INSTRUCTION MANUAL

VIBRATING WIRE PIEZOMETER VWP-3000 SERIES

includes VWT-9000 and VWPHT-3600

GEOSENSE

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1. VERSION CONTROL

Version	Date	Author	Approved	Issued
V1.0	Feb 2008	MC	MC	GC
V1.1	Dec 2008	MC	MC	GC
V1.2	Apr 2008	MC	MC	GC
V1.3	May 2009	MC	MC	GC
V1.4	Jun 2011	MC	MC	GC
V1.5	Jun 2011	MC	TC	GC
V1.6	Nov 2014	MC	TC	GC
V1.7	Apr 2015	MC	TC	GC
V1.8	Apr 2015	MC	TC	GC
V1.9	Jun 2017	MC	TC	GC
V1.10	Feb 2019	MC	TC	GC
V1.11	Feb 2019	MC	TC	GC
V1.12	Dec 2020	MC	TC	GC
V2.0	Aug 2025	TB	TC	GC

2. INTRODUCTION

This manual is intended for all users of **Geosense® Vibrating Wire Piezometers (VWP-3000 Series)** manufactured by **Geosense®** and provides information on their installation, operation and maintenance.

It is VITAL that personnel responsible for the installation and use of the piezometers READ and UNDERSTAND the manual, prior to working with the equipment.

2.1. General Description

The **Geosense® Vibrating Wire (VW) Piezometer** is an environmentally sealed sensor that is used to register changes in fluid pressure, generally in, but not limited to, underground locations.

VW Piezometers can be installed or included in many types of monitoring regimes and can be linked to various types of readout and recording equipment.

The primary uses for piezometers are:

- Soil and rock porewater (and pore gas) pressure measurement.
- Water level monitoring (groundwater or chambers)

With applications such as, but not limited to, the following:

- Embankment stability and safety monitoring
- Measuring water loads behind retaining walls
- Assessing soil consolidation
- Measurement of uplift pressures acting on structural foundations
- Verification of seepage patterns and models
- Slope stability monitoring
- Water level monitoring for Environmental control
- Tidal influence assessment
- Pump Testing

Particular features of **Geosense® Vibrating Wire Piezometers** are:

- Reliable long-term performance
- Rugged; suitable for demanding environments
- High accuracy.
- Insensitive to long cable lengths / joints

The **Geosense®** piezometer is based upon the 'industry standard' Vibrating Wire technology. When electronically excited, the sensor produces an output signal in the form of an alternating current. The frequency of the alternating current can then be readily converted to a pressure by applying a factory generated, individual calibration factor.

Frequency signals are particularly suitable for the demanding environments of geotechnical and civil engineering applications, since they are capable of long transmission distances without degradation. They are also somewhat tolerant of damp wiring conditions and resistant to interference from external electrical 'noise'.

The **Geosense®** range of VW piezometers are supplied in various configurations to suit varying installation environments and techniques. Each VW piezometer is fitted with a length of connecting cable, an internal temperature sensor and an electrical surge arrestor.

For standard piezometers, a filter is used to protect and separate the sensing diaphragm from the surrounding materials. The shape and porosity of the filter vary according to the model of piezometer.

- The filter housings for standard piezometers are sealed and fitted to the body by an ‘O’ ring.
- The filter housings for heavy-duty piezometers and pressure transducers have a threaded fitment and are sealed by an ‘O’ ring.
- The Push-in Piezometer has an annular filter located just behind the pointed tip.

For **Geosense®** Standard Piezometers, the filter is a sintered Stainless Steel 50-micron (μm) filter, sometimes referred to as Low (resistance to) Air Entry (LAE). However, a ceramic 3-micron (μm) 1 bar filter, sometimes referred to as High (resistance to) Air Entry (HAE) is available, where specifically required.

Figure 1: LAE (left) / HAE (right)

Figure 2: Push-in Tip Filter

The filter is mounted within a Stainless-Steel housing that is fitted onto the end of the sensor body.

The pressure transducer is fitted with a standard sintered stainless steel 50-micron (μm) filter fitted inside the bulkhead, into which a 1/4” BSP female thread is tapped. This offers protection to the diaphragm when connected to liquid or gas pressure sources.

The Push-in Piezometer has an annular filter located just behind the pointed tip. This filter is made of granular plastic (Vyon®), which has a pore size of approximately 50 microns.

Operating / Calibration Range

During calibration, the **Geosense®** range of VW piezometers are calibrated over a temperature range of –20ºC to + 80ºC to prove their function over a wide temperature range and provide the input data for any temperature compensation that may be required.

HOWEVER, as under normal conditions they are monitoring water, their practical operating temperature range will be above 0ºC. Where installations are carried out in sub-zero conditions, VW piezometers **must** be kept above freezing at all times, especially if the filter has been saturated with plain water. Anti-freeze can be used to extend the practical operating range, where appropriate.

Piezometers and Transducers are tested to 1.5 times (150%) their standard, calibrated, working range to prove their function at overpressure.

The calibration values will not be valid when the upper calibration value is exceeded. However, the validity of the calibration will not be affected, provided the overpressure percentage does not exceed 50% (applied pressure is 150% working range).

DO NOT ALLOW THE PIEZOMETER TO FREEZE WHEN FULLY SATURATED AS DAMAGE MAY OCCUR TO THE DIAPHRAGM WHICH WILL INVALIDATE ITS FUNCTION AND CALIBRATION

2.2. Theory of Operation

The Vibrating Wire Piezometer consists of a tensioned steel wire, anchored at one end to a flexible diaphragm (the sensing element) and at the other end to the inner body, all sealed into a stainless-steel shell. The internal parts of all **Geosense®** piezometers and transducers are identical. Only the thickness of the diaphragm, the geometry of the shell, and the filter arrangements change.

Two opposing coils are located within the inner body, close to the axis of the sensing wire. When a brief voltage excitation, or swept frequency excitation, is applied to the coils, a magnetic field is generated, causing the wire to oscillate at its resonant frequency. The wire continues to oscillate for a short period through the 'field' of the permanent magnets in the coils, thus generating an alternating current (sinusoidal) output.

The frequency of the generated current output is detected and processed by a vibrating wire readout unit, or by a data logger equipped with a vibrating wire interface, where it can be converted into 'Engineering' units of pressure.

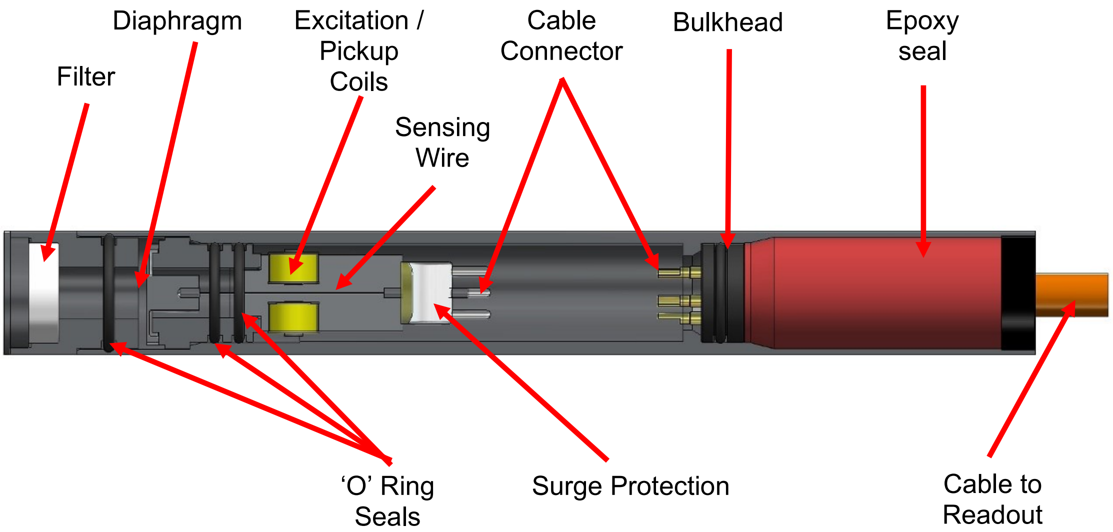


Figure 3: Schematic of Geosense® VWP-3000

As pressure is applied to the exposed side of the flexible diaphragm (gas or liquid), the diaphragm deflects, causing a change in the tension of the sensing wire behind it. The change in tension of the wire results in a change in the resonant frequency at which the wire oscillates. The change in the <u>square</u> of the frequency of oscillation is <u>directly</u> proportional to the pressure applied.

For further information see section 0.

3. VARIANTS

There are a number of variants of the **Geosense® VWP-3000 series**, designed for specific applications. Models in the VWP-3000 range are:

- VWP-3000 – (STANDARD) Standard construction with high & low air entry filters to measure groundwater elevations and pore pressures.
- VWP-3100 – (HEAVY DUTY) Heavy-duty body for direct burial in fills and dam embankments. Available with high & low air entry filters, standard and heavy-duty cable.
- VWP-3200 – (LOW PRESSURE) Low pressure version to measure groundwater elevations and pore pressures. Available with high & low air entry filters.
- VWP-3300 – (LOW PRESSURE VENTED) Low pressure vented version to compensate for barometric pressure changes. Available with high & low air entry filters.
- VWP-3310 – (STANDARD VENTED) Standard construction but vented to compensate for barometric pressure changes. Available with high & low air entry filters.
- VWP-3400 – (DRIVE-IN) Drive-in version available for use with SPT rods.
- VWP-3700 – (CORROSION RESISTANT) Titanium construction with high & low air entry filters to measure groundwater elevations and pore pressures in corrosive environments.

This manual is also suitable for the following variants:

- VWT-9000 – (THREADED) 1/4” BSP fitting for connection directly into hydraulic or pneumatic pressure lines.
- VWPHT-3600 Series – (HIGH TEMPERATURE) Stainless Steel construction designed for high temperature use.

3.1. VWP-3700 – (CORROSION RESISTANT) Titanium

Corrosion resistance piezometers are designed for use in chemically aggressive environments, such as mine tailings and leach pads, where standard vibrating wire piezometers may not be suitable for long-term monitoring. The use of components made from Titanium, along with enhanced sealing techniques, provides superior durability and resistance compared to the materials used within the standard piezometer.

The suitability can depend on a number of factors such as PH, concentration, composition, length of install and temperature. Additionally, the sensor can be provided with PUR or Stainless-Steel TEC cable; TEC cable requires additional care to be taken during installation to prevent damage to the inner conductors.

