USE OF MULTI-LEVEL WELLS IN DEVELOPING A 3-DIMENSIONAL UNDERSTANDING OF GROUNDWATER FLOW AND CONTAMINANT MIGRATION AT THE SAVANNAH RIVER SITE

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ABSTRACT

Understanding the flow of groundwater and contaminants in 3-dimensions, along with hydraulic properties, is instrumental in selection and implementation of successful remediation efforts. Advances in multi-level groundwater monitoring at the Savannah River Site (SRS) are enabling engineers and geologists to collect the needed characterization data in an efficient, cost-effective manner. The SRS has developed a new multi-level groundwater monitoring well, "StrataSampler", which is being deployed for characterization and monitoring at several large groundwater plumes on the SRS. The installation method used allowed collection of data during the drilling process allowing optimization of screen placement within the aquifers and minimization of drilling costs and waste generation. Data generated during the installation of the StrataSamplers along with data collected from the installed wells is being used to understand the 3-dimensional nature of contaminant fate and transport. The L-Area Southern Groundwater Operable Unit is the first full-scale deployment of StrataSampler wells at SRS. Twenty-two StrataSampler wells with a total of 52 sampling zones were installed. The installation, development, hydraulic testing, sampling of the StrataSamplers at this unit and the resulting understanding of the contaminant plumes will be discussed in the paper and presentation.

SRS, located in the Atlantic Coastal Plain, is underlain by a seaward thickening wedge of unconsolidated and semi-consolidated sediments. Fluvial erosion has developed a rolling terrain in the gently sloped coastal plain sediments that underlie SRS. The network of terraces, uplands, and streams combined with the heterogeneous sediments, produce 3-dimensional groundwater flow systems as groundwater migrates from recharge to discharge areas. The multi-levels wells have provided detailed information increasing our understanding of this groundwater flow system. Two of the three water bearing units are contaminated with both tritium and tetrachloroethylene (PCE) / trichloroethylene (TCE). Three distinct plumes have been identified. One plume consisting of tritium. The other two plumes consisting of tritium and PCE/TCE co-mingled. The effects of two surface water bodies on the groundwater flow and plume transport have been discerned from the data collected with the multi-level wells.

INTRODUCTION

The Savannah River Site, a Department of Energy facility, began operations in 1952 to support the national security of the United States. Five nuclear reactors were constructed and operated over much of the second half of the 20^{th} century. The first reactor began operations in late 1953 with the other four reactors following suit in the next several years. In addition to the reactors many support and testing facilities were constructed and operated. None of the reactors operate today. Disposal practices and unplanned releases over the years contributed to contamination of groundwater at the SRS. As characterization of the groundwater plumes has progressed over time, inestigators have strived to improve the techniques and tools used to obtain the data needed to understand groundwater and contaminant movement. L-Area is one of the reactor facilities undergoing characterization of its surface source units and groundwater. This paper discusses the groundwater characterization efforts at L-Area, the tools used and the resulting understanding of the contaminant and groundwater movement.

Description of L-Area

L-Area is located in the south-central portion of the Savannah River Site. L-Area facilities operated from the 1954 through present. Production of nuclear materials ceased in 1993. The facility is approximately 0.2 square miles. The groundwater characterization effort encompasses an area of approximately 2 square miles. Six potential sources of groundwater contamination have been identified for the groundwater plume. Previous characterization efforts at four potential source units have identified that three of these four units are contributors to the groundwater contamination. Two of these sources are earthen basins. The third source is a concrete basin. They all received waters associated with reactor operations. Two additional sources that have not been characterized are an inactive ash basin and an emergency retention basin. The ash basin would have received ash from a coal-fired power house. The emergency retention basin was constructed to receive water from the reactor in the case an emergency necessitated flooding the reactor chamber. The emergency retention basin was never used for its intended purpose.

Controlling surface features of groundwater flow are Pen Branch stream, L Lake and a groundwater divide, as shown in Figure 1. Pen Branch stream and L Lake are potential receptors for groundwater contamination. L Lake is a man-made lake that received cooling water from L-Reactor. This lake is maintained at a constant elevation of 190 ft msl. The lake is a gaining lake in its upper reach and a loosing lake in its lower reach. Pen Branch stream is a natural stream, dividing two watersheds. It is a gaining stream. (1)

CHARACTERIZATION ACTIVITIES

Summary of Early Activities

Early activities associated with L-Area included installation of shallow monitoring wells around the perimeter of the basins. Monitoring wells for these basins date back to 1975. In 1984 and 1985, 4 clusters of wells were installed throughout L-Area to provide general water chemistry of all the water bearing zones from surface to basement rock. The data obtained from these early wells provided the first indication of groundwater contamination at L-Area. In 1999, characterization efforts began to determine the lateral and vertical extent of contamination. This work involved using cone penetrometer technology (CPT) to obtain lithology and collect water samples in the shallow water bearing zones near the reactor facility and known or potential

