Instruction Manual

for the

Aquaread BlackBox™

Multiparameter Water Quality

Data Converter

(Software revision 2.00 and above)

Revision: P

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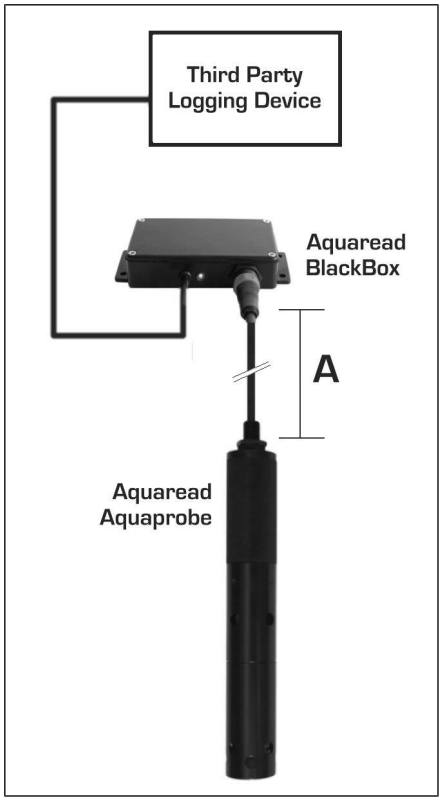
1. Introduction

This manual covers the setup, operation and maintenance of the Aquaread BlackBox at software revision 2.00 and above, and should be read in conjunction with the latest revision of the relevant Aquaread Aquaprobe Instruction Manual. **If your BlackBox is running earlier software, the output protocols may be different from those shown in this manual. In this case, contact Aquaread for an earlier version of this manual or return your BlackBox for software upgrade (chargeable).**

1.1. What does it do?



The Aquaread BlackBox is a data converter that allows any model of Aquaread water quality probe (Aquaprobe) to be interfaced directly to a third party processing, control or logging device. The distance 'A' between the BlackBox and the Aquaprobe can be up to 100 meters.

With a choice of industry standard digital interfaces and two analogue channels, the BlackBox offers a versatile and cost effective data collection solution utilising any of the advanced range of Aquaread multiparameter Aquaprobes.

The BlackBox features an integral barometric pressure sensor for automatic depth and DO correction and can output up to thirty-three water parameters plus barometric pressure on an SDI-12 or Modbus (RS485) Digital Interface. In addition, any two parameters can be chosen for output on the two independent 4 - 20mA analogue channels. Data is refreshed every two seconds.

Low current consumption and a rugged aluminium case make the BlackBox particularly suitable for long term unattended deployment.

For applications where water quality data needs to be collected remotely, the BlackBox is again the answer. In this configuration, logging device is replaced by a third party telemetry device that can transmit data to a remote monitoring station anywhere in the world.

1.2. The BlackBox and the Environment

The BlackBox is designed to be used outdoors and is rated to IP67, that is to say it is waterproof but it **is not** designed for submersion. Depth and Dissolved Oxygen measurements rely on the ability of the BlackBox to read atmospheric pressure. If the unit is submerged, the depth measurement feature will not work and the Dissolved Oxygen readings will be erroneous.

Please note that the socket on the BlackBox is only waterproof when the associated Aquaprobe plug is fitted. Without the plug fitted, water can enter the socket. Damage caused to the socket by water ingress is not covered by your warranty.

You may notice a small hole on the side of the unit. This is a waterproof vent for the internal barometric sensor. **Do not poke anything in this hole!** Doing so will cause major damage to the vent's waterproof membrane and invalidate your warranty.

2. Wiring Overview

The BlackBox is supplied with a screened multicore cable for connection to a variety of third party controller devices. This 6 core cable provides power in to the BlackBox and serial data out. If you have chosen to order a unit with the optional analogue channels, the BlackBox will be supplied with a 10 core cable.

Any cable cores that are not being used MUST be trimmed back and insulated from one-another, the power supply and ground. The screen (or shield) of the cable should be connected to chassis ground at the controller.

2.1. Important Information Regarding the Power Supply

If the Aquaprobe you are attaching to the BlackBox includes a **depth measurement** sensor (AP-700-D, AP-800-D, AP-2000-D, AP-5000 or AP-7000), power **must** be left applied to the BlackBox at all times. See section 4.3 Important Information Regarding Depth Measurement. If power saving is required, the white core (On/Off switch line) should be used to put the BlackBox to sleep.

If you are installing an AP-7000 with the BlackBox, power **must** be left applied to the BlackBox at all times. See section 8.4.23 Important note concerning AP-7000 self cleaning.

2.2. The Multicore Core Cable

The table below gives an overview of the cable core designations for the six/ten-core power/data cable. If you have not requested activation of the analogue channels, your BlackBox will be fitted with a six core cable. Please refer to the individual application wiring diagrams in the next section before making any connections.

Six / Ten Core Cable

Core Colour	Designation	Function
Red	Power supply +ve	10V – 14V DC +ve power supply input
Black	Power supply –ve	Power supply ground
Blue	RS485 - / SDI-12	RS485 – (B) (Modbus) or SDI-12 I/O
Green	RS485 +	RS485 + (A) (Modbus) I/O
White	On/Off switch line	Power control line (sleep mode)
Yellow	SDI-12 / Modbus	SDI-12 / Modbus select line
Brown	4 - 20mA Loop 1	Optional Analogue current loop 1 supply
Violet	4 - 20mA Loop 1	Optional Analogue current loop 1 return
Orange	4 - 20mA Loop 2	Optional Analogue current loop 2 supply
Pink	4 - 20mA Loop 2	Optional Analogue current loop 2 return

2.3. SDI-12 / Modbus Selection

The yellow core is used to select between SDI-12 or Modbus (RS485) serial data communications. Tying the yellow core to the +ve power supply will configure the digital output as Modbus (RS485). Tying the yellow core to ground will configure the digital output as SDI-12. Please note: the yellow core must not be left floating.

2.4. Sleep Mode When Configured for Modbus Output

The white core can be used to put the BlackBox into a low power sleep mode. If the white core is taken to a voltage above 6V, the BlackBox will run continuously and readings will be refreshed every 2 seconds. If the white core is taken to ground, the BlackBox will enter sleep mode.

When the white core is subsequently taken above 6V, the BlackBox will wake-up and re-enter normal running mode but **the data outputs will not be stable and valid for 40 seconds**.

If an AP-7000 is connected, the data outputs will not be stable and valid until **60 seconds** after wake-up.

2.5. Sleep Mode When Configured for SDI-12 Output

When configured for SDI-12 output, sleep mode can be configured to work automatically. If the white core is tied permanently to ground, the BlackBox will stay in sleep mode unless woken up by a 'measurement request' on the SDI-12 line. As soon as the data is ready to be sent (usually after 40 seconds), the BlackBox will issue a 'service request' to the controller. Once the controller has read the data, the BlackBox will automatically re-enter sleep mode.

If the BlackBox is running software revision 2.05 or below and an AP-7000 is connected, a self clean command will be sent to the Probe each time it is woken up. This will add a further 20 seconds to the time taken for the readings to be ready.

If the BlackBox is running software revision 3.00 and above and an AP-7000 is connected, a self clean command is not sent on each wake-up. Software revision 3.00 and above sends a self clean command every six hours, regardless of the mode selected. For this reason, it is very important that power is left applied to the BlackBox at all times.

If an AP-7000 is connected, see section 8.4.23 Important note concerning AP-7000 self cleaning.

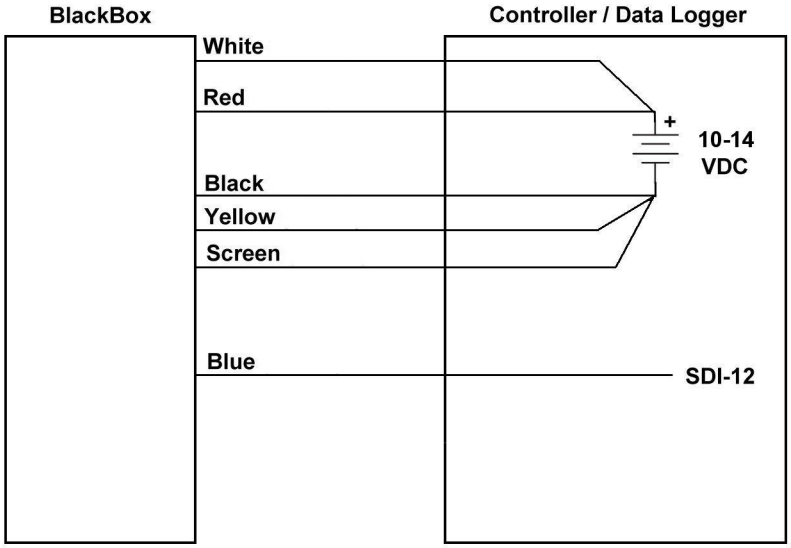
Please also refer to section 2.1 Important Information Regarding the Power Supply.

3. Application Wiring Diagrams

3.1. SDI-12 Digital Interface (always on)

In this configuration, the BlackBox is permanently on and SDI-12 data is instantly available on request. See section 8 for details of the SDI-12 data communication protocol.

Digital SDI-12 Operation (always on)



All cores not shown must be cut back and isolated

Six Core Cable Usage

Core Colour	Designation	Connection
Red	Power supply +ve	10V – 14V DC +ve power supply input
Black	Power supply –ve	Power supply ground
Blue	SDI-12	Controller SDI-12 I/O line
Green	RS485 +	Must be isolated and left floating
White	On/Off switch line	+ve power supply input
Yellow	SDI-12 / Modbus	Power supply ground
Screen	Screen / Shield	Power supply or chassis ground

In this configuration, power should be left on the BlackBox continuously.

If the controller has a switched output to control external devices, this can be connected to the white core (on/off switch line) and can be pulled to ground to put the BlackBox into sleep mode if power saving is required.

Please note: the white core must not be left floating.

If an AP-7000 is connected, see section 8.4.23 Important note concerning AP-7000 self cleaning.

