PRODUCT MANUAL

CTD-Diver® – DI28x Series

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The presence of the Waste Electrical and Electronic Equipment (WEEE) marking on the product indicates that the device is not to be disposed via the municipal waste collection system of any member state of the European Union. For products under the requirement of WEEE directive (2012/19/EU), please contact your distributor or local Van Essen Instruments B.V. office for the proper decontamination information and take back program, which will facilitate the proper collection, treatment, recovery, recycling, and safe disposal of the device.

CE COMPLIANCE STATEMENT (EUROPE)

We hereby declare that the device(s) described below are in conformity with the directives listed. In the event of unauthorized modification of any devices listed below, this declaration becomes invalid.

Type: Datalogger
Product Model: CTD-Diver (DI281, DI282, DI283, DI284)

Relevant EC Directives and Harmonized Standards:

1999/5/EC R&TTE Directive for Radio and Telecommunications Terminal Equipment in accordance to annex III to which this directive conform to the following standards:

Low Voltage Directive per EN60950-1 (2006)+A11 (2011) for Product Safety testing standard for "Information Technology Equipment"

EMC Directive EN 301 489-1 V1.8.1 / EN 301 489-17 V1.3.2 Electromagnetic emission and immunity for "Information Technology Equipment"

2014/30/EU Electromagnetic Compatibility directive, as amended by EN61326-1:2013

The product(s) to which this declaration relates is in conformity with the essential protection requirements of 2014/30/EU Electromagnetic Compatibility directive. The products are in conformity with the following standards and/or other normative documents:

EMC: Harmonized Standards: EN 61326-1:2013 Lab Equipment, EMC

IEC61000-6-3:2007 Emission standard for residential, commercial and light-industrial environments
IEC61000-4-2:2009 Electrostatic discharge immunity test
IEC61000-4-3:2006 Radiated, radio-frequency, electromagnetic field immunity test
IEC61000-4-4:2012 Electrical fast transient/burst immunity test
IEC61000-4-5:2006 Surge immunity test
IEC61000-4-6: 2014 Immunity to conducted disturbances, induced by radio-frequency fields
IEC61000-4-11:2004 Voltage dips, short interruptions and voltage variations immunity tests

I hereby declare that the equipment named above has been designed to comply with the relevant sections of the above referenced specifications. The items comply with all applicable Essential Requirements of the Directives.

Contents

1 Introduction

The CTD-Diver® is a compact, groundwater monitoring instrument for continuously measuring level, temperature and electrical conductivity in groundwater, surface water, and industrial waters. The data collected can be used to manage water resources, estimate hydraulic conductivity and other aquifer conditions. Examples of applications are:

- monitor potable water recharge areas for water supply,
- monitor tailings ponds, dewatering activities and water supply levels of mines,
- general site investigations for construction, and
- contaminant plume monitoring on spill sites, remediation sites, chemical storage facilities, landfill sites and hazardous waste storage sites.

The CTD-Diver is an easy-to-use datalogger featuring state-of-the-art electronics , a robust high precision pressure sensor for long term accuracy and a platinum 4-electrode conductivity sensor. The absolute pressure sensor requires minimal maintenance and re-calibration.

The CTD-Diver is a datalogger housed in a cylindrical casing with a suspension eye at the top. The suspension eye can be unscrewed and is designed to install the CTD-Diver into the monitoring well. The suspension eye also protects the optical connector. The electronics, sensors and battery are installed maintenance-free into the casing. The CTD-Diver is not designed to be opened.

The name of the datalogger, the model number, the measurement range and the serial number are identified on the side of the CTD-Diver. This information is etched using a laser and is consequently chemically neutral and not erasable.

1.1 About this Manual

This manual contains information about Van Essen Instruments' CTD-Diver with part number DI28x, see section 2.5, an instrument designed to measure groundwater levels, temperature and electrical conductivity.

This chapter contains a brief introduction to the CTD-Diver's measurement principles. Chapter 2 contains the technical specifications for the CTD-Diver as well as guidelines for Diver maintenance. Chapter 3 covers the deployment of Divers. This includes programming the Diver with the Diver-Office software. Subsequently, installation of Divers in monitoring wells and in surface water is discussed. There are three appendices that describe the use of Divers at varying elevation, the Diver communication protocol and a list of CTD-Diver accessories.

1.2 Operating Principle

The CTD-Diver is a datalogger designed to measure water pressure, temperature and conductivity. Measurements are subsequently stored in the CTD-Diver's internal memory. The CTD-Diver consists of a pressure sensor designed to measure water pressure, a temperature sensor, a 4-electrode conductivity sensor and a battery that powers the electronics that takes and stores the measurements. The CTD-Diver is an autonomous datalogger that can be programmed by the user. The CTD-Diver has a completely sealed inert ceramic enclosure. The communication between CTD-Divers and Laptops/field devices is based on optical communication.

The CTD-Diver measures the absolute pressure. This means that the pressure sensor not only measures the water pressure, but also the air pressure pushing on the water surface. If the air pressure varies, the measured water pressure will thus also vary, without varying the water level. The air pressure can be measured by a Baro-Diver and subsequently be used in the Diver-Office software to convert the CTD-Diver pressure readings into water level data.

1.3 Measuring Water Level

The CTD-Diver establishes the height of a water column by measuring the water pressure using the built-in pressure sensor. As long as the CTD-Diver is not submerged in water it measures atmospheric pressure, just like a barometer. Once the Diver is submerged this is supplemented by the water's pressure: the higher the water column the higher the measured pressure. The height of the water column above the Diver's pressure sensor is determined based on the measured pressure.

To measure these variations in atmospheric pressure a Baro-Diver is installed for each site being measured. The barometric compensation for these variations in atmospheric pressure can be done using the Diver-Office software, see www.vanessen.com for a free download. It is also possible to use alternative barometric data such as data made available online.

The barometrically adjusted water values can be related to a reference point such as the top of the monitoring well or Mean Sea Level (MSL) or any other vertical reference datum.

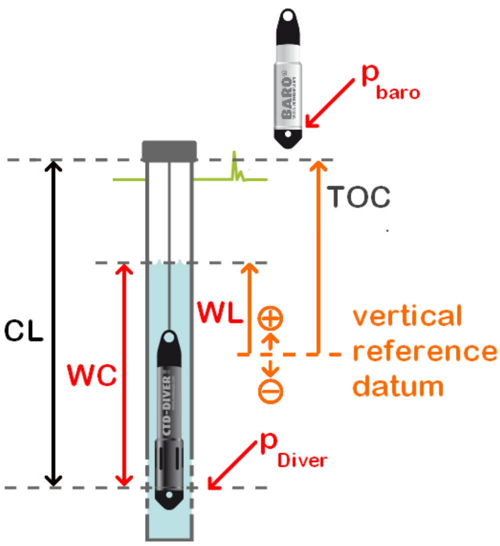
1.3.1 Converting Diver Data into Water Level

This section explains how to calculate the water level in relation to a vertical reference datum using the CTD-Diver and Baro-Diver's measurements.