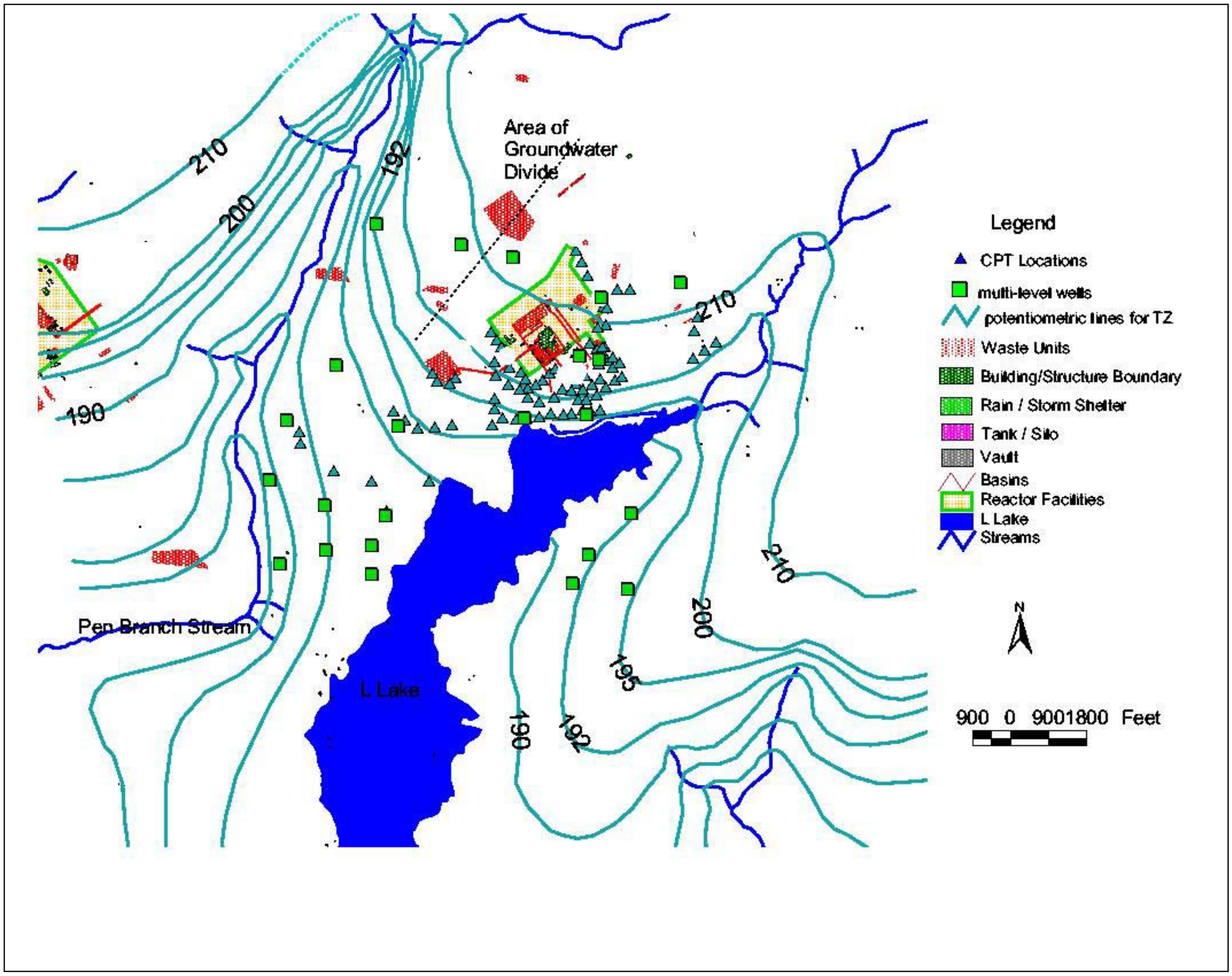

Figure 1. L-Area map with multi-level wells and groundwater flow directions identified.

source units. The CPT is typically limited to 150 feet or less depth at SRS. In L-Area the depth obtained allowed investigation of the top two water bearing zones (water table aquifer, identified as the transmissive zone (TZ) throughout this document and lower aquifer zone (LAZ)). The results indicated two plumes existed and a potential third. Two of the plumes emanated from the reactor facility and its adjacent discharge basins. These two plumes are both co-contaminated with tetrachloroethylene (PCE), trichloroethylene (TCE) and tritium above maximum contaminant limits (MCLs). The third plume consisted of tritium at levels above MCLs. This plume appeared to emanate from the emergency retention basin located to the west of the reactor facility.

Tetrachloroethylene and trichloroethylene were present in the aqueous phase above the 5 ppm MCL, but far below concentrations that would indicate the presence of dense non-aqueous phase liquids (DNAPL). Tritium (T), the third contaminant of concern, is present as tritiated water (HTO) in the groundwater with properties essentially that of water (H_20). Thus, it will travel as water without being preferentially sorbed to the soil. (2)

Regional Geology and Hydrogeology

SRS is located on the Atlantic Coastal Plain and is underlain by a seaward-thickening wedge of unconsolidated and semi-consolidated sediments. These sediments range from late Cretaceous to Holocene in age, as shown in Figure 2 (Thayer 1983). The work at L-Area consists of investigations of the upper zones of the Late Cretaceous age sediments to surface, referred to as the Coastal Plain sediments. The hydrostratigraphic units to be investigated are identified as the Gordon Aquifer and the overlying Upper Three Runs Aquifer (UTRA), as shown in Figure 2. The two aquifers are separated by the Gordon confining unit. These three units are identified as the Floridan Aquifer System.