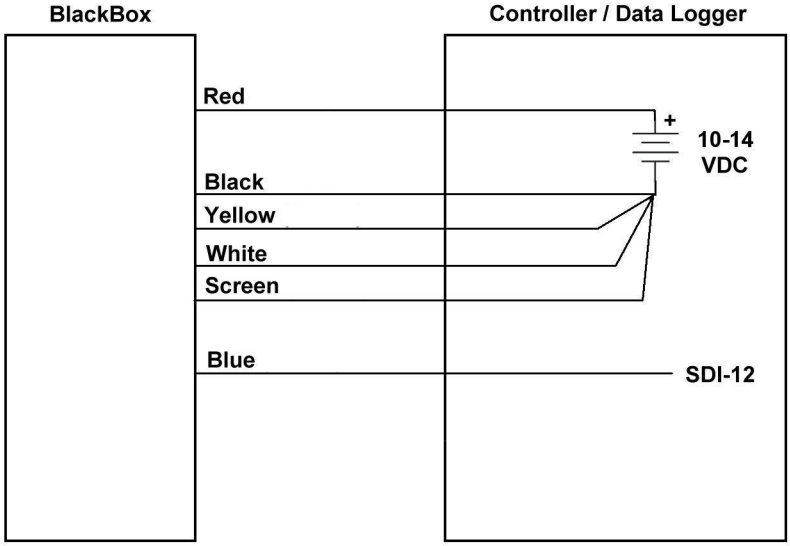
3.2. SDI-12 Digital Interface (auto sleep)

In this configuration, the BlackBox is usually in power saving (sleep) mode. Requests for data on the SDI-12 bus will wake the BlackBox up and there will be a delay of up to 40 seconds before data is ready.

If the BlackBox is running software revision 2.05 or below and an AP-7000 is connected, a self clean command will be sent to the Probe each time it is woken up. This will add a further 20 seconds to the time taken for the readings to stabilise.

As soon as the data is ready to be sent, the BlackBox will issue a 'service request' to the controller. Once the controller has read the data, the BlackBox will automatically re-enter sleep mode. See section 8 for details of the SDI-12 data communication protocol.

Digital SDI-12 Operation (auto sleep)



All cores not shown must be cut back and isolated

Six Core Cable Usage

Core Colour	Designation	Connection
Red	Power supply +ve	10V – 14V DC +ve power supply input
Black	Power supply –ve	Power supply ground
Blue	SDI-12	Controller SDI-12 I/O line
Green	RS485 +	Must be isolated and left floating
White	On/Off switch line	Power supply ground
Yellow	SDI-12 / Modbus	Power supply ground
Screen	Screen / Shield	Power supply or chassis ground

Please refer to section 2.1 Important Information Regarding the Power Supply.

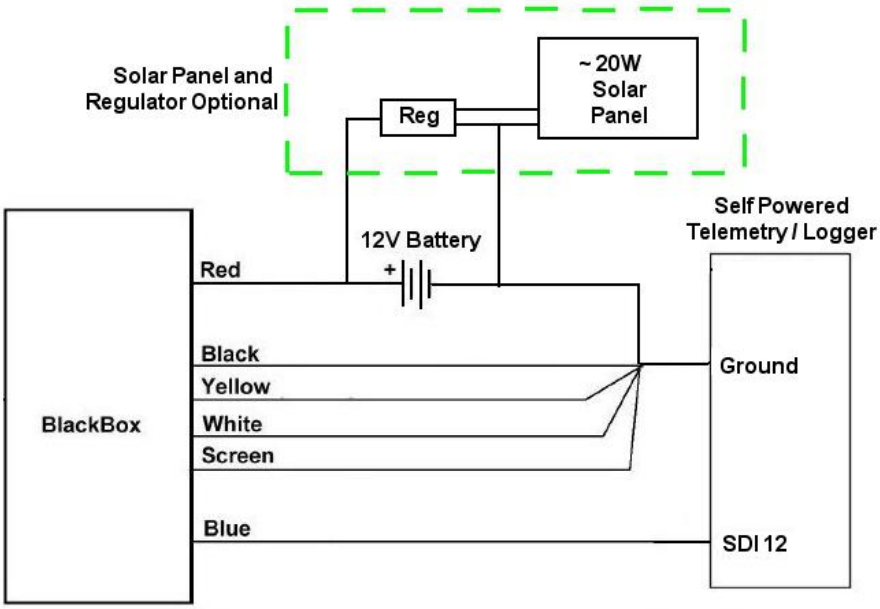
If an AP-7000 is connected, see section 8.4.23 Important note concerning AP-7000 self cleaning.

3.3. SDI-12 Digital Interface with Self Powered Telemetry and External Power

In this configuration, the telemetry or logging device connected to the BlackBox is self powered from internal batteries but the BlackBox and Aquaprobe are powered from an external battery, which can have a solar panel attached if required in order to maintain charge.

The BlackBox is usually in power saving (sleep) mode. Requests for data on the SDI-12 bus will wake the BlackBox up and there will be a delay of up to 40 seconds (60 seconds for an AP-7000) before data is ready. During this time power will be drawn from the external battery. After the reading, the BlackBox will re-enter sleep mode.

Digital SDI-12 Operation (auto sleep) With External Battery and Optional Solar Power Supply



All cores not shown must be cut back and isolated

Six Core Cable Usage

Core Colour	Designation	Connection
Red	Power supply +ve	10V – 14V DC +ve power supply input
Black	Power supply –ve	Power supply ground
Blue	SDI-12	Controller SDI-12 I/O line
Green	RS485 +	Must be isolated and left floating
White	On/Off switch line	Power supply ground
Yellow	SDI-12 / Modbus	Power supply ground
Screen	Screen / Shield	Power supply or chassis ground

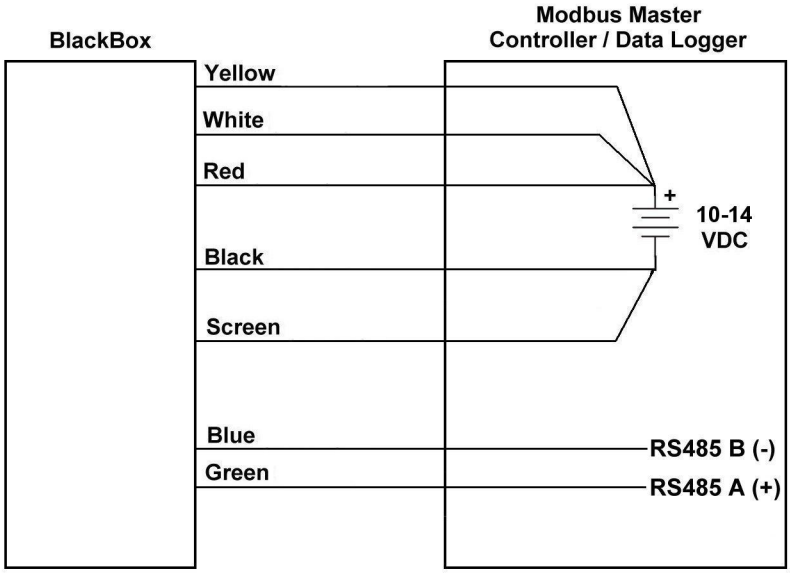
If the optional solar panel is to be used, the 12V battery should be sized at ~6Ah. If the solar panel is not going to be included, a larger 12V battery (such as a car or caravan battery) will be required, dependant upon the sampling rate and the proposed re-charge interval.

If an AP-7000 is connected, see section 8.4.23 Important note concerning AP-7000 self cleaning.

3.4. Modbus Master Digital Interface

In this configuration, the BlackBox is permanently on and Modbus data is instantly available on request. See section 9 for details of the Modbus data communication protocol.

Digital Modbus Operation



All cores not shown must be cut back and isolated

Six Core Cable Usage

Core Colour	Designation	Connection
Red	Power supply +ve	10V – 14V DC +ve power supply input
Black	Power supply –ve	Power supply ground
Blue	RS485 (-/B)	Controller RS485 (- or B) line
Green	RS485 (+/A)	Controller RS485 (+ or A) line
White	On/Off switch line	+ve power supply input
Yellow	SDI-12 / Modbus	+ve power supply input
Screen	Screen / Shield	Power supply or chassis ground

Please refer to section 2.1 Important Information Regarding the Power Supply.

If the controller has a switched output to control external devices, this can be connected to the white core (on/off switch line) and can be pulled to ground to put the BlackBox into sleep mode if power saving is required.

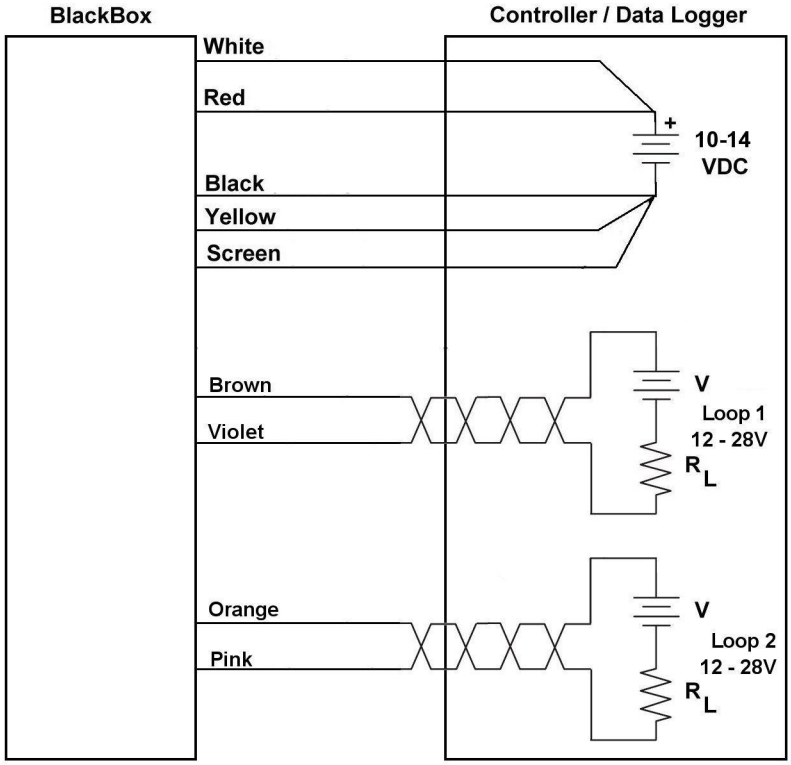
If the BlackBox is put into sleep mode, then the white core is subsequently taken above 6V, the BlackBox will re-enter normal running mode but the **data will not be stable and valid for 40 seconds**.

