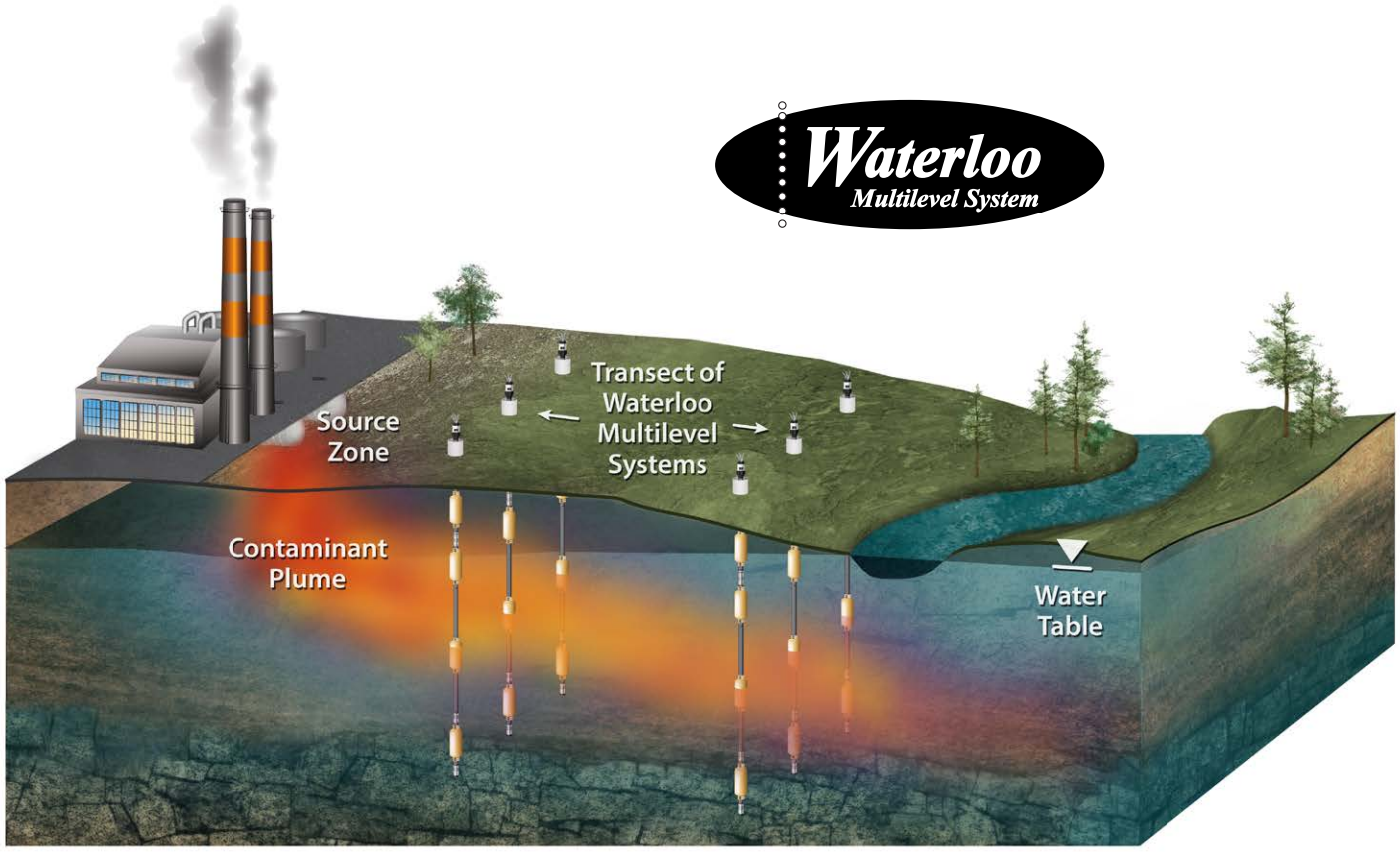
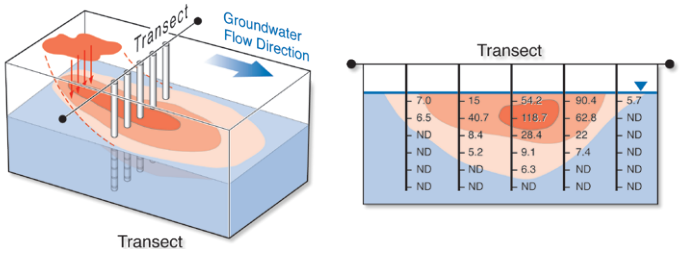