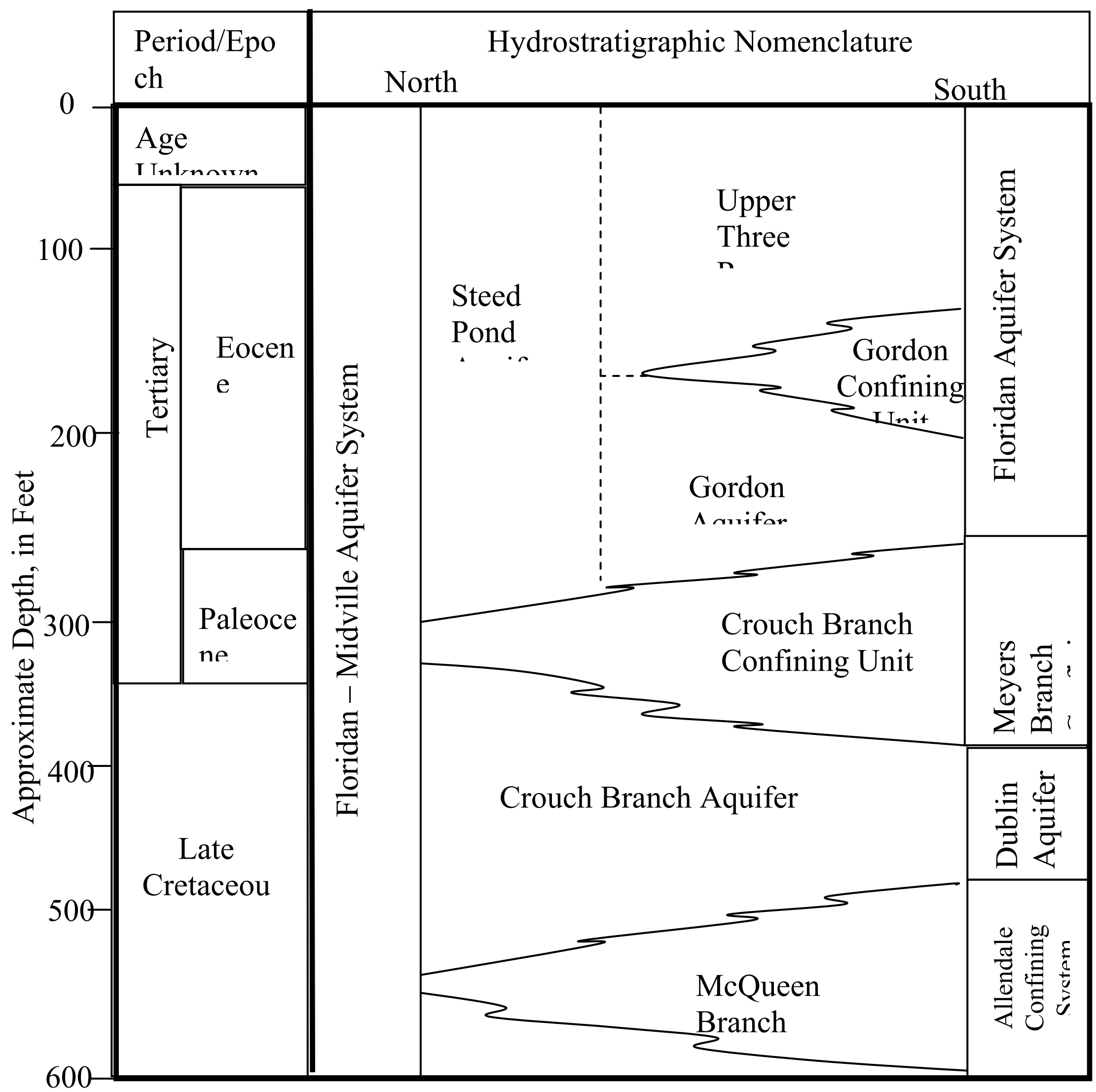

Figure 2. Generalized Hydrostratigraphic Column for Atlantic Coastal Plain Sediments at the Savannah River Site (3)

Gordon Aquifer

The Gordon aquifer is approximately 85 ft thick in L-Area with locations being as thick as 175 ft. The top of the Gordon aquifer occurs at an approximate elevation of –38 ft msl. The Gordon aquifer is composed of a greenish gray to gray, medium- to fine-grained sand that is well sorted in the lower portion of the unit; the upper interval is a fine- to medium-grained sand that is poorly sorted and calcareous. Overall, the Gordon aquifer occurs under confined, semiconfined, or leaky confined conditions throughout L-Area and throughout most areas of SRS.

Gordon Confining Unit ("green clay")

Near L-Area, the Gordon confining unit is continuous, separating the UTRA and the Gordon aquifers. The Gordon confining unit is known locally as the "green clay" and will be referred to as such throughout this document. The unit is on average 16 ft thick in L-Area, ranging from approximately 5 ft to 30 ft thick. The top of the unit is at an approximate elevation of 81 ft msl. The "green clay" is an olive gray glauconitic, sandy clay in the south part of L-Area, grading to a silty, clayey sand in the north part of L-Area. The unit is semiconfining, and may be a leaky confining unit in parts of L-Area. The hydraulic gradient across the Gordon confining unit is downward in L-Area.

Upper Three Runs Aquifer

The UTRA occurs between the water table surface and the Gordon confining unit. The aquifer is on average 113 ft thick in L-Area, ranging from 70 to 160 ft thick. It is informally divided into the upper aquifer zone (water table aquifer, also call the TZ) and the lower aquifer zone (LAZ). The two zones are divided by a discontinuous confining zone referred to as the "tan clay". The UTRA has a general downward hydraulic gradient across the "tan clay."

The LAZ is on average 45 ft thick in L-Area, ranging from 25 ft to 80 ft thick. The top of the LAZ is at an approximate elevation of 126 ft msl. The sediments are medium- to fine-grained, moderately to poorly sorted, silty and clayey sands, calcareous and fossiliferous limestone, clay, and silt; and moderately sorted coarse- to medium-grained sand, with minor amounts of silt and/or clay matrix.

