CL:AIRE

technical bulletin

CL:AIRE technical bulletins provide a source of detailed information on specific techniques, practices and methodologies currently being employed on sites in the UK within the scope of CL:AIRE technology demonstration and research projects. This technical bulletin focuses on multilevel sampling.

Multilevel Sampling

1. INTRODUCTION

The topic of this CL:AIRE Technical Bulletin is multilevel sampling systems for characterising contaminated groundwater. Contaminated groundwater can present considerable problems for landowners: it can occur at significant depth; sources of the contamination are not often obvious; it can migrate from one property to another; and groundwater flow directions can be altered due to seasonal variations or by pumping. In order to assess liability associated with contaminated groundwater, land owners must be able to characterise the nature and extent of contamination.

Contaminant migration in aquifer systems can be a complex process, especially in fractured bedrock and both difficult and expensive to characterise. Sampling and monitoring at many different levels in the subsurface from one sampling station location allows the actual or potential pathways for contaminant migration to be identified and monitored. The use of multilevel sampling systems allows landowners to optimise the amount of information they can obtain from their boreholes.

There are currently several options available for sampling groundwater at multiple levels from a "single" monitoring station location. The first option termed "multiple completions" involves clusters or nests of piezometers which include individually installed piezometers in individual boreholes or several piezometers completed in a single borehole. There are also manufactured multilevel sampling systems. These systems include simple continuous multichannel tubing and more complex engineered multilevel systems. The key features of each manufactured system will be discussed further in this bulletin. A CL:AIRE research project which focuses on the natural attenuation of petrol contaminated groundwater in a chalk aquifer, successfully applied one of the multilevel sampling systems described in this bulletin and is written up as a separate CL:AIRE Case Study Bulletin.

The advantages of manufactured multilevel samplers include:

- provides detailed three dimensional data leading to improved understanding of hydrogeological conditions and contaminant transport
- reduces drilling and installation costs
- results in fewer drilled holes and hence reduced site disturbance
- dedicated sampling avoids cross contamination
- minimises contaminant "short circuiting" which can occur with multiple completions
- minimises purge water volumes, reducing handling and disposal costs

2. TYPES OF MULTILEVEL SAMPLING SYSTEMS

The types of multilevel sampling systems discussed in this bulletin include:

Multiple completions
Continuous Multichannel Tubing
Waterloo Multilevel System
Westbay MP System

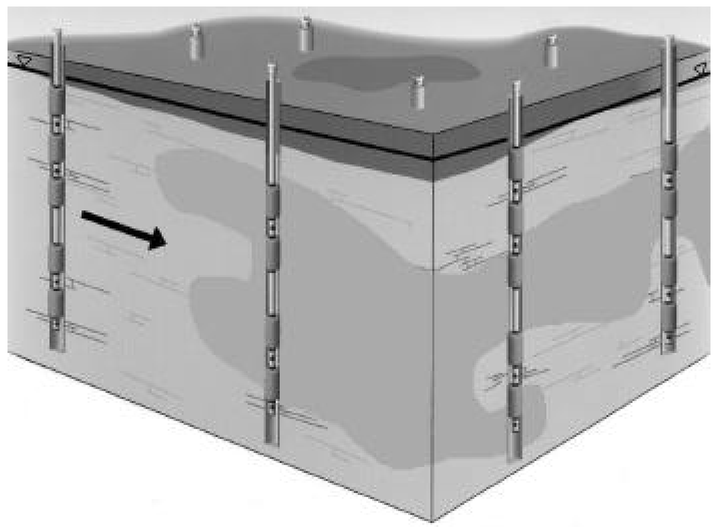

Figure 1: Schematic diagram of a typical multilevel well installation (adapted from Solinst Data Sheet))

2.1 Multiple Completions

Multiple completions in bedrock involve the drilling and installation of more than one piezometer in a single borehole (nested), or a number of piezometers in a cluster of boreholes (clustered) as shown in Figure 2. Each borehole is typically 150mm or 200mm in diameter and is drilled using rotary coring or open hole method.

Piezometers typically consist of 19mm or 50mm diameter plastic casing attached to a screen of either a perforated end section or a porous tip. The installation method will be similar for nested or clustered completions and is generally carried out as described below following best practice.