Why Multilevels: Provide a Clearer Understanding of Subsurface Conditions

Superior quality of data is captured when monitoring a series of discrete isolated intervals at various depths in a single borehole. The detailed information provided by Multilevels in the form of horizontal and vertical flow, in conjunction with discrete zone sampling for contaminants, is necessary for accurate site assessments.

- **Improve Site Assessments and Risk Management**
- Multilevels provide high resolution data for input into more representative 'dynamic' conceptual site models.
- Transects of Multilevels across a groundwater flow path provide the best data to use for Mass Flux calculations. This has proven to be an important tool for site assessments that require realistic estimates of maximum contaminant concentration/risk to receptors.



Multilevels Provide Three Dimensional Groundwater Data. Illustration courtesy of LFR Levine-Fricke and the American Petroleum Institute

- Optimize performance of active remediation by using detailed 3-D data from a series of Multilevels. Subsequently, transects can be used to evaluate the success of the chosen remediation option and identify any areas requiring improvements.

- **The Economics Make Sense**
- Proven cost reductions for drilling and drilling waste.
- Field personnel time and disposal costs are low, when purge volumes are reduced. The discrete interval that a Multilevel port encompasses allows for smaller purge volumes, rapid responses to level changes and is ideal for low flow sampling techniques.

- **Overcome Biases with Long Screened Wells**
- Contaminant mixing over long screens masks vertical variations resulting in underestimating the full extent of plumes and diluting the true concentration of contaminants.
- Ambient vertical flow within the well has potential to transmit contaminants to non-contaminated zones.

Waterloo Multilevel Groundwater Monitoring System*

The **Waterloo System** is used to obtain groundwater samples, hydraulic head measurements and permeability measurements from many discretely isolated zones in a single borehole.

The Waterloo System originated with Dr. John Cherry at the Groundwater Institute of the University of Waterloo in 1984. Ongoing development and refinement of the System by Solinst has taken place on a continuous basis since then.

Advantages of the Waterloo System

- Detailed depth of flow and concentrations
- Reduced project costs
- Purging and sampling times reduced
- Fewer drilled holes
- Reduced site disturbance
- Variety of monitoring options
- Isolate sampling at discrete contaminant zones
- High-resolution site characterization

**Manufactured under exclusive license from the University of Waterloo. Canadian Patent #1232836 U.S. Patent #5048605 & International Patents.*

Detailed 3-D Data

When a number of Waterloo Systems are used at a site, they allow detailed three-dimensional groundwater information to be obtained at a reasonable cost. Fewer drilled holes are an advantage and monitoring times are reduced.

The modular system can be customized for unique project requirements. This allows monitoring zones to be placed at desired depths using options suitable for either bedrock, overburden or combination applications.

Discrete zone monitoring is the only means of obtaining accurate data for site interpretation and assessments. Transects of Multilevels provide the detailed data necessary to calculate mass flux and conservatively assess risk to receptors.

Multi-Port Installations

- **Overburden or Bedrock Installations**
  - Allow monitoring of multiple zones in any geologic setting
  - Groundwater or vadose zone installations
- **Permanent Waterloo Packers**
  - Designed for bedrock or cased holes
  - Engineered for permanent seals

The Waterloo System Design Explained

The Waterloo System uses modular components which form a sealed casing string of various casing lengths, packers, ports, a base plug and a surface manifold. This allows accurate placement of ports at precise monitoring zones.

