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Evaluation of Sampling Systems for Multiple Completion Regional Aquifer Wells at Los Alamos National Laboratory

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**Evaluation of Sampling Systems for
Multiple Completion Regional Aquifer Wells
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by

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EXECUTIVE SUMMARY

A systematic evaluation of groundwater sampling systems used in multiple completion monitoring wells at Los Alamos National Laboratory (Laboratory) was performed to determine which system(s) might be most effective for optimizing data quality. The sampling systems evaluated include

- Westbay multiple port sampling system,
- BESST Inc., dual Barcad pump with packer,
- Baski packer with dual valve,
- Baski packer with dual pump, and
- Flexible Liner Underground Technology (FLUTe) sampling system.

Each of the sampling systems is described, and the advantages and disadvantages of each system are discussed. A set of evaluation criteria was developed, and each system is systematically evaluated with respect to each criterion. The evaluation criteria include

- design and materials,
- cost,
- installation and removal,
- maintenance,
- groundwater sample quality,
- groundwater-level monitoring,
- operational history, and
- long-term operational issues.

Data quality objectives (DQOs) of the groundwater monitoring project are also considered as a part of the system evaluations. One of the important DQOs of groundwater sampling is that representative groundwater samples be collected; thus, each system is evaluated for this objective under the groundwater sample quality criterion. The ability to adequately purge the well before collecting groundwater samples is important in meeting the DQOs.

Each sampling system is rated for each evaluation criterion by assigning a rating of 1 to 4 points, with 4 being the most desirable for use in a multiple completion regional aquifer well at the Laboratory. The results of the evaluation and rating of the systems indicate that the Baski packer systems are the most suitable for meeting the DQOs and requirements of the Laboratory Groundwater Monitoring Project, primarily because of the ability to adequately purge the wells before collecting samples. These systems also rate highly for their design and materials, minimal maintenance, operational history, and long-term

operational issues, but they lost some points for the complexity of installation and maintenance and for groundwater-level monitoring.

The second highest rated system was the FLUTe system, which rated highly for design, cost, ease of installation and removal, and minimal maintenance requirements. Although groundwater sample quality is probably better than other low-flow, no-purge systems, the lack of purging ability is a drawback with this system.

The lowest rated systems were the Westbay and Barcad systems, primarily because these systems could not be purged. The Westbay system also lost points because of cost, maintenance, and potential long-term operational issues. The Barcad system also lost points because of operational history and problems with groundwater-level monitoring.

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ACRONYMS AND ABBREVIATIONS

APV	access port valve
bgs	below ground surface
DI	deionized
DOE	Department of Energy
DQO	data quality objective
FLUTe	Flexible Underground Technologies
gal./min	gallon(s) per minute
I.D.	inside diameter
LANL	Los Alamos National Laboratory
LANS	Los Alamos National Security
LASO	Los Alamos Site Office (of DOE)
LC-LESH	Laboratory Counsel–Laboratory Environmental Safety and Health
L/min	liter(s) per minute
MP	multiple port (Westbay casing)
O.D.	outside diameter
Pi	pressure inside (Westbay casing)
Po	pressure outside (Westbay casing)
PP	pumping port (Westbay casing)
PVC	polyvinyl chloride
SOP	standard operating procedure
QA	quality assurance

1.0 INTRODUCTION

This paper provides a systematic evaluation of existing groundwater sampling systems installed in multiple completion regional aquifer and intermediate wells at Los Alamos National Laboratory (Laboratory or LANL). Existing systems and the number of each currently in use are

- Westbay multiple port (MP) sampling system (16),
- BESST, Inc., Barcad dual pump with packer system (1),
- Baski packer with dual-valve system and single pump (2),
- Baski packer with dual-submersible pump system (1), and
- Flexible Liner Underground Technologies (FLUTe) sampling system (1).

The evaluation was performed to

- optimize sampling systems to obtain representative groundwater samples that meet data quality objectives (DQOs) for groundwater quality monitoring and groundwater-level monitoring,
- standardize the equipment and procedures used in groundwater sampling at the Laboratory,
- minimize long-term operational costs by focusing on a single-system design, if feasible, and
- design and install future wells around a single-sampling system process.

DQOs for groundwater sampling are described in the “Quality Assurance Project Plan for the Groundwater, Surface Water, and Sediment Monitoring Program” (LANL 2004), and the groundwater-level monitoring is described in the Quality Assurance Project Plan for the Groundwater-Level Monitoring Project (LANL 2007). One of the important DQOs of groundwater sampling is that representative groundwater samples be collected; each system is evaluated for this objective under the groundwater sample quality criterion. The ability to adequately purge the well before collecting groundwater samples is an important aspect of meeting the DQOs.

This paper provides a brief history of operation of each well sampling system at the Laboratory and an evaluation of each system with regard to

- quality of design and materials,
- cost,
- installation and removal,
- operation and maintenance,
- quality of groundwater samples, especially with regard to the ability to purge,
- quality of groundwater-level monitoring data, and
- long-term operational issues.

For the evaluation, the systems are rated for each of these categories on a scale of 1 to 4, with 4 being the most desirable for use in a multiple completion regional aquifer well at the Laboratory. For comparison purposes, it was assumed that the systems are installed in a two-screen regional aquifer well at the Laboratory, which would be 1100 ft deep with a depth-to-water distance of 1000 ft. All systems are capable of such an installation, but some systems are additionally capable of installations with more than two screens. A summary describing the advantages and disadvantages of each system and whether each system operated according to manufacturer’s specifications is also provided.

Other multilevel sampling systems are available from different manufacturers in addition to the systems that are included in this report. Cursory review of some of the other available systems has not revealed a system that would be more appropriate for use in the deep Laboratory monitoring wells than those evaluated here. Other available multilevel systems are typically low-flow, no-purge systems that would tend to rate similarly to the low-flow, no-purge systems evaluated here.

Disclaimer: No representation or statements in this report are to be construed as an endorsement, approval, or disapproval of any product or system by the Laboratory, Los Alamos National Security (LANS), or the authors. The evaluation criteria used in this analysis are specific to deep monitoring well hydrogeologic conditions at the Laboratory and are based on the specific DQOs and unique geologic and hydrogeologic environment at the Laboratory. Evaluation of these systems in other settings with different criteria may yield entirely different results and conclusions.

2.0 WESTBAY MP-55 SYSTEM

The Westbay MP-55 system has been installed in 16 multiple completion wells at the Laboratory. Table 2-1 summarizes the Westbay completion wells. The Westbay MP-55 system is a **low-flow, no-purge** sampling system that is capable of sampling and monitoring a number of zones in each well. The “55” designation signifies the inside diameter (I.D.) of the Westbay casing in millimeters. Figure 2-1 is a schematic drawing of a Westbay installation showing the arrangement of the packer and port assemblies.

2.1 Design

Most Westbay systems at the Laboratory have been designed by Westbay personnel upon receipt of a final well completion drawing, with input from Laboratory personnel. This allows for compliance with Westbay systems design criteria. The Westbay system is a specially designed modular polyvinyl chloride (PVC) pipe system that is inserted into the well casing. Some of the modular components incorporate port openings that are positioned adjacent to the well screen and that allow for sampling and pressure measurements at each screen. Other components incorporate water-inflated packers that are located between screens to isolate each screen zone from other screens and from the atmosphere. Each screen interval is typically equipped with two monitoring ports and one pumping port (PP), although some screen intervals have been equipped with three monitoring ports. The monitoring ports provide for low-flow groundwater sampling and for attachment of a transducer for long-term groundwater pressure (level) monitoring. The pumping ports are designed for higher-flow sampling but have not been used routinely at the Laboratory (see Section 2.4). The Westbay design allows for monitoring of multiple screens within the 4.5-in.-well casing diameter used at the Laboratory; R-25 has the most monitoring zones (nine).

Table 2-1
Westbay MP-55 Completions at LANL

Well	Date Westbay Installed	No. of Screens	No. Intermediate Screens	No. Regional Aquifer Screens	No. Westbay Ports	No. Transducers 01/07	Westbay System Comment
CdV-R-15-3	09/17/00	6	3	3	21	3	Operational
CdV-R-37-2	10/08/01	4	1	3	12	3	Operational
R-5	07/17/01	4	2	2	12	4	Operational
R-7	02/25/01	3	2	1	10	3	Operational
R-8	02/23/02	2	0	2	8	2	Operational
R-9i	04/15/00	2	2	0	6	2	Operational
R-12	03/21/00	3	2	1	11	3	Westbay removed in 2006 for rehabilitation
R-14	11/23/02	2	0	2	7	2	Operational
R-16	12/14/02	4	0	4	12	3	Westbay removed and reinstalled in 2006, operational
R-19	09/11/00	7	2	5	22	7	Operational
R-20	01/18/03	3	0	3	9	3	Westbay removed in 2006 for rehabilitation
R-22	12/11/00	5	0	5	15	5	Operational, scheduled for rehabilitation
R-25	10/03/00	9	4	5	25	7	Operational
R-26	07/18/04	2	1	1	3	2	Screen 2 sampling port plugged, screen 1 port operational
R-31	04/07/00	5	1	4	16	4	Operational
R-32	12/14/02	3	0	3	7	3	Operational, scheduled for rehabilitation
Total		**64**	**20**	**44**	**196**	**56**	

Source: Westbay 2007.

Figure 2-1 Schematic diagram of Westbay sampling system

The design of the well and Westbay completion system must consider the following factors:

- The distance between well screens must be sufficient to allow placement of at least two Westbay packers between the screens to isolate each screen zone.
- Screens must be thoroughly developed before Westbay installation so that no effects of drilling or drilling fluids are present within the screen.
- The head difference between the top intermediate groundwater zone and the lowest regional aquifer head should not exceed 460 ft. The differential pressure rating of Westbay ports is 200 psi. If an intermediate port were to leak formation water into the Westbay casing, the differential pressure inside the Westbay casing at deeper regional aquifer ports should not exceed the rated pressure.
- Deionized (DI) water is placed inside the Westbay casing to reduce buoyancy of the casing in the well and to partially equilibrate formation pressures at deeper ports. The DI water level is typically located between the first and second screens in the regional aquifer, but for wells with only two screens, the deionized water level has been placed above the level of the regional aquifer.

The DI water level should be maintained between screens so that water pressure inside the Westbay casing (Pi) and the formation pressure outside the Westbay casing (Po) at any port are unequal. Maintaining the DI water level between screens allows detection of a leak of formation water into the Westbay casing where the DI water level may equilibrate with one of the screen zones. When this occurs and Pi equals Po, it may be difficult for operators to tell when the sampling device or a transducer is properly connected to a port.

The Westbay sampling system allows collection of groundwater samples from the water within the well screen present between the Westbay casing (2.5-in.-[outside diameter] O.D.) and the well screen (typically 4.5-in.-I.D.) over the full length of the screen. For a typical 10-ft long screen, the packers are 20 ft apart; thus, the volume of water in the well between packers in the well is about 15 gal. (0.76 gal./ft × 20 ft), and the volume of water within the screen is half that amount; longer screens would contain proportionately more water. Depending on the rate of groundwater horizontal flow in the formation and the hydraulic conductivity between the formation water and the well water, groundwater samples are collected partially or entirely from stationary water within the well. The Westbay packers seal the well water from the atmosphere so the water within the screens is not stagnant. Nonetheless, the sampled water may have been in long-term contact with well materials and drilling fluid residues (if present) and may not be sampled directly from the nonimpacted portion of the formation. Thus, groundwater samples may not be representative of formation water quality.

2.2 Materials and Costs

Westbay completion materials are manufactured exclusively by Westbay and are only available from Westbay Instruments, Inc., a Canadian subsidiary of Schlumberger, Inc. The PVC casing materials are of high quality, durability, and strength and are apparently adequate for the purposes employed in Laboratory wells. The cost to equip a dual-screen, regional aquifer monitoring well at the Laboratory with a Westbay system is approximately $100,000, not including installation.

Westbay transducers and sampling equipment are stainless steel and of high quality but are also the most costly of systems evaluated. Each Westbay transducer and sampling device costs $8,690 to $9,900. The transducers are connected in series to a small diameter stainless-steel cable that contains the electrical conductor. The data loggers and controllers are exclusive to Westbay and are also expensive, at about $7,500 each. The transducer cable is $1.20/ft and cable heads (two) for each transducer are $530. Thus, a Westbay transducer system in an 1100-ft well with two screens is about $30,000, excluding the cost of the casing materials and installation costs.

The transducer and sampling systems require a winch mechanism, two of which have been installed in trailers at the Laboratory. Each Westbay equipment trailer costs approximately $40,000, $20,000 for the trailer and $20,000 for the Westbay equipment. Routine maintenance is required on the winch mechanisms and sampling equipment. Any new Westbay systems installed at the Laboratory could use the existing sampling equipment.

Sampling equipment and transducers for monitoring groundwater levels are available only from Westbay. Thus, all materials must pass through customs and Laboratory export/import controls. Westbay systems are guaranteed for 1 yr after installation. The Laboratory has purchased spare Westbay casing materials that could be used to repair existing systems or to equip one or two new Westbay systems.

2.3 Installation and Maintenance

Westbay personnel are currently under contract to install and retrieve the Westbay MP sampling system in accordance with warranty requirements. Some maintenance of surface equipment, sampling equipment, and transducers can be performed by Laboratory personnel who are trained and certified Westbay operators, but most maintenance of casing, sampling, and transducer equipment must be performed by Westbay personnel, which requires shipping the equipment out of the country and having a service contract with Westbay. A subcontract with Westbay for parts and pieces is currently in place.

The Westbay PVC casing is installed inside a stainless-steel well casing and screen. Several packers are inflated between each of the screens to hydraulically isolate each screen in the well. The packers are inflated using DI water; no external gas pressure or routine monitoring is required to keep the packers inflated. The installation equipment is proprietary to Westbay, which requires the use of Westbay personnel and equipment for installation. Multiple packers are located between each screen to ensure hydraulic integrity of the screen zones; packer failure in the Westbay systems at the Laboratory has not been observed. Monitor ports are located between packers to check on the hydraulic integrity of the system. Westbay quality control procedures are used during and after installation to ensure proper operation of the system; these procedures appear to be thorough and adequate. Installation and quality assurance (QA) testing of a Westbay system in a dual-screen, regional aquifer monitoring well at the Laboratory take 3 to 5 d.

Solar panels and 12-volt batteries have been installed at each Westbay system to provide power for the data logger and transducer systems. Routine maintenance of these systems is minimal, and batteries have been replaced after up to 6 yr of service at two of the Westbay systems.

Maintenance of the Westbay down-hole components has been minimal. Maintenance of the sampling equipment and the transducer cables and transducers is routinely required during installation and retrieval of the transducers, which involves inspection of cables and cable connections, lubrication of cable connections with silicon grease, and inspection and maintenance of O-rings that seal connections. Routine maintenance of the winch and cable assemblies is also required, as is routine replacement of transducer and sampler O-ring and shoe assemblies. Laboratory personnel are trained to install and retrieve transducers, which must be performed each time the well is to be sampled. Installation and removal of the transducers from a Westbay two-screen regional aquifer well take about 2 h (3 h with travel time), and more time is required for wells that monitor more than two screens.

During the past 7 yr of Westbay system operations at the Laboratory, six transducers (about 10%) have failed and were shipped to Westbay for repair and recalibration. During this period, three of the data loggers have experienced problems and required repair. Transducers typically have a service life of 5 to 7 yr, but because transducers have not been continually installed in Laboratory wells, the service life may be longer. Transducer operations are continually monitored, and transducers are checked for accuracy each time they are removed from the wells. When a transducer fails, operation becomes erratic or measurements are outside of manufacturer's specifications, the transducer is returned for repair and calibration.

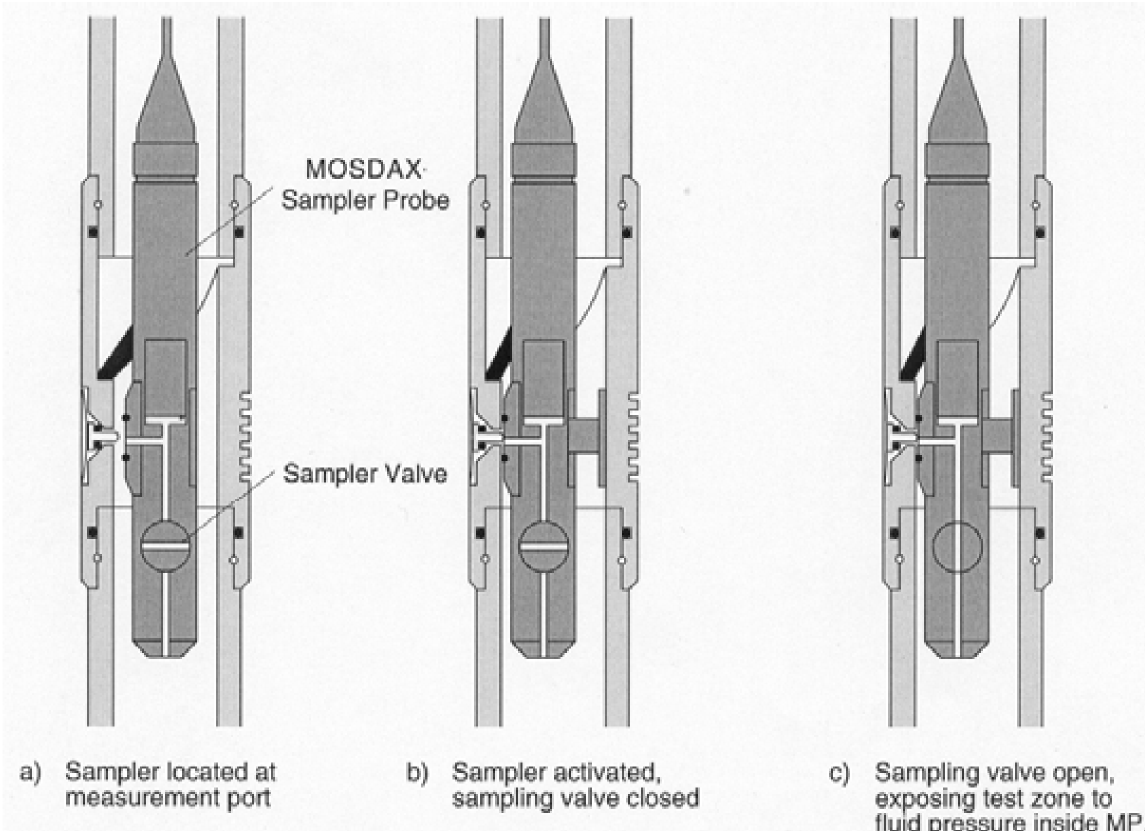
Corrosion of the transducer cable has occurred at several wells, necessitating the replacement of several cables.