Figure 4: VWP-3700 with PUR cable (left) or Stainless-Steel TEC cable (right)

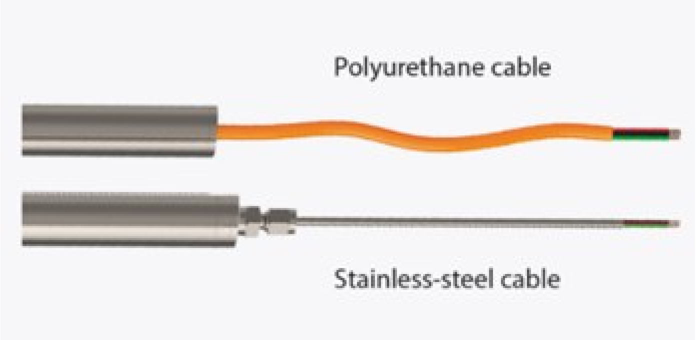


Figure 5: Polyurethane cable (PUR) and Stainless-Steel TEC

4. MARKINGS

Geosense® VWP-3000 (including VWT-9000 and VWPHT-3600) series instruments are labelled with the following information:

- Manufacturers name & contact details
- Product type
- Model
- Serial number
- CE mark / UKCA mark

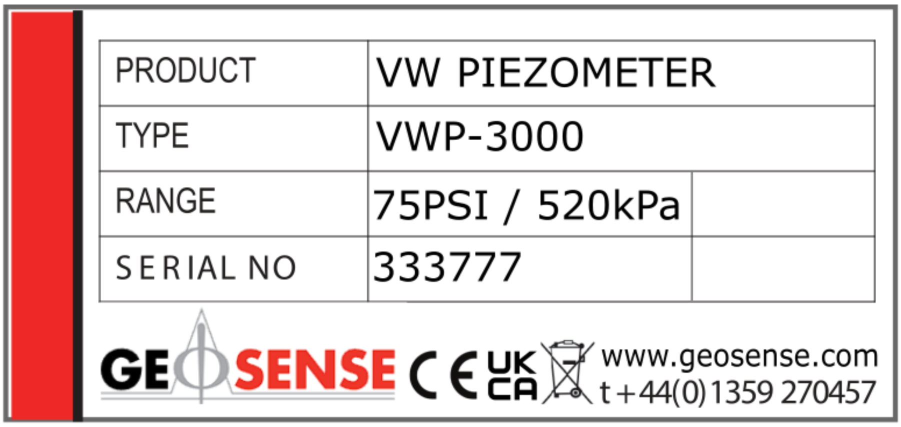


Figure 6: Piezometer Identification Label

5. WIRING CONFIGURATIONS

Geosense® Vibrating Wire Piezometers with standard cable options all follow the same uniform colour code for simplicity.

In some cases, custom armoured or multi-point cable may differ in colour coding. If this is the case, the calibration sheet will contain the bespoke colour coding for the cable to enable the user to correctly wire the sensors to any datalogger required.

Table 1: Wiring configurations

Wire Function	Colour	Sensor Output
VW+	Red	Frequency
VW-	Black	
Thermistor +	Green	Resistance
Thermistor -	White	
Shield	Bare metal wire	N/A

6. CONFORMITY

EU Declaration of Conformity

We

Geosense Ltd
Nova House, Rougham Industrial Estate, Bury St Edmunds, IP30 9ND, United Kingdom

declare under our sole responsibility that the product:

Equipment description: Vibrating Wire Piezometers

Model Numbers(s):
VMP-3000, VWP-3001, VWP-3100, VWP-3101, VWP-3200, VWP-3201, VWP-3300, VWP-3301, VWP-3400, VWP-3401, VWP-3405, VWP-500, VWP-500, VWP-600, VWP-3700, VWP-3710, VWT-3000, SGP-3400, SGP-3401, SGP-3450, SGP-3451, SGP-3500, SGP-3501, VWP-3130, VWP-3300, VWPHT-3600, VWPHT-3610, VWT-9000

to which this declaration relates are in conformity with all the essential requirements of the Restriction on the use of certain Hazardous Substances **2011/65/EU**

The following harmonised standards have been applied with respect to this product:

EN IEC 63000:2018

Authorised Person

Tim Clegg
Director

Date: 04/08/2025
Location: Bury St Edmunds, UK.

DoC-03001-CE – v2

UK Declaration of Conformity

Geosense Ltd
Nova House, Rougham Industrial Estate, Bury St Edmunds, IP30 9ND, United Kingdom

This declaration is issued under the sole responsibility of the manufacturer:

Equipment description: Vibrating Wire Piezometers

Model Numbers(s):
VMP-3000, VWP-3001, VWP-3100, VWP-3101, VWP-3200, VWP-3201, VWP-3300, VWP-3301, VWP-3400, VWP-3401, VWP-3405, VWP-500, VWP-500, VWP-600, VWP-3700, VWP-3710, VWT-3000, SGP-3400, SGP-3401, SGP-3450, SGP-3451, SGP-3500, SGP-3501, VWP-3130, VWP-3300, VWPHT-3600, VWPHT-3610, VWT-9000

The object of the declaration described above is in conformity with the following statutory requirements:

The Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment Regulations — SI 2012 No. 3032

References to designated standards/specifications in relation to which conformity is declared:

EN IEC 63000:2018

Signed for and on behalf of Geosense Ltd

Tim Clegg
Director

Date: 04/08/2025
Location: Bury St Edmunds, UK.

DoC-06001-UKCA – v2

7. DELIVERY

This section should be read by all users of equipment manufactured by **Geosense®.**

7.1. Packaging

Geosense® VW Piezometers are packed for transportation to site. Packaging is suitably robust to allow normal handling by transportation companies. Inappropriate handling techniques may cause damage to the packaging and the enclosed equipment. The packaging should be carefully inspected upon delivery and any damage **MUST** be reported to both the transportation company and **Geosense®**.

Once the shipment has been checked, it is recommended that **Geosense® VW Piezometers** remain in their original packaging for storage and transportation.

Cable should be handled with care. Do not allow it to be damaged by sharp edges, rocks for example, and do not exert force on the cable as this may damage the interim conductors and render the installation useless.

7.2. Handling

Whilst they are robust devices, **Geosense® VW Piezometer** series systems are precision measuring instruments. They and their associated equipment should always be handled with care during transportation, storage and installation.

Once the shipment has been inspected (see 7.3), it is recommended that the equipment remain in its original packaging for storage or onward transportation.

7.3. Inspection / Functionality Check Readings

It is important to check all the equipment in the shipment as soon as possible after taking delivery and well before installation is to be carried out. Check that all the components detailed in the documents are included in the shipment. Check that the equipment has not been physically damaged.

All **Geosense® VW Piezometer** instruments carry a unique identification serial number, which is located on the cable connection block or on the side of the cell (dependent on model).

Geosense® VW Piezometer instruments are supplied with individual calibrations, and these are available from www.geosense.com/geoconnect/

Calibration sheets should be kept safe and secure for future reference. See section 8.

Cable marks also carry the model, type and the length of cable fitted at the factory.

CHECK the piezometer readings against the factory 'Zero Readings' on arrival to ensure they have not changed significantly due to damage during transportation. This is a basic 'out of the box' functional check.

Prior to carrying out a reading check, ensure that the piezometers have been stored in a reasonably stable temperature for at least 30– 60 minutes.

To carry out the check, connect a Vibrating Wire readout to the bare cable ends (red connector to red wire and black connector to black wire) – The green and white connectors / wires are for the temperature sensor and are not required for this checking exercise - see the readout manual for connection guidance.

Record the values (and units) displayed on the readout together with the piezometer serial numbers.

The “CHECK” readings should coincide with the factory zero on the calibration sheet (see the example calibration sheet in Section 9) within +/- 50 digits after barometric and temperature corrections are made.

The elevation of the **Geosense®** factory is +60 metres above sea level, and barometric pressures change with altitude by approximately 1.2kPa per 100 metres.

Note – the check readings will be affected by changes in atmospheric pressure and temperature and so will not match the calibration certificate exactly.

If any components are missing or damaged, please contact **Geosense®**.

7.4. Storage

All **Geosense® VW Piezometer** instruments and associated equipment should be stored in an environment that is protected from direct sunlight.

It is also recommended that cables be stored in a dry environment to prevent moisture migrating along inside them in the unlikely event of prolonged submersion of exposed conductors. The cables should also be protected from rodents and traffic.

No other special requirements are needed for medium or long-term storage, although temperature limits should be considered when storing or transporting associated components, such as readout equipment.

8. CALIBRATION

All **Geosense® VW Piezometer** instruments are supplied with a calibration sheet like the example below.

GEOSENSE QUALITY FORM	
GQF-149	
ISS. 11	
DATE : AUG-24	
SIG. GC	

Nova House, Rougham Industrial Estate, Rougham, Bury St Edmunds
Tel: +44(0)1359 270457 - Fax: +44(0)1359 272860
Website: www.geosense.co.uk

STANDARD VW PIEZOMETER LAE CALIBRATION

Model:	**VWP-3000**	**Cal Date:**	**16/07/2025**	**Readout No:**	**2108**
Serial No:	**381100**	**Baro:**	**1009**	**Cable Length:**	**45m**
Works ID:	**G125 9 105**	**Temp °C:**	**20**	**M Marking:**	**1624m**

Applied Pressure		**Readings [digit]**			**Calculated Pressure**		**Error % FSO**	
psi	kPa	1st Cycle	2nd Cycle	avg.[digit]	lin.[kPa]	polyn.[kPa]	linear	polynomial
0.0	0.0	10063.4	10064.9	10064.2	0.8	0.0	0.23	0.00
10.0	69.0	9417.7	9418.9	9418.3	68.9	69.0	-0.04	0.00
20.0	138.0	8768.5	8769.6	8769.0	137.3	137.9	-0.21	-0.03
30.0	207.0	8112.1	8112.9	8112.5	206.5	207.1	-0.15	0.03
40.0	276.0	7454.4	7455.2	7454.8	275.8	276.0	-0.06	-0.01
50.0	345.0	6790.3	6791.1	6790.7	345.8	345.0	0.23	0.00

CALIBRATION FACTORS

	kPa per digit	**psi per digit**	**mH20 per digit**
Linear Factor (K)	-1.05398E-1	-1.52862E-2	-1.07477E-2

	kPa	**psi**	**mH20**
Poly Factor (A)	-5.53631E-7	-8.02946E-8	-5.64549E-8
Poly Factor (B)	-9.60663E-2	-1.39327E-2	-9.79607E-3
Poly Factor (C)			

	kPa per °C	**psi per °C**	**mH20 per °C**
Thermal (T)	7.10157E-2	1.02996E-2	7.24161E-3

THE EQUIPMENT USED IN THE CALIBRATION OF THE PRODUCT DETAILED ABOVE IS TRACEABLE TO NATIONAL/INTERNATIONAL STANDARDS

Digits = Hz^2 x 10^{-3}

Linear calc = k (kPa) * (Current Reading - Site Zero Reading) + T * (Current Temp - Site Zero Temp)

Polynomial calculation = A * $(Reading)^2$ + B * (Reading) + C + T * (Current Temp - Site Zero Temp)
C = -A * $(Site\ Zero\ Reading)^2$ - B * (Site Zero Reading)

CALIBRATED TO UKAS TRACEABLE STANDARD - ISO 9001:2015
THIS IS AN ELECTRONIC CERTIFICATE AND IS VALID WITHOUT A SIGNATURE

M MARKING TAKEN FROM SENSOR END, USED AS AN INDICATOR

9. INSTALLATION

This section of the manual is intended for all users of Vibrating Wire Piezometers manufactured by **Geosense®** and is intended to provide guidance with respect to their installation.

