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Multi-Level Groundwater Monitoring with the MP System®

Abstract

Defining the extent of a groundwater contaminant plume in geologic materials requires a three-dimensional array of sampling points. Such an array is commonly installed by placing a single access tube and inlet screen in each of a series of boreholes. With this method, the number of sampling points at a given site is generally limited by the high cost of drilling. An alternative is to install monitoring points at many levels in each drillhole. Multi-level monitoring can provide increased data density and therefore an improved understanding of site conditions. This paper describes how the MP System®, one type of multi-level monitoring well, is installed and operated. Field quality control procedures, 1) to verify the integrity of the access tube, inlet valves, and drillhole seals, and 2) to confirm the operation of measuring and sampling equipment, are also discussed.

Introduction

When groundwater contaminant plumes are suspected of having significant depth as well as lateral distribution, a three-dimensional array of monitoring points is needed to identify and characterize such plumes. Thus, groundwater data must be obtained from a number of different locations and from a number of different depths at each location. As a result, either a large number of drillholes are required, each with a separate instrument installed, or instruments must be combined and installed at Multiple levels in each of a smaller number of drillholes.

Multi-level groundwater monitoring devices have been described by many writers, some discussing the technical benefits and others the advantages to schedules and costs which can result when multi-level monitoring devices are used to reduce the number of drillholes required. Most important, however, are the advantages that accrue from the increased data density and from the field verification procedures that are available. The very fact that one is capable of accessing several different discrete zones in one monitoring well provides a testing and verification capability that is simply not possible in a single-level device such as a standpipe monitor well.

The basic requirements of any groundwater monitoring system are that it provide the user with the ability to measure fluid pressure, purge the monitoring zone, collect fluid samples, and undertake standard hydrogeologic tests, such as permeability tests and tracer tests. In addition, quality assurance plans for groundwater monitoring programs have led to a requirement for periodic testing and calibration of all aspects of groundwater monitoring devices.

Quality assurance plans normally require field verification tests immediately following installation and again at periodic intervals during the operating lifetime of the installation. In fact, few groundwater monitoring devices are designed to allow extensive field verification tests to be carried out. However, some types of multi-level monitoring instruments, such as the MP System® developed by Westbay Instruments Inc., were designed with field verification tests in mind (Patton and Smith, 1986). With such systems, questions of data quality can be readily addressed.

General Description of the MP System

The MP System is a modular multi-level groundwater monitoring device employing a single, closed access tube with valved ports. The valved ports are used to provide access to several different levels of a drillhole through a single well casing. The modular design permits as many monitoring zones as desired to be established in a drillhole. Furthermore, at the time of installation, zones may be added or modified without affecting other zones or significantly complicating the installation. As a result, the number and location of monitoring zones can be decided based on the information obtained during drilling. Only a broad scope of requirements need be defined in advance of drilling.

The MP System consists of casing components, which are permanently installed in the drillhole, portable pressure measurement and sampling probes, and specialized tools. The casing components include casing sections of various lengths, regular couplings, two types of valved port couplings with different capabilities, and packers, which seal the annulus between the monitoring zones. The MP System has been used in many different geologic and climatic environments in drillholes ranging from a few feet to over 4,000 ft (1,200 m) in length. The 1.5-inch (38 mm) I.D. MP38 System has been used in the field since 1978, while the 2.25-inch (55 mm) I.D. MP55 System was developed in 1990-91.

Casing Components

The casing components of the MP System are made in either plastic or stainless steel. While the illustrations are of plastic components, the descriptions of operating principles that follow apply to both types of materials. Most of the components referred to are shown in Figures 1 and 2.

Casing

MP casing is supplied in a number of different lengths to provide flexibility in establishing the position of monitoring zones and associated seals in the drillhole. Common nominal casing lengths are 2 ft (0.5 m), 5 ft (1.5 m) and 10 ft (3.0 m). Actual casing lengths are less than the nominal lengths to account for the lengths of the couplings. The casing ends are machined to mate with MP System couplings.

Telescoping casing sections are used to protect the casing string from damage when ground movements are anticipated or where measurements ofvertical displacements are desired.

Regular Couplings and End Caps

MP regular couplings are used to connect casing lengths where valved couplings are not required. The couplings incorporate O-rings for a positive hydraulic seal. A flexible shear rod provides a tensile connection. No adhesives are used when joining casings and couplings. MP38 regular couplings incorporate an internal, helical shoulder for the accurate location of probes and tools in the well. MP55 regular couplings do not incorporate a helical shoulder.

End caps are placed on the bottom of a casing string. They also incorporate an O-ring seal so that the entire casing string is hydraulically sealed during installation. End caps are frequently used to seal the top of the casing between monitoring periods.

Valved Couplings

There are two types of valved couplings, measurement port couplings and pumping port couplings. Measurement port couplings (or measurement ports) are used where pressure measurements and fluid samples are required. In addition to the features of a regular coupling (including the helical shoulder in the case of MP55), measurement ports incorporate a valve in the wall of the coupling, a leaf spring which normally holds the valve closed, and a cover plate or screen which holds the spring in place. When the valve is opened, an access port is provided for the groundwater to enter the coupling.

Pumping port couplings (or pumping ports) are used where the injection or withdrawal of larger volumes of fluid is desired than would be reasonable through the relatively small measurement port valve (such as for purging or hydraulic conductivity testing). Pumping ports incorporate a sleeve valve, sealed by O-rings, which can be moved to expose or cover slots that allow groundwater to pass through the wall of the coupling. A screen is normally fastened around the coupling outside the slots.

Annulus Seals

When there are many monitoring zones in a single drillhole, multiple seals are required to prevent fluid migration from one zone to another along the annular opening between the drillhole wall and the casing. Placement of these seals can be difficult with any groundwater monitoring device. However, considerable success has been achieved with three types of well completion used with the MP System, provided each is combined with appropriate drilling and placement methods.

With the MP System, seals can be obtained by: a) backfilling with alternating layers of sand and bentonite or grout, b) using hydraulic (water) inflated packers or c) using packers inside a cased well with multiple screens. Figure 1 illustrates a drillhole containing the MP System with packers. Figure 2 illustrates a single measurement zone where the MP System is completed by each of the three common methods. Each sealing method is possible in most environments, but in many situations one method will stand out as the most advantageous.

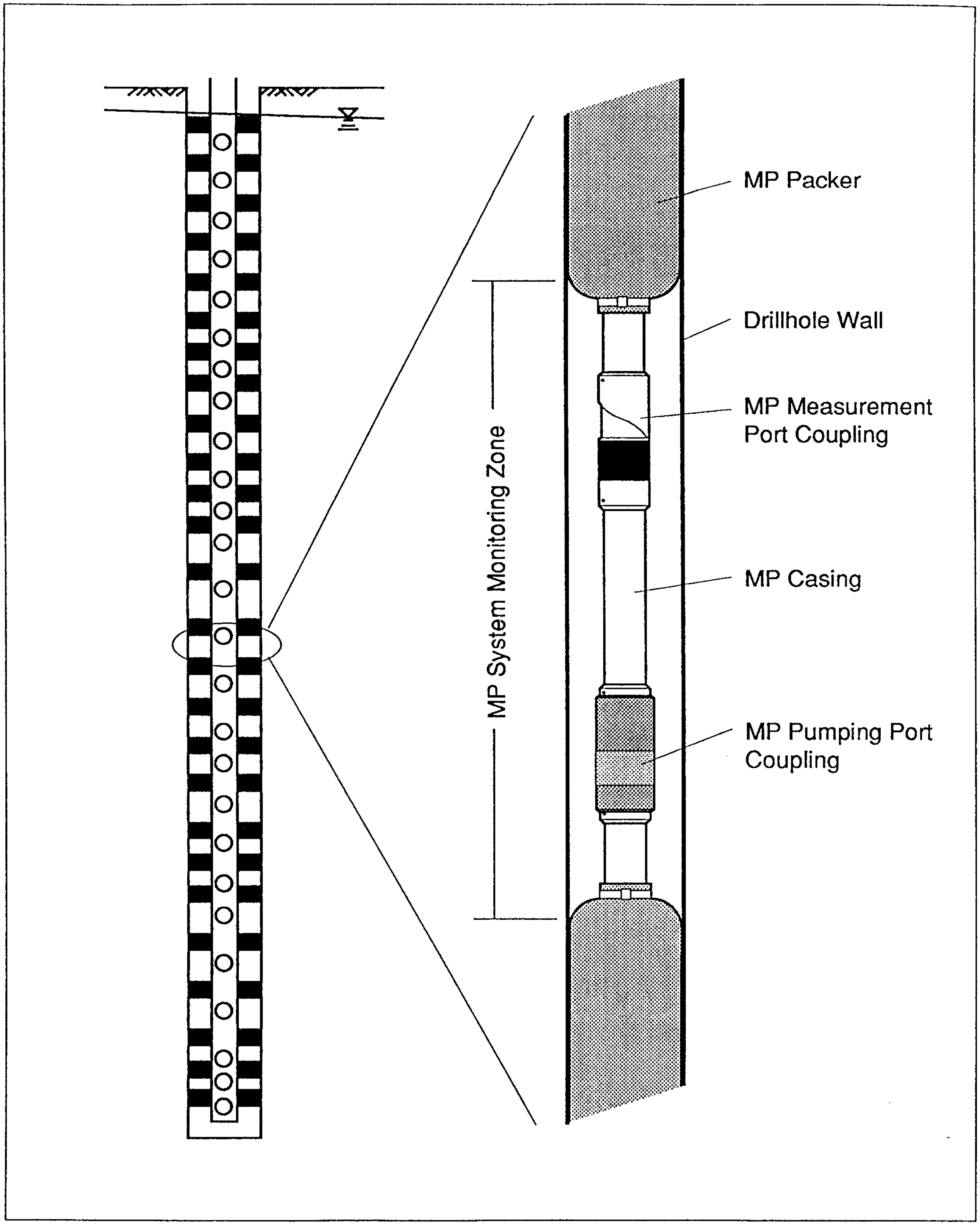

Figure 1. MP System installation with monitoring zones isolated by packers.