2.4 Groundwater Sample Quality

Groundwater sampling using the Westbay system is a **low-flow, no-purge** system. Each screen zone is isolated from the atmosphere by packers, which prevents stagnation of the water. Where the screens have been thoroughly developed, representative groundwater samples can be obtained that meet the current Laboratory DQOs. However, groundwater sample data indicate that 48% of the screens in Westbay wells at the Laboratory have drilling fluid impacts (LANL 2005d, LANL 2006). Experience at the Laboratory has shown that the Westbay sampling system does not meet the current Laboratory-site DQOs for collecting representative groundwater samples in wells where screens may not have been properly developed or where drilling impacts are present in the formation surrounding a well.

Using the Westbay system, groundwater samples are collected from water present within the well screen. If there is little or no continuous ambient groundwater movement through the filter pack and well screen, the sampled water may be in long-term contact with well materials and possibly drilling fluid residue and may not be representative of water in the formation. In a 4.5-in.-I.D. well with a Westbay MP-55 system installed, the volume of water between Westbay packers within a screen interval (inside the filter pack) is about 50 L (13 gal.).

A standard operating procedure (SOP) for sampling groundwater from Westbay systems has been developed (LANL 2005a). Groundwater is sampled by lowering a sampling device attached to (up to) four 1-L containers into the well. The containers are attached to a vacuum pump before each sampling run, and the pressure in the containers is lowered to about 2 psi. The vacuous containers are lowered to the port at the screen to be sampled, and when attached to the port, the containers draw water from the well into the sample containers. The landing of the sampling equipment at a port can sometimes be difficult. Westbay sampling procedures require the operator to record detailed pressure measurements inside and outside the Westbay casing each time sampling is performed to ensure proper operation of the system. The maximum volume sampled per run is 4 L for a sampling rate that depends on the depth of the port sampled. The average sampling rate for the >1000-ft Laboratory wells is approximately 4 L/h (1 gal./h). At this rate of production, purging is not practical, and sampling personnel costs are higher than those for systems using submersible pumps. Figure 2-2 shows how a sampling device or transducer is connected to a port.



Source: CLAIRE 2002.

Figure 2-2 Diagram showing how a Westbay sampler attaches to a port

The sampling equipment requires a dedicated trailer and winch system (Figure 2-3) and special training and certification for operators. The Laboratory has purchased two sampling trailers and has several trained and certified operators for the equipment. Operator errors during sampling or transducer operations can lead to costly equipment damage and potentially to cross-contamination of groundwater zones. Operation of the Westbay systems has not caused significant equipment damage or cross-contamination of zones in the 7 yr of Westbay operations at the Laboratory.

Westbay PPs are installed at each screen to potentially allow higher-flow sampling of each screen. The PPs are operated using compressed gas to open or close the PP sliding valve, which when open allows a much larger opening to the screen than do the monitoring ports. Opening a PP allows formation water to enter the Westbay casing where a submersible pump is used to pump the water to surface. Westbay demonstrated this method of sampling at R-16, but problems occurred with the submersible pump, and the demonstration was not entirely successful. The problem with this method of sampling groundwater from multiple screens is that potentially contaminated groundwater that enters the Westbay casing cannot easily be removed or decontaminated, and cross-contamination of groundwater samples from different zones could occur. Also, when using a PP, the (formerly) DI water level inside the Westbay casing equilibrates with the PP zone water level so that the Pi and Po pressure differential is lost at that screen interval, and future transducer and sampling operations at that screen may be more difficult.

Figure 2-3(A) shows the hoist mechanism used for Westbay sampling. The sampling device with the medial black face plate is just below the upper cable wheel and is shown connected to several sample collection containers. Figure 2-3(B) shows the winch mechanism that operates the sampling device. The Westbay systems functioned according to manufacturer's specifications during groundwater sampling.


(A)


(B)

Source: Alethea Banar.

Figure 2-3 (A) Hoist mechanism used for Westbay sampling; (B) Winch mechanism that operates sampling device

2.5 Groundwater-Level Monitoring

Groundwater level is monitored in Westbay wells by installing a dedicated transducer at a monitoring port in each screen. The transducers are manufactured by Westbay and cost about $9,000 each. The transducers are equipped with arm and shoe motors for landing at the ports and attaching to the port valves (Figure 2-2). The transducers are attached in series using a cable that is manufactured by Westbay; the cable lengths are specific for each distance between monitoring ports. The cable is connected to a data logger/controller that is also manufactured by Westbay. The Laboratory developed an SOP for operation of the Westbay transducers (LANL 2005b). Laboratory personnel are trained and certified in transducer operations and have training to splice, rehead, and repair these cables. New cables have been purchased from Westbay because cables for several wells have corroded and have required replacement.

The transducers must be removed from the well each time the well is sampled, which adds to the operational costs of groundwater-level monitoring. The data loggers are housed in an equipment cabinet at the well head and are powered by solar panels and 12-volt batteries. The data loggers are susceptible to cold weather and transient disturbances from lightning; several data loggers have failed and have been repaired or replaced. In 2006, the repair and/or replacement of two data loggers took over 9 months as a result of Westbay delays associated with relocating.

Transducers that were installed in dry intermediate zones were removed from service in early 2006 to provide spare replacements as needed. Westbay transducers are available in 100-, 250-, and 500-psi ratings.

Groundwater level cannot be measured manually with a Westbay system installed in a well. All water-level data are calculated based on the elevation of the port and the hydraulic formation pressure measured by the transducer. All Westbay transducers measure absolute pressure; therefore, atmospheric pressure influences on the water must be subtracted from the pressure measurements. An SOP has been developed for the calculation of water levels in Westbay wells (LANL 2005c); however, depending on the barometric efficiency of a well, uncertainties exist with groundwater-level data obtained entirely from transducer measurements.

Hydrologic data have been obtained for the regional aquifer from the multiple completion (four to seven screen zones) Westbay wells that are not obtainable from single- or dual-completion wells. The data from the multiple zones in some wells have provided insight into the three-dimensional characteristics of the regional aquifer. Such data presently are only available from the Westbay systems. Thus, although the Westbay systems are relatively costly to install and operate, other systems would require multiple nests or monitoring wells to obtain similar groundwater-level data, incurring drilling and completion costs that might be equal to or significantly greater than that of the Westbay system.

2.6 Operational History

The first Westbay system was installed in R-12 in March 2000, and the last Westbay system was installed in R-26 in July 2004. Careful attention to pressure data during groundwater sampling and transducer operations is necessary to obtain appropriate samples and water-level data. Current operation personnel are experienced and are collecting representative groundwater samples and water-level data.

Operation of the Westbay systems in 16 wells over 7 yr has been routine, and the systems generally operate according to the manufacturer’s specifications. Technical support from Westbay has almost always been responsive and helpful. Westbay systems in monitoring wells R-20, R-16, and R-12 were removed in 2006 to rehabilitate screens as part of a rehabilitation pilot study (LANL 2006). The system at R-16 was reinstalled in August 2006, but as of July 2007, the systems at R-12 and R-20 have not been reinstalled.

Historically, significant problems with using the Westbay system at the Laboratory have included the following.

- Low-flow sampling of screens has been problematic because of the presence of residual drilling fluids in the screen zones.
- DI water from within the Westbay casing was unknowingly sampled from several ports at R-31 in 2001. The level of the deionized water declined noticeably, which was documented in the Pi pressure data collected during sampling. Subsequent evaluation of the pressure data revealed the sampling error.
- Well R-12 has an intermediate zone with a head of 6073 ft, and the regional aquifer has a head of approximately 5695 ft. This head difference is about 380 ft. When port MP2A leaked into the Westbay casing in 2005, the Pi pressure at port MP3A was as high as 180 psi with a formation pressure (Po) of 15 psi. Such conditions approach the pressure rating of the port valves and can lead to cross-contamination of zones through the Westbay casing.
- Monitoring port MP2A in R-12 leaked formation water into the Westbay casing each time a transducer or sampling device was connected to the port. This caused the water level in the Westbay casing to rise and equilibrate with the intermediate zone, resulting in high pressures at the deeper ports and possible leaking of intermediate water to the regional aquifer. The DI water was bailed from the Westbay casing twice in 2005. MP2A continued to leak during sampling events, but transducer operations were moved to the MP2B port. When the Westbay casing was removed from R-12, a gouge was present on the port face plate that did not allow proper connection of equipment to the port. This is the only known occurrence of this at the Laboratory, but it could occur at other Westbay wells with further use.
- Leaks have occurred at monitoring ports during sampling and transducer operations that have cause the DI water level to equilibrate or partially equilibrate with formation pressures at the port. This has occurred at CdV-R-15-3, R-12, R-16 (caused by PP operation), and R-25.
- During sampling of R-14 in 2005, the sampling equipment was being raised out of the well when the sampling equipment separated from the cable and fell into the Westbay casing. The equipment lodged at the DI water level and was subsequently fished out of the casing without damage to the casing or to the sampling equipment. Corrosion of the cable at the connection with the sampling equipment is the suspected cause.
- Cable corrosion has been observed on the cables used for sampling and transducer deployment. Cables have been replaced as needed.

2.7 Long-Term Operational issues

Generally, the Westbay systems at the Laboratory have functioned as designed, with relatively minor equipment problems attributable to wear and tear from routine use. Systems have been in service for 5 to 7 yr without major problems. Groundwater sample issues have been attributed to the inadequate development of screens after well construction rather than from Westbay equipment or operational problems. However, the inability of the Westbay system to purge before sampling has proven to be a disadvantage. The scratched or gouged port face plate at R-12 MP2A is the only known instance of a Westbay casing problem. However, as the systems age, additional problems may be encountered.

Several Westbay data loggers have shown problems during cold weather, and some data loss has been experienced that might be attributable to transient voltage from lightning strikes. Equipment cabinets have been grounded to protect against lightning damage, transient protection has been provided for cabling, and data loggers were replaced.

Also, several transducers have shown signs of failure and have been replaced and/or repaired. Over the past several years, 6 out of 56 transducers have malfunctioned and have been sent to Westbay for repair. This represents about 10% of the Westbay transducers, which over 6 yr of service is a reasonable failure rate. Pressure transducers typically have operational lifetimes of 5 to 7 yr. Because the Westbay systems are aging, additional repair or replacement of transducer equipment may be needed in the next few years. A contract with Westbay is in place for obtaining replacement equipment.

Westbay technical support has been timely, responsive, and effective.

2.8 Westbay Sampling System Summary

The advantages and disadvantages of the Westbay sampling system are summarized in Table 2-2.

3.0 BARCAD DUAL-PUMP/PACKER COMPLETION SYSTEM (R-33)

The BESST, Inc., Barcad dual-pump and packer system was installed at R-33, a dual-screen completion well in the regional aquifer. The Barcad sampling system is a **low-flow, no-purge** sampling system. This system was selected as an alternative to the Westbay system and installed at R-33 in February 2005 by BESST, Inc., personnel. However, for several reasons, the Barcad system did not function properly until October 2006 when a permanent pressure system was installed to maintain a constant pressure on the packer. Table 3-1 summarizes the R-33 Barcad construction information.

3.1 Design and Materials

The Barcad pump and packer system for R-33 was designed by BESST, Inc., personnel, who were provided the well completion details. The Barcad pump is a pressure-activated foot valve (poppett valve) that closes when compressed nitrogen gas is applied to the water column inside the pump system. When the valve closes, the water inside the pump system is isolated from the formation water, and the compressed gas forces the water to the surface through a discharge tube. When pressure is removed from the system, the valve opens and allows the formation water to gravity flow into the pump system, thus recharging the pump system. Thereby, the “pumping” is done in cycles, and pump-cycle volumes are limited to the volume of water that is present in the pump system above the pump valve. Figure 3-1 illustrates the Barcad pump schematic design.

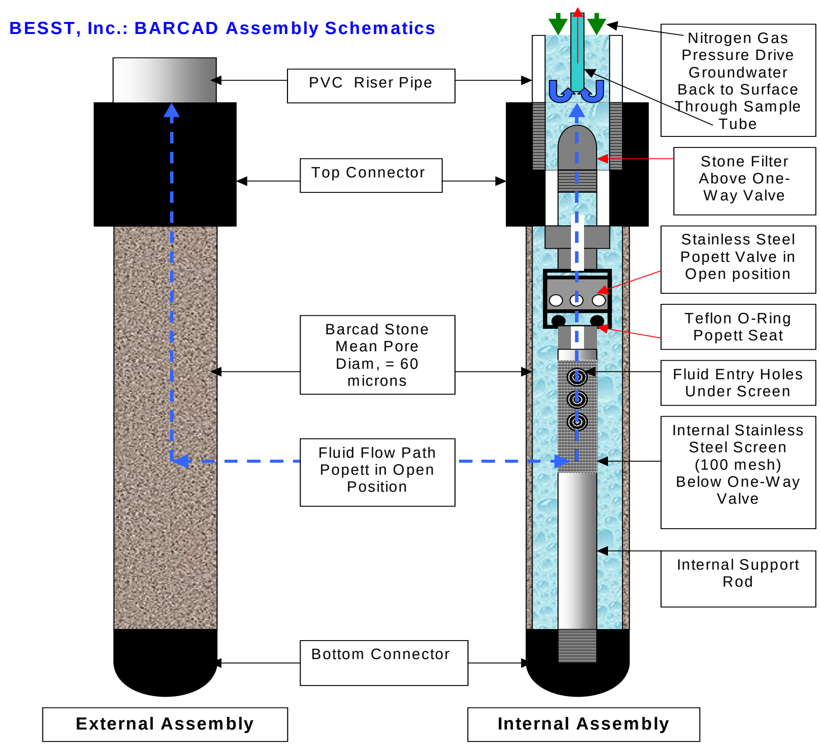
Table 2-2
Summary of Westbay Sampling System

Criteria	Advantages	Disadvantages
Design	System is well designed and durable.	Low-flow, no-purge sampling design
	Many screens can be monitored in one well.	Potential for possible cross-contamination
	Water-filled packers	Requires complex surface equipment including winches and sampling trailer and associated maintenance
Materials	Materials and equipment appear to be durable	Materials are only available from Westbay.
Cost	None	Cost of system is among highest of those compared.
Installation	None	Requires Westbay personnel and equipment to install/remove
		Installation/removal requires 3–5 d.
Maintenance	Packers do not require pressure or routine maintenance.	Surface and down-hole equipment require routine maintenance.
Groundwater Sampling	High voltage not is required.	Low-flow, no-purge sampling may not provide representative groundwater data.
	Many screens can be sampled in one well.	Potentially stagnant water is sampled between Westbay casing and well casing.
	Compressed gas is not required.	Specialized training for sampling personnel is required.
		Sampling flow rate is about 4 L/h or 28 L/d.
		Sampling time is about 1 d/screen.
		Unique equipment and trailer is needed for sampling.
	Pumping port is available for higher flow sampling.	Use of pumping port contaminates water inside Westbay casing and any tools in contact with water.
	Packers seal each screen zone from atmosphere so no stagnant water.	Volume of water inside well in contact with well materials cannot be purged.
Groundwater-Level Monitoring	Many screens can be monitored simultaneously.	Transducers and logging equipment are only available from Westbay.
		Transducers must be removed from well during sampling operations.
		Specialized training for personnel is required.
		Manual measurement of groundwater level is not possible.
Operational History	Systems have been in operation for 7 yr without significant problems.	Routine maintenance is required for cables and surface equipment
Long-Term Operational Issues	No compressed gas systems for packers or sampling	Routine maintenance is required for cables and surface equipment
	Annual electrical inspection is not required.	
	There is no need to maintain compressed gas systems for packers or sampling; annual electrical inspection is not required	As equipment ages, potentially expensive replacement and repairs will be likely required.

Table 3-1
Summary of R-33 Barcad Construction Information

	Zone 1	Zone 2
Screen Top Depth (ft)	995.5	1112.4
Screen Bottom Depth (ft)	1018.5	1122.3
Screen Top Elevation (ft)	5857.8	5740.9
Screen Bottom Elevation (ft)	5834.8	5731.0
Screen Length (ft)	23.0	9.9
Pump Intake Depth (ft)	1011.9	1114.9
Pump Intake Elevation (ft)	5841.4	5738.4
Depth to Top of Packer/Sump(ft)	1080.8	1122.3
Top of Packer/Sump Elevation (ft)	5772.5	5731.0
Depth to Sump Bottom (ft)	1080.8	1126.0
Sump Length (ft)	62.3	3.7
Sump Volume (L)	194.8	2.0
Comment	Regional aquifer	Regional Aquifer

Note: R-33 brass cap ground elevation is 6853.33 ft. All measurements are from this elevation.



Source: Barcad 2002.