It must be remembered that no two installations will be the same and it is inevitable that some 'fine tuning' of the following procedures will be required to suit specific site conditions.

It is VITAL that all personnel responsible for the use of piezometer Instruments READ and UNDERSTAND this manual, prior to working with the equipment

It is VITAL to check all the equipment in the shipment soon after taking delivery and well before installation is to be carried out. Check that all components that are detailed on the shipping documents are included.

9.1. Zero Pressure Reading

Vibrating wire transducers differ from most other pressure sensors in that they indicate a positive value at zero applied pressure. They will never read ZERO. Their readings at ZERO PRESSURE can vary significantly between sensors.

IT IS ESSENTIAL TO TAKE A ZERO READING
BEFORE
INSTALLATION IS CARRIED OUT

As with most transducers, do not directly handle the piezometer when recording the **ZERO PRESSURE** readings, as this will cause local temperature gradients across the body that will distort the readings.

Where piezometers are to be installed with their bodies orientated either horizontally or with their filters upwards, record their **ZERO PRESSURE** readings in a similar orientation.

In particular, piezometers with low pressure ranges can be very sensitive to orientation. Always obtain **ZERO PRESSURE** readings with the sensor orientated in the same direction in which it will finally be installed.

The method of obtaining a **ZERO PRESSURE** reference value is the same for all the models of sensor. Only the preparation and tip / filter configurations vary.

All **Geosense®** piezometers are fitted with Low Air Entry (LAE) filters, as standard. These should be removed for de-airing and prior to establishing their **ZERO PRESSURE** values.

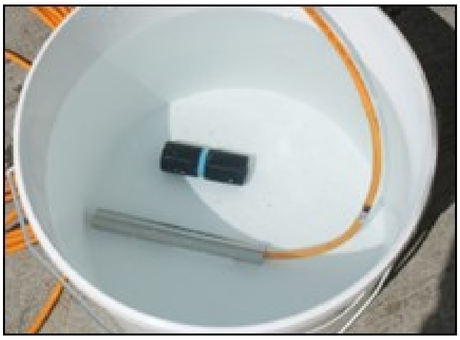
HAE filters are supplied separate from the piezometer bodies. They are factory de-aired and sealed into a PVC tube that is filled with a de-aired mixture of water and a non-toxic anti-freeze, Propylene Glycol. It is not necessary to fit these filters to the piezometers until they are to be installed.

Only Push-in piezometers are fully de-aired and assembled in the factory and sealed with a rubber sleeve. The rubber sleeve should be fitted to the tip to maintain saturation when being prepared for installation. The pushing action will remove it.

The Pressure Transducer is supplied with a filter inside its threaded bulkhead. The bulkhead has a threaded socket (1/4" BSPF) that is used for connection to liquid (or gas) pressure sources. The treaded bulkhead should be removed prior to establishing **ZERO PRESSURE** values.

Geosense® supplies HAE filters for their Standard and Heavy-Duty piezometers in a 'de-aired' condition so that they are ready for immediate onsite assembly and installation.

STEP 1 Fill a large bucket with clean, potable water, ideally at a temperature close to that of the local air temperature. Ensure that the bucket is away from any heat sources and shaded from the sun. Remove any fitted filters and place the piezometer(s) in the bucket.



Stir the water occasionally to ensure an even temperature. Leave the piezometer bodies covered with water for a minimum of 4 hours, preferably longer.

STEP 2 At the free end of the cable, connect the leads to a vibrating wire readout unit and occasionally monitor the transducer output by turning on the readout and observing the display (see the readout user manual for assistance).

Be sure to turn off the readout between periods of readings to avoid ‘heating’ the Vibrating Wire element.

STEP 3 Turn on the readout and, holding only the cable, lift the piezometer out of the bucket, allowing it to hang vertically downwards and immediately record 2 or 3 readings. Replace the piezometer in the water as before.

(If the piezometer is to be installed at an alternative angle; for example, horizontal or with the filter uppermost, record the ZERO PRESSURE in the intended final orientation)

After approximately two minutes of re-immersion, repeat and record another set of readings. Repeat three times, checking that the readings displayed are within +/- 0.5 digits of each other.

STEP 4 Record these readings together with the sensor serial number, local barometric pressure, approximate elevation above sea level, date and time.

STEP 5 Return the piezometer to the water or pack it carefully for installation at a later time.

The procedure for recording the **ZERO PRESSURE** for Push-in piezometers is the same as the standard piezometers explained above. However, these piezometers are supplied to site fully assembled and de-aired. The rubber sleeve, nose cone and filter have to be removed before the **ZERO PRESSURE** can be established.

STEP 1 Fill a large bucket with clean, potable water, ideally at a temperature close to that of the local air temperature. Ensure that the bucket is away from any heat sources and shaded from the sun. Place the piezometer(s) in the bucket.

STEP 2 Holding the piezometer underwater, roll back the rubber sleeve and unscrew the nose cone and filter. Leave all the parts in the water. Stir the water occasionally to ensure an even temperature. Since these have heavier piezometer bodies, leave them in the water for a minimum of 6 hours, preferably longer.

STEP 3 Once any inner temperature gradients have been removed by prolonged submersion at a stable temperature, the piezometer is ready to record the Zero Pressure values.

STEP 4 Connect and turn on the readout and, holding only the cable, lift the piezometer out of the bucket, allowing it to hang vertically downwards. Immediately record 2 or 3 readings and replace the piezometer in the water as before.

(If the piezometer is to be installed at an alternative angle; for example, horizontal, record the ZERO PRESSURE in the intended final orientation)

After approximately five minutes of re-immersion, repeat and record another set of readings. Repeat three times, checking that the readings displayed are within +/- 0.5 digits of each other.

STEP 5 Record these readings together with the sensor serial number, local barometric pressure, approximate elevation above sea level, date and time.

STEP 6 Return the piezometer to the water and ensure that no air is trapped inside the body.

Whilst remaining underwater, thread the filter and nose cone back onto the body of the piezometer.

STEP 7 Re-fit and un-roll the rubber sleeve to trap all the water in the body and filter. Carefully store until installation is to be carried out.

The rubber sleeve should remain in place as the installation is carried out. The pushing action will remove sleeve.

9.2. Preparation for Installation

Prior to installation of a piezometer, it is essential to establish and confirm details of the installation to be carried out. Some of the main considerations are listed below:

Intended Elevation and Depth to Piezometer?

This can be calculated as either the depth below a known level (ground level for example) or as the elevation with respect to a remote datum. For borehole installations, the final depth should be determined from the intended installation elevation and then marked on the cable to show the intended installed position.

For surface installations, a reference elevation could be determined and marked close to the final position of the piezometer.

Whichever positioning system is adopted, it is very important to determine and record the final elevation of the piezometer diaphragm and its orientation.

Borehole Installation Type / Specification

Where a piezometer is to be installed in a borehole, is it to be pushed into the base of the borehole; installed in a filter zone; grouted into the borehole or provided with a long filter for groundwater level monitoring?

One of the most common types of borehole piezometer installation is the sealed, sand filter pocket and is adopted where a single piezometer is to be used to register water pressures changes at a specific sub-surface horizon.

A more recently adopted borehole installation technique is the ‘Fully Grouted Method’. In this approach, there are no filter zones, and a specially designed grout is used to backfill the borehole and surround the piezometer(s). The grout design is a major consideration as it can significantly affect the system performance. This approach can be particularly advantageous where more than one piezometer is to be installed in a single borehole.

A full-length filter zone (or observation well) installation is probably the next most common. A filter material, commonly sand, is washed into a borehole as a backfill. It simply allows groundwater from any horizon to flow into the borehole to be registered by the piezometer, located close to the bottom of the borehole.

VW Piezometers are also commonly installed within standpipes, wells or as water level sensors. These are often ‘vented’ piezometers configured to compensate, automatically, for changes in atmospheric pressure.

Where a rapid response is required from a saturated material with a low permeability, a specially configured piezometer can be pushed into the undisturbed base of the borehole to provide an intimate connection to the pore water pressure at a particular horizon.

In softer material, the push-in piezometer can be pushed from ground level to its intended elevation, using hydraulic equipment such as a Cone Penetrometer machine. This removes the need for a borehole.

Surface Installation Type / Specification

Where a piezometer is to be installed at surface level (for example: as embankment fill is placed), is it to be pushed into a pre-formed cylindrical void or installed in a small, excavated pocket? Piezometers in these installations would normally be covered by fill material which would be compacted manually to a certain depth and then mechanically, thereafter.

In a location where high permeability material is present, a sand filter pocket type installation is preferred but the sand has to be enclosed within a permeable 'Geo-fabric' pocket to prevent it being 'lost' into the surrounding materials.

Where a piezometer is to be installed in a material with a low permeability, it is normally better pushed into a pre-formed void so as to maintain intimate contact with the surrounding material. (Sand pockets should be avoided in low permeability surface installations).

Filter Zone

A specially graded sand (commonly 600 - 1200 µm) is the most common material used to provide a filter zone within a borehole and support the borehole around the piezometer tip. The volume of material required will depend upon the diameter of the borehole and the length of the filter zone to be formed. Typically, a 0.5-metre-long filter zone is recommended, but it should be in accordance with specific project requirements and specifications.

In some cases, piezometers can be fitted inside small geotextile bags that are then filled with filter sand. This creates a small pre-formed filter pocket but also adds weight to the assembly to help with borehole installations. The filter bag should be fitted in advance of installation, filled with sand and allowed to soak in a bucket of water prior to placing.

Bentonite Seal

Where a sealed piezometer filter zone is to be formed in a borehole, highly compressed and dehydrated Bentonite in the form of either pellets, balls or chips is commonly used to form the seal and is commercially available in bagged form. Balls can also be created on site using Bentonite powder and manual labour; However, small man-made bentonite balls are only suitable for shallow boreholes with a diameter ≥ 100mm. This is because they are more difficult to use as they can break up before reaching their intended elevation in deeper boreholes.

Once in place, the Bentonite expands by absorbing water to form a highly impermeable borehole plug. Consequently, in dry boreholes, water must be added to allow the Bentonite to swell. Normally, a plug is only required above any filter zone, but a plug may also be used below a filter zone, for example, where the borehole extends beyond a piezometer filter base elevation.

Cable Marking

Cables should be marked with a unique identification system. Where multiple cables are to be grouped together along one route, markings should be repeated at regular intervals along the cable, so that in the event of cable damage, there may be a chance that the identification could be exposed, and the cables re-joined. Multiple cable marks are particularly important close to the ends of the cables. The spacing of markings can vary according to specific site requirements. As a guide, 5m to 10m is commonly applied, but closer spacing is applied nearer the ends.

Tools and Consumables

Obtain any tools necessary to carry out the installation. The following is a brief list of tools typically used during the installation of Vibrating Wire Piezometers. Some variation and addition may be necessary for different types of applications.

- Fibre measuring tape with a weight added to the end for borehole depth measurement and cable length measurement.
- Wire cutters and strippers
- Vibrating Wire Readout unit for checking the piezometer function
- Cable Marking system / equipment (e.g. coloured PVC Tapes)
- Grout mixing and placing equipment
- PVC tape
- Shovel for placing and levelling fill by hand
- Compactors - hand and mechanical

Fitting the Filter to the Piezometer.

