DRAFT

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INPARTICULAR THE LAST CHAPTERS NEED MUCH EDITING

DWLR

OPERATIONS AND MAINTENANCE

HYDROLOGY PROJECT

dwlr manual 026.doc

Table of contents

1 Introduction

Over last decade, it was recognised that the need for water quality and quantity data would largely increase. To meet these water data needs an effective Hydrological Information System (HIS) is to be established. The HIS comprises data collection, data transport, data validation, data processing, data storage and data dissemination components. For groundwater, the collection of water level data is partly automated by the introduction of Digital Water Level Recorders (DWLRs).

Under the Hydrology Project a substantial number of DWLRs has been commissioned and an even larger number is scheduled for purchase and commissioning. Many of the issues related to DWLR are still quite knew to the agencies, often needed information is difficult to access or not even available, which obviously hampers fulfilment of identified data needs.

This note is a compilation of technical notes on many DWLR issues that are encountered along the chain from data need identification up to the operation of a full fledged DWLR network.

The note is a draft version, many topics are under development by the related specialists. Comments on the selected topics as well as their contents would be much appreciated.

2 Identification of data needs

TG2-GW

3 Network site selection

TG2-GW

4 Instrument specification

The instrument specifications cover the following main subjects:

- end-user aspects: level and time accuracy, measuring range, measuring interval, cable length
- operational aspects: battery lifetime, memory capacity, ease of use
- lifetime aspects: reliability, environmental compatibility
- maintenance aspects: calibration, servicing, and repairs

The specifications as listed in the specification documents should not only be assessed on their individual meaning and importance but also in connection with the complete instrument. Omission of one or more specifications may jeopardise the procurement process or result in procurement of substandard instruments.

In next subchapters a number of key issues is discussed.

4.1 Standard DWLR specifications

Under the Hydrology Project, standard DWLR specifications have been formulated and have been formally approved by a Specification Committee of CGWB and the states. The DWLR specification document is attached in Annex C.

The standard specifications mainly focus on so-called vented gauge pressure sensor type water level recorders. These instruments basically measure water level by a pressure sensor submerged in the water. In many instruments the pressure sensor is integrated with the data acquisition and logging electronics.

At the well head, above the water surface, a cable with a data communication connector gives access to the data logger for a controlling device, i.e. the Data Retrieval System (DRS). Virtually all DWLRs apply serial communication by RS232 or RS422/485. For field use the DRS functions usually are implemented on a Palmtop PC or on a Hand Held Terminal. In office a Desktop PC can be used as well.

Air pressure is passed to the pressure sensor, often also to the electronics section, by a narrow tube integrated in the data communication cable. That cable doubles as suspension cable.

4.2 Aspects requiring special attention

- The vented gauge pressure sensor and/or the instrument electronics can be quickly damaged when exposed to moisture. Therefore, a proper moisture ingress protection/blockage scheme should be applied. Modern instruments apply a hydrophobic filter, or similar, in combination with an easily replaceable desiccator package. Instruments that do not incorporate an adequate moisture ingress protection scheme may eventually fail due to corrosion or choking of the vent tube by accumulation of condensed water.
- As the pressure sensor is suspended from a cable, the longitudinal cable properties affect the measurement accuracy. If for example the cable stretches, then the pressure sensor sinks a little further into the well and, as a result, the water head above the sensor seems to increase. The hydrogeologist will wrongfully interpret the increased head as a rise in water level. A number of level and size definitions used in relation to the use of pressure sensors in piezometers are presented in Annex A.
- The cable length has to be long enough to suspend the sensor to a depth below the lowest water level. How far the sensor should be below the lowest waterlevel depends on the anticipated variation of the lowest water level. If the lowest water level

is expected to drop over the years to come, it may be decided to order a longer sensor cable to allow for adjustment to deeper suspension in the piezometer. Suspended on the maximum cable length the instrument may reach the bottom of the well. However, it should be noted that the 'sensor head', that is the height of the water column above the sensor, should not exceed the sensor's measuring range.

- All parts that are submerged during deployment, viz. electronics container, cable, cable glands, connectors, should comply with the IP68 standard and that for a specified immersion depth of at least 2 times the pressure sensor measuring range. The cable entry into the sensor or the submerged electronics unit should have a water lock to block ingress of water into the sensor or electronics in case of a puncture or pinhole in the cable jack. Such puncture can originate from manufacturing or from handling, e.g. during recovery/(re-)installation in the field. The water lock usually is constructed of a mould of rubber compound (or flexible araldite) through which the cable wire and the vent tube are passed individually. Each wire/tube is surrounded by massive rubber which is tightly bonded to the wire/tube. This effectively blocks the ingress of water from a punctured cable.
  A detachable connector on the pressure sensor increases operational flexibility. Such connector may also act as a water blockage. However, the cable part of the connector should be moulded to the cable in order to protect the individual connector contacts against corrosion and short-circuiting due to water penetration.
  The use of cable glands is not recommended because it does not provide a water lock on the cable interior. Further, people tend to over fasten the nut of the cable gland, which will result in unreliable sealing.
- The ease of use of the instrument strongly depends on the DRS (Palmtop PC/Hand held terminal) software. The use of the software should require only single keystrokes to execute the main tasks. The data offload duration should be short, preferably only a few minutes to offload a completely filled memory. The graphics functions should be easy to use, only needing a few keystrokes to zoom in on the sections of interest. The user needs to focus on certain periods of interest and may want to scale the level/temperature readings for such periods.
- Given the transport time and formalities involved, there shall be no need to return instruments to the manufacture (Indian or foreign). Instead, servicing, re-calibration and battery replacement should be executed at the premises of the purchaser/supplier. Defective instruments should be replaced by spares.

4.3 Moisture ingress and alternative measuring principles.

To maintain reliability and long term accuracy, an effective moisture ingress protection scheme on the DWLR vent tube inlet is very much required. Such a moisture ingress protection must be based on a moisture blockage system, usually a hydrophobic filter, with a desiccator back-up to absorb most of the moisture that infiltrates into the vent system.

The desiccator should have ample capacity to cater at least the required servicing interval. The desiccator capacity depends on serviced vent volume of the instrument, i.e. including the vent tube, the pressure sensor reference cavity and possibly the electronics compartment in case of an integrated instrument.
The air-vent inlet needs to be fitted with a hydrophobic filter, e.g. a PTFE pellet, to impede any ingress of water droplets.

Alternatively, the hydrophobic filter may be replaced by a flexible bag. This would completely block the moisture ingress into the vent tube. The longer the cable, the larger the volume of the vent system, the larger the volume of the bag has to be. Further the bag has to be quite flexible, it should pass pressure changes but should not absorb pressure. Much like the hydrophobic filter, the bag has to be replaced after say one or two years.

Bubbler type pressure measurement

An alternative to the vented type pressure sensor is the bubbler. In that instrument the pressure sensor is not submerged but kept above the water. The water head is passed to the pressure sensor by compressed air. The air pressure is controlled in such a way that it balances the water head. A major advantage of this instrument is that there are no vulnerable parts exposed to the water. Over the years, the lowest water levels may change, e.g. fall due to overdraft, then the bubble pot at the bottom of the tube has to be lowered accordingly. This basically requires extension of the bubbler tube, which is simple and cheap.

Absolute pressure sensor

Yet another alternative is the absolute type pressure sensor. The absolute pressure sensor measures relative to vacuum. The vacuum is maintained in a cavity at the rear side of the sensing element. Due to the measuring principle, there is neither need nor possibility for a vent tube to pass the atmospheric pressure to the sensor. Without vent tube, the instrument is cheaper and easier to adapt to other suspension depths, provided that the pressure sensor and the electronics are integrated in a single enclosure.

Some implementations are completely sealed (welded) which effectively protects them against water ingress due to cable defects. In that case the built in battery capacity should be enough for at least 10 years of operation at say 1-hour data collection interval. The integrated instrument type can be suspended from a steel or Kevlar wire, which is easily adjustable to other depths.

A disadvantage of absolute pressure sensors is that a second instrument is needed to collect atmospheric pressure data for compensation purposes. A number of piezometer wells can be catered by a single atmospheric pressure recorder. The accuracy of the water level, after compensation for air-pressure effects, is less than with a similar but vented gauge instrument, because the data from two instruments have to be subtracted. Moreover, the farther the air pressure reference instrument is separated from the water level instruments the less representative the air pressure will be for the site of the piezometer. This limits the maximum range/area that can be serviced by a single air pressure recorder. The air pressure recorder can be made more accurate than the water level recorder because it is submitted to a smaller pressure range.

In practice, reliability can be considerably higher at the cost of a small decrease in accuracy.

5 Instrument procurement

Essential is that the procured instruments are effective for their purpose. Instruments should be easy to operate, they should produce accurate results and all that at an optimum price performance ratio. Defining instrument specifications should be a demand driven process, i.e. the data users should define their requirements and based on these the instrument specifications should be formulated. The specifications should aim at delivery of the data that are required for hydrological application.

In this Chapter the procurement process is addressed and some suggestions to accommodate the new requirements that are special for electronic instruments are given.

5.1 Present practice

Presently instrument procurement, to a large extent, is an administrative and document based process. The technical requirements are catered for by inclusion of general specifications into the bidding document. In a technical driven environment such general specifications may be adequate because then instruments will only be accepted (paid for) if they effectively meet the user's requirements. In an administration driven environment the technical effectiveness of the equipment/instruments under procurement may receive less attention which may result in, unknowingly, procurement of sub-standard instruments.

5.2 Suggestion for new practices

Instrument manufacturers and instrument users may combine their interests and efforts and co-operate to improve instrument quality and to select the proper instrument for the application. Both parties involved, i.e. purchaser and supplier, should not only communicate at administrative level but also at technical level. For that the purchaser requires in-house instrumentation expertise.

In the effort to increase instrument quality and effectiveness, the purchaser may give feedback to the supplier on difficulties encountered during installation/operation, and suggest improvements that would better meet the purchaser's requirements.

Interested manufacturers, thriving to bring their products to international standards, would be found prepared to take action. In this technical co-operation, gradually instrument quality and effectiveness would improve, and as a result more useful data can be collected, at less effort. This approach may result in costlier instruments, but instruments that work and meet the requirements should be preferred over cheap instruments decaying on racks in a storeroom.