Figure 3-1 Barcad pump system schematic diagrams

This type of pump system functions best when the water level is at least 30% of the distance between the pump and the surface. For example, in a 1020-ft-deep well with a screen from 996 to 1019 ft below ground surface (bgs) and the pump located at 1012 ft bgs (e.g., R-33, Screen 1), the water level should ideally be about 300 ft above the pump or about 700 ft bgs. Because the water level at R-33 is at 990 ft bgs, or 20 ft above the pump, the volume of water available to pump to the surface in a pump cycle is extremely limited. Therefore, BESST, Inc., personnel designed each of the R-33 Barcad pumps with a 27-ft-long, 2-in.-O.D. (1.87-in.-I.D.) "HydroBooster" or "volume booster" pipe connected to the top of the Barcad pump to provide an additional volume of water for each pump/purge cycle. Each volume booster contains 3.9 gal. (14.6 L) of water, which is the maximum volume of water that can be pumped/purged during a pumping cycle.

The Barcad pump is designed to be installed in either a well or a borehole. If installed in a borehole, the pump can be buried within filter-pack material because the housing is permeable stainless steel, polyethylene, or ceramic material that acts as a water filter; however, this type of installation would not be appropriate for the deep monitoring wells at the Laboratory. Multiple Barcad systems can be installed in a well or borehole. The dual Barcad system at R-33 is installed in a 4.5-in.-I.D. well that is 1126 ft deep; the screens are about 100 ft apart (Table 3-1). The Barcad system design allows for installation in wells with more than two screens; it may be possible to install Barcad pumps in monitoring wells (4.5 in.-I.D.) with up to four screens.

Groundwater samples obtained with the Barcad sampling system are collected from the water inside the well. For water samples collected from the upper screen zone above the packer, the water inside the well is in contact with the atmosphere and is considered stagnant water. At R-33 Screen 1, the volume of stagnant water in the well above the packer is about 80 gal. (Table 3-2). Water within the well below the packer is not exposed to the atmosphere but is in contact with well materials and may not be entirely representative of formation water. At R-33 Screen 2, the volume of water in the well below the packer is about 31 gal. It is doubtful that the low-flow, no-purge Barcad system design can collect representative groundwater samples in deep monitoring wells.

Fiber optic transducers were installed adjacent to each Barcad pump in R-33 to monitor groundwater levels. The transducers are ROCTEST Model FOP; the upper transducer has a rating of 75 psi, and the lower transducer has a rating of 150 psi. The transducers are connected by means of fiber optic cable to two FTI-10 signal conditioners manufactured by FISO Technologies, Inc. (FISO), which also provide data logging capability.

The Barcad sampling system is composed of a "pump" valve (Figure 3-1) that is 1.3 ft in length, 1.5-in.-O.D., and is made of durable inert materials. The pump consists of a poppett valve surrounded by a permeable housing that allows water to enter the valve and the associated HydroBooster. The HydroBooster is a 27 ft long, 2-in.-O.D. stainless-steel pipe attached above each pump in R-33.

The two screens in R-33 are separated by a TAM International, Inc., model SD packer that is 3.5-in.-O.D. (relaxed) with a nitrile packer surface. The packer is inflated using a 0.25-in.-O.D., 0.125-in.-I.D. NPT Teflon tubing. The packer, pumps, and HydroBoosters are suspended from the well head by a stainless-steel cable 0.25-in.-diameter. Two 0.25-in.-diameter Teflon tubes bundled in a polyethylene sleeve jacket are connected to each of the volume boosters and pump systems. Each tube bundle extends from the top of the HydroBooster to the surface. One tube supplies nitrogen gas to the top of the water column in the HydroBooster, and the other tube is for the discharge of the water from the pump system to the surface. The Laboratory developed a surface manifold system for operation of the pumps.

Table 3-2
R-33 Conventional Purge Volumes and Purge Times

	Zone 1	Zone 2
Water Level at Top of Zone (ft)	980.0	1083.3
Water Level at Bottom of Zone (ft)	1080.8	1126.0
Length Purge in Zone (ft)	100.8	42.7
Stainless Steel Casing I.D. (in.)	4.5	4.5
Tubing O.D. (in.)	2.0	2.0
Stainless Steel Volume (L)	300.7	119.0
Purge Volume Criteria (no. casing volumes)	1	1
Purge Volume (L)	300.7	119.0
Purge Volume (gal.)	79.4	31.4
Purge Rate (L/h)	5.9	9.3
Purge Rate (gal./h)	1.6	2.5
Purge Time (h)	51.0	12.8
Comment	1 casing volume	1 casing volume

3.2 Cost

The cost of the Barcad system is estimated to be about $20,000 for a dual-screen completion, including installation. Because of the simplicity of the installation compared with other multiple completion systems, the Barcad system is relatively inexpensive. Conventional transducers used with a Barcad system would be an additional $10,000.

3.3 Installation and Maintenance

BESST, Inc., personnel installed the Barcad pump system in February 2005. However, installation and maintenance of the system could probably be performed by any water well contractor equipped with design drawings and/or instructions.

The Barcad pump and packer system require little maintenance. The Laboratory installed an equipment cabinet at the well head in the spring of 2006 to house the pump tubing bundles and the transducer equipment. Before that time, all Barcad surface equipment was stored under a temporary cover for protection from the elements.

Pressure must be supplied to the packer to maintain the packer seal and to isolate the two screen zones in the well. Laboratory KSL personnel installed the dedicated compressed nitrogen tank and pressure system safety manifold in October 2006. Before that time, the packer was not fully inflated, and the two screen zones were in hydraulic communication. Maintenance of nitrogen tanks and packer pressure can be performed by Laboratory personnel.

The packer was inflated at R-33 on August 16, 2006, for testing the Barcad pump system. The packer leaked and the screen isolation failed about 3.5 d after inflation. In October 2006, a dedicated nitrogen tank was connected to the packer to maintain inflation.

During installation of the transducers in February 2005, the FISO signal conditioners were incorrectly recalibrated to zero. Thus, measurements from both transducers were zero until March 2006 when the signal conditioners were reprogrammed with the correct calibration data. Maintenance of the data-logging equipment has been performed by Laboratory and contractor personnel since the initial installation.

3.4 Groundwater Sample Quality

Groundwater sampling using the Barcad system is a **low-flow, no-purge** method that does not allow for purging of the well before collecting samples. Groundwater samples have been collected from the Barcad system at R-33 after discharging one cycle volume of the Barcad tubing system, which has been about 10 L (2.6 gal.) at Screen 1 and about 14 L (3.7 gal.) at Screen 2. The pump/purge rate of the Barcad system has been about 6 L/h (1.6 gal./h) from Screen 1 and about 9.3 L/h (2.5 gal./h) from Screen 2. The Barcad sampling system does not meet the current Laboratory-site DQOs for collecting representative groundwater samples from the formation because of its inability to adequately purge the well casing before sampling.

Table 3-2 summarizes the single casing purge volumes and purge times using the Barcad system at R-33. The packer location is about 30 ft above Screen 2, which results in a large volume of stagnant water at Screen 1 above the packer. The time to purge one casing volume from either Screen 1 or 2 would be prohibitive. BESST, Inc., personnel maintain that the low-purge/pump rates draw the water from the formation through the filter pack and the well screen directly into the Barcad pump, rather than drawing stagnant water in the well into the pump. This would be difficult to demonstrate.

Groundwater purging/sampling of the Barcad system is performed by applying pressurized nitrogen gas to the system, which forces the water to the surface. The amount of pressure is determined by the depth of the pump. At Screen 1, the pump is 1012 ft bgs; at 2.31 ft/psi of water, plus 10% for friction loss, the amount of pressure is about 480 psi. At Screen 2, the pump is 1115 ft bgs, so the pressure needed to bring water to the surface is about 530 psi.

The groundwater sampling characteristics of the Barcad pump systems at R-33 were obtained on August 16, 2006. In summary, the sampling characteristics include the following.

- The complete pump/purge cycle time at Screen 1 is about 100 min. The minimum time from gas-off to the next cycle gas-on is 50 to 60 min.
- The Screen 1 purge volume was 9.47 L, and the overall pump/purge rate was about 5.9 L/h.
- The complete pump/purge cycle time at Screen 2 is about 90 min. The minimum time from gas-off to the next cycle gas-on is about 25 min.
- The Screen 2 purge volume was 13.97 L, and the overall pump/purge rate was about 9.3 L/h. The pressure data measured during purging at Screen 2 indicate that a small leak may be present in the Barcad pump or associated piping during gas-on pump operation.

3.5 Groundwater-Level Monitoring

Groundwater-level monitoring equipment was installed with the Barcad system in February 2005. Fiber optic transducers manufactured by ROCTEST were installed at each Barcad pump. The fiber optic cable from each transducer connects at the surface to a FISO Model FTI-10 fiber optic signal conditioner and data logger. Table 3-3 summarizes the transducer information. The transducers were installed with the pump system and are not retrievable without removing the entire Barcad system.

Table 3-3
R-33 Transducer Information

Screen	Transducer SN	Rating (psi)	Gage Factor	Sensitivity (nm/psi)
1	PR0507	75	6001088	108.8
2	PR0506	150	6014840	48.40

No gage tubes for manual groundwater measurements or for insertion and removal of transducers were installed at R-33. Manual measurement of the water level at R-33 is not feasible because of the design of the Barcad system; the 2-in. volume booster at Screen 1 extends above the water table and does not provide enough space between the booster and the well casing to install a 1-in.-diameter gage tube. The two control tubing bundles from each Barcad pump and the two fiber optic cables are loosely banded to the support cable, preventing the safe insertion and retrieval of a water-level measuring tape.

Thus, groundwater levels in R-33 have been calculated from the known volume of the tubing and volume booster equipment and the purge volume from Screen 1. Because of uncertainties in the construction information pertaining to the intake depth of the return flow line in the volume booster, groundwater-level calculations cannot determine the water level with accuracy greater than about 0.5 ft.

Automated groundwater-level monitoring at R-33 has been plagued with problems since the transducers and associated data-logging equipment were installed in February 2005. One of the signal conditioners failed when the system was installed and was replaced by the Barcad manufacturer. The signal conditioners were calibrated to zero after installation of the transducers in the well, which caused all measurements to be zero until March 2006 when transducer calibration information was obtained from the manufacturer.

The FISO signal conditioners operate on 12-volt power; the manufacturer supplied a 120-volt to 12-volt converter with each signal conditioner for use in a laboratory setting. The initial installation of the transducer equipment included a solar panel to charge a 12-volt battery and an inverter to transform the 12-volt power to 120 volts. During the first year of operation, the inverter failed frequently, and power to the signal conditioners was lost, usually within a few days after resetting the inverter power. In March 2006, the 120-volt system was removed, and power to the signal conditioners was supplied directly from the battery, which proved to be much more reliable than the 120-volt system.

One of the FISO signal conditioners failed, and a replacement was obtained from the manufacturer in August 2006 (about $4,000). This was the second failure of one of the signal conditioners because one did not function during the initial installation in February 2005 and was replaced by BESST, Inc. The FISO signal conditioner light life expectancy is about 4.5 yr, which is similar to the life expectancy of other transducer equipment; however, it is at a replacement cost about three times higher than that of other equipment.

Composite water levels were measured at R-33 until October 2006 when a dedicated compressed nitrogen gas tank and safety manifold were constructed and connected to the packer system. Figure 3-2 shows the R-33 composite water level measured at each screen in July 2006. The water level fluctuates in response to pumping at nearby supply well PM-5. Note that the Screen 1 water level lags behind the Screen 2 water level, probably because of restricted water movement past the deflated packer.

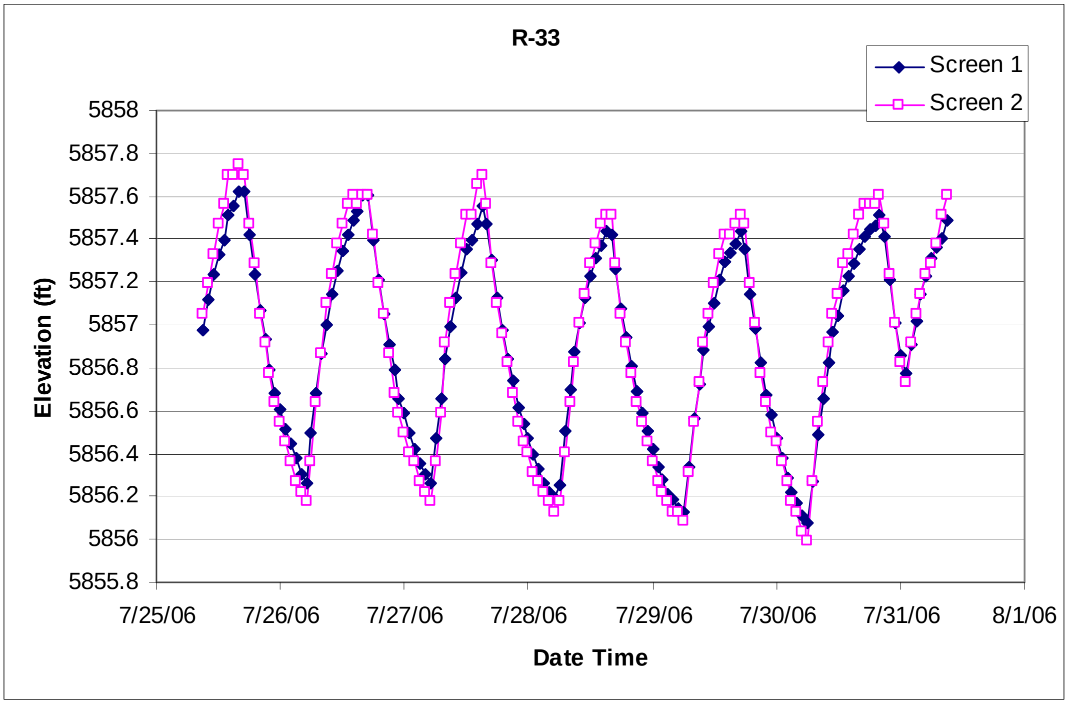


Figure 3-2 R-33 composite water level measured at each screen

Figure 3-3 shows the R-33 water levels at each screen with the packer properly inflated. The water level at Screen 2 responds to pumping of nearby water supply well PM-5; the water level declines about 7 ft each time PM-5 operates. With the packer inflated, the water level at Screen 1 does not show a significant response to PM-5 pumping.

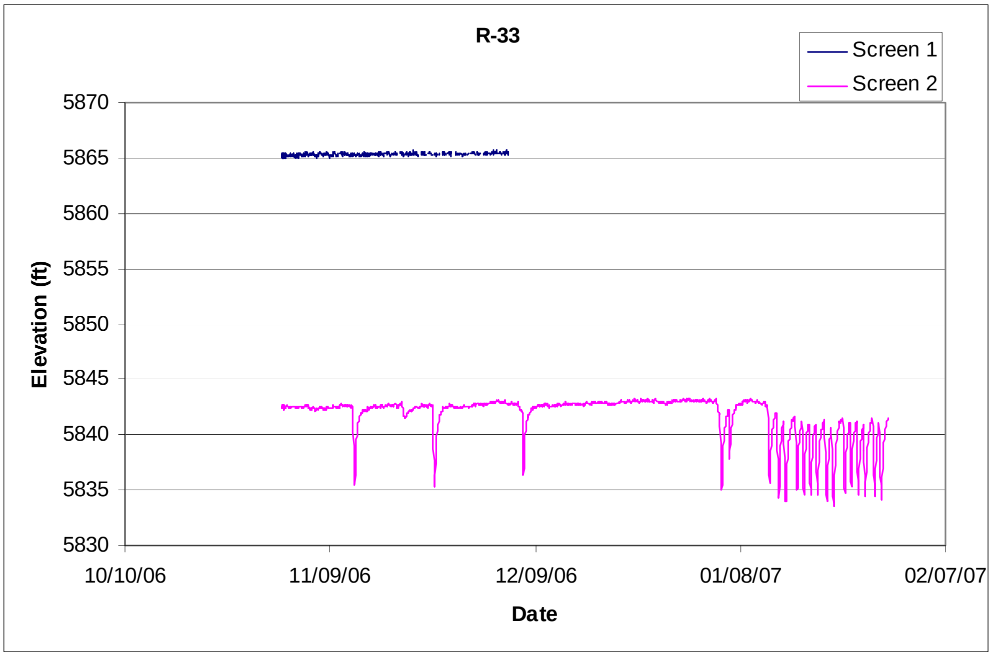


Figure 3-3 R-33 discrete zone water levels measured with the packer inflated

Groundwater-level monitoring at R-33 was fully functional in October 2006 when the packer was inflated, and a dedicated pressurized gas system was installed for the packer. However, intermittent problems continued with the FISO signal conditioners and data loggers, and data were lost from Screen 1 from December 2006 to January 2007 (Figure 3-3).

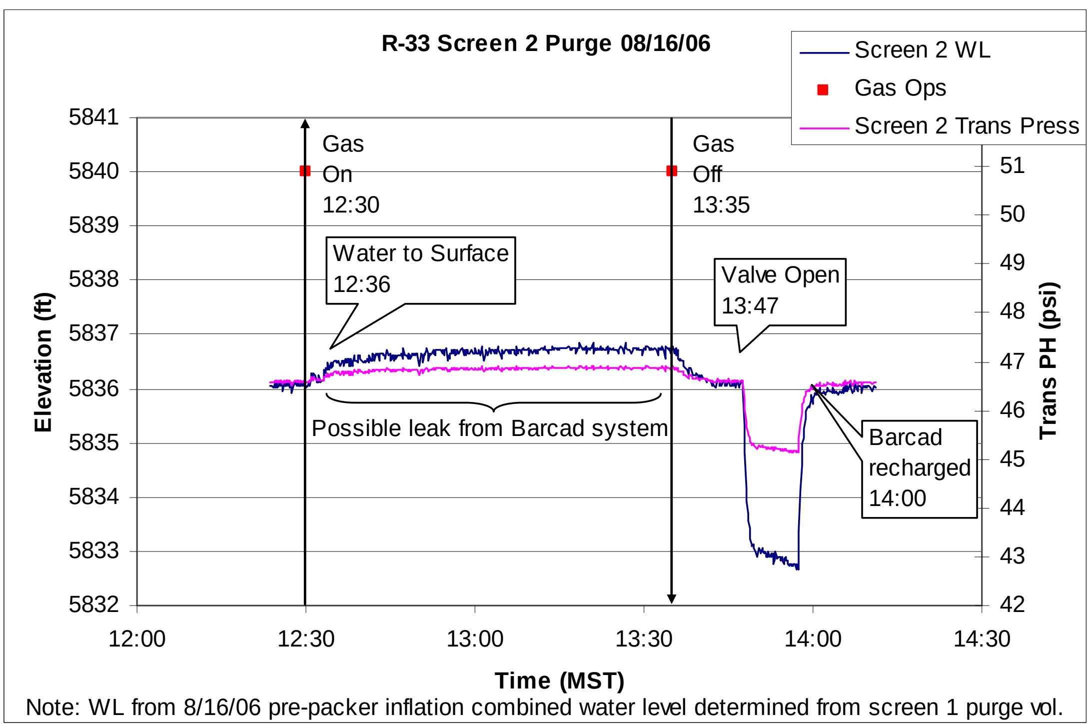


Figure 3-4 R-33 Screen 2 purge pressure time series on August 16, 2006

3.6 Operational History

BESST, Inc., personnel returned in March 2006 to complete installation of the system and transducers but were unable to obtain meaningful data from the transducers. The surface equipment for operation of the sampling system was subsequently installed over a year after the system was installed. Weatherproof equipment cabinets were installed in March 2006, and a dedicated pressurized gas tank was installed in October 2006. The transducer equipment was fully functional in November 2006.