The figure below represents an example of a monitoring well in which a CTD-Diver has been installed. In this case we are therefore interested in the height of the water level (WL) in relation to the vertical reference datum. If the water level is situated above the reference datum it has a positive value and a negative value if it is situated below the reference datum.

The top of casing (TOC) is measured in relation to the vertical reference datum and is denoted in the diagram below as TOC. The CTD-Diver is suspended with a cable with a length CL. If the cable length is not exactly known, it can be calculated from a manual measurement as described in section 1.3.2.

The Baro-Diver measures the atmospheric pressure (p_{baro}) and the CTD-Diver measures the pressure exerted by the water column (WC) above the CTD-Diver and the atmospheric pressure (p_{Diver}).



The water column (WC) above the CTD-Diver can be expressed as:

$$WC = 9806.65 \frac{p_{Diver} - p_{baro}}{\rho \cdot g} \quad (1)$$

where p is the pressure in cmH_2O, g is the acceleration due to gravity (9.80665 m/s^2) and ρ is the density of the water (1,000 kg/m^3).

The water level (WL) in relation to the vertical reference datum can be calculated as follows:

$$WL = TOC - CL + WC \quad (2)$$

By substituting WC from equation (1) in equation (2) we obtain:

$$WL = TOC - CL + 9806.65 \frac{p_{Diver} - p_{baro}}{\rho \cdot g} \quad (3)$$

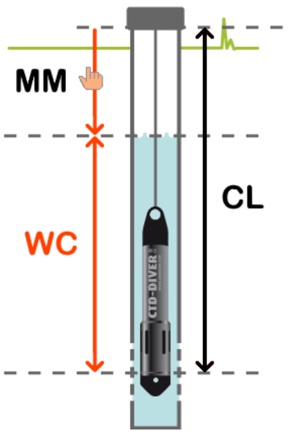
1.3.2 Calculating the Cable Length from a Manual Measurement

If the cable length is not exactly known, it can be determined using a manual measurement, see the figure below. The manual measurement (MM) is taken from the top of casing to the water level. The value of the water level is positive unless, in exceptional circumstances, the water level is situated above the top of casing.

The cable length can now be calculated as follows:

$$CL = MM + WC \quad (4)$$

where the water column (WC) is calculated based on the measurements taken by the CTD-Diver and the Baro-Diver.



Notes:

- If the pressure measured by the CTD-Diver and the Baro-Diver is measured at different points in time, it is necessary to interpolate. The Diver-Office software automatically performs this interpolation.
- It is possible to enter manual measurements into the Diver-Office software. The software subsequently automatically calculates the cable length.

Example

The top of casing is measured to be 150 cm above the Mean Seal Level (MSL): TOC = 150 cm. The cable length is not exactly known and therefore a manual measurement is taken. It turns out to be 120 cm: MM = 120 cm.

The CTD-Diver measures a pressure of 1,170 cmH_2O and the Baro-Diver measures a pressure of 1,030 cmH_2O. Substituting these values into equation (1), results in a water column of 140 cm above the Diver: WC = 140 cm.

Substituting the values of the manual measurement and the water column in equation (4) results in the following cable length: CL = 120 + 140 = 260 cm.

The water level in relation to MSL can now be easily calculated using equation (2): WL = 150 – 260 + 140 = 30 cm above MSL.

1.4 Measuring Temperature

All Divers measure the groundwater temperature. This can, for example, provide information about groundwater flows.

The temperature is measured using a semiconductor sensor. This sensor not only measures the temperature, but also uses the value of the temperature at the same time to compensate the pressure sensor and electronics for the effects of temperature to ensure the best possible performance.

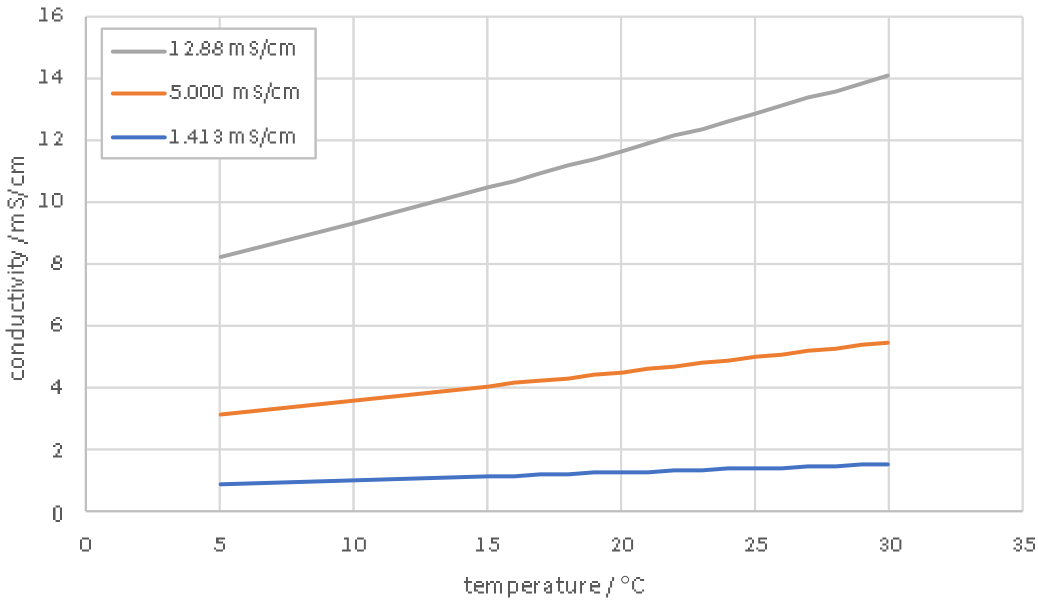
1.5 Measuring Conductivity

In addition to water levels and temperature, the CTD-Diver also measures the water's electrical conductivity in milli Siemens per centimeter (mS/cm). A change in conductivity may be caused by for example changes in water flow or increasing/decreasing pollution or salinization.

The conductivity is measured using a 4-electrode measuring cell. This type of measuring cell is relatively insensitive to sensor fouling, thus keeping maintenance to a minimum. *The measuring cell combined with the selected measurement method results in an electrolysis-free measurement system.*

The CTD-Diver measures the conductivity of a solution. The CTD-Diver can be programmed to measure either the true conductivity or the specific conductivity. The specific conductivity is defined as the conductivity as if the temperature is 25 °C. This setting must be programmed prior to starting the CTD-Diver.

The conductivity of a liquid depends on the type of ions in the liquid and to a significant degree on the liquid's temperature. This dependency is indicated on the packaging of the calibration solution. The diagram below displays the conductivity as a function of temperature for three different calibration liquids. The specified value of the calibration liquid is the conductivity of the liquid at 25 °C.



As a rule of thumb, it can be assumed that conductivity varies by 2% for each 1 °C change in temperature. This means that a calibration solution rated 5 mS/cm (at 25 °C) has a conductivity of approximately 4 mS/cm at 15 °C.