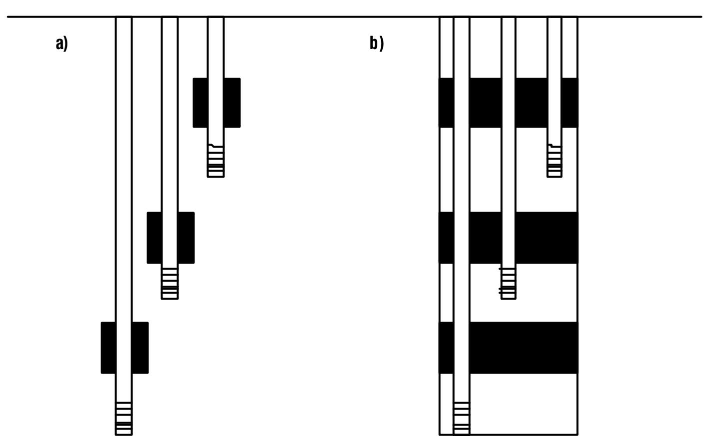

Figure 2: Layout of (a) clustered and (b) nested piezometers.

CL:AIRE (Contaminated Land: Applications In Real Environments) wishes to thank the following organisations for their support:
Department of the Environment (Northern Ireland) Department of the Environment, Food and Rural Affairs English Partnerships Environment Agency Scottish Enterprise
Scottish Environment Protection Agency Scottish Power Shanks Soil and Groundwater Technology Association UK Coal Unilever Viridor Waste Management Welsh Development Agency

Each borehole is drilled and cleaned out to the desired depth. A 0.2m layer of clean sand or gravel is placed at the base. The piezometer is then placed vertically within the borehole while additional sand is placed around the screen to form a filter extending approximately 0.3m above the top of the screen. A bentonite seal approximately 0.4m thick is placed on top of the sand filter and the remainder of the hole is backfilled. A bentonite seal is placed at the surface to prevent the infiltration of surface water. When multiple installations are required in a single borehole then the process is repeated. There is a danger with multiple completions that sand packs and bentonite seals around the well screens are not securely placed allowing groundwater to "short circuit" seals.

2.2 CONTINUOUS MULTICHANNEL TUBING

2.2.1 Introduction

The Continuous Multichannel Tubing (CMT) multilevel system is an economical approach to multilevel groundwater monitoring providing the simplicity of a bundle type installation with the benefits of backfilling or sealing around a single tube. Each system can be custom-built on site without leaving the hole open to deteriorate or contaminate. Each CMT system gives the option of up to 7 monitoring zones in a single tube and can be quickly installed in 64mm or larger boreholes. The CMT system has been installed to depths up to 90m.

2.2.2 Components

CMT is a continuously extruded 7-chambered or channelled high density polyethylene (HDPE) tube with 43mm OD. It is supplied in standard lengths of 30m, 60m or 90m. There are no joints in the CMT, which removes the risk of leakage. Screened sections and seals can be located precisely where needed and are constructed on site. Annular seals are installed as either backfilled bentonite or packers.

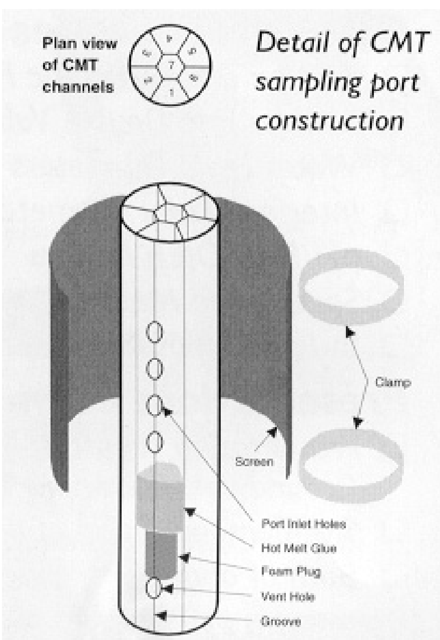

Figure 3: Detail of Solinst CMT sampling port construction.