Suggestions:

1. From an instrument manufacturer, it might be expected that he understands the hydrometric use of his products and takes pride in delivering effective instruments.
2. The purchaser would benefit from in-house instrumentation expertise, e.g. implemented by a hydrometrist. The hydrometrist should understand the principles and functioning of hydrometric instruments and their purpose.
3. Procurement procedures could be adjusted so that only functional instruments, meeting the technical specifications and fit for the application, are accepted. This may imply execution of pre-procurement tests on unknown instruments and in field performance assessment of operational instruments at the user's sites.
4. Any difficulties with operation of instruments, be it due to design flaws and/or poor quality should be communicated with interested manufacturers to be remedied in future products.

5.3 Specifications

The specifications should not only cater for the required hydrological data, but instead aim to specify integral instrument properties as well as the operational aspects.
A selection of aspects to consider is listed below.

- The product should meet the user's requirements, i.e. it should deliver the data as required for the user's application. This in particular affects the measuring range (Full-Scale range) and accuracy, the data recording interval, clock accuracy and data storage capacity.
- The accuracy specifications should cover the instantaneous and long-term accuracy under varying environmental and power supply conditions.
- The product should have sufficient capacity to meet the user's requirements.
- The operational conditions should be addressed.
- The product should be compatible with the environment of operation, e.g. it should sustain low and high temperatures, high humidity, dust, insects, attacks by rodents. Proper ingress protection levels for dust and moisture should be implemented in the product design. The definition of the international IP coding system is enclosed in Annex B.
- The design and manufacturing process should aim to maximise reliability, e.g. by selection of proper materials and components, over dimensioning, robustness, thorough testing etc.
  Electrical instruments should be protected against battery reversal, over voltages on all input/output lines, electrical interference, radio radiation and the like. On the other hand, the emission of electrical signals should be limited to within the pertaining national requirements.
  Software should be bug free, have watchdog monitoring, be of a modular design, easy to use, have spare program memory capacity and a measuring cycle with slack time. The user's communication, e.g. during offloading of the data, should never hinder the data collection. Further, the software should be user-fault tolerant and Y2K compliant.
- Proper measures should be implemented to adequately sustain the product under Indian conditions. The sustainability of an instrument or measuring system depends on many factors. Several levels can be distinguished, e.g. sustainable by the purchaser, by the supplier, by highly specialised institutes or by the manufacturer. Preferably, the purchaser can take care of it.
  Instruments that have to be send abroad for normal servicing should be avoided, servicing in India is much to be preferred. This may imply set up of support centres, maintaining stocks of spares, training of technicians, instrument operators etc.
  Adequate documents, manuals and guidelines, formulated in language and style that is easily understood by the purchaser's engineers should be part of the delivery.
- The product should be easy to maintain, this requirement should be part of the design and development process. Instruments should have as few adjustment points as possible, in modern there is virtually no need for potentiometers to be adjusted after manufacturing. Electronic instruments may have the adjustments implemented in software instead of hardware. Both instrument and its associated software should be accurately documented.
- Further, proper training and tools should be provided, there should be no need to return the product to the manufacturer for normal maintenance.
- The delivery should include an adequate amount of spares, tools and consumables.

It is recommended to add a Specifications and Requirements Form to the bid document. The form should address all the technical specifications that the bidder has to make available. Some bidders are used to fill in such forms by exactly copying the required specifications or by stating ‘complied’ or similar phrases of little substance. It is recommended to demand from the bidders to completely fill in all form entries and to give all the required details that pertain to the offered instruments. The bid evaluation would be much easier and more objective if all the technical specifications are available in a standardised format. It may be necessary to verify the supplier's specification claims.

Prior to giving the order, suppliers may be requested to demonstrate the offered instrument(s). The accuracy of the instrument and its ease of use have to meet the purchaser’s standards. At the same occasion, the quality and adequacy of the software (if any) and manuals, guidelines should be assessed. Special attention requires the compatibility of the instruments with the prevailing climatological and environmental conditions.
For large numbers and/or unknown instruments, execution of a performance test is recommended. The adequacy for the purpose may also be assessed under such a test.

5.4 Acceptance

The delivery of new instruments straight form the manufacturer not necessarily implies that these instruments will comply with the specifications. Instruments may have been damaged during transport, components may have broken down, software may have been corrupted or poorly set up, the instruments may suffer from a design flaw, a manufacturing error, a substandard quality assurance program, poorly implemented production tests and many other causes. Unfortunately, some suppliers and/or manufacturers may attempt to increase profit by using cheap sub-standard components.

Obviously, prior to deployment of the instruments, the purchaser wants to verify if all the deliverables comply with the specifications. As one of the tools in the effort to ascertain the instrument performance and to improve on quality, it is recommended to apply an acceptance protocol on each delivery. Not only the purchaser but also sincere manufacturers would benefit from that because the acceptance protocol would filter out the inferior 'hit and run' kind of supplier.

Typical subjects covered by the acceptance protocol are:
- availability and quality of documents and manuals
- calibration reports and data from the manufacturer
- ALL delivered instruments should be functionally tested
- ALL instruments should be submitted to some simple accuracy tests

With respect to the acceptance of the DWLRs it is recommended to announce the implementation of an Acceptance Protocol. The basic requirements for that Acceptance Protocol may be added to the Tender Document. It is of great importance that the delivered products do meet the specifications and are fit for the envisaged use. Application of an effective Acceptance Protocol ascertains for both the supplier and the purchaser that products passing the tests are functioning according to the specifications and will be accepted and paid for by the purchaser. Those instruments that fail to meet the acceptance criteria, are rejected and have to be replaced by properly functioning instruments, within a specified time. Chapter 6 addresses instrument testing in detail.

5.5 Performance monitoring

After acceptance of the instruments and installation in the field, their performance should be monitored. One reason is to collect statistical performance data on the instrument this to optimise maintenance and service planning. Further, the quality and reliability of the collected data is largely enhanced by routinely collected reference data.

For DWLR performance monitoring, manual observations by level tape, would give the required reference information. Comparison of the instrument data with the manual observations would allow assessment of the accuracy, stability, and reliability. Chapter 8 is dedicated to performance monitoring.

6 Instrument testing

This Chapter covers several tests and procedures for acceptance of new or serviced/repaired instruments.

The delivery of goods/instruments and software should be in accordance with the order placed with the Supplier. To formalise the process of delivery, an Acceptance Protocol is prescribed. The Acceptance tests described here are a sub-set from the Acceptance Protocol of the Bid document.

The Acceptance Protocol serves as a formal guidance during delivery of the DWLRs. Its primary goals are twofold.

1. Ascertain the delivery and completeness of all ordered products and related documents.
2. Check the functioning of the instruments and software in a formal way against the specifications, conditions and requirements by application of Acceptance Tests. The tests also verify the accuracy and stability of the instruments.

The Acceptance Protocol should be executed in close co-operation between the Supplier and the Purchaser, the findings shall be reported in an Acceptance Report.

Products should be accepted only if they meet the requirements and are functioning in compliance with the technical specifications, and the related documents are complete and correct. Defective products and any other discrepancies have to be replaced/resolved, within a pre-defined time frame.

The Acceptance Report lays down the findings and observations that were made during the execution of the Acceptance Protocol and is a formal document to record the acceptance or rejection of any item as covered in the Bid document. Any flaws or findings are to be reported. The forms and checklists filled out during the execution of the Acceptance Protocol are to be enclosed with the Acceptance Report.

The pre-installation test is less formal, it is executed to verify the completeness and functioning of instruments and related tools and accessories.

6.1 Test procedures

The basic procedures related to execution of the acceptance protocol and pre-deployment testing are attached in Annex E. Here a summary of the tests is given.

6.1.1 Acceptance test

The Acceptance Tests are executed in a formal manner, preferably in concert with the supplier's experts. The Acceptance Test Programme aims to identify the malfunctioning that are and those not compliant with the bid specifications. At least the following tests should be executed under the Acceptance Tests:

1. functional tests
2. clock accuracy test
3. zero stability test

Other tests from the list may be executed on a selection of the instruments.

The zero stability test has much in common with a standard field set-up and installation procedure. The main difference is that the instruments are kept dry and the venue is the office instead of the field. This makes the test also a good training vehicle. It is recommended to execute the zero stability test during at least 3 days, and on all units simultaneously to make comparison possible. An adequate recording interval is 30 minutes. All units that pass the tests can be released for field installation. The trainees may take part in the set-up of the instruments. After at least 3 days of undisturbed data collection the trainees may participate in data retrieval, data transfer to a PC and initial data evaluation.

6.1.2 Pre-installation test

The Pre-installation Tests are executed on routine basis without the need for the supplier's participation. The Pre-installation Test Programme aims to identify any malfunctioning instrument and the completeness of the tools and accessories. At least the following tests should be executed under the Pre-installation Tests:

1. functional tests
2. clock accuracy test
3. zero stability test

6.1.3 Test execution

In Annex E, a detailed description of several scale and stability tests is given. In particular the dry zero stability test is recommended for acceptance and pre-deployment testing.

Prior to execution of the tests, a detailed test script has to be drafted and agreed upon. Typically the test script should define:

- venue of the tests
- list of test types and sequence of execution
- number instruments to be submitted to each type of test
- the conditions and requirements for each type of test
- person(s) responsible for conducting the tests
- handling of failures and problems
- reporting requirements
- acceptance formalities

In addition, it is important that all activities and peculiarities (what, when, where, who, which instrument, etc.) are annotated and uniquely linked to the individual instruments and added to the instrument history file. In Chapter 8.3.1, the history file is explained in some more detail.

7 DWLR commissioning

Before a DWLRs can be effectively put into service, the following prerequisites have to be met:

1. the piezometer well should be ready
2. the DWLR should have been successfully tested
3. the related staff and engineers should have been adequately trained
4. a DWLR operations procedure should have been designed and implemented
5. for spatial comparison of water level data originating from different piezometers, the reduced level of each piezometer is needed

The DWLR testing is addressed in Chapter 6, the Training aspects are covered in Chapter 13 and the operational procedures in Chapter xxxxxxxxxxxxx. The commissioning aspects related to the piezometer well and the DWLR are covered here.