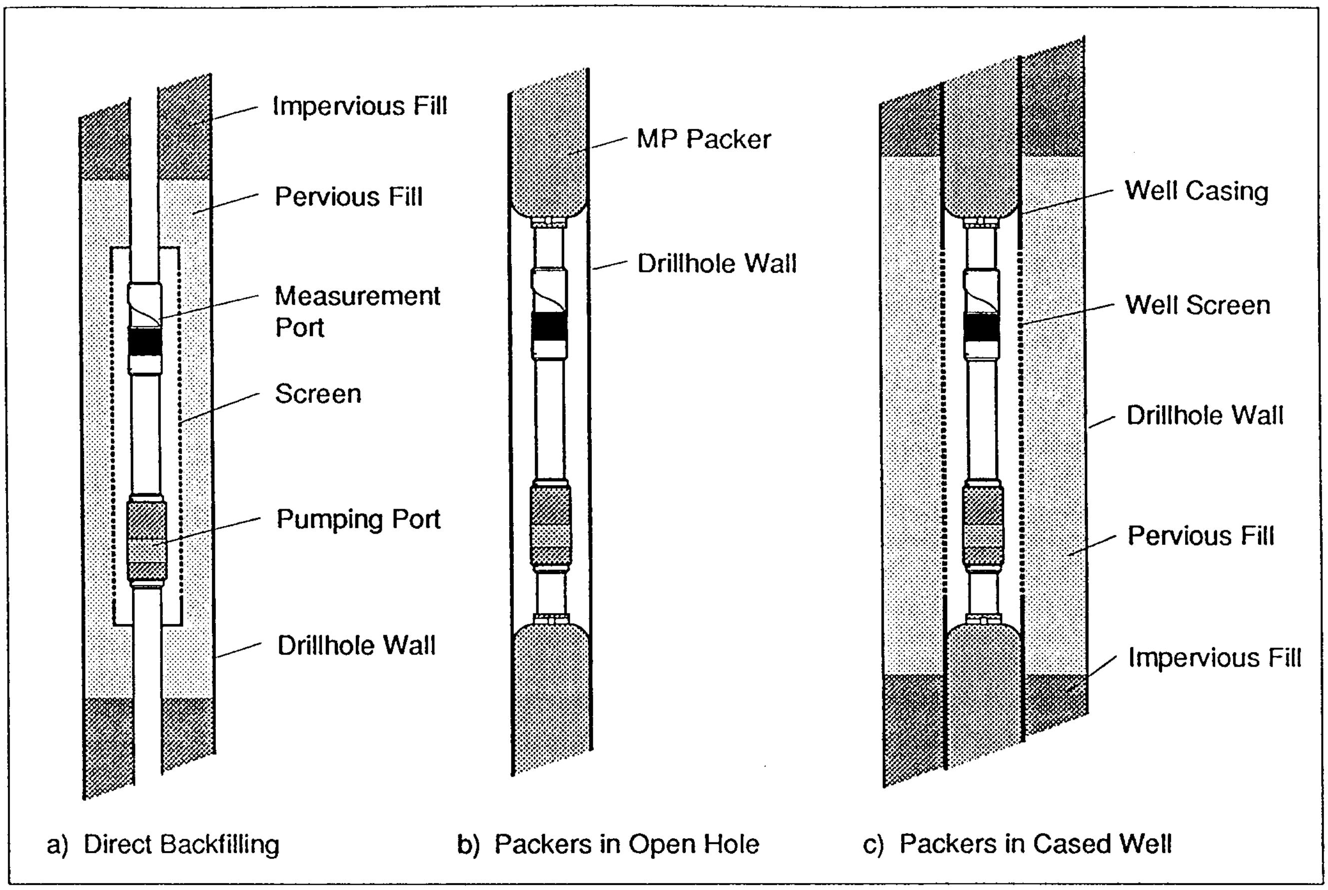

Figure 2. Common completion methods for the MP System.

Direct backfilling (Figure 2a) is recommended for: 1) large diameter drillholes, 2) shallow drillholes, 3) drillholes where little or no fluid circulation is anticipated in the hole during installation (i.e., when near-hydrostatic fluid pressures or low hydraulic conductivity is present over the length of the drillhole), and d) where packer gland materials are incompatible with the chemistry of the fluids present.

When direct backfilling is considered and fluid sampling is required, a very clean drilling method must be employed. While the MP System does permit purging of monitoring zones, the small size of the casing (particularly MP38) prevents sufficient energy being generated to develop the monitoring zone.

Backfill seals may include bentonite and/or grout slurries, bentonite chips or pellets or other materials with a relatively low hydraulic conductivity in comparison to that of the natural formations present.

MP casing packers incorporate an expandable gland mounted over a standard length of MP casing. The casing incorporates a one-way valve that allows fluid to travel through the wall of the casing into the packer and prevents this fluid from flowing back out of the packer. Gland lengths are typically 3 ft (~1 m).

Packers in an open borehole (Figure 2b) are typically recommended for: 1) small diameter drillholes (those too small for good quality backfilling to be achieved), 2) deep drillholes, and 3) sealing against significant flows (e.g., flowing artesian conditions) in the drillhole. When packers are used, field labour is reduced since packer inflation is generally much faster than backfilling. When using packers, additional measurement ports are installed between monitoring zones. Such additional ports provide additional fluid pressure data for quality assurance (QA) purposes.

Packers in a cased well (Figure 2c) is a completion method that has proven very successful, particularly for environments where available hole sizes are too large for packers and/or where drilling additives, such as mud, must be used. This completion method involves drilling a large diameter hole, typically 12-inch (300 mm) and installing a 4-inch (100 mm) (for MP38) nominal diameter well casing with multiple screens. The well screens are located at all of the desired monitoring levels, based on information gathered during and following drilling. Layers of backfill are placed to provide filters around the well screens and annular seals between. Each monitoring zone is then developed through the well casing. Following development, MP casing, ports and packers are installed inside the well casing. The MP packers are inflated against the inside of the well casing, providing interior annular seals between the monitoring zones. This completion method provides the ability to properly develop mud from deep mud-rotary drillholes, as well as to service the MP System during the operating life of the monitoring well.

Whenever casing packers are used, whether in open drillholes or cased wells, additional measurement ports are installed between monitoring zones for QA purposes. Measurements and tests carried out through these additional "QA ports" enable an evaluation of the effectiveness of each annulus seal. In open hole installations, such additional ports also provide added information on piezometric pressures in the portions of the drillhole between primary monitoring zones.

Screens and Filters

Where both pumping ports and measurement ports are being used and the ports are likely to be surrounded by sand fill or collapsed geologic material, a single well screen is generally placed over both the measurement port coupling and pumping port coupling in each monitoring zone as shown in Figure 2a. The screen helps ensure that the zone influenced by pumping through a pumping port coupling will extend to and include the region surrounding the adjacent measurement port coupling. Screen slot size and length should be chosen with a knowledge of local site conditions. If only fluid pressure measurements are required, a simpler fabric filter tube can be placed over the measurement port coupling and clamped at either end. This filter will help maintain the length of the monitoring zone and protect the measurement port valve from fine particles. The filter material should be compatible with the chemistry of fluids present.

Installation Procedures

Selection of Casing Components

The valved couplings (measurement port couplings and pumping port couplings) allow many monitoring zones to be established in a single drillhole. Horizons of hydrogeological interest are targeted on the basis of the best drillhole geologic and geophysical logs available. An installation log is prepared showing the locations of the casing components. If only fluid pressures are needed, only a measurement port coupling is required in each monitoring zone. If sampling, fluid withdrawal or fluid injection is anticipated, both a pumping port coupling and a measurement port coupling are recommended in each monitoring zone. This is the case illustrated in Figures 1 and 2.

The casing lengths are chosen based on the desired locations of the monitoring zones and sealing elements. This requires an interpretation of the hydrogeologic conditions anticipated in each drillhole. Caliper logs and borehole video can be useful in selecting packer locations.

If consolidation or heave is expected along the borehole axis, telescoping casing sections may be used to minimize the opportunity for compressional or tensile forces to damage the casing.

MP Casing Installation

The downhole MP System components - casing, couplings and packers- are laid out at the site of the proposed monitoring well in accordance with the casing installation log. At that time, any last minute adjustments required to make the positions of the monitoring zones and seals match hydrogeologic details of the drillhole are completed and the appropriate revisions made to the installation log.

Next, the required coupling is attached to the top of each length of casing. The casing layout is checked again for compliance with the installation log. Serial numbers of measurement ports, pumping ports and packers are recorded, indicating their position on the installation log. The length of all casing sections is measured and recorded on the log.

The casing string is then assembled by lowering the casing segments into the drillhole and attaching each successive segment to the adjacent coupling one at a time. As each successive MP casing section is attached to the string in the well, the section number is checked and recorded on the installation log. The coupling joint is then subjected to an internal hydraulic pressure to verify its hydraulic integrity and the test result is recorded on the log. At intervals during placement of the MP System casing clean water is added to the inside of the MP casing to reduce its buoyancy.

In collapsing soil and poor quality rock, MP casing with packers and screens may be installed through flush-jointed guide tube such as drill rods or casing. Table 1 provides ranges of drillhole, casing and guide tube sizes for the MP38 and MP55 Systems. Figure 3 illustrates the major stages of installing through a guide tube:
A) Following completion of drilling, the guide tube is positioned in the hole. All parts of the guide tube, including any shoe attached to the bottom, must be flush on the interior and of sufficient inside diameter to permit the MP components to pass through; B) The MP components are assembled and lowered into the guide

System	I.D.		Max. Depth		Drillhole/Casing Size		Min. Guide Tube Size	
	in.	mm	ft	m	in.	mm	in.	mm
Plastic MP38	1.5	38	1,500	450	3-4.5	75-115	3	75
Steel MP38	1.5	38	5,000	1,500	4-4.5	100-115	4	100
Plastic MP55	2.25	55	2,500	750	4.5-7	115-175	4.5	115
Steel MP55	2.25	55	6,600	2,000	4.5-7	115-175	4.5	115

Table 1. Important dimensions for the MP System.

tube in such a fashion that the packers and ports will be correctly positioned in the hole when the bottom of the MP is resting on the bottom of the drillhole; C) The guide tube is pulled back to expose a packer and that packer is inflated. The pulling/inflating sequence is repeated until all of the packers have been inflated. More than one packer may be exposed during each pull of the guide tube, depending upon the stability of the drillhole walls.