2.2.3 Installation

The best locations for monitoring ports and packed zones are determined from information taken from the borehole and core during or after drilling. A length of CMT tubing sufficient to reach from the surface to the deepest monitoring level is cut and the base is sealed using a foam plug and HDPE hot melt glue, all except the central chamber which is used as the deepest monitoring zone. The tubing is laid out on the ground and the locations for each port and packer (if packers are to be used) are marked. Ports are created by drilling holes in the appropriate channel. The base of the port is sealed with a foam plug and hot melt glue. The port area is wrapped with an appropriately-sized stainless steel mesh screen which is kept in place by nylon clamps. A vent hole is drilled below the sealed area to allow formation water to enter the chamber and reduce casing buoyancy. A detailed schematic of system components is provided in Figure 3. Packers are attached at the appropriate locations. The system can also accommodate dedicated pressure transducers. Once all of the ports and packers have been installed, the string is lowered into the hole to the desired depth and supported at the surface.

If packers are used in the installation, they are then inflated. If the system is being backfilled, then alternating layers of bentonite and sand are carefully placed at the correct depth to ensure that monitoring ports are surrounded by sand and sealed above and below with bentonite.

2.2.4 Measurements/Sampling

Water levels can be measured using narrow diameter water level meters. Water samples can be collected using specialised samplers, foot valves or a peristaltic pump.

2.3 WATERLOO MULTILEVEL SYSTEM

2.3.1 Introduction

The Waterloo Multilevel System (WMS) is a modular multilevel system which includes a closed casing string with up to 24 monitoring ports in each borehole depending on system configuration. The system has been installed in a variety of hydrogeological environments to depths up to 230m.

2.3.2 Components

The WMS system consists of casing components, which are permanently or temporarily installed in the borehole. Individual, small diameter lengths of tubing connect each isolated monitoring port to the surface through the inside of the casing where they can be accessed for groundwater sampling, hydraulic head measurements and hydraulic testing.

System components include casing sections which come in a variety of lengths, monitoring ports, tubing, packers, end cap and a surface manifold. The standard system is manufactured in 50mm diameter Schedule 40 PVC for installation inside a 75-100mm diameter borehole. The casing and packer bodies are also available in stainless steel, with tubing available in stainless steel, nylon or Teflon®.

Sections of casing are connected by means of a patented system of nylon shear wires and O-rings. This gives a reliable, leakproof joint that has been tested to 900 kg tensile load and leak tested to 1375 kPa internal pressure.

PVC or stainless steel monitoring ports are isolated by packers at each desired monitoring zone and are individually connected to the surface manifold with narrow diameter tubing. Details of packers and ports are provided in Figure 4. The maximum number of monitoring zones attached to tubing that can be accommodated in a standard casing is 8. If dedicated pumps are added, then the maximum number drops to 5. If only dedicated pressure transducers are installed then the maximum number of monitoring zones is 24.

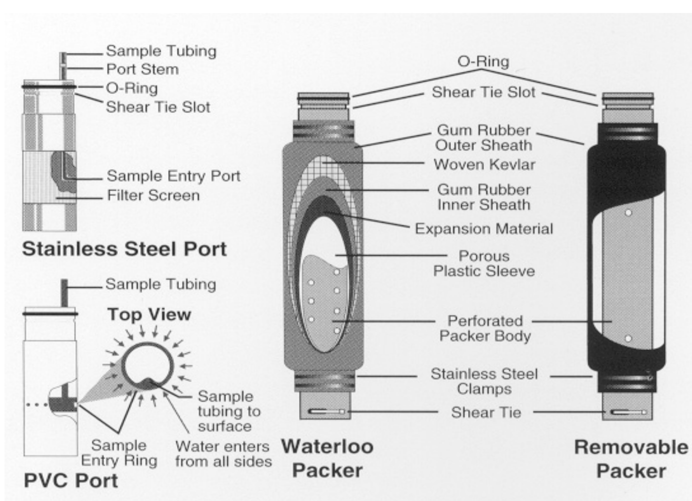

Figure 4: Waterloo ports and packers.

Packers include a permanent type and a removeable type. The permanent Waterloo packer uses a water activated sleeve fitted over the perforated packer body which expands to form an engineered seal against the borehole wall. Removable packers are made with natural gum rubber and are inflated hydraulically or pneumatically by pressurising the interior of the WMS casing string. These packers facilitate system maintenance and borehole decommissioning, simplify grouting of the hole and allow most of the system to be reused.