The DWLR commissioning includes installation of the instrument and putting it to work. Preferably, the supplier participates during the first commissioning of new DWLRs. The purchasing agency should strive to accumulate the required knowledge and become an expert user organisation.

7.1 Piezometer well

Installation of a DWLR requires a well or piezometer of appropriate diameter such that the lowering and raising of the instrument is possible. Normally and depending upon the chemical quality of groundwater and its corrosive nature, piezometer casing pipe made of mild steel (MS) or PVC are used. The diameters range from 70 mm to 150 mm. The smaller the piezometer diameter the better the response to changes in pressure head of the aquifer will be as the storage effect will be negligible. The well diameter should be sufficiently large to facilitate the collection of water (quality) sample by pumping. The piezometer casing-pipe protrudes to 0.5 m above ground level in order to avoid ingress of soil/dirt or storm water. The top of well/piezometer casing forms the reference point and is normally connected to mean sea level (MSL). The top casing pipe is completely grouted with cement to provide firm grip to the casing pipe.

The basic motive for installation of DWLRs is the requirement of historical water level data over a long period to assess the maximum and minimum levels, the fluctuations with time and the response to recharge/discharge conditions in the aquifer. Further, data are required on aspects such as recording of tidal effects, pumping tests, data collection etc.

Based on the details of depth to water level, seasonal fluctuation, long-term fluctuation, critical drought period level of water table, and a minimum submergence of the pressure sensor below the water table the cable length is to be established.

7.2 Reduced levels

The pressure sensor type of DWLR measures water level fluctuation relative to its internal reference. Usually the reference is the membrane of the pressure sensor. For many hydrogeological applications the water level data have to be related to the lithology and/or water level data of other sources, e.g. wells in the same aquifer and river stage. For a proper comparison, all these data have to be related to the same reference level, usually Mean Sea Level (MSL).

On the piezometer well a reference point is identified. In order to get a reproducible result, the reference point should be used for all water level measurements, both by tape and by

DWLR. The reference point should be clearly marked for unambiguous identification and it should be acute-angled for accurate measurement.

By levelling that piezometer reference point is connected to (MSL) benchmarks, e.g. GTS benchmarks or other benchmarks of established accuracy. For effective use, the piezometer well reference point should be on top of the well head and easily accessible as reference for manual observations by level tape. There should be no obstructions that may hamper the movement/use of the tape. The level tape can deliver the required accuracy only if it is vertical, without bends along obstructions.

7.3 Installation steps

The pressure sensor is lowered in the piezometer on its suspension/electrical cable to the desired depth. The top end of the cable is hooked to a special clamp on the well head, firmly keeping the sensor in position at the desired depth. A safety wire should be attached to avoid loss of the instrument due to error or failure of the main suspension. On the well head a steel case of appropriate size should be made to enclose the well head and all DWLR parts. Within the case the surplus cable may be stored. During data retrieval and other communications with the DWLR, that connectors is attached to the DRS. Therefore it should be easily accessible.

For the first month the recording interval should be 1 hour, later on the interval could be adjusted according to the temporal water level fluctuations in the piezometers, e.g. to 3, 6 or 12 hours

The site geologist/operator of DWLRs should be furnished with a detailed operation manual as well as trouble shooting guidelines. All DWLR operators need rigorous training to make them fully acquainted with the working principle of DWLRs.

In next Chapters the installation steps are presented. The installation steps given here are generic and intend to be a guideline, for detailed installation procedures of specific instruments, also the manufacturers manual and instructions should be observed.

7.3.1 Pre-installation

7.3.1.1 Materials

- instrument to be installed
- accessories required for deployment, e.g. electrical/suspension cable, suspension grip, safety catch, nose cone/pressure filter, desiccator, hydrophobic filter, communication cable to DRS, communication interface box to DRS/PC (required for some brands)
- spares, e.g. electrical/suspension cable (if any), suspension grip, safety catch, nose cone/pressure filter, desiccator, hydrophobic filter, communication cable to DRS, communication interface box to DRS/PC
- DRS
- high accuracy level tape
- volt/resistance meter
- manual/instruction sheets
- spare batteries for DWLR (if required)
- spare batteries and/or battery charger for DRS
- transport box

7.3.1.2 Checks prior to departure

- functioning of the DRS
- functioning of the DRS battery charger
- functioning of the DWLR
- remaining battery capacity of DWLR
- voltage/capacity of spare DWLR battery (if any)

- details on piezometer well and DWLR on log sheet, e.g. well code, latest retrieval date, well RL value, required instrument installation depth, DWLR Serial Number (S/N), pressure sensor S/N
- set the DRS clock to precise national time broadcast, i.e. the radio **beeps**. Time **announcements** are not accurate enough! If available, GPS time may be used instead, it is extremely accurate.

7.3.2 Installation

7.3.2.1 preparation

- take a manual level and date/time observation
- verify the S/N and measuring range of the sensor and DWLR
- prepare the sensor for installation by attaching pressure filter/nose cone (if required)
- prepare the sensor and cable for installation to the required depth relative to top of casing. Mark the required cable length.
  The cable should be carefully uncoiled by unrolling (i.e. rotating) instead of uncoiling. This to avoid coils and kinks in the cable. Coils/kinks in the cable would result in initial zero drift because off uncoiling/stretching of the cable over time.
- attach the suspension grip/clamp for the required suspension depth to the cable
- prepare the safety wire
- carefully suspend the sensor to the required depth, relative to the top of casing. Avoid shaving of the cable and banging of the sensor. The sensor can adjust to the water temperature and the cable can fully stretch.
- fix the cable grip to a strong, stable and rigid point
- attach the safety wire to another strong and rigid point
- check air vent hydrophobic filter
- install fresh desiccator

7.3.2.2 set-up

- start the DWLR application on the DRS
- connect to the DWLR
- open communications between DRS and DWLR
- enable recording of temperature (if supported)
- check DWLR date and time, and adjust if required
- check DWLR memory setting: it should be set to endless loop/ring type
- set the recording start time so that the readings are taken at integer intervals in such a way that at midnight a reading is taken.
  Example: if the recording interval is 30 minutes then recordings have to be made at 00h00, 00h30, 01h00, 01h30 etc.
- set the recording interval in such a way that the full 24h is covered by an integer number of record intervals
- time is to be presented in hhmmss format and **not** in AM/PM format.
- water levels have to be presented in metres with millimetre resolution, non SI units such as inches, feet etc. are not acceptable under the Hydrology Project.

- water level is to be presented as distance to water level (from Top of Casing). This makes water level records directly comparable with manual observations.
  Use an accurate level tape for this.
- connect the DWLR to ToC observing the manufacturer's instructions
- check the proper reading of the DWLR
- very the proper set-up of the DWLR
- shut down communications
- disconnect the DRS from the DWLR

7.3.2.3 Post-installation

- allow the DWLR to take as least one programmed record
- connect the DRS to the DWLR again
- take manual level tape and time/date observations.
- take instantaneous DWLR water level reading
- compare both readings
- offload the collected data from the DWLR
- check the offloaded data for consistency
- shut communication down and disconnect
- place end protection caps on the cable terminal
- check proper fixing of DWLR suspension and safety wire
- nicely coil the free end of the electrical/suspension cable taking care not to introduce kinks
- close the well head and attach safety lock
- close and lock the well housing

All actions and observations should be noted in the related log sheet. Time dependant observations should be given a time tag. Water level readings by level tape and DWLR should be taken quickly after each other to avoid difference due to change of water level between both observations.

8 Performance monitoring and operations

8.1 Introduction

Although the DWLRs were selected for proven reliability, they cannot be left without attention. The data return, i.e. the amount of collected data, and the data quality can be adversely affected by many causes resulting in damage and/or accuracy deterioration. Damage may be caused by vandals, rodents, collapse of the well, flooding, lightning strikes, insects, corrosion, fungi, moisture ingress, battery leakage, operator error and unfortunately many more causes. The accuracy may deteriorate due to any of the above mentioned damage causes but also due to drift of sensor and electronics, slippage of the suspension, change in water density, blockage of the air vent system, corrosion, sedimentation or salt deposition on the pressure sensor.

Unavoidably, problems will arise during large-scale deployment of DWLRs, and the Hydrology Project will not be spared. To avoid severe loss of data and/or deterioration of the data quality, proper measures have to be taken. Implementation of a performance-monitoring scheme is one of such measures. The performance-monitoring scheme primarily aims to limit the duration of data loss, if any, and to collect reference data for validation purposes. The sooner an instrument defect is detected, the less data might be lost. Therefore, the performance-monitoring interval should be as short as possible.

The quality of the validated data depends on the accuracy and reliability of the DWLR and also of the accuracy and amount of the reference data. Hence, also for validation purposes the performance-monitoring interval should be short. Moreover, the effect of errors caused by drift, e.g. of the clock, of the pressure sensor or of the suspension can be limited by timely verification and adjustment, if required.

The performance-monitoring interval could be set in such a way that the drift errors are effectively limited to acceptable margins and the chances of large data loss are minimised. Hence, a stable and reliable instrument may be visited less frequently than a drifting instrument and/or risky piezometer well. Initially, the performance-monitoring interval may be as short as possible to gain experience with the individual instruments and piezometer wells and to build adequate performance statistics. An assessment of the statistical data may result in an adjustment of the performance-monitoring interval.

8.2 Requirements for DWLR performance-monitoring

The following general requirements have to be met:

1. the piezometer well is properly prepared
   For the water level reference measurement a level (dipper) tape is used. In order to get a reproducible result, the well should have a reference point that is used for all water level reference measurements. The reference point should be clearly marked for unambiguous identification and it should be acute-angled for accurate measurement. All measurements, both by tape and by DWLR should be referenced to that point. The well interior should be easily accessible for the level tape, there should be no obstructions that may hamper the movement/use of the tape. The level tape can deliver the required accuracy only if it is vertical, without bends along obstructions.
2. the proper reference tools are available
   The time reference is derived from the clock of the DRS, the latter is synchronised with the national time reference or with GPS time. For verification of level measurements, accurate level tape is needed. The level tapes should have an accuracy that effectively exceeds the DWLR accuracy, at least by a factor of 2. Comparison of various level tapes is quite instructive. Differences of 5 mm/m are common. The level

tape may also be verified against an electronic distance meters, e.g. one that is integrated in a precision 'total station'.