Monitoring tubes attached to the stem of each port individually connect that monitoring zone to the surface. The standard system is built on 2" (50 mm) Sch. 80 PVC to fit 3"- 4" (75 - 100 mm) boreholes and uses 3 ft (915 mm) long packers. Stainless steel components and various diameters of monitoring tubing are available.

Modular Sealing Joints**

The slip-on joint design of the Waterloo System uses a nylon shear wire and a double o-ring seal. This gives reliable, leakproof joints so that the core of the Waterloo casing string is isolated from external formation waters. Groundwater is only accessible via the port stems and attached monitoring equipment. This water-tight seal also prevents contact between packer inflation water inside the casing and the formation water outside the casing.

O-Ring Joints with Shear Wire

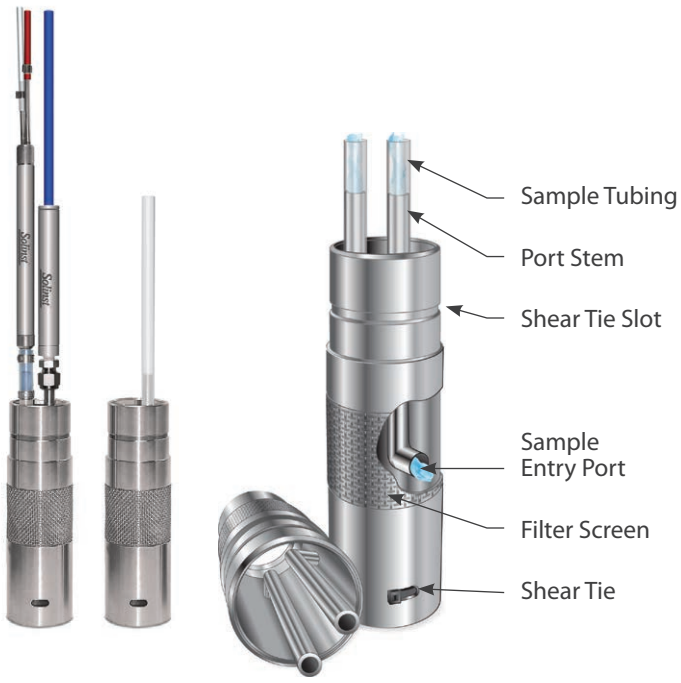
Customized Wellhead Manifolds

The manifold completes the system at surface. It organizes, identifies, and coordinates the tubes and/or cables from each monitoring zone.

The manifold allows connection to each dedicated transducer in turn, and a simple, one-step connection for operation of pumps. When dedicated pumps are selected, a unique wellhead allows individual zones to be purged separately, or purging of many zones simultaneously to reduce field times.

Multi-Purge Manifold Wellhead | *Permanent Waterloo Packer* | *Dedicated Sampling Pump and Transducer* | *2" PVC Casing & Plug*

*** US Patent 5,255,945*



Stainless Steel Ports

Permanent Waterloo Packer

Discrete Zone Port Technology

Waterloo System monitoring ports are constructed from 316 stainless steel. Ports are isolated by packers at each desired monitoring zone and are individually connected to the surface manifold with narrow diameter tubing. Thus formation water enters the port, passes into the stem, up into the monitoring tube attached to the stem, to its static level.

A sampling pump or pressure transducer may be dedicated to each monitoring zone by attachment to the port stem. Dual stem ports are available to allow both sampling and hydraulic head measurements from the same port. Alternatively, the monitoring tubes may be left open to allow sampling and hydraulic head measurements with portable equipment.

