Pacific Northwest National Laboratory
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Investigation of the Strontium-90 Contaminant Plume along the Shoreline of the Columbia River at the 100-N Area of the Hanford Site

D. P. Mendoza   B. G. Fritz
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M. J. Hartman   R. Mackley
F. A. Spane   B. N. Bjornstad
M. D. Sweeney   R.E. Clayton

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PACIFIC NORTHWEST NATIONAL LABORATORY
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Pacific Northwest National Laboratory
Richland, Washington 99352

Summary

Efforts are underway to remediate strontium-contaminated groundwater that discharges to the Columbia River at the 100-N Area of the Hanford Site. Past practices of the 100-N Area reactor liquid waste disposal sites have left strontium-90 sorbed onto sediments, leaving a continuing source of contaminant discharge to the river.

The Remediation Task of the Remediation and Closure Science Project assessed the interaction of groundwater and river water at the hyporheic zone. Limited data have been obtained at this interface of contaminant concentrations, geology, groundwater chemistry, affects of river stage and other variables that may affect strontium-90 release. Efforts were also undertaken to determine the extent, both vertically and horizontally, of the strontium-90 plume along the shoreline and to potentially find an alternative constituent to monitor strontium-90 that would be more cost effective and could possibly be measured under real-time conditions. A baseline of strontium-90 concentrations along the shoreline was developed to help assess remediation technologies.

Water sampling along the 100-N Area shoreline demonstrated that the horizontal strontium-90 plume was approximately 400 m long. This is consistent with other findings such as those found in the Innovative Treatment and Remediation Demonstration (ITRD) Project (ITRD 2001)[1]. The 1000 pCi/L contour was found in a narrow portion of the shoreline near well 199-N-46 and cluster NS-3A. The 100-pCi/L contour lies between horizontal array locations 1 and 2. The remainder of the aquifer tubes lies within the strontium-90 drinking water standards of 8 pCi/L. The vertical extent of the plume found concentrations to be at an elevation above 113 m with the highest concentrations found at ~116 m.

River stage influenced strontium-90 release into the river at various sample locations. However, not all samples along the 100-N Area shoreline demonstrated a clear relationship with varying river stage conditions and strontium-90 releases. Strontium-90 release is also affected by different water-table gradients and local geology. The general chemistry of water from river and aquifer tubes was similar to data from nearby monitoring wells and river samples. Variability in general water chemistry does not appear to be related to season or river stage changes except in two aquifer tubes that appear to be influenced by a groundwater plume high in sulfate, sodium, and calcium.

Slug tests in the river tubes yielded relatively low hydraulic conductivity values ranging from 0.08 to 1.6 m/day. Values at an elevation of ~116 m were an order of magnitude higher than measured values at higher or lower water table elevations. The high hydraulic conductivities were correlated with high concentrations of strontium-90 observed at elevations ranging between 115.5 to 116.5 m. These data indicate a potential "transmissive" layer at ~116 m compared to the hydraulic conductivity above and below this depth in which the contaminant would have a preferred pathway for release. Slug tests in well clusters 199-N-119, -120, and -121 ranged from 3.7 to 6.9 m/day, with the lowest values in the deepest well (from 109.9 to 111.4 m elevation).

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[1] ITRD. 2001. *Hanford 100-N Area Remediation Options Evaluation Summary Report*. Innovative Treatment and Remediation Demonstration Program. Office of Environmental Management, Subsurface Contaminants Focus Area. Sandia National Laboratories, Albuquerque, New Mexico.

Gross beta was found to be a good indicator of strontium-90 concentrations. Gross beta measurements require less sample volume and less analytical preparation than strontium-90 analysis. Gross beta is also significantly less costly to analyze. Strontium-90 concentrations at this location can be estimated as approximately one-half gross beta concentrations. No other parameters were found to be indicators of strontium-90. Specific conductance varied little in the aquifer tubes samples and could not be used as an indicator. The high-salt plume in this vicinity also affected samples in some of the aquifer tubes. Metals, ions, and field parameters demonstrated no obvious trend for strontium-90 indication.

Geology and bathymetry data were examined to determine their influence on strontium-90 distributions and discharge to the Columbia River. The highest strontium-90 concentrations in sediment samples from well 199-N-121 were in the lower Hanford and upper Ringold Formations. These results were consistent with those observed in wells installed for a treatability study being performed in the 100-N Area. Columbia River bathymetry surveys were conducted perpendicular to the centerline of the strontium-90 plume in the 100-N Area to obtain a better understanding of the river-bottom elevations. The bathymetry data reveal a gradual slope just beyond the rip rap that extends into the main river channel. There is a slightly elevated ridge near the middle of the river, but in general, no significant elevation changes or structural differences that might impact contaminant discharge have been observed at sampling locations along the 100-N Area shoreline.

A total petroleum hydrocarbon (TPH) assessment was performed just to the southwest of the strontium-90 plume along the 100-N Area shoreline. Six aquifer tubes were installed at different locations and depths perpendicular to identify the wells in which TPH values had been observed. The results indicated an elevated concentration of TPH at an elevation of ~116.0 m with concentrations ranging from 0.17-0.63 mg/L in four of the six new aquifer tubes, indicating a diesel discharge into the Columbia River. Appendix D contains the details of this diesel assessment.

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Acronyms and Abbreviations

DOE	U.S. Department of Energy
Ecology	Washington State Department of Ecology
FY	fiscal year
GPAP	Groundwater Performance Assessment Project
HEIS	Hanford Environmental Information System
HLAN	Hanford Local Area Network
ICP-MS	inductively coupled plasma-mass spectroscopy
MDL	minimal detection limit
ORP	oxidation reduction potential
PNNL	Pacific Northwest National Laboratory
PVC	polyvinyl chloride
RACS	Remediation and Closure Science Project
ROD	Record of Decision
SESP	Surface Environmental Surveillance Project
Sr	strontium

Acknowledgments

1.0   Introduction

This report describes the activities and results for an investigation conducted at the Hanford Site's 100-N Area during fiscal years 2004 through 2006. The work was performed under the Remediation Task of the Remediation and Closure Science (RACS) Project funded from the U.S. Department of Energy (DOE) Richland Operations Office through September 2006 and subsequently through a subcontract with Fluor Hanford, Inc.

1.1   Purpose and Scope

The purpose of the 100-N Area study was to better characterize strontium-90 contamination along the shoreline and its discharge to the Columbia River. Improved characterization of the plume will provide data that can be used in developing remedial action decisions and in implementing those decisions. This work was coordinated with various Hanford Site environmental monitoring projects including the Surface Environmental Surveillance Project (SESP) and the Groundwater Performance Assessment Project (GPAP).

Groundwater and shoreline seeps in the 100-N Area are being monitored for contaminants entering the Columbia River by different environmental monitoring projects. Prior to the water sampling efforts, assessment of strontium-90 concentrations along the 100-N Area shoreline were estimated using inland monitoring wells and a few shoreline wells. Previous investigations have acknowledged that additional shoreline monitoring was needed to assess the interaction of river and groundwater in a zone beneath the shoreline and to learn more about the influence of site-specific geological features in this zone. In particular, the dilution of strontium-90 with river water was examined by the RACS Project to determine to what extent river-stage fluctuation affected contaminant discharge to the river.

For this study, riverbed sampling tubes, shoreline aquifer tubes, and near-river monitoring wells were installed along the 100-N Area shoreline. Water levels, radionuclide concentrations, and water quality data have been collected since April 2004. Data from these sampling locations were used to better define the horizontal and vertical extent of the strontium-90 plume. These data can be used to validate computer simulations of the strontium-90 plume and to support remediation design for the 100-N Area.

1.2   Summary of Existing Information

Before sampling activities started, an extensive review of the available data was conducted. The following historical data set for the 100-N Area was reviewed before the research was initiated:

- Groundwater data from an extensive network of wells including several on the shoreline stored in the Hanford Environmental Information System (HEIS).

- Radiological data for water samples from 13 seep wells installed in the rip rap along the shoreline to facilitate riverbank spring sampling. These are sampled annually in the fall by the Near-Field Environmental Monitoring program, and results are currently reported in environmental annual reports (e.g., Perkins et al. 2004). The analytical results are not stored in the HEIS.

- Water-level data from a network of transducers in wells in the 100-N Area and adjacent to the Columbia River collected in support of several previous investigations and performance evaluation of

the pump-and-treat system for strontium-90. The results are stored in a contractor database and available in DOE's Virtual Library.

- Radiological and chemical data for Columbia River water and riverbank springs measured by the SESP and available in HEIS and reported annually in the *Hanford Site Environmental Report* (e.g., Bisping 2006).

- Data associated with biological monitoring of bi-valves along the river bottom have provided some indication of the lateral extent of contamination along the shoreline, but bi-valve tissue and shell concentrations are difficult to quantitatively compare to water concentrations. A better understanding of the bi-valve's uptake and depuration of strontium-90 is needed in order to correlate the data to contaminant discharge.

1.3 Background

The 100-N Area reactor operated from 1963 to 1986, was placed into cold standby in February 1988, and finally retired in October 1989. (Note: A detailed description of the 100-N Area with regard to historical operations and waste sites is presented in a Technical Baseline Report [Cote 1994]). Liquid effluent from the reactor was disposed to the ground in the 116-N-1 crib and trench from 1963 to 1985, and in the 116-N-3 crib and trench from 1983 to 1991 (DOE-RL 1998). Liquid waste disposed to these facilities contaminated the underlying vadose zone and groundwater with strontium-90 (Figure 1.1) and other contaminants. Both facilities have been excavated in recent years to remove the most heavily contaminated sediment. A groundwater pump-and-treat system operated from 1995 until March 2006 as an interim action to reduce the amount of strontium-90 reaching the Columbia River (ROD 1999).

Because the 100-N Area pump-and-treat system did not meet remedial action objectives of the 1999 Record of Decision (ROD) for Interim Action, DOE evaluated alternative treatment methods. In late 2005, DOE released a test plan for an alternative: sequestration of strontium-90 in the ground by apatite minerals (DOE-RL 2005a). The Washington State Department of Ecology (Ecology) agreed that DOE would conduct a pilot-scale field test and install a 91-m barrier in fiscal year (FY) 2006 (DOE-RL 2005b). DOE injected the chemicals to form the sequestration barrier where the highest concentrations of strontium-90 were observed at shoreline monitoring sites and in clam tissue. The objective is to create a permeable, reactive barrier near the shoreline that will capture strontium-90 as groundwater flows through a treatment zone.

1.4 Approach

The general approach adopted to accomplish the project objectives was to measure contaminant concentrations in pore water from the hyporheic zone, measure water levels and specific conductance in the aquifer, and develop a better understanding of the local geology by drilling some boreholes near the central portion of the strontium-90 plume. For this study, the hyporheic zone is defined as any location where surface water infiltrates into the underlying sediment and mixes with groundwater (Westbrook et al. 2005, Woessner 2000, and White 1993).

In FY 2004 and FY 2005, monitoring points were installed in the strontium-90 plume along the 100-N Area shoreline in the hyporheic zone. The network was designed to define the distribution of strontium-90 and other contaminants vertically and horizontally.
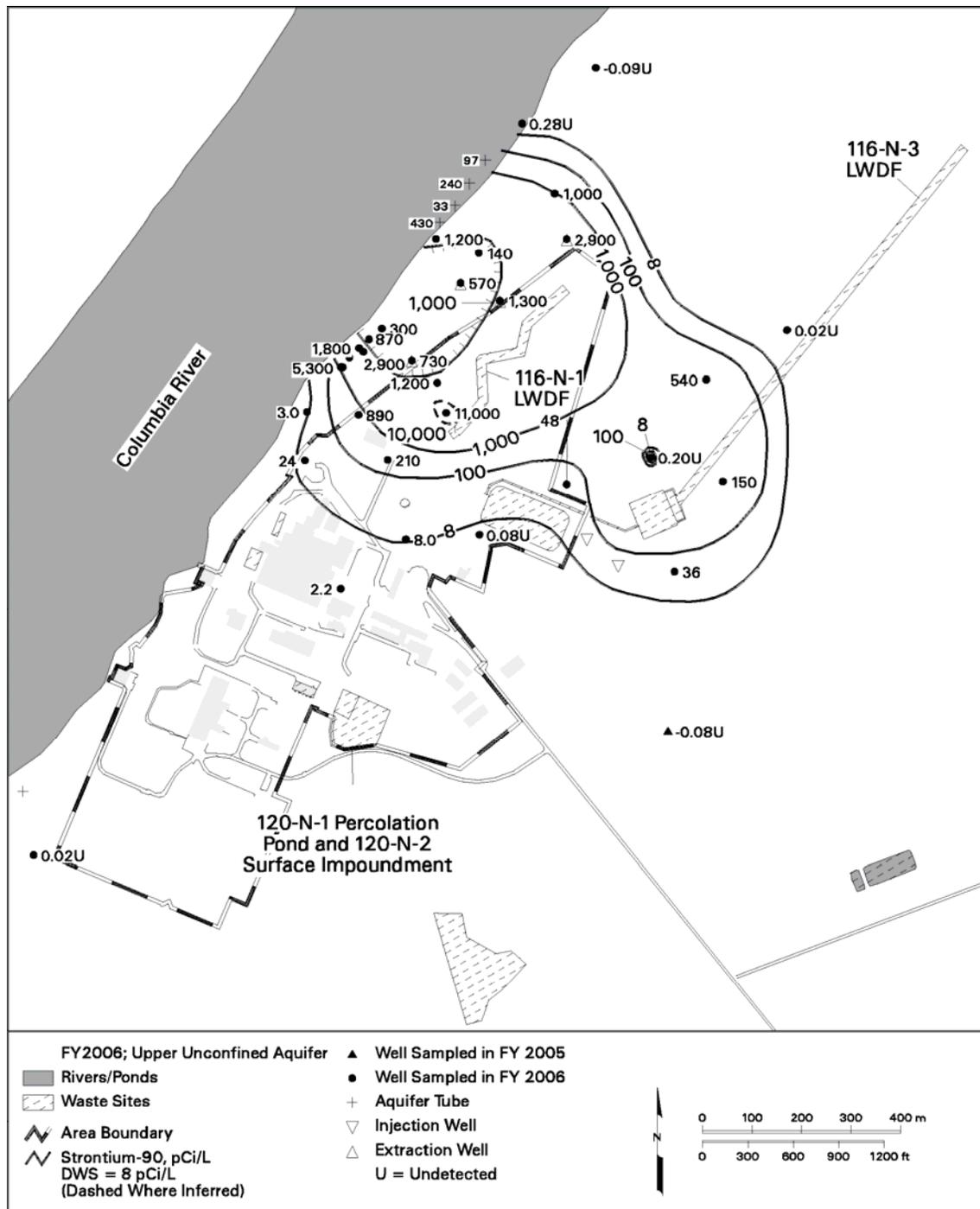
Figure 1.1. Well Locations and Strontium-90 Concentrations in 100-N Area Groundwater

Three wells were installed in a cluster on the shoreline to further define vertical strontium-90 distribution. These wells and tubes were sampled at various river stage conditions to investigate the effect of changes in water levels on contaminant concentrations near the river.

Some of the aquifer tubes were equipped with sensors to measure specific conductance, temperature, and water levels at frequent time intervals. An additional network of monitoring wells was also equipped with transducers to measure water levels automatically in the 100-N Area.

The data and information generated by study of the 100-N Area is intended to address the following issues:

- Effects of river stage on strontium-90 concentrations in the hyporheic zone

- Extent of strontium-90 contamination horizontally and vertically

- Relationship between strontium-90 and gross beta and determination of whether gross beta can be used as a strontium-90 indicator

- Location and characteristics of groundwater and contaminant discharge points into the river

- Impacts, if any, of the pump-and-treat system

- Role of groundwater/river interactions on strontium-90 binding and release in the sediment

- Dilution of the strontium-90 concentrations at the groundwater/river water interface within the riverbed

- Low-cost and rapid indicator parameters of contamination in the hyporehic zone to help streamline monitoring efforts.

2.0   Materials and Methods

2.1   River Tubes

In FY 2004, eight river tubes were installed at the 100-N Area shoreline. Three river tubes (NS-3A cluster; Figure 2.1) were placed in an estimated centerline of the strontium-90 plume based on data from inland monitoring wells and shoreline seep wells. Each river tube was installed at a different depth. The remaining five river tubes were installed approximately 30 m upstream and downstream of this cluster (NS-2A and NS-4A clusters; Figure 2.1). In February 2005, three additional river tubes were installed approximately 5 m farther into river from the original river tubes to examine the strontium-90 profile offshore in the Columbia River (NS-3B and NS-4B series; Figure 2.1).

The river tubes were constructed with 3.2-cm diameter pipe, both galvanized schedule 40 and black iron schedule 80. The two types of pipe were used interchangeably, depending on the strength requirements at individual installation locations. The screened portion of the river tubes consists of a length of pipe perforated with 1.3-cm-diameter holes over a 46-cm length and a hardened-steel tip. The perforated section is covered by an 80-mesh screen sandwiched between the pipe and an outer layer for protection (Figure 2.2).

Staff used a two-cycle jackhammer (BH-23, Wacker Corp.) to drive the river tubes into the river bottom. The jackhammer weighed approximately 20.4 kg and was operated by two people. Hardened-steel drive caps (W.W. Grainger, Inc.) were threaded onto the top of the screened portion of each river tube to provide a point of impact for the jackhammer. The section was driven nearly flush with the riverbed. The cap was removed, a drive coupling (Grainger) and pipe extension were added, the drive cap was attached to the top of the pipe extension, and driving with the jackhammer continued (Figure 2.3). This process was repeated until either the target depth was reached or the geology prevented further penetration. Once driving was completed, the river tube was developed by either pumping silt out of the bottom or pumping clean water down the river tube to push silt out of the top. Once developed, river tubes were capped and plumbed with sample tubing. The inlet of the sample tubing was located nominally in the middle of the screened section. The tubing was emplaced onshore above the high-water mark to allow sampling during high river stage conditions. Both polyethylene and polyvinyl chloride (PVC) tubing were used for sampling tubing. A few disadvantages of river tubes are a relatively long screen length (45.7 cm) and cost of materials (approximately $100 per river tube compared to $30 for an aquifer tube). The river tubes were also subject to corrosion, which affected metals concentrations in water samples, and the corrosion products may have provided a substrate for potential adsorption of radionuclides. The primary advantage of using river tubes over using aquifer tubes is that the larger pipe diameter allows for the installation of continuous water quality probes/sensors. The river tubes were temporary, and most have been decommissioned.
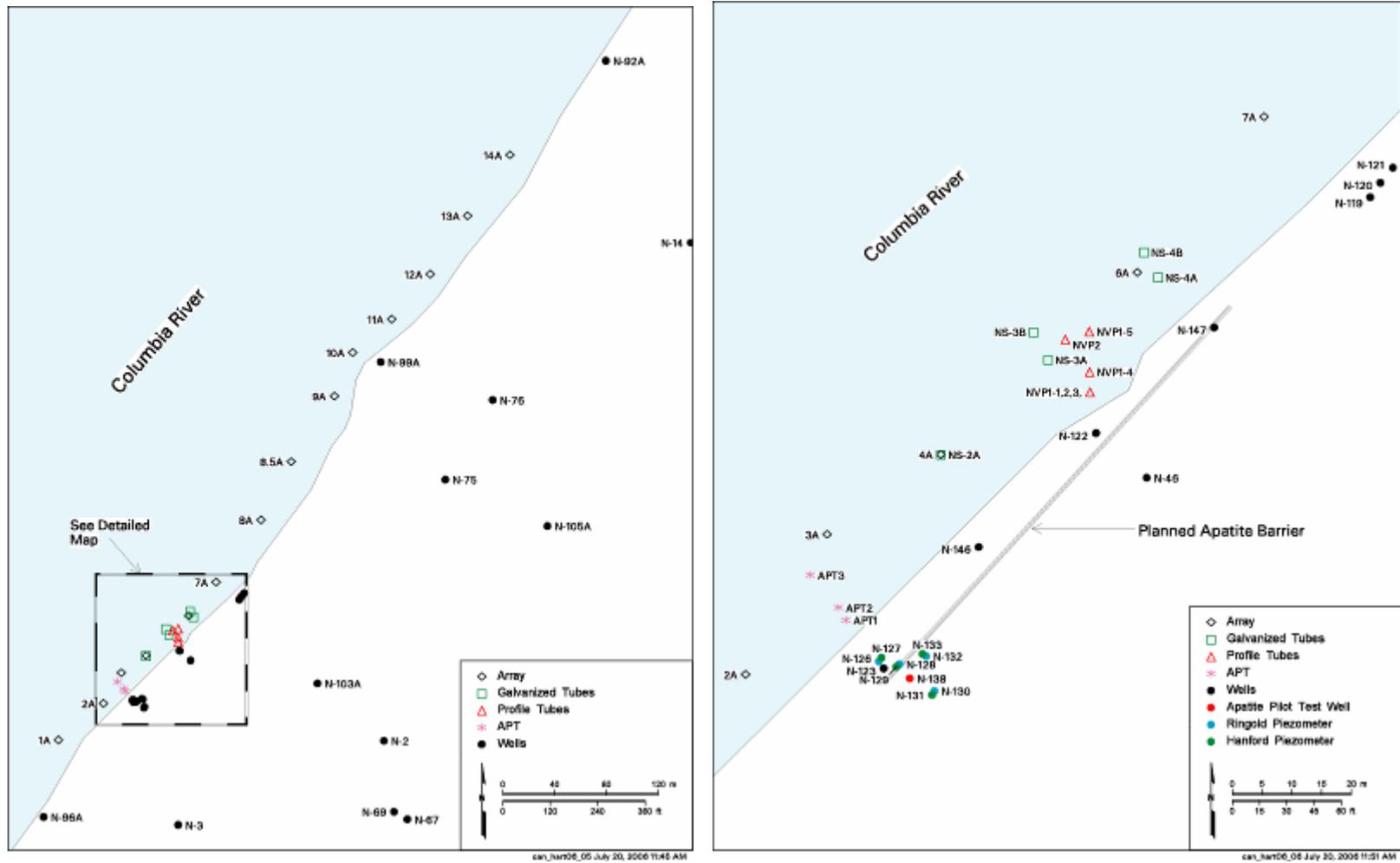
Figure 2.1. River Tubes, Aquifer Tubes, and Monitoring Wells in the 100-N Area Study Location
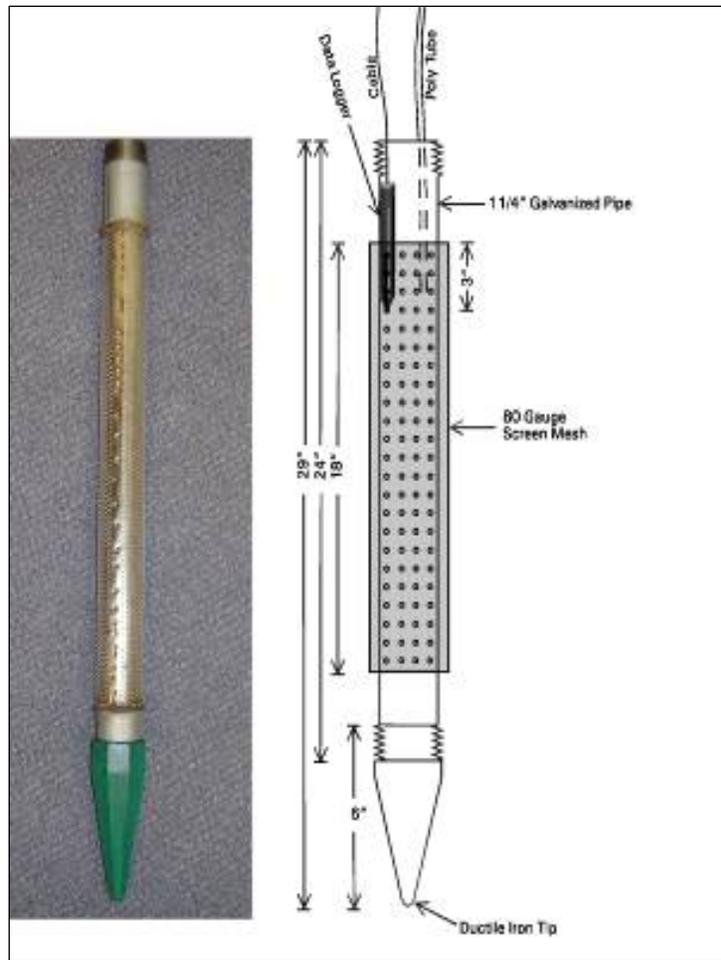
Figure 2.2. Photograph and Schematic of River Tube Construction Showing Drive-tip and Well Screen Section