3. the operator is properly trained
   Operators who execute the performance monitoring should be aware of the objectives for the performance monitoring. Moreover, the operator should be fully conversant with the DWLR and DRS.
4. a performance-monitoring checklist is available
   The performance monitoring at each station should be executed in compliance with a formal check list, this to collect all the required data in a standardised format which allows comparison of previous checklists pertaining to that station.
5. a station logbook is available
   The logbook of a station is the collection of all checklists pertaining to that station plus all other documents related to the performance of that station, i.e. it contains all the historical information pertaining to the station. From the historical data the operator may learn what aspects require special attention, e.g. zero drift (cable grip check), condensation (desiccator replacement), communication problems (spare cable required)

It is recommended to draft an operation and maintenance plan catering for:

- verification measurements
- system performance monitoring
- data recovery
- preventive maintenance
- fault handling

Some activities can be executed by field staff, others require thoroughly trained staff equipped with DRS.

8.3 Execution of performance monitoring

Performance monitoring should be part of standard procedures. Initially, after-set-up and commissioning of the instrument, performance is monitored rather frequently, later, after assessment of the collected data the monitoring interval may be optimised for best result at minimum effort and costs.

Especially in the first year of deployment, when the DWLR properties are not fully known yet, the performance should be monitored by taking regular and accurate (better than 0.01 m) verification measurements. Every important aspect of instrument performance should be monitored on a routine basis. The performance monitoring should be continued during the full operational lifetime of each DWLR. The performance-monitoring interval may be adjusted according to the findings. That is, if the DWLRs prove to function reliably, then the frequency of monitoring may be decreased to optimise cost versus data quality and data return.

Data recovery should be done at an appropriate interval, possibly in combination with preventive maintenance.

Preventive maintenance merely concentrates on keeping the instrument clean, changing desiccant timely and replacing batteries. Some maintenance aspects, like changing batteries, may only be executed by specialists. In particular in piezometer wells, featuring high salt concentrations, regular checks for corrosion and deposition of salts are required.

Accurate level tape has to be procured. The level tapes are to be used for reference purposes, they should have an accuracy that exceeds the DWLR accuracy.

8.3.1 administration and logging

- for each station a comprehensive history file should be maintained.
- for each DWLR a comprehensive history file should be maintained.
- all findings and activities related to the field stations, instruments used, observations made, and data collected should be logged into history file

8.3.2 organisation and preparation

- station history files
- site visit log sheets
- data/formulas for conversion of manual observation into DWLR reading or vice versa
- accurate level tape
- spare batteries for: DWLR, level tape (if electronic) and HHT/Palmtop
- verify HHT/Palmtop clock with national time or GPS time, make a note in the HHT/Palmtop logbook
- accurately set HHT/Palmtop clock to national time (up to a second)

8.3.3 Performance checks

Annotate all checks and their results in the station visit sheet, much like with the other activities and observations. Any remedial action should take place after instrument verification. Do not pull the instrument out of the water because this may affect its reading and/or hamper trouble shooting.

- check the piezometer housing for damage, tampering
- check the well for damage, tampering
- check the main and safety suspensions of the DWLR
- check for possible slip on the main suspension
- check for a safety line and its fixing
- check the cable for damage, kinks etc.
- check the cable termination for damage, dirt, moisture
- check if the reference point (a spot on the well head) is distinctly marked
- check the ingress protection on the air vent access opening, clean or replace hydrophobic filter if required
- check the desiccator for remaining capacity/saturation, replace if saturated
- annotate all observations/checks and any other observation that possibly may be of interest for DWLR operation, data validation and/or trouble shooting

8.3.4 verification

- do a manual water level observation with high accuracy level tape. For reproducibility reasons, preferably always the same level tape is used.
- annotate reading, time, observer name, and level tape identification (which tape was used)
- do an instantaneous DWLR level reading, annotate DWLR reading, date and time on the log sheet. The interval between instrument reading and manual observation should be kept short.
- all readings and observations should be in meters and not in feet. The resolution of readings and observation should be 1 mm.
- the instrument reading should be relative to instrument zero (head) or ToC. If the instrument gives level as head, i.e. water level above the sensor, then the ToC value is obtained by subtracting the head from the installation depth (relative to the well head). The ToC value should be positive and increase with falling water level, it is equivalent to a manual observation..
- verify both manual observation and instrument reading for consistency, for this historical data may be used.

- check/adjust the DWLR clock with the HHT/Palmtop clock: make log sheet entries of DWLR and DRS time. If the DWLR clock is adjusted, then make a another log sheet entry of the event and the time/date it was adjusted to
- do a DWLR battery voltage reading, make an entry in the log sheet, and assess if that voltage is sufficient to cover the next service period
- offload/retrieve the new data records from the DWLR
- do not erase the DWLR, first the offloaded data have to be stored and reliably backed up in office. It is recommended to keep all the data on the DWLR. This is most easy if the logger memory is organised in a ring structure. The ring structure implies that when the memory becomes completely filled, the oldest data gets overwritten by the new data.
  Under normal conditions, the offload function should automatically offload of the new data only. The already offloaded data does not have to be retrieved again, unless data were lost or corrupted during transport/transfer to data storage in office. In that case, there should be an offload option to retrieve data starting at a user-defined date: that is the date of the latest correctly transferred data.
- verify the internal consistency of the time series, e.g. by displaying a time series graph. This graph should display sufficient detail to make these verifications. For that the level and time scales should be adjustable and zooming-in on particular data events should be supported by the software.
- if any flaws in the data or functioning are detected then these have to be documented and reported immediately. Prior to departing, the DWLR operator may have to execute some trouble shooting tests and trials on site. Refer to the DWLR manual for details. The instrument should not be opened at that occasion.
  Returned in office, the flaw has to be reported and immediate actions have to be organised to remedy the DWLR problem.

- prior to disconnection of the DRS verify if the DWLR is in the required operational mode
- refit all connector caps
- close the well
- close and lock well housing

9 Maintenance

Both the piezometer well and the DWLR that is suspended in the well are subject to wear and tear. Further, the accuracy of the DWLR may degrade with time. To maintain their performance at the required level they need regular attention and maintenance.

For a proper maintenance system at least the following prerequisites have to be met:

- manpower
  The maintenance staff requires special training. The training should assess all aspects that may be of importance for maintenance and trouble shooting. For the maintenance staff, dedicated maintenance manuals and regulations should be available. The supplier, possibly in concert with the manufacturer, is to deliver all technical information, documents, manuals and training as required for a proper maintenance.
- tools and materials
  Special tools may be required for maintenance and testing, e.g. to clean the sensor, to execute advanced/detailed testing, to check and execute calibration. For instruments that communicate with the DRS via electrical cable, some instrument to test the continuity of communication cable would be useful. Further spares and consumables should be available.
- budget
  The maintenance costs add to the total operational costs and should be catered for in the annual budget. Initially, most of the costs may be covered by a Annual Maintenance Contract. Later the purchaser may decide to take the maintenance in its own hands, possibly with the assistance of the supplier or an expert service organisation.
- schedule
  Maintenance is to be executed in a certain time frame, for that is maintenance schedule is to be implemented.

The supplier may render his services to ascertain the proper functioning of the instruments in a well-trained users environment. This may be covered in an AMC contract.

In next sub-chapters, the maintenance aspects are assessed in more detail.

9.1 Manpower

Both purchaser and supplier will be involved in the maintenance of the piezometer wells and the DWLRs. The supplier may focus on the maintenance of the DWLRs, in particular in the first years when maintenance is covered under an AMC contract.

The supplier should meet certain criteria to qualify for the delivery and maintenance of the instruments. Basically the supplier should have the technical expertise on the DWLR, this is to be based on in-depth training by the manufacturer and ample field experience with DWLRs.

For regular maintenance of the DWLRs, in many cases, the purchaser does not have sufficient in-house capacity and capabilities. The supplier may provide that capacity, by setting up a maintenance organisation, preferably in the purchaser's state. The maintenance organisation should command adequately trained staff, have access to proper testing and verification tools/instruments and stock sufficient spare parts and consumables to remedy deficiencies.

An important component of the supplier's expertise is the capability to deliver training on the DWLR/DRS to observers, operators and maintenance staff. The success of DWLR deployment strongly depends on the user's capability to absorb the technical information and to properly operate the DWLR/DRS.
The training should cover a number of fields:

1. the waterlevel measurement in relationship to the hydro-geological application
2. the basics of the DWLR, e.g. pressure sensor, air-vent, moisture ingress protection, DRS, setting up of the DWLR, data retrieval, performance monitoring and assessment, maintenance, trouble shooting, data transfer to PC
3. in office exercises with DWLR and DRS
4. field installation including a number of exercises in practice
5. accuracy aspects, need for high quality level tape
6. standard field procedures, history file
7. fault handling, i.e. how to handle performance problems
8. maintenance
9. repairs
10. calibration

The level of training should depend on the required expertise. A maintenance engineer may require more in depth training than the day to day operator, whereas a manager in the office does not need to be involved in all the technical details, he may want to get an overall picture to allow him to take the proper decisions.

9.2 Tools and materials

Tools are needed at various levels, i.e. for normal operation, for trouble shooting and for repair and calibration. The same applies to spares and consumables.

Field operation
The field operators, while visiting the DWLRs with their DRS, need a high accuracy level tape to manually measure the depth to the water table. The manual observation is needed for comparison with the instantaneous DWLR reading during set-up and performance monitoring.

Some of the electrical cables used to connect the DRS to the DWLR are a bit vulnerable. The operator may permanently carry a spare. Also spare batteries for the DRS should be brought to the field.

Each field visit, the moisture ingress protection is checked. Required spares are replacements for the hydrophobic filter or separator bag, which ever applicable and desiccator cartridges.

Servicing and calibration
In particular for instruments that are procured in large quantities, there should be no need to dispatch them overseas for calibration purposes. If a calibration facility is not readily available, then the supplier may be approached to set-up such a facility.

Specialised calibration equipment is needed for the DWLRs. Such instruments could be a dead weight tester and/or a high accuracy (e.g. 0.01%) pressure sensor. For temperature tests and calibrations, a temperature-controlled cabinet should be part of the calibration facilities. There should be a facility to record pressure and temperature data against time in computer file.
For checking of the DWLR functioning in the field a portable calibrator would be useful. However, such calibrators cannot deliver sufficient accuracy for a precise calibration.