If an AP-7000 is connected, the data outputs will not be stable and valid for up to **60 seconds** after leaving sleep mode. See 9.7 Important note concerning AP-7000 self cleaning.

3.5. 4-20mA Current Loops

The two optional 4-20mA current loops are factory programmable only. The required outputs from the two current loops should have been specified at the time of ordering. If this was done, your BlackBox will have been supplied with a ten core cable and the analogue outputs will conform to your requested parameters and ranges.

Analogue 4-20mA Current Loop Operation



If Green and Blue cores are not being used for digital data, they must be cut back and insulated

In the configuration shown above, the BlackBox is permanently on and the current loops are permanently active. SDI-12 digital operation is also selected (yellow core).

Ten Core Cable Usage

Core Colour	Designation	Function
Red	Power supply +ve	10V – 14V DC +ve power supply input (see note 2)
Black	Power supply –ve	Power supply ground
Blue	RS485 - / SDI-12	RS485 – (B) (Modbus) or SDI-12 I/O
Green	RS485 +	RS485 + (A) (Modbus) I/O
White	On/Off switch line	Power control line (see note 3)
Yellow	SDI-12 / Modbus	SDI-12 / Modbus select line (see previous sections)
Brown	4 - 20mA Loop 1	Analogue current loop 1 supply (see note 1)
Violet	4 - 20mA Loop 1	Analogue current loop 1 return (see note 1)
Orange	4 - 20mA Loop 2	Analogue current loop 2 supply (see note 1)
Pink	4 - 20mA Loop 2	Analogue current loop 2 return (see note 1)

Note 1: The two 4-20mA current loop outputs are completely isolated from each other and from the rest of the BlackBox circuitry. Whilst the cores assigned to the two current loops are designated as supply and return respectively, they are, in fact, bi-polar and can be connected either way round.

Note 2: the BlackBox must have its normal power supply connected and the on/off switch line (white core) taken high in order for the current loop outputs to work. The current loop outputs operate independently from the digital output which can be used simultaneously if required.

Note 3: In this configuration, power should be left on the BlackBox continuously.

If the controller has a switched output to control external devices, this can be connected to the white core (on/off switch line) and can be pulled to ground to put the BlackBox into sleep mode if power saving is required.

If the BlackBox is put into sleep mode, then the white core is subsequently taken above 6V, the BlackBox will re-enter normal running mode but **the 4-20mA loops will not be stable and valid for 40 seconds**.

If an AP-7000 is connected, **the 4-20mA loops will not be stable and valid for 60 seconds** after leaving sleep mode.

If the BlackBox is running software revision 2.05 or below and an AP-7000 is connected, a self clean command will be sent to the Probe each time it is woken up.

If the BlackBox is running software revision 3.00 and above and an AP-7000 is connected, a self clean command is not sent on each wake-up. Software revision 3.00 and above sends a self clean command every six hours, regardless of the mode selected. For this reason, power should be left applied to the BlackBox at all times. If a low power mode is required between readings, use the on/off (sleep) line.

Please refer to section 2.1 Important Information Regarding the Power Supply.

4. Installation

The BlackBox features an aluminium flange with four 5mm (3/16”) mounting holes. The unit should be fixed using these mounting holes in a sheltered position where it can not become submerged in water.

4.1. Calibrating the Aquaprobe

Prior to use, the selected Aquaprobe should be fully calibrated using an Aquaread Aquameter or an AP-PC Kit and a set of calibration standards. See the latest revision of the relevant Aquaprobe Instruction Manual for calibration procedures.

4.2. Connecting the Aquaprobe

With the power switched off, the selected Aquaprobe should be plugged into the socket on the BlackBox. When the power is switched on, the bi-colour LED should light continuously in yellow for two seconds to indicate the probe has been successfully recognised and initialised. If the LED flashes red, this means there is a problem. Refer to section 4.5 LED Indications for more information.

4.3. Important Information Regarding Depth Measurement

Depth is measured in the Aquaprobe by a pressure sensor mounted inside the body of the probe. The depth measurement reference point on the Aquaprobe is the top row of holes in the sleeve. Depth is calculated by subtracting the barometric pressure being measured in the BlackBox from the water pressure being measured in the Aquaprobe. The pressure differential, once corrected for temperature and salinity (water density), is directly proportional to depth.

The depth measurement system uses the EC sensor to detect when the probe has been placed in water. All the time the probe is measuring an EC of zero, the depth will read zero and the depth zero datum will be kept updated.

For this reason, it is important to ensure the Aquaprobe is connected to the BlackBox, power is applied and the BlackBox has been awake and has taken readings (LED flashing yellow) **before the Aquaprobe is lowered into the water.** It is also important that power is left applied to the BlackBox at all times or the depth zero datum will be lost.

Please also refer to section 2.1 Important Information Regarding the Power Supply.

4.4. Normal Operation

Directly after the application of power, the BlackBox will light the bi-colour LED yellow for two seconds then proceed to take readings at two-second intervals. Each time a reading is taken, the LED will give a single, short yellow flash. Each time the BlackBox communicates with the controlling device, the LED in the BlackBox will light up yellow for ½ a second.

So, during normal operation, you should see the LED give a brief yellow flash every two seconds and a longer yellow flash periodically, depending on the sample rate set up in the controller.

If the BlackBox is configured in ‘auto sleep’ mode, readings will be taken for 40 seconds from power-up before the unit enters sleep mode. During this initial power-up period, the Aquaprobe should be **out of the water** in order to establish the depth zero datum.

When in sleep mode, the LED will not flash.

4.5. LED Indications

The BlackBox has a single, bi-colour LED positioned next to the probe socket. This LED is used to indicate the status of the BlackBox by flashing at various rates in either red or yellow. The chart below shows the possible combinations and what they mean.

Sequence	What it means	Action
Short yellow flash every 2 seconds	The BlackBox has just communicated with the Aquaprobe.	Normal operation. No action required
Long yellow flash	The BlackBox has just communicated with the controller device.	Normal operation. No action required
Single red flash every two seconds	BlackBox can not read the Aquaprobe.	See Troubleshooting below
Two short red flashes every 2 seconds	The Aquaprobe's pH electrode requires servicing or calibration.	See Troubleshooting below and the Aquaprobe manual.
Three short red flashes every 2 seconds	The probe's optical DO electrode requires servicing or calibration	See Troubleshooting below and the Aquaprobe manual.

If a probe error condition occurs, the short yellow flash that indicates probe communication will be replaced by one of the three red flashing sequences.

5. TROUBLESHOOTING

This section details some of the common difficulties you may encounter when using the BlackBox. Try all the suggested remedies. If your problem is still unresolved, contact our Service Department.

Problem	Cause / Remedy
The BlackBox LED does not flash at all.	✓ The unit may be in auto-sleep mode. ✓ Power supply problem. Check all connections. ✓ The white power control wire may be grounded causing the unit to be permanently asleep. ✓ The internal fuse may be blown. Remove lid and check fuse.
The BlackBox LED gives a single red flash even when the Aquaprobe is connected.	✓ Probably a poor connection. Disconnect the Aquaprobe plug, ensure there is no debris or moisture in the plug and socket, then re-connect the plug ensuring it is fully inserted and that the screw collar is fully tightened.
The BlackBox LED gives a double red flash every two seconds.	✓ This means the pH electrode fitted to the probe has dropped below 85% efficiency. Try cleaning the pH electrode and re-calibrating as described in the relevant section of the Aquaprobe manual. If that does not cure the problem, replace the pH/ORP electrode.
The BlackBox LED gives a triple red flash every two seconds.	✓ This means the Optical DO electrode on the Aquaprobe needs calibrating or the cap needs replacing. Perform a full DO calibration, first at DO Zero then at 100% DO as described in the relevant section of the Aquaprobe manual. If that does not cure the problem, replace the Optical DO Cap.
No output on the 4-20mA current loops.	✓ Current loops do not become live until 40 seconds after power on or wake-up. ✓ BlackBox not reading the Aquaprobe. Check LED indications.

6. DECLARATION OF CONFORMITY

The manufacturer declares that the equipment described herein is in compliance with the essential requirements and other relevant provisions of Directives 2004/108/EC and 1999/5/EC.

7. Technical Specification

Input Voltage	10V – 14V DC
Operating Temperature	-5ºC – 50ºC
Input Current* (awake)	~ 40mA (AP-Lite / AquaPlus / AP-700 - AP-2000 attached) ~ 80mA (AP-5000 or AP-7000 attached) ~ 300mA (AP-7000 during self cleaning cycle)
Input Current (asleep)	< 500µA
Protection Class	IP67 (must not be submerged due to barometric pressure sensor)
Dimensions	140mm x 65mm x 30mm (5.5” x 2.6” x 1.2”)
Weight	400g (14oz)
Connections	Probe socket & 1M screened power/data cable
Fixing	Aluminium flange with four 5mm (3/16”) mounting holes
Digital Interface	User selectable between SDI-12 and Modbus (RS485)
Update rate	All data is refreshed every 2 seconds when not in sleep mode
Current Loop Accuracy	+/-0.2mA (represents +/-1.25% of FS digital value)

*Input currents are shown as approximate because current consumption varies with the number and type of optional electrodes fitted to the Aquaprobe.

Aquaread reserves the right to alter specifications without notice.

8. SDI-12 Data Communication Protocol

SDI-12 is a standard for interfacing data recorders with microprocessor-based sensors. SDI-12 stands for serial/digital interface at 1200 baud. This section describes the protocol for communications between the BlackBox and SDI-12 data recorders complying with Version 1.3 of the SDI-12 standard.

8.1. Data Packet Formats

The BlackBox responds to commands sent to it by an SDI-12 data recorder. Command packets should have the format:

<a><command-data>!

where:

- <a> is the BlackBox address character (valid values are ASCII “0”-”9”, “A”-”Z”, “a”-”z” & “?”)
- <command-data> is a string of zero or more command dependent data characters (values in the range 0x20-0x7E, excluding 0x21 (ASCII “!”))
- the packet is terminated by 0x21 (ASCII “!”)