Casing without packers can be placed in various sizes of drillholes, with or without protective casing, as long as the drillhole diameter (and casing) is compatible with the backfilling method. Good backfilling techniques involve the use of one or more tremie pipes.

Once the MP casing has been placed in the drillhole, the packers are inflated (see Figure 3) or backfill is placed. If the MP casing was lowered inside a guide tube, the guide tube may be withdrawn all at once or in steps as the packer inflation or backfilling operation proceeds. An incremental casing withdrawal can reduce the opportunity for the drillhole wall to loosen and cave prior to the placement of seals.

Packer Inflation

Figure 4a shows the appearance of a casing packer when it has been placed in a drillhole before inflation. Figure 4b shows how the MP System casing packers are individually inflated using a packer inflation tool. This tool is lowered down the inside of the MP casing and is located in the correct position by the location arm seating in a coupling adjacent to the packer.

Two small packers (tool packers) are inflated, isolating the short segment of the casing containing the valve for the casing packer. At a pre-set pressure, the tool injection valve opens and water is injected into the casing packer. During inflation the vent-head mechanism on the tool holds open the measurement port beneath the packer. This vents the pressure in the zone below the packer, allowing the packer to square-off without generating unnatural squeeze pressures. Figure 4c shows the inflated MP packer after the inflation tool has been removed. At increments of volume during the inflation process, pumping is stopped and the fluid pressure of the inflation system is measured and recorded. The pressure/volume data is plotted and kept for quality assurance purposes.

Packer inflation proceeds from the bottom of the hole to the top. There are no permanent inflation lines leading to each packer. As a result, there is no limit to the number of packers that can be placed in a drillhole apart from the finite limitations of packer length and drillhole length.

Purging Monitoring Zones

The strategy for purging the monitoring zones may vary depending on site conditions. Figure 5 shows a typical sequence of events in drilling and completing a monitoring well. Figure 5a shows a typical drillhole environment where the invasion of drilling fluids and/or the unnatural circulation of formation fluids has caused groundwater adjacent to the drillhole to be nonrepresentative of the formation fluid. Once the casing and annular seals (packer seals are shown in Figure 5b) have been installed, it is usually desirable to remove the nonrepresentative fluid.This removal, or purging, can be done in one of two basic ways: 1) Purging by natural groundwater flow, or 2) Pumping to purge monitoring zones.

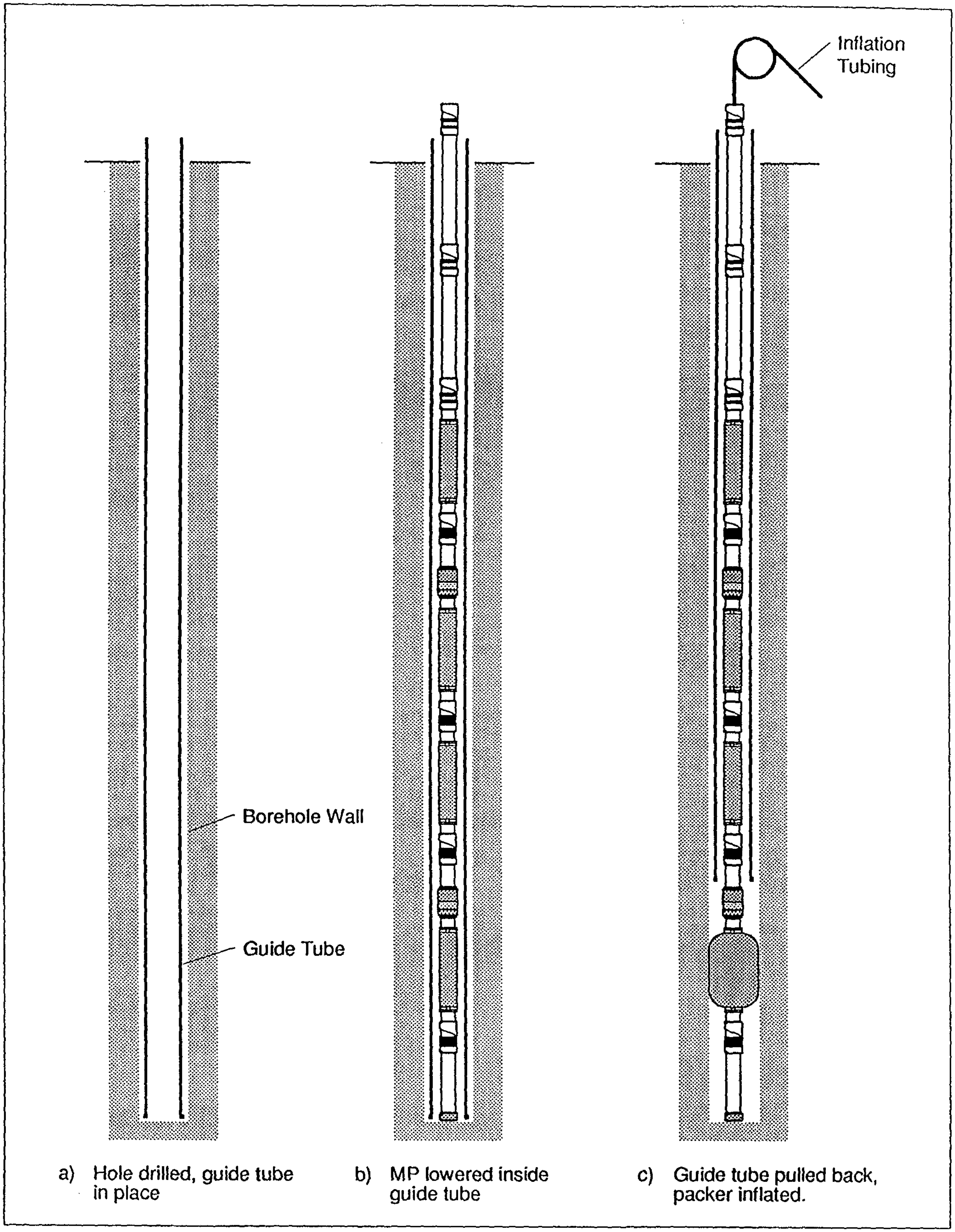

Figure 3. Installation of MP casing through a guide tube.

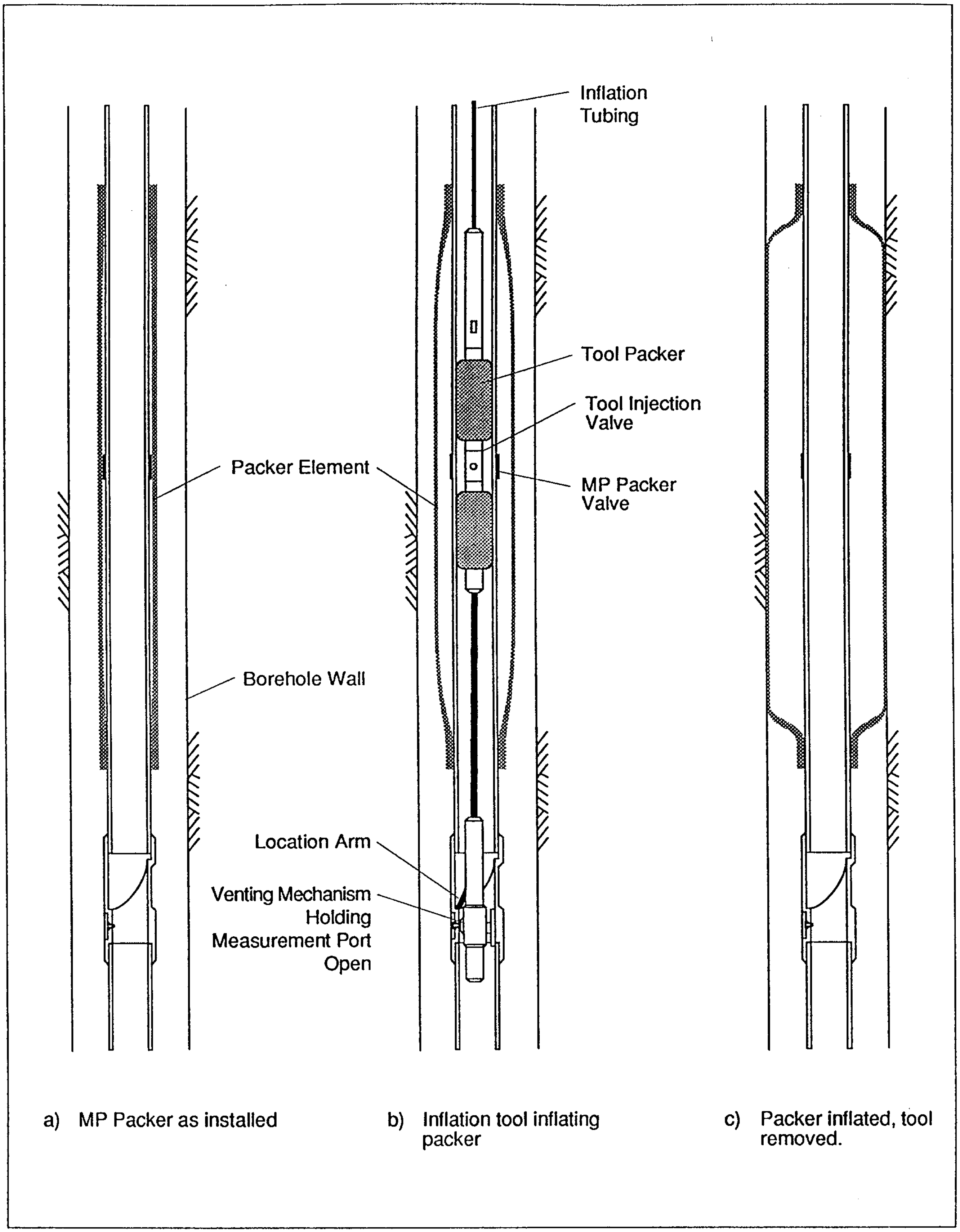

Figure 4. Steps in the inflation of an MP System packer.