Battery replacement is part of the servicing. The spare batteries should be delivered well in advance of the scheduled replacement and not at the time of procurement of the instruments to avoid loss of capacity.

Repair
Possibly, depending on the sophistication of the DWLR, advanced electronic tools are needed to properly repair defective the electronics. The maintenance provider should be prepared to invest in such tools.

It is recommended to have spare DWLRs in stock for quick replacement of failing instruments. The number of spare units needed is to be related to the reliability of the DWLRs. In this respect, the manufacturer should reveal the failure cum repair rate (units per annum) of the offered instrument model. Moreover, the manufacturer should take measures to arrange for spare availability for at least 10 years of instrument operation.

For reliable DWLRs, 1.5 times the annual failure rate with a minimum of 1 unit per version should be adequate, assuming that defective instruments are quickly and reliably repaired. If repair has to be executed overseas, which is advised against, then more spares have to be in stock, say 2 to 3 times the annual failure rate with a minimum of 2 units per version. In this context, a version is any unique part or component. Hence, also pressure sensors that have different measuring ranges and/or cable lengths, are different versions. The spare pressure sensors can best be fitted with the maximum cable length. Upon return of the repaired unit, the spare unit is to be replaced and to be put back in store.

The manufacturer may guarantee delivery and maintenance of the instruments for at least 10 years, however, he will not be capable to guarantee that he and/or his representative (if any) will stay in business during that period. In case of doubt, ample spares should be made available.

Like for all activities, but particularly for repairs and replacement of instrument in a piezometer, a clear and precise logbook is to be maintained by the purchaser.

9.3 Budget

For a continued use or deployment of DWLRs, the annual budgets should cover amongst others the following items:

- maintenance, e.g. AMC contracts
- consumables
- spare parts and spare instruments
- repair of defective instruments, cables
- scheduled calibration and after repairs
- handling of instruments under servicing, repair, calibration
- replacement of defective instruments
- manpower of all instrument and piezometer well related activities
- travel expenses
- training of new staff

The budget for each item depends on the local conditions, the type and make of instrument, the intensity of use, the remoteness of the station of deployment, etc.

9.4 Schedule

DWLR maintenance is executed according to a time schedule, hence, it is well planned and does not cover ad-hoc reacting on events of malfunctioning. In this context, maintenance is preventive aiming to avoid malfunctioning and/or to detect impending malfunctioning. As with the performance monitoring, defects may be detected and reacted upon, e.g. by initiating repair and/or arranging for a replacement instrument.

The maintenance schedule should be defined in concert with the supplier/manufacturer. The supplier may advise what calibration interval is required to maintain the specified accuracy under the operational conditions. Other aspects are the replacement of desiccator, hydrophobic filter, cleaning of the sensor, cable, main and/or backup batteries etc.

Occurrence of instrument faults can be handled in several ways, depending upon the importance given to the data return, available staff and funds etc. It is recommended to have a contingency plan catering for quick replacement of defective instruments. Practice has learned that field staff quickly adopts a relaxed attitude if they come to the conclusion that instrument operation is not deemed important by their management.

9.5 Execution

Maintenance activities can be separated in generic and instrument dependant activities. For the instrument dependant activities the manufacturer's guidelines should be followed.

1. maintenance

- the instrument and cable should be cleaned
- check for corrosion
- check for damage
- change of batteries
- change of desiccator
- re-calibration

It is critical that repair times are kept short in order to avoid excessive data loss and to keep the staff interested. A basic requirement is the ample availability of spares to allow for swift replacement of defective instruments and/or components.

10 Data handling

10.1 Standard DWLR file format

One of the goals of the Hydrology Project is standardisation of the procedures and formats related to the Hydrological Information System. In that context and for efficient import of data into the data processing and storage systems, the exported DWLR data should be in stored in text file in compliance with a standardised format.

That text file may have a section with header lines followed by a table with the data organised in columns. In the header and the data table, only SI units must be used. The standard format is explained below.

Header

- header lines with administrative information may precede the data.
  For a specific type of instrument, the number of the header lines must be constant, i.e. all instruments of a certain make/type should generate the same number of header lines. The contents of the header lines is used by the operator but will not be automatically assessed by the Data Entry Software (SW/GW DES). Header lines should be terminated by a <CR><LF> sequence.

The data table should be organised as follows:

- column 1: date in dd/mm/yyyy
  Leading zero's should be included, i.e. 06 February 2001 will be represented by 06/02/2001.
  The </> character may be omitted, then the format becomes ddmmyyyy.
- column 2: time in hh:mm:ss
  Time should be expressed in 24 hours and not in AM/PM representation Leading zero's should be included, i.e. 6 o'clock in the morning will be represented by 06:00:00.
  The <:> character may be omitted, then the format becomes hhmmss.
- column 3: water level in metres with millimetre resolution, e.g. 49.645 m.
- column 4: if temperature is measured then temperature in °C with 0.1°C resolution, e.g. 32.8 °C.

The column separator should be one of the following: <space>, <tab>, <comma>, or <;>. End-of-line is indicated by <CR><LF> sequence. Only one type of separator may be applied, and that for all instrument models and types originating from a single manufacturer.

All data lines should comply with this column format, empty lines or intermediate half filled lines, e.g. with date and/or time only, are not acceptable. Erroneous or missing data should be indicated by an error code, e.g. an impossible value like -999.999 for water level.

Example of a data line:

```
30/05/1998   11:00:04    12.582    28.7
30/05/1998   12:00:04   -99.999    28.7
30/05/1998   13:00:04    12.817   -99.9
```

Possibly not all suppliers can support these requirements within their standard software. In that case, they may also provide a separate conversion program that converts the exported data from an intermediate format into the HP standard format.

data entry

field time series should be stored on computer hard disk
a backup copy should be made on the hard disk of another computer, on CD-R or similar. Diskettes cannot be regarded as back-up or archiving media.
entry of the time series into the local data base.

archiving

all raw (field) data files have to be archived
all the printed/written field sheets should be archived

Instrument History File

For each instrument, an individual History File should be opened and maintained. This may be a new approach and therefore some explanation is given hereafter. In the History File the full instrument history and all documents generated are to be recorded. This also includes any changes, adaptations, repairs etc. made to the instruments.
Some document types and entries are listed below.

Instrument identification

The instrument identification uniquely defines the instrument particulars.

- Make, supplier, service provider, date of manufacturing, date of delivery
- Instrument make, model and serial number
- Instrument configuration
- Measuring range
- Cable type, length
- Manual version
- Instrument status: working, under calibration, under repair
- and the like

Functional tests

The functional tests are executed and unambiguously recorded. Obviously any failures or irregularities should be annotated accurately, as well as the actions taken and their results.

- Administrative data: what, when, where, who, which instrument and configuration
- List of tests
- Specifications for each test
- Result of each test
- Failures, actions, results

Piezometer well definition

The piezometer well definition is needed in order to link the instrument readings to MSL and the hydro-geological properties of the well. The piezometer identification should have sufficient detail to link it with the hydro-geological data recorded in the project database. The reference point on the piezometer well, as used for the level measurements, should be unambiguously depicted and its height above MSL defined. The particulars of the local benchmark (name, location, and co-ordinates, height above MSL, etc.) should be recorded for reference purposes. Following entries are indicative and not conclusive.

- Piezometer: District, name, location, co-ordinates, identification
- Photo, site plan
- Elevation relative to MSL
- Description of reference point particulars
- Identification of reference spot on piezometer well
- Local benchmark: district, location, identification, co-ordinates, height above MSL

Deployment

Another part of the history file covers the deployment: installation, servicing, maintenance, data retrieval etc. All facts have to be recorded, (what, when, where, who, which instrument and configuration). The suspended depth of the instrument relative to the reference point is to be annotated. Further, manual water level observations (when, who, level, reference) have to be taken regularly and verified with the instrument records. To allow for an accurate comparison, the time and other particulars of the manual observation must be recorded. The manual observations should coincide with the programmed automatic instrument readings. This is to be regularly repeated. Photo's on the mode of installation are very useful.

Some of the required entries are:

- Suspension depth relative to the reference point on the piezometer well
- Recording interval
- Photo's of deployed instrument and piezometer well
  Next two entries have to be repeated regularly
- Manual observations, taken concurrently with the instrument readings (instateneous measurements)
- Observer, date and time of manual reading
  The following entries are associated with any changes made to the instruments. Again, the 'what, when, where, who, which instrument and configuration' have to be recorded, for each event.
- Repairs: minor and major repairs and including change of silt filter or battery etc.
- Adaptations: e.g. replacement of EPROM, RTC clock speed adjustment
- Settings: these are the common operational settings such as recording interval, suspension depth and the like.

Calibration: most likely calibration is executed in a special workshop. Obviously calibration is a major event and has to be recorded and documented accurately and comprehensively. This implies also the method of calibration, reference instruments used (and including a paper trail to national standards or other proof of calibration cum accuracy), conditions during calibration, officers in charge etc.

1. Data collection and storage

Data have to be regularly retrieved. It is recommended to initially operate a relatively short data retrieval interval, which can be increased if the instrument's reliability has be established. Retrieved data have to be stored in a computer file in a systematic way.

The instrument shall have a function to adjust the level reading to the well reference level. The size of float and counter weight shall allow for free movement in a well. The Inner Well Diameter will be 100 mm.

1. All the collected test data should be loaded into PC files, in an organised manner, i.e. one directory/folder for each individual DWLR. These directories/folders will later receive the field data, reports, etc.
2. Pressure units are preferably expressed in Pa (or bar), indeed, be explained but not used.
3. The data on the DeskTop computers have to be organised in a transparent way. This can be achieved by maintaining a clear naming and directory system. It is common practice to maintain a unique folder/directory for each station.