Response packets have the format:

<a><response-data>[<crc>]<CR><LF>

where:

- <a> is the BlackBox's address character
- <response-data> is a string of zero or more command dependent data characters (values in the range 0x20-0x7E)
- <crc>, when present, is a string of 3 characters encoding the cyclic redundancy check of the response data (1st character in the range 0x40-0x4F, 2nd & 3rd characters in the range 0x40-0x7F)
- the packet is terminated by a carriage return followed by a line feed

The formats of the individual command/response packets that the BlackBox supports are described in the following subsections. Any measurement values that are invalid will be returned with all fields set to 9.

8.1.1. Acknowledge Active

This command allows the data recorder to check that the BlackBox is present on the SDI-12 bus.

Command	Response
<a>!	<a><CR><LF>

8.1.2. Address Query

This command allows the data recorder to obtain a sensor's address character. It must only be issued when there is just one sensor attached to the bus, otherwise all sensors will respond, causing bus contention.

Command	Response
?!	<a><CR><LF>

8.1.3. Change Address

This command allows the data recorder to assign a new address to the BlackBox.

Command	Response
<a>A<b>!	<b><CR><LF>

- <b> is a new address to be assigned to the unit (1 character, value “0”-”9”, “A”-”Z” or “a”-”z”)

8.1.4. Send Identification

This command allows the data recorder to retrieve some basic information about the BlackBox and the Aquaprobe attached to it.

Command	Response
<a>I!	<a><sdi-ver><vendor-id><model-nr><firmware-ver><serial-nr><CR><LF>

- <sdi-ver> is the version of the supported SDI-12 standard (“13” for version 1.3)
- <vendor-id> is an 8-character vendor identification string (“AQUAREAD”)
- <model-nr> is a 6-character Aquaprobe model string (e.g. “AP1000”)
- <firmware-ver> is the 3-digit Probe's firmware version string (e.g. “100” for v1.00)
- <serial-nr> is the Probe's serial number string (may be up to 13 characters)

8.1.5. Start Measurement

This command tells the BlackBox to start making a measurement.

Command	Response
<a>M!	<a><time><nr-values><CR><LF>

- <time> is the time in seconds (three digits) until the measurement will be ready
- <nr-values> is a single digit (“0”-“9”) specifying the number of measurements that will be returned by subsequent Send Data commands

8.1.6. Additional Measurements

This command tells the BlackBox to start making a measurement.

Command	Response
<a>M<set>!	<a><time><nr-values><CR><LF>

- <set> is a digit (“1”-”9”) indicating which set of additional measurements is being requested
- <time> is the time in seconds (three digits) until the measurement will be ready
- <nr-values> is a single digit (“0”-“9”) specifying the number of measurements that will be returned by subsequent Send Data commands

8.1.7. Start Measurement and Request CRC

This command tells the BlackBox to start making a measurement.

Command	Response
<a>MC!	<a><time><nr-values><CR><LF>

- <time> is the time in seconds (three digits) until the measurement will be ready
- <nr-values> is a single digit (“0”-“9”) specifying the number of measurements that will be returned by subsequent Send Data commands

8.1.8. Additional Measurements and Request CRC

This command tells the BlackBox to start making a measurement.

Command	Response
<a>MC<set>!	<a><time><nr-values><CR><LF>

- <set> is a digit (“1”-”9”) indicating which set of additional measurements is being requested
- <time> is the time in seconds (three digits) until the measurement will be ready
- <nr-values> is a single digit (“0”-“9”) specifying the number of measurements that will be returned by subsequent Send Data commands

8.1.9. Start Concurrent Measurement

This command tells the Black Box to start making a measurement.

Command	Response
<a>C!	<a><time><nr-values><CR><LF>

- <time> is the time in seconds (three digits) until the measurement will be ready
- <nr-values> is a two-digit number (“01”-“20”) specifying the number of measurements that will be returned by a subsequent D0 command

8.1.10. Additional Concurrent Measurements

This command tells the BlackBox to start making a measurement.

Command	Response
<a>C<set>!	<a><time><nr-values><CR><LF>

- <set> is a digit (“1”-”9”) indicating which set of additional measurements is being requested
- <time> is the time in seconds (three digits) until the measurement will be ready
- <nr-values> is a two-digit number (“00”-“20”) specifying the number of measurements that will be returned by subsequent D commands

8.1.11. Start Concurrent Measurement and Request CRC

This command tells the BlackBox to start making a measurement.

Command	Response
<a>CC!	<a><time><nr-values><CR><LF>

- <time> is the time in seconds (three digits) until the measurement will be ready
- <nr-values> is a two-digit number (“01”-“20”) specifying the number of measurements that will be returned by a subsequent D0 command

8.1.12. Additional Concurrent Measurements and Request CRC

This command tells the BlackBox to start making a measurement.

Command	Response
<a>CC<set>!	<a><time><nr-values><CR><LF>

- <set> is a digit (“1”-”9”) indicating which set of additional measurements is being requested
- <time> is the time in seconds (three digits) until the measurement will be ready
- <nr-values> is a two-digit number (“00”-“20”) specifying the number of measurements that will be returned by subsequent D commands

8.1.13. Start Verification

This command can be used to initiate the BlackBox’s self-tests.

Command	Response
<a>V!	<a><time><nr-values><CR><LF>

- <time> is the time in seconds (three digits) until the measurement will be ready
- <nr-values> is a single digit (“0”-“9”) specifying the number of numerical values that will be returned by subsequent D commands

8.1.14. Service Request

The service request is a signal sent by the BlackBox to indicate that a measurement has been completed and is ready to read.

Service Request	<a><CR><LF>

8.1.15. Send Data

This command is used by the data recorder to retrieve the measurement values after a measurement has been completed.

Command	Response
<a>D<sequence-nr>!	<a><values>[<crc>]<CR><LF>

- <sequence-nr> is a single digit (“0”-”9”) indicating the data packet number being requested
- <values> is a string of measurement results, each consisting of a sign character (“+” or “-”), 1-7 digits and an optional decimal point
- the <crc> field will be present if measurement with CRC was requested, and is a 3 byte string containing the encoded CRC of the response packet

The maximum size of the <values> field is 75 characters when following a concurrent measurement request, or 35 characters when following a non-concurrent measurement request.

8.1.16. Continuous Measurements

This command is used by the data recorder to retrieve measurements immediately without a separate Start Measurement command.

Command	Response
<a>R<set>!	<a><values><CR><LF>

- <set> is a digit (“1”-”9”) indicating which set of measurements is being requested
- <values> is a string of measurement results, each consisting of a sign character (“+” or “-”), 1-7 digits and an optional decimal point

The maximum size of the <values> field is 75 characters.

8.1.17. Continuous Measurements and Request CRC

This command is used by the data recorder to retrieve measurements immediately without a separate Start Measurement command.

Command	Response
<a>RC<set>!	<a><values><crc><CR><LF>

- <set> is a digit (“1”-”9”) indicating which set of measurements is being requested
- <values> is a string of measurement results, each consisting of a sign character (“+” or “-”), 1-7 digits and an optional decimal point
- <crc> is a 3 byte string containing the encoded CRC of the response packet

The maximum size of the <values> field is 75 characters.

8.2. BlackBox Address

The BlackBox stores an SDI-12 sensor address in its EEPROM. The sensor address is a single character from the set “0”-”9”, “A”-”Z” & “a-”z”. With the exception of the Address Query command, the BlackBox will only respond to commands beginning with its sensor address.

The BlackBox's sensor address is set to “0” during production. When a Change Address command is received, the new address will replace the sensor address in the BlackBox’s EEPROM and the BlackBox will only respond to subsequent commands (again with the exception of the Address Query command) sent to that new address. The BlackBox will always respond to the Address Query command, regardless of the stored sensor address.

8.3. Unit Identification

In its response to a Send Identification command, the BlackBox will report compatibility with SDI-12 version 1.3, the vendor ID “AQUAREAD”, a sensor model number string dependent upon the type of Aquaprobe connected to it (see Table 1), and the BlackBox's firmware revision number and serial number.

Probe Type	Model Number String
AP-100	“AP100 ”
AP-100 with depth	“AP100D”
AP-200	“AP200 ”
AP-200 with depth	“AP200D”
AP-300	“AP300 ”
AP-300 with depth	“AP300D”
AP-400	“AP400 ”
AP-400 with depth	“AP400D”
AP-500	“AP500 ”
AP-500 with depth	“AP500D”
AP-600	“AP600 ”
AP-600 with depth	“AP600D”
AP-700	“AP700 ”
AP-700 with depth	“AP700D”
AP-800	“AP800 ”
AP-800 with depth	“AP800D”
AP-900	“AP900 ”
AP-900 with depth	“AP900D”
AP-1000	“AP1000”
AquaPlus	“AQ+ ”
AP-2000	“AP2000”
AP-2000 with depth	“AP2KD”
AP-Lite	“APLITE”
AP-5000	“AP5000”
AP-7000	“AP7000”

Table 1: Probe Type Model Number Strings

8.4. Measurement Commands

On reception of any Start Measurement, Additional Measurement, Start Concurrent Measurement or Additional Concurrent Measurement command (with or without CRC request), the BlackBox will respond indicating a measurement time.

If the BlackBox is configured in ‘always on’ mode, the measurement time will be “000”. If the BlackBox is configured in ‘auto sleep’ mode, the measurement time can be up to “040”. Following the measurement time, the BlackBox will send the number of measurements it will be sending dependent upon the type of Aquaprobe connected to it.

If the measurement time sent by the BlackBox is “000”, the data recorder should immediately respond with a Send Data command, to which the BlackBox will respond with a packet containing appropriate measurements dependent upon the type of Aquaprobe connected to it and upon the measurement set requested. The response will also contain a CRC, if requested.

If the measurement time sent by the BlackBox is greater than “000”, the data recorder should wait for the BlackBox to send a Service Request before sending the Send Data command.

After sending this response, the BlackBox will relinquish control of the data line and wait for the data recorder to request the measurements with one or more Send Data commands.