Figure 2.3. Typical River Tube Installation Configuration Showing the Two-Cycle Jack Hammer, Drive Cap, Drive Pipe, Coupler, and River Tube

2.2 Aquifer Tubes

Between June 2005 and February 2006, 24 aquifer tubes were installed along the 100-N Area shoreline based on the data from the river tubes and wells. The river tube data showed that the highest concentrations of strontium-90 were observed at an elevation of ~116.0 m. Two clusters of five aquifer tubes were installed near the plume's centerline to monitor the vertical distribution of contamination. A second set of vertical profile tubes was installed in August 2005 with nine additional aquifer tubes that were installed along the 100-N Area shoreline to determine the horizontal distribution of strontium-90 release. The horizontal array tubes were all installed at an elevation of 116.0 m (Figure 2.4).
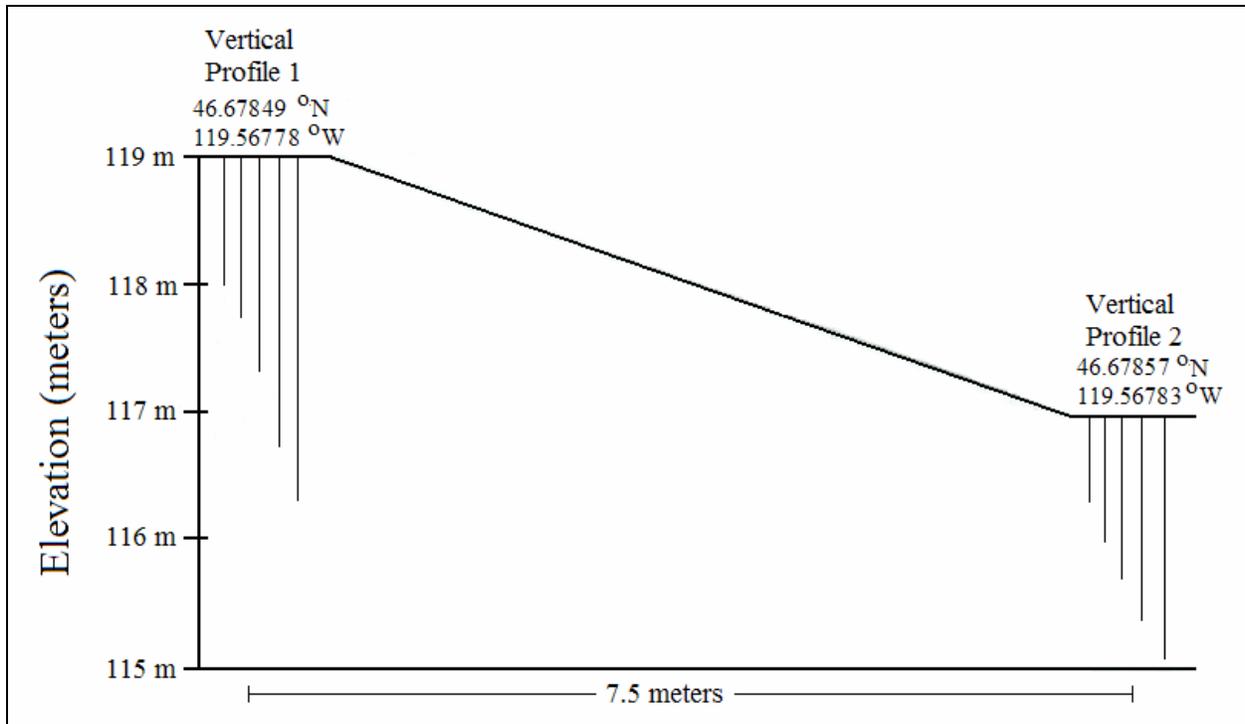
Figure 2.4. Relative Elevations and Locations of Vertical Profile Aquifer Tubes NVP-1 and NVP-2
(Note: the vertical and horizontal axes are not to the same scale)

The sampling port for each aquifer tube consisted of an 80-mesh stainless steel screen that was 15 cm long and 10 mm in diameter. Polyethylene tubing was attached to one end of the screen, and the other end was mated with a hardened-steel drive tip (Figure 2.5).

The aquifer tubes were installed by driving a hollow, 2.5-cm outer diameter, hardened-steel drive rod into the ground with the stainless steel tip attached to the end and the screen and tubing inside of the drive rod (Geoprobe® Systems[1]). A slotted drive cap that allows the tubing to come out the top of the rod was used so that the tubing was not pinched or damaged during the hammering process (Figure 2.5). Drive rod sections were added as needed to reach the desired depth. Driving was accomplished with a two-cycle jackhammer (or manually with a post driver) in a similar manner to the river tube installation.

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[1] Geoprobe is a registered trademark of Geoprobe Systems, Salina, Kansas.
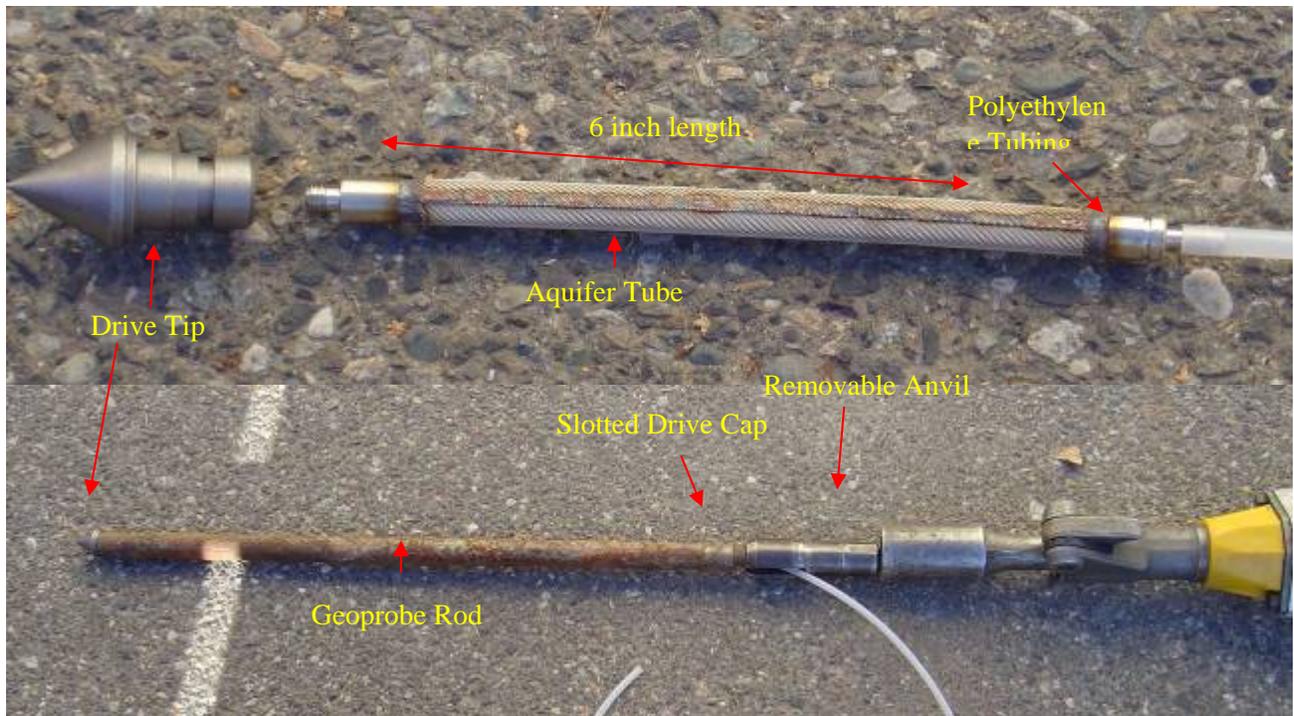
Figure 2.5. Components of the Screen Portion of an Aquifer Tube Used During Installation

Once the desired depth was reached, the drive rod was extracted either with pipe wrenches (for shallow points) or by using sledge hammers to pound up against an extraction plate custom fabricated for this project. As the drive rod was extracted, the tip, screen, and tubing were left behind in the ground. The tubing was run up the shoreline for future sampling. A peristaltic pump was attached to the tubing immediately after installation to develop the water flow in the aquifer tube. An alternative method of aquifer tube installation was employed at some locations. Only the tip was inserted into the end of drive rod, and driving proceeded as described above. Once the desired depth was reached, the screen and tube were inserted into the top of the drive rod, fed down, and threaded onto the tip. The drive rod was then removed leaving the aquifer tube in place for sampling. This alternative method was developed by Geoprobe Systems. However, this method did not work well at depths exceeding 2.0 m or in very loose, gravelly substrate. The largest advantages of using the aquifer tube are ease of installation at remote locations, due to the minimal amount of equipment required, and low cost.

2.3   Monitoring Wells

A cluster of three groundwater monitoring wells, 199-N-119, -120, and -121, was installed in 2004 to support the alternative remediation studies at the 100-N Area and provide multilevel monitoring access to the upper unconfined aquifer (Figure 2.1). Sediment core and water samples were collected during drilling to perform the following:

- Identify Hanford/Ringold Formation contact near the river
- Measure vertical variation in horizontal hydraulic conductivity (across formation contact)
- Measure variation in vertical groundwater chemistry
- Sample sediment for strontium-90 concentrations and cation-exchange capacities.

Grab samples of sediment were collected every 1.5 m from all three wells for archiving. The deepest well, 199-N-121, was sampled continuously from 3 m to total depth with a split-spoon sampler for laboratory analyses. Sediment samples were collected in 10-cm diameter Lexan liners pre-cut to 15-cm lengths. The liners were capped with sterile end caps under an inert gas environment.

The wells are constructed of 5-cm diameter, stainless-steel casing and wire-wrap screen. Well 199-N-119 monitors the upper portion of the unconfined aquifer, 199-N-120 monitors mid-depth, and 199-N-121 monitors the lower portion of the aquifer just above the Ringold upper mud unit (see Appendix C for well completions). These three wells were equipped with pressure transducers and sensors that measure specific conductance and temperature. In addition to these new wells, five existing wells were also outfitted with the same components. The augmentation of the water-level monitoring network at the 100-N Area was initiated in March 2004. The eight wells (Table 2.1) were instrumented with Druck PDCR 1830® pressure transducers[2]. Seven of the wells were also equipped with Campbell Scientific CS547A conductivity and temperature probes. All data collection utilized Campbell Scientific, Inc.© data logger models CR 510 or CR10X with MSX10 or MSX20 solar panels and PS100 12-volt power supplies and batteries. Each monitoring location was supplied with a Campbell Scientific RF400 spread spectrum radio and an appropriate Vertically Polarized 9dBd 900 MHz Yagi or a 3dBd 900MHz Collinear Omni antenna (Figure 2.6). All sites radio transmitted stored 15-minute averages of 60-second instrument scans to a central base antenna that communicated through a Campbell Scientific NL100-Network Link Interface to the local Hanford Local Area Network (HLAN). A desktop personal computer with HLAN connection was used to receive and store the monitoring network data.

Table 2.1. 100-N Area Wells with Pressure Transducers and Data Loggers

Well #	Well Depth (m)	Casing ID (cm)
199-N-62	24.57	15
199-N-67	23.35	15
199-N-69	31.27	15
199-N-74	25.73	10
199-N-80	37.72	10
199-N-119	6.32	5
199-N-120	8.46	5
199-N-121	12.28	5

2.4   Water Sampling and Analysis for River and Aquifer Tubes

As part of the RACS Project, eight major sampling events were conducted at periods of low, intermediate, and high river stages between April 2004 and June 2006. Samples were collected in order to fill data gaps pertaining to contaminant discharge along the 100-N Area shoreline. The samples were analyzed for metals, anions, radionuclides, alkalinity, and field parameters (Table 2.2). In particular, strontium-90 was assessed in order to establish a baseline for potential remediation strategies to reduce the amount of strontium-90 entering the Columbia River. Based on the data gathered as part of this effort, selected aquifer tubes have been added to the GPAP monthly sampling schedule. In addition to the major sampling events, minor sampling events were also conducted during this time frame. An abbreviated list of constituents was analyzed primarily examining gross beta.

Figure 2.6. Data Logger System at Well 199-N-74

Table 2.2. Constituents Measured in Samples Collected from River Tubes and Aquifer Tubes Along the 100-N Area Shoreline. The majority of samples were not analyzed for all constituents listed.

Field Measurements	Radionuclides	Metals (ICP-MS)[a]	Other
Specific conductance	Gross alpha	Silver	Alkalinity
Temperature	Gross beta	Aluminum	Bromide
pH	Tritium	Arsenic	Chloride
Oxidation reduction potential (ORP)	^{7}Be	Barium	Fluoride
	^{40}K	Beryllium	Nitrate
Dissolved oxygen	^{60}Co	Calcium	Phosphate
--	^{134}Cs	Cadmium	Sulfate
--	^{137}Cs	Cobalt	Bicarbonate (HCO_3)
--	^{152}Eu	Chromium	Carbonate (CO_3)
--	^{154}Eu	Copper	--
--	^{155}Eu	Iron	--
--	^{106}Ru	Potassium	--
--	^{125}Sb	Magnesium	--
--	^{90}Sr	Manganese	--
--	--	Molybdenum	--
--	--	Sodium	--
--	--	Nickel	--
--	--	Lead	--
--	--	Selenium	--
--	--	Strontium	--
--	--	Thorium	--
--	--	Thallium	--
--	--	Uranium	--
[a]ICP-MS = Inductively coupled plasma-mass spectroscopy			

[2] Druck PDCR 1830 is a registered trademark of Campbell Scientific, Inc., Logan, Utah.

Water samples were collected from river tubes and aquifer tubes (Table 2.3) with peristaltic pumps using procedures established for the Hanford Site SESP (Hanf and Poston 2000). A field water quality meter was used to determine when each sampling point had been adequately purged for sample collection. Water was pumped until the specific conductance of the sample reached constant values.

During sample collection, staff measured temperature, specific conductance, pH, total dissolved solids, and oxidation reduction potential with a hand-held meter (Ultrameter™[3]). Water quality parameters were measured by rinsing out the meter's cells three times. Each cell was then filled, and the measurements were recorded on appropriate paperwork. Occasionally, dissolved oxygen was also measured in the field samples using a hand-held luminescent meter (HQ10, Hach Company). For the dissolved oxygen measurements, a small container was filled with sample, and the end of the meter was immersed into the sample liquid. When filling the container, the tubing was kept below the water level in the container to minimize re-oxygenation of the sample. Water quality parameters were recorded after the entire sample container had been filled. Specific conductance was usually measured and recorded both before and after sampling to allow an evaluation of changing conditions during the sample collection.

During the three comprehensive sampling events, samples were analyzed for the constituents listed in Table 2.2. For monthly sampling, samples were collected and analyzed for an abbreviated list that included gross beta concentrations and field parameter measurements only. In addition to the water samples collected for this project, the GPAP sampled selected aquifer tubes, seep wells, and monitoring wells monthly for gross beta and quarterly for a more extensive list of constituents. Groundwater monitoring was integrated with sampling and analyses conducted by this project to fill in data gaps as well as track the strontium-90 pathways. Data generated by these sampling efforts are stored in HEIS, along with other monitoring data for Hanford Site groundwater and surface water.

2.5   In Situ Monitoring

Continuous monitoring sensors were installed in all three NS-3A river tubes and in selected tubes in cluster NS-2A and NS-4A. These sensors measure temperature, pressure, and specific conductance at frequent time intervals. The sensors were LTC Leveloggers® (Solinst Canada, Ltd.[4]). The leveloggers have self-contained memory allowing measurement and storage of data at a frequency selected by the user. Initially, the leveloggers were set to record data every 10 minutes. After several months, it became apparent that this frequency produced more data than was needed, and a 30-minute frequency was adopted.

An additional data logger was also installed temporarily on the riverbed to record river depth and temperature. These measurements were correlated with measurements made at the nearby river stage gauging station and confirmed that both sites produced similar values. The riverbed data logger was removed after a short time.

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[3] Ultrameter is a trademark of Myron L Company, Carlsbad, California.

[4] LTC Leveloggers is a registered trademark of Solinst Canada, Ltd., Canada.

Table 2.3. River Tubes, Aquifer Tubes, and Wells Installed for the Remediation and Closure Science Project

Tube Name	Installation Date	Washington State Plane Coordinates.(NAD 83)		Elevation (m NAVD 88)			Casing Diameter (cm)	Comment
		Northing	Easting	Land Surface	Top of Screen	Bottom of Screen		
River Tubes								
NS-2A-23	2/18/2004	149925.4	571292.3	117.0	116.8	116.3	3.25	Removed 9/06
NS-2A-87	2/22/2004	149925.4	571292.3	117.0	116.1	115.7	3.25	--
NS-2A-168	2/24/2004	149925.4	571292.3	117.0	115.3	114.8	3.25	--
NS-3A-10	2/18/2004	149941.2	571310.5	117.0	117.0	116.5	3.25	Removed 9/06
NS-3A-176	2/18/2004	149941.2	571310.5	117.0	115.3	114.8	3.25	
NS-3A-87	2/24/2004	149941.2	571310.5	117.0	116.1	115.6	3.25	Screen rusted out late 2005; Removed 9/06
NS-3B-40	2/21/2005	149945.1	571308.2	116.0	115.6	115.1	3.25	Removed 9/06
NS-3B-52	2/21/2005	149945.1	571308.2	116.0	115.5	115.0	3.25	Removed 9/06
NS-4A-17	2/24/2004	149954.8	571328.7	117.3	117.1	116.7	3.25	Removed 9/06
NS-4A-138	2/24/2004	149954.8	571328.7	117.3	115.9	115.4	3.25	Removed
NS-4B-31	2/21/2005	149959.0	571326.0	--	--	--	--	Removed 9/06
Vertical Profile Aquifer Tubes								
NVP1-1	6/20/2005	149936.0	571317.4	119.0	118.0	117.9	0.64	--
NVP1-2	6/20/2005	149936.0	571317.4	119.0	117.8	117.6	0.64	--
NVP1-3	6/20/2005	149936.0	571317.4	119.0	117.3	117.2	0.64	--
NVP1-4	6/20/2005	149938.5	571317.6	118.5	116.8	116.6	0.64	--
NVP1-5	6/20/2005	149938.5	571317.6	118.5	116.3	116.2	0.64	--
NVP2-116.3	8/2/2005	149945.0	571313.8	117.0	116.3	116.2	0.64	--
NVP2-116.0	8/2/2005	149945.0	571313.8	117.0	116.0	115.9	0.64	Also part of horizontal array
NVP2-115.7	8/2/2005	149945.0	571313.8	117.0	115.7	115.6	0.64	--
NVP2-115.4	8/2/2005	149945.0	571313.8	117.0	115.4	115.3	0.64	--
NVP2-115.3	8/2/2005	149945.0	571313.8	117.0	115.1	115.0	0.64	--
Horizontal Array Aquifer Tubes[a]								
Array-1A	8/2/2005	149860.2	571224.9	117.2	116.0	115.9	0.64	--
Array-2A	8/2/2005	149888.8	571259.6	116.6	116.0	115.9	0.64	--
Array-3A	8/2/2005	149911.4	571273.7	116.6	116.0	115.9	0.64	--
Array-4A	8/2/2005	149925.4	571292.3	117.0	116.0	115.9	0.64	--
Array-6A	8/2/2005	149955.7	571325.6	116.7	116.0	115.9	0.64	--
Array-7A	8/2/2005	149981.7	571347.1	116.9	116.0	115.9	0.64	--
Array-8A	8/3/2005	150029.7	571381.4	117.0	116.0	115.9	0.64	--
Array-8.5A	2/9/2006	150074.55	571404.56	117.1	116.0	115.9	0.64	--

2.9

Table 2.3. (cont.)

| Tube Name | Installation Date | Washington State Plane Coordinates.(NAD 83) | | Elevation (m NAVD 88) | | | Casing Diameter (cm) | Comment |
		Northing	Easting	Land Surface	Top of Screen	Bottom of Screen		
Array-9A	8/3/2005	150125.4	571437.5	117.0	116.0	115.9	0.64	--
Array-10A	11/10/2005	150158.5	571451.0	N/A	116.0	115.9	0.64	--
Array-11A	11/10/2005	150184.5	571481.3	N/A	116.0	115.9	0.64	--
Array-12A	11/10/2005	150219.3	571511.5	117.1	116.0	115.9	0.64	--
Array-13A	2/9/2006	150264.1	571541.6	117.6	116.0	115.9	0.64	--
Array-14A	2/9/2006	150312.0	571642.0	117.6	116.0	115.9	0.64	--
Monitoring Wells								
199-N-119	4/2/2004	149968.3	571364.5	122.3	117.8	115.7	5	Shallow
199-N-120	4/2/2004	149970.8	571366.2	122.4	114.9	113.4	5	Mid-Depth
199-N-121	4/2/2004	149973.3	571368.3	122.4	111.4	109.9	5	Bottom of aquifer
[a] Array tube names prefixed by "N116m" (e.g., N116mArray-2A).								

2.6   Hydraulic Conductivity Testing

Hydraulic conductivity was measured by conducting slug tests in triplicate at each of the river tubes (Butler 1998). To perform the test, an airtight pressure-regulating wellhead assembly was threaded to the top of each tube. The assembly consisted of a 5-cm ball valve coupled to a 20-cm section of schedule-40 PVC containing a small valve stem for pressurization. A pressure transducer (Instrumentation NW model 9800) was lowered into the river tube to measure changes in hydraulic head during the test. A modified rubber stopper was used to seal the transducer cable's entry into the tube assembly. The system was pressurized with a portable battery-powered air compressor (Black and Decker VersaPak[®] cordless inflator[5]), causing the water level in the river tube to be depressed downward. The change in water level was measured by the transducer and recorded by an electronic data logger (Campbell Scientific[®] CR10x[6]). When the water level in the tube was sufficiently depressed, the air compressor was shut off and the ball valve simultaneously opened, marking the beginning of the slug test. When the pressure was released, the data logger recorded the pressure response (rising water level) with respect to time.

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[5] VersaPak is a registered trademark of Black and Decker, Hunt Valley, Maryland.

[6] Campbell Scientific[®] CR10x is a registered trademark of Campbell Scientific, Inc., Logan, Utah.

3.0 Geology

The 100-N Area near-surface stratigraphy comprises a variety of different gravel-dominated sedimentary units. These include, from oldest to youngest: 1) Ringold Formation Unit E, 2) Hanford formation, 3) recent coarse-grained alluvial deposits, and 4) man-made backfill materials placed over the older deposits (Figure 3.1). Details of the stratigraphy (Figure 3.1) are based on geologist's logs from a series of wells installed on the shoreline for the apatite barrier (DOE-RL 2005b).

3.1 Ringold Formation

The Ringold Formation Unit E is a fluvial deposit laid down between about 5 to 8 million years ago by the ancestral Columbia River as it deposited sediment within the subsiding Wahluke Syncline. This unit consists of relatively uniform, bimodal, clast-supported sandy gravel to silty sandy gravel that is overall moderately to well-sorted (Lindsey 1992, 1995; Hartman and Lindsey 1993). Occasional lenses of well-sorted sand may also be present. Clast-supported gravels typically contain arkosic sandy matrix filling interstices of well-rounded and polished pebbles and cobbles (Figure 3.2). Matrix material may also contain up to 10% silt and/or clay. The sand fraction generally contains <30% basalt rock fragments and >70% quartz, feldspar, and mica. Up to 50% of gravel clasts may consist of basalt, with the remainder mostly quartzite, granitic, gneiss, or other volcanic clasts. Outcrop exposures of Ringold Formation Unit E show weak stratification and imbrication.

Because of its relatively old age (Miocene-Pliocene), sediments of the Ringold Formation are often weathered due to extended contact (several million years or more) with groundwater. Evidence for this weathering includes well-developed iron-oxide coatings on mineral grains and weathering rinds on gravel clasts. Because of iron-oxide coating, most deposits of Ringold Formation Unit E are shades of brown. Relative to younger stratigraphic units, the Ringold Formation is more consolidated due to long-term compaction, weathering, and localized cementation. Because of a higher concentration of secondary alteration products like oxide coating and clay, the Ringold Formation may adsorb contaminants more effectively.