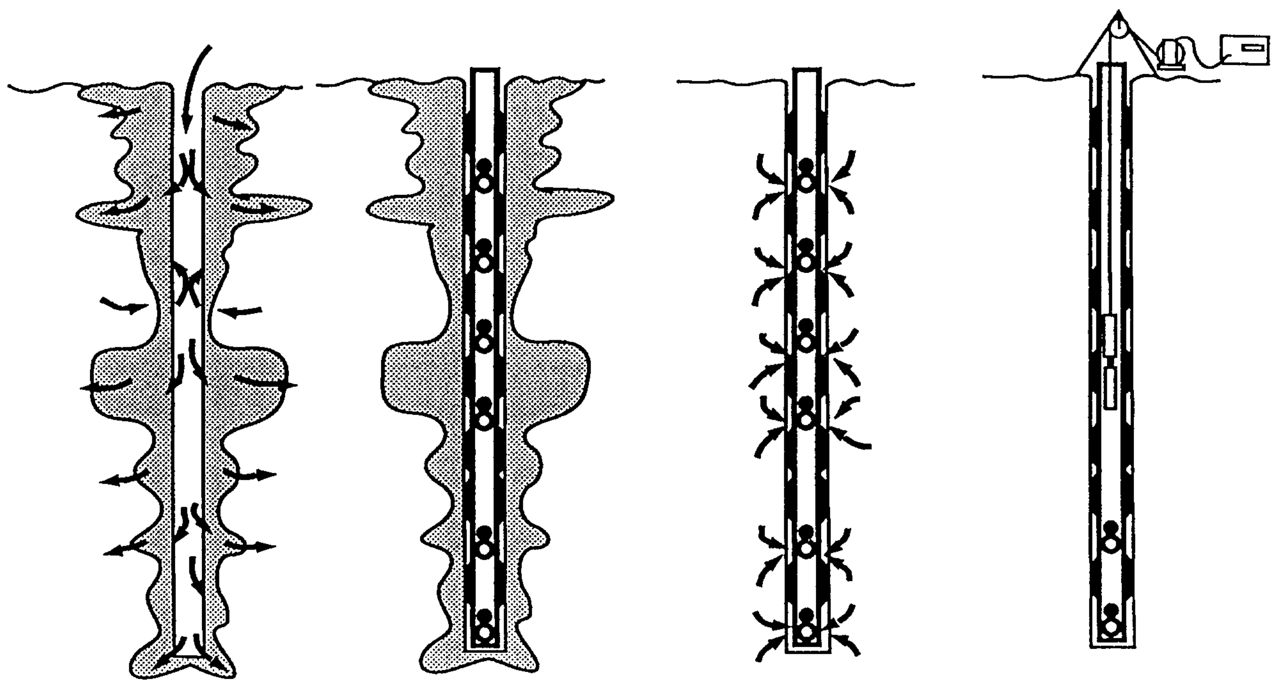

Figure 5. Typical sequence of events in purging monitoring zones.

Purging by natural groundwater flow is attractive, particularly in environments where groundwater flow is understood to be relatively rapid. In such an environment, unnatural fluids introduced during drilling may no longer be adjacent to the drillhole by the time the monitoring system has been installed. In such a case, there may be little to be gained from the investment of time and resources to pumping an arbitrary volume of water from each monitoring zone. Rather, fluid samples might be collected over a period of time and analytical results compared in order to evaluate the stabilization of conditions in the monitoring zone.

When purging by natural flow is not acceptable, monitoring zones can be purged by pumping. Zones may be pumped individually or several at a time (as shown in Figure 5c). Individual hydrogeologists and hydrochemists may prefer different purging techniques depending upon local conditions. However, the purging procedures are essentially the same as would be used for a single standpipe piezometer. One procedure which has been successfully used is described below.

1) An acceptable and convenient tracer is added to the drill fluid during drilling.

2) After the casing has been installed and the packers have been inflated, the pumping ports in all or a portion of the monitoring zones are opened with the use of an open/close tool.

3) Fluid from the inside of the MP casing is pumped out of the well. The volume of fluid removed and the pumping time will depend on many factors including: the drilling method, the length of time the hole was left open prior to completion, the hydrogeological conditions in the drillhole, and the accuracy required. The use of a tracer can be helpful in determining when the pumping is completed.

4) Once pumping has been completed, all the pumping ports except one are closed with the use of the open/close tool. With one pumping port open, the MP casing is hydraulically identical to a standpipe piezometer. A quantity of fluid may be pumped from inside the MP casing to complete the development of this monitoring zone. Hydrogeologic testing of this zone and its adjacent casing seals can be done at this time. For example, slug tests can be undertaken to obtain transmissivity and storativity values. This

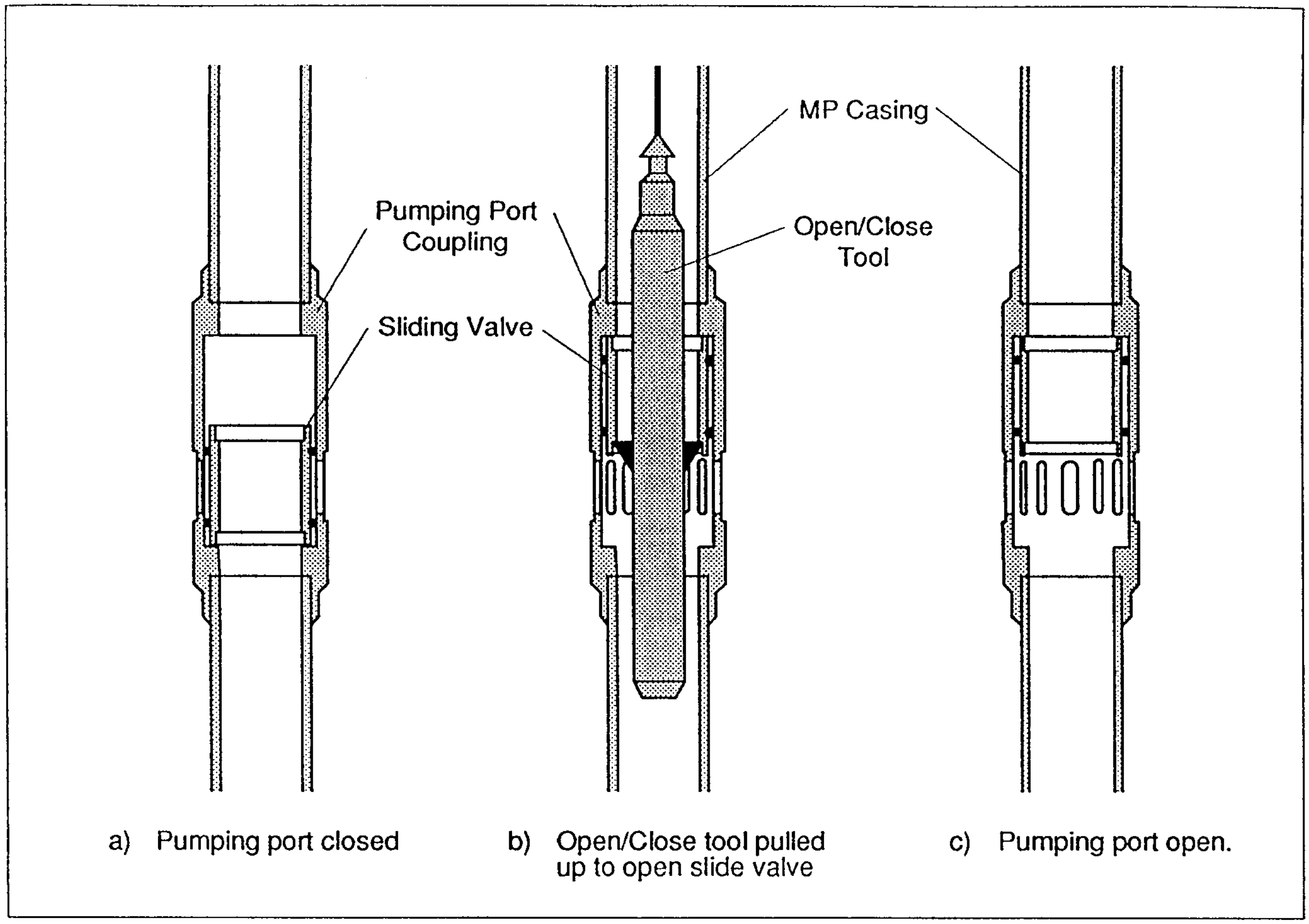

Figure 6. Operation of an MP pumping port.

pumping port can then be closed, the next one opened and the process repeated.

Following purging, the MP System is ready for sampling and for pressure measurements as indicated in Figure 5d.

Operation of the Pumping Ports

To operate the pumping port valve, an open/close tool is used as illustrated in Figure 6. This tool has spring-loaded "jaws" which can be mechanically activated from the surface. The pumping port is shown closed in Figure 6a. To open the valve, the tool is lowered on a wireline with the jaws extended and pointing upward (i.e., so that they will catch on shoulders when the tool is raised). In this condition, the jaws will spring through the couplings as the tool is lowered to just below the desired pumping port coupling. The tool is then pulled up so that the jaws engage the bottom shoulder of the sliding valve. By continuing to pull up on the wireline, the valve can be opened, as in Figure 6b. Once the valve is opened, the jaws can be collapsed into the housing and the tool recovered. With this one valve opened, fluids can be added to or removed from the monitoring interval by injecting or pumping from the MP casing. Other zones may still be monitored in the normal manner using a pressure probe or sampling probe as they will not be hydraulically connected to the interior of the casing.

To close the pumping port coupling, the open/close tool is brought to the surface and the housing is reversed so that the jaws point downward (i.e., the tool will stop on exposed shoulders when the tool is lowered). The tool is lowered to the open pumping port with the jaws collapsed into the housing. Once the tool is located near the pumping port, the jaws are released and the valve is closed by tapping on the top shoulder of the sliding valve with the tool.