The first Send Data command will have a sequence number “0” and for subsequent Send Data commands the sequence number will be incremented by 1 (unless data is re-requested due to a transmission/reception error, in which case the sequence number will not change).

The size limit of the <values> field in the data response packet may require that the measurements returned by the BlackBox be split across multiple data responses. The data recorder will continue to request data packets until it has received the expected number of measurement values (as reported in the response to the Start Measurement/Additional Measurement/Start Concurrent/Additional Concurrent Measurement command).

After a Start Measurement or Additional Measurement command & response, the data recorder may abort the measurement by sending a command to another probe (preceded by a break frame) or a command other than Send Data to the BlackBox.

After a Start Concurrent Measurement or Additional Concurrent Measurement command & response, the data recorder may abort the measurement by sending a command other than Send Data to the BlackBox. (The data recorder may send commands to other probes on the same SDI-12 bus without aborting a concurrent measurement.)

If the data recorder sends any Send Data command to the BlackBox not preceded by any form of measurement start command or after aborting a measurement sequence, then the response will not contain any data values.

On reception of a Continuous Measurement command (with or without CRC request), the BlackBox will respond with a packet containing appropriate measurements dependent upon the type of Aquaprobe connected to it and upon the measurement set requested. The response will also contain a CRC, if requested.

Table 2 details the measurements provided by the BlackBox and the following subsections describe the contents of the measurement related packets for each type of Aquaprobe.

Field name	Measurement	Units
<baro>	Barometric pressure	mbar
<temp>	Temperature	°C
<ph>	pH	pH
<orp>	Oxidation/reduction potential	mV
<turb>	Turbidity	NTU (Nephelometric Turbidity Units)
<cond>	Electrical conductivity	µS/cm
<cond20>	Electrical conductivity (corrected to 20°C)	µS/cm
<cond25>	Electrical conductivity (corrected to 25°C)	µS/cm
<res>	Electrical resistivity	kΩ.cm
<sal>	Salinity	PSU (Practical Salinity Units)
<tds>	Totally dissolved solids	mg/L

<ssg>	Specific seawater gravity	σ_t
<do>	Dissolved oxygen	mg/L
<do-sat>	Dissolved oxygen	% saturation
<depth>	Probe depth	m
<aux1>	AUX1 measurement	dependent upon type of electrode fitted
<aux2>	AUX2 measurement	dependent upon type of electrode fitted
<aux3>	AUX3 measurement	dependent upon type of electrode fitted
<aux4>	AUX4 measurement	dependent upon type of electrode fitted
<aux5>	AUX5 measurement	dependent upon type of electrode fitted
<aux6>	AUX6 measurement	dependent upon type of electrode fitted
<nh3>	Ammonia concentration	mg/L

Table 2: Measurements and Units

8.4.1. AP-100

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0003<CR><LF>
<a>D0!	<a><baro><temp><ph><CR><LF> or <a><baro><temp><ph><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! up to <a>M9! or <a>MC1! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00003<CR><LF>
<a>D0!	<a><baro><temp><ph><CR><LF> or <a><baro><temp><ph><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-100 continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><CR><LF> or <a><baro><temp><ph><crc><CR><LF>

Command	Response
<a>R1! to <a>R9! or <a>RC1! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.2. AP-100 with Depth

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0004<CR><LF>
<a>D0!	<a><baro><temp><ph><depth><CR><LF> or <a><baro><temp><ph><depth><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! up to <a>M9! or <a>MC1! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00004<CR><LF>
<a>D0!	<a><baro><temp><ph><depth><CR><LF> or <a><baro><temp><ph><depth><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><depth><CR><LF> or <a><baro><temp><ph><depth><crc><CR><LF>

Command	Response
<a>R1! to <a>R9! or <a>RC1! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.3. AP-200

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0003<CR><LF>
<a>D0!	<a><baro><temp><turb><CR><LF> or <a><baro><temp><turb><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! up to <a>M9! or <a>MC1! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00003<CR><LF>
<a>D0!	<a><baro><temp><turb><CR><LF> or <a><baro><temp><turb><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><turb><CR><LF> or <a><baro><temp><turb><crc><CR><LF>

Command	Response
<a>R1! to <a>R9! or <a>RC1! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.4. AP-200 with Depth

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0004<CR><LF>
<a>D0!	<a><baro><temp><turb><depth><CR><LF> or <a><baro><temp><turb><depth><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! up to <a>M9! or <a>MC1! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00004<CR><LF>
<a>D0!	<a><baro><temp><turb><depth><CR><LF> or <a><baro><temp><turb><depth><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><turb><depth><CR><LF> or <a><baro><temp><turb><depth><crc><CR><LF>

Command	Response
<a>R1! to <a>R9! or <a>RC1! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.5. AP-300

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><cond><cond20><cond25><CR><LF> or <a><baro><temp><cond><cond20><cond25><crc><CR><LF>
<a>D1!	<a><res><sal><tds><ssg><CR><LF> or <a><res><sal><tds><ssg><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0002<CR><LF>
<a>D0!	<a><do><do-sat><CR><LF> or <a><do><do-sat><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00011<CR><LF>
<a>D0!	<a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><CR><LF> or <a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-300 continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><CR><LF> or <a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><crc><CR><LF>

Command	Response
<a>R1! to <a>R9! or <a>RC1! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.6. AP-300 with Depth

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><cond><cond20><cond25><CR><LF> or <a><baro><temp><cond><cond20><cond25><crc><CR><LF>
<a>D1!	<a><res><sal><tds><ssg><CR><LF> or <a><res><sal><tds><ssg><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0003<CR><LF>
<a>D0!	<a><do><do-sat><depth><CR><LF> or <a><do><do-sat><depth><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00012<CR><LF>
<a>D0!	<a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><CR><LF> or <a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><crc><CR><LF>
<a>D1!	<a><depth><CR><LF> or <a><depth><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-300 with Depth continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><CR><LF> or <a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><depth><CR><LF> or <a><depth><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.7. AP-400

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0004<CR><LF>
<a>D0!	<a><baro><temp><ph><turb><CR><LF> or <a><baro><temp><ph><turb><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! up to <a>M9! or <a>MC1! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00004<CR><LF>
<a>D0!	<a><baro><temp><ph><turb><CR><LF> or <a><baro><temp><ph><turb><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><turb><CR><LF> or <a><baro><temp><ph><turb><crc><CR><LF>

8.4.8. AP-400 with Probe

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0005<CR><LF>
<a>D0!	<a><baro><temp><ph><turb><depth><CR><LF> or <a><baro><temp><ph><turb><depth><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! up to <a>M9! or <a>MC1! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00005<CR><LF>
<a>D0!	<a><baro><temp><ph><turb><depth><CR><LF> or <a><baro><temp><ph><turb><depth><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><turb><depth><CR><LF> or <a><baro><temp><ph><turb><depth><crc><CR><LF>

Command	Response
<a>R1! to <a>R9! or <a>RC1! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.9. AP-500

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><cond><cond20><CR><LF> or <a><baro><temp><ph><cond><cond20><crc><CR><LF>
<a>D1!	<a><cond25><res><sal><tds><CR><LF> or <a><cond25><res><sal><tds><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0003<CR><LF>
<a>D0!	<a><ssg><do><do-sat><CR><LF> or <a><ssg><do><do-sat><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00012<CR><LF>
<a>D0!	<a><baro><temp><ph><cond><cond20><cond25><res><sal><tds><ssg> <do><CR><LF> or <a><baro><temp><ph><cond><cond20><cond25><res><sal><tds><ssg> <do><crc><CR><LF>
<a>D1!	<a><do-sat><CR><LF> or <a><do-sat><crc><CR><LF>

AP-500 continued...

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><cond><cond20><cond25><res><sal><tds><ssg> <do><CR><LF> or <a><baro><temp><ph><cond><cond20><cond25><res><sal><tds><ssg> <do><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><do-sat><CR><LF> or <a><do-sat><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.10. AP-500 with Probe

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><cond><cond20><CR><LF> or <a><baro><temp><ph><cond><cond20><crc><CR><LF>
<a>D1!	<a><cond25><res><sal><tds><CR><LF> or <a><cond25><res><sal><tds><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0004<CR><LF>
<a>D0!	<a><ssg><do><do-sat><depth><CR><LF> or <a><ssg><do><do-sat><depth><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00013<CR><LF>
<a>D0!	<a><baro><temp><ph><cond><cond20><cond25><res><sal><tds><ssg> <do><CR><LF> or <a><baro><temp><ph><cond><cond20><cond25><res><sal><tds><ssg> <do><crc><CR><LF>
<a>D1!	<a><do-sat><depth><CR><LF> or <a><do-sat><depth><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-500 with Depth continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><cond><cond20><cond25><res><sal><tds><ssg> <do><CR><LF> or <a><baro><temp><ph><cond><cond20><cond25><res><sal><tds><ssg> <do><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><do-sat><depth><CR><LF> or <a><do-sat><depth><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.11. AP-600

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><turb><cond><CR><LF> or <a><baro><temp><ph><turb><cond><crc><CR><LF>
<a>D1!	<a><cond20><cond25><res><sal><CR><LF> or <a><cond20><cond25><res><sal><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0004<CR><LF>
<a>D0!	<a><tds><ssg><do><do-sat><CR><LF> or <a><tds><ssg><do><do-sat><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00013<CR><LF>
<a>D0!	<a><baro><temp><ph><turb><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><turb><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>
<a>D1!	<a><do><do-sat><CR><LF> or <a><do><do-sat><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-600 continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><turb><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><turb><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><do><do-sat><CR><LF> or <a><do><do-sat><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.12. AP-600 with Depth

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><turb><cond><CR><LF> or <a><baro><temp><ph><turb><cond><crc><CR><LF>
<a>D1!	<a><cond20><cond25><res><sal><CR><LF> or <a><cond20><cond25><res><sal><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0005<CR><LF>
<a>D0!	<a><tds><ssg><do><do-sat><depth><CR><LF> or <a><tds><ssg><do><do-sat><depth><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00014<CR><LF>
<a>D0!	<a><baro><temp><ph><turb><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><turb><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>
<a>D1!	<a><do><do-sat><depth><CR><LF> or <a><do><do-sat><depth><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-600 with Depth continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><turb><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><turb><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><do><do-sat><depth><CR><LF> or <a><do><do-sat><depth><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.13. AP-700