The top of the "tan clay" confining zone, which separates the LAZ and water table, occurs at an approximate elevation of 141 ft msl. The unit is on average 15 ft thick, ranging from 4 ft to 37 ft thick. The unit is composed of lobes of interbedded clay, sandy clay, clayey sand and sand. The clays are clean to sandy (up to 40%), predominantly grayish yellow or orange to brownish yellow. The clayey sands and sandy clays are orange yellow to brown yellow, fine- to medium-grained and poorly sorted. The sands are predominantly brownish yellow, fine- to very coarse-grained, poorly to well sorted and wet.

The TZ is on average 53 ft thick, ranging from 20 to 80 ft thick. The water table is at an approximate elevation of 192 ft msl. The sediments are comprised of coarse- to medium-grained tan sands, moderately sorted with minor amounts of silt and/or clay matrix, and medium- to coarse-grained silty sands that are poorly to moderately sorted. Interbeds of sandy and silty clay (1 to 10 ft thick) are abundant, and pebble layers occur locally.

Conceptual Model

The working conceptual model at this phase of the investigation is the following:

- Tritium is present in a separate plume to the west of the reactor facility, as shown in Figure 3. The source of this contamination appears to be the emergency retention basin. The lateral and vertical extent of the plume is not known. Based on historical information that indicates a single discharge to this basin in 1985 during a test prior to restart of the reactor, this plume is expected to be small in lateral and vertical extent and low in tritium concentration. The downgradient extent of the plume is not known. The movement of this tritium plume is not known but is most likely controlled by hydraulic forces associated with L Lake and Pen Branch stream.

- Contaminants emanating from the reactor facility to L Lake are commingled into two plumes, as shown in Figure 3. The results of CPT sampling were used to bound the width of the plumes close to the sources in the TZ. The shapes of the plumes indicate several sources. The contaminants are stratified in the soil column. The data indicate the higher concentrations of the three contaminants of interest are located in sandy zones above the "tan clay" in the TZ. Water sample results indicate contamination may be present in the LAZ. At some locations where the CPT penetrated into the LAZ, the three contaminants of interest were detected. Water samples from CPT locations close to L Lake indicate the presence of the three contaminants of interest above MCLs. Thus, it is inferred that contaminants are discharging to L Lake in the TZ. Insufficient data is present at this time to determine if groundwater in the LAZ flows into or below L Lake.

Data Gaps and Methods Selected to Resolve Unknowns

The three plumes identified with the initial CPT work were not fully defined as to their vertical and lateral extent. In addition, there was not a thorough understanding of the groundwater flow system.

The early investigations had been within the 0.2 square miles of the reactor facility. Review of the early data indicated this area would have to be expanded to identify the lateral extent of the contamination as the plumes moved downgradient. The unknown with the two PCE/TCE/tritium plumes was the vertical extent of the contamination. CPT tools would not be sufficient to probe greater depths to find the vertical extent of the contamination. The lack of monitoring wells/piezometers within all water bearing zones of interest made it difficult to understand the flow patterns of the groundwater and contaminants. This became of great importance once the tritium contamination to the west of the reactor facility was identified, as no wells existed in this area.

A challenge was to identify the discrete zones in which the contaminants were flowing within the aquifers to allow accurate placement of the well screens and to accomplish this in a more cost efficient and timely manner. One goal was to choose an option that would allow collection of data during the drilling process to enable optimization of screen placement within the aquifers