Permanent Packers: Engineered Seal

Permanent packers ensure long term integrity of seals in cored bedrock holes and cased wells. They use a water activated expansion sleeve fitted over the perforated packer body. A layer of porous plastic distributes water evenly to the packer expansion material. A Rubber/Kevlar/Rubber sheath envelops the expansion material. The Kevlar layer provides strength to bridge across large fissures. The pliant gum rubber forms an effective seal against the borehole wall.

Water is added to the inside of the sealed casing string after installation. The water passes through the packer body into the expansion sleeve, causing the material to expand. Thus an engineered seal is permanently formed against the borehole wall.

Waterloo System Installation

Installation of the Waterloo System starts with the base plug and lowermost sections. The components are joined together in the order required. As each new port is put into position a new monitoring tube, dedicated pump and/or transducer is connected to it. Successive components are threaded over these tubes, building the casing string, until the Waterloo System is complete. Typically, installations are completed in a day, using a 3-4 member team. Solinst can provide Waterloo System training on request.

Waterloo System Flexibility

The Waterloo System is flexible to meet your design criteria. Each Waterloo System is customized to suit unique monitoring needs, and subsurface site conditions:

- Bedrock or overburden applications
- Groundwater or vadose zone monitoring

Packers and ports are installed precisely to monitor each isolated, discrete zone of interest, eliminating any cross-contamination across zones.

Overburden Applications

Waterloo Multilevel Systems can be used to monitor multiple zones within unconsolidated formations, as well as in bedrock.

There are three methods of Waterloo System installation:

- Within the drill stem or temporary casing. Flowing sand formations are allowed to collapse around the Waterloo System.
- Within the drill stem or temporary casing using standard tremie methods to place sand around the ports and bentonite seals in the annular space between the monitoring zones, as the drill stem or temporary casing is lifted.
- Within a cased and screened well, using packers to seal zones.

Installation within Wellscreen/Casing

A permanent 3" or 4" casing and screen string can be installed by a drilling contractor using typical sand and bentonite placement methods. Then a Waterloo System can be installed within the screen and casing string with ports and permanent packers.

Borehole Size Considerations

Waterloo packers are designed for use in 3"- 4" boreholes (75 - 100 mm). Systems can be installed in larger boreholes using:

- Placement of sand and bentonite to isolate specific monitoring zones
- 3-4" screen and casing, installed within a larger hole, completed by installing a Waterloo System with packers.

Using core logs to identify placement of Ports and Packers (left). Multi-Purge Manifold with transducers and dedicated pumps for four zone monitoring (right).

Standard 2" (50 mm) Waterloo System	
Site Dependent Monitoring Options	**# Zones**
Dedicated Pumps and Open Tubes	6
Dedicated Pumps and Transducers	8
Dedicated Pumps Only	12
Open Tubes Only (varies with tube size)	15
Dedicated Pressure Transducers Only	24

Number of Monitoring Zones Per Hole

The maximum number of monitoring zones for a Waterloo System is determined by the number of tubes and/or cables that will fit inside the casing string. This number is dependent on the monitoring options chosen. Systems can be designed to monitor from 2 to as many as 24 zones.

Monitoring Options

- **Dedicated sampling pumps and/or pressure transducers**

  Each monitoring port may be fitted with a dedicated sampling pump and/or pressure transducer. This maximizes the speed with which each data set can be obtained, and eliminates the need to decontaminate and repeatedly lower portable devices. The sampling pumps are suitable for sampling many types of contaminants, including VOCs (Volatile Organic Compounds).

  Purge volumes are very small. With dedicated pumps all zones can be purged simultaneously. Ports with two stems allows a dedicated pump and a transducer to be placed at exactly the same level.

- **Open tubes**

  The most basic version uses open tubes attached to each port. This option allows monitoring with a portable sampler and a narrow diameter Water Level Meter. This provides a very economical and flexible multilevel monitoring device.

- **Mix of open tubes and dedicated equipment**

  A third option is to choose a mix of open tubes and dedicated equipment in different zones. This method combines the advantages of less expensive portable equipment for shallower zones and the more time efficient dedicated equipment for deeper zones.