Groundwater samples were collected from R-33 using the Barcad system in June 2005, February 2006, July 2006, and October and November 2006. Because the packer was not properly inflated until October 2006, groundwater samples collected before this time were not discrete zone samples but were from the composite water in the well. Because of the >20-ft head difference between the screens in the well, the source of water collected from both screens was likely Screen 1. Water-level data obtained after inflation of the packer in October 2006 indicated that the leak rate from Screen 1 to Screen 2 was approximately 1150 gal./d. Thus, all groundwater samples from R-33 before October 2006 likely represent Screen 1 water quality. This is substantiated by the analytical results that do not show a significant difference between water collected from each screen before October 2006.

During the testing of the Barcad system on August 16, 2006, with the gas on to the Screen 2 Barcad pump, elevated pressure (0.3 psi) was measured by the transducer at Screen 2; the elevated pressure quickly decayed after the gas was turned off (Figure 3-4). This pressure response may indicate a leak from the Barcad pump valve or associated volume enhancement pipe during purge/pump operations. Such a leak may cause recovery of a reduced volume of water from the pump system during pumping/purging and a slightly longer gas-on time. The calculated volume of water in the Barcad pump system at a water elevation of 5836 ft is 14.74 L; however, the recovered volume of water from Screen 2 (13.97 L) indicates that about 0.77 L of water leaked from the Barcad pump system during gas-on operations.

3.7 Long-Term Operational Issues

The Barcad sampling system is relatively simple to operate, and the manufacturer claims the system is reliable for many years. Compressed nitrogen gas must be supplied to keep the packer inflated and the two screen zones isolated. Thus, a tank of compressed gas must be maintained at the well site, and the packer pressure and tank pressure must be routinely monitored by operations personnel.

The fiber optic transducers are permanently installed with the pump system, and any repair or maintenance would require removing the Barcad system from the well. The fiber optic signal conditioners have been unreliable, particularly when compared with the operation of other transducers at the Laboratory. The Barcad design at R-33 does not allow for manual groundwater-level measurement of the 4.5-in.-diameter well, which represents a significant drawback. The transducer and signal conditioner manufacturers are both Canadian companies.

The Barcad system is simpler in design, installation, operation, and maintenance than the Westbay and Baski systems and appears to operate according to manufacturer’s specifications. However, this type of sampling system may not be appropriate for the deep monitoring well requirements at the Laboratory, especially with regard to purging water from the well. The pump/purge rate of the Barcad system averages 6 L/h (1.6 gal./h) from Screen 1 and 9.3 L/h (2.5 gal./h) from Screen 2. These slow purge/pump rates increase the operational costs of collecting groundwater samples from R-33. Depending on the volume of water needed for a sample, the sampling of R-33 typically takes 2 d, whereas other dual-completion wells with conventional pumps can be sampled in less than 1 d.

3.8 Barcad Sampling System Summary

The advantages and disadvantages of the Barcad sampling system are summarized below in Table 3-4.

Table 3-4
Summary of Barcad Sampling System

Criteria	Advantages	Disadvantages
Design	Relatively simple design	Low-flow, no-purge sampling design
	Potentially could accommodate three or four screens.	Design is not appropriate for deep regional aquifer wells.
Materials	Few materials but durable	None
Cost	Relatively low-cost system	None
Installation	Relatively quick and easy installation/removal	None
	Any knowledgeable contractor could install/remove.	
Maintenance	Little or no maintenance for equipment	Packer requires supplemental pressure source.
Groundwater Sampling	No complex equipment is required for sampling.	Low-flow, no-purge sampling may not provide representative groundwater data.
	High voltage is not required.	Sampling flow rate is from 6 to 9 L/h.
		Sampling time is about 1 d/screen.
		Compressed gas required for sampling
		Continuous compressed gas must be maintained to packer to isolate screen zones.
		Large volume of stagnant water is in well.
Groundwater Level Monitoring	None	Manual measurement of groundwater level is not possible.
		Fiber optic transducer equipment has been unreliable.
		Transducer equipment is not removable without removing entire sampling system.
Operational History	None	Fiber optic transducer equipment has been unreliable.
		Surface equipment was not installed when system was installed.
		Manufacturer support is lacking.
		Packer does not hold pressure without auxiliary pressure source.
Long-Term Operational Issues	Relatively simple to operate	Compressed gas is required for packer inflation and sampling operations.
	Annual electrical inspection is not required.	

4.0 BASKI PACKER WITH DUAL VALVE SYSTEM (R-10, R-17)

The Baski packer with dual-valve system is a **high-flow** sampling system capable of conventional purging of a well. The Baski packer with dual-valve/single-pump system has been installed in two dual-screen wells at the Laboratory: R-10 and R-17. The system isolates each screen zone by means of an inflatable packer. Pressure-activated valves are situated at each screen and connected by 1-in.-diameter pipe to the pump. The pump is located above the packer and is shrouded to isolate the pump and obtain water from whichever valve is open (Figure 4-1). Thus, only one submersible pump is required to obtain discrete groundwater samples from two screens. The pump at R-10 is capable of pumping 12 gal./min, which provides quick **conventional purging and sampling** of each zone in the well.

4.1 Design and Materials

The Baski packer with dual-valve/single-pump system for R-10 and R-17 was designed by Baski, Inc., in association with Kleinfelder, Inc., personnel. The packer and the access port valves (APVs) are manufactured by Baski, Inc. The pump is a conventional submersible electric pump manufactured by Grundfos equipped with a shroud assembly that isolates the pump within the production piping. Figure 4-1 illustrates the components of the Baski packer and dual-valve system at R-10. The design represents recent innovations in environmental well technology.

The packer inflation line is also connected to the “close” side of each APV to provide a positive pressure on the valves in the closed position. To open the APVs, pressure in excess of the packer pressure and the water-column pressure in the drop pipe must be applied to the “open” side of the valve (Baski 2006).

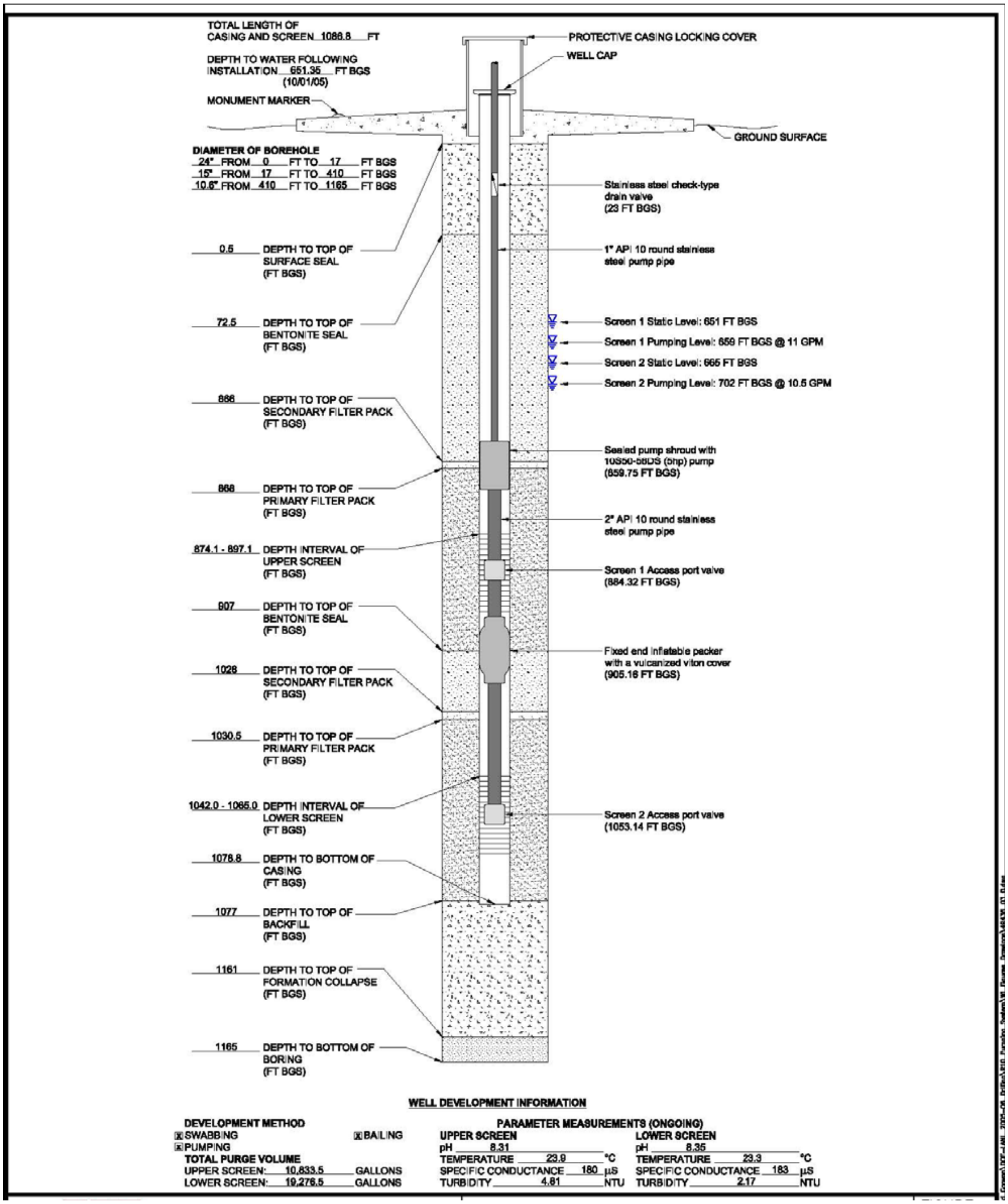
The Baski packer with dual-valve sampling system collects water from within the well. The water in the well above the packer is in contact with the atmosphere and is stagnant; however, the ample pump and purge rates of the system allow for purging the conventional three casing volumes or more in a reasonable time (see Tables 4-1 and 4-2) before collection of samples. Thus, groundwater samples are representative of formation water.

The Baski packer is made of stainless steel and multiple-ply reinforcement rubber materials with a DuPont Viton cover. The packer is resistant to permanent deformation and can return to the original outside diameter after inflation (Baski 2006).

The Grundfos stainless-steel submersible pump is attached to 1-in.-diameter stainless-steel production tubing (drop pipe) that extends to the surface. The standard pump from the manufacturer was retrofitted with inert materials for additional suitability for environmental sampling. A foot valve is located at the top of the pump and another is located at the base of the production pipe.

The Baski APVs are sleeve-type valves of stainless steel construction. The packer and the APVs are operated through 0.25-in.-nylon tubing that extends from the surface to the top of the pump shroud, from the bottom of the pump shroud to the top of the packer, and from the bottom of the packer to the lower APV. The nylon tubing connects to 0.125-in. stainless-steel tubing through the pump shroud and to 0.1875 in.-nylon tubing through the packer. Stainless-steel Swagelok and Ferulok fittings are used to connect the nylon tubing with the stainless-steel tubing, and with the packer and APVs.

Where the control lines pass through the pump shroud, O-rings and Swagelok fittings provide the seal between the water in the well at Screen 1 and the water inside the pump shroud. Baski guidance states that the O-rings are to be coated and lubricated with Dow 11 grease and Dow 200-20cs lubricant.



Source: Kleinfelder June 2006.

Figure 4-1 Schematic diagram of the Baski packer and dual-valve system in R-10

Table 4-1
R-10 Calculated Purge Volumes

	Zone 1	Zone 2
Water Level Top of Zone (ft bgs)	652.0	658.0
Bottom Zone (ft bgs)	905.2	1081.6
Length Purge in Zone (ft)	253.2	156.8
Casing I.D. (in.)	4.5	4.5
Tubing O.D. (in.)	1.2	2.0
Casing and Tubing Volume (L)	848.4	678.0
Purge Volume Criteria, No. Casing Volumes	1	1
Purge Volume (gal.)	848.4	678.0
Purge Volume (L)	224.2	179.1
Purge Rate (L/min)	45.4	45.4
Purge Rate (gal./min)	12.0	12.0
Purge Time (min)	18.7	14.9
Comment	1 casing volume	1 casing volume

Table 4-2
R-17 Calculated Purge Volumes

	Zone 1	Zone 2
Water Level Top of Zone (ft bgs)	1036.5	1037.5
Bottom Zone (ft bgs)	1101.2	1140.9
Length Purge in Zone (ft)	64.6	36.8
Stainless Steel Casing I.D. (in.)	4.5	4.5
Tubing Diameter (in.)	1.2	1.0
Stainless Steel Casing and Tubing Volume (L)	346.6	294.8
Purge Volume Criteria, No. Casing Volumes	1	1
Purge Volume (L)	346.6	294.8
Purge Volume (gal.)	91.6	77.9
Purge Rate (L/min)	9.5	9.5
Purge Rate (gal./min)	2.5	2.5
Purge Time (min)	36.6	31.2
Comment	1 casing volume	1 casing volume

The water-level gage tubes are 1-in. schedule-80 flush joint threaded PVC pipe. The bottom 1-ft of the upper screen gage tube was perforated with 0.25-in.-drill holes to allow monitoring of the water level at Screen 1; the bottom of the gage tube is capped with a PVC end cap. The PVC gage tube for the lower-screen interval ends above the pump shroud with a PVC end cap that is fitted with a 0.25-in.-stainless-steel Ferulok fitting. The lower zone gage tube is connected to 0.25-nylon tubing that connects to a 0.125-in.-stainless-steel tube through the pump shroud and to 0.1875-in.-nylon tubing through the packer. The 0.1875-in-nylon tubing extends a few feet below the packer and is open at the end, providing access for gaging the water level at Screen 2 below the packer.

In R-17 and R-23i (Section 5), the bottom of the lower zone 1-in. PVC gage tube was fitted with a stainless-steel screen to prevent plugging of the smaller diameter 0.25-in.-nylon tubing by debris. The bottom of the 0.1875-in diameter tubing below the packer was attached to a stainless steel Ferulok fitting with a stainless-steel screen to prevent plugging of the bottom of the gage line. Additionally, the 0.125-in.-stainless-steel tubing through the pump shroud was replaced with 0.1875-in.-stainless-steel tubing at R-17 to provide a larger diameter gage tube through the pump shroud.

4.2 Cost

The cost of a Baski packer with dual-valve system for a dual-completion well is estimated to be $120,000, including installation, the packer, which is about $20,000, and the APVs, which are about $15,000 each. The specialized tooling and machining required for these systems is where most of the cost is incurred. The transducer equipment for a dual completion well is an additional $10,000.

4.3 Installation and Maintenance

The Baski packer/valve/pump system was installed by Kleinfelder, Inc., personnel using a water well completion rig. The installation of the system is complex with multiple control lines, numerous control line fittings, production drop tubing, and gage tubes that must fit into the 4.5-in.-diameter well casing. The control line fittings, especially the packer inflation tubing compression fittings, must be pressure tested during installation for QA and to ensure that no significant leaks are present in the system. Baski, Inc., provided the installation contractor instructions, schematics, and QA procedures for installation (Baski 2006).

Appropriate line pressure must be supplied to the packer and the closed side of the APVs to maintain the packer inflation and to keep the APVs closed. If pressure is not maintained to the packer and APVs, the packer will deflate and the valves may open, creating a conduit for cross-contamination of water between screens.

The minimum packer pressure required at a Baski packer system is the sum of the pressure needed to inflate the Viton rubber packer (50 psi), the pressure of water above the packer, and the differential pressure above and below the packer (Baski 2006).

R-10, Screen 2 has a head about 14 ft lower than Screen 1, for a pressure differential of about 6 psi and a water level about 254 ft above the packer. The minimum packer pressure at R-10 is 50 psi plus (254 ft/2.31 ft/psi) 110 psi plus 6 psi, for a minimum total of 166 psi. With an additional 10% of the minimum packer pressure for friction losses, a total packer pressure at R-10 would be 185 psi.

R-17, Screen 2 has a head about 2 ft lower than Screen 1, for a pressure differential of about 1 psi. The minimum packer pressure required at R-17 is 50 psi plus (66 ft/2.31 ft/psi) 29 psi plus 1 psi, for a minimum total of 80 psi. With an additional 10% of the minimum packer pressure for friction losses, a total packer pressure at R-17 would be at least 90 psi.

4.4 Groundwater Sample Quality

Groundwater purging and sampling using the Baski packer with dual-valve system is a **high-flow** system capable of purging that is relatively fast compared with other multiple-completion regional aquifer sampling systems. The Baski system at R-10 has a pumping rate of 12 gal./min and at R-17 has a pumping rate of 2.5 gal./min. The differences in the production rates for these wells are a consequence of formation limitations at each well rather than limitations of the sampling system. The Baski packer with dual-valve sampling system appears to meet current Laboratory-site DQOs for collecting representative groundwater samples from the formation because it has the ability to adequately purge the well before sampling.