The table below lists several typical conductivity values for various types of water.

Type	Conductivity [mS/cm]
Tap water	0.2 – 0.7
Groundwater	2 - 20
Seawater	50 - 80

1.5.1 Specific Conductivity

The specific conductivity of an electrolyte solution is defined as the conductivity if the solution is at a certain – reference – temperature. The specific conductivity is an indirect measure of the presence of dissolved solids such as chloride, nitrate, phosphate, and iron, and can be used as an indicator of water pollution.

The following equation is used for calculating the specific conductivity K_{Tref} from the measured conductivity K.

$$K_{Tref} = \frac{100}{100+\theta(T-T_{ref})} \cdot K \qquad (5)$$

where:

K_{Tref} = Specific conductivity at T_{ref}

K = Conductivity at T

T_{ref} = Reference temperature (25 °C)

T = Sample temperature

θ = Temperature coefficient (1.91 %/°C)

The temperature coefficient used in the CTD-Diver is 1.91 %/°C and the reference temperature is 25°C. The setting to measure conductivity or specific conductivity can be programmed into the CTD-Diver by the user.

1.6 CTD-Diver Model

The Diver models described in this manual are from the DI28x Series: the CTD-Diver. The CTD-Diver measures absolute pressure, temperature and conductivity.

CTD-Diver

This Diver is manufactured using a zirconia (ZrO_2) casing with a 22 mm diameter. The CTD-Diver can store a maximum of 144,000 measurements (date/time, pressure, temperature and conductivity) in its working memory and 144,000 measurements in its backup memory.

The CTD-Diver samples pressure, temperature and conductivity and has the following measurement options:

- Fixed length intervals in fixed length or continuous memory.
- Average values.
- Pre-programmed or user-defined pump tests.
- Event-based. The CTD-Diver only stores measurements once the user-adjustable variation limit set for the conductivity measurement is exceeded.

The CTD-Diver is available in the following pressure ranges: 10 m, 50 m, 100 m and 200 m.

1.7 Factory Calibration Procedure

Each CTD-Diver is calibrated for pressure, temperature and conductivity:

1. First the CTD-Diver is individually calibrated and tested at several temperature and pressure values to ensure superior performance. The CTD-Diver is calibrated for the lifetime of the instrument, as long as it is used within its specified range.
2. Then the conductivity sensor is individually calibrated and tested at several conductivity values. The factory calibration is stored permanently in the CTD-Diver.

A calibration certificate is available upon request.

2 Technical Specification

2.1 General

There are four CTD-Diver models with different pressure ranges for pressure, temperature and conductivity measurements. The table below lists the general specifications of the CTD-Diver.

Diameter	Ø 22 mm
Length (incl. suspension eye)	~ 135 mm
Weight	~ 95 grams
Materials	
Casing	Ceramic (zirconia ZrO_2)
Pressure sensor	Piezoresistive ceramic (alumina Al_2O_3)
Conductivity sensor	4-electrode with platinum electrodes
Suspension eye	Nylon PA6 glass fiber reinforced (30%)
nose cone	ABS
O-rings	Viton®
Communication	
Interface	Optically separated
Protocol	Serial RS232, a limited set of commands is available as specified in Appendix II
Memory capacity	288,000 measurements
working	144,000 measurements
backup	144,000 measurements
Memory	Non-volatile memory. A measurement consists of date/time, pressure, temperature, and conductivity Continuous and fixed length memory
Battery life*	Up to 10 years, depending on use
Theoretical battery capacity	2 million measurements + 1000× full memory readouts + 2000× programming
Clock accuracy	Better than ± 1 minute per year at 25 °C
	Better than ± 5 minutes per year within the operating temperature range
CE marking	EMC in accordance with the 89/336/EEC directive Basic EN 61000-4-2 standard
Emissions	EN 55022 (1998) + A1 (2000) + A2 (2003), Class B
Immunity	EN 55024 (1998) + A1 (2000) + A2 (2003)

* The CTD-Diver is always in stand-by when not making a measurement. The power consumption of the integrated battery is dependent on the temperature and usage.
If the CTD-Diver is used, stored or transported for extended periods of time under high temperature, this will adversely affect the life of the battery. The battery's capacity at lower temperatures is reduced, but this is not permanent. This is normal behavior for batteries.
Excessive programming, high frequency sampling and data reading will reduce the battery capacity.

** The accuracy of the clock is highly dependent on temperature. The clock is actively compensated for temperature variations.

2.2 Environmental

Ingress protection	IP68, 10 years continuously submerged in water at 200 m

2.3 Transportation

Suitable for transportation by vehicles, ships and airplanes in the supplied packaging.

Resistance to vibration	In accordance with MIL-STD-810.
Mechanical shock test	In accordance with MIL-STD-810, for light-weight equipment
Temperature	-20 °C to 80 °C (affects battery life)

2.4 Temperature

Measurement range	-20 °C to 80 °C
Operating Temperature (OT)	0 °C to 50 °C
Accuracy (max)	± 0.2 °C
Accuracy (typical)	± 0.1 °C
Resolution	0.01 °C
Response time (90% of final value)	3 minutes (in water)

2.5 Pressure

The specifications for water pressure measurements vary by CTD-Diver model. The specifications below apply at operating temperature.

	DI281	DI282	DI283	DI284	Unit
Water column measurement range	10	50	100	200	mH_2O
Accuracy (max)	± 2.0	± 10.0	± 20.0	± 40.0	cmH_2O
Accuracy (typical)	± 0.5	± 2.5	± 5.0	± 10.0	cmH_2O
Long-term stability	± 2	± 10	± 20	± 40	cmH_2O
Resolution	0.2	1	2	4	cmH_2O
Display resolution	0.058	0.192	0.358	0.716	cmH_2O
Overload pressure	15	75	150	300	mH_2O

2.5.1 Water Column Measurement Range

The height of water above the CTD-Diver that can be measured.

2.5.2 Accuracy (maximum)

Accuracy is the proximity of measurement results to the true value. The algebraic sum of all the errors that influence the pressure measurement. These errors are due to linearity, hysteresis and repeatability. During the CTD-Diver calibration process a CTD-Diver is rejected if the difference between the measured pressure and the applied pressure is larger than the stated accuracy.

2.5.3 Accuracy (typical)

At least 68% of the measurements during the calibration check are within 0.05% FS of the measurement range.

2.5.4 Long-term Stability

The stability of the measurement over a period of time when a constant pressure is applied at a constant temperature.

2.5.5 Resolution

The smallest change in pressure that produces a response in the CTD-Diver measurement.

2.5.6 Display Resolution

The smallest increment in pressure that the CTD-Diver can measure.

2.5.7 Overload Pressure

The pressure at which the CTD-Diver pressure sensor will catastrophically fail.