When the vertical profile aquifer tubes were installed for this project, driving the points became more difficult between 116 and 115.5 m elevation, which may have indicated the top of a less permeable layer within the Ringold Formation.

A silt and clay-rich unit in the Ringold Formation, informally called the Ringold upper mud[1], forms the base of the uppermost aquifer in the 100-N Area. The elevation of the top of the upper mud at the shoreline in well 199-N-122 is 108.8 m NAVD88. The mud elevation in a series of boreholes installed along the shoreline in 1994 (Johnson et al. 1995) ranges from 105.4 to 111.6 m. The upper mud in well 199-N-121 is within this range (109.9 m). Farther inland, well 199-N-80 reached the upper mud at 109.5 m elevation. This well penetrated 4.9 m of clay and was completed in a thin (1.5 m) sand unit underlain by more clay.

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[1] The 100-N Area "upper mud" unit may not correlate to the fine-grained unit beneath the 100-H Area, also informally termed the upper mud.
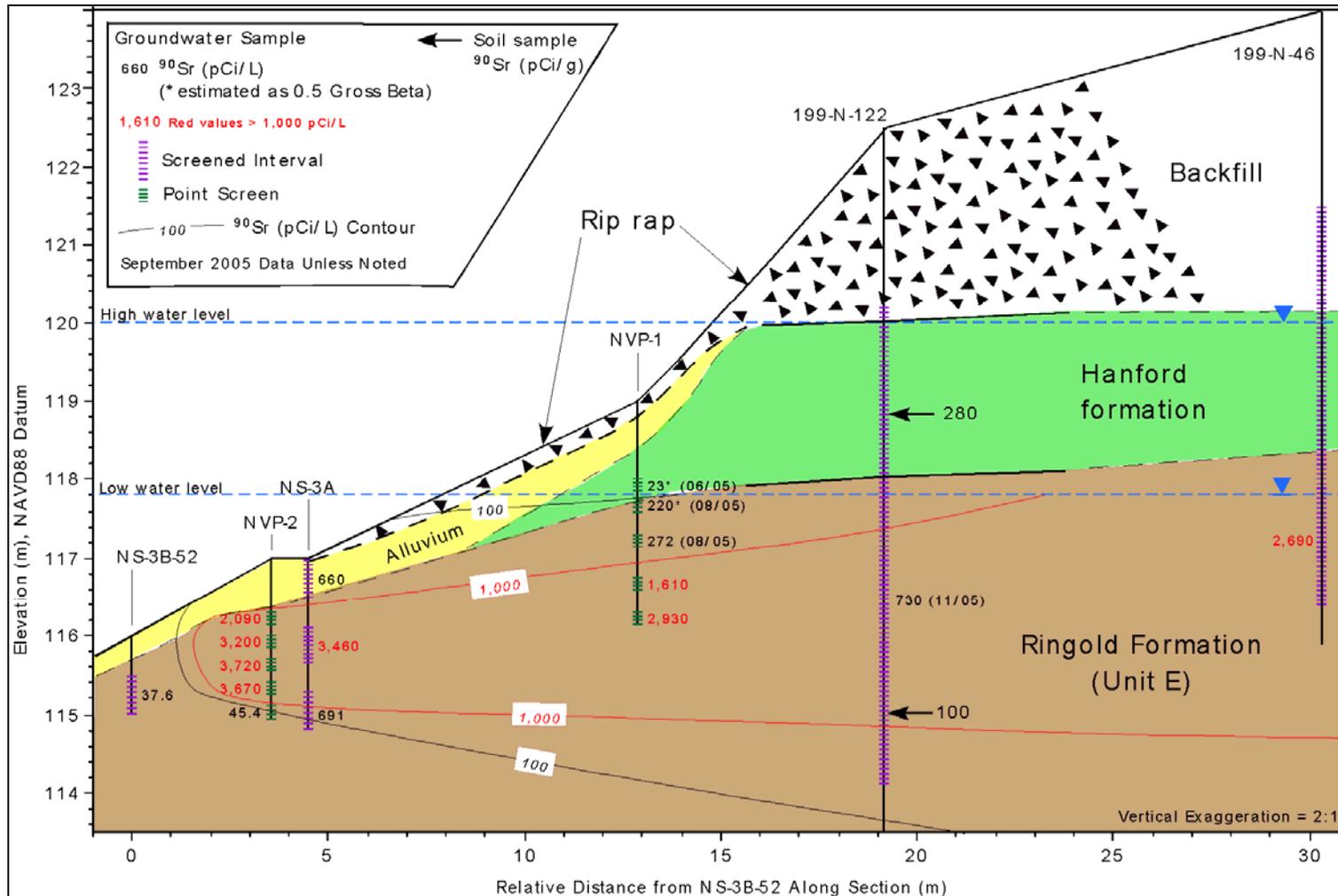
Figure 3.1. Hydrogeologic Cross Section and Contaminant Distribution within the Stronium-90 Plume at the 100-N Area (discussed in Section 5.0). The Ringold upper mud unit is below the base of this figure at ~109 m elevation.

Figure 3.2. Ringold Formation Unit E Sandy Gravels Exposed Along the Base of the White Bluffs on the Hanford Reach along the Columbia River. Note how the formation is semi-consolidated, relatively homogeneous, and clast supported with sand filling all matrices between gravel clasts. The distinct reddish color is due to pervasive coatings of secondary iron oxide from millions of years of weathering. Quarter used for scale.

3.2   Hanford Formation

Deposits of the Hanford formation (informal name) in the vicinity of the 100-N Area consist of the gravel-dominated facies (DOE-RL 2002). The gravel-dominated facies of the Hanford formation consists of highly heterogeneous layers of poorly sorted sandy gravel to silty, sandy gravel and sand. Gravels range from clast-supported to matrix-supported. Clast-supported gravels most often contain a poorly sorted matrix of silt and sand but sometimes contain no matrix at all (Figure 3.3). Both gravel and sand particles are often coated with a thin layer of powdery, fine-grained silt.

The gravel-dominated facies is composed dominantly of unweathered, angular to somewhat rounded fragments of basalt that were laid down rapidly during the waning stages of periodic, cataclysmic Ice Age flooding. Because of its young age (13,000-20,000 years before the present), the Hanford formation appears relatively "fresh" and unweathered compared to the underlying Ringold Formation. Due to the high concentration of dark basalt clasts and lack of weathering, the gravel-dominated facies of the Hanford formation are predominantly gray. Unlike the Ringold Formation, the gravel-dominated Hanford formation may also contain especially large boulders of basalt up to 1 m in diameter.

A major erosional unconformity is present at the contact between the Ringold and Hanford formations, with approximately 3 to 5 million years of geologic time missing between the two stratigraphic units. This sharp, sudden break between the two formations results in a large contrast in the hydraulic conductivities, which affects the flow of groundwater, contaminant transport, and distribution. The Hanford formation is relatively loose and coarse compared to the Ringold Formation, which is highly compacted and cemented resulting in lower conductivity.
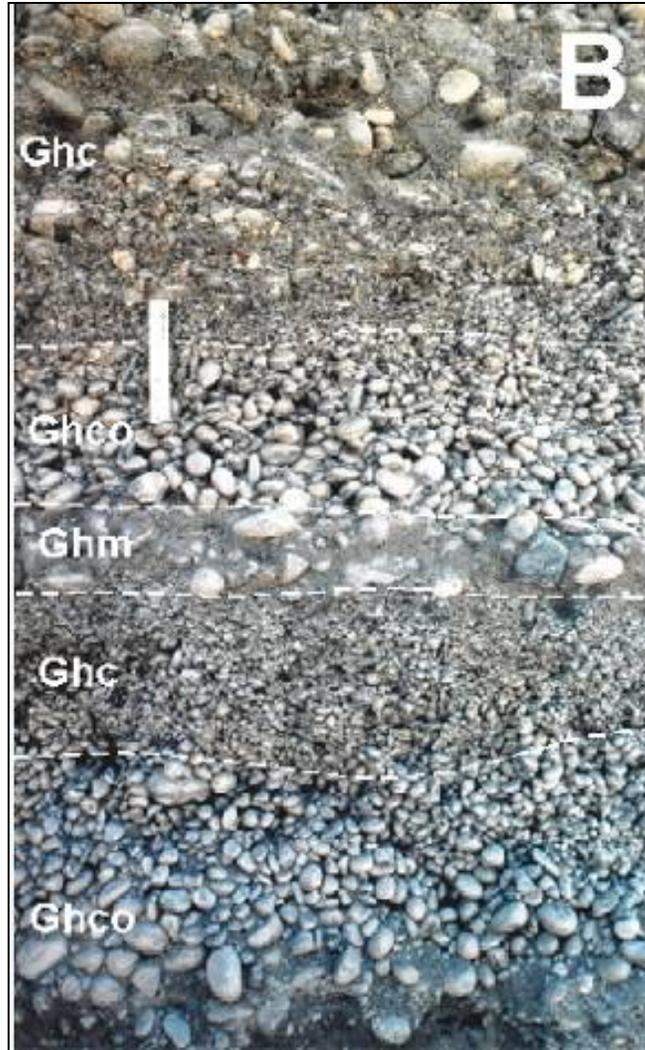
Figure 3.3. Cataclysmic Flood Deposits (Hanford formation) Adjacent to the Columbia River Exposed in a North Richland Quarry. Note the heterogeneity between several beds of clast-supported (Ghc) to matrix-supported (Ghm) gravels. Also note the open-work fabric, or lack of matrix between gravel clasts, within some of the clast-supported gravel layers (Ghco).

3.3   Recent Coarse-Grained Alluvial Deposits

Since the last Ice Age floods about 13,000 years ago, the Columbia River re-established its channel in a position immediately adjacent to the 100-N Area. During this period, the river locally removed part or all of the Hanford formation flood gravels along the channel bottom. The coarse-grained alluvium consists of reworked deposits of the Hanford formation and the Ringold Formation, where the modern river has incised through the flood deposits into the underlying Ringold Formation (Figure 3.1). The extent of coarse-grained alluvium is naturally restricted to the high water levels of the modern Columbia River. The rounded, coarse-grained, Holocene-age alluvium, referred to as HDc (rnd) in DOE-RL (2002), develops to the present day.

Because the alluvium consists of reworked Hanford and Ringold Formation deposits, it shares characteristics of both of these units. Depending on what formation the present river channel is in contact with, the alluvium consists of a mixture of iron-stained, well rounded, and polished pebbles and cobbles of the Ringold Formation as well as subangular to subrounded, unweathered basalt clasts of the Hanford formation. These are continually being picked up and moved downstream along the riverbed, especially during periods of seasonal flooding. Because these deposits are young, they generally do not display any secondary weathering and are loose and unconsolidated (Figure 3.4).

Figure 3.4. Recent Alluvium Exposed in the Riverbank Near the 100-F Area. Note the loose, unconsolidated and unweathered nature of the gravelly deposits. In the center of the photo a pen is shown for scale. The character of alluvium in the 100-N Area is similar, but no exposures are present.

3.4 Backfill

Since the beginning of the Manhattan Project in the 1940s, portions of the 100-N Area have been covered with up to several meters of backfill material. Along the riverbank, this material includes large boulders of angular basalt (rip rap) that were installed in 1984 to cover riverbank springs that contained radiological contamination. Above the riverbank, the backfill material consists of mostly disturbed gravel-dominated Hanford formation that was already present in the area or trucked in from a nearby source. As such, the non-rip-rap material shares most of the same characteristics as undisturbed Hanford formation, except its internal structure has been destroyed and may be slightly less consolidated than that of the original deposits.

3.5 Stratigraphy in Wells 199-N-119, -120, and -121

A cluster of three wells was installed on the shore as described in Section 2.3 (see Figure 2.1 for location). The sediment encountered during drilling was predominantly silty, sandy gravel from the surface to 12.5 m deep (109.9 m elevation), where the deepest well tagged the Ringold upper mud unit (100% silt at this location). Borehole logs are available through the Hanford Well Information System. A well completion summary for each well can be seen in Appendix C.

4.0   Hydrogeology

This section describes the hydrogeology of the unconfined aquifer in the 100-N Area, presents results of slug tests and a bathymetric survey of the river, and discusses changes in hydraulic head with river stage.

4.1   Unconfined Aquifer

The unconfined aquifer beneath the 100-N Area is mostly contained in the sands and gravels of the Ringold Formation Unit E (Hartman and Lindsey 1993). During high river stage, the aquifer rises up into the Hanford formation. The depth to the water table varies from less than 1 m near the Columbia River to ~21 m farther inland (Hartman 2000). The base of the unconfined aquifer is a fine-grained unit ~12 m beneath the water table.

Groundwater levels may fluctuate as much as 2 m per day as a result of seasonal and diurnal changes to discharge from Priest Rapids Dam on the Columbia River. During low water levels the saturated zone is mostly restricted to the Ringold Formation. However, during intermediate to high river stage the saturated zone extends up into the Hanford formation. The highest water levels rise to near the top of the Hanford formation near the Columbia River (Figure 3.1). Because of its coarser, open-work texture and lack of consolidation, the flow of groundwater through the gravel-dominated Hanford formation is generally at least an order of magnitude greater than the Ringold Formation Unit E.

The average direction of groundwater flow beneath the 100-N Area is to the north and northwest (toward the Columbia River). However, near the shore, flow direction is variable (see Section 4.4) (Hydrogeologic, Inc. 1999).

4.2   Slug Testing

The results of slug testing of river tubes ranged from 0.08 to 1.6 m/day. The hydraulic conductivity near 116 m elevation were an order of magnitude higher than the hydraulic conductivity measured above and below 116 m (Figure 4.1). This may indicate a layer of more permeable material that provides a pathway for the contaminated groundwater to move through towards the river. This elevation is close to the interface of the natural riverbed and the overlying rip rap and backfill.

Results of slug testing for hydraulic conductivity in the new well cluster (199-N-119,-120,-121) ranged from 3.7 to 6.9 m/day, with the lowest values in the deepest well (Table 4.1). Appendix A includes more detailed discussion of these slug test results.
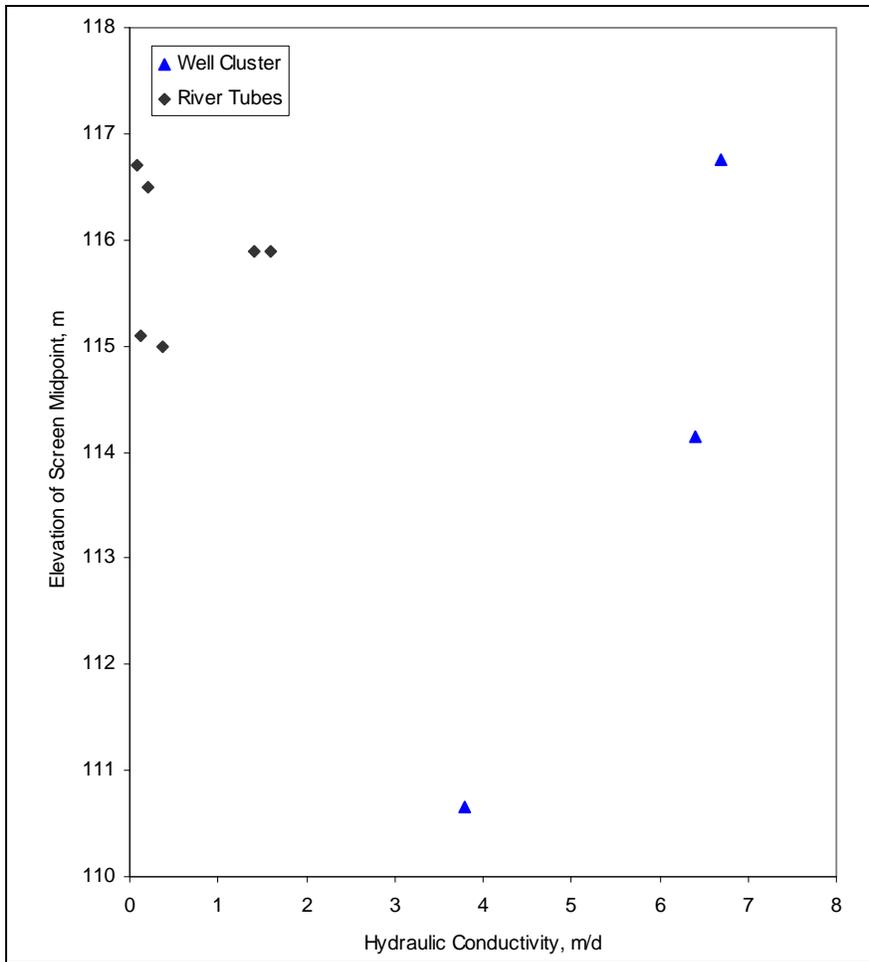
Figure 4.1. Results of Slug Tests in 100-N Area River Tubes and Well Cluster (199-N-119,-120,-121) in Meters per Day (m/day).

Table 4.1. Slug Test Analysis Results for Wells 199-N-119, 199-N-120 and 199-N-121

Well	Screen Elevation (m)	Hydraulic Conductivity (m/day) Bouwer and Rice Analysis[a]		Hydraulic Conductivity (m/day) Type-Curve Analysis[a]		Comments
		Inner Zone[b]	Outer Zone[b]	Inner Zone[b]	Outer Zone[b]	
199-N-119	115.7 – 117.8	11.6 (10.6 – 12.5)	4.3 (4.2 – 4.5)	16.5 (15.6 – 17.3)	6.7 (6.5 – 6.9)	Heterogeneous formation response
199-N-120	113.4 – 114.9	NA	5.3 (5.2 – 5.3)	NA	6.4 (6.4 – 6.5)	Homogeneous formation response
199-N-121	109.9 – 111.4	NA	3.7 (3.4 – 3.9)	NA	3.8 (3.7 – 4.0)	Homogeneous formation response ; test interval located above Lower Mud – boundary layer, type-curve solution used

NA = not applicable
[a]Analysis methods: Bouwer and Rice (Bouwer 1989); type-curve (Butler 1998); listed value = average; range shown in parentheses.
[b]Assumed to be uniform within the well-screen test section. For tests exhibiting a heterogeneous formation response only. Outer zone analysis results are considered representative of in-situ formation conditions.

4.3 Bathymetry Data

Columbia River bathymetry surveys were conducted perpendicular to the centerline of the strontium-90 plume in the 100-N Area to obtain a better understanding of the river-bottom elevations (Figure 4.2). The contours of the river bottom were assessed to help delineate the potential area of contaminant discharge into the Columbia River. The bathymetry data reveal a gradual slope just beyond the rip rap that extends into the main river channel. There is a slightly elevated ridge near the middle of the river, but in general, no significant elevation changes or structural differences that might impact contaminant discharge have been observed at sampling locations along the 100-N Area shoreline.

The elevation of the riverbed can be used to estimate where the hydrostratigraphic layers are exposed on the riverbed. The river at the 100-N Area is underlain by Ringold Formation Unit E gravels, and perhaps in some locations, by the Ringold upper mud unit. From assessing the hydrogeologic cross section and the bathymetry data, it does not appear that the river cuts through the entire thickness of the Ringold mud unit.

4.4 Hydraulic Head

4.4.1 Hydraulic Gradients Along Shoreline Region

Pressure sensors installed in river tubes within the hyporheic zone can be used to evaluate the vertical hydraulic gradient in the subsurface near the river. Evaluation of the river elevation, water table elevation for the aquifer near the river, and the head elevations measured in the river tubes was complicated by differences between the surveyed elevations of the river and the aquifer pressure sensors and river tube pressure sensors. Before these complications were discovered, the river tubes were removed, and no additional surveys could be performed. The head elevations in the aquifer tubes needed adjustment; this was done by adjusting the calculated head elevations in the river tubes such that they were between the elevation measured in the river and well N-8S at midnight on 4/23/04. This was a time period with low water and less than 4 cm difference in head elevation between the river and N-8S for a 6-hour time

period. The adjustment was on the order of 20 cm, so it likely stemmed from different benchmarks having been used in the surveying.

These data illustrate that the vertical hydraulic gradient across the hyporheic zone along the 100-N Area shoreline can be approximated with measurements of water level elevation in the river and the near-shore aquifer. The head elevations in the river tubes were in-between the elevations measured in the river and the near shore aquifer (Figure 4.3).
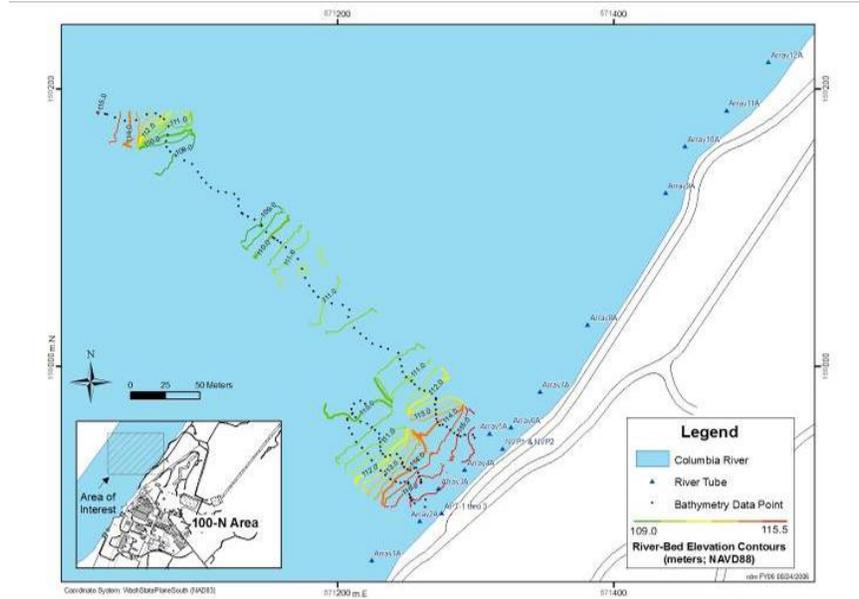
Figure 4.2. Results of the Columbia River Bathymetry Survey at the 100-N Area
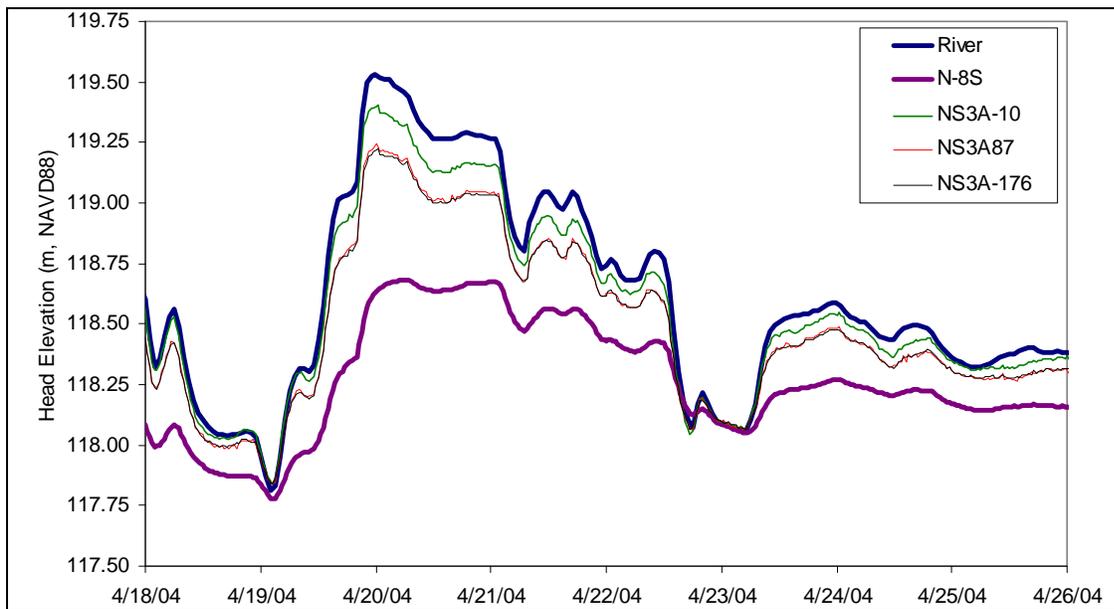
Figure 4.3. Time Period Used for River Tube Elevation Correction