Filters can be fitted immediately after the **ZERO PRESSURE** has been recorded, just prior to installation or any time between. Once fitted, it is VITAL that the filters remain saturated, so the piezometers should be stored and transported in water.

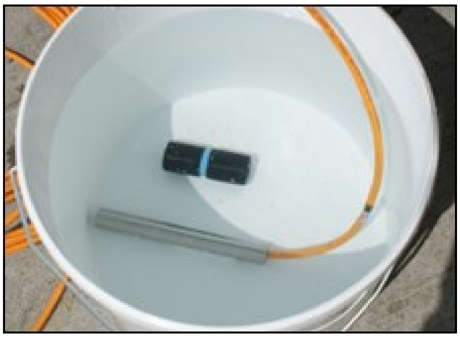
Standard Low Air Entry filters must be saturated prior to installation. Remove them from the piezometer or transducer and soak in clean water for at least 1 hour prior to re-assembly.

The special High Air Entry filters are de-aired in the factory and supplied sealed, in a small tube filled with de-aired liquid.

Fitting the filters to the Piezometers is similar for all piezometers.

9.3. Refitting Filter

STEP 1 Fill a large container with clean, potable water and place the piezometer into it, together with the filter(s). Where LAE filters are to be used, they will be in their transport tube.



STEP 2 To remove HAE filters from a transport tube, maintain it underwater, and remove one of the end covers. As the tube is full of water, this will not be easy to achieve. A small wire can be used to break the seal between the tube and the cap to help release any vacuum.

STEP 3 Maintaining all of the components underwater, remove one of the filters from the tube.

STEP 4 With all the components underwater, ensure that there is no air inside the end of the piezometer and insert the filter.

STEP 5 Carefully push the filter onto the piezometer.

Standard Low Air Entry filters are easily pushed onto the piezometer body, expelling any air from the filter.
High Air Entry filters are more difficult. Once the 'O' ring has engaged, it may be necessary to rotate the filter whilst applying pressure, to fully fit the filter.

STEP 6 Once fully fitted, the gap between the piezometer body and the filter body will be closed.

STEP 7 Maintain the piezometer in the water container or transfer it to another water-filled transport container (a water bottle makes a good transport container).

Care must be taken when fitting HAE filters to Low Pressure piezometers and transducers.

Always connect the readout to the cable and ensure that pressures induced during the filter fitting process DO NOT exceed the maximum operating range.

9.4. Installation Procedures – Boreholes

Each piezometer installation is different and requires both 'Common Sense' and a general understanding of the sub-surface conditions. There are many approaches to piezometer installation and, in addition to these broad installation guidelines,

Geosense® is committed to providing technical support to help engineers and technicians adjust their procedures to match particular site conditions and requirements.

Where possible, boreholes should be flushed with clean water prior to installation operations, particularly if excessive sediment remains suspended in the water.

Each piezometer is supplied with a unique identification on its body and on the attached cable; however, steps should be taken, perhaps with the aid of coloured tapes, to mark the cable so that there is no confusion over piezometer identification. This is particularly important for installations where more than one piezometer is to be installed in one location.

9.4.1. Cased Boreholes with Filter Pocket

When forming a borehole for a piezometer installation, it is sometimes necessary to use a temporary steel sleeve or 'casing' to hold the hole open during drilling and installation operations. The following describes a series of steps that could be adopted to carry out a piezometer installation in such a fully cased borehole. This procedure can be adapted where boreholes are only partially cased.

STEP 1 Before drilling the hole, it is important to ascertain the depth at which the piezometer is to be installed. An indication of the ground conditions may also be helpful.

STEP 2 The borehole should be formed to a depth of approximately half the sand filter depth below the intended elevation of the piezometer tip. If a Bentonite plug is required at the base of the borehole, it will have to be drilled further to accommodate the plug.

STEP 3 Before commencement of installation, the depth of the hole should be re-checked, and the procedure you intend to follow should be confirmed with the engineer and discussed with the driller.

STEP 4 Confirm that all materials are available (filter sand, Bentonite pellets or balls and backfilling grout). The piezometer to be installed should be transported to the borehole locations in a container of clean water.

STEP 5 Check the drill hole to ensure that the full depth is clear and free of obstructions and that any casing is free and can be withdrawn when needed.

STEP 6 CHECK INITIAL READING OF PIEZOMETER.

Where necessary, record a reading from the piezometer to confirm that it has not been damaged since establishing the ZERO PRESSURE readings (see Section 9.1).

STEP 7 Where necessary and possible, fill the borehole with clean water.

STEP 8 If a Bentonite plug is required at the base of the borehole, pull any temporary casing back so that its lowest level corresponds to the top of the intended plug. Slowly drop Bentonite pellets / balls down the borehole. Be sure not to let the pellets / balls plug or stick to the inside of the casing by checking the depth using a weighted tape. Ensure that the Bentonite level always remains below the bottom of the casing. (Feeding pellets / balls into the borehole too quickly will result in 'bridging' of casing and make completion of the installation very difficult). The top of any base plug must be below the intended piezometer installation elevation. Check frequently using a weighted tape.

STEP 9 Once any plug has been formed (if required), the casing should be pulled to about 500mm (or in accordance with specification) above the new base of the borehole (the intended top of the filter zone), and filter sand should be slowly added to fill the borehole up to the depth at which the piezometer diaphragm is to be installed. Check frequently using a weighted tape.

Water can be used to wash sand off the sides of the borehole, down to the filter zone.

Allow time for the sand to settle through the water and form the filter. A common fault is to rush this operation, resulting in poor installation.

STEP 10 With the filter securely fitted to the piezometer, lower it slowly down onto the sand at the base of the borehole and record another check reading.

If the piezometer reaches the base of the borehole and its position does not correlate with the mark on the cable, check the depth and marks again.

Any difference between the intended and actual elevation MUST be recorded.

STEP 11 If necessary, coil up and feed the piezometer cable into the casing so that the drilling rig can be used to extract the casing. Ensure that there is enough slack cable to prevent the casing from pulling the piezometer back up the borehole. (This will have to be repeated whenever casing is to be raised or removed.)

When a section of casing is removed, the cable is passed through it.

STEP 12 Ensure that the lowest part of the temporary casing is above the elevation of the top of the filter and add more clean filter sand on top of the piezometer.

Continually check the level of the sand using the weighted tape.

Fill until the full filter pocket has been formed.

STEP 13 Pull the casing back another 500mm (or as project specification requires) and add a Bentonite seal of specified thickness. This could comprise pure Bentonite pellets / balls as described above for the base plug. Continue to pull the casing a little at a time whilst adding the Bentonite pellets. Once the borehole is sealed to the specified thickness. Check the piezometer readings again.

(In a 100mm diameter borehole the 5kg of Geosense Mikolit® Bentonite pellets will produce a seal approximately 500mm long)

STEP 14 Fill the remaining void with Grout as shown in the grouting procedure (see section 9.7).

STEP 15 The piezometer installation is now complete, but the initial in-situ piezometer readings have yet to be recorded. Since the piezometric balance may have been disturbed by the installation operations, a series of piezometer readings may have to be recorded so as to determine when the piezometric balance has re-established.

Only then can a true set of in-situ pore pressure readings be recorded.

STEP 16 Terminate the installation as specified. It is important to terminate the cable above ground level in a waterproof enclosure or with a waterproof connector. Protect the installation from construction traffic and mark its location.

9.4.2. Open (Uncased) Boreholes

When forming a borehole for instrument installation, it may not be necessary to use a temporary steel sleeve or ‘casing’ to hold the hole open during drilling and installation operations. These holes may be described as ’open holes’. The following describes a series of steps that could be adopted to carry out a piezometer installation in an open or uncased borehole. It is similar to, but simpler than, the procedure for the cased borehole (section 9.4.1).

1) Before drilling the hole, it is important to ascertain the depth at which the piezometer is to be installed. An indication of the ground conditions may also be helpful.

2) The borehole should be formed to a suitable depth below the intended elevation of the piezometer tip. If a Bentonite plug is required at the base of the borehole, it will have to be drilled further to accommodate the plug.

3) Before commencement of installation, the depth of the hole should be re-checked, and the procedure you intend to follow should be confirmed with the engineer and discussed with the driller.

4) Confirm that all materials are available (filter sand, Bentonite pellets or balls and backfilling grout). The piezometer to be installed should be transported to the borehole locations in a container of clean water.

5) Check the drill hole to ensure that the full depth is clear and free of obstructions.

6) CHECK the FUNCTIONALITY of the PIEZOMETER. If necessary, record a reading from the piezometer to confirm that it has not been damaged since establishing the ZERO PRESSURE readings.

7) Where necessary and possible, fill the borehole with clean water.

8) If a Bentonite plug is required at the base of the borehole, slowly drop Bentonite pellets / balls down the borehole. Be sure not to let the pellets / balls plug or stick to the inside of the borehole. Feeding pellets / balls into the borehole too quickly will result in ‘bridging’ of the hole and make completion of the installation very difficult. The top of any base plug must be below the intended piezometer installation elevation.

9) Once the plug has been formed (if required), filter sand should be slowly added to fill the borehole up to the depth at which the piezometer is to be installed. Use a weighted fibre tape to control the level of the filling materials.

10) With the filter securely fitted to the piezometer, lower it slowly down onto the sand at the base of the borehole and record another reading.

11) Add more clean filter sand on top of the piezometer to provide the required filter above the piezometer level. Continually check the level of the sand using the weighted tape.

12) Add a Bentonite seal of specified thickness. This should comprise Bentonite pellets / balls as described above for the base plug. Once the borehole is sealed to the specified thickness, check piezometer readings again.

13) Fill the remaining void with grout as detailed in section 9.7.

14) The piezometer installation is now complete. In-situ piezometer readings should now be recorded. Since the piezometric balance may have been disturbed by the installation operations, a series of piezometer readings may have to be recorded so as to determine when the pressure balance has re-established. Only then can a true set of in-situ pore pressure readings be recorded.

15) Terminate the installation as specified. It is important to terminate the cable above ground level in a waterproof enclosure or with a waterproof connector. Protect the installation from construction traffic and mark its location with a highly visible stake.

9.4.3. Push-in Installations

Some installations require a Piezometer to be pushed into undisturbed material at the bottom of a borehole or pushed into soft ground from the surface. For this purpose, **Geosense®** produces a specially designed Push-in Piezometer. The installation involves the use of a pushing adaptor connected to steel placing rods, drilling rods or Cone Penetration Testing (CPT) rods. The rod(s) must be strong enough to withstand the load that will be required to push a piezometer body into the material at the base of the borehole or from ground level to its intended elevation.

Only purpose-built PUSH-IN piezometers can be used for this type of installation.

A special pushing adaptor is required to support and push the piezometer body into the base of a borehole. This adaptor is a purpose-built component, normally manufactured by **Geosense®**, that would be supplied or modified to suit the size and thread of the rods to which it will be connected.

Figure 7: Push-in adaptor for BSP pipe or CPT rods

Figure 8: Push-in adaptor for drill rods

The design of the adapter is such that once the piezometer has been pushed to the required elevation, the rods and adaptor can be extracted, leaving the piezometer in place.