Pumping from a discrete screen zone is accomplished by applying gas pressure to the open side of one of the APVs in the zone from which samples are to be collected. The pressure applied to the APV must be higher than the packer pressure, and at R-10 about 400 psi is used to open the valves (Kleinfelder 2006b). Water flows into the pump and production pipe. After an APV is opened, the electric submersible pump is activated, and water is pumped to the surface. The submersible electric motor requires a 460-V, three-phase power supply. There are two check valves in the drop pipe, one in the pump and another at the base of the drop pipe; therefore, water should flow to the surface almost immediately after filling the pipe above the weep hole, which is located 24 ft bgs (Kleinfelder 2006c).

Table 4-1 summarizes the purging requirements for one casing volume for each screen in R-10. At R-10 Screen 1, the calculated casing volume is the volume of water above the packer less the volume of water displaced by the Screen 2 water-level gage tube, plus the volume of water in the drop pipe. For R-10 Screen 2, the calculated casing volume includes all water below the packer plus the volume of water in the drop pipe above the packer and the volume of water in the gage tube. The purge time for one casing volume from each zone at R-10 is calculated based on the pump rate of 12 gal./min.

Table 4-2 summarizes the casing volumes for each zone at R-17. The calculations are similar to those described for the R-10 screen zones. The purge time for one casing volume from each zone at R-17 is calculated based on the pump rate of 2.5 gal./min. The lower pump rate at R-17 was designed for the lower formation hydraulic conductivities found at R-17 and is not a limitation of the sampling system.

4.5 Groundwater-Level Monitoring

Groundwater-level monitoring using conventional manual and transducer methods is possible using the Baski packer/pump system. Two 1-in.-diameter water-level gage tubes are installed from the surface to above the pump shroud as described in Section 4.1.

R-10 and R-17 were each equipped with two in situ Level Troll 500 transducers, at a cost of about $10,000 per well (transducers plus cables package). The transducers are removable from the gage tubes for servicing, and manual water-level measurements are possible by using the gage tubes.

Transducers were installed in R-10 on July 26, 2006. Figure 4-2 shows the available water-level data from the two gage tubes in R-10. The Screen 1 water-level data indicate an appropriate response to atmospheric pressure and show a relatively stable water level over 4 months. The drawdown resulting from pumping Screen 1 during system testing February 20, 2007, and from sampling on February 21, 2007, was about 7 ft.

However, the Screen 2 water-level data show a slow, steady decline with no response to atmospheric pressure. During sampling on October 26, 2006, the water level in the Screen 2 gage tube rose 1.6 ft when the lower APV was opened. After sampling, the Screen 2 water level showed a decline similar to that before sampling (Figure 4-2). The water-level data from the Screen 2 gage tube indicate a possible plugging of the small-diameter gage line that connects to the bottom of the PVC tube (Allen and Koch, 2007). The increase in apparent water level during sampling was likely a response to momentary equilibration of Screen 2 with the higher head present in the sampling system after the Screen 1 APV was opened for sampling. It appears that the small-diameter tubing connected to the Screen 2 gage tube was able to fill the PVC gage tube, but gravity flow from the gage tube back down the small-diameter tubing to Screen 2 was obstructed. The construction of the R-10 Screen 2 gage lines did not include filters or screens to prevent debris from blocking or plugging the small 0.125-in.-diameter tubing.

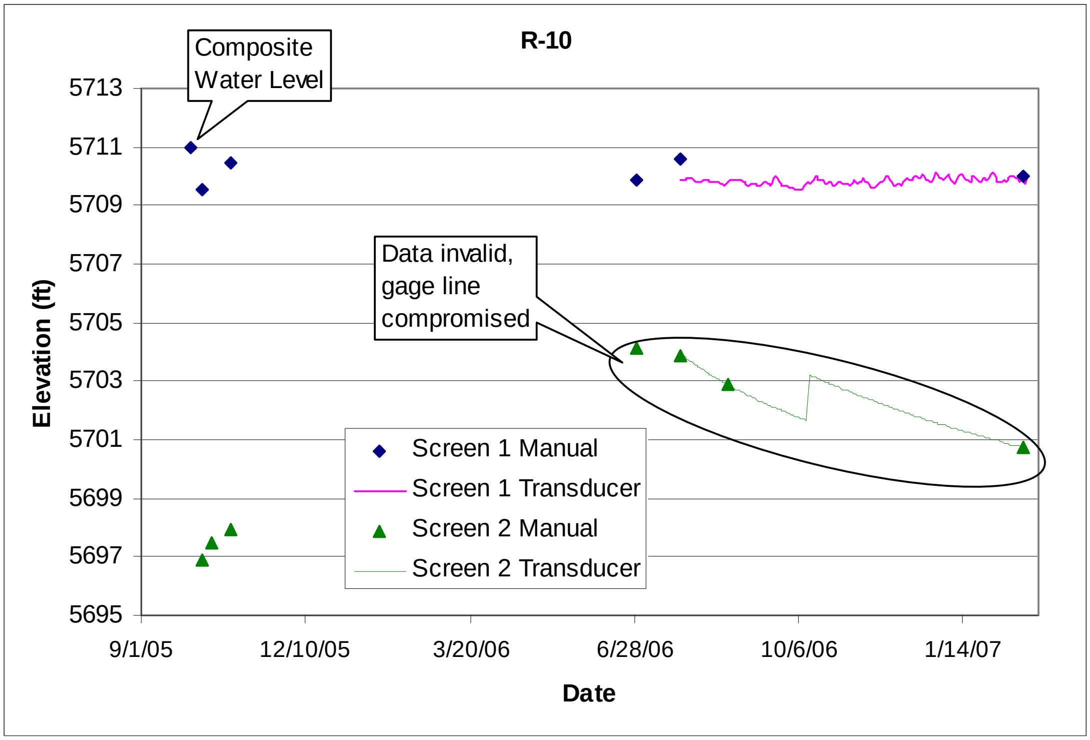


Figure 4-2 R-10 water-level data

About 2 gal. of water was added to the Screen 2 gage tube after sampling on February 21, 2007, to force the blockage out of the tubing. Resulting transducer data show the increased water level in the gage tube, but the water level did not decline normally, indicating that the Screen 2 gage tubing was still plugged. Additionally, an attempt was made to remove the water from the R-10 Screen 2 gage tube by bailing with a 0.75-in.-diameter bailer to dislodge material clogging the small-diameter connection tubing. However, the bailer would not go below about 30 ft bgs in the 1-in.-diameter gage tube, probably because banding of the gage tubes to the drop pipe may have distorted the shape of the PVC gage tube.

At R-17, the bottom of the lower zone 1-in. PVC gage tube was fitted with a stainless-steel screen to prevent plugging of the smaller diameter 0.25-in.-nylon tubing by debris that might enter. Also, the bottom of the 0.1875-in.-diameter tubing below the packer was fitted with a stainless-steel screen to prevent plugging of the gage line. Additionally, at R-17 the 0.125–in.-stainless-steel tubing through the pump shroud was replaced with 0.1875-in.-stainless-steel tubing to provide better water flow and equilibration of Screen 2 pressures through the connecting tubing.

Figure 4-3 shows the water-level responses to test operations at R-17 on December 12, 2006. Note that the Screen 1 water level responded immediately to pump operations, but the Screen 2 gage tube showed a delayed and muted water-level response. This was likely caused by restricted water flow in the small diameter (0.1875 in.)-tubing that passes through the pump shroud to the PVC gage tube. This response at the gage line for Screen 2 should not impair long-term groundwater-level monitoring and should only be observed during pumping operations.

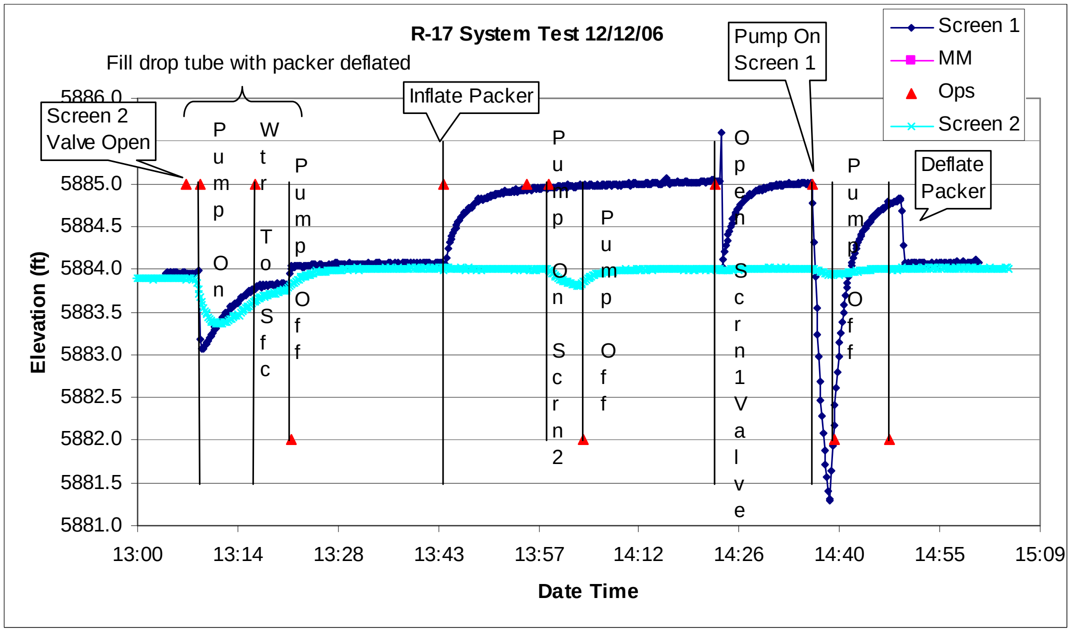


Figure 4-3 Water-level responses at R-17 during system testing

4.6 Operational History

The R-10 Baski packer with pump system was installed in R-10 in May 2006 and in R-17 in December 2006. Therefore, operational history of the Baski systems at the Laboratory is limited. When R-10 was sampled in June and October 2006, the system appeared to operate according to manufacturer's specifications (except for the lower screen water-level gage tube), and samples were collected from each zone.

When the R-17 system was installed, tests were performed to ensure that all parts of the system operated appropriately. The Screen 2 gage tube consists of 0.1875-in.-stainless-steel tubing through the pump shroud and protective screens at the bottom of the 1-in. PVC and the bottom of the 0.1875-in.-nylon gage tube. The tubing provided adequate water-level data but showed a muted and delayed response to pumping.

The Baski packers with dual-valve systems in R-10 and R-17 appear to function according to manufacturer's specifications. The lower screen water-level gaging tube at R-10 appears to be partially plugged with debris. However, the gage tubing design was modified at R-17 where plugging has not been observed.

4.7 Long-Term Operational issues

There are nine through-port fittings that pass through the upper pump shroud and four fittings that pass through the lower pump shroud. If any of these fittings were to leak, water sampled from Screen 2 through the deep APV and the pump could be contaminated with water from Screen 1.

The Baski packer/valve/pump system is relatively complex in design and installation. The system is a unique one-of-a-kind, not off-the-shelf system; thus, as-built drawings have been difficult to obtain. Problems that may arise with installed components would probably require removing and reinstalling the system, which would take a minimum of 4 to 6 d. The packer pressure must be routinely monitored by operations personnel, and pressure may need to be added at times, or a dedicated compressed nitrogen tank may need to be installed at the well. The Baski manufacturing facility and technical support are located in Denver, Colorado; therefore, there are no issues associated with working with foreign-owned companies.

4.8 Summary of Baski Packer with Dual-Valve System

The advantages and disadvantages of the Baski packer with dual-valve sampling system are summarized in Table 4-3.

5.0 BASKI PACKER WITH DUAL-PUMP SYSTEM (R-23i)

A Baski packer with dual-pump system was installed in the deep R-23i monitoring well. This system incorporates a Baski packer to isolate the two screen intervals and a dedicated pump within each interval to provide discrete groundwater samples; no valves or associated control lines are used in the dual pump system. This sampling system is a relatively high-flow system capable of pumping rates adequate for conventional purging and sampling. Pumping rates at R-23i of 1.6 gal./min and 1.9 gal./min were designed for the specific capacity of the formation; higher flow rates may be obtained with this system in other wells.

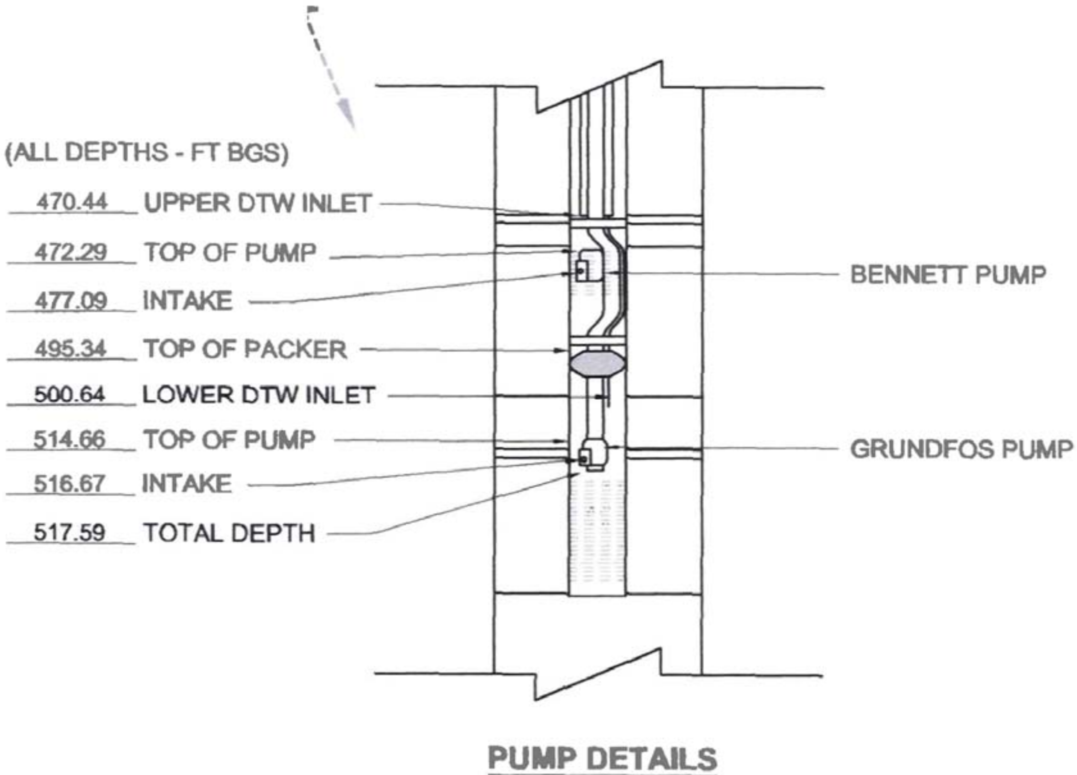
5.1 Design and Materials

The design of the R-23i Baski packer and dual-pump system was developed by Baski, Inc., personnel. This system was designed specifically for R-23i (Figure 5-1) and includes an electric submersible Grundfos pump below the packer and a pressure-activated double-action Bennett reciprocating piston pump above the packer. As at the R-10 and R-17 Baski packer systems, two 1-in.-diameter PVC gage lines are installed for monitoring groundwater levels at each screen.

Figure 5-1 shows the design of the R-23i Baski packer and dual-pump system. The unique design incorporates a U-shaped bend in the 1.25-in.-diameter stainless-steel drop pipe above the packer and the electric submersible pump. R-10 and R-17 use a 1-in.-diameter stainless-steel drop pipe, but this was increased to 1.25-in.-diameter for R-23i to better support the weight of the packer and pump systems. The U-shaped portion of the pipe is about 4 ft long and allows for strapping the Bennett pump onto the pipe to remain within the diameter of the well casing.

Table 4-3
Summary of Baski Packer with Dual-Valve Sampling System

Criteria	Advantages	Disadvantages
Design	High-flow system is capable of purging.	Current design is limited to two screens.
	Leading technology valve, pump, packer design	Gage tube for lower zone groundwater-level monitoring needs better design.
Materials	High quality	Specialized components are available from single source.
Cost	High quality	System cost is among highest compared.
Installation	High quality	Installation is relatively complex.
		Installation/removal takes several days.
Maintenance	Little or no maintenance is required.	Packer pressure requires routine monitoring.
Groundwater Sampling	One conventional submersible pump used to sample multiple zones	Appropriate pressure must be maintained to packer to isolate screen zones.
	Flow rates are up to 12 gal./min.	High voltage is required for pump operation and sampling.
	Flow rates are adjustable for lower permeabilities.	
	Conventional purging of casing volumes	
	Purge and sample two screens take less than 1 d.	
Groundwater-Level Monitoring	Manual measurement of two screen zones is possible through 1-in.-diameter gage tubes.	Small-diameter tubing from lower screen zone through packer/pump to gage tube has plugging problem.
	Utilizes conventional transducer equipment	Water-level response through small diameter gage tubing is muted and possibly compromised.
	Transducers are removable for service/repair.	
Operational History	Sampling operations appear to meet expectations.	Systems were installed for less than 1 yr, operational history limited.
Long-Term Operational Issues	The second system installed at R-17 was refitted with larger diameter tubing for the deep screen gage line.	Lower-zone gage tubing at R-10 appears to be plugged and not operational.
		Packer pressure requires routine monitoring.
		Annual electrical inspection is required.
		Replacement parts may be difficult to obtain.
	Baski support available domestically from Denver, Colorado.	Repair/maintenance would likely require removal of complex system.



Source: Kleinfelder 2007.