An analysis of water level elevation data from January 2004 through October 2004 indicates the near-shore water-table elevation is controlled by the river, and it responds slower than the changing river stage (Figure 4.4). As a result, at times the river elevation is lower than the near-shore water-table elevation, resulting in a horizontal hydraulic gradient toward the river, and at other times the opposite occurs, and there is potential for water movement from the river into the hyporheic zone (ITRD 2001, Hydrogeologic, Inc. 1999).
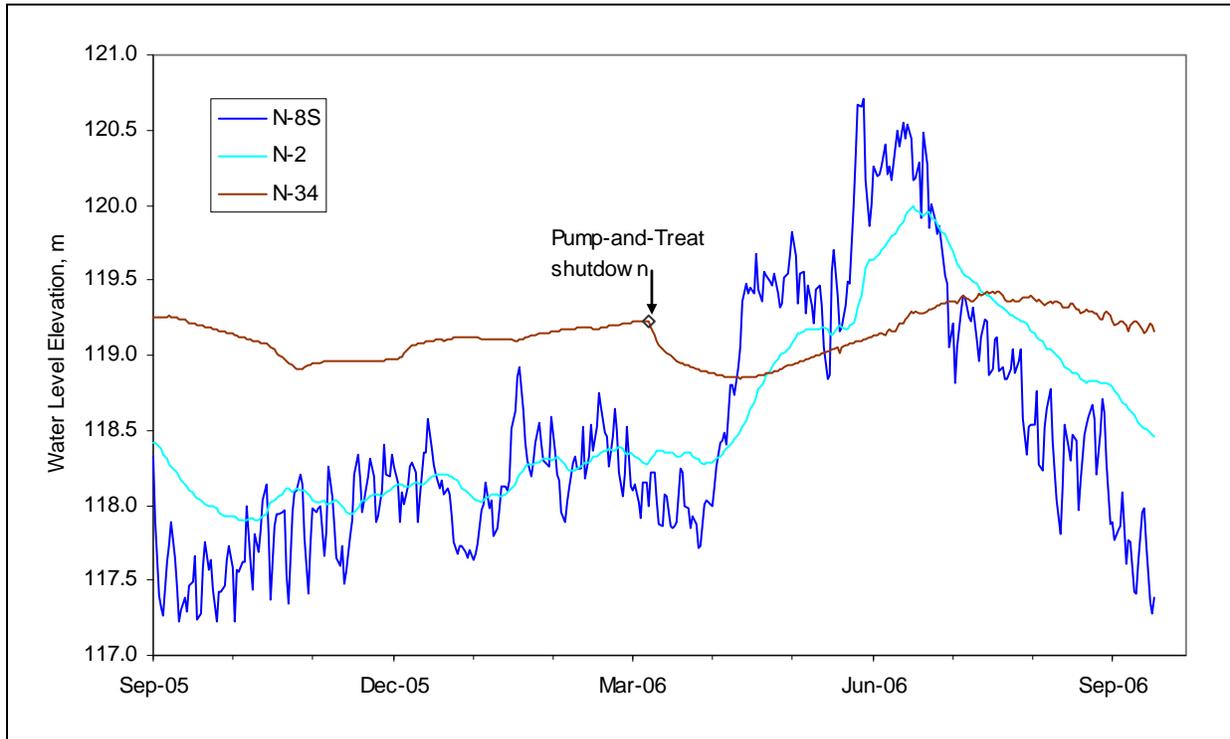
Figure 4.4. Daily Average Water Levels in Three 100-N Area Wells. Note reversed gradient between April and June 2006. Water-level drop in well 199-N 34 in March 2006 is a response to cessation of treated water injection to a nearby well.

5.0   Strontium-90 and Gross Beta Monitoring Results

This section discusses the results for strontium-90 and gross beta monitoring in river tubes, aquifer tubes, and near-river wells. Strontium-90 is a relatively expensive analysis compared to gross beta, so an evaluation was conducted to determine if strontium-90 is the principal contributor to gross beta concentrations and can therefore be used as an indicator of strontium-90 concentrations in the 100-N Area. Section 5.1 presents the evaluation of gross beta and strontium-90 concentrations. Section 5.2 describes distribution of the plume horizontally and vertically. Section 5.3 discusses gross beta and strontium-90 trends with time. Hydraulic conductivity measured in the river tubes along the 100-N Area shoreline provides a possible explanation for higher strontium-90 concentrations measured near the 116-m elevation.

5.1   Evaluation of Gross Beta as Indicator of Strontium-90

The initial set of sampling focused on the original eight river tubes installed along the shoreline. The data shown in Figure 5.1 were taken from river tubes in clusters NS-2A,-3A, and 4A. Gross beta and strontium-90 samples were analyzed from each of the river tubes during nine sampling events starting in April 2004 and ending in December 2005. There is a very strong correlation between gross beta and strontium-90 (Figure 5.2), which suggests that strontium-90 is the principal contributor to beta activity in these samples. The strontium-90 concentration is approximately half of the gross beta value, as revealed by the linear regression equation. A 2-sigma error places the confidence interval at 10-20% for each sample. In the water samples collected, yttrium-90 is in secular equilibrium with strontium-90. With no other substantial beta emitters observed in the 100-N Area, half of the reported gross beta value would be strontium-90.

The data collected were under varying river stage conditions showing no affect on gross beta versus strontium-90 relationship. Gross beta was used as a surrogate for strontium-90 and the primary analysis during the sampling events in order to determine a baseline for strontium-90 along the 100-N Area shoreline.
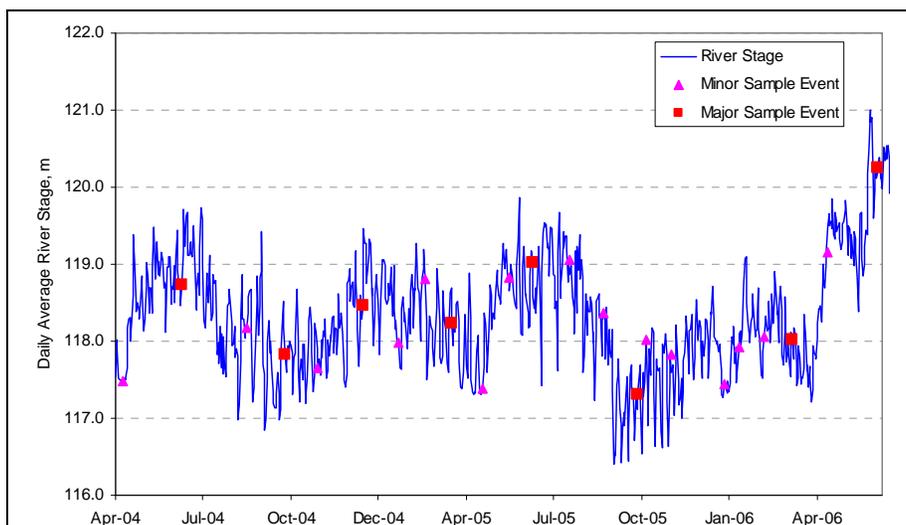
Figure 5.1. Daily Average Columbia River Stage at the 100-N Area and River Tube Sampling Events
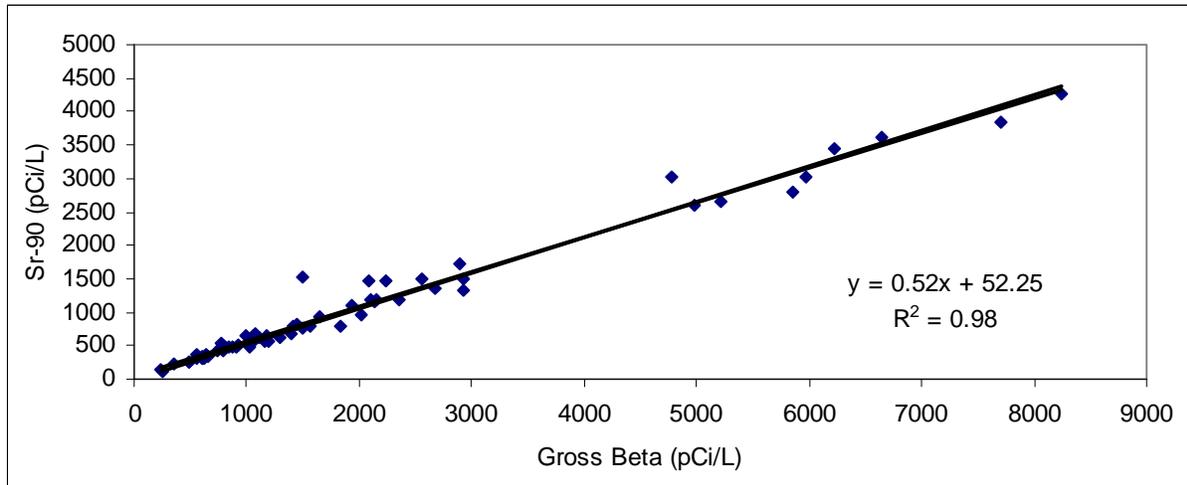
Figure 5.2. Linear Regression Analysis Between Strontium-90 and Gross Beta Concentrations in River Tube Clusters NS-2A, NS-3A, and NS-4A at the 100-N Area

5.2   Strontium-90 Distribution

The general distribution of the strontium-90 plume near the top of the unconfined aquifer in the 100-N Area is well known and stable (Hartman et al. 2006 and 2007; see also Figure 1.1). However, details of distribution at the river shore horizontally, and especially vertically, were not well defined prior to this study. This section presents results of strontium-90 and gross beta monitoring in the river tubes, horizontal array, and vertical profile tubes. Section 5.3 discusses strontium-90 and gross beta trends.

Figure 5.3 shows the distribution of strontium-90 in the study area in fall 2005. The highest concentrations (>1,000 pCi/L) consistently were detected in a few tubes at the previously identified center of the plume. The upstream extent of the plume at the 8 pCi/L drinking water standard is between aquifer tube Array-1A and well 199-N-96A.

The north part of the horizontal array (Array-8A through -14A) shows strontium-90 concentrations in the tens to hundreds of pCi/L. The inland portion of this plume may possibly have been affected by the pump-and-treat system, which drew down the water table into a less-contaminated portion of the aquifer. Groundwater extraction ceased in March 2006, and strontium-90 concentrations will be assessed to see if there is an increase in this portion of the plume, which would provide evidence that the pump-and-treat did have an affect on this area (Hartman et al. 2007). Strontium-90 concentrations in well 199-N-92A (the northernmost data point in Figure 5.3) are >1,000 pCi/L. Section 5.2.1 discusses results from the horizontal array in more detail.

Limited data from river tubes NS-3B and NS-4B indicate that strontium-90 concentrations decrease rapidly with distance from the shore. For example, the strontium-90 concentration in September 2005 in tube NS-3A-87 was 3,460 pCi/L, while tubes NS-3B-40 and -52 had concentrations of 49.9 and 37.6 pCi/L, respectively, at an elevation of approximately 115.3 m.
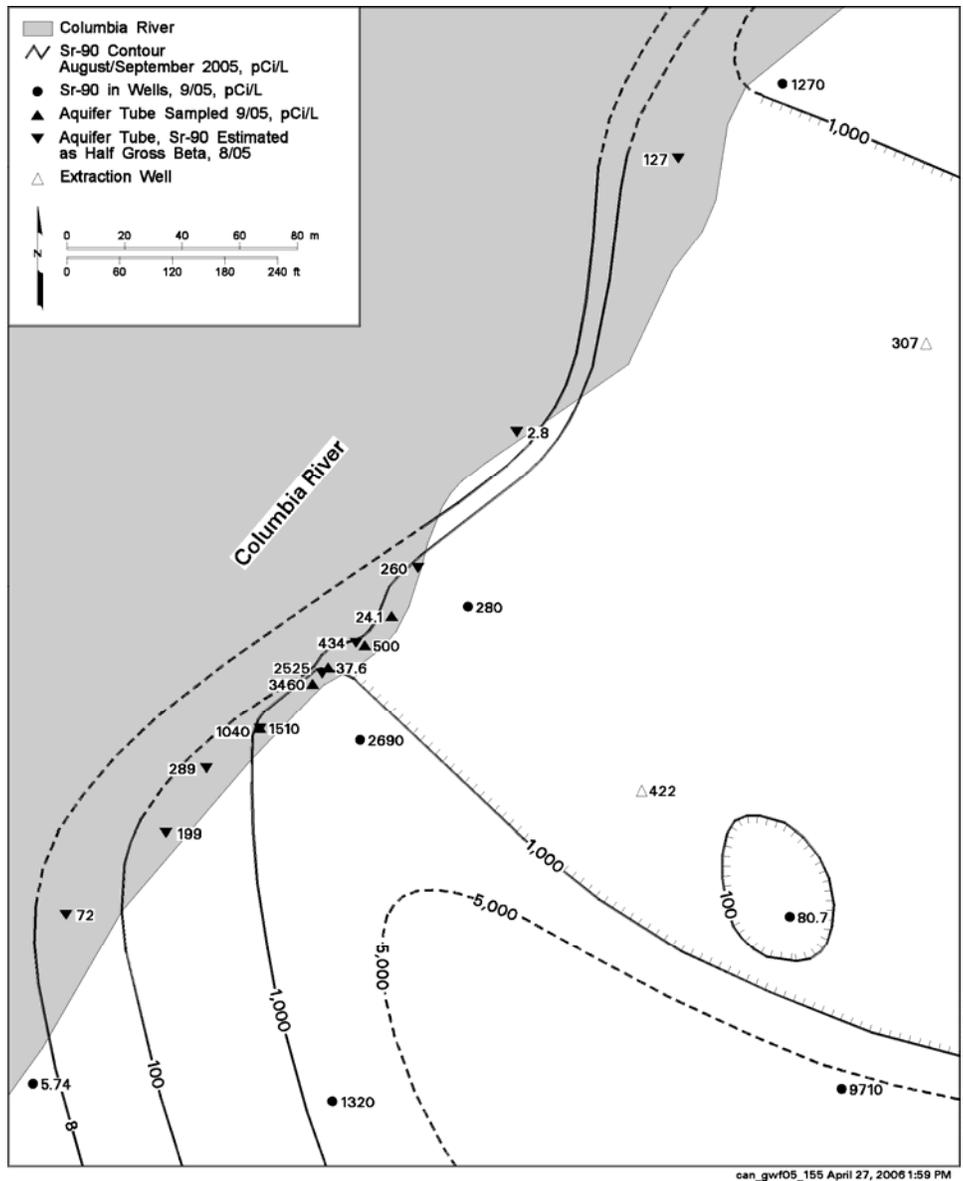
Figure 5.3. Strontium-90 Distribution at the 100-N Area Shoreline, Fall 2005

5.2.1   Horizontal Array

A cluster of aquifer tubes was installed at multiple depths in June and August 2005 to provide more information about the vertical distribution of stronium-90 in the hyporheic zone along the shoreline. The highest strontium-90 concentrations in the clusters used for vertical profiles were at an elevation of approximately 116 m above mean sea level. Based on these results, a horizontal array of 14 aquifer tubes was installed at the 116-m horizon along the 100-N Area shoreline between August 2005 and February 2006 (Figure 2.1).

The horizontal array of aquifer tubes was installed to determine the lateral extent of the strontium-90 plume at the shoreline. The spacing between tube sites in the array was approximately 30 m, and

locations were positioned to be close to the bi-valve sampling locations, where sampling was previously conducted as part of a 100-N Area ecological risk assessment (DOE-RL 2006).

Nine aquifer tubes were installed in a horizontal array in August 2005 (Figure 2.1). Strontium-90 concentrations in eight of the nine aquifer tubes (estimated from gross beta results) were above the strontium-90 drinking water standard (8 pCi/L) (Figure 5.4). The centerline of the plume is between Array-4A and -6A.

Based on data from Array-1A through -9A, five additional aquifer tubes were added downstream of Array-9A in September 2005 and March 2006. One tube also was added between Array-8 and Array-9. Water samples collected from the northern part of the horizontal array (Array-8A through -14A) had strontium-90 concentrations in the tens to hundreds of pCi/L (Figure 5.4). Groundwater extraction by the pump-and-treat system ceased in March 2006. Water samples collected from the aquifer tubes in April, May, and June 2006 revealed no noticeable change in the concentrations after the pump-and-treat system was shut down along the 100-N Area shoreline.

Water samples collected from all the tubes in the horizontal array except Array-8A had strontium-90 concentrations above the drinking water standard. These values were observed at various river stages (Figure 5.4). The aquifer tube with the maximum strontium-90 concentration (NVP2-116.0) showed lower concentrations during high river stage, perhaps because of dilution with river water. However, other aquifer tubes did not show a consistent relationship between concentration and river stage. These river stage and contaminant concentration trends are discussed in more detail in Section 5.3.
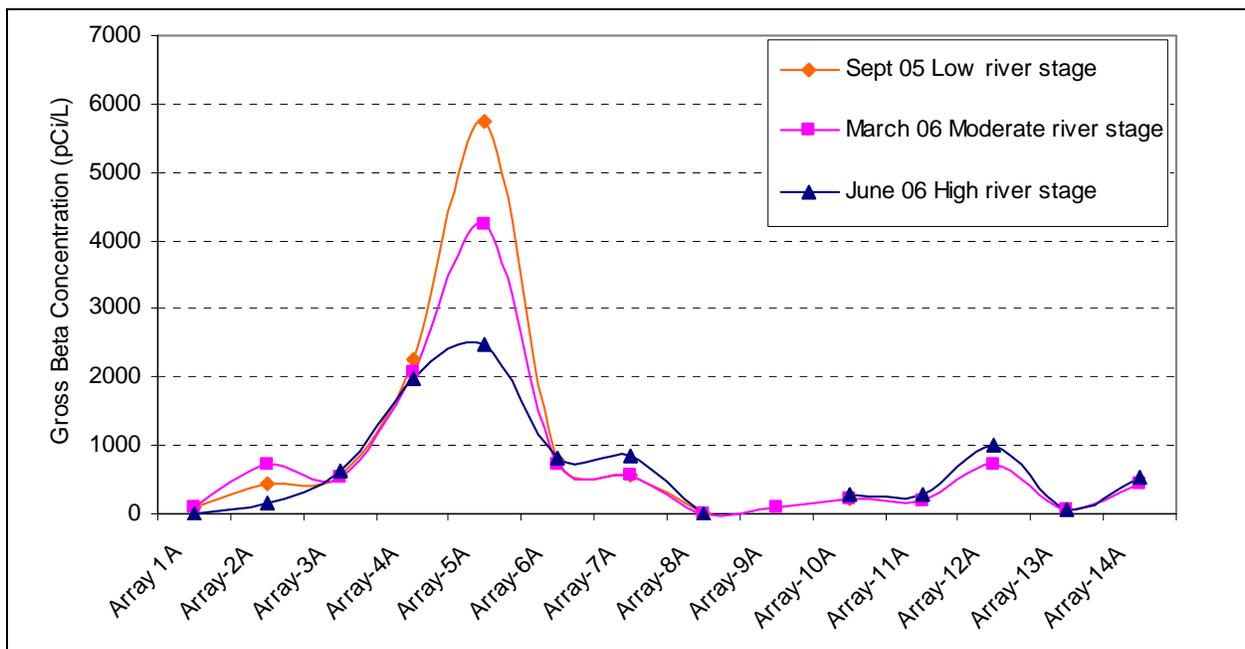
Figure 5.4. Gross Beta Concentrations in Horizontal Array Aquifer Tubes at the 100-N Area Shoreline. Strontium-90 concentrations are approximately half the value of the gross beta concentrations.

5.2.2 Vertical Distribution in the Aqueous Phase

The highest concentrations of strontium-90 in water samples from river tubes were observed at cluster NS-3A. In particular, NS-3A-87 cm consistently had the highest concentrations, typically greater than 4,500 pCi/L. Figure 5.5 shows that the highest concentrations appear at an elevation of approximately 116 m.

To define the vertical distribution of strontium-90 contamination in greater detail, clusters of aquifer tubes were installed at varying elevations. Two clusters of aquifer tubes were installed adjacent to river tube cluster NS-3A. One set of tubes was installed above the rip-rap covering the shoreline (NVP-1), and the second set of was installed in the rip-rap (NVP-2) (Figure 2.4). The first cluster of vertical profile tubes was installed in June 2005, and the second cluster was installed in August 2005.

Figure 5.6 shows average gross beta concentrations with depth in the vertical profile aquifer tube clusters (June 2005 to May 2006). The shallowest aquifer tubes could not be sampled when river stage was moderate or low because the water level dropped below the screens. The highest concentrations were seen at elevations of 115.7 m and 115.4 m with an average concentration of 6,370 and 6,140 pCi/L, respectively. Both vertical profiles have an aquifer tube at an elevation of 116.3 m, yet the average gross beta concentrations are higher in NVP-1 by a factor of 1.5. The average specific conductance is very similar at both sites, so sample dilution does not explain the difference. The difference may simply be due to spatial variability.
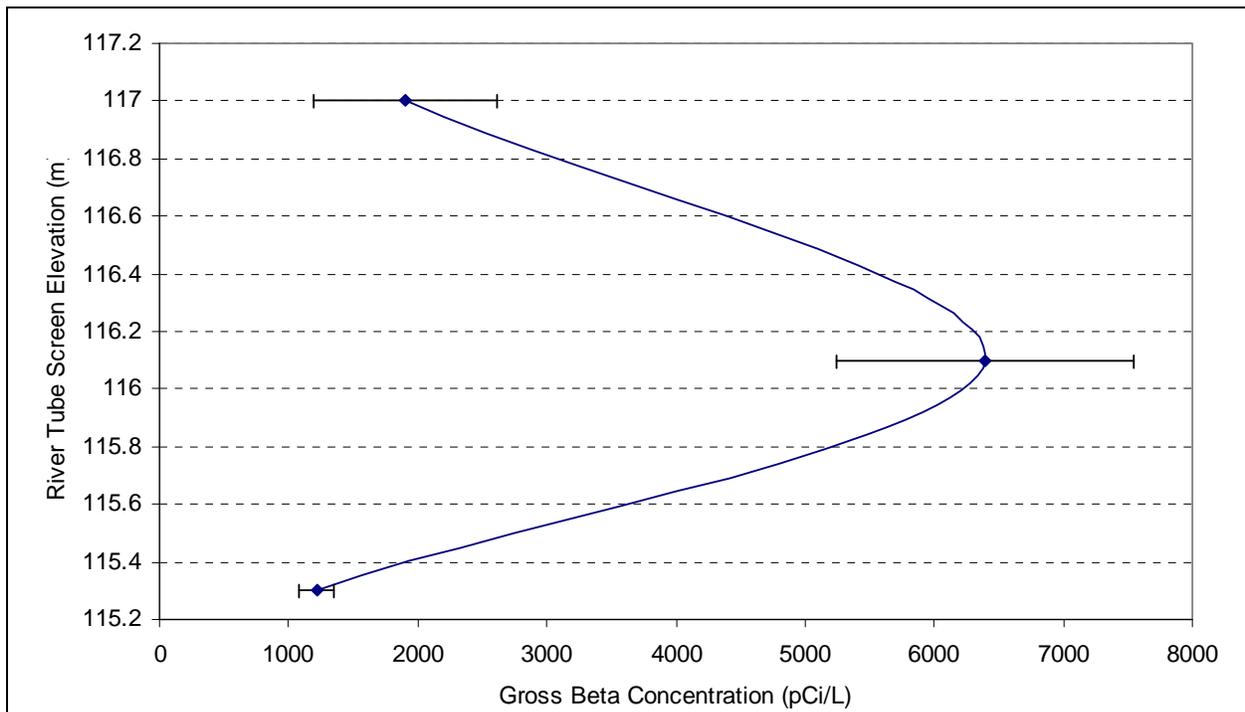
Figure 5.5. Average Gross Beta Concentration versus Elevation at River Tube Cluster NS-3A at the 100-N Area. Average for approximately 20 water samples per river tube cluster from April 2004 to May 2006
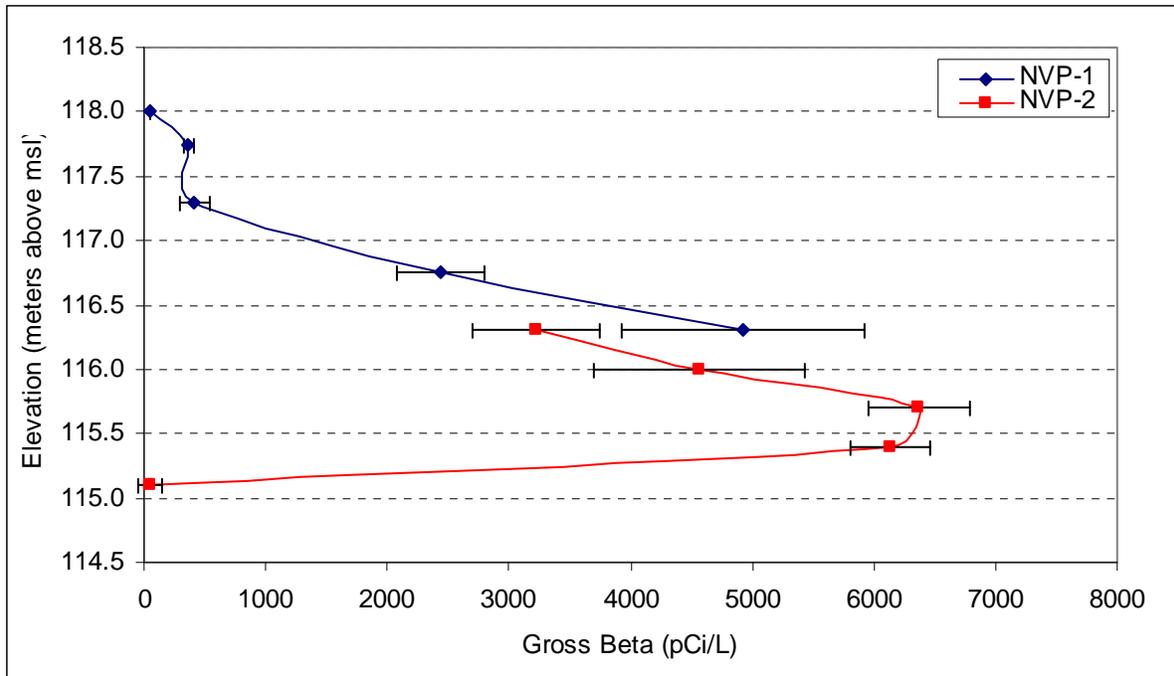
Figure 5.6. Average Gross Beta Concentration versus Elevation at Vertical Profile Tubes Along the 100-N Area Shoreline. The data were averaged over eight different water sampling events between June 2005 and April 2006. Note the higher elevation points did not always produce a water samples.