- **Water level monitoring only**

  The Waterloo System can comprise pressure transducers only, for pressure monitoring in up to 24 discrete zones.

Dedicated Sampling Pumps

Dedicated equipment reduces the time and effort required to obtain data, as equipment is not lowered down the borehole and purge volumes are reduced. It gives significant cost savings and avoids cross contamination.

For long term or frequent sampling Waterloo Systems most commonly use the gas drive, Solinst Double Valve Pumps with stainless steel and PTFE valves. A pump is connected directly to the stem of each port and dual line polyethylene or PTFE tubing connects the pump to the wellhead manifold.

Pump control units are simple to use. They have quick-connect couplings with only a single connection to the manifold required. Samples from all levels are easily and rapidly obtained. Purging from some or all levels simultaneously is accommodated by the multi-purge feature of the manifold.

Dedicated Transducers

Dedicated pressure transducers allow rapid and accurate measurement of temperature and total water pressure. Unless static water levels are shallow, transducers are the preferred method of water level measurement, both from an efficiency and an accuracy point of view.

The transducers commonly chosen for use in the Waterloo System are unvented vibrating wire transducers, which are very accurate and rugged. They have superior long term operation with minimal drift over time. They can be read with a manual readout, or with a datalogger which can provide remote, unattended monitoring and telemetry, if desired. Transducers are available with pressure ranges from 50 psi to 435 psi. (350 kPa to 3 MPa).

Dedicated Sampling Pump & Transducer

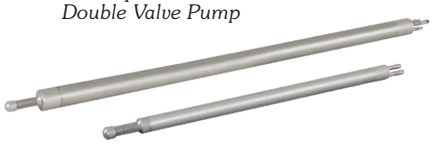
Collecting a sample from a dedicated DVP and taking pressure measurements with Model 404 Geokon Vibrating Wire Readout (above).

Low Flow Purging and Sampling

Purge volumes are very small due to the small annular space and tubing diameters used in the system. Consequently, even though flows are low, sampling is rapid, especially with dedicated pumps when all zones can be purged simultaneously.

Dedicated Bladder Pumps and Double Valve Pumps, (DVP), as well as a portable DVP are ideal for use when low flow sampling and purging techniques are desired.

Model 407 Bladder Pump and 408 Double Valve Pump



Flexible Groundwater Sampler

The Micro Double Valve Pump (Micro DVP) provides high quality samples, uses coaxial PFAS-free PTFE tubing, and is small enough to fit in 1/2" (13 mm) ID tubing. The unique combination of flexibility and size make the pump ideal for sampling at depth in small flexible tubes.

Model 408M Double Valve Pump

Discrete Zone Water Level Monitoring

Water level measurements can be made in Waterloo ports fitted with an open tube using the narrow, Model 102 Water Level Meter. It has a P4 probe, 4 mm (0.157") OD x 38 mm (1.5") long.

Sampling may be performed in open tubes using a Mini Inertial Pump, Micro Double Valve Pump, or a Peristaltic Pump.

Model 102 P4 Water Level Meter

Monitoring Sites Where the Waterloo System Has Been Used

The Waterloo System has been specified by various industries and consultants for numerous sites across the United States, Canada and overseas. Waterloo Systems have been specified and approved at several sites with Superfund or RCRA designations and in each of the U.S. E.P.A. regions.