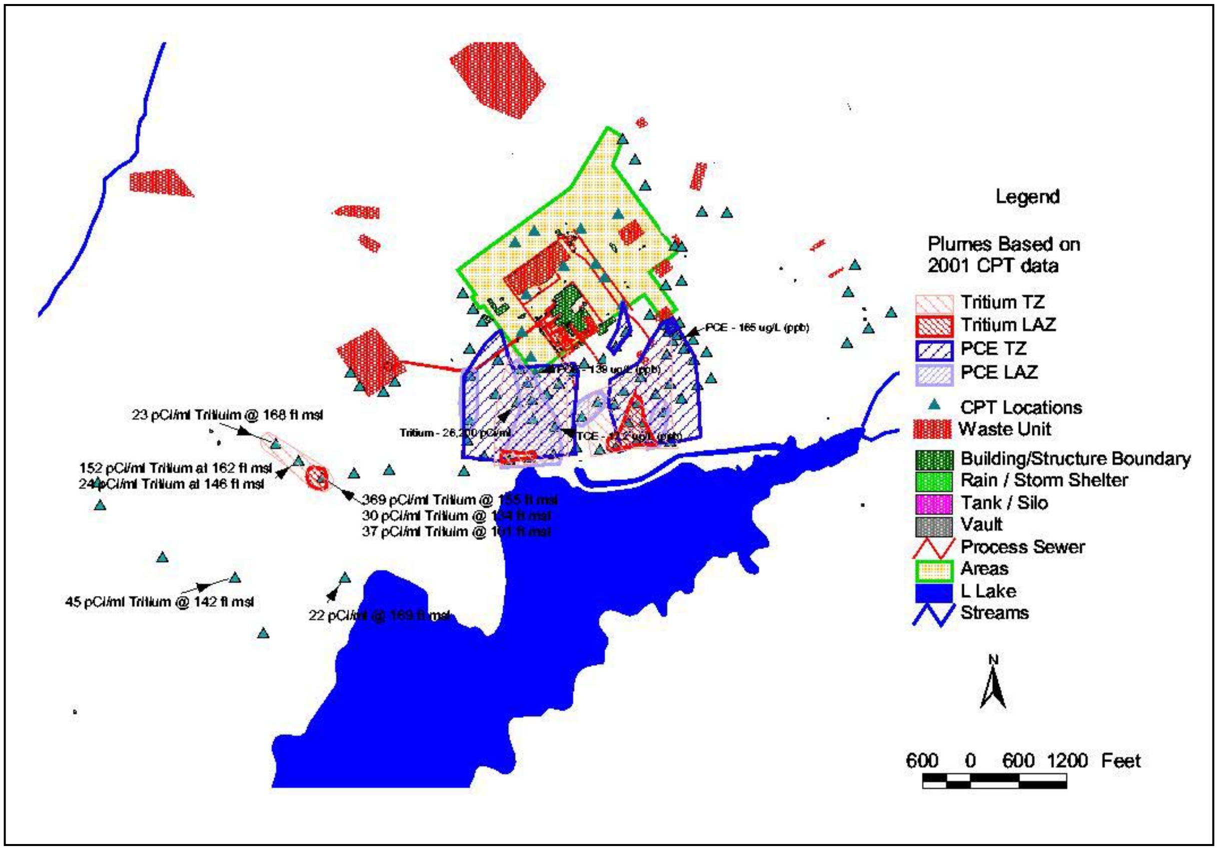

Figure 3. 2-dimensional representation of tritium and PCE plumes based on existing wells and CPT data.

while keeping our costs and waste generation to a minimum. After review of the options available, the decision was made to install Strata-Sampler multi-level wells using the sonic drilling technique. The Strata-Sampler multi-level wells were developed at SRS and have had successful use in projects at SRS and in Russia. The sonic drilling method was chosen because high quality core and water samples would be obtained during drilling operations, providing information for selecting screen zones. In addition, no drilling mud is needed which would minimize difficulties with developing the well screens. Temporary surface casing is used when drilling through a confining unit (i.e. green clay); thus, eliminating the cost of permanent steel surface casing.

Description of Strata-Sampler Multi-Level Wells

The conceptual hydrogeologic model for L-Area described previously suggests the presence of 3-dimensional groundwater flowpaths that potentially traverse 200 feet and several hydrostratigraphic units vertically and laterally. Ideally, the multi-level sampling stations would be installed along key flowpaths based on the conceptual model.

A multi-level groundwater monitoring network was designed to collect the information necessary to identify the 3 dimensional flowpaths. StrataSamplers were chosen because they are unique among the current options for multi-level groundwater monitoring in several ways including: use of well casing with standard ASTM F480 threads, does not require proprietary sampling equipment, large diameter riser allow use of a wide variety of sampling pumps and pressure monitoring equipment. A sealed annulus creates a sampling chamber between a common piece of well screen and pipe used as a pass through for the StrataSampler, Figure 4. The riser is connected to the sampling zone by a sampling tube that penetrates the wall of the pass through. This configuation allows the use of a wide range of materials for a riser depending on the intended use of the StrataSampler and the types of sampling and monitoring equipment to be used.

A four-inch diameter StrataSampler with ASTM F480 threads and 0.020 inch slot screen was used with 1-inch diameter flush threaded PVC pipe for the riser. The 1 inch riser facilitated the use of larger diameter inertial pumps such as the Wattera and bladder pumps.

FIELD ACTIVITIES

The work in this phase of characterization involved the identification of groundwater contamination and areas of surface recharge and discharge. Fifty-two (52) screens at 22 locations, as shown in Figure 1, were installed to enable collection of water samples for chemical analyses and measurement of groundwater elevations. During installation, field logs were prepared describing the geology and water samples were collected at several depths within each aquifer. After completion of the wells, field parameters were collected during sampling events, water level measurements were made monthly and hydraulic conductivity determined for each well. During this same period of time investigations were conducted in Pen Branch stream to determine baseflow conditions and water elevations. The baseflow measurements provided water elevation and stream flow data. This data was used to interpret where the stream was gaining water from the subsurface (i.e. a discharge point for the groundwater) and to provide input to the potentiometric maps for the unit.

Installation and Development Of Strata-Sampler Multi-level Wells

Drilling was conducted with the sonic drilling technology that combines harmonics (vibration) and rotation as the basis for tool advancement. Sonic drilling uses water as the fluid medium as opposed to mud rotary which uses mud. As the boreholes were drilled and core was recovered, the geologist overseeing the field operation would write a field description of the core and would identify zones that appeared to be good waterbearing zones for water sampling. As those depths were identified the drilling operation would discontinue and the IsoFlow water sampling system used by the drilling company would be installed downhole and a water sample obtained. A benefit of the IsoFlow method is that information is gained on the rate the sampled zone will produce water. Based on the conceptual model, the zones of interest were those that would have flowing water. The water samples were submitted to the analytical laboratory for analysis on a 24 hour turn around basis. Upon receipt of the analytical results, the results and the core descriptions were reviewed together to allow screen placement in those zones with the highest concentrations of contaminants. Several water samples were collected in each water bearing unit in each borehole. After selecting screen zones, the multi-level well was installed in the same manner as other monitoring wells with one exception. One-inch diameter PVC riser pipe was

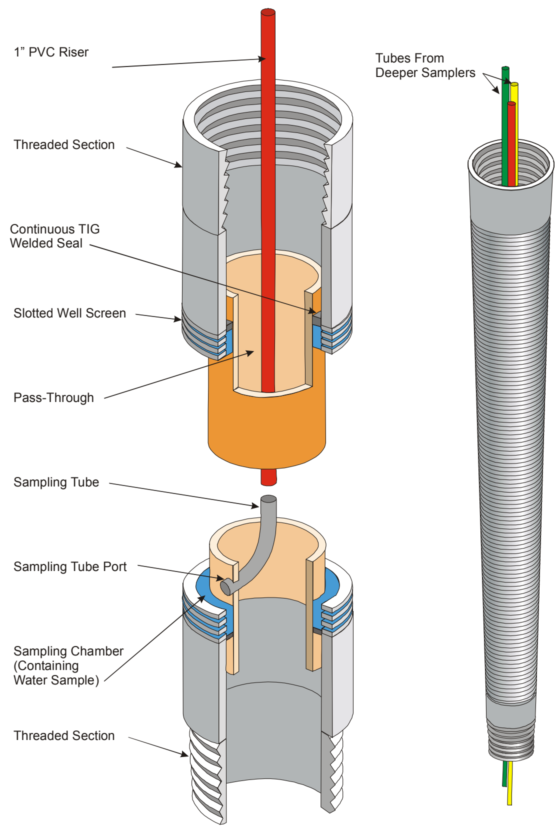

Figure 4. Sketch of StrataSampler used in construction of multi-level wells.