2.6 Conductivity

Measurement range*	30 mS/cm	120 mS/cm	300 mS/cm
Accuracy**	±2% of reading with a minimum of 20 µS/cm		
Resolution	1 µS/cm	4 µS/cm	10 µS/cm

* User adjustable

** Undefined when reading > 120 mS/cm

2.7 Sample Interval and Methods

The minimum and maximum sample interval plus the various sample methods available for the CTD-Diver are listed below.

Sample interval	1 sec to 99 hours
Sample methods	• Fixed length intervals in fixed length or continuous (ring) memory. • Average values over a specified period. • Pre-programmed pump tests or user-defined pump tests (no backup memory). • Event-based. In this case the CTD-Diver only stores measurements once the variation limit set for the conductivity measurement is exceeded. This variation limit is user adjustable (no backup memory).

2.7.1 Fixed

When this method is selected, the CTD-Diver will take and store samples in regular time intervals.

For example, with a 10-second fixed record interval, the CTD-Diver will take a measurement every 10 seconds on all channel settings and then store these values in internal memory, with the date and time.

For the CTD-Diver there are two methods for storing data:

- Fixed Length Memory – The CTD-Diver will take measurements at a sample interval set by the user, for example every hour. When the number of samples reaches 144,000, i.e. the memory is full, the CTD-Diver stops measuring.
- Continuous Memory – The CTD-Diver will take measurements at a preset sample interval data. When the memory fills up, new samples begin overwriting the oldest records.

2.7.2 Averaging

When programmed with the Averaging Sample method, the CTD-Diver samples data at a specified "fast" rate (Sample Interval) and then stores an average of these values at the specified averaging rate (Record Interval).

Example

Record Interval: 1 hour

Sample Interval: 1 Minute

When programmed and started with these settings, the CTD-Diver will read a sample every minute, and record an average of the samples every 1 hour.

For surface water applications it is recommended using the averaging sampling method. This way the effects of waves are 'averaged out'.

2.7.3 Event Based

When you select this method, the CTD-Diver compares each conductivity sample to the last stored conductivity sample and calculates a difference. A new sample is only stored when:

- The difference exceeds the specified difference (percentage) from the last stored sample on the conductivity measurement.
- If no samples were stored for the past 250 samples.

If you select this method, the Variation field will be displayed. In the Variation field, specify the appropriate difference threshold. Enter this difference as a percentage of the total conductivity range. The percentage must lie between 0.1% and 25%.

Example

The conductivity range is set to 120 mS/cm, the Variation field is set to 2% and the sample interval is set to 30 seconds. A new sample will be stored when it deviates more than 120 × 2% = 2.4 mS/cm from the previously stored sample.

The CTD-Diver is started at 12:00:00. It will immediately record a sample (pressure, temperature and conductivity). The recorded conductivity is 23 mS/cm. After 30 seconds, the CTD-Diver takes a new sample: the conductivity is 23.5 mS/cm. This sample will not be recorded, because the difference is 0.5 mS/cm, which is less than 2.4 mS/cm.

Also, for the next 249 samples the difference is less than 2.4 mS/cm, so no samples are recorded. However, when the 250th sample is taken, it is recorded (at 14:05:00) regardless the difference.

2.7.4 Pumping Tests

The CTD-Diver can be programmed with a pumping test logging scheme. Generally, the logging interval is short at the start and increases when the pumping tests progresses.

There are two pre-programmed pumping tests available for the CTD-Diver. These are as listed in the two tables below. In addition, user-defined pumping tests can be programmed in the CTD-Diver.

A pumping test is defined by a base sample interval (from 1 second to 99 hours) and up to 10 different logging steps. For each step the number of samples that must be taken must be set plus the Interval Multiplier (1 to 250). The interval between two successive samples is equal to the Base Sample Interval multiplied by the Interval Multiplier. For example, if the Base Sample Interval is 3 seconds and the Interval Multiplier is 5, then the sampling interval is 15 seconds. Note: The Base Sample Interval is equal for all steps.

Aquifer Log Scale Test - 3 Day

Base Sample Interval: 1 second

Step	Number of samples	Interval multiplier	Interval between samples	Duration
1	600	1	1 seconds	10 minutes
2	1080	5	5 seconds	90 minutes
3	5400	10	10 seconds	15 hours
4	136920	30	30 seconds	47 days

Aquifer Log Scale Test - 2 Month

Base Sample Interval: 5 seconds

Step	Number of samples	Interval multiplier	Interval between samples	Duration
1	120	1	5 seconds	10 minutes
2	270	4	20 seconds	90 minutes
3	900	12	60 seconds	15 hours
4	1800	60	5 minutes	150 hours
5	140910	240	20 minutes	1957 days

3 CTD-Diver Installation and Maintenance

3.1 Introduction

In practice the CTD-Diver is suspended in a monitoring well and the Baro-Diver is installed at the surface for recording barometric pressure. Atmospheric pressure data must be used to compensate the pressure measurements recorded by the CTD-Diver for variations in atmospheric pressure. In principle, a single Baro-Diver is sufficient for an area with a radius of 15 kilometers depending on terrain conditions. Also see *Appendix I – Use of CTD-Divers at Varying Elevations*. A 10-meter change in elevation is the equivalent of a barometric pressure change of approx. 1 cmH2O or 1 mbar.

The following sections describe how to install the CTD-Diver and Baro-Diver.

3.2 Configuring and Reading the CTD-Diver

A CTD-Diver must be programmed with the desired sample method, sample interval, and monitoring point name before it is deployed. The CTD-Diver can be programmed, started, stopped and its data read using the Diver-Office software. The latest version of Diver-Office can be downloaded for free from www.vanessen.com. Once the software is installed, a CTD-Diver can be connected to the computer through a USB Reading Unit (part no AS330), a Smart Interface Cable (part no. AS346) or the Diver-Gate(M) (part no. AS345).