The Ringold Formation may retain more contaminants than the Hanford formation because of its lower hydraulic conductivity and its more reactive oxide coatings and adsorbent, fine-grained sediments. This is suggested by many samples with measured strontium-90 concentrations exceeding 1000 pCi/L in groundwater from the saturated Ringold Formation (Figure 3.1).

The geologic cross section (Figure 3.1) shows the strontium-90 plume near the shoreline. Concentrations greater than 100 pCi/L in groundwater are estimated to be restricted to the upper 3 m of the aquifer at elevations between 115 and 118 m in Ringold Formation Unit E. The maximum strontium-90 concentrations in groundwater were measured between 115.5 and 116.0 m in elevation. Strontium-90 concentrations remained above the 8 pCi/L drinking water standard in the deepest tubes (elevation ~115.1 m), so the bottom of the plume was not defined. However, data from monitoring well pairs farther inland show that strontium-90 is undetected at an elevation of 113 m.

Shoreline well 199-N-46 gives gross beta concentrations similar to the NS-3A cluster. The well has a "baseline" gross beta concentration of ~3,400 to 4,000 pCi/L when river stage is above ~118 m (approximate depth of Hanford-Ringold contact) (Figure 5.7). When the river stage is lower, gross beta values nearly double because the river dilution is not prevalent in well 199-N-46. However, this same dilution is not observed in other aquifer or river tubes because they are positioned in the Ringold Unit while a large part of the screened interval in N-46 is in the Hanford formation (Figure 3.1).
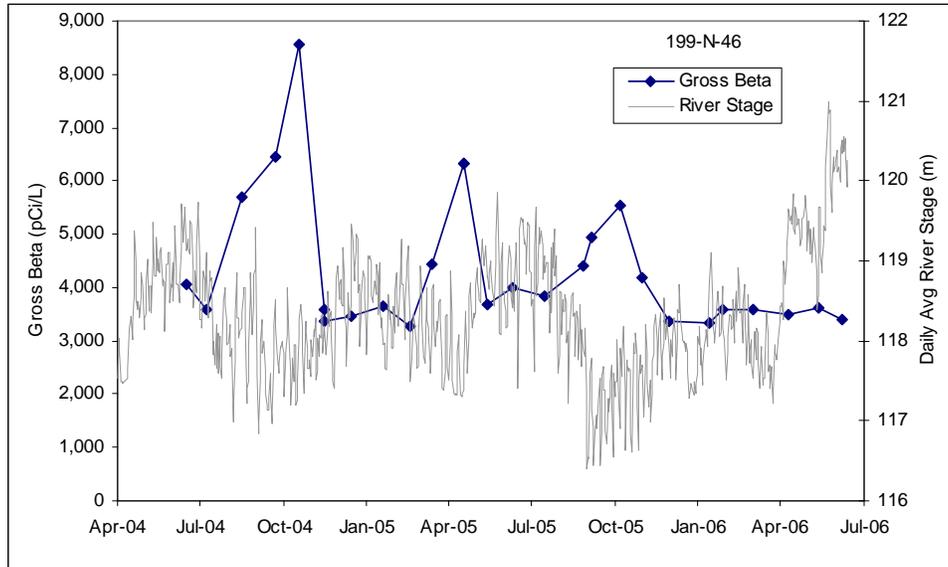
Figure 5.7.   Gross Beta Concentrations in Shoreline Monitoring Well 199-N-46 and Daily Average River Elevation at the 100-N Area

5.2.3   Vertical Distribution in the Solid Phase

Sediment samples were collected and analyzed for strontium-90 during the installation of wells 199-N-121, 199-N-122, and 199-N-123. The highest concentrations were observed at an elevation of 117.0 to 119.0 m, in the Hanford formation in the sediment (Figure 5.8). This is interesting because the highest aqueous concentrations of strontium-90 were found at a lower elevation in the aquifer and at a high river stage in the river tubes. The center well, 199-N-122, had the highest concentrations in sediment samples of the three wells. This well is located near the center of the groundwater plume at the shoreline.

5.3   Strontium-90 and Gross Beta Trends

Based on observations in aquifer tubes elsewhere on the Hanford Site and with the shoreline monitoring wells, we expected to see dilution in the 100-N Area river tubes and aquifer tubes during times of high river stage, with corresponding decreases in strontium-90 and specific conductance. This was not the case for observations at the 100-N Area shoreline. As seen in Figure 5.9, some of the highest concentrations of gross beta were observed during periods of high river stage (e.g., NS-3A-87 and NS-4A-138). Increased strontium-90 concentrations during high river stage may be caused by strontium remobilizing when the sediment inland of the tubes is re-saturated during high river stage (Peterson and Poston 2000). A previous study showed that strontium-90 sorption was fairly rapid and reversible (Serne and Legore 1996). However, this relationship between gross beta and river stages was not observed in all the river tubes.

The aquifer tubes showed no clear relationship between gross beta and river stage (Figure 5.10). Tube NVP2-116.0 did show a decline in gross beta as river stage increased in spring 2006, but other tubes in the cluster did not show a similar pattern.
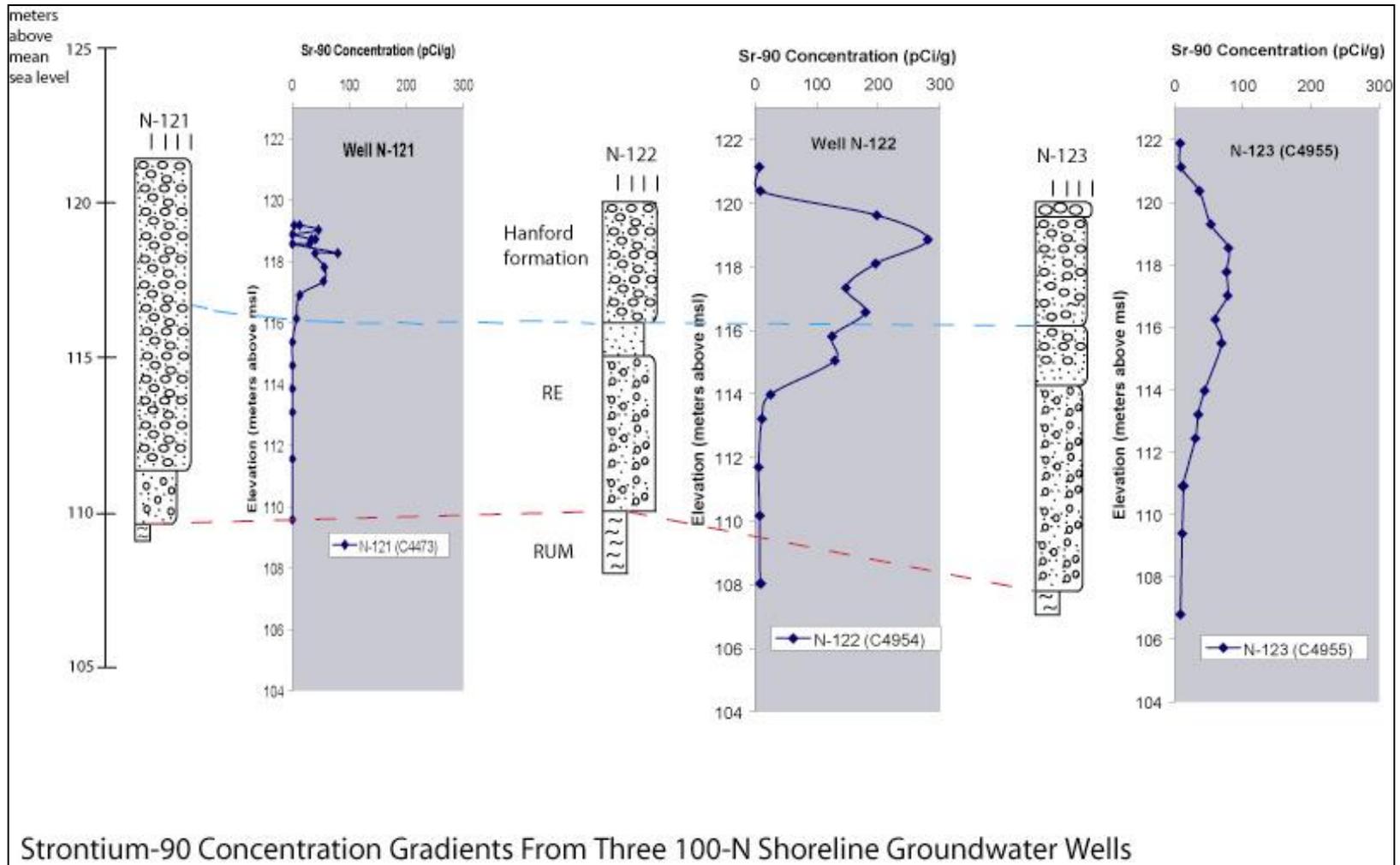
Figure 5.8. Strontium-90 Concentrations Measured in Sediment Samples Collected From Wells 199-N-121, 199-N-122, and 199-N-123
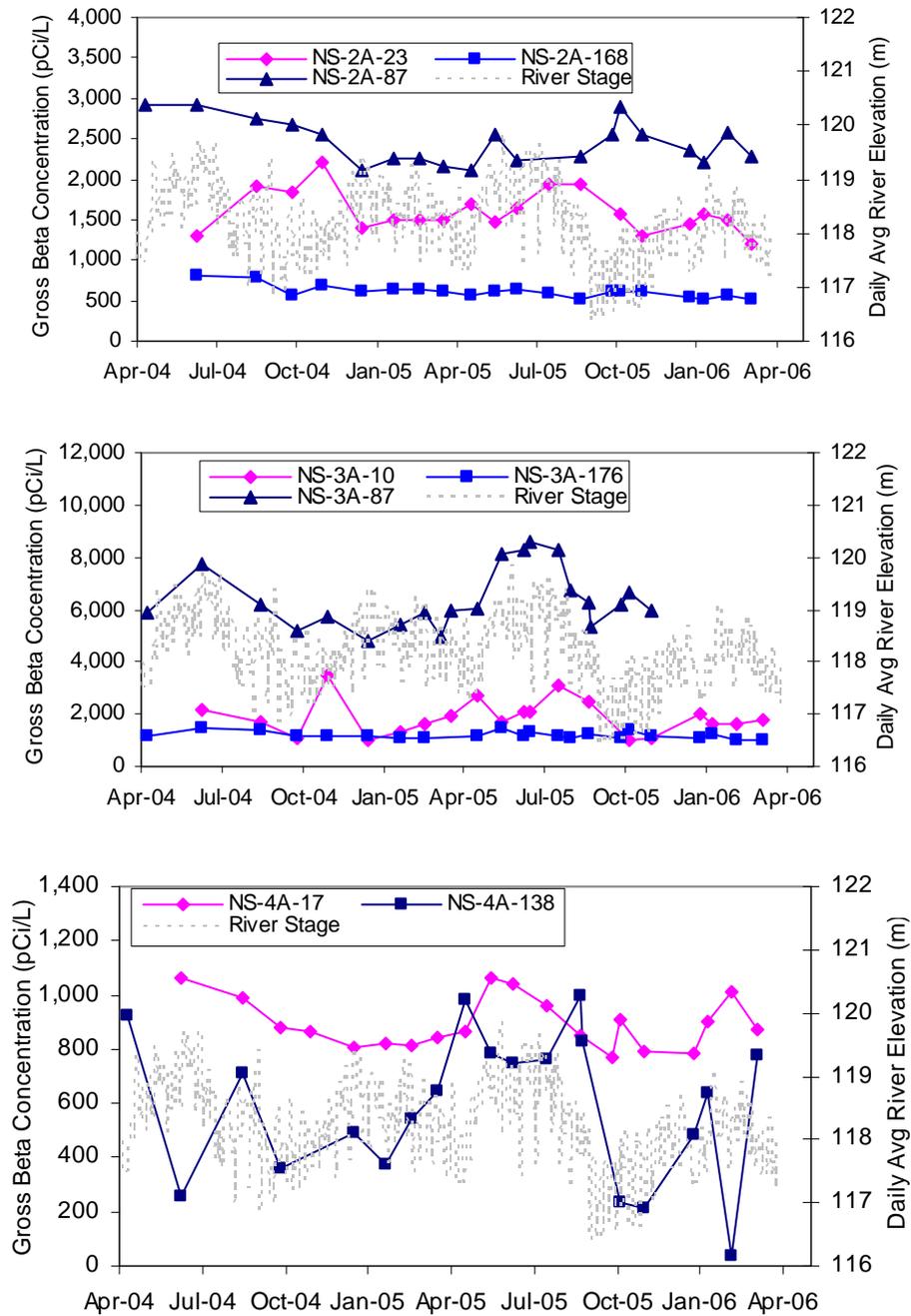
Figure 5.9. Gross Beta Concentrations in Measure in the NS-2A (Top), NS-3A (Middle), and NS-4A (Bottom) River Tubes

Tube NVP2-116.0 was sampled every 15 minutes for 6 hours in November 2005 using an automated sampler. Gross beta activity showed an overall decline, with a maximum of 8,800 pCi/L near the beginning of the period and a low of 4,800 pCi/L near the end of the period (Figure 5.11). The river stage rose approximately 2 m during the period of sampling. Specific conductance rose only slightly during the

sampling period, from 132.5 to 135.8 µS/cm. The pH began at 6.5 and increased and stabilized at 7.2 about halfway through the sampling period.
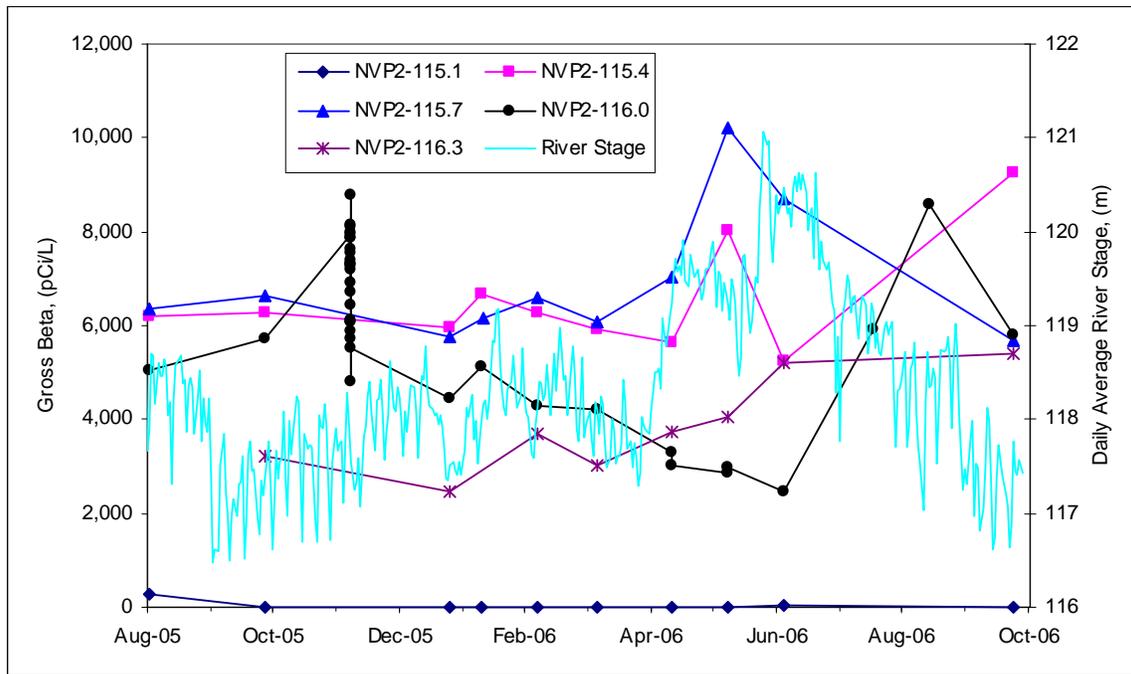
Figure 5.10. Gross Beta Concentrations in Vertical Profile Aquifer Tubes and River Elevation at the 100-N Area Shoreline
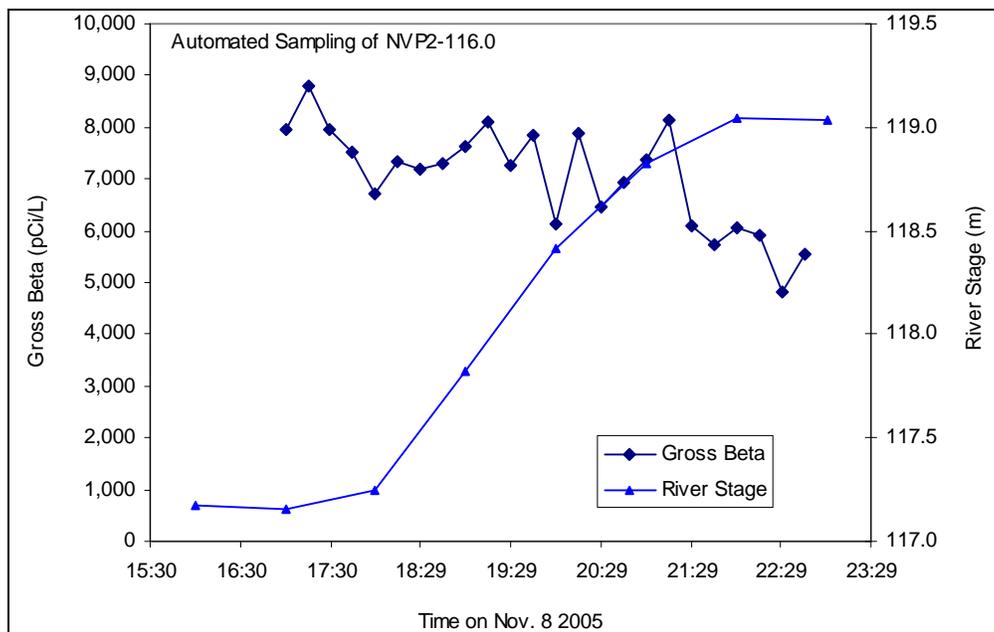
Figure 5.11. Automated Sampling Results for Aquifer Tube NVP2-116.0 at the 100-N Area Shoreline

The river stage at the start of the sampling period was ~117 m within Ringold Formation Unit E (Figure 3.1). The level rose above the Hanford-Ringold contact (~118 m) about midway through the sampling period and was at ~119 m at the end of sampling. The Hanford formation is absent at the location of tube NVP2-116.0, which is completed in Ringold Formation Unit E. As the water table rose into the Hanford formation inland of the tube location, gross beta concentrations in tube NVP-116.0 declined.

6.0   Field Parameters

Water quality parameters were measured during each sampling event. These data included specific conductance, temperature, dissolved oxygen, oxidation reduction potential, and pH. The data were obtained using portable field instrumentation and taken at the time the water samples were being collected. In addition to these parameters, cluster NS-3A was equipped with Solinist data loggers.

In other shoreline areas of the Hanford Reach, a moderate to strong correlation between specific conductance and contaminant concentration has been observed. The difference between the specific conductance of river water and groundwater has allowed researchers to estimate the dilution of groundwater by river water in some of these areas. It was suspected that a similar correlation would be observed for strontium-90 at the 100-N Area using specific conductance or one of the other water quality parameters. However, this proved not to be the case. Specific conductance showed no consistent correlation with river stage in the 100-N Area river tubes or aquifer tubes. This contrasts with results observed in aquifer tubes in other parts of the Hanford Site, where infiltration of river water during high river stage causes dilution of contaminants (i.e., lower concentrations).

6.1   Specific Conductance

Specific conductance was measured in the field for every water sample obtained. The specific conductance was measured prior to sampling until a steady value was achieved to verify that standing water in the sampling tube had been purged. At the completion of water sampling, the specific conductance was measured again to verify that conditions had remained stable.

Specific conductance values ranged from 120-190 µS/cm in the river tubes for all water samples collected April 2004 through April 2006 (Figure 6.1). No obvious trend was observed in any of the river tubes because they seem to have behaved independently of each other. River tube NS-3A-87 cm showed an increase in specific conductance with increasing river stage in May 2005, while NS-3A-10 cm and NS-3A-176 cm showed a decrease (Figure 6.1). The shallowest river tubes were expected to be most influenced by river water dilution, but this was not always the case. For example, in June 2004, the shallowest river tubes in clusters NS-3A and NS-4A had the highest specific conductance during an elevated river stage.

The specific conductance, on average, was approximately 150 µS/cm, indicating that river tube samples are dominated by river water (the specific conductance of river water averaged 120-140 µS/cm along the 100-N Area shoreline). Specific conductance at groundwater monitoring wells ranged between 300-450 µS/cm and was even higher in wells affected by a contaminant plume. As noted, most of the time the river tubes had measured specific conductance only slightly higher than river water.

Specific conductance increased in several river tubes in spring 2006 (Figure 6.1). This was especially dramatic in NS-4A-138, where specific conductance increased to over 300 µS/cm in May and June 2006. The increase is suspected to be caused by corrosion of the metal tubing. An increase in concentrations of iron and other metals has been observed in this and other river tubes.