The Waterloo System has been used for:

- Defining groundwater flow patterns
- Performance monitoring of pump and treat systems
- Identification and determination of spatial distribution of contaminants
- Early warning system/detection of migrating contaminants

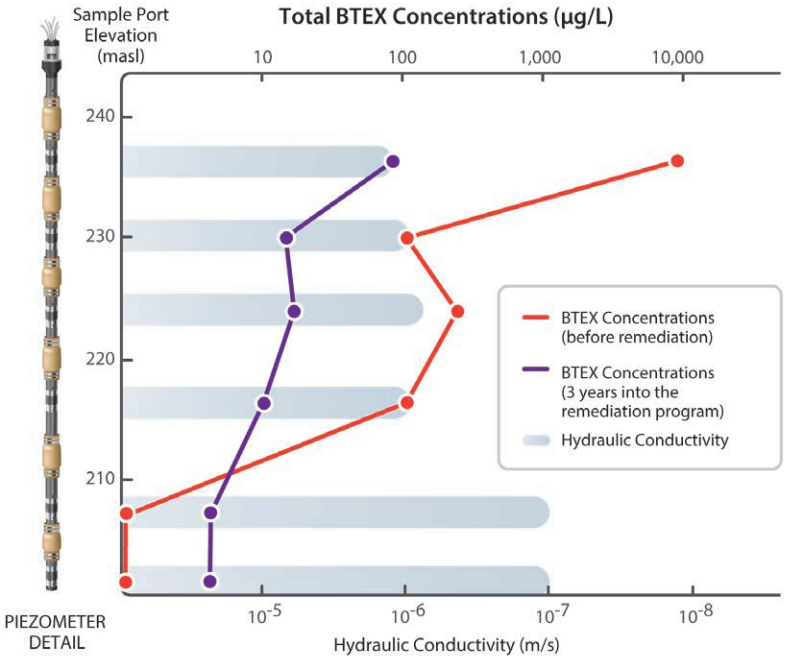
Projects

Waterloo Systems have been used to monitor:

- Salt water intrusion
- Industrial cleanups
- Pipeline leaks
- Dam leakage/rehabilitation
- Contaminant identification/cleanup
- DNAPL & LNAPL spill sites
- Waste disposals/landfills
- Soil gas surveys

Reliable Data

The effectiveness of the Waterloo System is proven by its ability to accurately and repeatedly obtain pressure and groundwater chemistry data from several distinct zones in a single borehole. The data set below shows a decrease in Total BTEX contamination due to ongoing pump and treat operations at an oil pipeline leak.



Underground oil pipeline leak assessment. Three 45 m (150 ft) installations. Two point rising head permeability tests were conducted in each interval of the Multilevel System. (See diagram showing contaminant distribution at left.)

A Waterloo System to Suit Your Application

Your Waterloo System can be designed to suit your unique application and site requirements.

Each design can be based on your:

- Drilling method
- Zones of interest
- Preferred monitoring methods
- Cost considerations
- Borehole depth, diameter and type
- Site geology

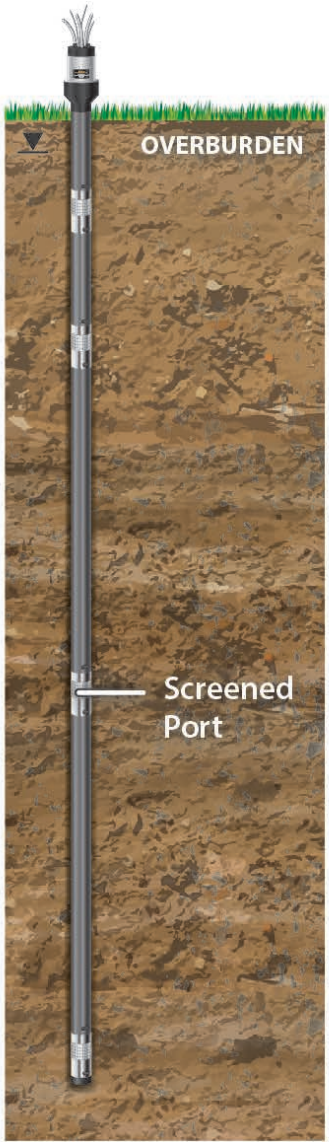
Your system can be designed to suit the size and depth of your borehole, whether there is casing present or not. You can decide on the number of zones to be monitored and the depth these zones will be placed. Select your preferred monitoring options, and any special materials that you may require.