The manifold is placed at the top of the casing string and ensures that the inside tubing and any cabling is kept separate and ordered. It allows a simple, one step connection for operation of transducers or pumps.

2.3.3 Installation

A typical WMS can be installed quickly and easily by two people, in a few hours, without the use of a drilling rig. Starting with the base plug and lowermost sections, the components are joined together in the order required in the hole. A ground clamp supports the suspended string in the borehole as it is being assembled. 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 and cabling, building the casing string. Installation of the manifold completes the system.

2.3.4 Measurements/Sampling

There are a number of options for monitoring. In open tubes, water levels can be measured using narrow diameter water level meters. Water samples can be collected using specialised samplers, foot valves or a peristaltic pump. Alternatively, dedicated pressure transducers and gas drive pumps can be installed.

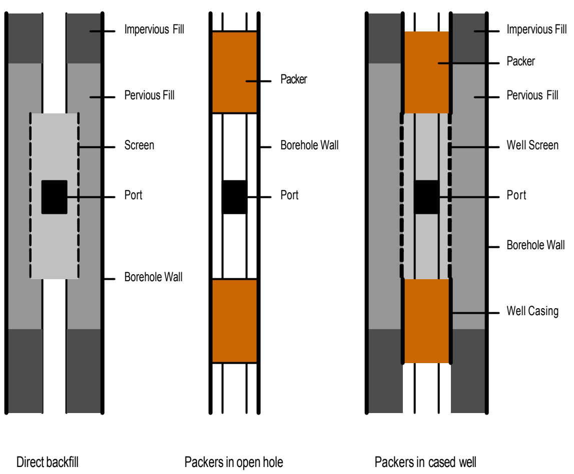

Figure 5: Common completion methods for both the Solinst Waterloo System and the Westbay MP System (adapted from Solinst and Westbay corporate literature).

2.4 WESTBAY MP SYSTEM

2.4.1 Introduction

The MP System is a modular multilevel system which employs a single, closed access tube with valved ports, which provide access to different levels of a borehole through a single well casing. The modular design permits numerous monitoring zones to be established in a borehole and modifications can be made to the number and location of ports at the time of installation. The MP System has been used in many different geologic and climatic environments in boreholes up to 1,200 m in depth.

2.4.2 Components

The MP System consists of casing components, which are permanently installed in the borehole. Portable probes, and specialised tools are used to take hydraulic measurements and groundwater samples.

The casing components include casing sections of various lengths, couplings, end caps, and packers, which seal the annulus between the monitoring zones. The casing sections of the MP System are manufactured in either PVC plastic or stainless steel in nominal lengths of 0.5m, 1.5m and 3.0m and are available in 38mm and 55mm diameters. Regular couplings are used to connect casing lengths where valved couplings are not required. The couplings incorporate O-rings for a positive hydraulic seal and do not use adhesives. A flexible shear rod provides a tensile connection. Two types of valved couplings, measurement port couplings and pumping port couplings allow measurement of fluid pressure and groundwater sampling respectively. Monitoring ports are protected with nylon or stainless steel screens. End caps are placed on the bottom of a casing string. They incorporate an O-ring seal so that the entire casing string is hydraulically sealed during installation.

When there are many monitoring zones in a single borehole, annular seals are required to prevent fluid migration from one zone to another along the annular opening between the borehole wall and the casing. Annular seals can be installed by: a) backfilling with alternating layers of sand and bentonite or grout, b) using hydraulic (water) inflated packers to seal between the casing string and the borehole wall or c) using packers inside a cased well with multiple screens, and the screened areas backfilled with alternating layers of sand and bentonite/grout. Types of annular seals are shown in Figure 5. Pumping ports and measurement ports are protected by screens.

2.4.3 Installation

Prior to installation, subsurface horizons of interest are identified from site characterisation information and an installation log showing all of the component parts of the multilevel system is prepared. The system component parts are laid out at the site according to the sequence shown on the installation log and checked off the installation log as they are inserted into the borehole. Once installed, the packers are inflated proceeding from the bottom of the hole, or the system is backfilled.