There are two types of pushing adaptors to match the Push-in VW Piezometer supplied by **Geosense®**. Where drilling rods are to be used to push the piezometer only into the base of the borehole, it is suggested that the cable from the piezometer passes out from the side of the pushing adaptor and up outside the rods. This will make it easier to withdraw the rods once the installation has been finalised. Obviously, the piezometer cable must not be attached to the drilling rods as the installation is inserted into the borehole, and care must be taken to protect the cable.

For pushing deeper into a borehole base, the cable must remain inside the rods to protect it, as with BSP tube or CPT rods.

The borehole may be cased or uncased. The final installation procedure will need to be created to include the following variations and based upon the previously described borehole installation procedures.

1) Prepare the piezometer and obtain the ZERO PRESSURE reading as described in section 9.1 and transport it to the drilling location

2) Base grouting need not be carried out since the intention is that the piezometer will be pushed into undisturbed material at the base of the borehole.

3) With the specially designed pushing shoe fitted to the lower end of the first rod, the piezometer must be pushed up inside the shoe until it is firmly in place against the back of the shoe.

4) As the rods are lowered into the borehole, the cable must be restrained to prevent the piezometer from dropping out of the shoe and to maintain control of the cable.

5) Always count the rods into the hole to be sure of the piezometer elevation at any time. (In soft ground, heavy rods could push the piezometer past its intended location without applying any driving force).

Never rotate the lower rods when adding further rods. This may cause the piezometer cable to become wrapped around the rods and will result in a failed installation due to either cable damage or pulling the piezometer back out of its intended location when the rods are extracted.

6) When the piezometer is just above the base of the borehole, connect a portable readout to the piezometer cable to monitor any changes in the pressure registered by the piezometer, particularly when it is being pushed into the base.

7) If necessary, use hydraulic equipment (rig head or jacking ram) to apply gradual loading to the rods to push the piezometer to its intended elevation.

These pressures MUST NOT significantly exceed the maximum pressure shown on the calibration sheet. If it exceeds the calibrated values by more than 50%, irreparable damage to the piezometers may occur. The calibration and ZERO PRESSURE values would then be invalidated. The piezometer would not then provide any useful data.

8) No filter zone is required. Bentonite pellets can be used to provide a plug behind the piezometer, but generally, the borehole would be backfilled with Bentonite / Cement grout once the rods have been extracted. When water is present in the borehole, grouting must be carried out from the bottom of the hole upwards, using a tremie pipe. Where the borehole is dry, liquid grout can be placed from the top.

Where a Cone Penetrometer Testing Rig (CPT rig) is to be used to place the piezometers, it will be necessary to use a special adaptor shoe and to run the piezometer cable up inside the CPT rods. Each rod must be threaded over the cable as pushing is carried out. A standard electronic CPT pushing head can be used to allow the cable to pass through under the pushing head. A pre-driven CPT hole with a 'lost' head can also be utilised to prevent pressure build-up on the piezometer.

This system can be a cost-effective solution where piezometers are to be installed in soft ground, but care must be taken not to damage the cable when the CPT rods are withdrawn.

9.4.4. Borehole Installation (Fully Grouted Method)

This is an alternative method of installing either single or multiple piezometers in a single borehole. Rather than creating a filter pocket or pushing the tip into the parent material, the piezometer(s) are commonly supported on a PVC or polyethene pipe in a borehole. The borehole is then backfilled with a specially designed cement & bentonite liquid grout mix.

1) Drill the borehole below the required depth of the piezometer. Flush the borehole with water or biodegradable drilling mud to remove drilling fluids and cuttings.

2) Prepare the piezometer by obtaining the **ZERO PRESSURE** reading as described in section 9.1 and transport it to the drilling location.

3) Establish the elevation of the base of the borehole.

4) Piezometer(s) are commonly attached to a PVC or polyethene pipe to maintain their position in the borehole. This pipe can double as the tremie pipe for placing the grout. They are also commonly installed in an inverted orientation, with their filters facing up.

Figure 9: VWP-3000 attached to a PVC tremie pipe

5) Measure along the support tube and mark the piezometer elevations with reference to the top of the borehole, remembering that the elevation of the Piezometer sensing element (diaphragm) is measured just behind the filter. Also consider that the tube will rest on or close to the base of the borehole if it is not independently supported from the top.

6) Use strong tape to attach the piezometers to the tube. Also, use tape to attach the cable(s) to the pipe, along its length. Fix the cable at regular intervals to prevent it from tangling or snagging.

7) If the piezometer(s) are to be installed together with inclinometer casing, they can be attached to the casing.

8) Lower the piezometer assembly to its intended location, referring to the marks placed on the tubes. If a separate Tremie pipe is to be used to place the grout, it must be installed together with the piezometers and NOT afterwards.

9) The properties of the grout are very important for fully grouted piezometer installations. A suitable grout mix must be designed to closely replicate the properties of the surrounding materials (see section 9.7).

10) Back-fill the borehole with liquid grout. Use either of the grout mixtures detailed in Section 5.6 as a starting point for the grout mix. Add the cement to the water first, and then add the bentonite. Adjust the amount

of bentonite to produce a grout that is a 'just pumpable' mix (heavy cream consistency). If the grout is too thin, the solids and the water will separate. If the grout is too thick, it will be difficult to pump.

11) Extreme care must be taken to ensure that the piezometer(s) remain supported and undisturbed whilst any drill casing is removed, and the grout reaches an initial set.

12) Readings taken immediately after installation will be high but will decrease as the grout cures. Once it has cured, the response time lag caused by the grout itself is believed to be measured in minutes.

13) Terminate the installation as specified. It is important to terminate the cable(s) above ground level in a waterproof enclosure or with a waterproof connector.

14) Protect the installation from construction traffic and mark its location with a highly visible stake. Hydration of the grout may take time in low-permeability soils and have an impact on the curing time.

9.4.5. Deep Borehole Installation

Significant challenges may be faced during the installation of deep piezometers, which are defined as having a depth greater than 50m.

These installations create a range of challenges, the impact of which increases with depth.

These challenges include:

- The positioning of the response zone
- Placing of the piezometer,
- Protection of the sensor and cable
- Backfilling of the borehole

All of these will have significant impacts on a successful installation.

For further information on Deep Piezometer Installations, please contact **Geosense®**.

9.5. Installation Procedures - Trenches and Pockets

This type of installation is carried out where the intended piezometer position is accessible. Commonly, this would be during the construction of a structure where the piezometer would form part of a future monitoring regime. Typically, this might include embankments, culverts, cut-and-cover tunnels, dams, etc.

In materials that have a low permeability, no sand pocket should be included in the installation since this would lead to a reduced response time and may provide a trap for air, which would render the piezometer less responsive.

In granular materials, where permeability is medium or high, a sand filter pocket can be formed around the piezometer tip.

In some installations, particularly where saturation of the piezometer location is due to occur after a long period (dams, for example), the piezometer can be orientated so that its filter end is raised above the cable entry end. This will help to minimise the risk of air being trapped around the diaphragm when saturation occurs.

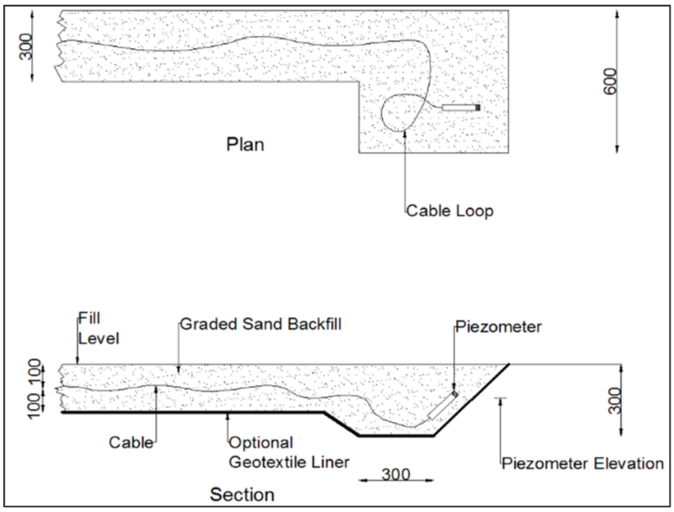
Alternatively, to maintain short-term saturation (in highly permeable, tidal locations, for example), piezometers can be installed with their filter downwards, in a small plastic container filled with saturated coarse sand. This will prevent water from draining away, thereby maintaining the tip in a saturated condition.

Once again, no two installations are the same, but common practice in most materials involves excavating a small pit in the material in which the piezometer is to be installed. Once in position, the piezometer should be surrounded by the material in which it is being installed. This will ensure that its environment replicates, as closely as possible, the surrounding conditions.

Where piezometers have to be connected to extension cables, this would preferably be carried out prior to installation. In some cases, however, this may not be possible. Cables must be marked with identification prior to installation.

9.5.1. Permeable Materials

STEP 1 Once the cable route has been defined, excavate a trench (minimum 300mm deep) along the route from the piezometer installation location to the intended cable termination point. Where compaction of backfilled material is critical (dams for example), the trench should have sides raked at an angle of a minimum 45 degrees.



STEP 2 Create a small pocket (minimum 300mm x 300mm x 300mm) into which the piezometer can be installed. Check the elevation of the pocket to ensure that the piezometer will be installed at the correct level.

STEP 3 Having prepared the piezometer for installation and recorded its site Zero Pressure Reading (see Section 9.1), bring it to the site for installation. Check the function of the piezometer using a portable readout.

STEP 4 Where the excavation is in a granular material, place a layer of Geotextile material in the base and up the walls of the excavation, then a 100mm layer of graded sand in the base of the trench and pocket.

STEP 5 Carefully remove the piezometer from the water-filled container and place it in the sand pocket as shown.

STEP 6 Coil the cable in the pocket to form a loop as shown. This helps to reduce the risk of cable damage due to excessive settlement or stretching.

STEP 7 Lay a section of the cable into the trench and backfill the pocket and trench with stone-free sand as shown in the above sketch. It may help to pour some water over the sand to assist with compaction.

STEP 8 Complete the cable laying operation, snaking the cable in the trench only when particularly specified. Laying the cable in a 'zig-zag' or 'snaking' pattern is sometimes specified with the intention of reducing the risk of cable breaks due to stretching.

Figure 10: VWP cable protected by flexible conduit and trenched away from borehole towards logger (out of picture to left)

STEP 9 Backfill the trench with sand, ensuring it is free from stones or any material that could damage the cables.

STEP 10 Before resuming any further filling operations, check the piezometer's function using a portable readout.

STEP 11 Add the excavated fill over the sand to complete the backfilling and compact with mechanical plant.

9.5.2. Impermeable Material

STEP 1 Once the cable route has been defined, excavate a trench (minimum 300mm deep) along the route from the piezometer installation location to the intended cable termination point. Where compaction of backfilled material is critical, the trench should have sides raked at an angle of a minimum of 45 degrees.

