 (1)
Parameter # 9 – Density of Water				
40102	2	R1	float	Measured value, p
40104	1	R1	ushort	Parameter Id = 14 (density of water)
40105	1	R1/W2	ushort	Units Id 129 = g/cm^3 (default)
40106	1	R1	ushort	Data Quality Id
40107	2	R1/W3	float	Off line sentinel value (default = 0.0)
40109	1	R1	16 bits	Available Units = 0x0001 (1)

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. The device will present a sensor id that matches the factory configured pressure sensor according to the table below.

Sensor Id	Description
14	5 PSI full-scale gauge pressure with level, temperature, and conductivity
15	15 PSI full-scale gauge pressure with level, temperature, and conductivity
16	30 PSI full-scale gauge pressure with level, temperature, and conductivity
17	100 PSI full-scale gauge pressure with level, temperature, and conductivity
18	300 PSI full-scale gauge pressure with level, temperature, and conductivity
19	500 PSI full-scale gauge pressure with level, temperature, and conductivity
20	15 PSI full-scale absolute pressure with level, temperature, and conductivity
21	30 PSI full-scale absolute pressure with level, temperature, and conductivity
22	100 PSI full-scale absolute pressure with level, temperature, and conductivity
23	300 PSI full-scale absolute pressure with level, temperature, and conductivity
24	500 PSI full-scale absolute pressure with level, temperature, and conductivity

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 1-9 for the Aqua TROLL.

7.7 Alarm Enable Bits

This register provides for the capability to enable and disable Hi/Lo alarms and warning values. The setpoints 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 Sensor Blocks

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.

7.10 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

7.11 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

7.12 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.

7.13 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.

7.14 Sensor Calibration Registers

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

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
40118	1	R1	ushort	Sensor data register map version
40119	1	R1	ushort	Sensor firmware version * 100
40120	2	R1/W3	float	Pressure Offset, P_o (default = 0.0)
40122	2	R1/W3	float	Specific Gravity (default = 1.0)
40124	2	R1/W3	float	Level Reference, L_r (default = 0.0)
40126	2	R1/W3	float	Pressure Reference, P_r (default = 0.0)
40128	2	R1/W3	float	Cell Offset, K_0 (default = 0.0)
40130	2	R1/W3	float	Cell Constant, K (default = 1.0)
40132	2	R1/W3	float	Reference Temperature, T_{ref} in °C (default = 25)
40134	2	R1/W3	float	Alpha Coefficient α_0 (default = 1.0)
40136	2	R1/W3	float	Alpha Coefficient α_1 (default = -0.0191)
40138	2	R1/W3	float	Alpha Coefficient α_2 (default = 0.0)
40140	2	R1/W3	float	Alpha Coefficient α_3 (default = 0.0)
40142	2	R1/W3	float	Alpha Coefficient α_4 (default = 0.0)
40144	2	R1/W3	float	Alpha Coefficient α_5 (default = 0.0)
40146	2	R1/W3	float	Alpha Coefficient α_6 (default = 0.0)
40148	2	R1/W3	float	Alpha Coefficient α_7 (default = 0.0)
40150	2	R1/W3	float	Beta Coefficient β (default = 1.0)
40152	2	R1/W3	float	TDS Conversion Factor CF_{TDS} in ppt (default = 0.65)
40154	2	R1/W3	float	Local gravity constant (pg) for density corrected level calculations (default = 0.0 for no correction)

7.14.1 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.

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

7.14.2 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:

$$P_m = P - P_o$$

7.14.3 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	$L_m = L_r + L(P_m – P_r)$

7.14.4 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.

7.14.5 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 are in the range 0.9 to 1.1 inclusive. This register can be written 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. The value contained in the specific gravity register is ignored.

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

7.15 Other Aqua TROLL Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
47000	1	R1	ushort	Probe Register Map Template Version (1)
47001	1	R1	ushort	External Power Voltage (millivolts)
47002	1	R1	ushort	Internal Battery Voltage (millivolts)
47003	2	R1	ulong	Total Measurements Counter
47005	2	R1	ulong	Battery Measurements Counter
47007	1	R1/W3	ushort	Parameter buffer timeout (milliseconds), 0-5000, default = 1750

7.15.1 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.

7.15.2 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.

7.15.3 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.

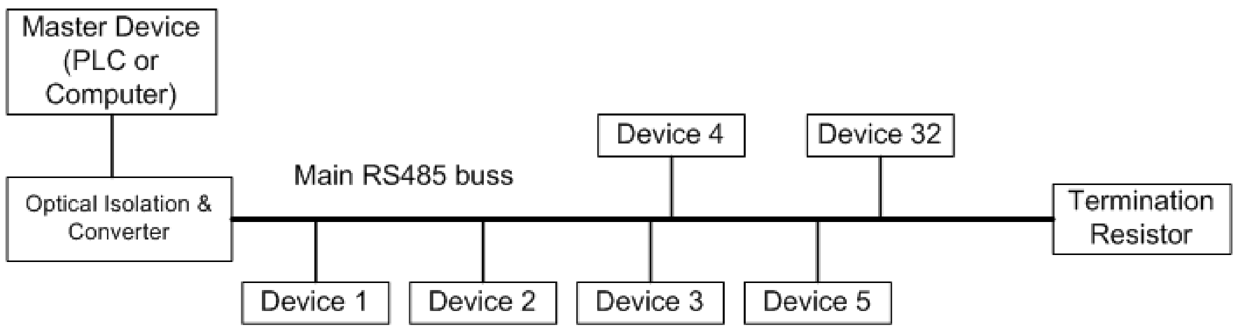
7.15.4 Analog Control Registers

Register	Size (registers)	Mode & Access Level (R/W)	Data Type	Description
49501	1	R1/W3	ushort	Current loop sensor number (can only be 1)
49502	1	R1/W3	ushort	Current loop parameter number (1-N, default = 1)
49503	2	R1/W3	float	20 mA setpoint (I_{20}, default = 100)
49505	2	R1/W3	float	4 mA setpoint (I_4, default = 0)
49507	1	R1/W3	ushort	Current loop enable (0 = off, 1 = on, default = 0)

8 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: Parameter Ids

Id	Parameters
1	Temperature
2	Pressure
3	Depth
4	Level, Depth to Water
5	Level, Surface Elevation
6	Latitude
7	Longitude
8	Altitude
9	Actual Conductivity
10	Specific Conductivity
11	Resistivity
12	Salinity
13	Total Dissolved Solids
14	Density of Water
15	Specific Gravity

Appendix B: Unit Ids

Id	Abbreviation	Units
Temperature (1-16)		
1	C	Celsius
2	F	Fahrenheit
3	K	Kelvin
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)
Depth, DTW, Level, Altitude (33-48)		
33	mm	millimeters
34	cm	Centimeters
35	m	Meters
36	km	Kilometer
37	in	Inches
38	ft	Feet
Latitude, Longitude (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
Total Dissolved Solids (113-128)		
113	ppm	Parts per million
114	ppt	Parts per thousand
Density (129-144)		
129	g/cm^3	Grams per cubic centimeter

Appendix C: 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.

Appendix D: 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