11 Validation and processing

The collected test data have to be assessed for irregularities; the findings have to be reported, also in a structured manner. If any irregularities are found, then these have to be reported in detail and subsequently communicated with the supplier for quick repair/replacement. (Instruments returning from repair and replacements have to be tested).

validation

- the raw (field) data may not be changed, if any changes have to be made, then these should be stored in new files. Changes should be accurately documented.
- if data repairs/adjustments are required, then an assessment should to be made whether any remedial action is required, e.g. adjustment of procedures, repair of instrument
- data validation should be executed based on simple physical and instrumental criteria

The collected test data have to be assessed for irregularities; the findings have to be reported, also in a structured manner. If any irregularities are found, then these have to be reported in detail and subsequently communicated with the supplier for quick repair/replacement. (Instruments returning from repair and replacements have to be tested).

12 data usage

13 Training

Manuals

Appropriate and complete documentation for observer, operator, maintenance engineer, service engineer, should be part of the delivery.

Competence

1. The observers and instrument operators should be thoroughly trained.
2. To support decision-taking management, engineers understanding the functioning and limitations of instruments must be available.
3. Data requirements have to be translated into instrument specifications. The responsible engineer should have in-depth instrumentation understanding and knowledge of the available products in the market. The engineer should be capable to discuss the specifications with suppliers, at a technical level.
4. For the evaluation of the technical bid sections, the responsible engineer should be capable to interpret the technical documentation, brochures and data sheets. Further, he should understand the ways the suppliers apply to evade his scrutiny.
5. The purchaser's staff should be aware how to handle the instruments, how to operate and how to maintain.

Presently, many field observers have little to no experience with automated field instruments. Hence, all the aspects related to such instruments and software are virtually new to them. To make training and instrument use effective, manuals and training materials should not only assess the purely instrumental issues but also focus on basic and conceptual aspects. A comprehensive glossary and index must be part of the documents. The style of explanation should be text based and largely enhanced by graphics.

Staff appointment and training

The staff involved should be capable not only to learn the tricks to use the instrument but also to have a practical understanding and overview of the functioning of the DWLR.
It is planned to have WRD staff trained in operation and handling of the DWLRs during field installation by the supplier. This, of course, is a very practical approach and should be pursued. However, to get most benefit out of the field training, it may be considered to have the staff attend a preparatory training on e.g. a demo instrument, several weeks or a month before the start of deployment.

1. The moisture ingress protection at the air-vent access should be explained. Moreover, the replacement of desiccator and of the hydrophobic filter should be elaborated.
2. There appears to be no operations/observations training. At least the monitoring of the instrument's functioning and comparison of instrument readings with manual observations should be a training component. In particular the conversion for instrument reading data to manual reading, i.e. actual water level, should be fully understood by the observers and others involved in instrument data elaboration and assessment. In addition, the implications of accessing the instrument by Palmtop on the power consumption and battery autonomy should be touched upon.
3. Instrument maintenance has to be part of the training. A distinction should be made between maintenance by observers and by the service provider.

The importance of prudent and timely operations should be made very clear. In addition, the controlling office and the service provider should interact swiftly also with the observers in the field. It is very important that any problems encountered with the data and/or in the field should be assessed and remedied immediately.

Annex A Piezometer definitions

Introduction

This Note assesses some critical aspects related to installation of Pressure Sensor Type DWLR. First a number of water level definitions is given form the instrumental point of view. These definitions are given for reference purposes in this Note and are not intended to be scientifically comprehensive. Based on the water level definitions some guidelines for cable length and measuring range are presented.

Depth to water table

The depth to the water table is the distance from the top of the well/casing to the water table, it is measured by level tape. In ground water measurements, the water level is often expressed as Top of Casing (ToC) reading.

Water level fluctuation

The level of the water table fluctuates over time. The fluctuations occur at several time scales, e.g. fast due to local withdrawal and gradual by seasonal effects. Over the years the average water level may also vary due to long-term effects, e.g. recharge and overdraft. In particular close to a withdrawal point the water level fluctuations can be rapid and large.

Lowest water level

The lowest water level is the lowest level to which a water table may fall, the ToC reading is largest then. While planning the piezometer well, the lowest water level that may be experienced during the operational lifetime of the well is assessed. The unbalance between recharge and withdrawal, if any, is part of the assessment. In case of over-withdrawal, e.g. during and after a failing monsoon, the water level may fall considerably.

Highest water level

Similar to the lowest water level, the highest water level is also affected by the balance between recharge and withdrawal. At highest water level, the ToC reading is smallest.

Maximum water level fluctuation

The observed maximum water level fluctuation is the difference between the highest and the lowest observed water levels. Similarly, the anticipated maximum water level fluctuation is the difference between the highest and lowest anticipated water levels. The anticipated maximum water level fluctuation comprises the climatological effects and the planned changes e.g. related to recharge projects and variation in withdrawal.

Cable length

The cable length of the pressure sensor sets the maximum depth to which the sensor can be suspended in the well. In order to enable the measurement of the lowest water level, the cable should be long enough to suspend the sensor below the lowest water level. For stable operation of the pressure sensor, the water level should not fall below say 0.5 m above the sensor, that is, the sensor should at least be submerged by 0.5 m.

While estimating the cable length, the lowest water level, expressed as distance to top of casing (ToC), that is anticipated during the lifetime of the sensor is determined. In case of doubt about the lowest water level, a safety margin may be added. Obviously, the deepest suspension depth cannot exceed the well depth. The sensor cable length should at least equal the ToC distance plus the before mentioned 0.5 m for permanent submergence. Further the cable length should be extended by a about 1 m for easy connection of the Data Retrieval System (DRS) at the well head/ToC.

For logistic reasons the number of cable different lengths may be limited, e.g. by lumping cable length increments to say 5 m, e.g. 30, 35, 40 m etc. Surplus cable, if any, can be eased into the well for safe storage.
Conclusion: the cable length should at least equal the distance to the lowest anticipated water level plus a margin of 0.5 (submergence) +1 m (handling).

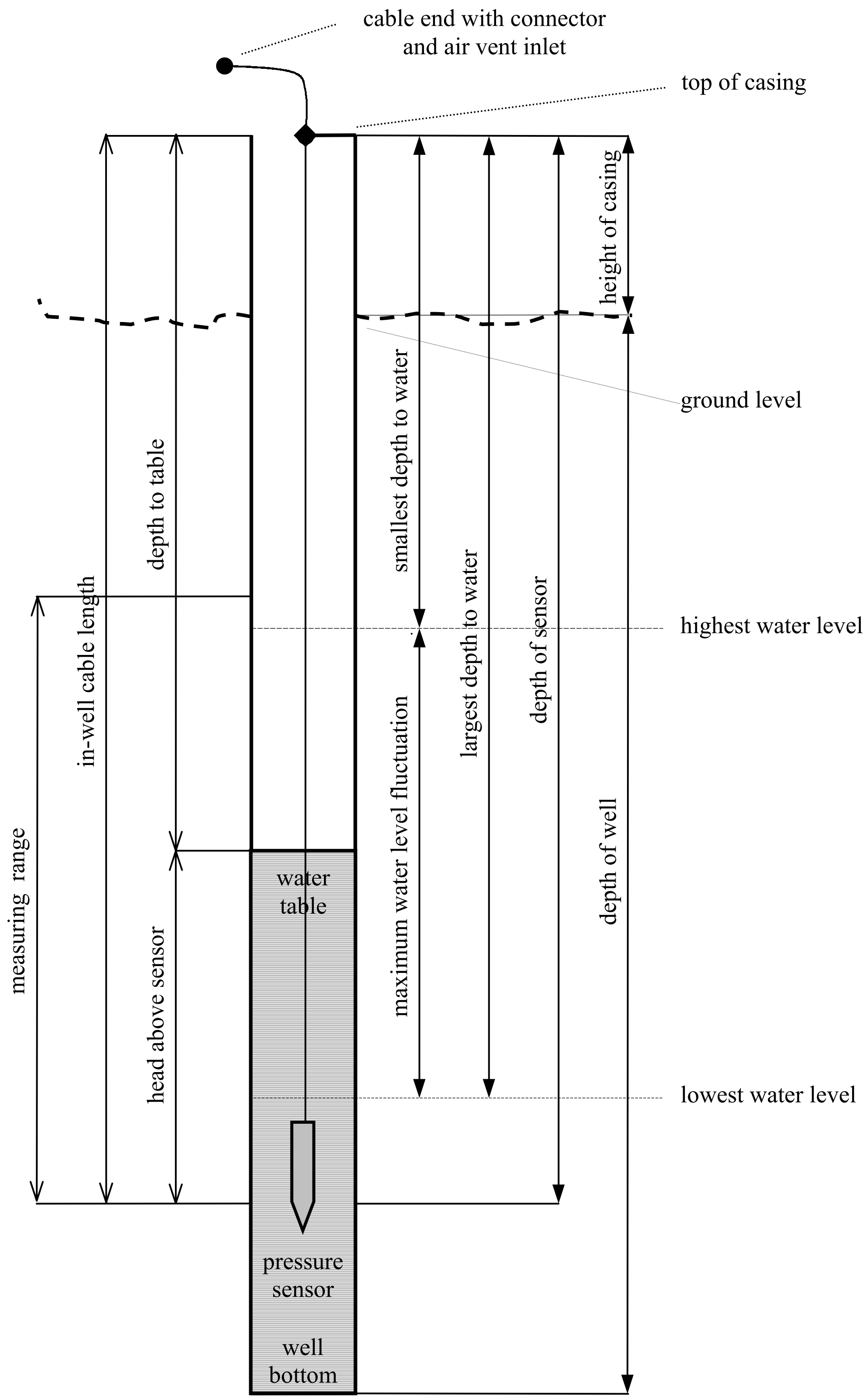
Measuring range
The measuring range indicates the maximum fluctuation that the sensor can measure in compliance with its accuracy specifications. In case the applied pressure exceeds the measuring range, most instruments will generate erroneous data or error flags. The calibration may be permanently affected when the applied pressure exceeds twice the measuring range. A water level (pressure) that exceeds 3 times the measuring range may damage the sensor beyond repair.

The sensor measuring range should exceed the maximum anticipated water level fluctuation. More precisely, the maximum head above the pressure sensor should not exceed the measuring range of the sensor.