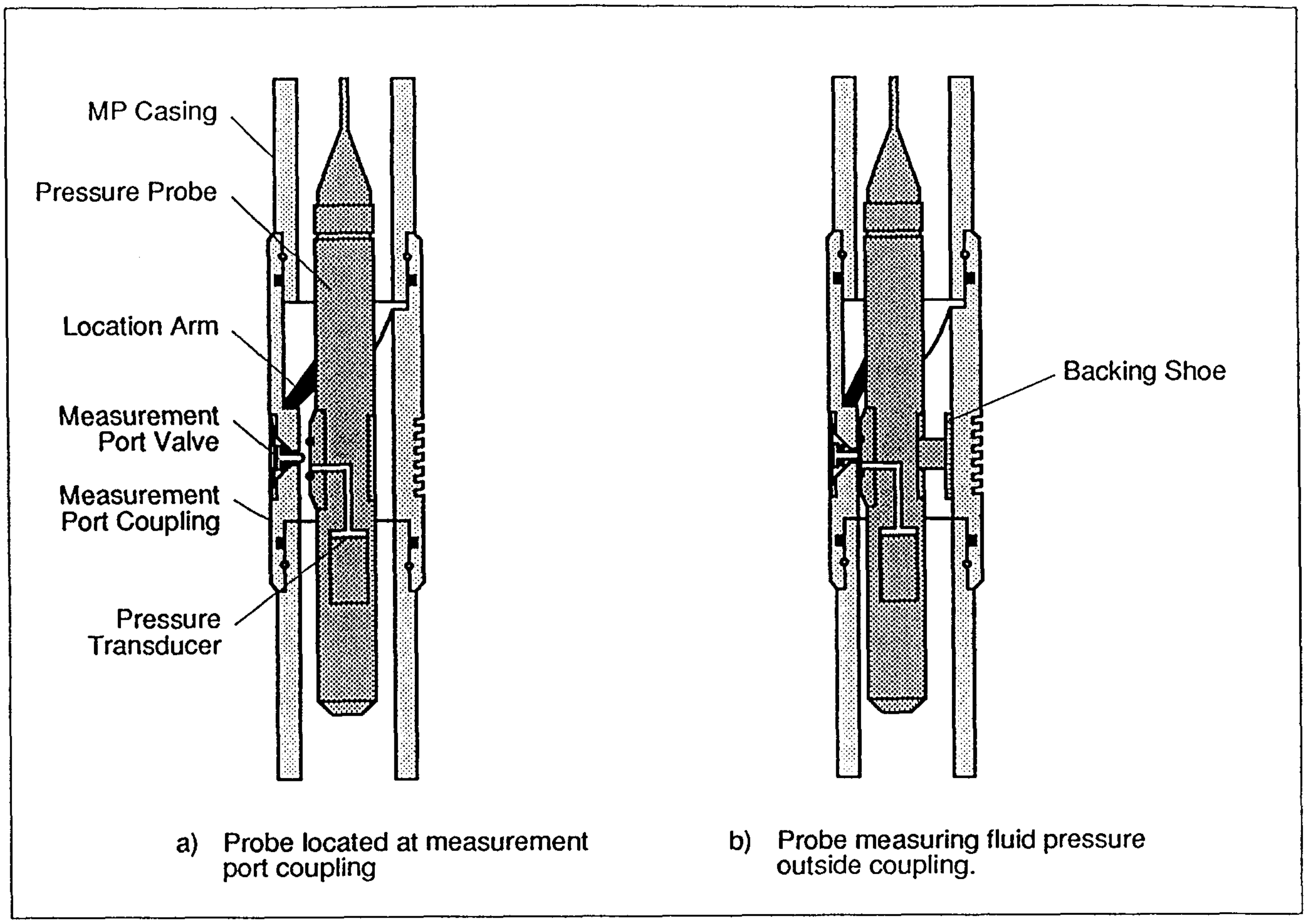

Figure 7. Operation of a pressure probe.

Testing and Monitoring

Fluid Pressure Measurements

Fluid pressure measurements can be made at each location in a drillhole where an MP measurement port coupling has been installed. The measurement coupling includes a helical landing ring and a leaf spring valve which is normally closed. The fluid pressure is measured using a MOSDAX® pressure probe which incorporates a location arm, a backing shoe, a face seal, and a fluid pressure transducer. These features are shown on Figure 7. The probe is operated on a cable connected to an interface and portable computer at the top of the monitoring well. Using MProfile™ software, the computer displays the pressure both graphically and digitally, along with transducer temperature, well information and probe status (see Figure 8).

The following procedure is used to make fluid pressure measurements. The probe is lowered to a point below the first measurement port to be accessed (usually the deepest). The location arm is released from within the probe body. The probe is raised to just above the measurement port coupling and then lowered until the location arm rests on the helical landing ring in the coupling. The weight of the probe causes it to rotate into position at the correct depth and orientation to operate the valve (Fig. 7a). At this point the pressure transducer is measuring the fluid pressure inside the MP casing at that depth. This reading will be displayed on the surface computer and is recorded. If convenient, the depth to water inside the MP casing is also measured and recorded at this time as a check on the pressure transducer.

The backing shoe is then activated. It pushes the probe to the wall of the coupling so that the face seal on the probe seals around the measurement port valve at the same time as the face of the probe pushes the valve open. The transducer is now hydraulically connected to the fluid outside the coupling and isolated from the fluid inside the casing (Fig. 7b). The reading displayed on the surface computer will be the fluid pressure in the formation outside the measurement port. The pressure outside the port can be observed as long as desired and recorded as often as desired. After the reading has been recorded, the probe backing shoe is deactivated (retracted) and the valve in the coupling reseals. The probe will again be

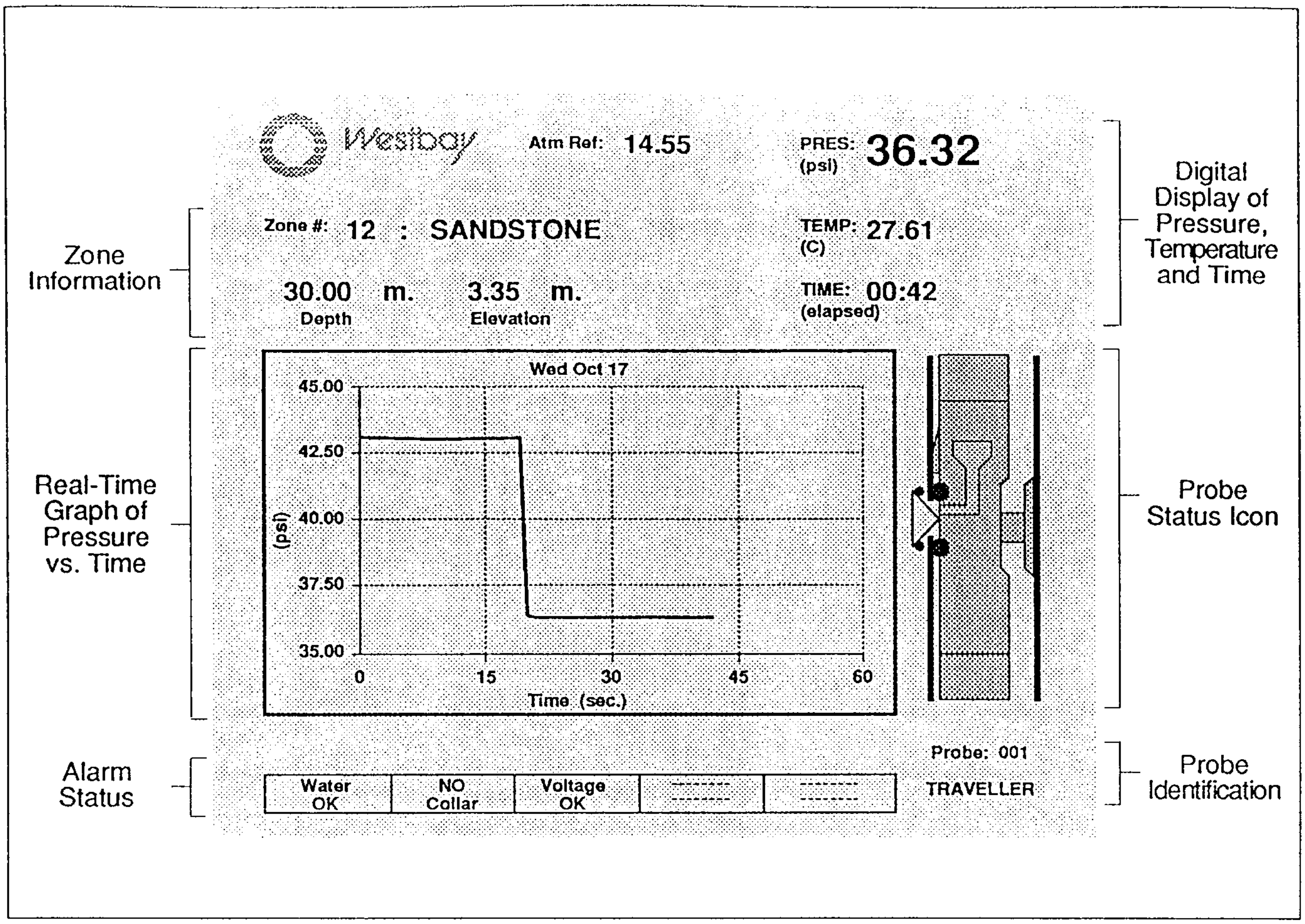

Figure 8. Data display on surface computer when using MProfile software to operate a MOSDAX pressure probe.

measuring the fluid pressure inside the MP casing (Fig. 7a). The pressure in the casing is again recorded, for quality assurance purposes.