Figure 5-1 R-23i Baski packer with dual-pump system

The R-23i Baski dual-pump system design does not require valves, which reduces the number of control lines to the surface and the complexity of sampling. However, with the 1.25-in.-diameter discharge pipe for the electric submersible pump, the two 1-in.-diameter gage tubes, and the packer inflation tube and tubing bundle for the Bennett pump, it is unlikely that this sampling system could be installed in a well with more than two screens.

The pumps, the packer supports, and the production tubing for the submersible electric pump are stainless steel. The Baski packer is covered with durable DuPont Viton. The packer is inflated using 0.25-in.-nylon tubing.

The Bennett pump has a 0.125-in.-stainless-steel cable that could be used to support the pump assembly in a single completion well, but the Bennett pump in R-23i is supported by banding to the 1.25-in.-diameter riser production tubing for the electric submersible pump. The Bennett pump has three tubing lines that extend to the surface: 0.50-in.-clear Teflon production tubing, 0.375-in.-poly pump pressure line, and 0.375-in.-poly air discharge line.

The water-level monitor gage tubes are 1-in.-diameter PVC tubes that extend from the surface to above the submersible Bennett pump (for lower screen) and to just below the Bennett pump (for the upper screen). The lower 1 ft of the upper screen gage tube is “slotted” with 0.25-in.-drill holes. The gage tube for the bottom screen is fitted with an end PVC cap that was drilled and fitted with a stainless-steel Ferulok connector for the 0.1875-in.-nylon tubing that extends down through the packer. The bottom of the 1-in.-PVC tubing and the bottom of 0.1875-in.-tubing were both fitted with stainless-steel screens to prevent clogging of the small diameter gage tubing, similar to the installation at R-17.

5.2 Cost

The cost of a Baski packer with dual-pump system for a dual-completion well is estimated to be $100,000, including installation, the packer, which is about $20,000, and the two pumps. The specialized tooling and machining required for these systems are where most of the cost is incurred. The transducer equipment for a dual completion well is an additional $10,000.

5.3 Installation and Maintenance

Installation of the R-23i packer with dual-pump system was performed by Kleinfelder, Inc., personnel using a water well installation-type rig. The installation is less complicated than the Baski packer with dual-valve system but significantly more complex than a single-completion pump system. Installation required pressure testing the packer tubing fittings for QA to ensure that no major leaks were present. Baski, Inc., provided the installation contractor instructions and schematics and QA procedures for installation (Baski 2006)

The drop pipe for the electric submersible pipe has a weep hole below ground surface to drain the pipe and prevent freezing. However, the production tubing for the Bennett pump does not have a weep hole and does not drain. Instructions provided with the Bennett pump direct that the upper portion of the production tubing should be bailed so that the water level is below the ground surface to prevent freezing.

Primary maintenance activities at R-23i will include maintaining pressure to the packer. Because the packer pressure line is not connected to valves, as in the Baski dual-valve system, packer pressure may be easier to maintain. It is not known if maintenance will be required for the two pumps, but the maintenance requirements for the pumps may not be significantly different than maintenance for the valves in the dual-valve system.

R-23i, Screen 3 has a head about 8 ft lower than Screen 2, and the water level is about 50 ft above the packer; thus, the minimum packer pressure at R-23i would be about 50 psi plus 22 psi (50 ft /2.31 ft/psi) plus 4 psi, for a minimum pressure of about 75 psi. With an additional 10% of the minimum packer pressure for friction losses, the total packer pressure at R-23i would be about 85 psi.

5.4 Groundwater Sample Quality

Groundwater sampling using the Baski packer with dual-pump system is a high-flow system capable of purging the well. The Baski system at R-23i has a pumping rate greater than 1 gal./min at each screen. The pumping rates are a consequence of the aquifer properties rather than a limitation of the sampling system. The Baski packer with dual-pump sampling system appears to meet current Laboratory-site DQOs for collecting the representative groundwater samples from the formation because of the ability to adequately purge the well before sampling.

Groundwater sampling at R-23i is performed by operating the Grundfos electric submersible pump for the deep screen and the Bennett reciprocating piston pump for the upper screen. Operation of the electric submersible pump requires an electric generator; operation of the Bennett pump requires compressed nitrogen gas and a pressure system. Each pump has a separate discharge pipe or tube at the well head.

Table 5-1 summarizes the purge requirements for the two deep screens at R-23i. The purge volumes for Screen 2 incorporate the volume of water in the well casing above the packer, including water in the drop pipe but exclude the volume of the Screen 3 gage tube. The purge volume for Screen 3 includes the volume of water in the well below the packer and the volume of water in the drop pipe and the gage tube. The pump rate for each pump was measured during testing on December 15, 2006.

Table 5-1
Summary of Purge Volumes at R-23i

	Zone 2	Zone 3
Water Level Top of Zone (ft bgs)	448.0	456.0
Bottom Zone (ft bgs)	495.3	550.7
Length Purge in Zone (ft)	47.3	52.4
Stainless Steel Casing I.D. (in.)	4.5	4.5
Tubing (in.)	1.2	1.0
Stainless Steel Casing and Tubing Volume (L)	160.5	246.2
Purge Volume Criteria, No. Casing Volumes	1	1
Purge Volume (L)	160.5	246.2
Purge Volume (gal.)	42.4	65.0
Purge Rate (L/min)	4.9205	6.056
Purge Rate (gal./min)	1.3	1.6
Purge Time (min)	32.6	40.7
Comment	1 casing volume	1 casing volume

During testing of the pump systems on December 15, 2006, the Bennett pump at Screen 2 was operated with a gas pressure of 140 psi; the pump was operated for about 10 min; water flowed at the surface after 2 min; the flow rate was 1.3 gal./min. The Grundfos pump at Screen 3 was operated for about 8 min; water flowed at the surface after 3 min at a flow of 1.6 gal./min.

Groundwater samples were collected from R-23i using the Baski packer and dual-pump system in February 2007. The sampling system functioned appropriately according to manufacturer's specifications.

5.5 Groundwater-Level Monitoring

Groundwater-level monitoring using conventional manual and transducer methods is possible using the Baski packer with dual-pump system. Two 1-in.-diameter water-level gage tubes are installed from the surface to the Bennett pump as described in Section 5-1.

R-23i was equipped with in situ Level Troll 500 transducers in each gage tube at a total cost of about $4,500 including cables. The transducers were installed in R-23i on December 15, 2006, and were used to monitor the water-level responses during system testing. Figure 5-2 shows the water-level responses measured at Screen 2 during the testing. The packer was inflated by applying 200 psi to the packer line. The maximum head separation observed in the well during testing on December 15, 2006, was about 6.2 ft, but static conditions did not appear to have been achieved, especially at Screen 2.

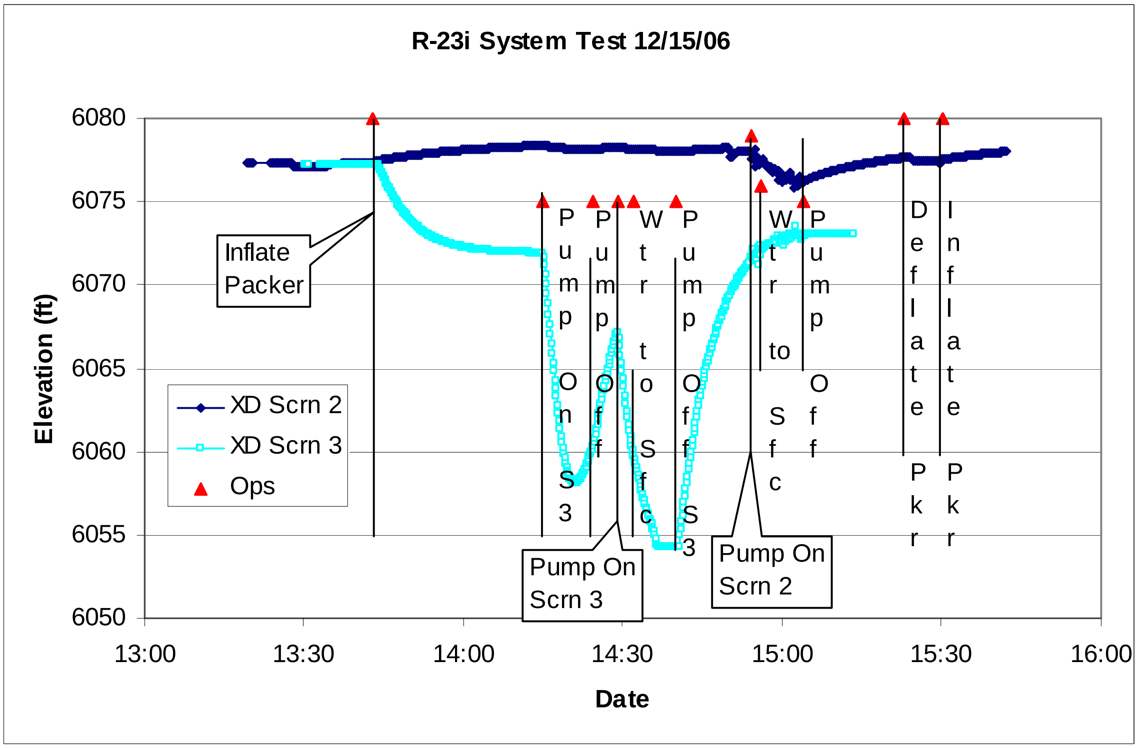


Figure 5-2 R-23i water-level responses during system testing

During the two pumping events at Screen 3, the water level at Screen 2 showed an immediate response in drawdown and recovery. The total drawdown during the second pumping event was about 0.3 ft. The distance between Screens 2 and 3 is 44 ft.

The Bennett pump at Screen 2 was operated initially for about 30 s to adjust the operating pressure. The Bennett pump was activated using 140 psi and operated for about 10 min; water flowed at the surface after 2 min at a flow rate of 1.3 gal./min. After 10 min, the drawdown at Screen 2 was about 2 ft. The transducer data show a wider range of water levels during operation of the Bennett pump, indicating that vibration from the pump was causing fluctuating water levels in the gage tubes. The water level was still declining when the pump was turned off; thus, equilibrium pumping conditions were not obtained at Screen 2.

After the Bennett pump was turned off, the water level at Screen 2 recovered a bit faster than previously observed after packer inflation (Figure 5-2). After 19 min, the Screen 2 water level had recovered 1.6 ft, or 80% of the amount of drawdown.

Figure 5-3 shows the groundwater-level data from the two gage tubes in R-23i. The Screen 2 water-level data indicated an appropriate response to atmospheric pressure and showed a relatively stable water level over 3 months. Screen 3 water-level data showed a muted response to atmospheric pressure for about 3 wk after the system was installed. Then the water level in the gage tube slowly rose about 0.7 ft over 4 wk and plateaued at 6071.4 ft while showing no response to atmospheric pressure. The water-level data from the Screen 3 gage tube indicated that the connection tubing may have become constricted or plugged in the 2 wk following installation. It appears that the water level in the gage tube rose because of barometric pumping but was not able to drain from the gage tube back into the formation, probably because of some constriction acting like a foot valve.

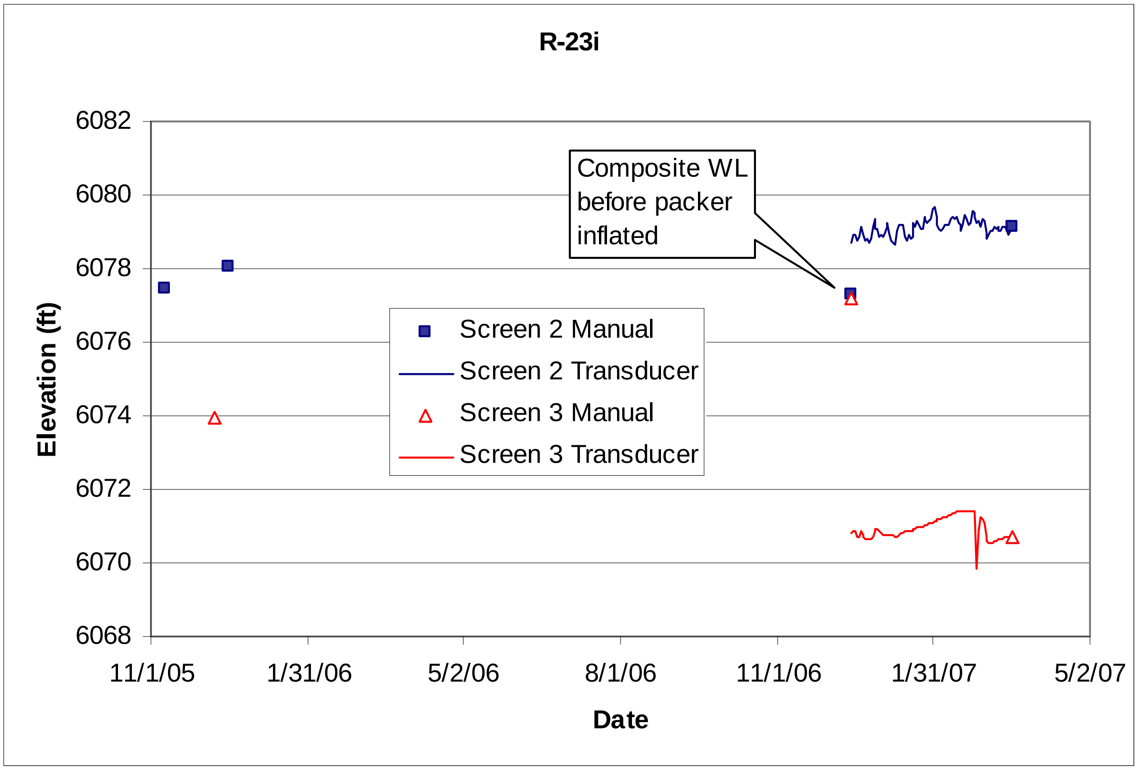


Figure 5-3 R-23i groundwater-level monitoring data

During groundwater sampling of R-23i on February 26 and 28, 2007, the water level in the Screen 3 gage tube showed significant fluctuation caused by pump vibration, and the water level declined about 0.7 ft, probably as a result of vibration of the pumps partially dislodging the plugging material. For a few days after sampling, the water level in the Screen 3 gage tube responded appropriately to atmospheric pressure, but after about a week, the water level showed indications of rising in response to barometric pumping with restricted draining capability from the gage tube. The data indicated that partial plugging of the connection tubing was occurring in the R-23i Screen 3 gage tube, similar to the plugging observed at the R-10 Screen 2 gage tube.

5.6 Operational History

The R-23i Baski packer with dual-pump system was installed so recently that very limited operational history is available. During testing of the pump systems on December 15, 2006, and groundwater sampling in February 2007, both operated according to manufacturer's specifications. Based on the requirement to purge three casing volumes (see Table 5-1) and to collect 10 gal. of sample, purging and sampling time would be about 1.8 h at Screen 2 and about 2.2 h at Screen 3.

5.7 Long-Term Operational Issues

During testing of the pump systems on December 15, 2006, the water-level data indicated that significant vibration of the gage tubes occurred when the Bennett pump was operated. Other pump systems have not shown similar vibration during pump operation. Such vibration over time could negatively impact the pump and packer installation. If some down-hole equipment were to vibrate loose over time—such as the Bennett pump, which is strapped to the drop pipe—retrieval of the system could be difficult.

Other long-term operational issues include the following.

- Pressure to the packer supply line must be supplied to maintain the isolation between Screens 2 and 3 in R-23i.
- Although the discharge pipe from the electric submersible pump has a weep hole near the surface to prevent freezing of the pipe, there is no similar drain present in the discharge tubing from the Bennett pump. After operation of the Bennett pump, the water in the discharge tubing must be displaced or bailed to below ground surface to prevent freezing.

5.8 Summary of Baski Packer with Dual-Pump System

The advantages and disadvantages of the Baski packer with dual-valve sampling system are summarized in Table 5-2.

6.0 FLEXIBLE LINER UNDERGROUND TECHNOLOGIES (FLUTe SAMPLING SYSTEM)

The FLUTe system has been installed in one intermediate groundwater monitoring well at the Laboratory. Well LAWS-01 was installed adjacent to the Los Alamos Canyon weir (LA Weir) to monitor surface-water infiltration from the weir into the underlying Cerros del Rio basalts (Stone and Newell 2002). The well was completed with four screens to a total depth of 280 ft in April 2001, and the FLUTe system was used to collect groundwater samples and to monitor groundwater levels at the four screens during 2001 and 2002 (Stone et al. 2004). The well has not been routinely monitored since 2003, but the FLUTe system and associated transducers are still in place. The FLUTe sampling system is a **low-flow, no-purge** system that operates like the Barcad system but with higher flow rates.

Table 5-2
Summary of Baski Packer with Dual-Pump Sampling System

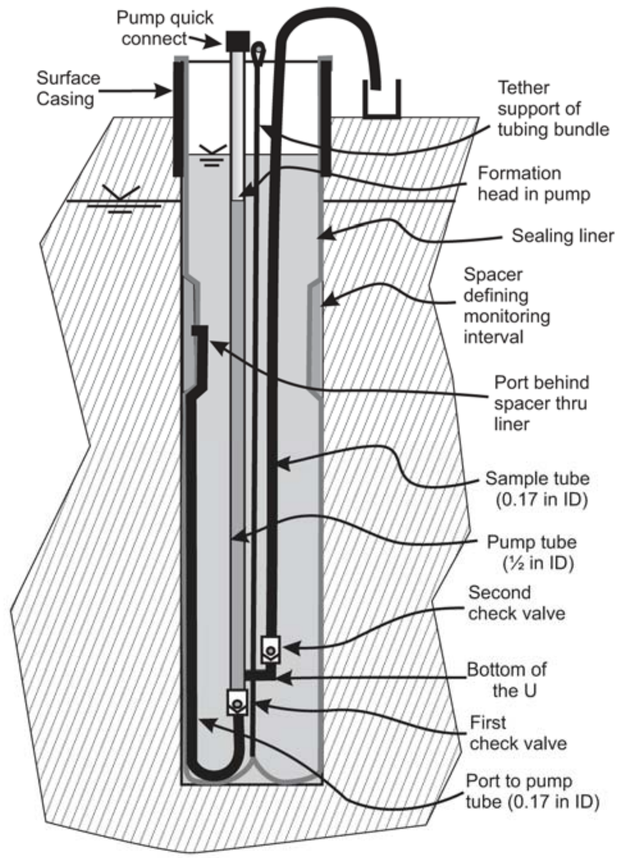
Criteria	Advantages	Disadvantages
Design	High-flow system is capable of purging.	Current design is limited to two screens.
	Specialized packer, pump design	Gage tube for lower-zone groundwater-level monitoring needs better design.
Materials	High quality	Specialized components are available from single source.
Cost	None	System cost is among highest compared.
Installation	None	Installation is relatively complex.
		Installation/removal take several days.
Maintenance	Little or no maintenance is required.	Packer pressure requires routine monitoring.