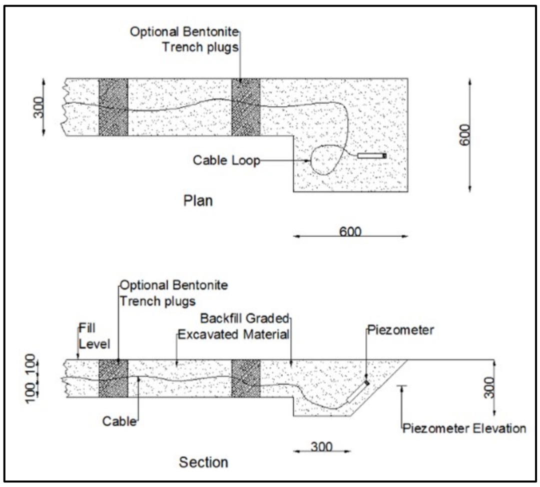


Figure 11: Piezometer in a pocket in an impervious material

STEP 2 Place a minimum 100mm thick layer of graded backfill in the base of the trench. The backfill should be similar to the excavated material, graded to remove any stones or objects that may damage the cable. The backfill material must have a low permeability.

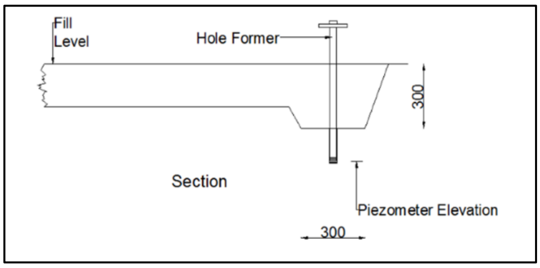


Figure 12: Forming hole for piezometer in impervious material

STEP 3 Create a small pocket (minimum 300mm x 300mm x 300mm) into which the piezometer can be installed. Check the elevation of the pocket to ensure that the piezometer will be installed at the correct level. See sketches for level details.

STEP 4 Place a 100mm layer of graded backfill in the base of the pocket.

STEP 5 The piezometer can be either placed in the pocket and surrounded with selected, stone-free fill material, or it can be pushed into a pre-formed socket in the base of the pocket.

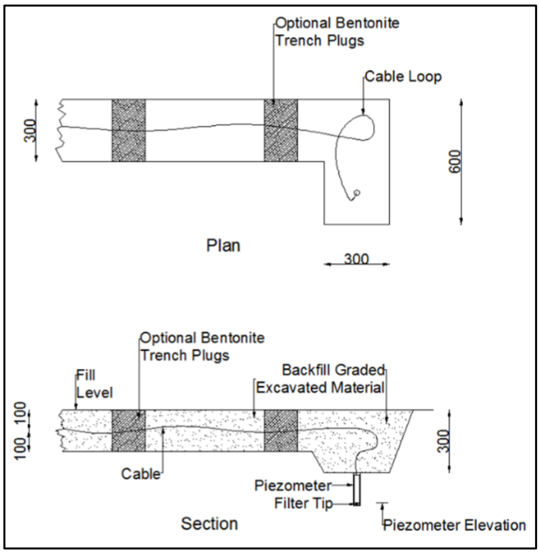


Figure 13: Piezometer pushed into an impervious material

STEP 6 To form a socket, make or obtain a ‘mandrel’. This should be the same diameter as the piezometer, and the socket is generally formed so that the whole piezometer body can slide into it.

STEP 7 Having prepared the piezometer for installation and recorded its site Zero Pressure Reading (see section 9.1), bring it to the site for installation in a water-filled container. Check the function of the piezometer prior to its installation, using a portable readout.

STEP 8 Carefully remove the piezometer from the water-filled container and place it in the pocket or into the socket, as shown in the sketches.

STEP 9 Coil the cable near the piezometer, forming a loop as shown.

STEP 10 Lay a section of the cable into the trench and backfill the pocket and trench with graded material as shown in the sketch. Carefully compact the material around the piezometer by hand, using **only** light handheld machines around the cable.

STEP 11 Complete the cable laying operation, snaking the cable in the trench only where specified, and backfill the trench with graded material, compacting it in layers to ensure an adequate seal.

STEP 12 Before resuming any further filling operations, check the piezometer's function using the portable readout.

STEP 13 Bentonite can be used to provide additional sealing material. Either Bentonite powder can be mixed into all the backfill material used in the impervious zones or pellets / balls of partially saturated Bentonite can be used to form plugs at intervals along the cable route (see Figure 12).

STEP 14 Extension cables should be marked / coded at regular intervals so that, in the event of damage, they could possibly be traced and reconnected.

9.6. Installation Procedures – Observation Wells or as Water Level Transducer

Vibrating Wire Piezometers can be installed in Observation Wells or Standpipe Piezometers to monitor water levels.

It must be remembered that the standard piezometer is a sealed unit and is therefore sensitive to pressure changes only on one side of its diaphragm. When installed in a well that is open to atmosphere, the piezometer reading WILL BE affected by changes in atmospheric pressure in addition to any changes in water level.

When an accuracy better than ±100 mm head of water is required, the piezometer readings must be adjusted for changes in atmospheric pressure. Atmospheric pressure could be monitored by an on-site recording barometer or by a low-pressure range VW Transducer that is dedicated to monitoring atmospheric pressure.

Alternatively, special 'vented' VW Piezometers are available. In these instruments, the rear of the diaphragm is 'vented' to atmospheric pressure by a fine tube included in a special cable. This removes the need for barometric compensation as both sides of the diaphragm are affected by changes equally. These are often employed where only small pressure changes are expected or water level monitoring (reservoirs, etc.)

For shallow installations, it is acceptable to suspend the piezometers on their connecting cables. For deeper installations, it is recommended that they be supported on stainless steel suspension cables.

Installation

1) Carry out all pre-installation checks and record the site Zero Pressure reading(s) as described in Section 9.1 of this manual.

2) Measure and mark the cable to indicate the level at which the piezometer should be installed. It should be located either at a specified depth or just below the minimum expected 'Low Water' level.

3) If turbulence is expected in the well, fit a perforated centraliser to keep the piezometer stable inside the well tube.

4) Lower the piezometer into the well and secure the signal cable or suspension cable at the top to maintain the piezometer in position.

5) Terminate the piezometer installation as required. It is important to terminate the cable above ground level in a waterproof enclosure or with a waterproof connector. Protect the installation from construction traffic and mark its location with a highly visible stake.

6) Vented piezometer cable is usually terminated close to the top of the installation using a special vented terminal / junction box.

9.7. Grouting

Backfilling of boreholes and other excavations for piezometer installation often calls for the preparation and installation of grout.

Grout should be mixed in a purpose-designed grout mixer to ensure a complete mix.

The primary function of the grout is to provide a backfill material into the annulus space around the piezometer, so that the entire install monitors the conditions effectively. With a piezometer this is primarily hydraulic conductivity.

Commonly, the components and proportions of the mixture are designed to reflect the characteristics of the material (hydraulic conductivity) into which it is to be placed. Where a specific design is not required, generalisations can be made with regard to the mix proportions.

Since the materials also vary from batch to batch, it is important to use representative samples of the material that will be used on site when preparing samples for lab testing and mix design.

Where the grout is to be used to backfill for a borehole, the commonly adopted mix proportions, by weight, would be as follows:

Table 2: Grout Mix for Hard and Medium Soil (Including Fully Grouted Method)

Materials	Weight	Ratio by Weight
Portland cement	50 kg	1
Bentonite	15 kg	0.33
Water	(125 kg) 125 Litres	2.5

Table 3: Grout Mix for Soft Soils

Materials	Weight	Ratio by Weight
Portland cement	50 kg	1
Bentonite	20 kg	0.4
Water	(325 kg) 325 Litres	6.5

Mikkelsen, P.E. and Green, G.E., 2003. Piezometers in fully grouted boreholes. In: Proceedings of the Symposium on Field Measurements in Geomechanics (FMGM 2003), Oslo, Norway, September.

When installing piezometers, the grout viscosity should be pumpable and the use of additives in grouts (such as plasticiser) should be avoided.

British Standards Institution (BSI), 2020. BS EN ISO 18674-4:2020 — Geotechnical investigation and testing – Geotechnical monitoring by field instrumentation – Part 4: Measurement of pore water pressure: Piezometers. London: British Standards Institution.

10. DATA HANDLING

The function of an instrument is to provide useful and reliable data. Accurate recording and handling of the data is essential if it is to be of any value.

10.1. Monitoring the Piezometer Readings

Geosense® Vibrating Wire Piezometers include both pressure and temperature sensors. Where a piezometer is installed in a zone where its temperature is likely to fluctuate significantly, records of both pressure and temperature data should be recorded. This data can then be used to assess any temperature effects on the pressure readings.

10.1.1. Portable Readouts

Geosense® offer a range of readout and data logging options. Specific operation manuals are supplied with each readout device.

Below is a brief, step-by-step procedure for use with the Geosense® VWR1 portable readout.

STEP 1 Connect the signal cable from the sensor to the readout following the wiring colour code. Conductor colours may vary depending on the extension cable used. Commonly, these are:

Colour	Function	VWR1 Output
Red	VW +	Frequency (Hz) (Digits)
Black	VW -	
Green	Temp +	Resistance (Ohms) (Temperature)
White	Temp -	

Whilst it is not critical that the polarity be observed for most Vibrating Wire instruments, a better signal may be obtained if the correct polarity is adopted. Since the temperature sensor is a Thermistor, its connection polarity is not important.

STEP 2 Power on the unit by holding the power button. Set the range for the sensor using the “RANGE” button, or if unsure, set the range to “A” which is Auto mode.

STEP 3 Once on, press the “ACQ” button to take a single reading. Holding the button down will set the unit to take continuous readings.

STEP 4 The readings from the sensor will be shown on the screen. The units can be changed by pressing the two bottom buttons (“**B/Hz**” and “**°C/Ω**”)

10.2. Data Loggers

A number of data loggers are available to automatically excite, interrogate and record the readings from Vibrating Wire instruments. These include the GeoLogger Linx, WISOS 480 and MESHNET, and equipment manufactured by Campbell Scientific Ltd.

11. DATA REDUCTION - UNITS

11.1. Overview

The tension of a sensor wire can be measured by detecting the frequency at which it naturally vibrates. The following is a description of the units commonly used by the instrumentation industry.

11.2. Frequency Units (Hz)

If the wire is ‘excited’ electronically the frequency at which it vibrates can be measured. The units used to express frequency are Hertz (Hz).

The disadvantage of these units is that there is no ‘linear’ conversion from ‘change in Hertz’ to ‘change in wire tension’.

11.3. Linear Digits (B)

In order to overcome the problem of a linear conversion described above, the frequency value can be squared, thereby rendering it linear, but quite large. To reduce its size, it is often divided by 1000. The expression $Hz^2/1000$ (or $Hz^2 \times 10^{-3}$) is the most commonly adopted as a ‘linear’ digital output.

$$Digits\ [B] = Frequency\ [Hz]^2 \div 1000$$

11.4. Period Units (P)

Some readout devices utilise the 'counter' function available in many common integrated circuits.