3.2.1 Configuring a CTD-Diver

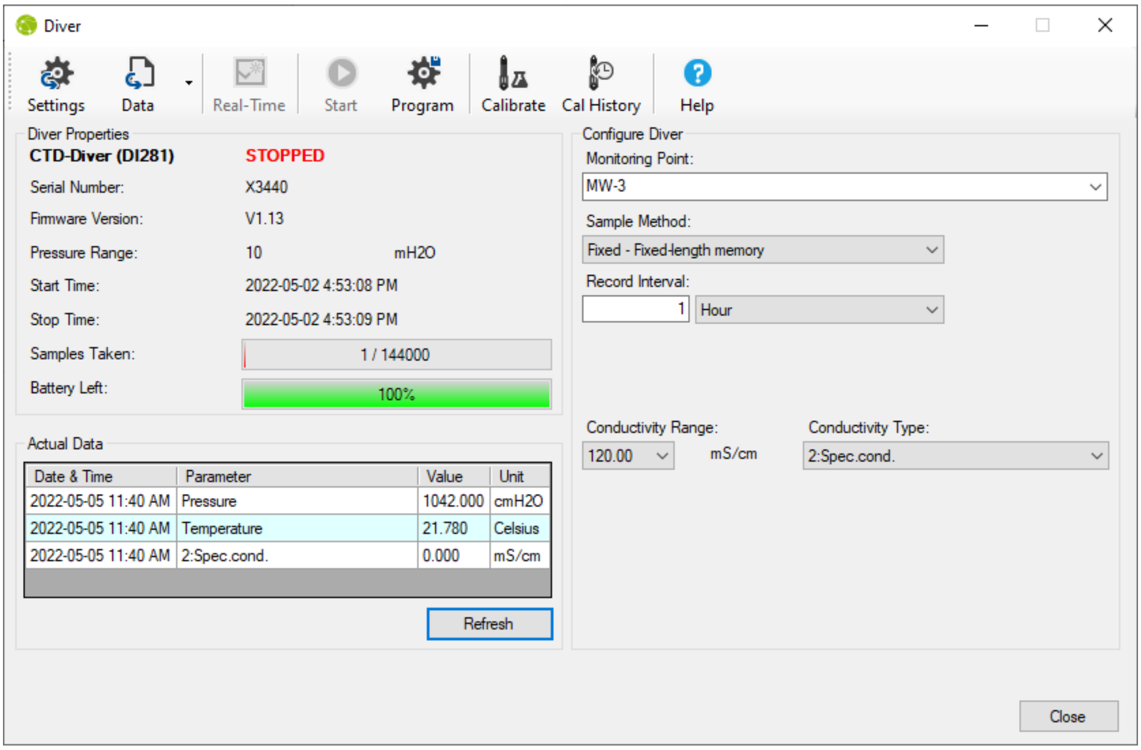
Open the Diver-Office software and click the Diver button to open the Diver window. See the image below for an example where the following settings were entered:

- monitoring point name: “MW-3”,
- sample method: “Fixed – Fixed-length memory”,
- record interval: 1 hour,
- conductivity range: 120 mS/cm,
- conductivity type: specific conductivity.

After entering the settings, the Diver must be programmed by clicking the Program button.

The conductivity range can be set to 30, 120 or 300 mS/cm. Select the range corresponding to the expected measurement values. A higher range reduces the resolution of the measurements. When the actual measurement value exceeds the conductivity range, then stored value is clipped to the maximum value.

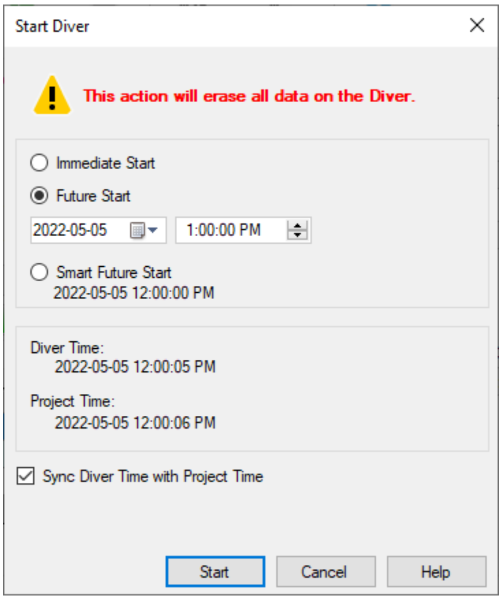
Set the conductivity type to the desired type. See section *1.5.1 Specific Conductivity* for more details.



Once the settings are successfully programmed into the CTD-Diver the Start button will be enabled. Clicking the Start button opens the Start Diver dialog as shown below. Here you can select from the following three start methods:

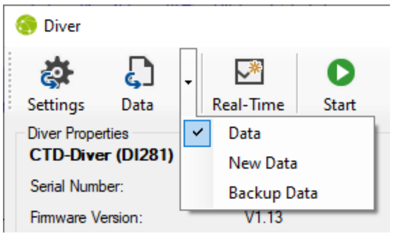
- Immediate Start - Select this option to start the CTD-Diver immediately. Upon clicking [Start], the Diver will begin to take and record samples, as defined in the CTD-Diver settings
- Future Start - Select this option to start the CTD-Diver at a specified time in the future. Use the date and time boxes to enter the desired future start time.
- Smart Future Start - This option is useful in situations where you want to stop the CTD-Diver, download its data and then continue collecting data at the specified sample interval.

After selecting the desired start method, click the [Start] button to save the start settings to the CTD-Diver.



3.2.2 Reading Data from a CTD-Diver

Click the Data button to download data from the CTD-Diver. Click the down arrow next to the Data button to change the mode/type of data download:



Depending on the sample interval the following 3 options are available:

- Data - download all the data recorded by the Diver.
- New Data - download only newly recorded data (since the last data download). This option is not available when the sample interval is 5 seconds or less.
- Backup Data - download data from the previous monitoring session.

During the data download the progress is indicated by a progress bar. Once the data has been downloaded it will be exported if this option is selected in the Project Settings. Subsequently, the program will jump to the tree view where the downloaded time series will be selected and a graph/table of the data will be shown.

3.3 Installation in a Monitoring Well

CTD-Divers are normally installed below the water level/table in a monitoring well. The depth at which a CTD-Diver can be suspended depends on the instrument's measurement range. Further information about the CTD-Diver's range is contained in the chapter 2 *Technical Specification*.

First determine the length of the non-stretch suspension cable (part no MO500) based on the lowest groundwater level. Provide for the required additional length for attaching the cable to the suspension eye of the Diver and at the upper end when you cut the wire to size.

Next use cable clips (part no MO310) to attach the ends of the cable to the monitoring well's end cover and the Diver's suspension eye, respectively.

To determine the distance of the pressure sensor in the monitoring well requires the precise length of the cable to be known, to which the distance to the location of the pressure sensor in the Diver must be added to obtain the overall effective cable length. This is depicted in the diagram below.

It is also possible to install the CTD-Diver with a communication cable (part no AS2xxx). This cable allows you to readout the CTD-Diver at the top of the monitoring well by using a Smart Interface Cable (part no AS346).

Note that in small diameter wells the installation and removal of the CTD-Diver may affect the water level.

3.4 Installation in Surface Water

If a CTD-Diver is used in surface water, it is important that there is sufficient circulation around the CTD-Diver's sensors.

Sedimentation, algae and plant growth should be minimized as much as possible to ensure the CTD-Diver measures the surrounding water level.

Position the CTD-Divers deep enough so that they remain below a possible ice layer.

A steel protective cover that can be locked should be used to prevent vandalism or theft of the CTD-Diver.

CTD-Divers can also be used to indirectly measure discharge. In such a case, the CTD-Diver can be installed in a monitoring tube/screen next to a weir.

3.5 Use of CTD-Divers at Varying Elevation

CTD-Divers can be used at any elevation ranging from 300 meters below sea level to 5,000 meters above sea level. Appendix I contains further information on the use of CTD-Divers at varying elevation.

3.6 Use in Seawater

The CTD-Diver is an excellent choice for use in semi-saline water/seawater. The CTD-Diver has a ceramic casing that does not corrode and is inert to most substances.