Measuring Pressure in Low Permeability Environments

Very low permeability environments present a special challenge for measuring fluid pressures. When the routine profiling procedures described above are followed, a stable pressure may be observed through the measurement port. However, the act of opening the port may have been sufficient to change the pressure in the monitoring zone, and if the zone is very tight, that pressure change may not dissipate quickly enough to be observed. In such an environment it is always difficult to determine the validity of a static measurement unless some form of dynamic test is carried out as well. In the case of the MP System, this is done throught the use of a MOSDAX sampler probe. As illustrated in Figure 9a), the MOSDAX sampler incorporates all of the features of a pressure probe, plus a valved passage which is controlled via the surface computer. With the sampling valve closed the probe acts identically to a pressure probe and thus may be used for single-probe profiling. The difference is that once the probe is located and activated (Fig. 9b), the fluid level inside the MP casing may be adjusted to a level slightly higher or lower than the piezometric level in the monitoring zone. The sampling valve is then opened (Fig. 9c), exposing the monitoring zone to the fluid pressure in the MP casing. In very low permeability environments, no water will flow during this time. The sampling valve may be kept open for a specified period of time (such as one minute). The sampling valve is then closed (Fig. 9d) and the pressure recovery in the monitoring zone is recorded vs. time (Fig. 10). Standard analytical methods can be applied to the pressure recovery data in order to determine the apparent pressure in the monitoring zone. The same procedure can be used for testing hydraulic conductivity in low-k zones.

Pressure Monitoring Methods

The two principle methods of monitoring fluid pressure with the MP System are illustrated in Figure 11. Single probe profiling (Fig. 11a) involves an operator

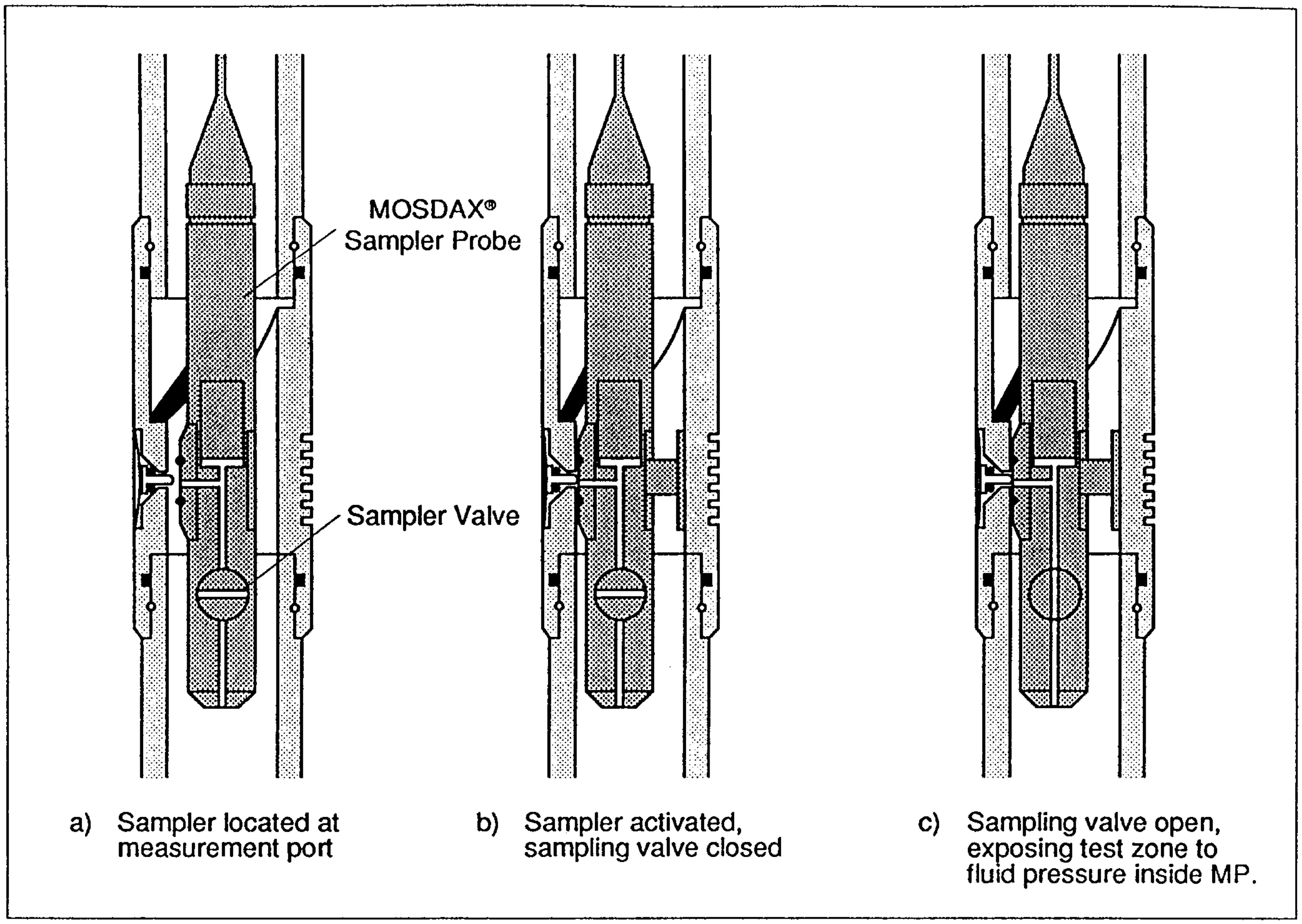

Figure 9. Using a sampler probe for testing hydraulic conductivity and verifying fluid pressure measurements in low permeability environments.

travelling to each well with a set of portable equipment including a pressure probe, cable and reel, interface and computer. The operator manually locates the probe at each measurement port and carries out fluid pressure measurements one at a time. MProfile stores the data on disk with each record tagged as to the location of the probe in the well, date, time, and probe status. Single probe profiling is generally adequate for monitoring fluid pressure up to a frequency of once per month.

When pressure measurements are desired more frequently than is reasonable for single-probe profiling, or when continual observation and recording of unanticipated events is required, the monitoring well can be configured for automated datalogging (Fig. 11b). Any or all of the measurement ports in a well may be selected for automated monitoring. Lengths of cable are made up to span the distance between each probe and the next. The string of probes and cable is assembled and lowered into the well. The datalogger and a computer are attached at the surface and the lowermost probe is located and activated in the appropriate measurement port. The

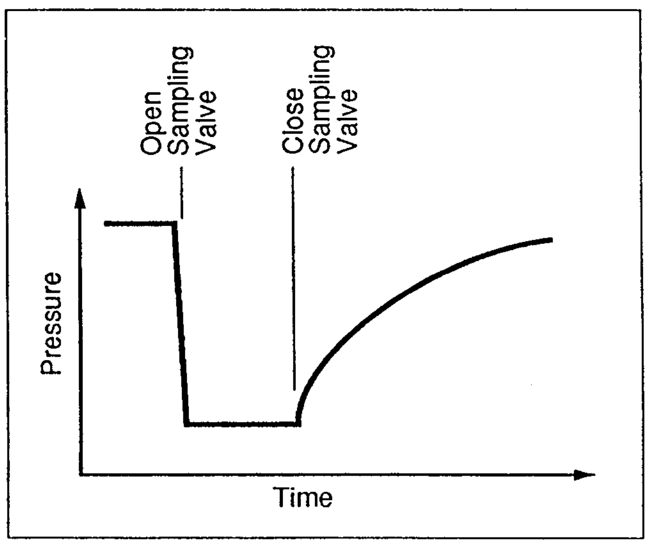

Figure 10. Typical data record from a test in a low permeability zone using sampler.

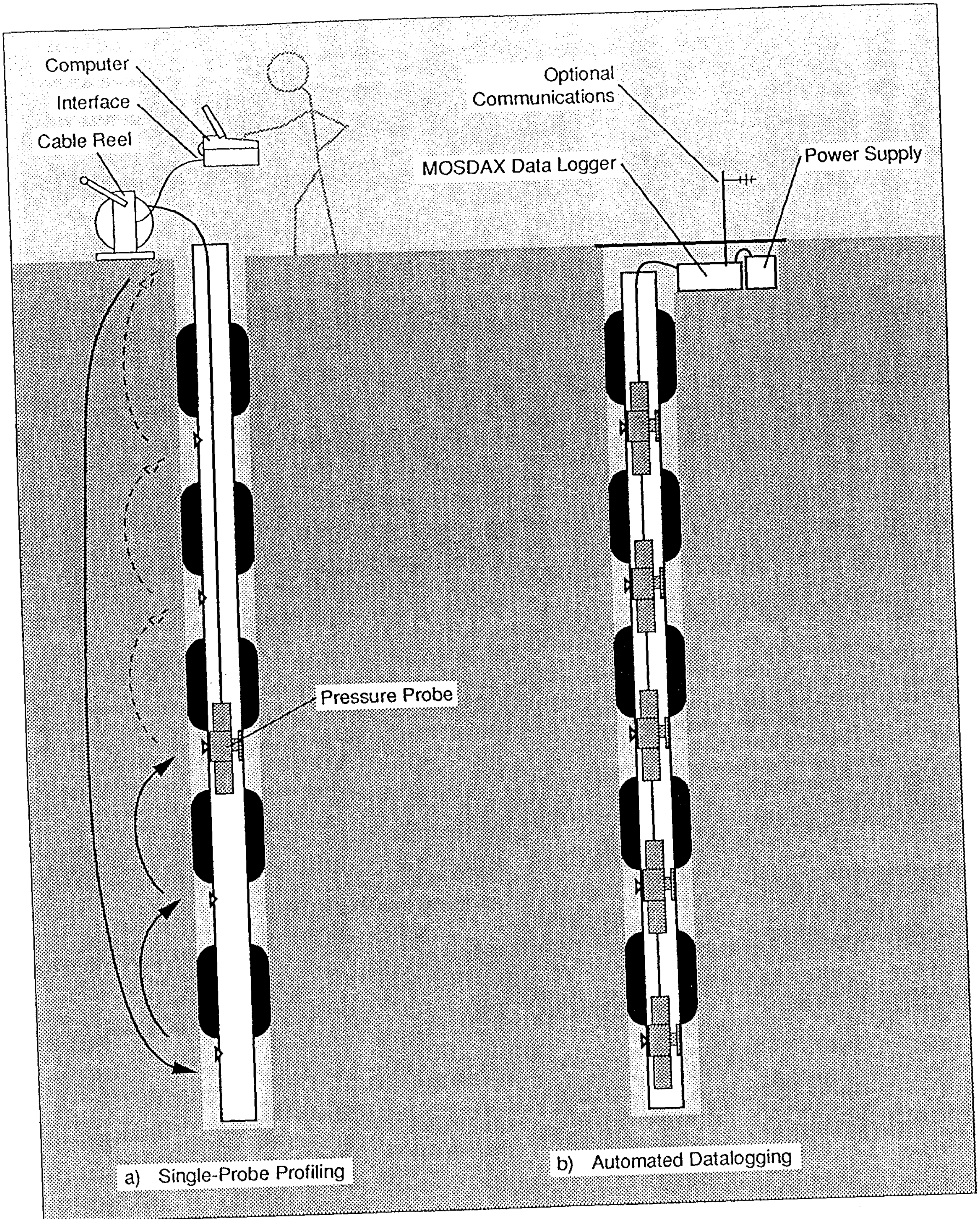

Figure 11. Methods of monitoring fluid pressure with the MP System.

remaining probes are located and activated sequentially from the bottom of the well to the top. Once all of the probes are activated, the computer is used to program the datalogger.