connected from each Strata-Sampler and run to ground surface through the annular space of the 4" diameter PVC casing. This 1" diameter pipe is the sampling port for each Strata-Sampler.

The methods of development used for standard wells are employed for the Strata-Sampler multi-level wells. The difference being, the size of the pumps employed. The development equipment must fit inside the 1" diameter drawtube connected to the Strata-Sampler screen. The purpose of the well development is to remove the fines that may be present in the gravel pack. A Waterra Hydrolift II, inertial pump, was chosen for the development pump. The system included a 3/4" OD stainless steel footvalve and 5/8" OD high density polyethylene (HDPE) tubing. This setup allowed for pumping at rates up to 1 gallon per minute (gpm). Development of the multi-level wells took from several hours to several days, depending on the formation in which the screen was set. SRS has a pre-defined level of 15 NTU to consider a well developed. This level was obtained in some wells, but not all. As the contaminants of interest are low concentrations (<200 ppb) of PCE and TCE and tritium, low turbidity levels are not as critical as for instance with metals analysis.

Hydraulic Testing of Multi-Level Wells

Air pressurized slug tests were performed on the 52 screens in L-Area for determination of hydraulic conductivity. Data from the tests were analyzed using the Bouwer and Rice (4) and the Hvorslev (5) methods for determining hydraulic conductivity from slug tests. The software package "AQTESOLV" (HydroSOLVE, 1997) was used to analyze the data. A special well head apparatus was designed for the tests. The well head assembly, constructed of aluminum materials, was designed to screw into PVC fitting attached to the 1" riser pipe of each screen and provide an air-tight pass through for a pressure transducer cable. The assembly was fitted with a pressure gauge, a fitting for the air-supply line and a ball-valve for relieving the air pressure in the well. In-Situ Mini-Troll 15 psig and 30 psig pressure transducers with 100 ft and 200 ft of cable, respectively, was threaded through the assembly to facilitate data collection.

The data was analyzed to determine hydraulic conductivity using both the Bouwer and Rice (4) and Hvorslev (5) methods. Both the confined and unconfined solutions were used, dependent on the well. The wells installed in the TZ were analyzed using the unconfined methods and the wells installed in the LAZ and the Gordon aquifers were analyzed using the confined methods. Figure 5 is representative of the raw data obtained from the slug tests. A simple observation from the raw data is that recovery rates decrease from the Gordon Aquifer upward into the TZ. Thus, hydraulic conductivity would also decrease from the Gordon Aquifer to the TZ. The wells were all screened in zones described as sand to very silty sand. The hydraulic conductivity values calculated for the screened zones average 1 ft/day for the TZ, 1.2 ft/per day for the LAZ and 2 ft/day for the Gordon Aquifer. This is consistent with hydraulic conductivity ranges for silty sand to clean sand in unconsolidated deposits, as reported in the literature by Freeeze and Cherry (6).

Sampling the Multi-Level Wells

Two rounds of comprehensive analyses are to be performed on these wells followed by evaluation of the data to set up a routine sampling protocol, if necessary. At this time both rounds of comprehensive sampling of these wells has been completed with one set of data received. The analysis suites are for volatile and semi-volatile organic contaminants, pesticides and PCBs, metals and radionuclides. The analytical results indicate the presence of TCE, PCE and tritium. Field parameters were collected during the sampling of all wells. In addition, monthly water levels have been measured for each well once it was installed. Most wells have a minimum of 6 rounds of water level readings. This data is used to further define the contaminant plumes and to refine the investigators understanding of the groundwater flow system.

Refinement of the Conceptual Model based on Multi-Level Wells Data and Stream Hydraulic Data

The additional data gathered from the multi-level wells provided detailed information concerning the geologic make-up of the soils in the LASG OU along the contaminant levels. The water level data from the wells along with the hydraulic information collected along Pen Branch stream were used to generate site-specific potentiometric surfaces for the LASG OU, as shown in Figure 1. Combining all the data allows the investigators to refine the conceptual model for the OU.

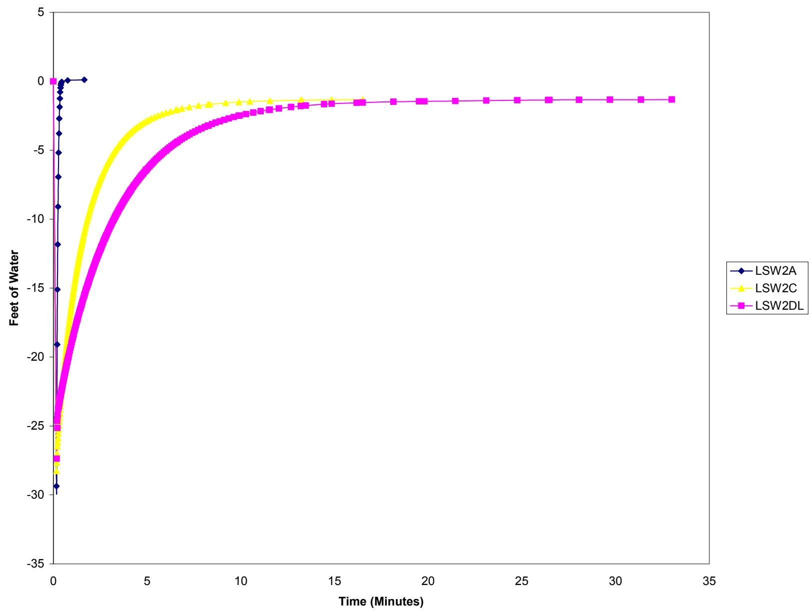

Figure 5. Typical graph of recovery rate for the 3 aquifers of interest (A – Gordon Aquifer, C – LAZ and DL-TZ)