3.7 Biofouling

Biofouling is the undesirable accumulation of microorganisms, plants, algae, or animals on wetted structures. This is especially prominent in surface water monitoring in warm environments. Biofouling causes an algal growth on the electrodes of the CTD-Diver. This may affect the conductivity readings and increases the need for maintenance. Removing the biological materials from the electrodes can be damaging over a prolonged period and increase time spent in the field.

The Diver Copper Shield (part no AS350) protects the CTD-Diver from biofouling and reduces maintenance cost. There are many methods that can be used to prevent and remove the bioaccumulations. However, these methods can be expensive and detrimental to the environment. The Diver Copper Shield is a copper coil shield specifically designed to significantly reduce the growth of algae on the electrodes. Thus, reducing the need for maintenance and reducing the time spent on site.

3.8 CTD-Diver Maintenance

The CTD-Diver casing can be cleaned with a soft cloth. Calcium and other deposits can be removed by soaking the CTD-Diver in commercially available acidic cleaner (such as cleaning vinegar) and/or sodium bicarbonate (commonly known as baking soda or bicarbonate of soda).

Notes:

- Only use diluted acidic solutions if the CTD-Diver has severe build-up of, for example, lime scale and other cleansers are not effective.
- Never use any hard brushes, abrasives or sharp objects for cleaning the CTD-Diver and always rinse it properly with clean water after cleaning, particularly near the flow-through openings. Do not use any powerful jets. This could damage the pressure sensor.

3.9 User Conductivity Calibration

3.9.1 Introduction

The conductivity sensor is, in contrast to the pressure and temperature sensor, sensitive to pollution and fouling. Therefore, it is recommended to check the sensor regularly. A simple verification consists of two steps. First, take the CTD-Diver out of the well and shake it dry. Then take an actual reading, the reading should be 0 mS/cm. The reading may be slightly higher if the conductivity sensor is not completely dry. Second, immerse the CTD-Diver in a conductivity calibration solution. Ensure, that there are no air bubbles trapped inside the conductivity measurement cell. Take another actual reading and compare with the value of the calibration solution.

Note: If the CTD-Diver is set to read Conductivity (and not Specific Conductivity), ensure that the reading is corrected for temperature.

If the deviation is greater than the specified accuracy it is recommended to recalibrate the CTD-Diver. It is important to note that this calibration should be performed in an environment with a stable temperature. It is necessary to make use of good reference fluids and clean tools in order to perform a proper and reliable recalibration.

The conductivity accuracy specification of the CTD-Diver for the full 0-120 mS/cm measurement range can only be achieved if the CTD-Diver is calibrated at all four calibration points: 1.413; 5.000; 12.88 and 80.00 mS/cm.

If you choose to use the CTD-Diver in a specific application, you may decide to perform the calibration on 1 or 2 points. This means that the CTD-Diver meets the specifications in that measurement range. The CTD-Diver may deviate somewhat from the specifications outside the calibrated measurement range.

Example: If the CTD-Diver is used in a measurement range of 2-3 mS/cm, perform the user calibration at 1.413 and/or 5.000 mS/cm. The CTD-Diver will consequently be within the specifications for the 1.413 to 5 mS/cm measurement range.

If the user calibration is later carried out at the four calibration points, then the CTD-Diver will once again meet its specifications for the full measurement range.

Note: When the CTD-Diver has not been used for an extended period take the following steps prior to calibration. Program the CTD-Diver with a one-minute sample interval and start the CTD-Diver. Immerse the CTD-Diver in tap water for at least 24 hours.

Important: Prior to each reference measurement and/or calibration, the CTD-Diver must be thoroughly rinsed in demineralized water. After it has been rinsed it may not be touched by bare hands since the reference liquid can easily become contaminated by residual contaminants and/or residual salts left on hands. This invalidates a reference measurement/calibration since the reference has become distorted. This effect is highest at the low conductivity values.

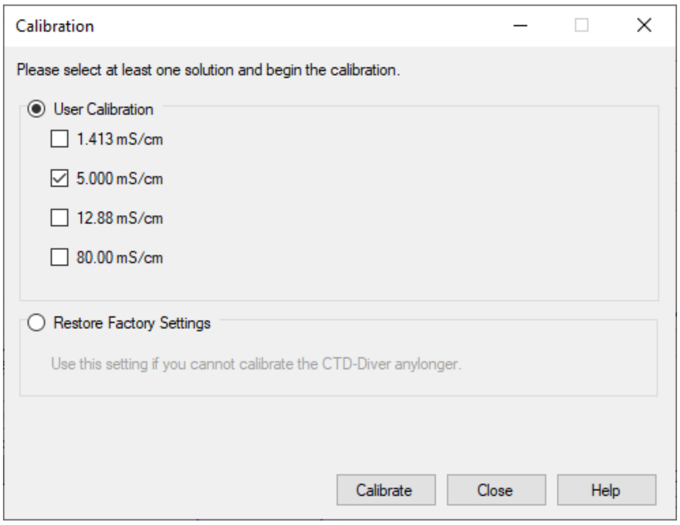
Erroneous or improper calibration can negatively affect the accuracy of the CTD-Diver.

Cleanliness during calibration is especially important. All salt residues adhering to the CTD-Diver will negatively affect the accuracy of the calibration liquid. Therefore, a calibration solution may never be used twice.

Temperature differences, between the conductivity solution and the CTD-Diver, may also cause errors (extended acclimatization is required).

3.9.2 Perform a User Calibration

To calibrate a CTD-Diver, open the Diver-Office software and click the Diver button to open the Diver window. Click the **Calibrate** button located in the **Diver** dialog toolbar. This button is only visible when a CTD-Diver is connected and only enabled when the logging status of the CTD-Diver is stopped. Upon clicking the **Calibrate** button, the following dialog will display.



Select the check boxes next to the calibration solutions that will be used to calibrate the CTD-Diver. Click the Calibrate button to begin calibrating the CTD-Diver.

Next, you will be prompted to immerse the CTD-Diver in the selected solution. Click OK to continue. If you are using multiple solutions, you will be prompted to calibrate from the lowest to the highest concentration.

Diver-Office will then calibrate the CTD-Diver according to the specified solutions. It is important to keep the CTD-Diver connected until the success message appears. If the calibration fails:

- check to make sure you are using the appropriate calibration solution,
- ensure that the CTD-Diver is connected securely to the Reading Unit,
- ensure that the CTD-Diver's sensors are submerged in the solution.

3.9.3 Restore Factory Settings

Select this option to reset the CTD-Diver calibration to its factory settings. This option can be useful if you are experiencing difficulties calibrating the CTD-Diver.

When this option is selected, click the Calibrate button to perform the reset.

4 Appendix I – Use of CTD-Divers at Varying Elevations

CTD-Divers can be used at any elevation ranging from 300 meters below sea level to 5,000 meters above sea level. It is however recommended that all Divers and the Baro-Diver forming part of the same network be used at the same elevation (whenever possible).