Recording of pressure measurements may be carried out on a simple time basis (e.g., one reading per hour or one per day), or the logger may be programmed to continually scan each probe and record pressures if a specific threshold value is exceeded. Each probe may be assigned an independent threshold (i.e., record data if probe 1's reading changes by 1 ft of water, probe 2 by 3 ft, etc.).

The datalogger may stand unattended, in which case an operator would periodically visit the site to download the stored data, or the datalogger may be connected to a telemetry system such as an RF modem, cell phone system, or landline. When connected to a communication device, a second threshold can be designated for each probe which will cause the logger to transmit an alarm signal to the host computer.

A unique aspect of monitoring in the MP System is that unusual pressure readings can often be verified by means of an in-situ calibration check. When an alarm condition is received, a natural first reaction is to question the validity of the measurement ("is it real, or is it the instrument?"). When datalogging with the MP System, if an alarm were received, the operator can log onto the well via remote communications, deactivate two or more probes including the one causing the alarm and compare their measurements of the fluid pressure within the MP casing. The column of fluid inside the MP casing is independent of all of the monitoring zones and thus serves as a reference pressure source. If the deactivated probes agree on the internal pressure, the alarm condition can be taken to be valid and the probes can be reactivated to resume monitoring. If the probe cauaing the alarm did not agree with the others, instrument error might be suspected. In such a case, an operator could visit the well, remove the string of probes, replace the offending probe and reinstall the string to resume monitoring. The offending probe could then be calibrated and serviced in a laboratory.

Fluid Sampling

Fluid samples are obtained by lowering a sampling probe and sample container to the desired measurement port coupling. As shown on Figure 12, the sampling probe operates in similar fashion to the pressure probe except that a groundwater sample is drawn through the measurement port coupling. Whenever the sampling probe is operated with the sampling valve closed, it is identical to a pressure probe, supplying the same data.

The procedure for taking a groundwater sample is as follows. A clean, empty sample container is attached to the sampling probe. The probe and container are prepared (e.g., evacuated) in a manner suited to the specific project and the sampling valve is closed to prevent the fluid inside the MP casing from entering the sample container. The probe and container are lowered to below the selected measurement port coupling. The location arm is released and the probe is positioned in the measurement port coupling (Fig. 12a). The fluid pressure inside the MP casing is recorded.

The backing shoe is activated and pushes the probe to the wall of the coupling so that the face seal on the probe seals around the measurement port valve at the same time as the face of the probe pushes the valve open. The interior passage of the probe is now hydraulically connected to water outside the coupling (Fig. 12b), but no fluid movement takes place. During this operation the change in fluid pressure is observed at the surface and may be recorded.

The sampling valve in the probe is opened, allowing fluid from outside the measurement port to flow through the probe and enter the sample container (Fig. 12c). The fluid displayed at ground surface drops and then recovers as the fluid in the container builds to formation pressure. Once the container is full, the sampling valve is closed (Fig. 12b), the backing shoe is deactivated (retracted) (Fig. 12a) and the fluid pressure inside the MP casing is once again recorded. The sampling probe and sample container are then pulled to the surface. The sampling probe can then be cleaned, a clean container attached and the procedure repeated.

When using a non-vented sample container, the fluid sample is maintained at formation pressure while the probe and container are returned to the top of the well. Once recovered, there are a variety of methods of handling the sample:

- the sample may be depressurized and decanted into alternate containers for storage and transport,
- the sample container may be sealed and transported to a laboratory with the fluid maintained at formation pressure,
- the sample may be transferred under pressure into alternate pressure containers for storage and transport.

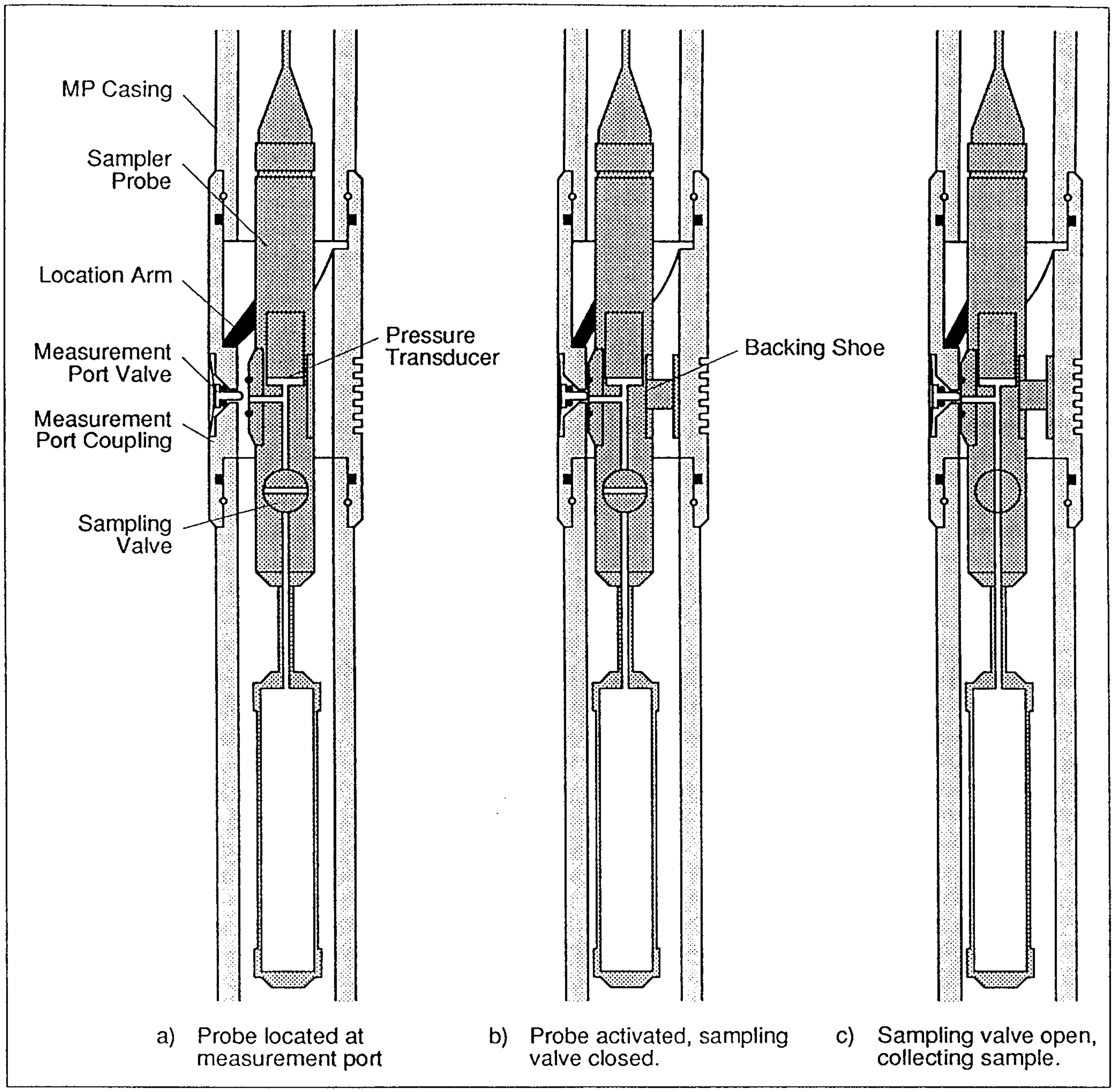

Figure 12. Operation of a sampler probe.

The advantages of this discrete sampling method can be summarized as follows:

1) The sample is drawn directly from formation fluids outside the measurement port. Therefore, there is no need for pumping a number of well volumes prior to each sampling event. Because there is no pumping prior to sampling, the sample is obtained with minimal distortion of the natural groundwater flow regime, the storage and disposal of large volumes of hazardous purge fluids is eliminated, and operator exposure to hazardous fluids is reduced.
2) The lack of pumping means samples can be obtained quickly, even in relatively low permeability environments.
3) The sample travels a short distance into the sample container, typically from 1 to 2 ft (0.3 to 0.6 m), regardless of depth.
4) The risk and cost of storing and disposing of hazardous purge fluids is virtually eliminated.

Hydraulic Conductivity Testing

A variety of different test methods can be employed to measure the hydraulic conductivity of formation materials with the MP System. These include variable head, constant head and pressure-pulse tests.

Variable head tests are the single well test method most commonly used with the MP System. Using these types of tests in the MP System, hydraulic conductivities between 10^{-2} and 10^{-8} cm/sec can be measured.

For variable head tests the valved pumping port couplings are used to provide the hydraulic connection between the interior of the MP riser tube and the test zone. In cases where monitoring zones are to be purged, it is convenient to carry out hydraulic conductivity testing just prior to or following purging. The head (fluid level) inside the MP casing can be adjusted while all port valves are closed, then the selected pumping port can be opened in a controlled manner (pumping port operation is described in the discussion of purging). This allows accurate measurement of both the initial head change and the time at which the head change is applied (t_0). The pumping port valve is opened rapidly (in less than one second), which satisfies the theoretical requirement that an instantaneous head change be applied to the tested zone.