Period Units represent the time taken for the wire to vibrate over one full oscillation, expressed in seconds. Due to the very small size of the number generated, most equipment manufacturers display the unit multiplied by either 1000 (10^3) or 10000000 (10^7).

The relationship between Period units and Frequency units is expressed as

$$Period\ [P] = 1 \div Frequency\ [Hz]$$

Period units are convenient to measure, but do not have a linear relationship to the 'change in wire tension'.

11.5. Calibration Factor

Each VW Piezometer is supplied with a Calibration certificate to enable conversion from the raw data (in the units described above) into engineering units such as kPa (kilopascals).

The value of the calibration factor will vary depending on the engineering units into which the raw data is to be converted.

Readings from VW sensors are typically in a form that is a function of frequency rather than in units of pressure.

To convert the frequency readings to units of pressure, a calibration factor must be applied to the recorded values. For Vibrating Wire Piezometers, the calibration factors are unique to each unit.

12. DATA REDUCTION - FORMULAE

12.1. Linear Calculation

A linear calculation can also be used to calculate the change in load from site zero reading using the current averaged readings; however, this comes with a slight drop in accuracy, which is stated on the calibration sheet, though for most applications, this accuracy is still sufficient.

$$[pressure] = k \times (R_1 - R_0) + T \times (T_1 - T_0)$$

k = Constant from calibration sheet of required units
R_1 = Current reading in digits [B]
R_0 = Site zero reading in digits [B]
T = Temperature compensation constant
T_1 = Current temperature [Celsius]
T_0 = Site zero temperature [Celsius]

Geosense® recommends all pressures are reported as pascals in order to conform with the International System of Units (SI).

Resultant units for pressure are determined by which constants are used.

12.2. Polynomial Calculation

Each **Geosense®** VWP is calibrated by increasing pressure in incremental steps and recording the data whilst in a temperature-controlled environment.

The readings are averaged, and a regression is done with applied pressure versus the averaged readings to get the piezometer constants. The constants are used in the polynomial formula below for calculating the current pressure.

$$[pressure] = A \times (R_1)^2 + B \times (R_1) + C + T \times (T_1 - T_0)$$

A = Constant from calibration sheet of required units
B = Constant from calibration sheet of required units
C = Calculated constant from zero reading
R_1 = Current reading in digits [B]
T = Temperature compensation constant
T_1 = Current temperature [Celsius]
T_0 = Site zero Temperature [Celsius]

The constant of C shown on the calibration sheet (section 8) needs to be calculated by the user using the following formula:

$$C = -A \times (R_0)^2 - B \times (R_0)$$

A = Constant from calibration sheet of required units
B = Constant from calibration sheet of required units
C = Calculated constant from zero reading
R_0 = Site zero reading in digits [B]

Geosense® recommends all pressures be reported as pascals in order to conform with the International System of Units (SI).

Resultant units for pressure are determined by which constants are used.

12.3. Check Equations

The following equation is presented as a check for the user to validate their calculations. Use the variables and constants provided in Table 4 and check your calculations against the results in Table 5, Table 6 and Table 7.

Table 4: Provided values for variables and constants for the purpose of checking equations only

Constant/Variable	Value	Units	Source
k	-1.05398E-01	kPa per digit	Calibration Certificate
T	7.10157E-02	kPa per °C	Calibration Certificate
R1	9418.30	digits (B)	Current reading
R0	10064.20	digits (B)	Site zero reading
T1	12.46	Celsius	Current reading
T0	19.21	Celsius	Site zero temperature
A	-5.53631E-07	kPa factor	Calibration Certificate
B	-9.60663E-02	kPa factor	Calibration Certificate

Table 5: Check results for linear pressure calculation

Resultant	Value	Units	Source
Linear pressure	67.5972122250	kPa	Linear equation for pressure (section 12.1)

Table 6: check results for polynomial C constant

Resultant	Value	Units	Source
Polynomial C	1022.9067005317	kPa factor	Polynomial equation for pressure (section 12.2)

Table 7: Check results for polynomial pressure calculation

Resultant	Value	Units	Source
Polynomial pressure	68.5366194919	kPa	Polynomial equation for pressure (section 12.2)

12.4. Temperature (Thermistor)

The majority of VW sensors carry an onboard thermistor (3KΩ at 25°C) for accurate temperature measurement. The raw output of this sensor is a resistance, normally measured in ohms (Ω).

$$T = \left(\frac{1}{A + B \times (ln\,R) + C \times (ln\,R)^3}\right) - 273.15$$

A = 1.4051E-03
B = 2.3690E-04
C = 1.0190E-07
T = Temperature in Celsius
R = Resistance (ohms)

12.4.1. Resistance vs. Temperature

Table 8: Resistance to Temperature Lookup Table (Celsius)

Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp	Ohms	Temp
201.1K	-50	**16.60K**	-10	**2417**	30	**525.4**	70	**153.2**	110
187.3K	-49	**15.72K**	-9	**2317**	31	**507.8**	71	**149.0**	111
174.5K	-48	**14.90K**	-8	**2221**	32	**490.9**	72	**145.0**	112
162.7K	-47	**14.12K**	-7	**2130**	33	**474.7**	73	**141.1**	113
151.7K	-46	**13.39K**	-6	**2042**	34	**459.0**	74	**137.2**	114
141.6K	-45	**12.70K**	-5	**1959**	35	**444.0**	75	**133.6**	115
132.2K	-44	**12.05K**	-4	**1880**	36	**429.5**	76	**130.0**	116
123.5K	-43	**11.44K**	-3	**1805**	37	**415.6**	77	**126.5**	117
115.4K	-42	**10.86K**	-2	**1733**	38	**402.2**	78	**123.2**	118
107.9K	-41	**10.31K**	-1	**1664**	39	**389.3**	79	**119.9**	119
101.0K	-40	**9796**	0	**1598**	40	**376.9**	80	**116.8**	120
94.48K	-39	**9310**	1	**1535**	41	**364.9**	81	**113.8**	121
88.46K	-38	**8851**	2	**1475**	42	**353.4**	82	**110.8**	122
82.87K	-37	**8417**	3	**1418**	43	**342.2**	83	**107.9**	123
77.66K	-36	**8006**	4	**1363**	44	**331.5**	84	**105.2**	124
72.81K	-35	**7618**	5	**1310**	45	**321.2**	85	**102.5**	125
68.30K	-34	**7252**	6	**1260**	46	**311.3**	86	**99.9**	126
64.09K	-33	**6905**	7	**1212**	47	**301.7**	87	**97.3**	127
60.17K	-32	**6576**	8	**1167**	48	**292.4**	88	**94.9**	128
56.51K	-31	**6265**	9	**1123**	49	**283.5**	89	**92.5**	129
53.10K	-30	**5971**	10	**1081**	50	**274.9**	90	**90.2**	130
49.91K	-29	**5692**	11	**1040**	51	**266.6**	91	**87.9**	131
46.94K	-28	**5427**	12	**1002**	52	**258.6**	92	**85.7**	132
44.16K	-27	**5177**	13	**965.0**	53	**250.9**	93	**83.6**	133
41.56K	-26	**4939**	14	**929.6**	54	**243.4**	94	**81.6**	134
39.13K	-25	**4714**	15	**895.8**	55	**236.2**	95	**79.6**	135
36.86K	-24	**4500**	16	**863.3**	56	**229.3**	96	**77.6**	136
34.73K	-23	**4297**	17	**832.2**	57	**222.6**	97	**75.8**	137
32.74K	-22	**4105**	18	**802.3**	58	**216.1**	98	**73.9**	138
30.87K	-21	**3922**	19	**773.7**	59	**209.8**	99	**72.2**	139
29.13K	-20	**3748**	20	**746.3**	60	**203.8**	100	**70.4**	140
27.49K	-19	**3583**	21	**719.9**	61	**197.9**	101	**68.8**	141
25.95K	-18	**3426**	22	**694.7**	62	**192.2**	102	**67.1**	142
24.51K	-17	**3277**	23	**670.4**	63	**186.8**	103	**65.5**	143
23.16K	-16	**3135**	24	**647.1**	64	**181.5**	104	**64.0**	144
21.89K	-15	**3000**	25	**624.7**	65	**176.4**	105	**62.5**	145
20.70K	-14	**2872**	26	**603.3**	66	**171.4**	106	**61.1**	146
19.58K	-13	**2750**	27	**582.6**	67	**166.7**	107	**59.6**	147
18.52K	-12	**2633**	28	**562.8**	68	**162.0**	108	**58.3**	148
17.53K	-11	**2523**	29	**543.7**	69	**157.6**	109	**56.8**	149

13. BAROMETRIC PRESSURE CONSIDERATIONS

In some locations, barometric pressure varies by a small amount, except when there are storms. In other locations, normal weather may bring barometric pressure changes as large as 35 mb (0.35 mH_2O) during a day, and 70 mb (0.70 mH_2O) during a year.

If a piezometer is sealed into a borehole to measure pore-water pressure, the only pressure acting on the piezometer's diaphragm is the water pressure at that depth, and a barometric correction need not be applied. Even if it is later found that there is a relationship between barometric pressure and pore-water pressure, it will probably not be necessary to apply any correction, as any influence will be negligible.

If the piezometer is measuring the water level in a standpipe or well that is open to atmosphere, the pressure measured by the piezometer is the combined pressure of water and the air above the surface of the water. If the barometric pressure drops, the piezometer will show a decreased pressure, even if the water level remains unchanged. To eliminate the measurement uncertainty introduced by changes in barometric pressure, a correction can be applied.

Either a vented piezometer or an additional low-pressure VW Transducer can be used to measure atmospheric pressure. The following is an example of how to carry out the correction using data from a special barometric transducer or other weather station information:-

1) Obtain barometric pressure readings on site at the time of reading the piezometer. Ideally, the barometer should provide the actual pressure of the atmosphere at the location of the monitoring site. Off-site reports from weather stations can also be adequate for this purpose since it is only the relative change in pressure that will be used to calculate the effect. The same source of pressure that was noted when the piezometer zero values were recorded must be used for all subsequent readings.

2) Subtract the barometer reading obtained when the site zero reading value was recorded from the current barometer reading in millibars. This is the barometric pressure correction value.

3) Convert the barometric correction value to the engineering units being used for the piezometer data, by multiplying it by the applicable factor (for example:- 0.1 for kPa, 0.014504 for psi or 0.0101972 for mH_2O).

4) Add the barometric correction, in engineering units, to the pressure reading, remembering that the compensation could be positive or negative.

14. MAINTENANCE

Geosense® Vibrating Wire Piezometers are basically maintenance-free devices for most applications, but the following should be considered during the service life:

- Keep away from direct sunlight to avoid large thermal affects.
- Avoid any impacts or significant vibration which can damage internal sensors.
- Keep cables away from physical damage.
- Keep cable ends waterproof.
- Where a VWP cable terminates into a logger, make sure the connection is watertight.

15. TROUBLESHOOTING

Where damage to a sensor or cable is suspected, this guide illustrates the way in which simple resistance checks can be taken to identify the possible cause of the problem.

Resistance checks can be made with most types of multimeters, which are readily available in the market.