The relationship between atmospheric pressure variations and elevation is exponential, rather than linear:

$$P_H = P_0 \cdot \exp[-(M \cdot g \cdot H)/(R \cdot T)]$$

where

P_H = atmospheric pressure at elevation height H

P_0 = atmospheric pressure at reference height

$M = 28.8 \cdot 10^{-3}$ kg/mol (molecular mass of air)

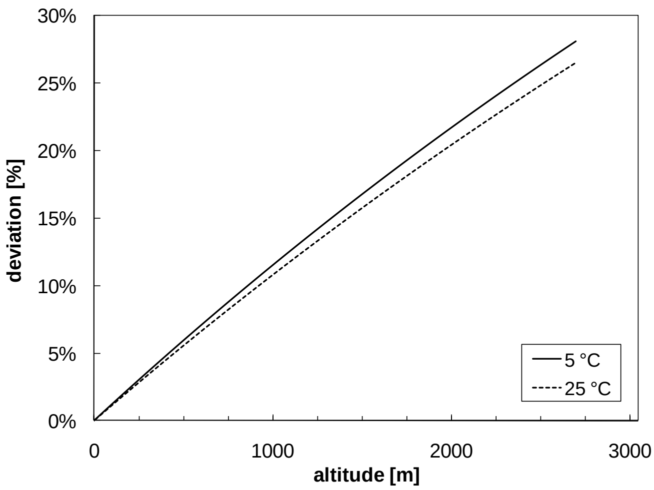
$g = 9.81$ m/s^2 (standard gravity)

H = height in meters

R = 8.314 J/mol/K (gas constant)

T = temperature in Kelvin

If the Baro-Diver is placed at a different elevation from the other Divers in a monitoring network, it is possible for a deviation to occur in the barometrically compensated data due to the relationships referred to above. The graph below illustrates the deviation in the barometric data as a function of the variation in elevation at 5 °C and 25 °C.



To determine the relative barometric pressure deviation relative to P_0 at 5 °C (T = 278.15°K) at a height differential of H, the above referenced formula can be used:

$$(P_H - P_0) / P_0 = 1 - \exp[-(M \cdot g \cdot H)/(R \cdot T)] \times 100\% \qquad (6)$$

By substituting the data, a relative deviation of 1.2 % at a height differential of 100 m is obtained. At a height differential of 1,000 m this increases to 11.5 %.

We therefore recommend that all Divers and the Baro-Divers in a network be placed such that the mutual height differentials are minimized.

If necessary, multiple Baro-Divers can be deployed to avoid the abovementioned issues.

5 Appendix II – CTD-Diver Communication Protocol

5.1 Introduction

The CTD-Diver supports a set of commands that allows the user to communicate with the Diver through other software than Diver-Office. The following commands are available:

- reading measured/stored data
- read date/time
- read serial number
- read monitoring point name
- real-time pressure, temperature and conductivity value including time stamp
- read sample mode (record method and interval)
- read product ID, name, and firmware version
- read remaining battery capacity
- read status: started, stopped, future start, free memory

5.2 Serial Port Settings

Bitrate: 9600
Parity: None
Databits: 8
Stopbits: 1

5.3 Frame Format

The frame format for a command/response is:

STX (1 byte)	Length (1 byte)	OC (2 bytes)	Payload (n bytes)	CC (1 byte)

field	size	description	remarks
STX	1 byte	Start of text, value is 0x02	Used to identify start of command
Length	1 byte	Length of frame	Number of bytes in frame including STX and Checksum
OC	2 bytes	OpCode	Identifies the OpCode type
Payload	n bytes	Data field (n bytes)	Data in command or response
CC	1 byte	Checksum	Ones' complement of the low byte of the sum of all bytes excluding CC

Time-out:

- All bytes must be sent with a maximum delay of 30 ms between the bytes.
- When the delay exceeds 30 ms, a communication error response will be sent.

Response:

- Response will only follow when STX is detected.
- Response will follow the command with a delay of 0 to 500 ms (depending on OpCode and/or other Diver operations).
- If the frame format is incorrect, the OpCode is not supported or the checksum is not correct, then a communication error will be sent when STX is detected.

5.4 List of Commands

5.4.1 Read Date/Time

Read the date/time of the Diver clock.

Command:

STX	5	CL	None	CC

Response:

STX	22	CL	YY/MM/DD HH:MM:SS	CC

Data field length is 17 characters per described format

YY/MM/DD HH:MM:SS = Date/time format 17 characters

5.4.2 Read Monitoring Point Name

Read the name of the monitoring point programmed by the user.

Command:

STX	5	MP	None	CC

Response:

STX	25	MP	XXXXXXXXXXXXXXXXXXXX	CC

Data field length must be 20 characters

XXXXXXXXXXXXXXXXXXXX = Monitoring point name 20 characters

Example	Description
MW-3␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣␣	20 characters (all ASCII)

5.4.3 Read Serial Number

Read the unique serial number of the Diver.

Command:

STX	5	SN	None	CC

Response:

STX	15	SN	XXXXXXXXXX	CC

Data field length is 10 characters

XXXXXXXXXX = Serial number 10 characters

Example	Description
`X3440␣␣␣␣␣`	10 characters (all ASCII)

5.4.4 Read Real Time Pressure, Temperature and Conductivity Value

Read a real-time pressure, temperature and conductivity value of the Diver including a time stamp. If this command is given the Diver will take a reading immediately whether the Diver is logging or not. This data will not be stored in the Diver memory.

Command:

STX	5	RT	none	CC

Response:

STX	52	RT	YY/MM/DD HH:MM:SS:XXXXX.XXXZZZZZZ.ZZZ:KKKKK.KKK	CC

Data field length is 47 characters per described format

YY/MM/DD HH:MM:SS = Date/time format 17 characters

XXXXX.XXX = value Level (in cmH_2O and with 3 decimal) 9 characters

ZZZZZZ.ZZZ = value Temperature (in degrees Celsius with 3 decimals) 9 characters

KKKKK.KKK = value Conductivity (in mS/cm with 3 decimals) 9 characters

Example	Description
`22/05/06␣15:38:47:␣1048.491:␣␣␣22.700:␣␣␣␣4.860`	47 characters (all ASCII)

5.4.5 Read Recorded Pressure, Temperature and Conductivity

Read the data recorded by the Diver. Each data record consisting of a time stamp, pressure, temperature and conductivity value must be read separately.