For rising head tests the water level inside the MP casing is bailed or pumped down to a pre-determined level below the static water level in the test zone. For falling head tests the water level is raised to a level above the static water level in the zone to be tested. Measurement equipment is set in place and the pumping port valve is opened. Recovery of the water level in the MP casing is measured and recorded vs. time. A water level tape or pressure transducer is commonly used to record the water level changes. Figure 13 shows a typical record of water levels during a rising head hydraulic conductivity test.

Slug tests are carried out by opening the pumping port coupling at the zone to be tested and allowing the water level in the MP casing to equilibrate to the static water level for that zone with measurement equipment in place. The initial head change is then applied by rapidly lowering a displacement slug (a length of solid rod or sealed pipe) into the water. The recovery of the water level is measured and recorded vs. time. The slug test can be repeated and recorded again when the slug is removed from the water. Figure 14 shows a typical record of water levels during a slug test of hydraulic conductivity.

Data from variable head hydraulic conductivity tests may be analysed using any preferred calculation method. The most commonly used methods are those of Hvorslev (1951), Cooper et al. (1967) and Bouwer and Rice (1976). Selection of these or any other analytical method should be based upon an assessment of how well the test conditions comply with the simplifying assumptions inherent in the analytical method.

In very low permeability environments (hydraulic conductivity less than 10^{-7} or 10^{-8} cm/sec) the formation fluid pressure can be changed with very little fluid movement. As a result, tests can be carried out through the measurement port valve rather than the pumping port valve. Using a sampler probe with a transducer the zone to be tested may be exposed to the fluid pressure inside the MP casing for a period of time (see Fig. 9 and discussion of measuring fluid pressure in low-k environments). The zone may then be shut-in and the recovery of fluid pressure over time measured and recorded. Figure 10 shows a data record from such a test.

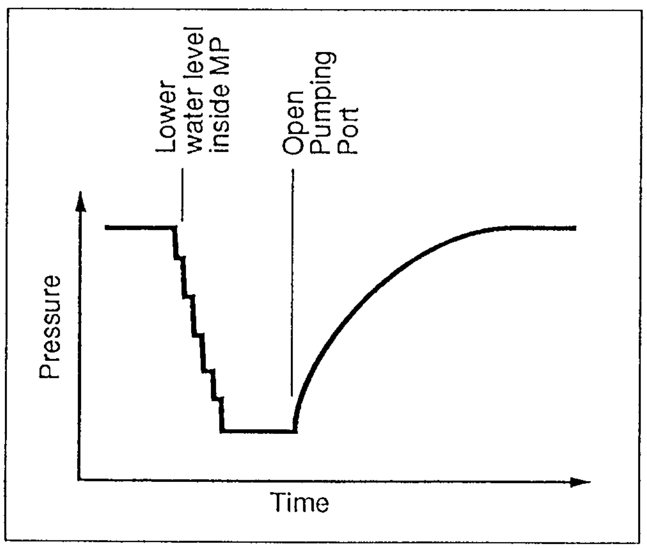

Figure 13. Typical data record from a rising head test.

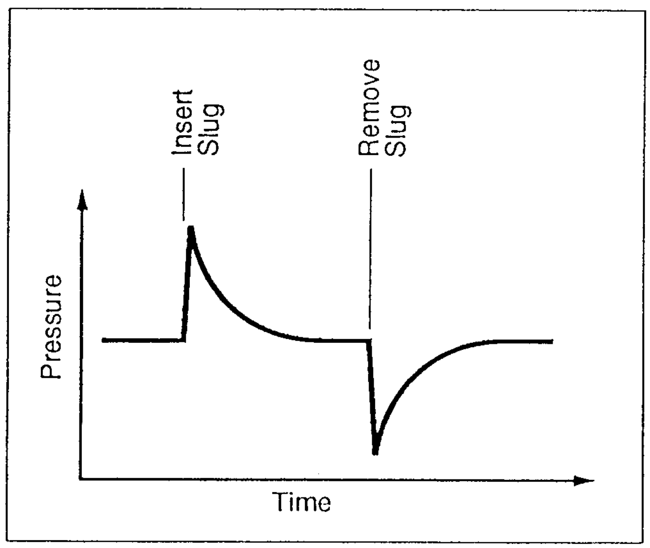

Figure 14. Typical data record from a slug test.

Field Quality Control

There are two distinctive parts to any quality assurance program. The first involves manufacturing and testing procedures which avoid the production or installation of equipment that may result in the collection of erroneous data. The second involves field operational procedures which will ensure that erroneous data are not generated as a result of the failure of any component to function as intended. Although the first part is necessary to allow the installation of useful monitoring wells, the second must also be rigorously applied to identify sources of erroneous and misleading results.

The MP System has many unique features for field quality control which clearly separate it from other types of groundwater monitoring instrumentation. These features are the result of designing components in response to the stringent requirements of users in the fields of nuclear and hazardous waste management.

Quality control tests are carried out at various points during the field use of the MP System and tend to be grouped into three periods: during installation, following installation, and during routine monitoring.

During Installation

During installation of the MP System the following operations form part of the quality control procedures:

Drill core or cuttings and geophysical logs are carefully checked to see that monitoring zones and annular seals are placed at the optimum positions. In cased wells, the well casing is inspected to verify that the interior surfaces are suitable for establishing good quality packer seals and backfill is placed under carefully controlled conditions with frequent measurements of material depths.

Westbay casing components are carefully inspected to see that critical surfaces are undamaged, sealing O-rings are clean and in place, and components are correctly oriented. Serial numbers are recorded along with component position in the installation. These operations link the field quality control to production test results.

As each section of MP casing is attached, the connection is pressurized with water and observed for any signs of leakage. Test results are recorded on the installation log.

During inflation of each MP packer, incremental volumes and pressures are recorded and plotted. These data allow an evaluation of drillhole conditions and provide the first indication of the quality of the annular seal obtained.

Following Installation

Immediately following installation further checks are carried out to verify the operation of the system. These include the initial pressure profile which serves to confirm the operation of the inlet valves of the measurement port couplings. Observed head differences across exterior casing seals directly indicate the seal effectiveness. Where such head differences are not observed, the annular seals can be artificially stressed by opening a pumping port in one monitoring zone and withdrawing or adding a slug of water from inside the casing while using the pressure probe to observe the pressure response in the monitoring zone on the other side of the seal. In cased wells and wells in low permeability environments, stresses can be applied through measurement ports in order to evaluate seal integrity.

Additional measurement ports are routinely installed between monitoring zones, further enhancing the ability to carry out thorough quality control tests.

Fluid can be added to packers at any time following installation and the pressure at which further fluid injection occurs can be compared with the injection pressures recorded during the initial inflation.

During Routine Monitoring

A number of quality control checks are built into the routine monitoring procedures.

When measuring fluid pressures, the pressures measured inside the MP casing at each measurement port are recorded immediately before and after the measurement made through the port. These inside casing values serve a number of purposes: 1) comparison of the two values confirms that the transducer was operating the same way after the reading as before, 2) comparison of the inside values from one set of measurements to the next confirms transducer stability over the intervening time period (assuming the water level inside the casing is the same), and 3) if the head of fluid inside the MP casing is known, an in-situ calibration check of head of water versus transducer output is obtained. Any unacceptable changes which show up during monitoring can be checked and corrected through laboratory calibration of the instrument.

Water sampling procedures with the MP System improve quality control because: 1) the short flow path between the formation and the container greatly reduces the surface area contacted by the sample, 2) the contacts between the water sample and the atmosphere are eliminated, 3) observing and recording the water level inside the MP casing during sampling confirms that the sample obtained is from outside the casing, and 4) sampling without purging reduces the disturbance of the natural system, minimizing unnatural changes in chemistry. Sampling methods can be varied to compare the effects of atmospheric contact versus no atmospheric contact and maintaining the sample under pressure versus allowing depressurization of the sample.

During water sampling, sample blanks and spikes may be collected using identical procedures for sampling, preservation, handling and shipping. Travel blanks and spikes may also be collected using identical procedures for handling, preservation and shipping. The chemical analyses of samples obtained using the MP System may be compared with those of samples collected from the same zone by alternate means.

Finally, the pumping port may be reopened should further purging appear to be desirable.

For both fluid pressure and water quality data, the MP System can provide corroborative data. That is, a high density of data can be obtained in a single installation so that significant changes in piezometric pressure and/or water quality can appear as transitions along a depth profile. Thus, neighboring values will corroborate one another rather than indicating abrupt changes which would cause one to question anomalous values.

Serviceability

In the event that quality control testing should reveal a component which is not operating properly, various steps can be taken to remedy the problem including, if certain cases, removing the MP casing string, replacing faulty components and reinstalling the string.

Table 2. Summary of major quality control aspects of the MP System.

Provides the Ability to Verify	
Well Integrity	✓
Individual Seals	✓
Sample Origin	✓
Fluid Pressures	✓
Well is Serviceable	✓

Summary

The modular nature of the MP System permits a large number of monitoring zones to be accessed through valves placed inside a single closed tube or casing installed in a single drillhole. Such a monitoring system can provide a detailed view of the variation of piezometric pressure and water quality with depth. The valved couplings permit purging of the well following installation and allow all standard hydrogeologic tests to be carried out in each zone. Routine sampling is carried out without repeated purging, eliminating the need to store and dispose of large volumes of purge fluid and reducing operator exposure to hazardous fluids. The valves also permit an evaluation of the condition of exterior casing seals at any time after installation. Casing packers allow multiple seals to be established easily and quickly, providing the required hydraulic isolation of each monitoring zone. The modular design of the downhole components means the number and location of monitoring zones and seals can be modified on the basis of the best information available in the field at the time of installation. The exact depth of monitoring zones need not be known when equipment is purchased.

Field quality control procedures have been established which permit the quality of a well installation and the proper operation of testing and sampling procedures and equipment to be routinely verified. Thus, groundwater data and the additional data required to define the quality of the field data can be routinely collected. Furthermore, when a high density of groundwater monitoring zones are installed by using multi-level monitoring wells, the redundant monitoring points can provide important corroborative field data to an extent which is not available with single level monitoring wells. The result is a monitoring system which provides data with a degree of defensibility unattainable with any other monitoring method, single or multi-level.

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