Results of water samples from the multi-level wells adjacent to L Lake in the area of the co-mingled plumes confirmed contaminant presence in the UTRA above MCLs, Table I. Contaminants appear to be stratified, with the highest concentrations (26,200 pCi/ml of tritium, 165 µg/L of PCE and 17 µg/L of TCE) located in the TZ. Water level data obtained from the multi-level wells indicate that groundwater in both the TZ and LAZ of the UTRA discharge into L Lake in the region of the co-mingled plumes. The water level data does not indicate groundwater flowing beneath L Lake in the UTRA.

Results of water samples from the multi-level wells located between L Lake and Pen Branch stream indicate the presence of tritium in the wells adjacent to L Lake, Table II. The plume appears to be long and narrow and of low concentration (<200 pCi/ml). Higher tritium concentrations were measured above the "tan clay". However, concentrations above MCLs were measured in wells screened in the LAZ of the UTRA. The refined potentiometric surfaces indicate the direction of flow is from the lake towards the stream. Review of time trend data for water levels of all wells in L Area that are screened in the UTRA indicate water levels have dropped approximately 15 ft in the period 1998 through 2002, Figure 6. Raising the water levels for all wells by 10 feet (15 feet is a period of high rainfall) would bring some water level elevations above the 190 ft msl elevation at which L Lake is maintained. This would shift the potentiometric lines and flow would be toward both L Lake and Pen Branch, Figure 7. The direction of contaminant flow would be dependent on which side of the high the source was located. From the existing data, it appears the emergency retention basin is located on the L Lake side of the high. Thus flow was towards L Lake until the drought began and groundwater levels decreased to a level below 190 ft msl; thus, changing the flow patterns.

Table I. Depth Profile of tritium, PCE and TCE concentrations at CPT locations where highest concentration of each analyte was detected.

CPT Location ID	Sample Elevation and Aquifer Unit	Tritium Conc. (pCi/ml)	PCE Conc. (µg/L or ppb)	TCE Conc. (µg/L or ppb)
LSCPT3	198 (TZ)	18	165	0.8
	187 (TZ)	5	2	ND
	170 (TZ)	3	ND	ND
	155 (TZ)	2	ND	ND
LSCPT22	164 (TZ)	26	1	14
	148 (TZ)	29	4	17.2
	135 (LAZ)	210	4	4
	100 (LAZ)	612	9	2
	90 (LAZ)	8	3	2
LSCPT23	179 (TZ)	16	ND	ND
	163 (TZ)	11800	34	10
	150 (TZ)	26200	41	8
	134 (LAZ)	3420	116	ND
LSCPT74	180 (TZ)	7	ND	ND
	164 (TZ)	161	88	ND
	154 (TZ)	178	31	ND
	132 (LAZ)	349	50	ND
	88 (LAZ)	55	13	ND
	72 (LAZ)	29	2	ND
LSCPT99	194 (TZ)	4	ND	ND
	180 (TZ)	19	48	ND
	172 (TZ)	4	139	ND
	166 (TZ)	3	2	ND
	156 (TZ)	15	4	ND

Table II. Water sample results from multi-level wells located between L Lake and Pen Branch stream.

Well ID with Aquifer Unit	Tritium Results (pCi/ml)	
	Round 1 Sampling (July 2002)	Round 2 Sampling (Dec 2002)
LSW 8C (LAZ) (1)	25	28.9
LSW 8DL (TZ) (1)	41.4	34
LSW 9C (LAZ) (2)	19.3	111
LSW 9DL (TZ) (2)	66.7	30.6
LSW 10C (LAZ) (3)	ND	ND
LSW 10DL (TZ) (3)	1.5	2.2
LSW 11C (LAZ) (2)	12.5	10.8
LSW 11DL (TZ) (2)	57.1	62.6
LSW 12A (Gordon Aquifer) (3)	ND	ND
LSW 12C (LAZ) (3)	2.4	2.6
LSW 12DL (TZ) (3)	<1	ND
LSW 13C (LAZ) (4)	<1	ND
LSW 13DL (TZ) (4)	2	2
LSW 14C (LAZ) (2)	18.6	19.5
LSW 14DL (TZ) (2)	5.3	5.8
LSW 15C (LAZ) (4)	ND	ND
LSW 15DL (TZ) (4)	2.4	2.7

Note: 1. near basin, 2. near lake, 3. midway between lake and stream, 4. near stream