Command:

STX	15	SD	XXXXXXXXXX	CC

Data field length is 10 characters per described format

XXXXXXXXXX = Record number 10 characters (first record is record number 1; last record number is 144,000)

Example	Description
`10000␣␣␣␣␣`	10 characters (all ASCII)

Response:

STX	52	SD	YY/MM/DD␣HH:MM:SS:XXXXX.XXX:ZZZZZ.ZZZ:KKKKK.KKK	CC

Data field length is 47 characters per described format

YY/MM/DD HH:MM:SS = Date/time format 17 characters

XXXXX.XXX = value Level (in cmH_2O with 3 decimals) 9 characters

ZZZZZ.ZZZ = value temperature (in degrees Celsius with 3 decimals) 9 characters

KKKKK.KKK = value conductivity (in mS/cm with 3 decimals) 9 characters

Example	Description
`22/05/06␣16:00:21:␣1049.016:␣␣␣21.130:␣␣␣␣4.976`	47 characters (all ASCII)

5.4.6 Read Product ID, Name and Firmware Version

Command:

STX	5	PI	none	CC

Response:

STX	25	PI	PP:XXXXXXXXXX:VVVVVV	CC

Data field length is 20 characters per described format

PP = Diver type 2 characters; type is 24 for CTD-Diver

XXXXXXXXXX = Product name Diver 10 characters

VVVVVV = Firmware version number 6 characters

Example	Description
`24␣:CTD-Diver:␣V1.13`	20 characters (all ASCII)

5.4.7 Read Product Status and Free Memory

Read the logging status and the free memory of the Diver. The logging status is either STARTED, STOPPED, or FUTURE START. The free memory indicates how many records (time stamp, pressure and temperature value) can be read until the Diver memory is full.

Command:

STX	5	PS	None	CC

Response:

STX	25	PS	XXXXXXXXXXXXX:MMMMMM	CC

Data field length is 20 characters per described format

XXXXXXXXXXXXX = Logging status Diver (STARTED, STOPPED, FUTURE START) 13 characters

MMMMMM = Free memory 6 characters from 0 to 144,000

Example	Description
STARTED␣␣␣␣␣␣:143914	20 characters (all ASCII)

5.4.8 Read Sample Method and Interval

Read the Diver's sample method and interval. The available sample methods are fixed time interval – continuous (FIXED␣RING) and fixed time interval – fixed length memory (FIXED␣␣␣␣␣), i.e. the Diver will stop logging when its memory is full.

Command:

STX	5	RS	None	CC

Response:

STX	35	RS	XXXXXXXXXX:YYYYYYYYY:ZZZZZZZZZ	CC

Data field length is 30 characters per described format

XXXXXXXXXX = Record method 10 characters

YYYYYYYYY = Record interval 9 characters

ZZZZZZZZZ = 9 spaces (not used)

XXXXXXXXXX	YYYYYYYYY	ZZZZZZZZZ
FIXED␣␣␣␣␣	xx␣SEC␣␣␣	␣␣␣␣␣␣␣␣␣
FIXED␣RING	xx␣MIN␣␣␣	␣␣␣␣␣␣␣␣␣

5.4.9 Read Remaining Battery Capacity

Read how much capacity of the battery is left from the initial capacity (%). Note that this is an estimated and calculated value and not a measured value.

Command:

STX	5	BC	None	CC

Response:

STX	15	BC	XXXXXXXXXX	CC

Data field length is 10 characters per described format

XXXXXXXXXX = Remaining battery capacity in percentage 10 characters

Example	Description
␣␣␣␣␣␣␣␣␣58	42 % battery capacity used and 58 % battery capacity remaining

5.4.10 Failure/Error Response

A Diver error response will be returned in the following format:

STX	15	FL	XXXXXXXXXX	CC

Data field length is 10 characters per described format

XXXXXXXXXX = Failure/error description 10 characters

Results	Description
TIME-OUT␣␣	Time-out occurred when still expecting characters
UNKNOWN␣OC	OpCode not recognized
ERROR␣CC␣␣	Checksum received incorrect
WRONG␣LEN␣	Length byte value incorrect
ERROR␣DATA	Data field incorrect (value incorrect)

6 Appendix III – CTD-Diver Accessories

6.1 Diver-Office software

Program Diver dataloggers and download measurements onto your PC. Export the data to a spreadsheet or modeling program. Diver-Office is a flexible "project-based" measurement software package designed for exchanging Diver data. Diver-Office is easy-to-use and has an intuitive user interface.

- Barometric compensation
- Units: Metric and U.S.
- 8 languages: Chinese, Dutch, English, French, German, Polish, Portuguese and Spanish

Free download from www.vanessen.com

6.2 USB Reading Unit

The Diver USB Reader can be used for programming or reading the Diver. Connect the USB Reader to the USB port of your PC or Laptop. Simply insert the Diver into the base of the USB Reading Unit and you are ready to communicate with your Diver.

The USB Reading Unit can be used in the field or the office.

Part no: AS330

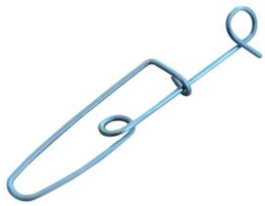
6.3 Stainless Steel Cable

Divers may be suspended on a stainless-steel wireline. This is an inexpensive method of deployment, and if in a well, allows the Diver to be easily locked out of sight and inaccessible.

Part no: MO500

6.4 Cable Clip

The cable clip provides an easy way to connect a Diver to a stainless-steel cable. The cable clip can also be used to attach the stainless-steel cable with the Diver to the top of casing.



Part no: MO310 (10 pcs)

6.5 Diver Copper Shield

The Diver Copper Shield protects the CTD-Diver from bio-fouling and reduces maintenance cost. The Diver Copper Shield is a copper coil shield specifically designed to significantly reduce the growth of algae on the electrodes. Thus reducing the need for maintenance and reducing the time spent on site.

Part no: AS350

6.6 Smart Interface Cable

The Diver Smart Interface Cable allows you to communicate with a Diver that has been deployed with the communication cable. The Smart Interface Cable has a mating connection for the communication cable on one end, and a standard USB port on the other, for connection to a laptop computer.

The Smart Interface Cable allows for data download, programming settings, or starting/stopping the Diver while in the field.

Part no: AS346

6.7 Communication Cable

Deploying a Diver on a Diver communication cable saves time on downloading and provides real time data from a Diver. Connect your laptop equipped with Diver-Office to the Diver Data Cable using the USB Interface Cable to program and read data from the Diver.

Available in lengths from 1 meter to 500 meter.

Part no: AS2xxx

xxx = length in meter, e.g 10 meter cable is AS2010

6.8 Diver-Mate

The Diver-Mate is designed for simple and fast download of data, increasing download efficiency while reducing data transfer errors.

The Diver-Mate can store Diver data from hundreds of Divers. Used in combination with a Diver communication cable, this downloading unit stores data in a non-volatile memory drive, meaning that even if the battery is empty the data will still be available. A full battery can support more than 10 days of operational use and a LED will indicate when the battery voltage is low.

Part no: DM421

vanEssen Instruments

6.9 Diver-Link

The Diver-NETZ remote monitoring system integrates field instrumentation with wireless communication and data management to effectively manage groundwater resources. A key part in this system is the Diver-Link, a compact 4G/LTE telemetry unit. The Diver-Link is suitable for the continuous long- and short-term monitoring projects.

Diver-Link is easy-to-install in a variety of borehole locations such as flush mount and stick-up wells. The Diver-Link transmits data from up to 3 Diver data loggers over a cellular network. Easily integrate Diver-Link into the Diver-HUB web portal for real-time management of site data, monitoring equipment and water levels.

Part no: DN4xx