During development of your plans, the Solinst technical staff will be pleased to help review the options and customize a Waterloo System that best suits your needs. Below are four examples of installations that may apply to your project:

Bedrock

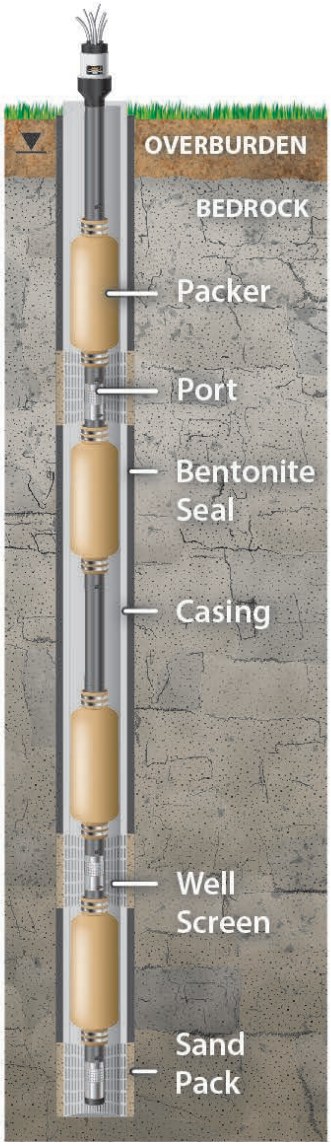
Permanent Packers in Cored Hole

Overburden



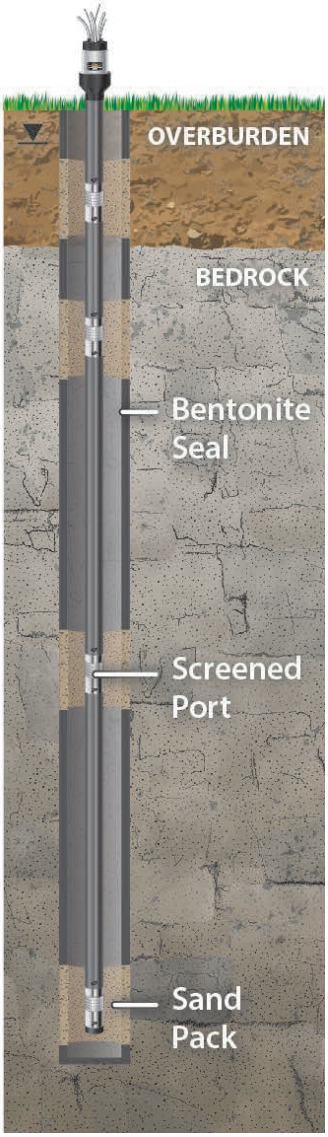
Direct Burial: Formation Collapse with Screened Ports

Bedrock and/ or Overburden



Permanent Packers in Screened Casing

Bedrock and/ or Overburden



Direct Placement: Sand and Bentonite with Screened Ports

Four Waterloo Systems were installed to monitor a chlorinated compound release. Systems were installed at depths ranging from 131 m – 229 m (430 ft – 750 ft), with most monitoring 7 zones. The Ports were constructed with both Double Valve Pumps and Vibrating Wire Transducers.

Contaminant investigation at a U.S. Air Force Base. Waterloo Systems installed to 213 m (700 ft) in overburden using screened and cased wells. Up to 6 zones per hole with dedicated pumps and transducers.

An investigation of hydraulic properties beneath a large waste site. Waterloo Multilevel Systems were chosen to allow water quality sampling and to help determine the zones of highest permeability within the aquifer.

Five Waterloo Systems were installed to 33.5 m (110 ft) in fractured bedrock to help characterize a historical chlorobenzene plume at the site of a proposed groundwater pump and treat site. Vibrating Wire Transducers and Double Valve Pumps were dedicated at each of the 4 monitoring zones.

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