Table 5-2 (continued)

Criteria	Advantages	Disadvantages
Groundwater Sampling	Two conventional submersible pumps are used to sample multiple zones.	Appropriate pressure must be maintained to packer to isolate screen zones.
	Flow rates are possible up to 12 gal./min.	Bennett pump vibration could cause problems.
	Flow rates are adjustable for lower permeabilities.	High voltage is required for pump operation and sampling.
	Conventional purging of casing volumes	Compressed gas is required for Bennett pump operation.
	Purge and sample two screens take less than 1 d.	
Groundwater-Level Monitoring	Manual measurement of two screen zones is possible through 1-in.-diameter gage tubes.	Small diameter tubing from lower-screen zone through packer/pump to gage tube has plugging problem.
	Utilizes conventional transducer equipment.	Water-level response through small-diameter gage tubing is muted and possibly compromised.
	Transducers are removable for service/repair.	
Operational History	Sampling operations appear to meet expectations.	Systems were installed for less than 6 months, operational history limited.
		Lower-zone gage tubing at R-23i may be compromised.
Long-Term Operational Issues	Baski support available domestically from Denver, Colorado.	Packer pressure requires routine monitoring.
		Replacement parts may be difficult to obtain.
		Annual electrical inspection is required.
		Repair/maintenance would likely require removal of complex system.

6.1 Design and Materials

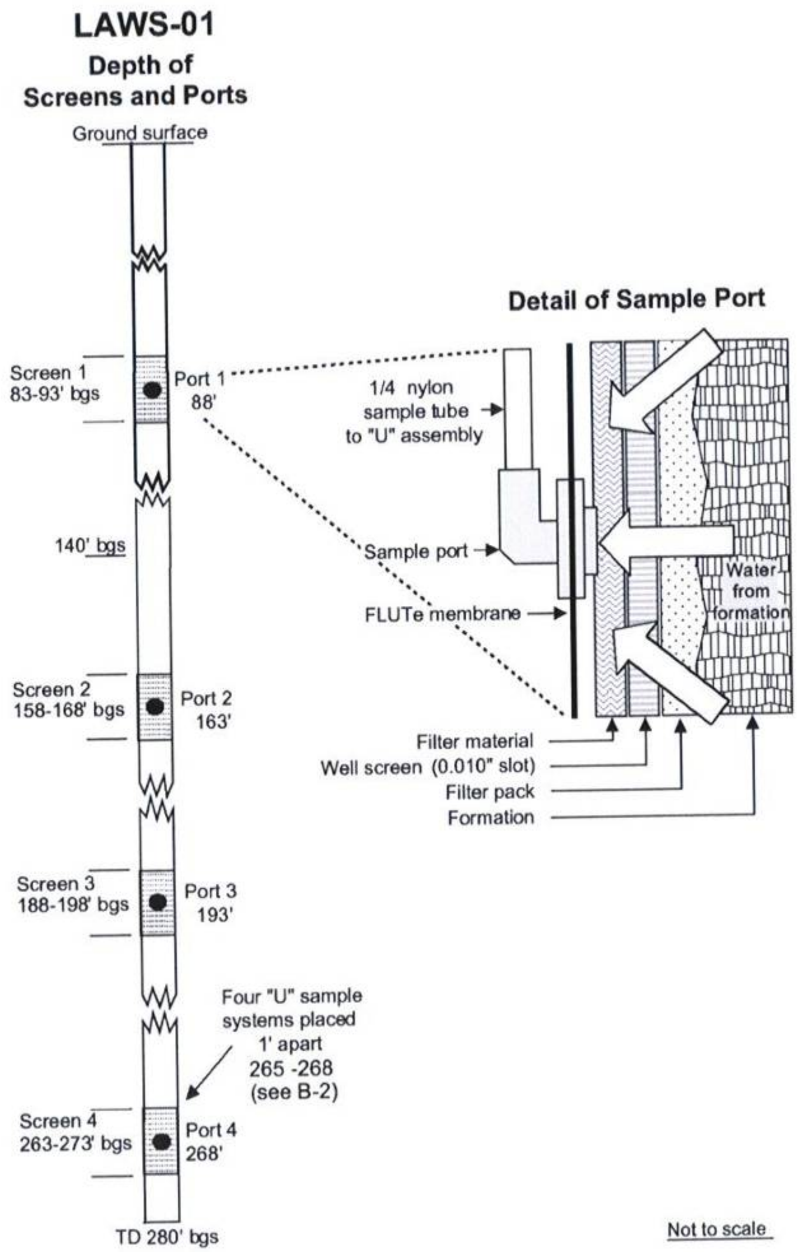
The water FLUTe sampling system is composed of a flexible liner of polyurethane coated nylon fabric that is everted into a borehole or a well casing. At selected points along the liner that coincide with well screen locations, ports are installed through the membrane for the collection of groundwater samples. Small-diameter (0.25 in.)-nylon connects the ports with a U-tube sampling device that is located at the bottom of the well. Figure 6-1 illustrates the deployment of the FLUTe system, and Figure 6-2 shows the FLUTe system installation at LAWS-01. The liner fills the entire volume of the well casing; therefore, sampling ports are located immediately adjacent to the well screen. This design avoids sampling potentially stagnant water from within the well casing; groundwater samples are collected directly from the formation through the filter pack.



Source: FLUTe 2006.

Figure 6-1 Schematic representation of the FLUTe system

The design for groundwater sampling is based on gravity flow of water from the formation into the system tubing. This design functions best when the depth of water in a well is at least 30% of the total depth of the well to allow for a sufficient volume of water in the tubing lines. For example, in a 1120-ft-deep well with a screen from 996 to 1019 ft bgs with the sampling system located at the bottom of the FLUTe system at 1100 ft bgs (e.g., R-33 Screen 1), the water level should ideally be a minimum of 300 ft above the bottom of the well or 800 ft bgs. Because the water level at R-33 is at 990 ft bgs, or 110 ft above the sampling system, the volume of water available to pump to the surface is limited. Therefore, FLUTe uses a slightly larger diameter tubing (0.50-in. on the recharge side of the U-tube and 0.375-in. on the flow side) to provide additional water volume for each pump/purge cycle. However, the extra volume in the larger diameter tube does not fully compensate for the low-water depth to total-depth ratio present in Laboratory regional aquifer wells.



Source: Stone and Newell 2002.

Figure 6-2 Diagram of the FLUTe system at LAWS-01

The FLUTe design uses the liner as a packer in conventional well systems to isolate each screen zone in the wells (Figure 6-2). Up to eight ports can be installed in a 4.5-in.-diameter well; a larger-diameter well could accommodate additional ports.

The FLUTe flexible liner is made of polyurethane-coated nylon fabric. The tubing is either polyvinylidene fluoride or Teflon, and the U-tube is stainless steel with brass and stainless-steel connections. The materials are custom assembled by FLUTe personnel before installation.

6.2 Cost

The cost for a dual-port Water FLUTe simple-valve tubing sampling system for an 1100-ft well is about $40,000 (FLUTe 2007), not including installation, which is relatively inexpensive. Equipping with transducers is an additional $10,000.

6.3 Installation and Removal

Installation and removal of the FLUTe sampling system is performed by FLUTe personnel. Installation is relatively simple and typically takes 1 d. The top of the liner is attached to the surface casing (Figure 6-1), and water is added to the interior of the liner. The weight of the water pulls downward and everts the liner in the well. The water pressure on the everting end of the liner is the driving mechanism of the installation (FLUTe 2007).

The rate of installation of a Water FLUTe sampling system is dependent on the depth and diameter of the hole, the relative transmissivity of the formation, the depth to the water table, and the rate at which water can be supplied to fill the liner.

Removal of the FLUTe system requires pumping the water out of the inside of the liner and pulling the liner out of the well from the bottom up. Removal is also accomplished within 1 d.

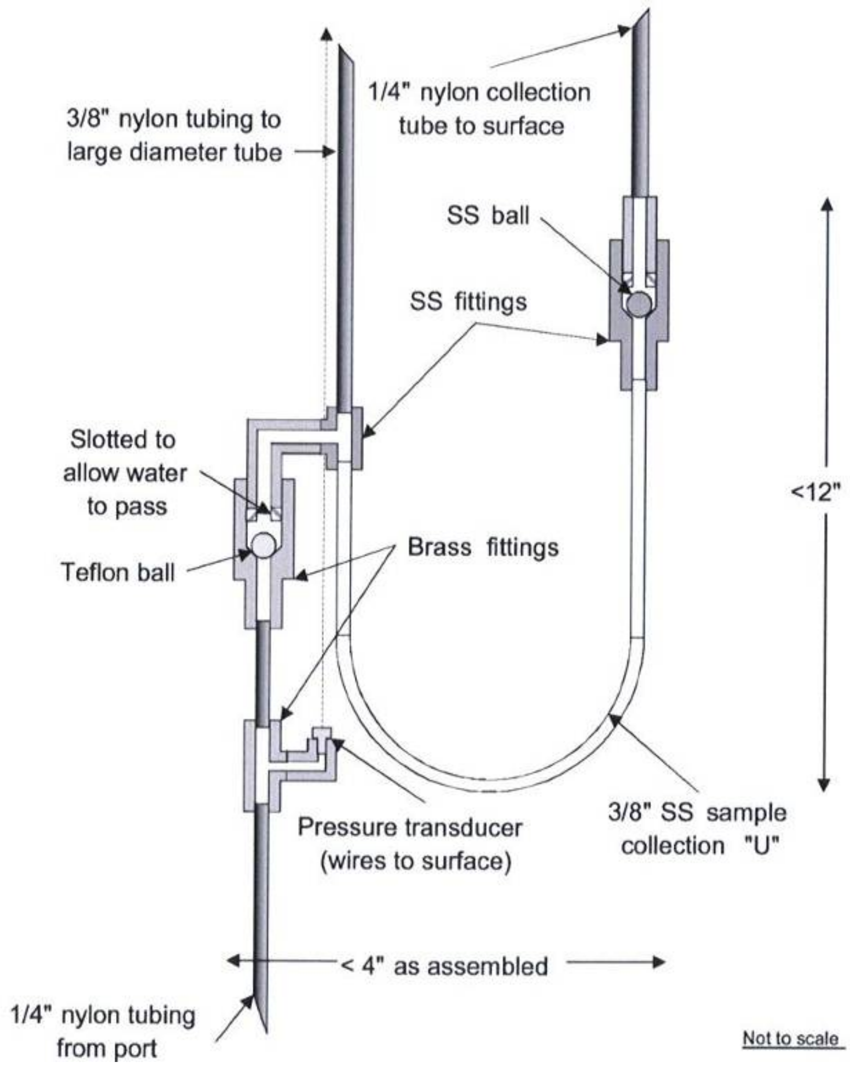
6.4 Maintenance

Minimal maintenance is required for the Water FLUTe system. No pressurized gas is needed to maintain packer pressure because packers are not used. Periodic checking of the water level inside the FLUTe liner annually and before sampling events is needed to maintain adequate pressure on the liner to keep the liner against the well casing and to prevent cross-contamination of screens.

6.5 Groundwater Sampling

Groundwater sampling using the FLUTe system is a low-flow, no-purge system that does not require typical purging because the liner displaces all water within the well. Where a screen is properly developed and drilling impacts are not present in the formation surrounding a well, the FLUTe sampling system will likely collect samples representative of the formation and would thus meet current Laboratory-site DQOs for the collection of representative samples. However, where drilling impacts may be present in the formation surrounding a well, the low-flow ability of the FLUTe system may not be able to adequately purge the surrounding formation water before the collection of groundwater samples. In this case, the FLUTe system may not meet Laboratory-site DQOs for the collection of representative groundwater samples.

Samples are obtained using a U-tube device such as that illustrated in Figure 6-3. There is a separate U-tube device for each port; the U-tubes are located at the bottom of the well at the base of the liner. Groundwater flows from the screen through the liner membrane (Figure 6-2) and into the port and system tubing.



Source: Stone and Newell 2002.

Figure 6-3 Schematic diagram of the FLUTe sampling system U-tube

Because the FLUTe port is located at the wall of the well screen, this sampling system does not allow for the presence of potentially stagnant water within the well casing (as do the Westbay and Barcad systems). Water that enters the port in a FLUTe system enters directly from the filter pack and the formation and is representative of the formation water. However, two-stroke cycles of the system should be performed before collecting samples to purge existing water from the system tubing.

Flow to recharge the system tubing is driven by the head of water at the port and the distance between the port and the bottom of the well where the U-tube is located. If only a few feet of water are present above the bottom of a well, flow will be slower than if several hundred feet of head are present above the port. The water in the port tubing flows past a Teflon ball check valve and into the U-shaped sampling device. Two nylon tubes connected to the U-tube extend to the surface. One tube has a larger diameter (0.5 in.) to accommodate a volume of water; pressure is applied to this tube (compressed nitrogen gas), which forces the water in the U-tube to the surface through the 0.375-in.-production tube.

To purge the tubing, a sufficiently high pressure is used to evacuate all water from the U-tube system and force the gas back to surface. During sampling, a lower pressure is used so that gas does not extend to the bottom of the larger diameter tubing; this prevents aeration of the samples, increases the rate of recharge from the formation, and reduces pump cycle time. The flow rate is estimated to be 2 L/min (0.5 gal./min), 10 times faster than the Barcad system but 5% to 10% the rate of the Baski packer with pump systems.

After purging the system tubing, the formation water from the port tube will fill the recharge side of the U-tube to the level of the water in the formation. In the R-33 example, 120 to 146 ft of water will fill the large-diameter tube connected to the U-tube. The volume of water available for one pump/purge/stroke cycle is equal to the volume of the water inside the tubing. A check valve on the production side of the U-tube maintains water in the production tubing to the surface. A check valve on the port tube prevents backflow of water from the U-tube system to the formation. In a FLUTe installation in a well such as R-33, the total tubing volume at Screen 1 would be about 8.2 L and at Screen 2 about 7.3 L. At a pump/purge rate of 2 L/min, the purge time of two tubing volumes would be 17 min for Screen 1 and 15 min for Screen 2.

Mr. Carl Keller of FLUTe indicated that a system installed in an 1100-ft deep regional aquifer well at the Laboratory would probably require additional stacked U-tube systems to lift the water to the surface. Additional U-tubes would limit the pressure in the production tubing. Mr. Keller indicated that the U-tubes would be staged at 400-ft intervals; one system would pump into the next system above, and cycling would be performed on alternate U-tube systems during pumping. Thus, three U-tubes would be installed for each port, which would potentially limit the FLUTe system to only two or three screens in deeper wells. This modification to the FLUTe sampling system increases complexity of pumping and sampling operations and may reduce the overall flow rate because of the extra cycling step. A specially designed manifold for controlling the gas pressure to the appropriate U-tubes during pumping cycles would likely be needed to facilitate sampling activities.

6.6 Groundwater-Level Monitoring

Groundwater-level monitoring using the FLUTe system is possible by connecting transducers to the port tubing upstream of the Teflon ball valve (Figure 6-3). In relatively shallow wells to about 300 ft, a water-level meter could be inserted in the 0.5-in.-diameter tubing to tag the water level. The measurement can only be performed immediately after purging the tubing when the tubing has equilibrated with the formation water level because the Teflon ball valve does not allow the water level in the U-tube assembly to lower with a declining formation water level. Thus, real-time measurement or monitoring of water level in the U-tube system is not possible. In the deep regional aquifer wells at the Laboratory, manual measurement of the water level in a FLUTe system would likely be impossible. Therefore, calibration of transducer measurements may be problematic.

Transducers for monitoring groundwater levels can be installed in the FLUTe system in the tubing line from the port to the U-tube and upstream of the Teflon ball valve (Figure 6-3). Typically, conventional compensated in situ transducers are used with the FLUTe system. If a transducer requires maintenance, the bottom of the flexible liner must be brought to surface to remove and replace the transducer. A two-port FLUTe system could possibly be installed with 1-in.-PVC gage tubes for measuring groundwater levels and enhancing pump cycle volumes and rates.

6.7 Operational History

The FLUTe system installed at LAWS-01 operated according to manufacturer's specifications for the 2 yr that the weir wells were monitored from 2001 to 2003. Personnel operating the system reported quick and efficient groundwater sampling. The transducers were connected to a Campbell Scientific 21X data logger equipped with a cell phone for transmitting data to the office.

6.8 Long-Term Operational Issues

Maintenance of the FLUTe sampling system is minimal and does not require maintaining pressure to a packer like other systems. A transducer failure would require removing half of the liner system to replace a transducer, but with hardly any moving parts, the sampling system should operate normally for the long term.

6.9 Summary of FLUTe Sampling System

The advantages and disadvantages of the FLUTe sampling system are summarized in Table 6-1.

7.0 SYSTEM EVALUATION AND SUMMARY

The different sampling systems installed in Laboratory multiple completion wells have been described, and aspects of each system including design and materials, installation, cost, sampling and monitoring characteristics, and operational history have been discussed. These elements constitute the evaluation criteria for each system. The evaluation criteria are used to compare and contrast the systems and are the basis for a relatively simple rating system of 1 to 4 with 4 being most desirable. The information and length of history available for each system varied; therefore, ranking was sometimes difficult and often subjective, but it provides a comparison among systems. Additional experience with each system may prompt significant changes in the rankings presented here.