When the river tubes were initially installed, Solinst data loggers were placed in five of them to continuously track specific conductance over an extended period of time. The data loggers showed similar observations to those illustrated in Figure 6.1. After approximately 1.5 years, all data loggers were removed from the river tubes.
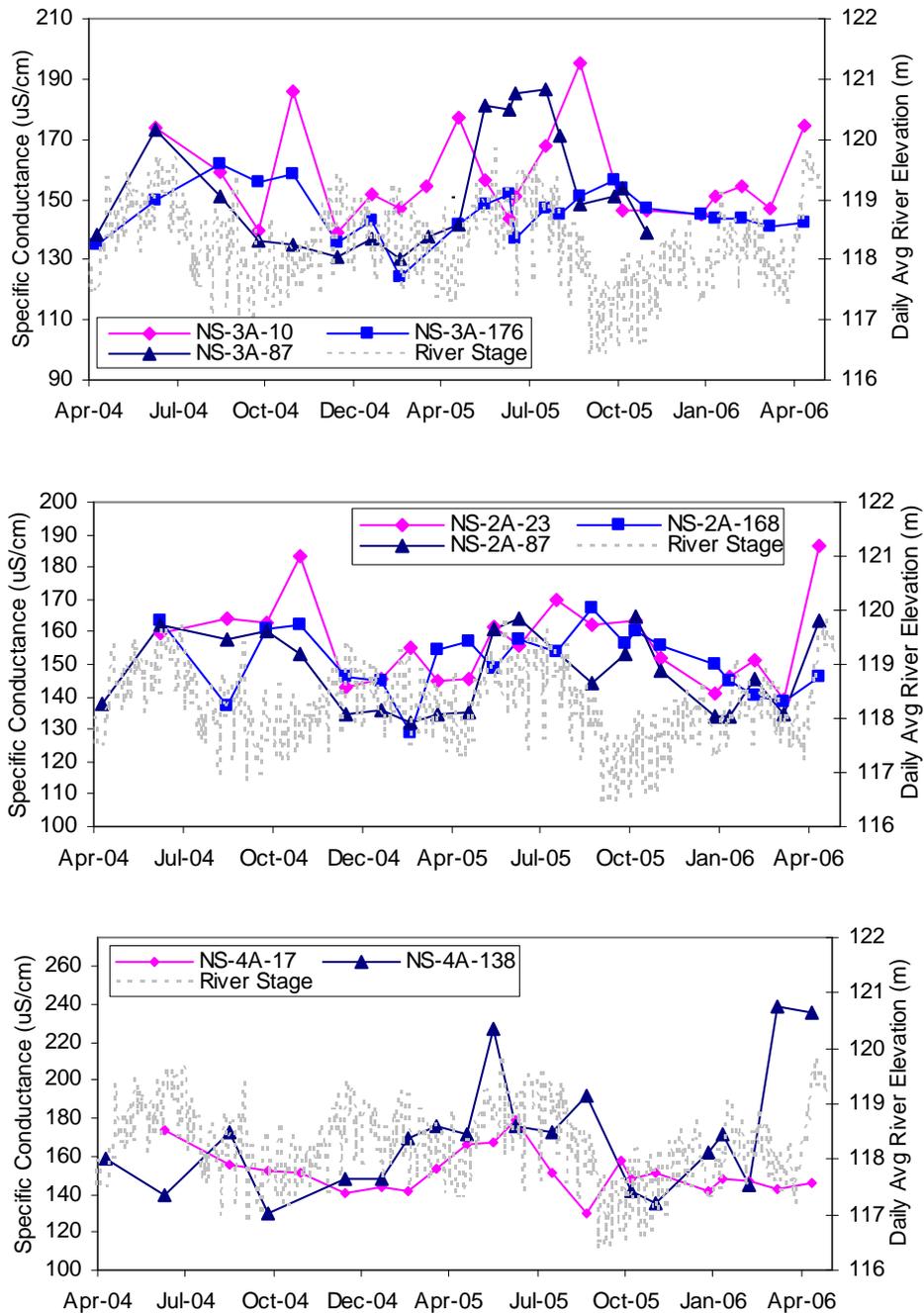
Figure 6.1. Specific Conductance in the NS-2A (Top), NS-3A (Middle), and NS-4A (Bottom) River Tube Clusters at the 100-N Area

6.2

Specific conductance values measured in water samples collected from the horizontal array were approximately the same as the river tubes with the exception of Array-2A (Figure 6.2). This tube may be affected by a high-specific conductance groundwater plume that originated in the 120-N-1 Percolation Pond and is evident in inland monitoring wells (Hartman et al. 2006, Section 2.5). However, Array-2A results from the April, May, and June 2006 sampling events indicate that the specific conductance was similar to those found in the other horizontal array sampling locations. The change may have been caused by dilution or a change in groundwater flow direction due to increased river stage.

Specific conductance in vertical profile tubes ranged from 140-160 µS/cm, which was similar to the horizontal array and river tubes. Slightly higher specific conductance values were observed at the lower elevations of the vertical profile (Figure 6.3).
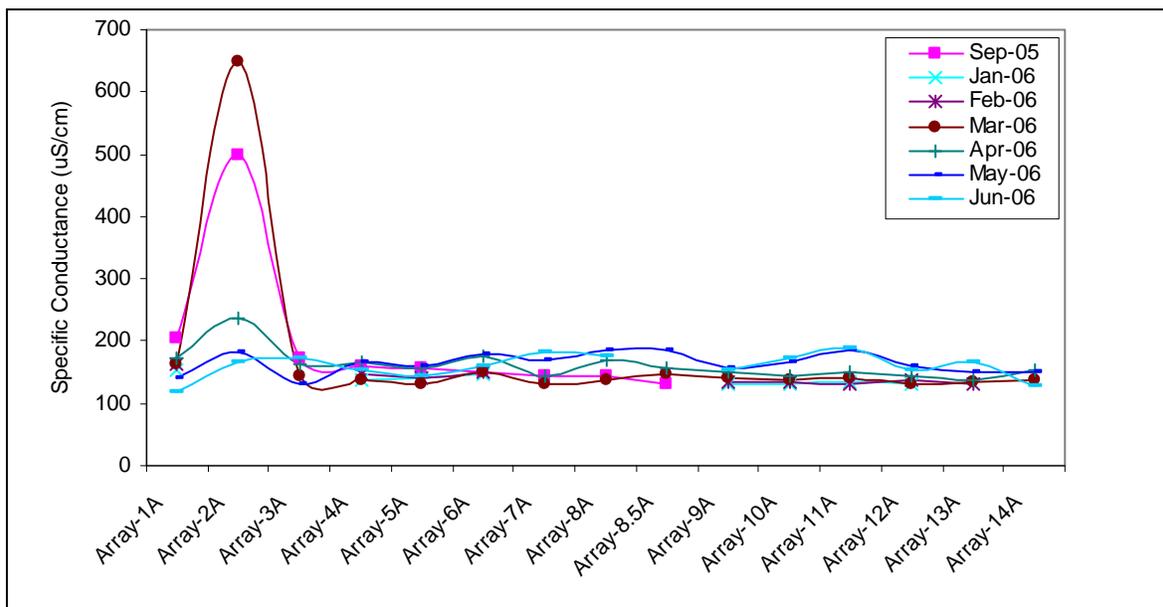
Figure 6.2. Specific Conductance in Horizontal Array Aquifer Tubes at the 100-N Area

6.2 Specific Conductance Versus Gross Beta

Specific conductance values showed no consistent correlation with gross beta concentrations in the samples measured in the 100-N Area river tubes or aquifer tubes. This contrasts with aquifer tubes in other parts of the Hanford Site, where high river stage causes dilution in contaminant concentrations.

A good correlation was observed between gross beta concentrations and specific conductance values in only one river tube and one aquifer tube. A correlation ($r^2 > 0.9$) was observed in NS-3A-87 cm, and a similarly high correlation ($r^2 > 0.9$) was observed in Array-2A (Table 6.1). As Figure 6.4 indicates, specific conductance and gross beta trends were parallel in NS-3A-87 cm. River tube NS-3A-87 rusted out in fall 2005 and can no longer be sampled. Nearby aquifer tube NVP2-116.0 does not show a good correlation between gross beta and specific conductance (Figure 6.4).
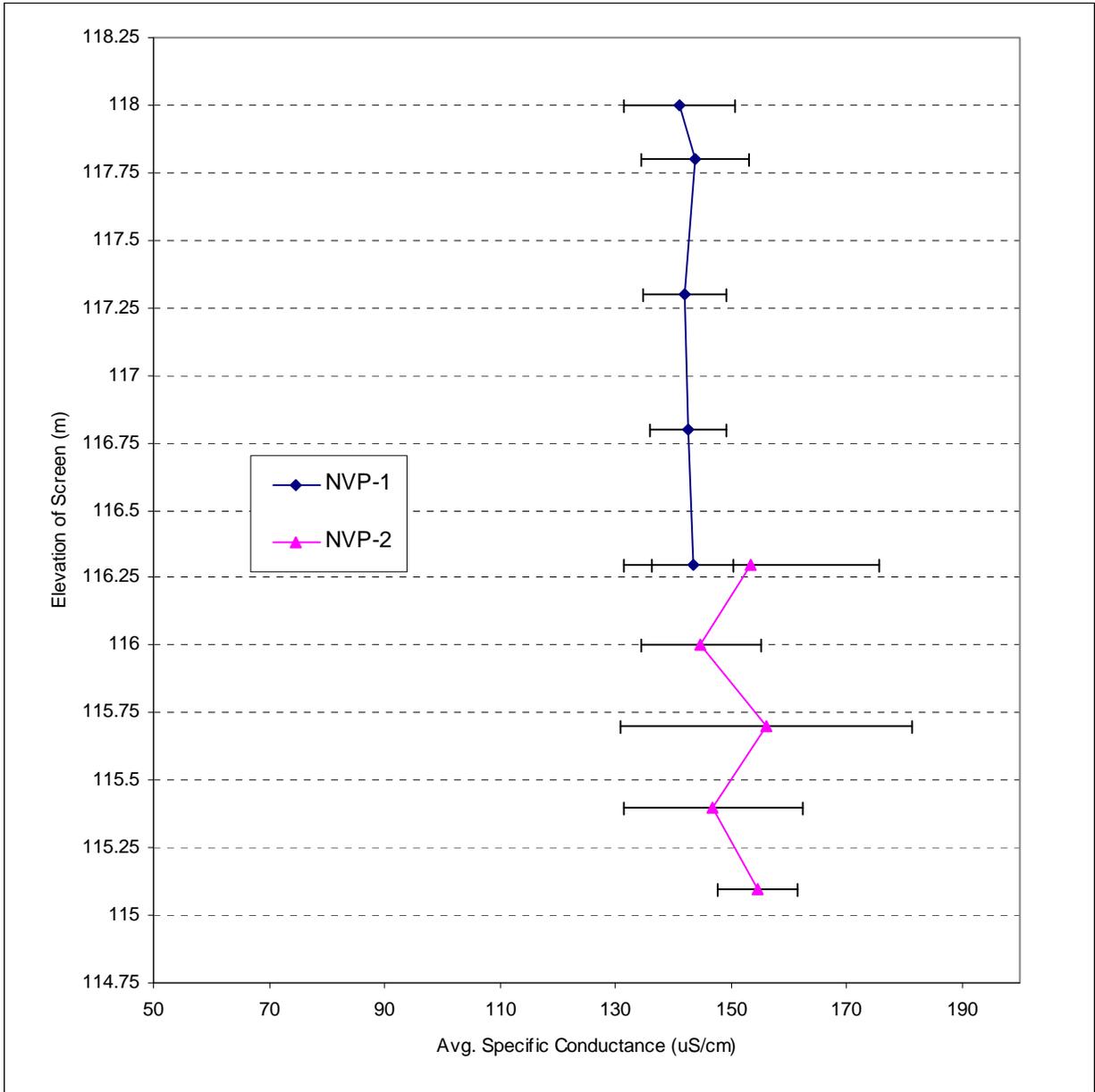
Figure 6.3. Average Specific Conductance in Vertical Profile Aquifer Tubes at the 100-N Area (June 2005 to June 2006)

Analysis of the data in river tubes NS-3A-10 and NS-3A-176 demonstrates a correlation between gross beta and specific conductance of 0.60 and 0.09, respectively. The deeper river tube was expected to have a better correlation due to less river dilution, but this was not the case. In the NS-2A cluster, the strongest apparent correlation was in the shallower tubes compared to the deepest tube, which demonstrated no apparent correlation (Table 6.1).
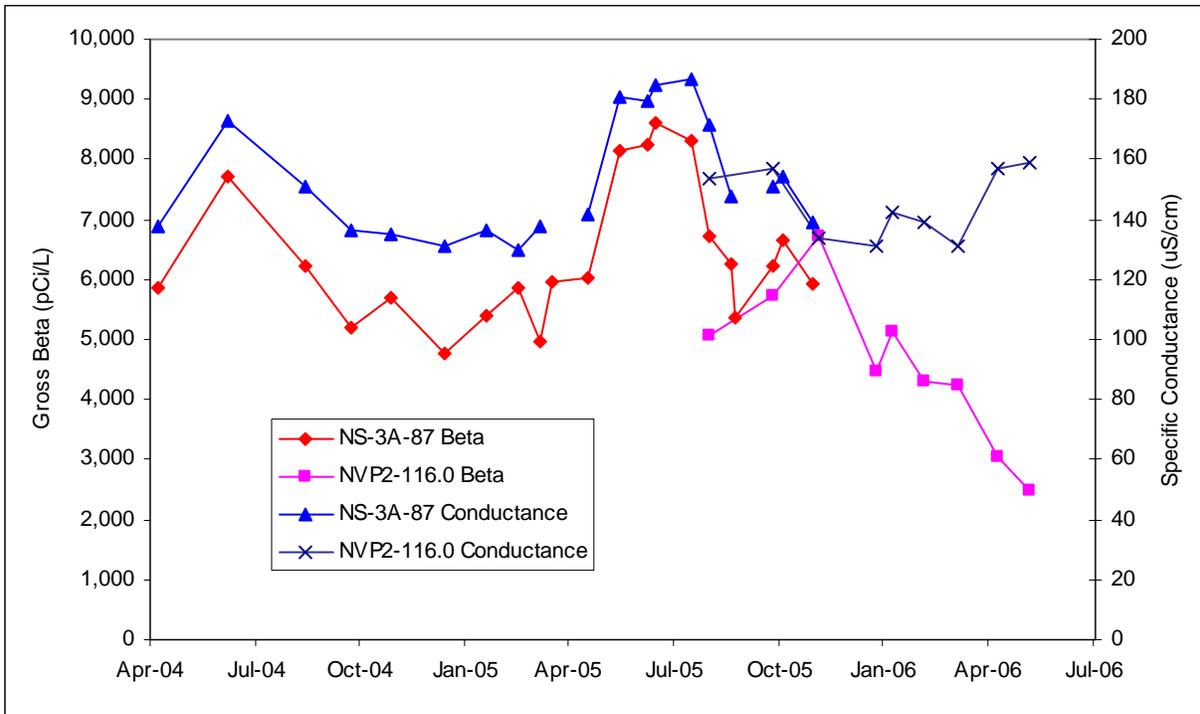
Figure 6.4. Specific Conductance Values and Gross Beta Concentrations in River Tube NS-3A-87 and Aquifer Tube NVP2-116.0 at the 100-N Area

Aquifer tubes showed the same lack of correlation between strontium-90 concentrations and specific conductance as the river tubes, except in Array-1A and -2A. Specific conductance measured in these tubes, particularly Array-2A, typically has been higher than in the other tubes, averaging ~200-400 µS/cm. Metals and anion data indicate Array-2A is influenced by a groundwater plume from the 120-N-1 percolation pond (Hartman et al. 2006). The plume is high in sulfate, sodium, calcium, and bicarbonate. Previous research has shown that calcium and sodium ions cause strontium-90 to desorb from aquifer sediments thereby mobilizing strontium-90 (Serne and LeGore 1996). Array-1A is less affected by the high salt plume even though it is closer to the source. Average specific conductance in that aquifer tube averages ~170 µS/cm, which is closer to levels observed in the downstream aquifer tubes.

Based on the data observed, specific conductance measurements do not demonstrate a consistent or strong enough correlation with gross beta concentrations or river stage to be an indicator of groundwater/river interaction in the hyporheic zone in the 100-N Area. The only strong correlation was observed at NS-3A-87, but at none of the other sampling locations.

Table 6.1. R-squared Values for Gross Beta Concentration Versus Specific Conductance Values in Aquifer Tubes and River Tubes (all data through May 2006) at the 100-N Area

River or Aquifer Tube	R-squared value	Correlation +/-
NVP1-1	0.47	Negative (few data)
NVP1-2	0.69	Negative
NVP1-3	0.13	Negative
NVP1-4	0.00	None
NVP1-5	0.62	Positive
NVP2-116.3	0.62	Positive
NVP2-116.0	0.36	Negative
NVP2-115.7	0.54	Positive
NVP2-115.4	0.44	Positive
NVP2-115.1	0.26	Positive (excluded outlier)
Array-1A	0.82	Positive
Array-2A	0.93	Positive
Array-3A	0.06	None
Array-4A	0.01	None
Array-6A	0.69	Positive
Array-7A	0.37	Positive
Array-8A	0.02	None
Array-9A	0.42	Positive
Array-10A	0.25	Positive
Array-11A	0.14	Positive
Array-12A	0.63	Positive
Array-13A	--	Insufficient data
Array-14A	--	Insufficient data
NS-2A-23cm	0.48	Positive
NS-2A-87cm	0.42	Positive
NS-2A-168cm	0.06	None
NS-3A-10cm	0.60	Positive
NS-3A-87cm	0.92	Positive
NS-3A-176cm	0.09	None
NS-4A-17cm	0.45	Positive
NS-4A-138cm	0.65	Positive

6.3   Dissolved Oxygen and Oxidation Reduction Potential

The amount of dissolved oxygen in Columbia River water at the 100-N Area was measured at ~10 mg/L. Dissolved oxygen in river tube and aquifer tube samples varied more than expected, from 2 to 10 mg/L. Figure 6.5 shows the dissolved oxygen trend for tube NS-3A-10, which is representative of the other tubes.

Moser et al. (2003) noted the presence of sulfate-, nitrate-, and iron-reducing bacteria in streambed pore water on the Hanford Site creating anoxic regions that exist within the hyporheic zone. Although most water in the hyporheic zone is oxidizing, in certain locations and under certain conditions, microbes may consume the oxygen. Temperature of the pore water, which varied seasonally from 5 to 24°C during the reporting period, may be a factor in the variability of microbial growth and dissolved oxygen levels (Figure 6.5). No noticeable trends are observed with dissolved oxygen and contaminant concentrations.
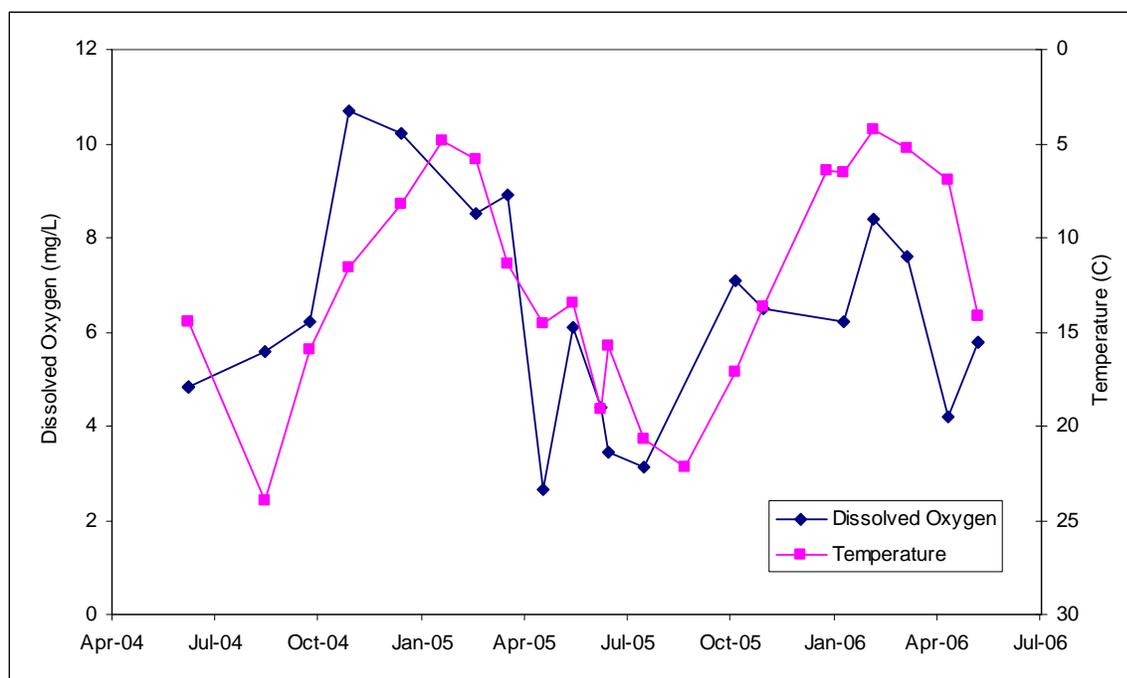
Figure 6.5. Dissolved Oxygen and Temperature in River Tube NS-3A-10 at the 100-N Area

Measured oxidation reduction potentials show no correlation with gross beta concentrations or river stage (Figure 6.6). This parameter seemed to follow similar trends in the river tubes in each cluster. A comparison of measured oxidation reduction potential with all the river tubes demonstrated no noticeable trends with all the river tubes behaving in a similar manner with respect to contaminant release.

6.4   Values for pH

Values for pH in river tubes and aquifer tubes generally ranged from 6.5 to 8.5 (Figure 6.7), with no correlation with gross beta concentrations or river stage. For pH measurements, the tubes did not all trend similarly. The range of pH in well 199-N-46 was 7.5 to 8.0, which is more indicative of groundwater in the 100-N Area. The pH of river water typically ranges from 6.5 to 8.0.
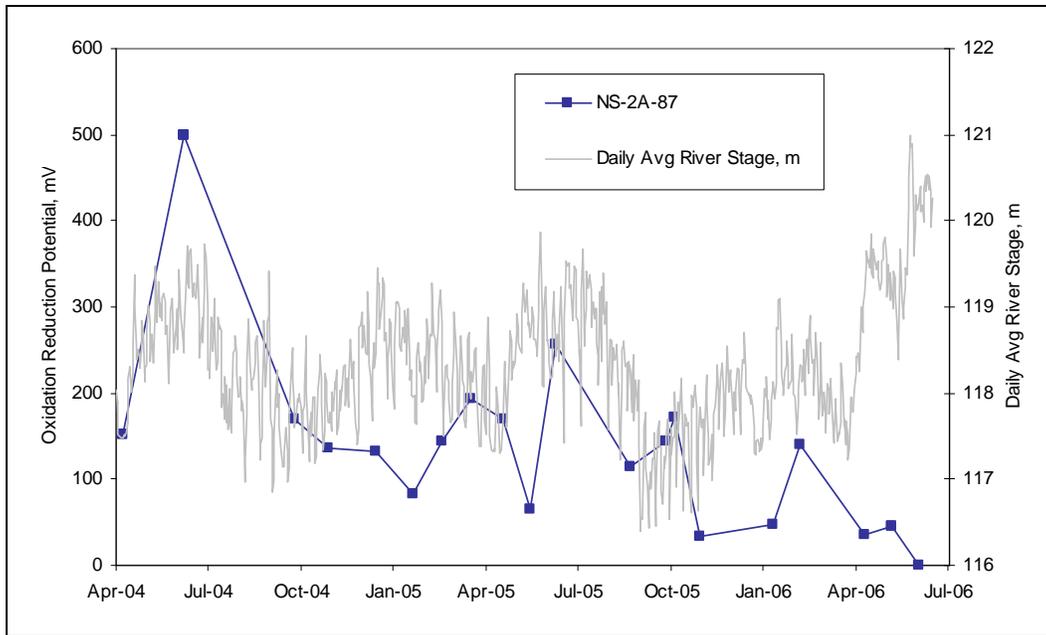
Figure 6.6. Oxidation Reduction Potential in River Tube NS-2A-87 and River Stage
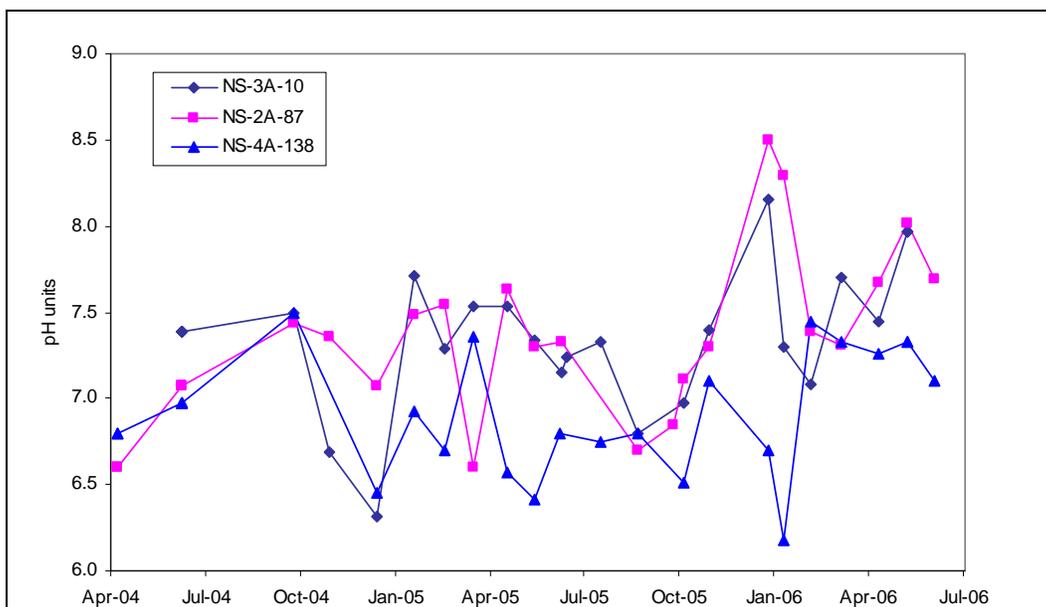
Figure 6.7. pH in Selected River Tubes at the 100-N Area

6.5 Temperature

Temperatures varied seasonally in samples from river tubes, ranging from 5 to 25ºC (Figure 6.8). Shallow tubes NS-2A-23 and NS-3A-10 generally showed larger variations than deeper tubes, as expected. Shoreline well 199-N-46 showed a damped response, while inland well 199-N-2 had relatively constant temperatures, between 19.5 and 20.5ºC, because it is far enough inland to be dominated by groundwater flow.