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><CR><LF> or <a><baro><temp><ph><orp><cond><crc><CR><LF>
<a>D1!	<a><cond20><cond25><res><sal><CR><LF> or <a><cond20><cond25><res><sal><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0004<CR><LF>
<a>D0!	<a><tds><ssg><do><do-sat><CR><LF> or <a><tds><ssg><do><do-sat><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00013<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>
<a>D1!	<a><do><do-sat><CR><LF> or <a><do><do-sat><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-700 continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><do><do-sat><CR><LF> or <a><do><do-sat><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.14. AP-700 with Depth

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><CR><LF> or <a><baro><temp><ph><orp><cond><crc><CR><LF>
<a>D1!	<a><cond20><cond25><res><sal><CR><LF> or <a><cond20><cond25><res><sal><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0005<CR><LF>
<a>D0!	<a><tds><ssg><do><do-sat><depth><CR><LF> or <a><tds><ssg><do><do-sat><depth><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00014<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>
<a>D1!	<a><do><do-sat><depth><CR><LF> or <a><do><do-sat><depth><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-700 with Depth continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><do><do-sat><depth><CR><LF> or <a><do><do-sat><depth><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.15. AP-800(software version 3.53 and below) and AP-900

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><turb><CR><LF> or <a><baro><temp><ph><orp><turb><crc><CR><LF>
<a>D1!	<a><cond><cond20><cond25><res><CR><LF> or <a><cond><cond20><cond25><res><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0005<CR><LF>
<a>D0!	<a><sal><tds><ssg><do><do-sat><CR><LF> or <a><sal><tds><ssg><do><do-sat><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00014<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><turb><cond><cond20><cond25><res><sal> <tds><CR><LF> or <a><baro><temp><ph><orp><turb><cond><cond20><cond25><res><sal> <tds><crc><CR><LF>
<a>D1!	<a><ssg><do><do-sat><CR><LF> or <a><ssg><do><do-sat><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-800 and AP-900 continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><orp><turb><cond><cond20><cond25><res><sal> <tds><CR><LF> or <a><baro><temp><ph><orp><turb><cond><cond20><cond25><res><sal> <tds><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><ssg><do><do-sat><CR><LF> or <a><ssg><do><do-sat><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.16. AP-800 with Depth (software version 3.53 and below), AP-900 with Depth & AP-1000

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><turb><CR><LF> or <a><baro><temp><ph><orp><turb><crc><CR><LF>
<a>D1!	<a><cond><cond20><cond25><res><CR><LF> or <a><cond><cond20><cond25><res><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0006<CR><LF>
<a>D0!	<a><sal><tds><ssg><do><do-sat><CR><LF> or <a><sal><tds><ssg><do><do-sat><crc><CR><LF>
<a>D1!	<a><depth><CR><LF> or <a><depth><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00015<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><turb><cond><cond20><cond25><res><sal> <tds><CR><LF> or <a><baro><temp><ph><orp><turb><cond><cond20><cond25><res><sal> <tds><crc><CR><LF>
<a>D1!	<a><ssg><do><do-sat><depth><CR><LF> or <a><ssg><do><do-sat><depth><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-800 with Depth (software version 3.53 and below), AP-900 with Depth & AP-1000 continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><orp><turb><cond><cond20><cond25><res><sal> <tds><CR><LF> or <a><baro><temp><ph><orp><turb><cond><cond20><cond25><res><sal> <tds><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><ssg><do><do-sat><depth><CR><LF> or <a><ssg><do><do-sat><depth><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.17. AquaPlus Probe

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><cond><cond20><cond25><CR><LF> or <a><baro><temp><cond><cond20><cond25><crc><CR><LF>
<a>D1!	<a><res><sal><tds><ssg><CR><LF> or <a><res><sal><tds><ssg><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0002<CR><LF>
<a>D0!	<a><do><do-sat><CR><LF> or <a><do><do-sat><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00011<CR><LF>
<a>D0!	<a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><CR><LF> or <a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><CR><LF> or <a><baro><temp><cond><cond20><cond25><res><sal><tds><ssg><do> <do-sat><crc><CR><LF>

AquaPlus Probe continued...

Command	Response
<a>R1! to <a>R9! or <a>RC1! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.18. AP-2000 and AP-700/800 (software version 4.00 and above)

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><CR><LF> or <a><baro><temp><ph><orp><cond><crc><CR><LF>
<a>D1!	<a><cond20><cond25><res><sal><CR><LF> or <a><cond20><cond25><res><sal><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0007<CR><LF>
<a>D0!	<a><tds><ssg><do><do-sat><aux1><CR><LF> or <a><tds><ssg><do><do-sat><aux1><crc><CR><LF>
<a>D1!	<a><aux2><nh3><CR><LF> or <a><aux2><nh3><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00016<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>
<a>D1!	<a><do><do-sat><aux1><aux2><nh3><CR><LF> or <a><do><do-sat><aux1><aux2><nh3><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-2000 and AP-700/800 (software version 4.00 and above) continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><do><do-sat><aux1><aux2><nh3><CR><LF> or <a><do><do-sat><aux1><aux2><nh3><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

Note: AP-700s running software version 4.00 and above will output in this format with invalid data in the <aux1>, <aux2> and <nh3> fields.

AP-800s running software version 4.00 and above will output in this format with Turbidity data in the <aux1> field and invalid data in the <aux2> and <nh3> fields.

8.4.19. AP-2000 with Depth and AP-700/800 with Depth (software version 4.00 and above)

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><CR><LF> or <a><baro><temp><ph><orp><cond><crc><CR><LF>
<a>D1!	<a><cond20><cond25><res><sal><CR><LF> or <a><cond20><cond25><res><sal><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0008<CR><LF>
<a>D0!	<a><tds><ssg><do><do-sat><aux1><CR><LF> or <a><tds><ssg><do><do-sat><aux1><crc><CR><LF>
<a>D1!	<a><aux2><nh3><depth><CR><LF> or <a><aux2><nh3><depth><crc><CR><LF>

Command	Response
<a>M2! up to <a>M9! or <a>MC2! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00017<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>
<a>D1!	<a><do><do-sat><aux1><aux2><nh3><depth><CR><LF> or <a><do><do-sat><aux1><aux2><nh3><depth><crc><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

AP-2000 with Depth and AP-700/800 with Depth (software version 4.00 and above) continued...

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><do><do-sat><aux1><aux2><nh3><depth><CR><LF> or <a><do><do-sat><aux1><aux2><nh3><depth><crc><CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

Note: AP-700s running software version 4.00 and above will output in this format with invalid data in the <aux1>, <aux2> and <nh3> fields.

AP-800s running software version 4.00 and above will output in this format with Turbidity data in the <aux1> field and invalid data in the <aux2> and <nh3> fields.

8.4.20. AP- Lite

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0003<CR><LF>
<a>D0!	<a><baro><temp><aux1><CR><LF> or <a><baro><temp><aux1><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! up to <a>M9! or <a>MC1! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00003<CR><LF>
<a>D0!	<a><baro><temp><aux1><CR><LF> or <a><baro><temp><aux1><CR><LF>

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><aux1><CR><LF> or <a><baro><temp><aux1><crc><CR><LF>

Command	Response
<a>R1! to <a>R9! or <a>RC1! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.21. AP-5000

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><CR><LF> or <a><baro><temp><ph><orp><cond><crc><CR><LF>
<a>D1!	<a><cond20><cond25><res><sal><CR><LF> or <a><cond20><cond25><res><sal><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0009<CR><LF>
<a>D0!	<a><tds><ssg><do><do-sat><aux1><CR><LF> or <a><tds><ssg><do><do-sat><aux1><crc><CR><LF>
<a>D1!	<a><aux2><aux3><aux4><nh3><CR><LF> or <a><aux2><aux3><aux4><nh3><crc><CR><LF>

Command	Response
<a>M2! or <a>MC2!	<a>0001<CR><LF>
<a>D0!	<a><depth><CR><LF> or <a><depth><crc><CR><LF>

Command	Response
<a>M3! up to <a>M9! or <a>MC3! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00019<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>
<a>D1!	<a><do><do-sat><aux1><aux2><aux3><aux4><nh3><depth><CR><LF> or <a><do><do-sat><aux1><aux2><aux3><aux4><nh3><depth><crc> <CR><LF>

AP-5000 continued...

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! up to <a>C9! or <a>CC1! up to <a>CC9!	<a>00000<CR><LF>

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><do><do-sat><aux1><aux2><aux3><aux4><nh3><depth><CR><LF> or <a><do><do-sat><aux1><aux2><aux3><aux4><nh3><depth><crc> <CR><LF>

Command	Response
<a>R2! to <a>R9! or <a>RC2! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.22. AP-7000

Sequence initiated with Start Measurement command:

Command	Response
<a>M! or <a>MC!	<a>0009<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><CR><LF> or <a><baro><temp><ph><orp><cond><crc><CR><LF>
<a>D1!	<a><cond20><cond25><res><sal><CR><LF> or <a><cond20><cond25><res><sal><crc><CR><LF>

Sequences initiated with Additional Measurement command:

Command	Response
<a>M1! or <a>MC1!	<a>0008<CR><LF>
<a>D0!	<a><tds><ssg><do><do-sat><aux1><CR><LF> or <a><tds><ssg><do><do-sat><aux1><crc><CR><LF>
<a>D1!	<a><aux2><aux3><aux4><CR><LF> or <a><aux2><aux3><aux4><crc><CR><LF>

Command	Response
<a>M2! or <a>MC2!	<a>0004<CR><LF>
<a>D0!	<a><aux5><aux6><nh3><depth><CR><LF> or <a><aux5><aux6><nh3><depth><crc><CR><LF>

Command	Response
<a>M3! up to <a>M9! or <a>MC3! up to <a>MC9!	<a>0000<CR><LF>

Sequence initiated with Start Concurrent Measurement command:

Command	Response
<a>C! or <a>CC!	<a>00020<CR><LF>
<a>D0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>
<a>D1!	<a><do><do-sat><aux1><aux2><aux3><aux4><aux5><aux6><nh3> <CR><LF> or <a><do><do-sat><aux1><aux2><aux3><aux4><aux5><aux6><nh3><crc> <CR><LF>

AP-7000 continued...