15.1. Measuring Coil Resistance

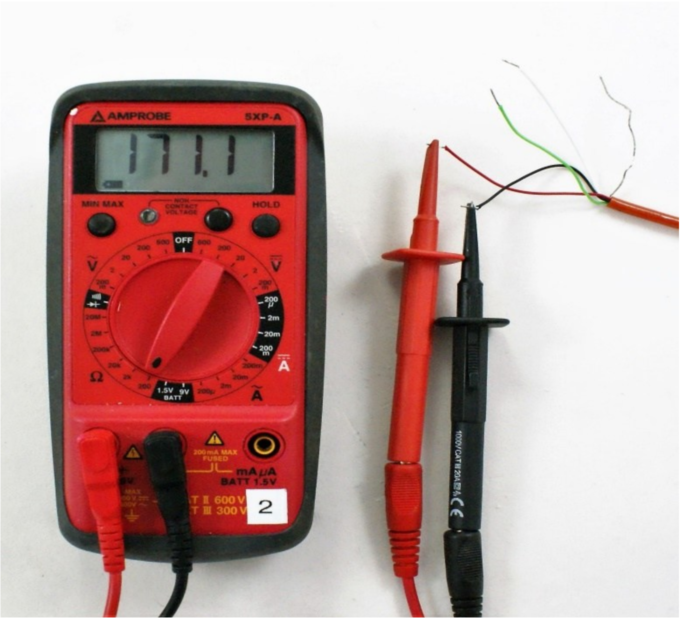


Figure 14: Multimeter measuring resistance across the red and black cores (coils)

STEP 1 Set the range and measurement type to "ohms (Ω)". Ensure the leads are connected to the correct ports.

STEP 2 Connect the multimeter suitably to measure the resistance across the red and black VW coil wires. The polarity of the connection does not matter.

STEP 3 Compare the reading to the table.

Gauge Type	Value	Units
VW Piezometer	~160	Ohms (Ω)
VW Strain gauge	~180	Ohms (Ω)
VW Load cell	~50	Ohms (Ω)
VW Sister Bar	~50	Ohms (Ω)
VW Spot Weld Strain Gauge	~50	Ohms (Ω)

Readings should be within 10% of these values, if they are outside of this range it is likely the sensor or the cable has been damaged.

NOTE Long cable lengths may increase resistance values.

15.2. Measuring Thermistor Resistance

Figure 15: Multimeter measuring resistance across the green and white cores (thermistor)

STEP 1 Set the range and measurement type to “ohms (Ω)”. Ensure the leads are connected to the correct ports.

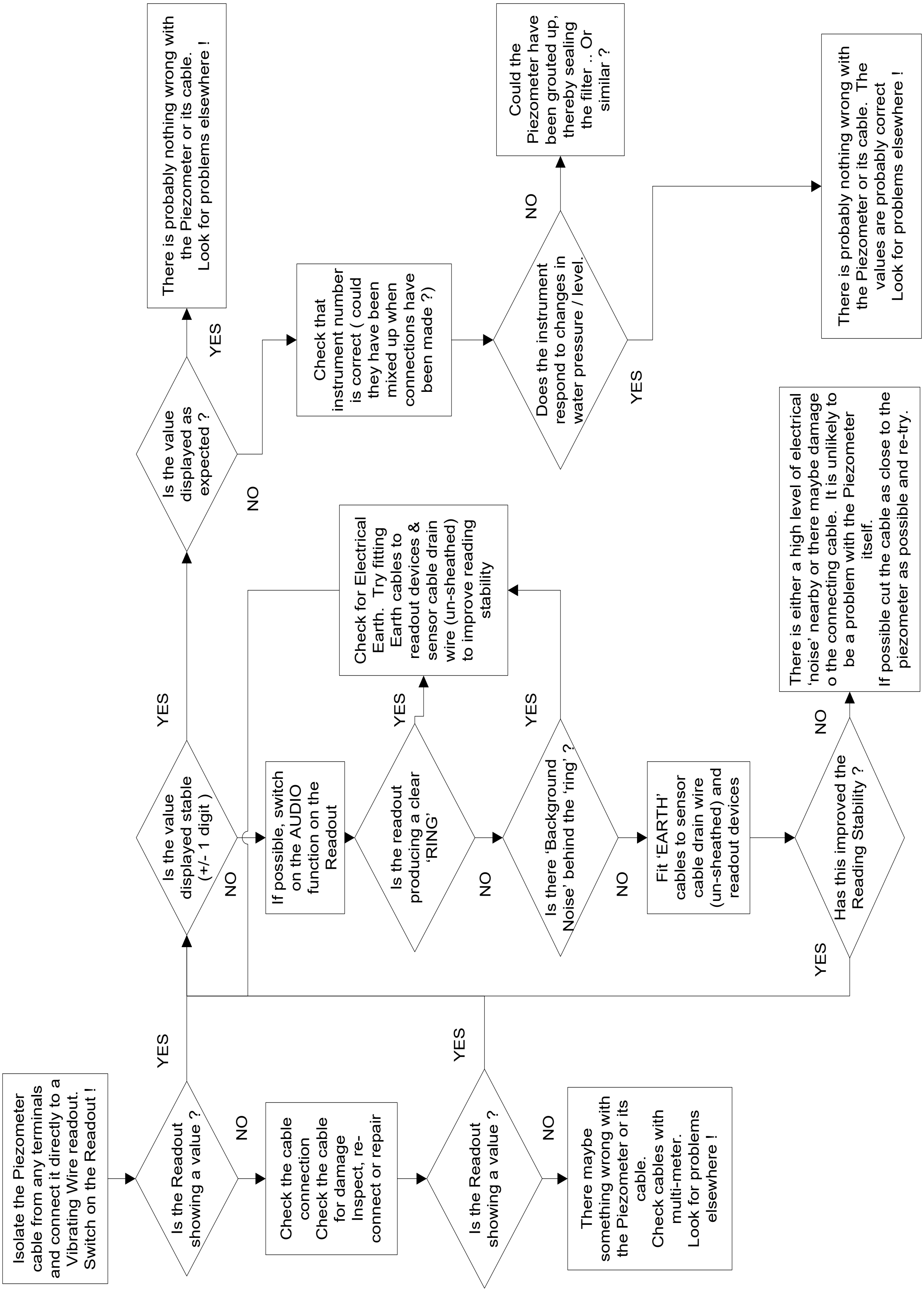
STEP 2 Connect the multimeter suitably to measure the resistance across the green and white VW thermistor wires. The polarity of the connection does not matter.

STEP 3 Compare the reading to the table.

Temperature	Value	Units
10°C	5971	ohms (Ω)
15°C	4714	ohms (Ω)
20°C	3748	ohms (Ω)
25°C	3000	ohms (Ω)
30°C	2417	ohms (Ω)
35°C	1959	ohms (Ω)

NOTE Long cable lengths may increase resistance values.

15.3. Troubleshooting Workflow



15.4. Resistance Diagnostics

Where damage to a sensor or cable is suspected, this guide illustrates the way in which simple resistance checks can be taken to identify the possible cause of the problem.

Resistance checks can be made with most types of multimeters, which are readily available in the market.

16. SPARE PARTS

As a Vibrating Wire Piezometer is a sealed unit, it is neither serviceable nor does it contain any replaceable parts.

Replacement filter units are available as follows:

Part number	Description
VWT-300101	LAE (Low Air Entry) Stainless Steel filter assembly
VWT-300102	HAE (High Air Entry) Ceramic filter assembly.

Civil engineering sites are hazardous environments, and instrument cables can be easily damaged if they are not adequately protected. **Geosense®** can therefore provide the following parts that may be required to effect repairs to instrument cables:

· PU-coated 4 Core cable with foil shield and copper drain.

· PVC-coated, armoured, 4 Core cable suitable for direct burial.

· Epoxy jointing kit for forming a waterproof cable joint.

Please contact **Geosense®** for prices and availability of the above components.

17. RETURN OF GOODS

17.1. Returns Procedure

If goods are to be returned for either service/repair or warranty, please fill in the information via the website https://www.geosense.com/returns/ where a **Returns Authorisation Number** together with **a Returns Form** will be automatically generated and sent to you via email.

The **Returns Form** should be sent together with the returned goods.

17.1.1. Chargeable Service or Repairs

Inspection & Estimate

It is the policy of **Geosense®** that an estimate is provided to the customer prior to any repair being carried out. A set fee for inspecting the equipment and providing an estimate is also chargeable.

A valid purchase order (credit customer) or advance payment for the inspection fee(s) is required before inspection can take place. In the event of a warrantable claim being accepted, the value will be credited back to the customer's account (credit customer) or refunded (pre-payment customer).

17.1.1. Warranty Claim

(See Limited Warranty Conditions)

This covers defects which arise as a result of a failure in design or manufacturing. It is a condition of the warranty that the **VW Strain Gauge** must be handled and used in accordance with the manufacturer's instructions and has not been subjected to misuse.

In order to make a warranty claim, tick the warranty claim box under **REASON FOR RETURN** on the website and return the goods as above. You will then be contacted and informed whether your warranty claim is valid.

17.2. Packaging and Carriage

All used goods shipped to the factory **must** be sealed inside a clean plastic bag and packed in a suitable carton. If the original packaging is not available, **Geosense®** should be contacted for advice. **Geosense®** will not be responsible for damage resulting from inadequate returns packaging or contamination, under any circumstances.

17.3. Transport & Storage

All goods should be adequately packaged to prevent damage in transit or intermediate storage.

18. LIMITED WARRANTY

The manufacturer (**Geosense Ltd)** warrants the **VWP** manufactured by it, under normal use and service, to be free from defects in material and workmanship under the following terms and conditions:

Sufficient site data has been provided to **Geosense®** by the purchaser as regards the nature of the installation to allow **Geosense®** to select the correct type and range of **VWP** and other component parts.

The **VWP** equipment shall be installed in accordance with the manufacturer's recommendations.

The equipment is warranted for **2 years** from the date of shipment from the manufacturer to the purchaser.

The warranty is limited to the replacement of parts, which are determined to be defective upon inspection at the factory. Shipment of defective parts to the factory shall be at the expense of the Purchaser. Return shipment of repaired/replaced part or parts covered by this warranty shall be at the expense of the Manufacturer.

Unauthorised alteration and/or repair by anyone which causes failure of the unit or associated components will void this **LIMITED WARRANTY** in its entirety.

The Purchaser warrants through the purchase of the **VWP** equipment that he is familiar with the equipment and its proper use. In no event shall the manufacturer be liable for any injury, loss or damage, direct or consequential, special, incidental, indirect or punitive, arising out of the use of or inability to use the equipment sold to the Purchaser by the Manufacturer.

The Purchaser assumes all risks and liability whatsoever in connection with the **VWP** equipment from the time of delivery to the Purchaser.

HEAD OFFICE

Nova House
Rougham Industrial Estate
Rougham, Bury St Edmunds
Suffolk IP30 9ND
England

+44 (0)1359 270457
sales@geosense.com
support@geosense.com

NORTH AMERICA OFFICE

15 West 38th Street
Suite 632
New York
NY 10018

+1 518-920-3483
sales@geosense.com
support@geosense.com

www.geosense.com