6.8
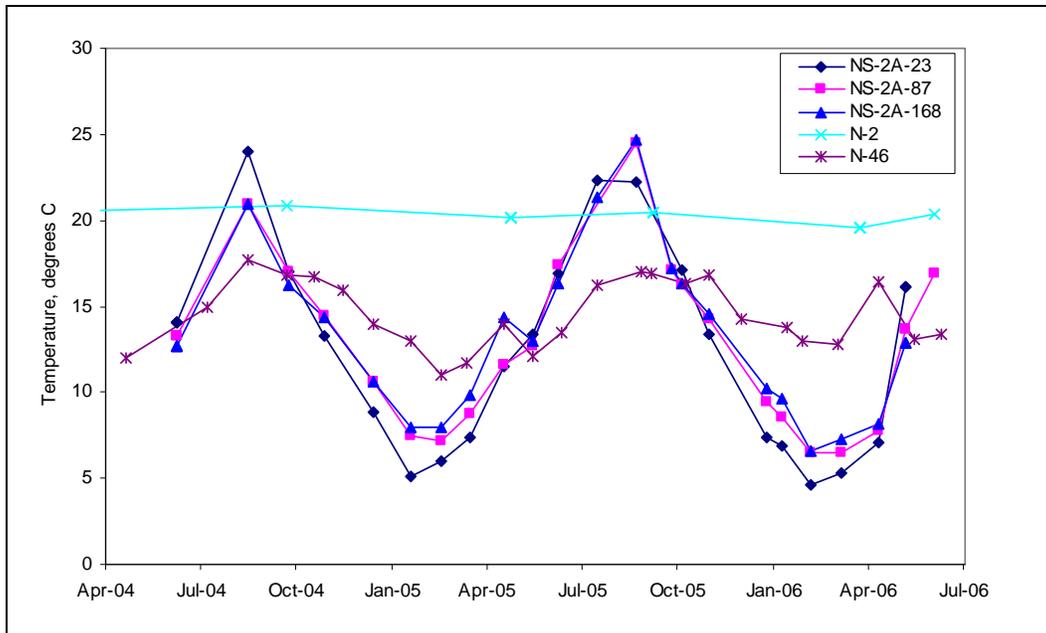
Figure 6.8. Temperature in Selected River Tubes and Wells 199-N-2 and 199-N-46 at the 100-N Area

7.0   Metals Results

Concentrations of metals were assessed during major water sampling events (Table 7.1). Examination of river stage in shallow groundwater at the 100-N Area shoreline and metal concentrations demonstrated that changing river levels did not play a significant role in diluting metal concentrations in the hyporheic zone. Trends in the concentrations of major metals (sodium, calcium, and magnesium) were similar to the specific conductance trends discussed in Section 6.0. In general, using metal concentrations exhibits no benefit for estimating strontium-90 concentrations or groundwater/river mixing in the hyporheic zone.

Water samples have historically been collected as both filtered and unfiltered samples depending on project-specific requirements. Unfiltered samples provide the most conservative measurement of concentration and are desirable when evaluating potential dose or other impacts. Filtered samples provide a measure of the dissolved contaminant in solution, which is the material available to actually move through the zone of interaction. All the samples collected were filtered, with the exception of those collected September 25, 2004 and December 27, 2005. No significant changes were observed in the results in filtered versus unfiltered samples.

Average concentrations of metals in river tubes and aquifer tubes along with the minimum and maximum measured values are displayed in Table 7.1. Results were consistent except for horizontal Array-2A. As noted in Section 6.1, this tube may be influenced by a high-conductance plume from the former 120-N-1 percolation pond. Calcium was detected up to 104 mg/L and sodium was detected at 15 mg/L, which was similar to values observed in nearby monitoring wells.

A review of selected metals (both filtered and unfiltered) for surface freshwater quality criteria for toxic pollutants indicated that only copper and lead exceeded the chronic toxicity level (6.0 µg/L and 1.1 µg/L, respectively). Out of the 35 samples analyzed for copper, only one sample (filtered) was above the toxicity level. Out of the 39 samples analyzed for lead, only four samples exceeded the toxicity level (three filtered, one unfiltered). Sample concentrations were close to the instrument detection limits. These factors and lack of repeated detections suggest these results were not significant.

Analysis of the data indicates that river dilution plays no significant factor in the concentration of metals in shallow groundwater. For estimating concentrations of strontium-90 in groundwater discharge into the river at the zone of interaction, metals seem to have no correlation and show no ability to act as an indicator for strontium-90 release.

Table 7.1. Average Values of Filtered Metals in River Tubes and Aquifer Tubes (all data through June 2006)

Constituent	Minimum Value (µg/L)	Maximum Value (µg/L)	Average (µg/L)	Number of samples (filtered)	Comments
Antimony	U	U	U	U	--
Arsenic	0.23	14.2	1.05	55	--
Barium	13.8	80.3	27.15	110	--
Beryllium	0.53	0.99	< 1	7	--
Cadmium	0.004	0.114	0.025	31	--
Calcium[a]	16,587	103,698	25,260	118	--
Chromium	0.118	5.29	1.06	41	--
Cobalt	U	U	U	U	--
Copper	0.175	5.2	1.5	28	--
Iron[b]	11.4	1,980	30.1	31	--
Lead	0.00647	2.04	< 1	39	--
Magnesium	3,470	12,241	4,415	78	--
Manganese	0.648	1,490	91.6	80	--
Molybdenum[c]	0.44	1.23	0.71	8	--
Nickel	0.176	8.68	1.0	59	--
Potassium	833	3,260	1,402	61	--
Selenium	0.05	0.74	< 1	34	--
Silver	U	U	U	U	--
Sodium	1,251	15,294	2,825	117	--
Strontium	75	290	103	78	--
Thorium	0.001	0.11	< 1	23	--
Uranium	0.04	5.1	< 1	51	--
Vanadium	1.5	6.7	3.5	7	--
Zinc	0.5	2,436	347	96	--

[a] For Horizontal Array 2A, all calcium values above 50,000 µg/L. Most likely due to high conductivity plume.
[b] NS-4A-138 cm had three values over 200 µg/L. Average taken without including these values, which more than likely indicated screen corrosion.
[c] Only listed value on table that used non-filtered data to report average.
U = Result below detection limits.

8.0 Alkalinity and Anions Results

Anions were also analyzed for water samples collected from river tubes and aquifer tubes at the 100-N Area. No obvious trends were observed with river stage in any of the three clusters of aquifer tubes. Alkalinity ranged from 50 to 90 mg/L, chloride ranged from 0.9 to 2.6 mg/L, and sulfate ranged from 5.9 to 12 mg/L. Fluoride was detected in some samples, generally at levels below 100 µg/L. The majority of additional anions assessed were below the analytical reporting limits. Alkalinity, indicative of bicarbonate, demonstrated no notable trends with river stage or contaminant discharge.

Figure 8.1 shows sulfate in well 199-N-46 and river tube NS-3A-87 cm. Similar trends were observed in the tube and the well, although well 199-N-46 had a higher average sulfate concentration than the river tubes. Well 199-N-46 is located approximately 9.1 m inland of cluster NS-3A. The screened elevation at well 199-N-46 is from 116.4 m to above the water table (equivalent to NS-3A-10 and NVP1-1 through -4).
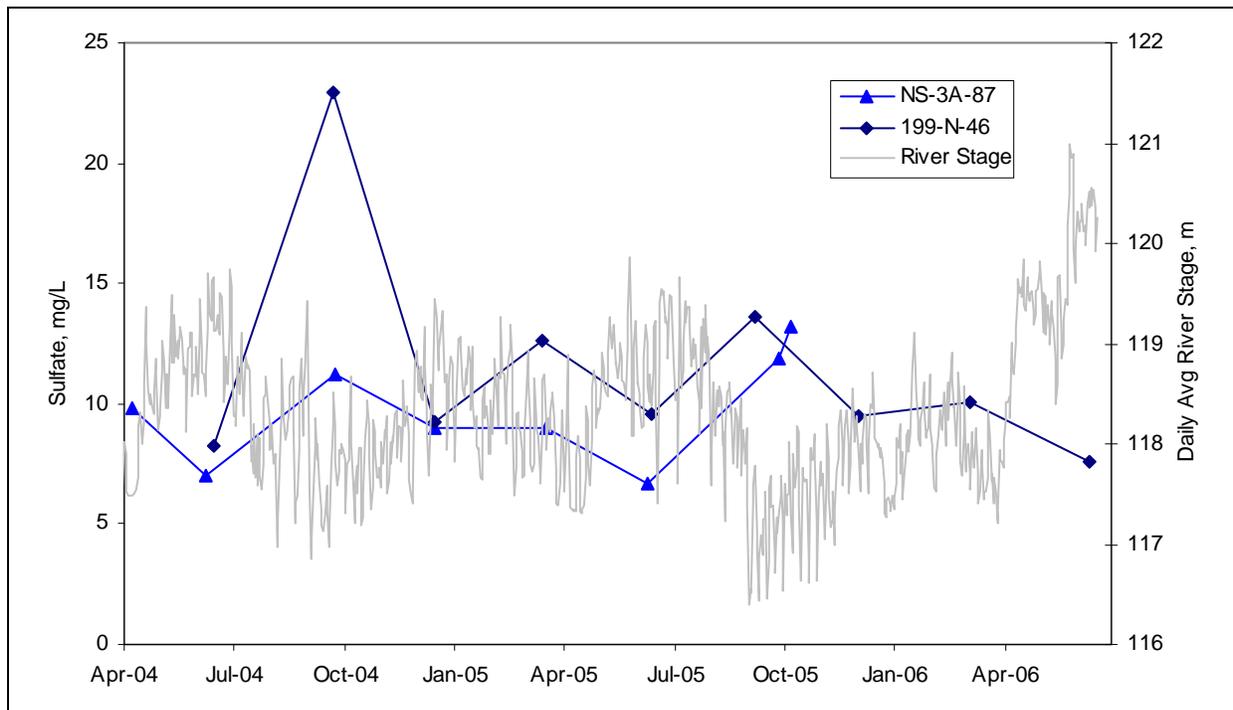
Figure 8.1. Sulfate Concentrations in River Tube NS-3A and Well 199-N-46, with Daily Average River Elevation at the 100-N Area

Anions in horizontal array and vertical profile aquifer tubes had comparable values to the river tubes, except for Array-2A. Sulfate was detected up to 136 mg/L in Array-2A, reflecting the influence of the 120-N-1 high-salt containing groundwater plume as discussed previously. Array-1A also demonstrated a higher concentration of some constituents compared to other sampling locations, but not as high as Array-2A.

9.0   Tritium and Gamma-Emitters

Tritium and gamma-emitting radionuclides were analyzed periodically in water samples from river tubes and aquifer tubes. Tritium was undetected, except in three river tubes during the September 2005 sampling event. Tritium was detected in NS-2A-87 cm, NS-2A-168 cm, and NS-3A-176 cm at concentrations of 732, 585, and 822 pCi/L, respectively. The 100-N Area tritium plume intersects the Columbia River north of the horizontal array (Figure 2.4.5 in Hartman et al. 2004), so lack of detectable concentrations of tritium was not surprising.

Gamma-emitting radionuclides cobalt-60 and cesium-137 were present in liquid effluent discharged to the ground in the 100-N Area but were not detected in any water samples collected from aquifer tubes or river tubes.

10.0 Well Cluster

A cluster of three monitoring wells, 199-N-119, -120, and -121 (Figure 2.1) was drilled for the RACS Project in 2004. Sediments from the deepest well (199-N-121) were sampled for strontium-90 and other constituents (see Appendix B). The completed wells have been routinely sampled for water. Well depths and construction information are listed in Appendix B.

10.1 Analytical Results for Sediment Samples and Pore Water

The highest strontium-90 concentrations in sediment samples from well 199-N-121 were in the lower Hanford and upper Ringold Formations (Figure 10.1; Appendix B). These results were consistent with those observed in wells installed for the pilot-scale treatability study (DOE-RL 2005b).

Tritium concentrations in pore water samples from well 199-N-121 were below the detection limit. For all samples, the detection limit was ~10^6 pCi/L because of the small sample volume.

Sediment samples also were analyzed for technetium-99, and the concentration in pore water was calculated. Detection limits for these samples were higher than for typical water samples because of the small sample size. Only one sample had a calculated pore water concentration above the detection limit (Figure 10.2). This sample was from a depth of 4.9 m and had a concentration of 809 pCi/L. The result is probably biased high because of de-saturation of the sample at the time of collection.

Sediment samples also were analyzed for metals and anions, with the results tabulated in Appendix B.

The 1:1 water extract data were manipulated to derive the pore water composition of the sediments. From knowledge of the moisture content of the sediment samples taken from the cores, the amount of deionized water that would be needed to make the water extract exactly one part water (total of native pore water and added deionized water) to one part by weight dry sediment was calculated. The ratio of the total volume of water in the extract to the native mass of pore water is the dilution factor. The assumption was that the deionized water diluted the existing pore water and did not dissolve any of the solids in the sediments. Thus, by correcting for the dilution, an estimate could be made of the actual chemical composition of the native pore water in the vadose zone sediments.

For the tritium samples, the process was the same except that the sample was generated using distillation in a Lachat tube/heater block and using 3 g of soil to 5 mL of water. The calculation to derive pore water concentration was the same as described above.

10.2 Geophysical Logging

Geophysical logging was conducted by S.M. Stoller Corporation[1] on these three monitoring wells. These data were collected in March 2004. The gamma logging was performed to investigate the presence of any radionuclides in this area. The data were also used as a qualitative assessment of the geology of this area. A geologic interpretation of this area was done by looking at the cuttings during drilling of these three wells and the other eight wells installed for the apatite pilot test.

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[1] S.M. Stoller Corporation, Richland, Washington.

A cable-type spectral gamma logging system was employed for this task. Logging procedure MAC-HGLP 1 6 5, Rev. 0 was followed. APTEC SUPERVISOR software was used to analyze the data in the field. A repeat analysis was performed at each well to ensure the unit was functioning correctly.

Well 199-N-119 showed cobalt-60 at 2.4, 2.7, and 7.2 m (bgs) at concentrations near the minimal detection limit (MDL) (0.1 pCi/g). Well 199-N-120 showed cobalt-60 at 3.0 and 8.4 m (bgs) at concentrations near the MDL (0.1 pCi/g). Well 199-N-121 showed cesium-137 at 0.6 m (bgs) at concentrations near the MDL (0.2 pCi/g). Photopeaks of cobalt-60 were also observed at 2.4 and 3.4 m (bgs), but the software did not determine these photopeaks to be statistically significant.

No significant findings were observed in the geophysical logging data on radionuclides or in the geology. See Appendix B for the full set of gamma log data reports for each well.
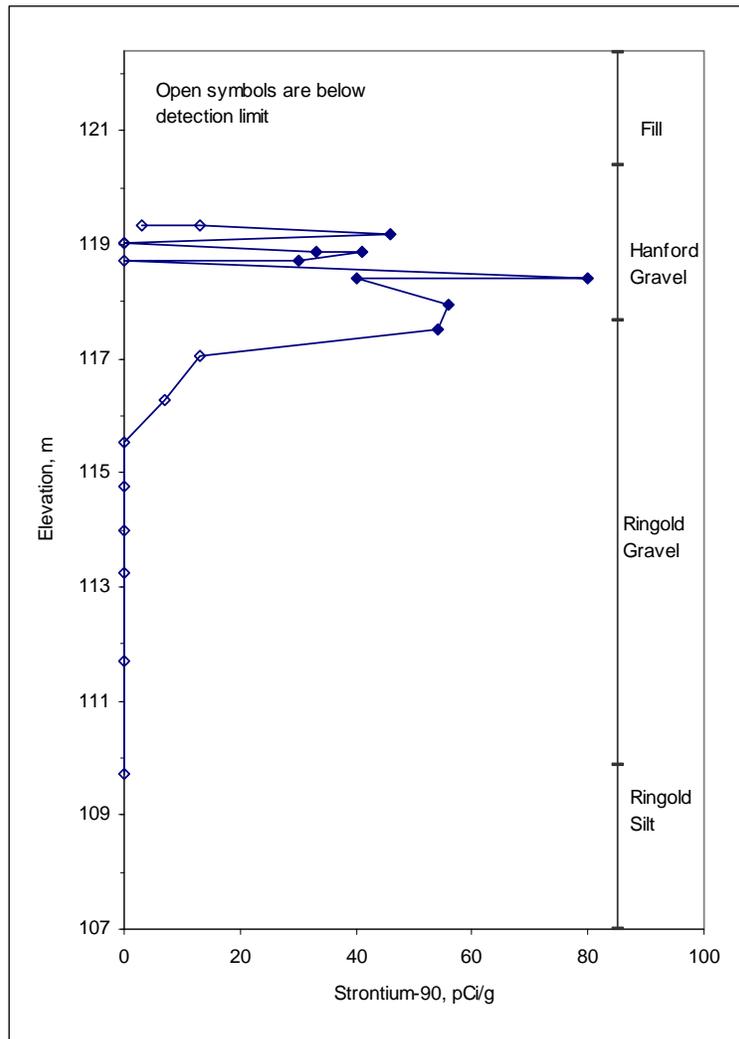
Figure 10.1.   Strontium-90 Concentrations Measured in Sediment Samples from Well 199-N-121 at the 100-N Area
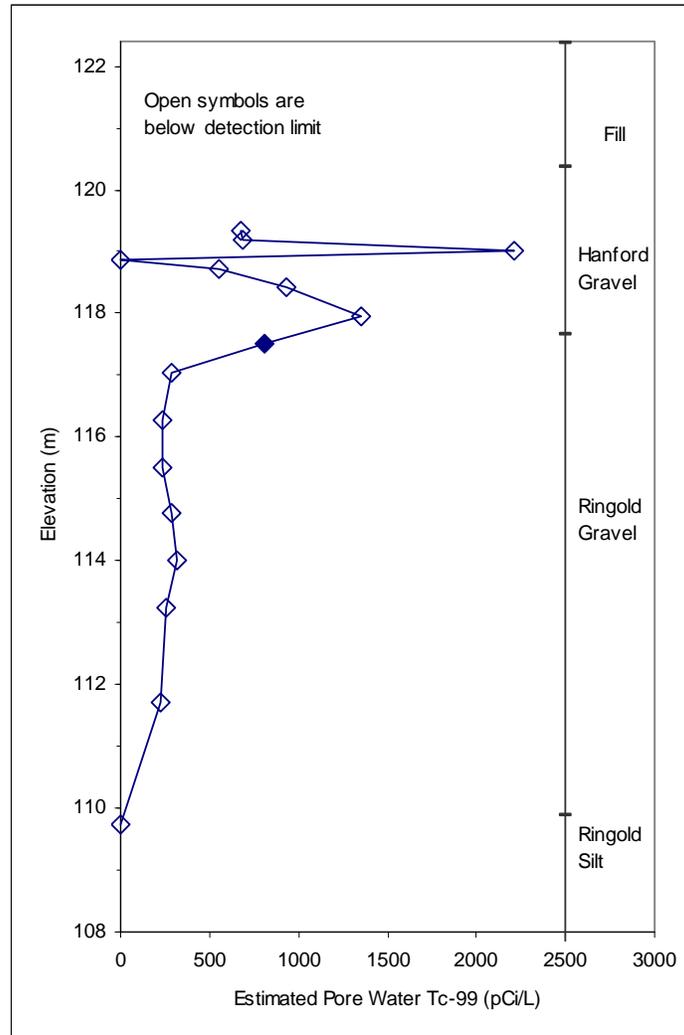
Figure 10.2.   Estimated Technetium-99 in Pore Water from Sediment Samples from Well 199-N-121 at the 100-N Area. Detection limits were high because of small sample size. Results may be biased high because of sample desaturation of the sample at time of collection.

10.3 Groundwater Monitoring Results

Gross beta concentrations for water samples collected from the multi-depth well cluster are plotted in Figure 10.3. The well cluster is located downstream of the plume centerline.

Well 199-N-119, which is screened across the average water table (115.7 to 117.8 m elevation), consistently has the highest gross beta concentrations (average ~400 pCi/L). Mid-depth well 199-N-120, screened from 113.4 to114.9 m, has beta concentrations an order of magnitude lower. Well 199-N-121, which is completed at the base of the aquifer from 109.9 to 111.4 m, has very low levels of gross beta (average 4 pCi/L). These results are consistent with the conceptual model illustrated in Figure 3.1.
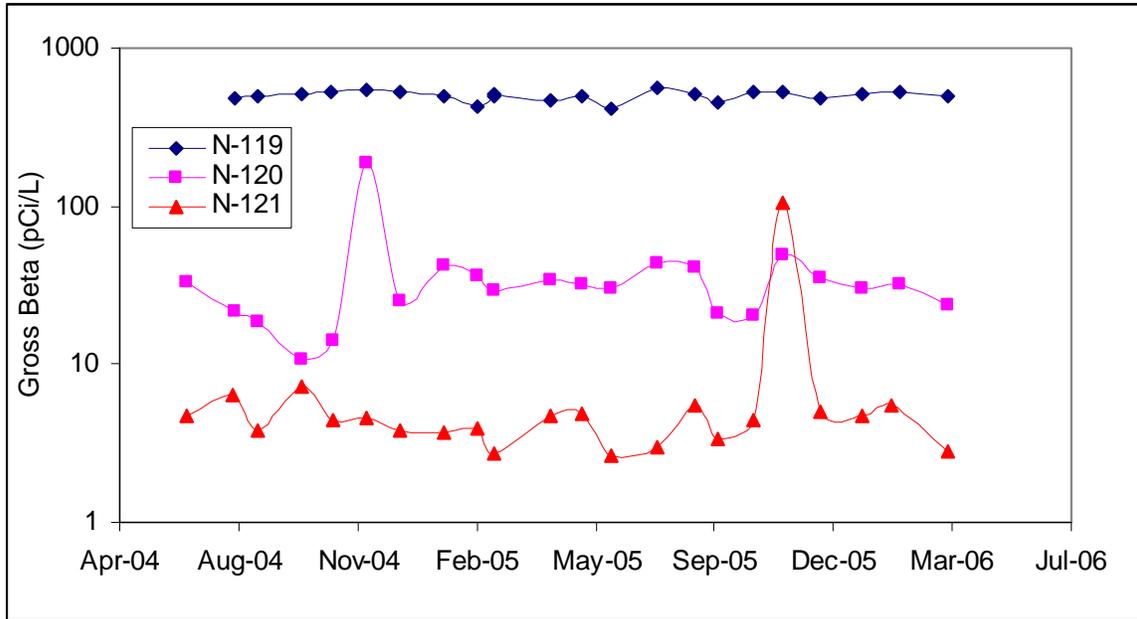
Figure 10.3. Gross Beta Concentration in Multi-Depth Well Cluster at the 100-N Area

Tritium was undetected in wells 199-N-119 and 199-N-120 but was detected in the deeper well, 199-N-121, at concentrations ranging between 597 to 1760 pCi/L. The main tritium plume in the 100-N Area discharges to the river north, downstream of the study area. Gamma-emitting radionuclides were not detected in these shoreline monitoring wells.