Sequences initiated with Additional Concurrent Measurement command:

Command	Response
<a>C1! or <a>CC1!	<a>00001<CR><LF>
<a>D0!	<a><depth><CR><LF> or <a><depth><crc><CR><LF>

Command	Response
<a>C2! up to <a>C9! or <a>CC2! up to <a>CC9!	<a>00000<CR><LF>

Sequences initiated with Continuous Measurement command:

Command	Response
<a>R0! or <a>RC0!	<a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><CR><LF> or <a><baro><temp><ph><orp><cond><cond20><cond25><res><sal><tds> <ssg><crc><CR><LF>

Command	Response
<a>R1! or <a>RC1!	<a><do><do-sat><aux1><aux2><aux3><aux4><aux5><aux6><nh3> <CR><LF> or <a><do><do-sat><aux1><aux2><aux3><aux4><aux5><aux6><nh3><crc> <CR><LF>

Command	Response
<a>R2! or <a>RC2!	<a><depth><CR><LF> or <a><depth><crc><CR><LF>

Command	Response
<a>R3! to <a>R9! or <a>RC3! to <a>RC9!	<a><CR><LF> or <a><crc><CR><LF>

8.4.23. Important note concerning AP-7000 self cleaning

The SDI-12 and MODBUS protocols do not have provision for activating the AP-7000's self cleaning mechanism. BlackBoxs running software revision 2.05 and below will automatically command a cleaning cycle to be carried out on initial power-up and each time the system is woken up from sleep mode. **In order to reduce wear on the cleaning mechanism and electrodes, a maximum reading rate of once per hour is recommend.**

BlackBoxes running software revision 3.00 and above will automatically command a cleaning cycle every six hours, regardless of the mode selected. For this reason, **power must be left applied to the BlackBox at all times** and readings can be taken as often as required. If a low power mode is required between readings, use the on/off (sleep) line. See section 2.5 for further details.

8.5. Verification Command

On reception of a Start Verification command, the BlackBox willll respond indicating a measurement time of “000” and no data values. If the data recorder follows this with a Send Data command, the BlackBox will respond with a packet containing no data values.

Command	Response
<a>V!	<a>0000<CR><LF>
<a>D0!	<a><CR><LF>

8.6. Cyclic Redundancy Check

The cyclic redundancy check included in responses to the Send Data command is calculated on the contents of the response, starting with the sensor address character and ending with the last response character before the start of the CRC field.

The CRC field is composed of three characters in the range 0x40-0x7F, which encode the 16-bit CRC value as follows:

1st character: binary $0100C_{15}C_{14}C_{13}C_{12}$
2nd character: binary $01C_{11}C_{10}C_9C_8C_7C_6$
3rd character: binary $01C_5C_4C_3C_2C_1C_0$

where C_n is the *n*th bit of the CRC.

The algorithm for calculating the CRC is as follows:

```
Set crc = 0
For each message character c:
   Set crc = crc XOR c
   Repeat 8 times:
        If least significant bit of crc is 1,
                Shift crc right by one bit
                Set crc = crc XOR 0xA001
        Otherwise,
                Shift crc right by one bit
```

9. Modbus Communication Protocol

The BlackBox supports the slave device side of the Modbus communication standard in RTU mode, and responds appropriately to commands sent to it by a Modbus master device.

9.1. Electrical Interface

In the BlackBox, Modbus is implemented over a half-duplex RS-485 serial interface.

9.2. Data Frame Format

Each data frame transferred via the RS-485 interface represents one byte of data. A data frame has the following format:

- 1 start bit (space/0)
- 8 data bits (least significant bit first)
- 1 even parity bit
- 1 stop bit (mark/1)

9.3. Communication Sequence & Timing

All Modbus communication transactions are initiated by the master. The master initiates a transaction by transmitting a command packet. Commands fall into two categories: broadcast and unicast.

Unicast commands are addressed to an individual slave. The addressed slave must process the command and send an appropriate response packet back to the master.

Broadcast commands must be received and processed by all slaves on the bus, and no response packet must be sent by any of the slaves. Slaves must not transmit anything unless they are responding to a command from the data recorder.

When the BlackBox is not already involved in any Modbus communication sequence, it will continually monitor the RS-485 bus for data. Any byte preceded by at least 3.5 character times of idle line will mark the start of a command packet and the packet will be terminated by 3.5 character times of idle line.

If a gap of more than 1.5 but less than 3.5 character times of idle line occurs between any bytes during packet reception, then the packet will be regarded as incomplete and will be discarded. If the BlackBox detects a parity or CRC error in a packet received from the master device, it will discard the packet.

If the slave address in the command matches the BlackBox's slave address, the BlackBox will process and respond to the command, otherwise it will ignore the command. If the slave address in the command is zero (indicating a broadcast command), the BlackBox will process the command but send no response.

If responding to a command, the BlackBox will ensure that the RS-485 bus is idle for at least 3.5 character times between the end of the command and the beginning of the response.

9.4. Data Packet Format

All Modbus data packets have the format:

Field	Size	Content
<a>	1 byte	Slave address (valid values 0x01-0xF7 when a single slave is addressed, 0x00 for commands broadcast to all slaves)
<function-code>	1 byte	Function code that identifies the function of the data packet (valid values 0x01-0x7F for commands & successful responses, 0x81-0xFF for exception responses)
<data>	0-252 bytes	Function dependent data
<crc>	2 bytes	16-bit cyclic redundancy check

In broadcast commands sent by the master, the address byte will contain 0. In unicast commands, the address byte will contain the address of the slave device to which the command is being sent.

In responses from slaves, the address byte will contain the address of the slave which generated the response.

If the BlackBox successfully handles a command, its response will contain the same function code as the command. If it cannot successfully handle a command, the Black Box will generate an exception response with the function code set to 0x80 + the command's function code.

In the <data> field, numerical values of size greater than 8 bits are transmitted most significant byte first. In the <crc> field, the CRC is transmitted least significant byte first.
The maximum packet size is 256 bytes.

Table 3 summarises the Modbus functions supported by the BlackBox and the following subsections describe their command & response packet formats.

Function	Function Code
Read Holding Registers	0x03
Read Input Registers	0x04
Write Holding Register	0x06
Write Holding Registers	0x10
Report Slave ID	0x11

Table 3: Supported Modbus Functions

9.4.1. Exception Responses

If a command is unsupported or has invalid parameters, the BlackBox will return an exception response of the format:

Field	Size	Content
<a>	1 byte	Slave address
<exception-function-code>	1 byte	Function code of the command + 0x80
<exception-code>	1 byte	The type of exception 1 – Unsupported command function code 2 – Invalid data address in command 3 – Invalid data value in command
<crc>	2 bytes	CRC

9.4.2. Read Holding Registers

This command reads one or more Modbus holding registers, and has the format:

Field	Size	Content
<a>	1 byte	Slave address
<function-code>	1 byte	0x03
<start-address>	2 bytes	Base address of the block of registers to be read (0x0000-0xFFFF)
<nr-registers>	2 bytes	The number of registers to be read (0x0001-0x007D)
<crc>	2 bytes	CRC

NOTE: The address in the <start-address> field is the register number – 1.

On reception of this command, the BlackBox will check that <nr-registers> is greater than zero and less than or equal to 0x7D. If this range check fails, the BlackBox will return an exception response with exception type 3.

If the above range check succeeds, the BlackBox will check that all addresses in the specified block refer to valid holding registers. If not, then the BlackBox will return an exception response with exception type 2.

If the above checks succeed, the BlackBox will send a response with the format:

Field	Size	Content
<a>	1 byte	Slave address
<function-code>	1 byte	0x03
<values-size>	1 byte	Size in bytes of <values> field (equal to 2 x <nr-registers>)
<values>	<values-size> bytes	Block of data containing the values of the requested registers, 2 bytes per register, registers in order of increasing address from <start-address> onwards
<crc>	2 bytes	CRC

9.4.3. Read Input Registers

This command reads one or more Modbus input registers and has the format:

Field	Size	Content
<a>	1 byte	Slave address
<function-code>	1 byte	0x04
<start-address>	2 bytes	Base address of the block of registers to be read (0x0000-0xFFFF)
<nr-registers>	2 bytes	The number of registers to be read (0x0001-0x007D)
<crc>	2 bytes	CRC

NOTE: The address in the <start-address> field is the register number – 1.

On reception of this command, the BlackBox will check that <nr-registers> is greater than zero and less than or equal to 0x7D. If this range check fails, the BlackBox will return an exception response with exception type 3.

If the above range check succeeds, the BlackBox will check that all addresses in the specified block refer to valid input registers. If not, then the BlackBox will return an exception response with exception type 2.

If the above checks succeed, the BlackBox will send a response with the format:

Field	Size	Content
<a>	1 byte	Slave address
<function-code>	1 byte	0x04
<values-size>	1 byte	Size in bytes of <values> field (equal to 2 x <nr-registers>)
<values>	<values-size> bytes	Block of data containing the values of the requested registers, 2 bytes per register, in order of increasing address from <start-address> onwards
<crc>	2 bytes	CRC

9.4.4. Write Holding Register

This command writes a value to a single Modbus holding register and has the format:

Field	Size	Content
<a>	1 byte	Slave address
<function-code>	1 byte	0x06
<address>	2 bytes	Address of the register to be written (0x0000-0xFFFF)
<value>	2 bytes	Value to be written to the register (0x0000-0xFFFF)
<crc>	2 bytes	CRC

NOTE: The address in the <start-address> field is the register number – 1.

On reception of this command, the BlackBox will check that <address> refers to a valid holding register. If not, then the BlackBox will return an exception response with exception type 2.

If the above check succeeds, the BlackBox will set the register to the specified value and echo the received command packet as its response.