From logistic viewpoint, the larger the measuring range, the more wells can be serviced with a certain instrument. The logistic choice would be for a single large measuring range that would cater for all anticipated water level fluctuations. However, pressure sensor accuracy is expressed as a percentage of the measuring range, i.e. it is proportional to the measuring range. Under the Hydrology Project, the accuracy is specified as 0.1% (or 0.05%) of the Full Scale measuring range. In example, a sensor with a 10 metre measuring range is accurate to 0.1% of 10 m, which equals 0.01 m, whereas a sensor of equal (0.1%) accuracy specification but with a measuring range of 50 m is accurate to 0.05m. In practice, the logistics have to be balanced against the accuracy requirement.

Conclusion: the sensor measuring range should not be smaller that the anticipated maximum fluctuation plus the 0.5 m submergence margin.

Definitions and measures of piezometer well with pressure sensor



Annex B Ingress Protection Rating

Electronic instruments, but also many mechanical instruments, can only function properly if they are protected against ingress of solid matter and moisture. This can be achieved by placing them in proper enclosures. Internationally, the level of protection is specified by so called (Ingress Protection) IP codes. Table 1, gives a summary of the IP codes for objects and liquid. The first digit in the IP code refers to ingress of objects and the second to liquid.

IP code	first digit (protection against objects)	second digit (protection against liquid)
0	no protection	no protection
1	objects larger than 50 mm	vertically dripping water
2	objects lager than 12 mm	dripping water (angles up to 15° from vertical)
3	objects lager than 2.5 mm	sprayed water (up to 60^o from vertical)
4	objects lager than 1 mm	water from all directions limited ingress permitted
5	limited dust ingress	low pressure water jets from all directions limited ingress permitted
6	totally dust proof	pressure jets of water from all directions limited ingress permitted
7		immersion up to 1 m
8		indefinite immersion @ xx metre

Table 1: Ingress Protection Codes

Next, Table 2, gives a general overview of the environmental specifications required for several operational conditions. In some cases, specifications are adjusted to specific needs.

environment	temperature	humidity	protection
office/laboratory	10 to 40 ºC	0 to 85%	IP44
permanent in field	0 to 60 ºC	0 to 100%	IP65
permanent in well	0 to 50 ºC	0 to 100%	IP65
permanently submerged	0 to 50 ºC	N/A	IP68
hand operated in field	0 to 50 ºC	0 to 95%	IP55

Table 2: General environmental specifications and protection code

These specifications also apply on connectors and cables.

Annex C DWLR specifications

Annex D Level tape specifications

Annex E Acceptance protocol

Annex F DWLR basics

Annex G Glossary

Resolution and Accuracy

It is very important to state in the specification document the measuring **resolution** and **accuracy** (measurement uncertainty) required. There is a subtle, but important difference between the definition of the terms 'resolution and 'accuracy' for water level measurement. Also, sometimes people erroneously use one term when they really mean the other.

'Resolution' means the degree of precision of measurement units that can be obtained with any one method of measurement e.g. the minimum resolution on a graduated metric ruler or tape is normally 1 mm i.e. it is divided into 1 mm intervals. The 'accuracy' of that measurement, however, is entirely dependent on how good the calibration of the ruler was during production and also on how accurately the human eye/brain combination can read the scale. This is often a function of both the viewing distance and eyesight.

For DWLR's accuracy is usually expressed as a percentage of Full Scale Output (FSO) or Full Range Output (FRO) which mean the same thing (See section III.5.1.7.2). For example most modern pressure sensors have an accuracy of +/- 0.1% of FSO. This means if the measuring range is 10 m it will measure to +/- 10 mm i.e. the absolute accuracy is +/- 10 mm. However, if the same sensor was only measuring over a scale of 0.5 m, it would still have an absolute accuracy of 10 mm, so the percentage accuracy would increase to 10/500 x100 = +/- 2%. It is very important to specify the measuring accuracy required both in absolute and % of FSO terms. Normally for most stage-discharge river applications an accuracy of +/- 10 mm is required or desirable.

Hysteresis

The maximum difference in output, at any value within the specified range, when the value is approached first with increasing and then with decreasing value". This reflects the degree to which any two separate determinations of the same true value may differ if the previous states of true input have been respectively less than and greater than the present true input state.

- There is a working analogy with Stage Discharge Relations, which may differ between rising and falling hydrograph limbs.

- A low Hysteresis value is clearly desirable, and is normally expressed as "x%FRO(BSL) and often as a combined statistic with linearity.

Linearity

A sensor would be perfectly linear in its response to changing water level, if a small change in water level, anywhere on the measuring range of the sensor, would result in the same change of the presented instrument reading. In a non-linear instrument the presented instrument reading change would also depend on the water level proper. Example: in non-linear instrument, at midrange water levels the presented change in reading might be correct whereas at low water level it could be too small and at high water level too large.

1. **FRO** Stands for **Full Range Output** (sometimes **FSO - Full Scale Output**), and is used to indicate that any given value of pressure sensed by the device in question may be expected to be accurate to within a stated percentage of the FRO value e.g. +/-0.1%FRO (a typical value for a modern-day device).

2. **BSL** Stands for **Best Straight Line** - "a line midway between the two parallel straight lines closest together and enclosing all Output vs. actual pressure (water level) values on a calibration curve. In other words, out of all individual points over the range between zero and full

scale applied pressure that have actually been tested, as part of a calibration exercise, the worst-case deviations of actual sensor output from "true" output, above and below the Best Fit Straight Line to the range of test points available define the location of the line itself. This is illustrated in figure III.5.1.20.

Given indication of the two defining values referred to above, it may be known that a sensor will represent true pressure state, at any point within its intended operating range, and in terms of its inherent linearity characteristic, within + or - x% of the full scale value itself.

An important, and sometimes operationally relevant, inference of this is that, in terms of absolute accuracy i.e. how accurate a sensed value may be, at any part of the sensor's operational range as a percentage of itself, low range values will be less accurately represented than high.

Repeatability
The ability of a sensor to reproduce output readings when the same measured value is applied to it consecutively, under the same conditions, and in the same direction.

Zero Offset
The range within which the vented gauge pressure type DWLR reading may be expected to lie when in air. In other words, the reading may not deviate from zero by more than a specified margin, e.g. 0.02 m. The zero offset usually is compensated for during the instrument set-up procedure. The remaining error source then is the zero stability.

Zero Stability
Zero stability is expressed as the maximum change of zero offset that is permitted over a period of time, usually 1 year. In order to maintain rated accuracy, the zero change should be regularly checked.

Pressure sensors (transducers)
The term pressure sensor is applied to devices which convert changes in water pressure and hence water level into electrical signals which can be recorded remotely from the point of measurement (Fig. III.5.4.18). A typical sensor consists of:

a) a mechanical force-summing device, perhaps a diaphragm or a bellows and resonating quartz crystal, which is displaced by the pressure head of water
b) a device which converts the mechanical displacement to an electrical signal.

The electrical signal is transmitted by a connecting cable to a solid state logger or to an associated interface for analogue to digital conversion before storage in the logger memory.

Table 1: Units of Pressure

1 Bar	10.215 metres at 20°C
	100,000 Pascals -
	14.5038 Pounds Per Square Inch (lbs/in^2)
	1 decaNewton per square centimetre (daN/cm^2)
1 millibar	1 hectoPascal (hPa)
1 metre (head)	97.895 milliBars (mBar)
deca	times 10
hecto	times 100
milli	times 0.001

the Pascal is the Systeme International d'Unites (SI) unit of pressure measurement; also historically referred to as the Newton per Square Metre (N/m^2)

- In a typical pressure sensor design an electrical supply voltage or current is applied to one part of the circuit and an equivalent electrical signal sensed as an output from another part of the circuitry. The output is related to the degree of applied pressure at the sensor diaphragm. Conditioning/signal processing circuitry is necessary to accurately sense and discriminate the resulting output and convert it into a form for storage on a logger in digital format.

Flash Powering

Earlier pressure sensors and loggers made relatively large demands on power. However, technology was developed, similar to that referred to for shaft encoders (See section III.5.1.5.7) whereby a typical pressure sensor could be “flash powered” for literally a few micro-seconds. and an output obtained that was (a) meaningful in measurement terms and (b) adequately repeatable.

This having been established, the way opened to design sensor interface electronics for data loggers and telemetry outstations that could power suitable pressure sensors "quasi-continuously" i.e. the state of the sensor could be "read" so frequently as to be virtually continuous (and therefore capable of observing rapid change, if so required), while only draining battery-supplied power for a very small fraction of the time. Eventually, "powered-for-life" data loggers were to enter the marketplace that could be self-supporting, and monitor (among other things) pressure, for an intended working lifetime of up to ten years - all from a battery the size equivalent of a torch cell.

Temperature Effects

Even though the effect may be small, may be well understood, and may be capable of electronic (or, even, software) compensation, to a lesser or greater extent all pressure sensors are sensitive to changing ambient temperatures. Typical expressions of this phenomenon include:-

- Temperature Error Band "The Error Band applicable over stated environmental temperature limits" - normally expressed as "%FRO", and representing the additional error (i.e. *on top of* non-linearity, etc.) associated with changes of ambient temperature (at the sensor) outside the limits specified.

- Thermal Zero/Span Shift "The Zero Shift due to changes of the ambient temperature from Room Temperature to the specified limits of the Operating Temperature Range" - analogous to the Temperature Error Band, but applying solely to the accuracy with which true zero (or Full Scale) input is represented as output.

- Compensated Temperature Range The range of ambient temperatures within which there is in-built compensation to nullify the potential effects of changing temperature upon device output - usually expressed as an upper and a lower temperature value e.g. "-2^{o}C to +30^{o}C"

Ageing Effects (Or Long Term Drift)

Over a sufficiently long period of time, any of the performance characteristics of a pressure sensor device may alter, due to the simple ageing process altering the physical state of its component parts - quite aside from the effects of general operational stress or of chemical processes (oxidation as a result of moisture ingress, for example, or corrosion through the ingress of gaseous chemicals).

A pressure sensor is, inevitably, an assemblage of numerous separate components, made of almost as many different materials, each with its own characteristic reactions to thermal cycling. At every material interface, a greater or smaller degree of stress will be engendered whenever the materials' temperatures change and, accumulating, over many such cycles, physical changes take place that can affect the overall device calibration.

The existence of the ageing process should be recognised through **periodic calibration checks** of all operational parameters detailed in the basic device specification - at intervals of time no longer than (say) three years, with less wide-ranging tests applied (in the field if necessary) at no greater than annual intervals.