Table 7-1 summarizes the evaluation criteria and rating system for each criterion. Table 7-2 summarizes the rankings developed for each sampling system. A brief discussion of each criterion and ranking for each system follows.

7.1 Design and Materials

The Westbay MP system is technically advanced and capable of monitoring multiple zones in a well. Monitoring well R-25 has the most monitoring zones at nine, but many more monitoring zones are possible with this system, and no other system has the capability of a virtually unlimited number of monitoring zones. Additionally, the Westbay casing design is unique, and the operation of the sampling and transducer equipment is technically advanced. The Westbay MP materials are durable, specially designed, and constructed of PVC casing with multiple packers for isolating each zone. The packers are inflated with water so that no pressurized gas is needed. No significant problems have been noted in materials in 7 yr of Westbay operations. Rating: 4

Table 6-1
Summary of FLUTe Sampling System

Criteria	Advantages	Disadvantages
Design	Relatively simple design	Low-flow sampling design
	Potentially could accommodate up to four screens	Design was not tested for deep regional aquifer wells.
Materials	Flexible nylon fabric with tubing is unique.	Durability of liner for multiple insertions questionable
Cost	Relatively low cost system	
Installation	Quick and easy 1 d installation/removal	Manufacturer usually installs and removes.
	Any knowledgeable contractor could install/remove.	
Maintenance	Little or no maintenance for equipment	Maintain water level inside liner
Groundwater Sampling	No complex equipment is required for sampling.	Low-flow sampling may not provide representative groundwater data.
	Purging of well is not required.	Sampling flow rate is reported to be 2 L/min.
	No stagnant water in well	Sampling time is 1 d/2 screens.
		Sampling is accomplished using gas pressure system.
	High voltage is not required.	Sampling requires alternate cycling of stacked U-tubes.
Groundwater-Level Monitoring	Uses conventional transducer equipment	Manual measurement of groundwater level not possible
		Transducer equipment is not removable without removing bottom half of liner system.
Operational History	Functioned appropriately in four-screen intermediate well at LANL	No long-term operational history at LANL
		No operational history in regional aquifer wells
Long-Term Operational Issues	Relatively simple to install and operate	Routing monitoring of water level inside liner
	Annual electrical inspection is not required.	
	Manufacturer is local company.	

Table 7-1
Sample System Rating Criteria

Criteria	Rating: 1	Rating: 2	Rating: 3	Rating: 4
Design and Materials	Nonfunctional	Functional but inadequate*	Functional and adequate	Superior
Cost	Unrealistically cheap or prohibitively expensive	Relatively expensive	Relatively inexpensive	Cost-effective
Installation/Removal	Very complex	Complex	Relatively simple	Very simple
Maintenance	Very involved	Involved	Routine and straightforward	Occasional and simple
Groundwater Sample Quality	Unrepresentative, does not meet DQOs	Questionably representative, does not meet DQOs	Representative, meets DQOs	Representative and superior, meets DQOs
Groundwater-Level Monitoring	Nonfunctional	Functional but inadequate	Functional and adequate	Superior
Operational History	Nonfunctional	Functional but inadequate	Functional and adequate	Superior
Long-Term Operational Issues	Very involved	Involved	Straightforward	Simple

* Inadequate means that the system does not meet requirements for Laboratory deep monitoring wells.

Table 7-2
Sample System Evaluation Criteria and Ratings

Evaluation Criteria	System Ratings: Westbay Multiple Port	Barcad Dual Pump Packer	Baski Packer Dual Valve	Baski Packer Dual Pump	FLUTe Sampling System
Design and Materials	4	2	4	4	3
Cost	2	3	2	2	3
Installation/Removal	2	3	2	2	3
Maintenance	2	3	3	3	4
Groundwater Sample Quality	2	1	4	4	2
Groundwater-Level Monitoring	3	2	2	2	3
Operational History	3	2	4	4	3
Long-Term Operational Issues	2	2	4	4	3
Total	**20**	**18**	**25**	**25**	**24**

The Baski packer with dual-valve system (installed in R-10, R-17) is also technically advanced with control lines for operating the two valves and a single submersible pump capable of pumping from either zone. A design problem in the groundwater-level monitoring gage tube for the lower screen zone at R-10 was apparently corrected for the R-17 installation, but the problem appears to also occur at R-23i. Rating: 4

The Baski packer with dual-pump system (installed in R-23i) is also technically advanced and was designed specifically for the groundwater characteristics at R-23i but could be employed at other dual-completion wells. The dual-pump design uses a submersible electric pump below the packer and a dual-action piston pump above the packer. Both Baski packer systems incorporate separate gage tubes that enable manual measurement of groundwater levels and use of conventional transducer equipment. The Baski packer with dual valve and packer with dual-pump systems are stainless steel except for the PVC gage lines used for groundwater-level monitoring. Nylon tubing provides pressurized gas for packer inflation and valve operation. These systems appear to be made with high-quality materials. Rating: 4

The Barcad packer with dual-pump design (installed in R-33) is simpler than the other systems. The pump is actually a foot valve, which is the only moving part in the system. This design of sampling system may not be the best for the deep wells at the Laboratory that have a relatively low ratio of water column to total depth. A ratio of 30% or more would better suit this design. For this reason, the HydroBooster was designed into the Barcad system, but the HydroBooster does not significantly overcome the inherit design problem. The Barcad system was not designed for manual measurement of the water levels, which was considered a drawback in design. The Barcad pumps are stainless steel with stone or ceramic intake ports on the valve intakes; the HydroBooster is stainless-steel pipe. The system uses relatively few materials compared with the other systems; therefore, direct comparison is difficult. Rating: 2

The FLUTe sampling system (installed in LAWS-01) is similar to the Barcad system in design and relatively simple compared with the other systems. The U-tube and ball valves allow recharge of the tubing through gravity flow of groundwater from the formation. The design of the U-tube sampling system at the bottom of the well rather than at the ports allows for more water to recharge the system than the Barcad system, but the design may not be the best for the deep wells at the Laboratory that have a relatively low ratio of water column to total depth. A ratio of 30% or more would better suit this design. For this reason, the FLUTe system is equipped with a 0.5-in.-diameter recharge tube, but this does not entirely overcome the inherit design problem. The FLUTe system is not designed for manual measurement of the groundwater levels but does use conventional transducers. The FLUTe system is an inert fabric liner that lines the inside of the well casing and seals and isolates each screen interval. The system materials are relatively inexpensive and durable. Rating: 3

7.2 Cost

For comparison of sampling systems, the systems are assumed to be installed in an 1100-ft well with 4.5-in.-diameter casing with two screens, similar to R-33 at the Laboratory. The selection of a groundwater sampling system should not be based solely on cost; the system must have the functionality and sophistication necessary for each specific monitoring well application.

The system cost for a dual completion Westbay well is estimated to be $100,000. The transducers for a dual completion Westbay well are $30,000, and the surface equipment is about $40,000; however, this expense is not required for additional systems. Also, the Laboratory has already purchased components to equip one or two new Westbay wells. Thus, one or two new Westbay wells could be installed at no additional material expense. A review of multilevel sampling systems in Britain indicated that the Westbay MP system was about twice the cost of the other systems in the comparison (CLAIRE 2002). The Westbay system is the most expensive system of those compared. Rating: 2

The Baski packer with dual-valve system and the Baski packer with dual-pump system are similar in cost for a dual-completion well. The cost is estimated to be $100,000 to $120,000, similar to the cost of a Westbay system. One system has a single submersible pump and two down-hole stainless-steel valves, whereas the other system has two submersible pumps but no down-hole valves. Both systems have stainless-steel production tubing that extends from the electric submersible pumps to the surface and that provides support for the system from the well head. The transducer equipment for these dual completion systems costs about $10,000. Rating: 2

The Barcad system is the least expensive system because of its simplicity of design and materials. Teflon tubing bundles operate each pump, and no pipe extends to the surface. The fiber optic transducer equipment that was installed with the dual-completion Barcad system costs about $15,000. Rating: 3

The FLUTe system for an 1100-ft well with two ports costs $40,000 plus installation, which takes 1 d. Transducers and associated logging equipment cost an additional $10,000. Rating: 3

7.3 Installation and Removal

Installation and removal of the Westbay sampling system involves proprietary Westbay equipment, and the installation procedure is complex. To date, installation has been performed only by Westbay personnel. The installation takes several days and includes making up the PVC casing, packer inflation, pressure testing, weight distribution, etc. Because of this complexity of installation and the required proprietary equipment, the Westbay installation was given a rating of 2.

Installation of the Baski packer with dual-valve system is also complex and takes several days but can be performed by a knowledgeable contractor experienced in well operations. The tubing connections for the operation of the packer and valves are complex with multiple connections through the pump shroud and packer. Pressure testing all fittings during installation is required and time-consuming. Two PVC water-level gage tubes are installed alongside the production tubing, which complicates the installation. Rating: 2

Installation of the Baski packer with dual-pump system is simpler than the packer with dual-valve system, with fewer control lines, and the packer pressure line is not complicated by connection to the two valves. This system also has the two PVC gage tubes installed alongside the production tubing. Rating: 2

The Barcad system installation is much simpler than the Westbay and Baski systems because there are no pipe connections to the surface; the Barcad system is supported by a small stainless-steel cable. Whereas the installation of the other systems requires a derrick rig, installation and removal of the Barcad system could be accomplished with a smaller power reel system. Rating: 3

Installation and removal of the FLUTe system is relatively quick and simple and is accomplished in less than a day. Rating: 3

7.4 Maintenance

Maintenance of the Westbay sampling system primarily involves the surface equipment used for sampling and transducer operations. The relatively complex equipment needed to support the system requires regular maintenance. A pressure system is not needed to maintain the Westbay packers because they are filled with water, but a vacuum pump is required for sampling. The transducers must be removed from the Westbay system each time samples are collected, which is an additional maintenance burden. No annual electrical inspection is required. Rating: 2

The Baski packer systems require maintenance of compressed gas at the well head to provide pressure to the packer and valves, but as long as the submersible pumps function appropriately, little maintenance should be required. Annual electrical inspection of the control box is required. The conventional transducer equipment is easily removed and serviced. Rating: 3

The Barcad system also requires maintenance of compressed gas at the well head to provide pressure to the packer. The fiber optic transducers are permanently installed; therefore, any maintenance requires removal of the system. The data loggers have been temperamental and have required routine maintenance. No annual electrical inspection is required. Rating: 3

The FLUTe system is virtually maintenance free. The water level in the liner should be checked before each sampling event. The conventional transducers would require routine operational inspection; removal and replacement would involve removing half of the liner and would be relatively simple. No annual electrical inspection is required. Rating: 4

7.5 Groundwater Sample Quality

The Westbay sampling system is a low-flow, no-purge system that averages about 4 L/h (1 gal./h) for the deep Laboratory wells. Where drilling impacts are not present in the formation surrounding a screen and where screens have been properly developed, the low-flow Westbay system appears to be capable of collecting representative groundwater samples. Where screens were not fully developed before installation of the Westbay system or where drilling impacts are present in the formation, concerns about representative samples have arisen. Sampling of the deep multiple screen wells at the Laboratory typically takes two to three personnel 3 to 5 d, which is labor and time intensive. Because the Westbay system does not allow purging of the well and thus may not collect samples representative of the formation, the system does not meet the current Laboratory-site DQOs for groundwater sampling at some multiple completion wells (LANL 2005d). Rating: 2

The Barcad sampling system at R-33 is also a low-flow, no-purge system that produces about 6 L/h (1.6 gal./h) from R-33 Screen 1 and about 9.3 L/h (2.5 gal./h) from R-33 Screen 2. A large volume of stagnant water in the casing is impossible to purge with this system. Where screens may not be fully developed before installation of the Barcad system, concerns about samples being representative of the formation could be present. Sampling of this dual-completion well typically takes 2 d. Because the Barcad system does not allow purging of the well and therefore samples representative of the formation cannot be collected, the system does not meet the current Laboratory-site DQOs for groundwater sampling. Rating: 1

The Baski packer and submersible pump systems are capable of sampling groundwater at a rate ranging from 1.3 to 10 gal./min. These systems allow for conventional purging and sampling of a well, which meet current Laboratory-site DQOs for groundwater sampling. Dual-completion wells can be sampled in 1 d. Rating: 4

Groundwater sampling using the FLUTe system is similar to the Barcad system except that the sampling devices are located at the bottom of the well where additional water is available for faster recharge of the system with higher flow rates. The FLUTe liner displaces the water in the well; thus, no stagnant water is present in the well casing as in the Barcad (and possibly Westbay systems. Sampling is low-flow, and only purging of the system tubing (two cycles) is required before collecting samples. Flow rates are reported to be about 2 L/min, which is 10 times faster than flow rates of the Barcad and Westbay systems. However, stacked U-tubes are required for deeper wells, which require cycling of alternate U-tube systems, resulting in slightly more complex sampling, and flow rates may be reduced. Because the FLUTe system does not allow purging of the filter pack and surrounding formation water, the system may not meet current Laboratory-site DQOs for the collection of representative groundwater samples at some completion wells where screens are not properly developed and/or where drilling impacts are present in the formation. However, at wells where drilling impacts are not present in the formation and the screens are properly developed, the FLUTe system may meet current Laboratory-site DQOs for the collection of representative samples. Rating: 2

7.6 Groundwater-Level Monitoring

The Westbay system incorporates transducers connected in series to monitor pressure at selected zones in a well. The system does not allow for manual measurement of water levels, but water-level data are available from up to seven zones in R-25, which has provided a unique data set for the regional aquifer that is not available using the other systems. Rating: 3

The Baski packer systems incorporate separate gage tubes that provide access to each screen zone using conventional transducer equipment and manual measurement methods. A design problem at R-10 that resulted in line plugging was apparently remedied at R-17, but a similar problem occurs at R-23i. Rating: 2

The existing Barcad system was installed with fiber optic transducers that cannot be removed without removing the entire system. The transducer equipment was not installed correctly, and numerous problems have been encountered with this transducer system. Also, no gage tubes were installed to allow for manual measurements, although it might be possible to retrofit the Barcad system to include gage tubes like those in the Baski packer systems. Rating: 2

The FLUTe system incorporates conventional transducers attached to the tubing at each port. Groundwater levels cannot be measured manually on a routine basis for calibration of the transducers. One-inch diameter tubes could possibly be installed from the surface to the U-tube for a two-port well, but the ball valves in the U-tube system do not allow real-time groundwater-level measurements. This system would allow measurement of the groundwater level after purging the tubing and allowing equilibration with groundwater. Rating: 3

7.7 Operational History

The Westbay sampling system has been in operation at the Laboratory for 7 yr and has operated according to manufacturer's specifications. Routine maintenance and repair and replacement of parts for associated service equipment have been required. Rating: 3

The Barcad system operates according to manufacturer's specifications. However, the R-33 installation was not furnished with surface equipment such as a pressure manifold for sampling operations and compressed gas to maintain packer pressure. The data loggers have failed several times and have required repair and replacement. This system was not fully functional until about 1.5 yr after installation. Rating: 2

The Baski packer with dual-valve system at R-10 was installed in May 2006, and the system at R-17 was installed in December 2006. The Baski packer with dual-pump system at R-23i was also installed in December 2006. Thus, the operational history of these systems is limited. Testing of the sampling systems after installation and operation during sampling events indicates that the systems operate according to manufacturer's specifications. Rating: 4

The FLUTe system functioned appropriately in the 280-ft deep LAWS-01 well for 3 yr. However, this system has not been used or tested in a deep regional aquifer well at the Laboratory but would likely function better than the Barcad system. Rating: 2

7.8 Long-Term Operational Issues

The Westbay system requires significantly more surface support equipment than other systems— trailers, winches, vacuum pumps, cables, etc.— that will also require maintenance, repair, and replacement. Rating: 2

The Baski packer with dual-valve system relies on the integrity of the down-hole pump and valves, the long-term reliability of which will determine the long-term viability of the system. Inspection of the packer pressure system and an annual electrical inspection of the electrical box are required. Rating: 4

The Baski packer with dual pump system relies on the integrity of the two down-hole pumps, which will determine the long-term viability of the system. The vibration created by the Bennett piston pump may impact long-term operations. Inspection of the packer pressure system and an annual electrical inspection of the electrical box are required. Rating: 4

The Barcad system is reported to have long-term serviceability. However, pressure data recorded during a pumping event at Screen 2 indicated that a small leak may have occurred at the Barcad valve. Technical support from the Barcad manufacturer has been limited: Rating: 2

The FLUTe system has relatively little maintenance requirements; therefore, long-term operational issues should be minimal. Rating: 3

8.0 CONCLUSIONS

A systematic evaluation was made of pump systems installed in multiple completion monitoring wells at the Laboratory. Nine evaluation criteria for each system were developed. These include

- system design,
- system materials,
- system cost,
- installation and removal,
- maintenance,
- groundwater sampling,
- groundwater-level monitoring,
- operational history, and
- long-term operational issues.

Each system was described and discussed with regard to the evaluation criteria, and a rating system was developed in an effort to provide a systematic ranking of each system. The ratings were based on the requirements of a deep regional aquifer well at the Laboratory and were specifically based on a 4.5-in.-diameter, two-screen well that is 1100 ft deep with a water level at about 1000 ft. An important component of the evaluation was the ability of each system to meet current Laboratory-site DQOs with respect to the collection of representative groundwater samples.

Based on the evaluation, the Baski packer and submersible pump systems ranked the highest, followed by the FLUTe and the Westbay systems. The Barcad system was ranked the lowest. However, this evaluation and ranking are based on operational history and experience at the Laboratory for application in deep regional aquifer wells with a deep water table. This evaluation does not address the suitability of these systems at other sites.

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