9.4.5. Write Holding Registers

This command writes a set of values to a contiguous block of Modbus holding registers and has the format:

Field	Size	Content
<a>	1 byte	Slave address
<function-code>	1 byte	0x10
<start-address>	2 bytes	Base address of the block of registers to be written (0x0000-0xFFFF)
<nr-registers>	2 bytes	The number of registers to be written (0x0001-0x007B)
<values-size>	1 byte	Size in bytes of <values> field (equal to 2 x <nr-registers>)
<values>	<values-size> bytes	Block of data containing the values to be written to the registers, 2 bytes per register, in order of increasing address from <start-address> onwards
<crc>	2 bytes	CRC

NOTE: The address in the <start-address> field is the register number – 1.

On reception of this command, the BlackBox will check that <nr-registers> is greater than zero and less than or equal to 0x7B. If this range check fails, the BlackBox will return an exception response with exception type 3.

If the above range check succeeds, the BlackBox will check that all addresses in the specified block refer to valid holding registers. If not, then the BlackBox will return an exception response with exception type 2.

If the above checks succeed, the BlackBox will set the registers to the specified values and send a response with the format:

Field	Size	Content
<a>	1 byte	Slave address
<function-code>	1 byte	0x10
<start-address>	2 bytes	Base address of the block of registers (0x0000-0xFFFF)
<nr-registers>	2 bytes	The number of registers (0x0001-0x007B)
<crc>	2 bytes	CRC

9.4.6. Report Slave ID

This command allows the master to retrieve identification information from the slave, and has the format:

Field	Size	Content
<a>	1 byte	Slave address
<function-code>	1 byte	0x11
<crc>	2 bytes	CRC

On reception of this command, the BlackBox will return a response with the format:

Field	Size	Content
<a>	1 byte	Slave address
<function-code>	1 byte	0x11
<data-size>	1 byte	The size of the rest of the packet, from <slave-id> to <data> inclusive (31 for format v1)
<slave-id>	1 byte	0x00
<run-status-indicator>	1 byte	0xFF
<format-ver>	1 byte	Version number indicating the format of the rest of the packet (currently 0x01)
<data>	28 bytes (format version 1)	Block of data containing product information
<crc>	2 bytes	CRC

Format version 1 of the <data> block is:

<serial-nr>	9 bytes	The BlackBox's serial number (an ASCII string)
<fw-ver>	2 bytes	The BlackBox's firmware version number x 100
<probe-model-nr>	6 bytes	The model number of the probe attached to the BlackBox (see Table 1)
<probe-serial-nr>	9 bytes	The serial number of the probe attached to the BlackBox
<probe-fw-ver>	2 bytes	The attached probe's firmware version number x 100

9.5. Register Map

The Modbus specification defines 4 classes of addressable data: discrete inputs, coils, input registers & holding registers. The characteristics of these classes are shown in the table below.

	Read Only	Read/Write
Single bit	Discrete Inputs	Coils
16-bit	Input Registers	Holding Registers

Modbus Data Classes

The BlackBox will implement all of its registers as holding registers or input registers. The single bit classes and the command functions for accessing them are not implemented.

The holding registers allowing configuration of the BlackBox are summarised in the table below.

Register Number	Register Address (used in Modbus commands)	Description
1	0x0000	Slave address (1 – 247)
2	0x0001	Modbus mode (0 = RTU, 1 = ASCII)
3	0x0002	Serial communication speed (1200, 2400, 4800, 9600, 19200, 38400, 57600)
4	0x0003	Serial communication parity (0 = none, 2 = even, 3 = odd)

Modbus Holding Registers

The input registers provide a way to read the probe measurements and are summarised in the table below.

Register Number	Register Address (used in Modbus commands)	Description	Probe Models for which Register Exists
1	0x0000	Barometric pressure (mbar)	All
2	0x0001	Temperature (°C × 100)	All
3	0x0002	pH × 100	AP-100, AP-400, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AP-2000, AP-5000, AP-7000
4	0x0003	Oxidation/reduction potential (mV × 10)	AP-700, AP-800, AP-900, AP-1000, AP-2000, AP-5000, AP-7000
5	0x0004	Turbidity (NTU × 10)	AP-200, AP-400, AP-600, AP-800*, AP-900, AP-1000
6	0x0005	Electrical conductivity (µS/cm) – upper 16 bits	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
7	0x0006	Electrical conductivity (µS/cm) – lower 16 bits	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
8	0x0007	Electrical conductivity (corrected to 20°C) (µS/cm) – upper 16 bits	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
9	0x0008	Electrical conductivity (corrected to 20°C) (µS/cm) – lower 16 bits	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
10	0x0009	Electrical conductivity (corrected to 25°C) (µS/cm) – upper 16 bits	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
11	0x000A	Electrical conductivity (corrected to 25°C) (µS/cm) – lower 16 bits	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
12	0x000B	Electrical resistivity (Ω·cm) – upper 16 bits	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000

13	0x000C	Electrical resistivity (Ω·cm) – lower 16 bits	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
14	0x000D	Salinity (PSU × 100)	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
15	0x000E	Total dissolved solids (mg/L)– upper 16 bits	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
16	0x000F	Total dissolved solids (mg/L) – lower 16 bits	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
17	0x0010	Specific seawater gravity (σ_t × 10)	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
18	0x0011	Dissolved oxygen (mg/L × 100)	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
19	0x0012	Dissolved oxygen (% air saturation × 10)	AP-300, AP-500, AP-600, AP-700, AP-800, AP-900, AP-1000, AquaPlus, AP-2000, AP-5000, AP-7000
20	0x0013	Probe depth (cm)	All probes with depth sensor fitted
21	0x0014	AUX1 measurement – upper 16 bits	AP-800†, AP-2000, AP-Lite,AP-5000, AP-7000
22	0x0015	AUX1 measurement – lower 16 bits	AP-800†, AP-2000, AP-Lite, AP-5000, AP-7000
23	0x0016	AUX2 measurement – upper 16 bits	AP-2000, AP-5000, AP-7000
24	0x0017	AUX2 measurement – lower 16 bits	AP-2000, AP-5000, AP-7000
25	0x0018	AUX3 measurement – upper 16 bits	AP-5000, AP-7000
26	0x0019	AUX3 measurement – lower 16 bits	AP-5000, AP-7000
27	0x001A	AUX4 measurement – upper 16 bits	AP-5000, AP-7000
28	0x001B	AUX4 measurement – lower 16 bits	AP-5000, AP-7000
29	0x001C	AUX5 measurement – upper 16 bits	AP-7000
30	0x001D	AUX5 measurement – lower 16 bits	AP-7000
31	0x001E	AUX6 measurement – upper 16 bits	AP-7000
32	0x001F	AUX6 measurement – lower 16 bits	AP-7000
33	0x0020	Ammonia concentration (mg/L x 100) – upper 16 bits	AP-2000, AP-5000, AP-7000 (if ammonium electrode fitted)
34	0x0021	Ammonia concentration (mg/L x 100) – lower 16 bits	AP-2000, AP-5000, AP-7000 (if ammonium electrode fitted)

Modbus Input Registers

* AP-800 running software version 3.53 or below. † AP-800 running software version 4.00 or above

All measurement values are two's complement numbers (i.e. top bit set to represent a negative value). Any AUX values that are invalid will be returned as 0x80000000.

All AUX electrode measurement values are output at the measured value x 100.

9.5.1. Slave Address

The BlackBox stores a Modbus slave address in its EEPROM. The sensor address is a single byte value in the range 1-247. The BlackBox will only process and respond to unicast commands if the slave address in the command matches the BlackBox's slave address.

The BlackBox's slave address is set to 1 during production. If the BlackBox receives a command that writes to holding register 1, and the value written is in the range 1-247, the new address will replace the slave address in EEPROM and the BlackBox will only respond to subsequent unicast commands sent to that new address.
If the value written is not in the range 1-247, then the sensor address will not be changed. Note also that the slave address in the response to the command that wrote the new address will be the original slave address, not the new one.

9.5.2. Serial Communication Speed

The BlackBox stores the baud rate used for Modbus communications in its EEPROM. The serial communication speed is set to 19200 during production. If the BlackBox receives a command that writes to holding register 3, and the value written is 1200, 2400, 4800, 9600, 19200, 38400 or 57600, the new speed will replace the old speed in EEPROM and the BlackBox will switch over to the new speed immediately after responding to the command.

9.5.3. Serial Communication Parity

The BlackBox stores the parity type used for Modbus communications in its EEPROM. The serial parity is set to even during production. If the BlackBox receives a command that writes to holding register 4, and the value written is 0 (none), 2 (even) or 3 (odd), the new parity type will replace the old parity type in EEPROM and the BlackBox will switch over to the new parity type immediately after responding to the command.

9.5.4. Input Registers

The input registers hold the measurements read from the probe.

9.6. Cyclic Redundancy Check

The cyclic redundancy check is calculated on the entire contents of the packet, starting with the slave address and ending with the last byte before the start of the CRC field.

The CRC field is composed of the two bytes of the CRC value, least significant byte first, most significant byte second. (Note that this is the opposite order to multi-byte values in the <data> field of the packet.)

The algorithm for calculating the CRC is as follows:

```
Set crc = 0xFFFF
For each message character c:
   Set crc = crc XOR c
   Repeat 8 times:
        If least significant bit of crc is 1,
                Shift crc right by one bit
                Set crc = crc XOR 0xA001
        Otherwise,
                Shift crc right by one bit
```

9.7. Important note concerning AP-7000 self cleaning

The MODBUS and SDI-12 protocols do not have provision for activating the AP-7000's self cleaning mechanism.

BlackBoxs running software 2.05 and below will automatically command a cleaning cycle to be carried out on initial power-up and each time the system is woken up from sleep mode.

In order to activate the self cleaning mechanism, toggle the on/off (sleep) line. **Remember to allow at least 60 seconds after wake-up before sampling the data to allow the readings to stabilise.**

In order to reduce wear on the cleaning mechanism and electrodes, a maximum reading rate of once per hour is recommend.

BlackBoxes running software revision 3.00 and above will automatically command a cleaning cycle every six hours, regardless of the mode selected. For this reason, **power must be left applied to the BlackBox at all times** and readings can be taken as often as required.

If a low power mode is required between readings, use the on/off (sleep) line. **Remember to allow at least 60 seconds after wake-up before sampling the data to allow the readings to stabilise.**

See section 2.4 for further details.