2.4.4 Measurements/Sampling

Fluid pressure measurements, hydraulic conductivity testing, and fluid sampling can be carried out. Specialised sampling tools are sent down the hole on a cable attached to the appropriate controller devices at surface, and are located at the appropriate port at the appropriate depth interval. Single fluid pressure measurements can be measured by manually controlling a pressure probe. Alternatively the process can be automated allowing multiple samples to be collected. Hydraulic conductivity can be measured using variable head, constant head and pressure-pulse tests. Fluid samples are collected using a sampler probe which is returned to the surface where the sample is transferred to an appropriate container. The sampler probe is illustrated in Figure 6.

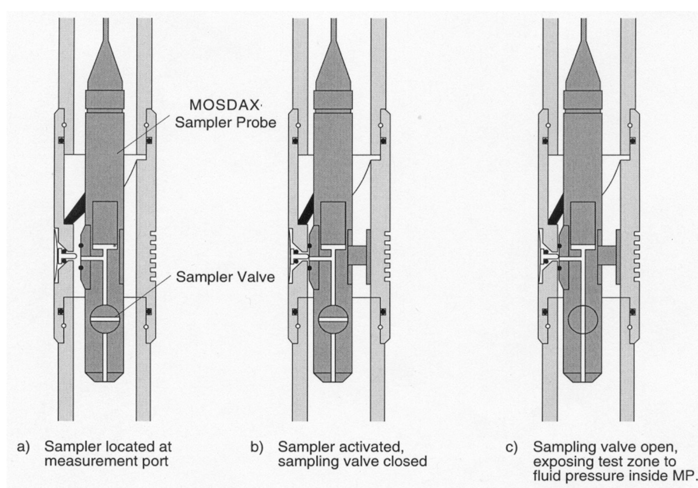

Figure 6: Using a sampler probe to measure fluid pressure.

3. COSTS

Table 1 provides illustrative costs for comparing the different groundwater sampling systems discussed in this bulletin. These costs have been provided by the UK suppliers whose details are provided in section 4. To try to ensure equivalent costing, the costs have been calculated for a 30m deep borehole using four different sets of conditions (Scenarios 1-4) which vary according to the number of sampling ports (3 or 7) and the type of seal (backfill or packer seals) used to isolate each port. The costs

Table 1: Illustrative costs for different groundwater sampling systems.

	No. of ports	Seal	Set-up costs (£)	Drilling costs (£)	Downhole Material Costs[1] (£)	Total (£)
Individual Piezometers						
Cluster type						
Scenario 1	3	Backfill	240	960	840	**2040**
Scenario 2	7	Backfill	560	1792	1568	**3920**
Nested type						
Scenario 1	3	Backfill	80	480	612	**1172**
Scenario 2	7	Backfill	240	1136	1258	**2634**
Solinst CMT						
Scenario 1	3	Backfill	80	480	1400	**1960**
Scenario 2	7	Backfill	80	480	1550	**2110**
Solinst Waterloo System						
Scenario 1	3	Backfill	80	480	1910	**2470**
Scenario 2	7	Backfill	80	480	2660	**3220**
Scenario 3	3	Packer[2]	80	480	2500	**3060**
Scenario 4	7	Packer[2]	80	480	4100	**4660**
Westbay MP System						
Scenario 1	3	Backfill	80	480	4200	**4760**
Scenario 2	7	Backfill	80	480	6700	**7260**
Scenario 3	3	Packer[2]	80	480	6800	**7360**
Scenario 4	7	Packer[2]	80	480	11000	**11560**

[1] Including initial tooling costs.
[2] The costs of the packered seal for the Solinst Waterloo System and the Westbay MP System have been calculated using the cheapest available option.

themselves are split into three categories: set-up costs; drilling costs; and downhole material costs which include initial tooling costs. The same basis for calculating the set-up and drilling costs has been used for the five sampling options to highlight the differences in downhole material costs. Total costs do not include delivery of the system, technical support and sampling/monitoring equipment.