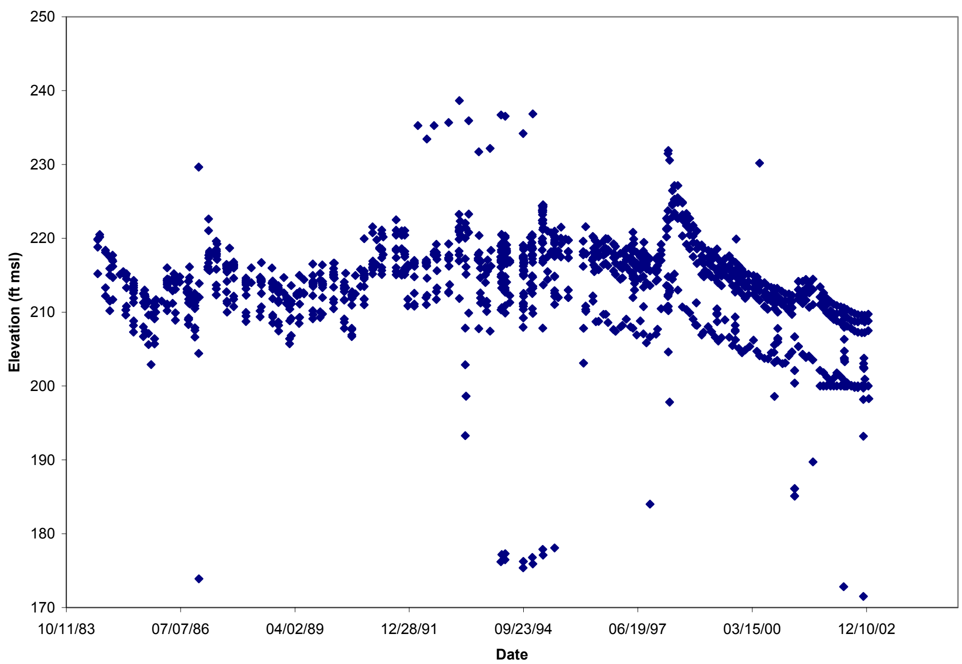

Figure 6. Time trend data of water levels from L-Area Wells (time period 1984 through 2002).

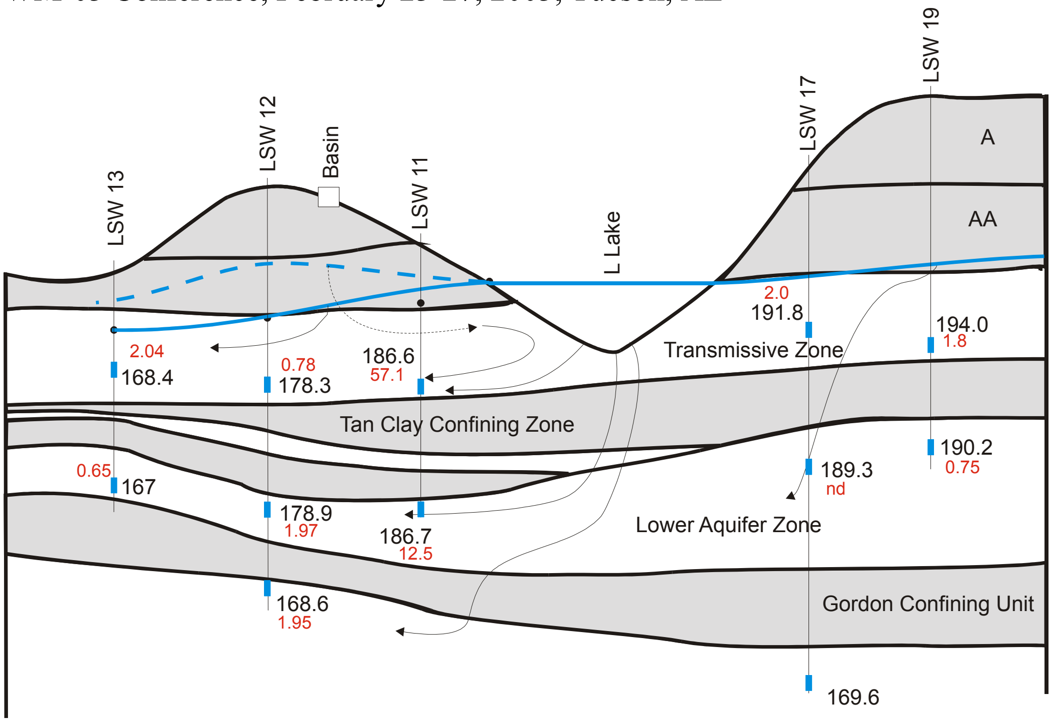

Figure 7. Hydrogeoloic cross-section aligned with current day flow patterns in the TZ. Groundwater flow paths changed due to declining potentiometric surfaces for shallow aquifer zones and filling of L Lake (in 1985). Dashed blue line shows potentiometric surface during normal rainfall periods. Continuous blue line shows potentiometric surface 4 years into a drought cycle. Flow in the LAZ has a significant component of flow perpendicular to the cross-section.

CONCLUSIONS

A comprehensive characterization effort is key to accurately understanding the fate and transport of contaminants in groundwater systems. This characterization effort is not limited to collection of subsurface samples for contaminant analysis but includes collecting data related to the geology and hydraulics of the subsurface and hydraulics of any surface water bodies that may act as direct recharge or discharge points. Ensuring the characterization is comprehensive is the responsibility of the investigators. This is accomplished by starting with a conceptual model that is continually refined as additional data is collected. This process may be repeated several times and take several years worth of effort to develop a conceptual model the investigators believe explains what is and has occurred in the subsurface. The conceptual model is used as the basis for identifying data gaps that lead to identifying the additional data needed to eliminate those gaps. The additional data is collected with standard methods, such as the CPT tools, and with non-standard methods, such as the sonic drilling water sampling system and the multi-level wells. When the investigators conclude the characterization to be complete, the data is provided to the modelers as input data for fate and transport models. Upon developing a fate and transport model, the conceptual model can be used as a check on the ability of the model to represent the field conditions.

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