In any organisation that uses pressure sensors as an everyday hydrometric tool on which reliance is to be placed, a high quality, portable Pressure Tester is an essential support device. This device, in turn, should be subject to rigorous quality assurance procedures that allow its performance to be traced back confidently to an accepted Standard.

Vulnerability To Atmospheric Electro-Magnetic Effects

Pressure sensors are not only delicate in their mechanical construction (at least at the pressure sensing diaphragm), they can be sensitive also electrically. They are essentially (in the main) low-voltage, low-current devices. Also, the essence of their installation places, more often than not, their sensing element at some significant distance from other associated electronics, joined by (perhaps) many metres of power and signal cable - potentially a very effective antenna.

Ambient Electric "Noise

Ambient Electric "Noise is present everywhere and, without appropriate precautions, can easily be picked up by instrumentation cabling to a degree that swamps the signal characteristic of interest. To protect against this, sensor cabling is invariably of the screened variety, and normally works effectively to exclude unwanted electrical noise. However, care is needed at installation time to ensure that the total integrity of cable screening is preserved. Joining lengths of cable is best avoided and, if unavoidable, requires the utmost care.

In joining sensor cable lengths, great care is also required to preserve the integrity of the ventilation tube. Similarly, in routing cabling between sensor and instrumentation, care is required to ensure that the ventilation tube is not blocked by being kinked.

Lightning

Lightning can also be a source of danger to sensors and their associated instrumentation (indeed it is a hazard to most electronic devices deployed outdoors, or in the near-outdoors). In the case of submerged pressure sensors, a very effective path to earth may be provided for the high static voltages generated by atmospheric electricity as lightning.

Where possible, electronic protection against high transient voltages should be incorporated in the installation design of all such devices - taking manufacturers' advice as appropriate.

Almost inevitably, however, there will be instrumentation losses from time to time to lightning activity - relative incidence being, often, quite location-specific, with some sites much more vulnerable than others. Spares-holding policies should take this into account.

If recourse is had to such a multi-sensor operational strategy, care will also need to be taken to consider the Over-Ranging Capability of one or more of the deployed sensors i.e. its ability to withstand, without damage to its performance, pressures significantly in excess of its nominal range. Note that a "Four-Times-Range" over-pressure provision is likely to be readily achievable by many commonly-available proprietary sensors.

Table 2: Glossary of terms

Absolute pressure sensor#	A sensor that has an internal reference chamber sealed at or close to 0 psia (full vacuum) and normally provides increasing output voltage for increases in pressure.
Accuracy#	The combined error of nonlinearity, repeatability, and hysteresis expressed as a percent of full-scale output.
Bridge resistance#	The nominal value of the individual legs that make up a complete Wheatstone Bridge.
Bridge#	A Wheatstone bridge configuration utilising four active strain gauges.
Burst Pressure#	The maximum pressure that may be applied without physical damage to the sensing element.
Calibration#	The comparison of sensor voltage outputs against the outputs of a reference standard.
CPU#	Central Processing Unit, it is the motor of the data logger.
Creep#	The change in sensor output occurring with time, whilst under pressure, and with all environmental conditions and other variables remaining constant. Usually measured with rated pressure applied and expressed as a percentage of rated output over a specific period of time.
Deflection#	The change in length along the primary axis or distance a diaphragm moves at the centre between no-pressure and rated pressure conditions.
Diaphragm#	The sensing membrane of a pressure sensor which is deformed when pressure is applied.
Differential Pressure#	Pressure measured relative to a reference pressure. Referred to as pounds per square inch (differential) or psid.
EEPROM#	Electrically Erasable Programmable Read Only Memory)
Excitation#	The external electrical supply voltage and/or current applied to a sensor for its proper operation.
Excitation, electrical#	The voltage or current applied to the input terminals of the sensor.
Firmware#	This is a term used to describe the program that runs the Troll. This is factory set and but can be up-loaded via PC for field upgrades. The firmware version number is recorded under the Derive Information screen in Win-Situ and Dos-Situ. The firmware is stored in ROM.
Full scale output#	The algebraic difference between the minimum output (normally zero) and the rated capacity.
Full scale#	See Rated Capacity.
Gauge pressure sensor#	A sensor which measures pressure relative to the atmospheric pressure.
Gauge pressure#	The pressure above (or below) atmospheric. Represents positive difference between measured pressure and existing atmospheric pressure. Can be converted to absolute by adding actual atmospheric pressure value.
Hysteresis#	The maximum difference between output readings for the same measured point, one point obtained while increasing from zero and the other while decreasing from full scale. The points are taken on the same continuous cycle. The deviation is expressed as a percentage of full scale.
Insulation (isolation)	The DC resistance expressed in ohms measured between any electrical connector pin or lead wire and the sensor body or case.

resistance#	Normally measured at 50 VDC.
Linearity#	The maximum deviation of the calibration curve from a straight line between zero and full scale, expressed as a percentage of full scale and measured on increasing trajectory only.
Newton#	(N), unit of Force; namely, "that force which, applied to a mass of 1 kilogram, gives it an acceleration of 1 m/s^2 (metre per second squared)
Noise#	Short term fluctuations in a output signal without change of circumstances: e.g. stable water level, constant temperature.
Offset#	The range within which the vented gauge pressure type DWLR reading may be expected to lie when in air. In other words, the reading may not deviate from zero by more than a specified margin, e.g. 0.02 m. The zero offset usually is compensated for during the instrument set-up procedure. The remaining error source then is the zero stability.
Output#	The electrical signal measured at the output terminals which is produced by an applied input to a sensor.
Overrange, safe#	The maximum pressure or load which may be applied to the sensor without causing a permanent change in the performance specifications.
Pascal#	(Pa), unit of Pressure, being "the pressure produced by a force of 1 Newton applied, uniformly distributed, over an area of 1 square metre".
Pressure Sensor#	Provides a linear D.C. voltage output proportional to applied pressure.
Proof Pressure#	The maximum pressure that may be applied without changing performance beyond specifications.
PSI#	Pounds per square inch
Psia#	Pounds per square inch absolute.
Psig#	Pounds per square inch gauge.
RAM#	Random Access Memory: short term memory will be lost if loss of power
Range#	The measured values, over which a sensor is intended to measure, specified by their upper and lower limits.
Rated capacity#	The maximum measurand that a sensor is designed to measure within its specification.
Repeatability#	The ability of a sensor to reproduce output readings when the same measured value is applied to it consecutively, under the same conditions, and in the same direction. Repeatability is expressed as the maximum difference between output readings as a percent of full scale.
Resolution#	The smallest change in mechanical input which produces a detectable change in the output signal.
Response Time#	The length of time required for the output to rise to a specified percentage of its final value as a result of a step change in pressure.
ROM#	Read Only Memory: permanent memory
RTC	Real Time Clock, internal clock of the data logger; it is a separate hardware component. Some dataloggers deploy software based clocks, these usually are less accurate.
Safe Overload#	The maximum pressure specified as a percentage of rated capacity which can be applied without causing permanent change in the performance specifications.

Sensing element#	The part of the sensor which reacts directly in response to the measurand.
Sensitivity#	The ratio of change in sensor output to a change in the value of the measurand.
Sensor#	A device (or medium) that converts energy from one form to another. The term is generally applied to devices that take physical phenomenon (pressure, temperature, humidity, flow, etc.) and convert it to an electrical signal.
Span#	The algebraic difference between the limits of the range from zero to full scale.
Specifications#	The group of error limits within which each device will operate.
Strain gauge#	A measuring element for converting force, pressure, tension, etc., into an electrical signal.
Temperature compensation#	The utilisation of supplementary devices, materials, or components within the sensor to minimise sources of error caused by changing temperature.
Temperature effect on span#	The change in rated output due to a change in ambient temperature. Usually expressed as ± a percentage change in rated output per ºC change in ambient temperature, over the compensated temperature range.
Temperature effect on zero#	The change in zero balance due to a change in ambient temperature. Usually expressed as ± a percentage change in rated output per ºC change in ambient temperature over the compensated temperature range.
Temperature, compensated#	The range of temperature over which a sensor can operate up to full scale and still meet all specifications.
Temperature, operating#	The range of temperature over which a sensor may be safely operated up to full scale without causing failure, but specifications may not be met.
Thermal Error#	The maximum change in output, at any pressure value within the specified range, when the temperature is changed from room temperature to specified temperature extremes.
Thermal Zero Shift#	The zero shift due to changes of the ambient temperature from room temperature to the specified limits of the operating temperature range.
Transmitter#	A sensor that has a 4-20 mA two wire output.
Transmitter#	A sensor that has a 4-20 mA two wire output.
Transverse sensitivity#	Signal output as a result of acceleration perpendicular to the sensitive axis. Specified as a percentage of sensitive axis output for equivalent right angle acceleration or as a decimal fraction.
Ultimate Overload#	The maximum pressure specified as a percentage of rated capacity which can be applied without producing a structural failure.
Vacuum#	Vacuum measured relative to ambient atmospheric pressure. Referred to as pounds per square inch (vacuum) or psiv.
Vented (gauge) pressure sensor#	A sensor that has an internal reference chamber that is connected to atmospheric pressure.
Wet/dry differential#	A differential pressure sensor or transmitter that uses a metal diaphragm at the wet port where fluids can be applied, and no diaphragm at the dry port. The dry port exposes the internal circuitry to the medium, so only clean dry gas can be applied to this port.
Wet/wet differential#	A differential pressure sensor or transmitter that has a metal diaphragm in each pressure port to permit fluid into both ports.

Wetted parts#	The diaphragm and pressure port material that comes in direct contact with the medium (gas, liquid).
Zero adjustments#	Used when `setting up' a sensor to adjust the output signal to zero when zero load/pressure is applied.
Zero balance#	The output signal of the sensor with rated excitation and with no-pressure applied, usually expressed as a percent of rated output.
Zero return#	The difference in zero balance measured immediately before rated pressure application of specified duration and measured after removal of the pressure, and when the output has stabilised.
Zero stability#	Zero stability is expressed as the maximum change of zero offset that is permitted over a period of time, usually 1 year. In order to maintain rated accuracy, the zero change should be regularly checked.