For the three individual piezometers (both cluster and nested) depths of 10, 20 and 30m are used in the calculations and for the seven cluster piezometers depths of 4, 8, 12, 16, 20, 25 and 30m are used. A problem with calculating the costs for seven nested piezometers is that practically this number will not fit in a single borehole. For this option, therefore, an array of three boreholes is used in the calculation containing 3, 2 and 2 piezometers respectively, with corresponding piezometer depths of 12, 20, 30m for the triple installation and 4, 16m and 8, 25m for the two double installations.

Table 1 shows that the cheapest option for 3 sampling ports (Scenario 1) is to use a nested piezometer configuration which is approximately half the price of the next cheapest options - the Solinst CMT and the individual cluster piezometers. However, for Scenario 2, involving 7 sampling ports, the Solinst CMT is less expensive than both the individual piezometers options. This suggests that cost benefits for single borehole, multilevel systems (one set-up and drilling cost) may be observed when a higher number of sampling ports are required, but for a small number then individual piezometers may be more cost effective. It should be borne in mind that nested piezometers can be difficult to install and that the integrity of the seals can be compromised if sand pack or bentonite seals are improperly placed.

This observation is investigated further in Figure 7. The figure compares the costs of the five different sampling options with an increasing number of ports (1-7), based on the information used for calculating the costs in Table 1. The figure illustrates that for the example costs provided in Table 1 there are cross-over points where it becomes more cost-effective to use multilevels as opposed to individual piezometers (either cluster or nested). For Solinst CMT, the two sets of cross-over points are between 2-3 ports, and between 5-6 ports for cluster and nested piezometers respectively. For the Solinst Waterloo System, there is a cross-over point between 4-5 sample ports for the cluster piezometer, but there is no such point for the nested type.

The use of packers to seal sample ports increases the cost of both the Solinst

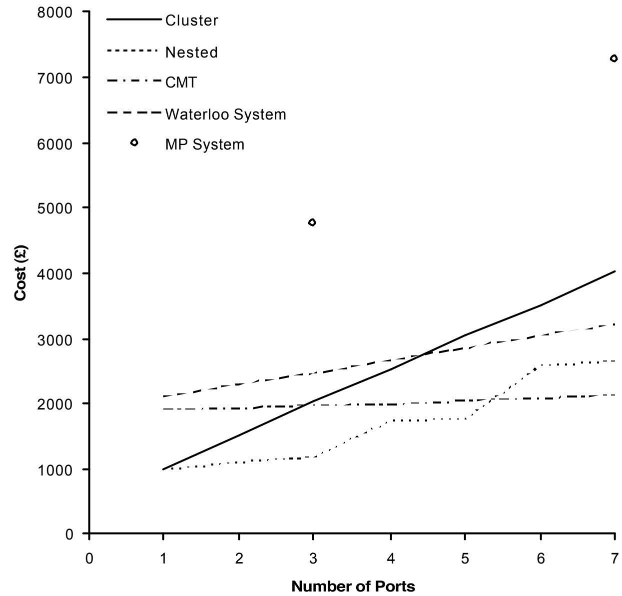

Figure 7: Cost comparison curves for the different groundwater sampling systems.

Waterloo System and the Westbay MP System. However, there are not always benefits to be gained by using them. For instance, packers will only work effectively if the rock is competent, if however, the rock is highly fractured then backfill methods may be more suitable.

As mentioned above, the costs provided in Table 1 are for materials and installation only. Each system requires different types of specialist sampling and/or monitoring equipment which will inevitably add to the total cost. This equipment varies significantly in terms of both its complexity and availability and ranges from simple off-the-shelf check valves in an individual piezometer; to narrow diameter tubing for CMT and Waterloo systems; to proprietary, highly specialised equipment for the Westbay MP System. For example, in the Westbay System it would cost upwards of £40 000 to purchase a cable reel, sampler probe, bottles and a readout unit which is why it is often more cost-effective to rent the equipment, along with trained engineers, at rate of approximately £550/day.

It is important to understand that the selection of a groundwater sampling system is unlikely to be based solely on its cost. The chosen system must have the required level of functionality and sophistication for each specific application and this depends on borehole conditions and the degree of borehole information required.

4 Contact Details

The CMT and Waterloo Multilevel Systems are products of Solinst Canada Ltd (www.solinst.com). The authorised agents for Solinst in the UK are Waterra (UK) Ltd: -
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