11.0 Conclusions

The remediation task of the RACS Project has been to identify and collect data that could be used to update the conceptual model for strontium-90 along the shoreline of the Columbia River at the 100-N Area, and also be used to assess remediation approaches. This work was initiated in 2004 and was performed in conjunction with other environmental monitoring projects. In collecting these data, an effort was made to identify parameters that could be used as a surrogate to identify strontium-90 more cost effectively and with potential to monitor concentration levels in a real-time setting. The following are the major conclusions of this study.

Gross beta as an indicator of strontium-90: Gross beta is a reliable indicator of strontium-90 in 100-N Area groundwater, is less expensive to analyze, and requires less sample volume and less analytical preparation. Strontium-90 concentrations at this location can be estimated as approximately one-half gross beta concentrations.

Specific conductance as an indicator of strontium-90: Specific conductance cannot be used as an indicator of strontium-90 in 100-N Area shoreline samples. Specific conductance in aquifer tube samples varies little, further complicating any relationship that could be used to indicate strontium-90. The specific conductance of some tubes is influenced by a high-conductance plume from a non-radioactive source.

Metals, ions, and field parameters: Metals, ions, and field parameters cannot be used as indicators of strontium-90. No obvious trends were correlated with the concentrations or values of these parameters.

River fluctuations: River fluctuations play a role in strontium-90 release but with no obvious general trend. Location of the aquifer and river tube samples demonstrated different trends during river fluctuation due to the geology.

Strontium-90 distribution: Data from the river tubes, aquifer tubes, and monitoring wells were used to better define the strontium-90 distribution in the aquifer near the 100-N Area shoreline, horizontally and vertically.

- Figure 5.3 shows strontium-90 distribution in groundwater at the study area. The 1,000 pCi/L contour encompasses a narrow portion of the shoreline near well 199-N-46 and river tube cluster NS-3A. The 100-pCi/L contour lies between horizontal array locations 1 and 2, and all of the aquifer tubes lie within the area with strontium-90 concentrations above the 8 pCi/L drinking water standard.

- Figure 3.1 is a cross section through the most contaminated part of the study area. The vertical extent of contamination in the aquifer at levels above 100 pCi/L near the shore correspond to an elevation of 115 to 118 m, based on tube cluster NS-3A and vertical profile cluster NVP-2. This corresponds to the top of Ringold Formation Unit E.

- In the solid phase (sediments), the highest concentrations of strontium-90 are at an elevation of 117 to 119 m, primarily in the Hanford formation.

Seasonal fluctuations in strontium-90 at shoreline: No clear seasonal trends in strontium-90 concentration were evident in the river tubes or aquifer tubes. Specific conductance was relatively stable throughout the year. Variability in strontium-90 did not appear to relate to specific conductance or river stage.

Groundwater chemistry: The general chemistry of water from river and aquifer tubes was similar to data from nearby monitoring wells and river samples. Variability in the chemistry does not appear to relate to season or river stage, except in two aquifer tubes that appear to be influenced by a plume high in sulfate, sodium, and calcium.

Stratigraphy: Data from this study confirmed the conceptual model of the aquifer in Ringold Formation Unit E and the base of the aquifer in the Ringold upper mud unit. The upper mud unit appears to continue beneath the Columbia River adjacent to the 100-N Area.

Aquifer tests: Slug tests in the river tubes yielded hydraulic conductivity values ranging from 0.08 to 1.6 m/day. Values at an elevation of ~116 m were an order of magnitude higher than at higher or lower elevations. Slug tests in well cluster 199-N-119, -120, and -121 ranged from 3.7 to 6.9 m/day, with the lowest values in the deepest well (109.9 to 111.4 m elevation).

Diesel contamination: Additional aquifer tubes were installed to determine if diesel was being discharged into the Columbia River. The results indicated an elevated concentration of TPH at an elevation of ~116.0 m with concentrations ranging from 0.17-0.63 mg/L in four of the six new aquifer tubes installed. Appendix D contains the details of this diesel assessment.

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Appendix A – Slug Tests

Appendix A – Slug Tests in Monitoring Wells

At the time of testing, the water table was within the Ringold Formation at all three well locations. Wells 199-N-120 and 199-N-121 exhibited homogeneous formation conditions. Well 199-N-119 exhibited a heterogeneous formation response with a radial boundary separating a high permeability inner zone and an outer lower permeability zone. Figure A.1 shows a diagnostic test plot for well 199-N-119 that shows the heterogeneous formation condition and where inner and outer zone conditions control the test response regime. Figure A.2 shows the heterogeneous test formation response for well 199-N-119 as it compares to the homogeneous formation responses for wells 199-N-120 and 199-N-121. Figure A.3 is a composite plot of the hydraulic conductivity values for all three wells plotted versus test interval depth, which provides a qualitative profile for hydraulic conductivity for the combined sites. Figures A.4 through A.7 are selected analysis plots for the Bouwer and Rice and type-curve analysis methods for each well site.
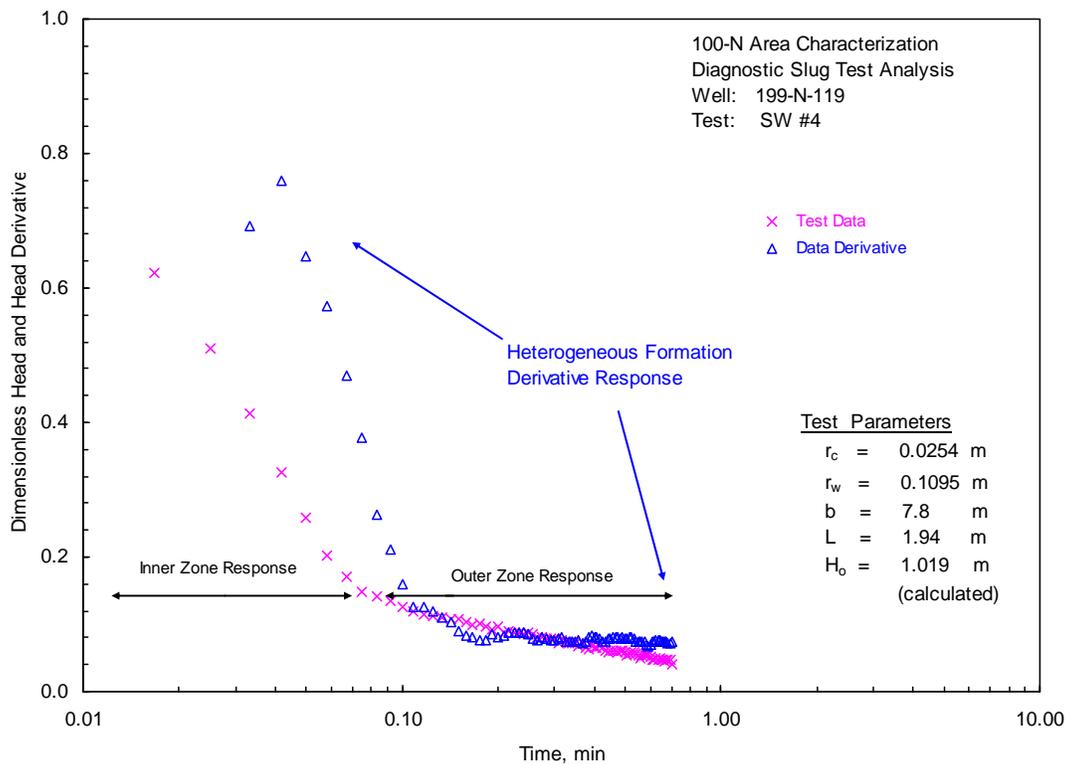
Figure A.1. Diagnostic Slug Test Analysis: Well 199-N-119
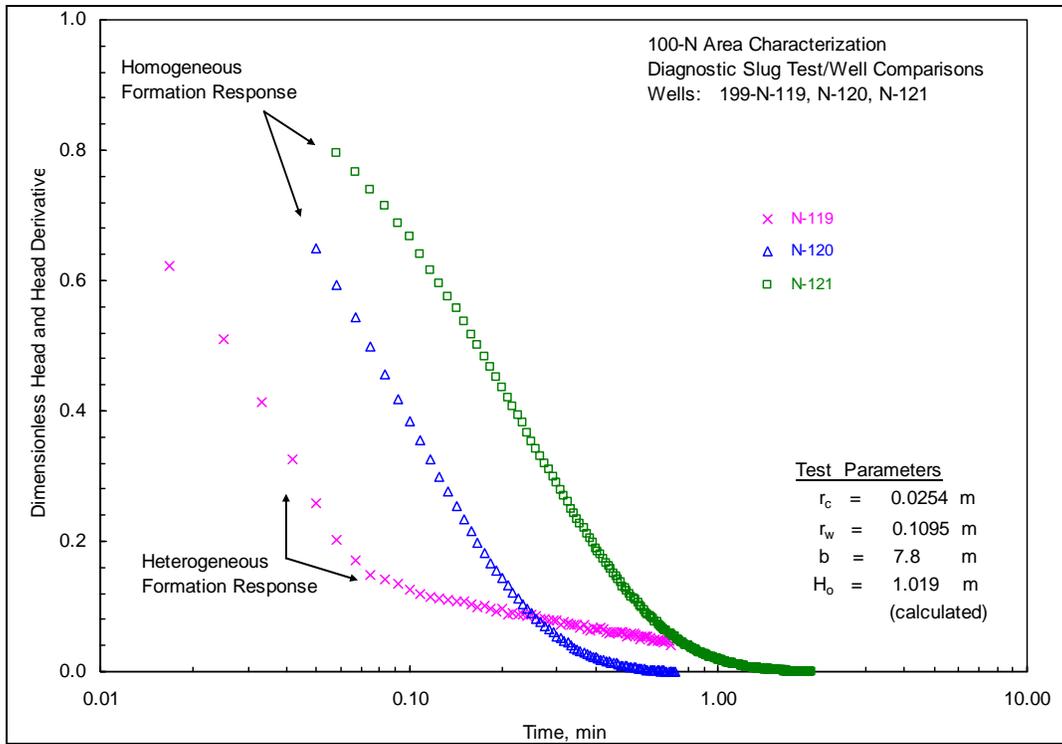
Figure A.2. Diagnostic Slug Test Response Comparison for Wells: 199-N-119, 199-N-120, and 19-N-121
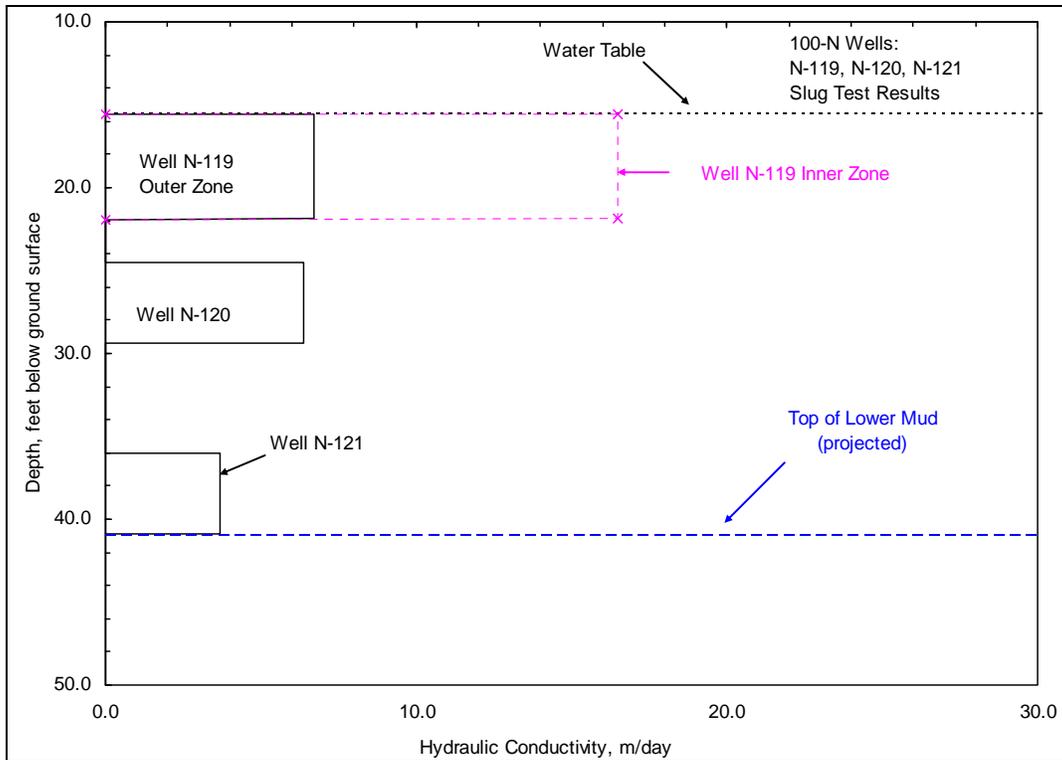
Figure A.3. Composite Vertical Distribution of Hydraulic Conductivity for Wells N-119, 199-N-120, and 199-N-121
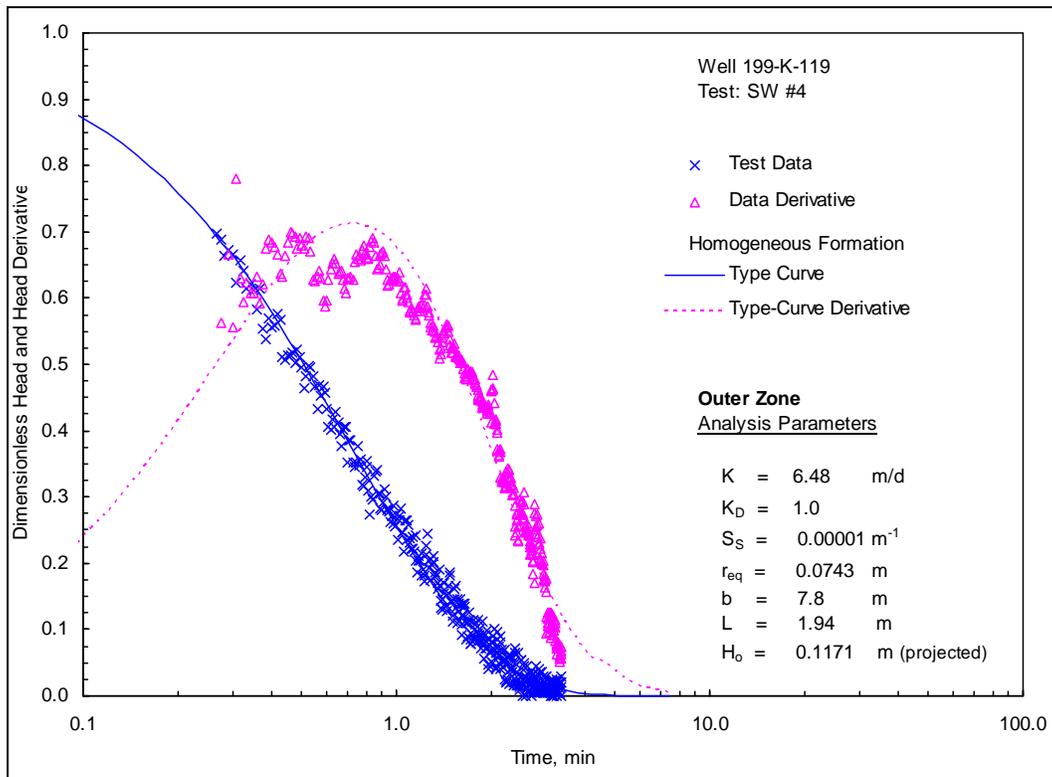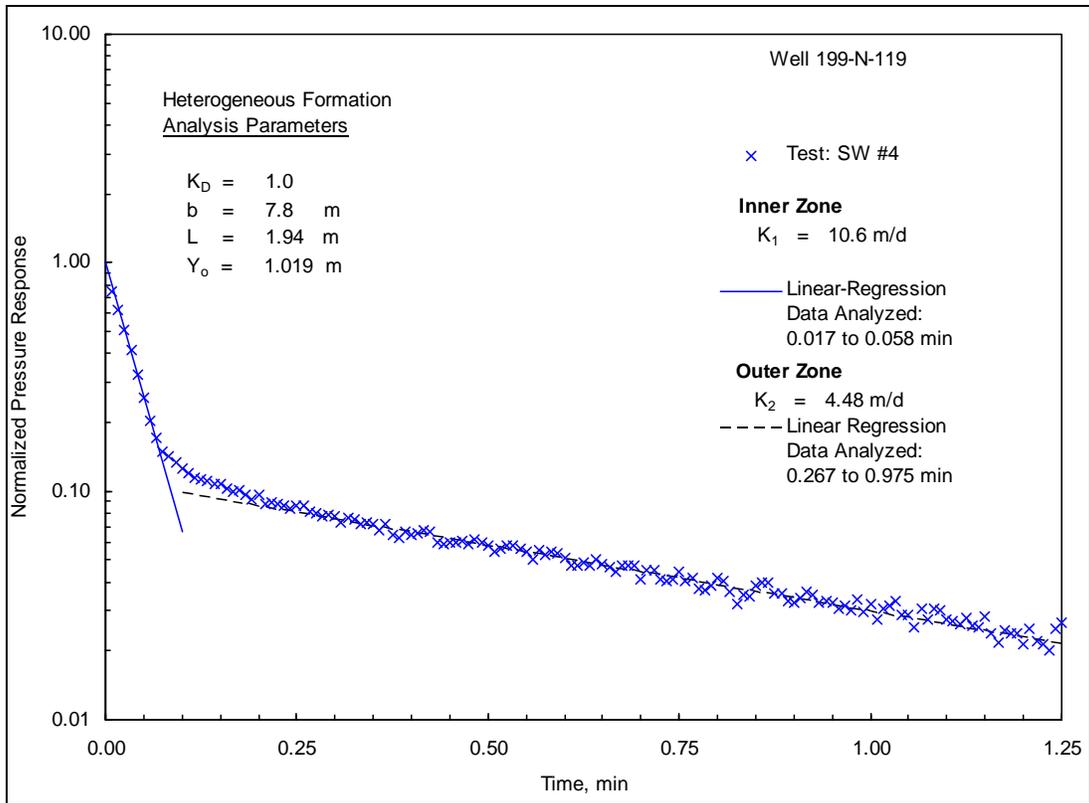
Figure A.4. Selected Slug-Test Analysis Plots for Well 199-N-119. Bouwer and Rice method (top) and type-curve method (bottom).
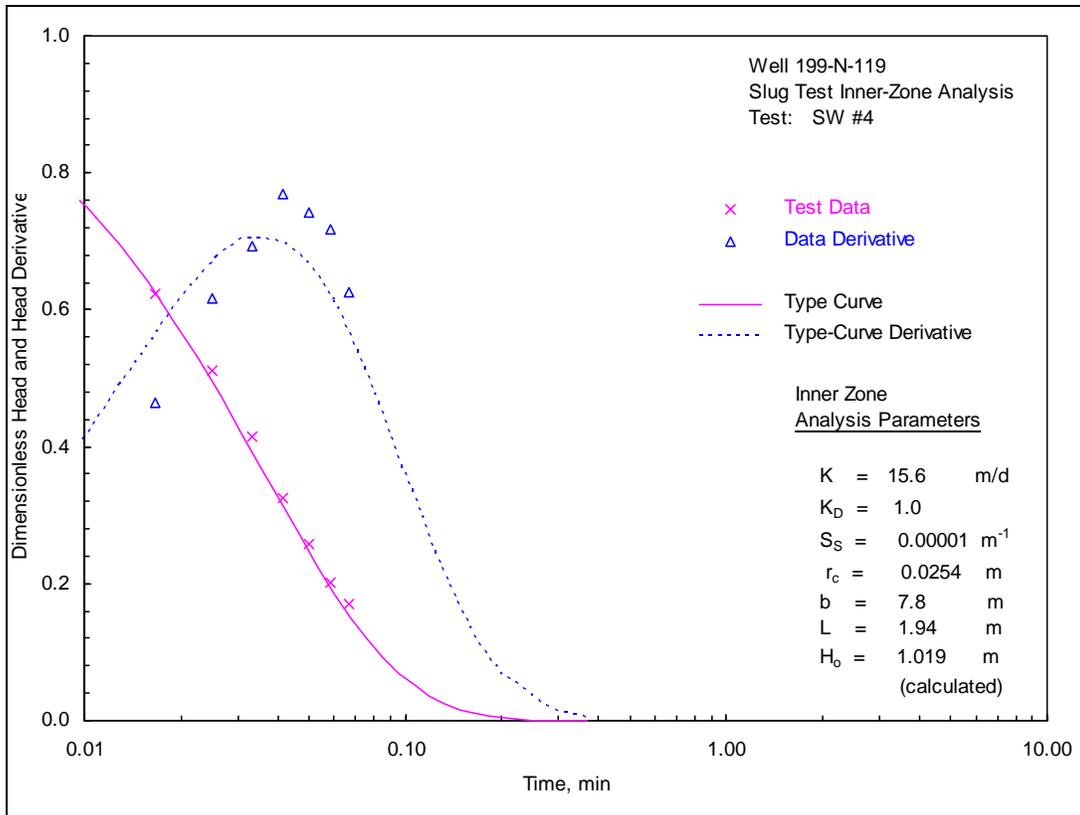
Figure A.5. Selected Slug-Test Analysis Plot for Well 199-N-119: Type-Curve Inner Zone Analysis
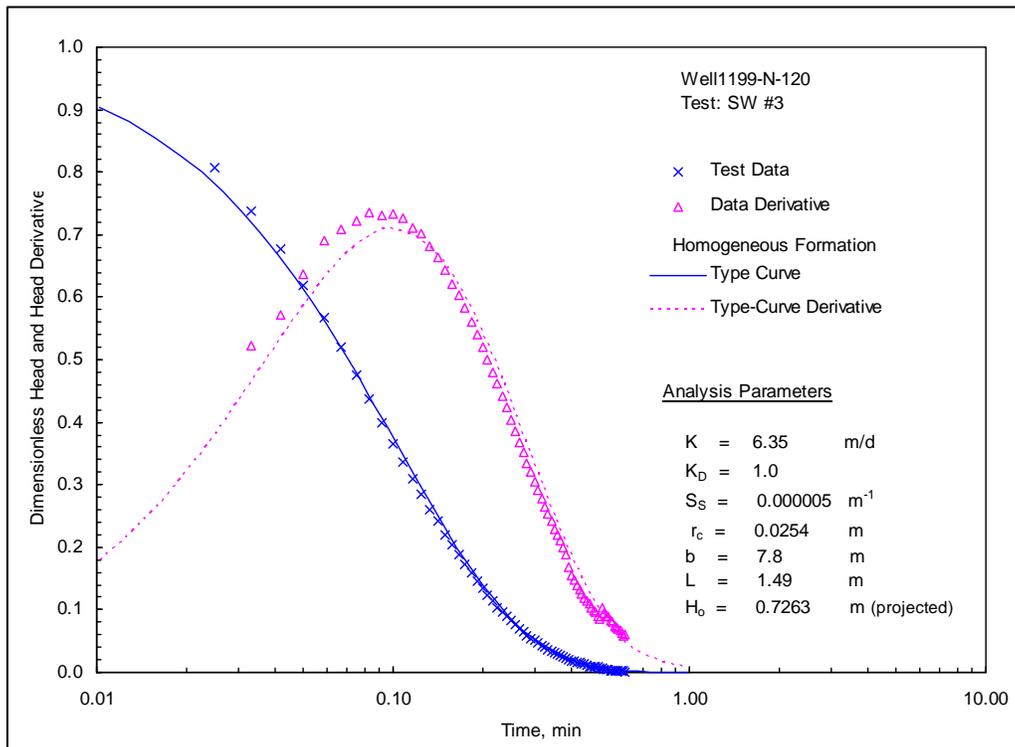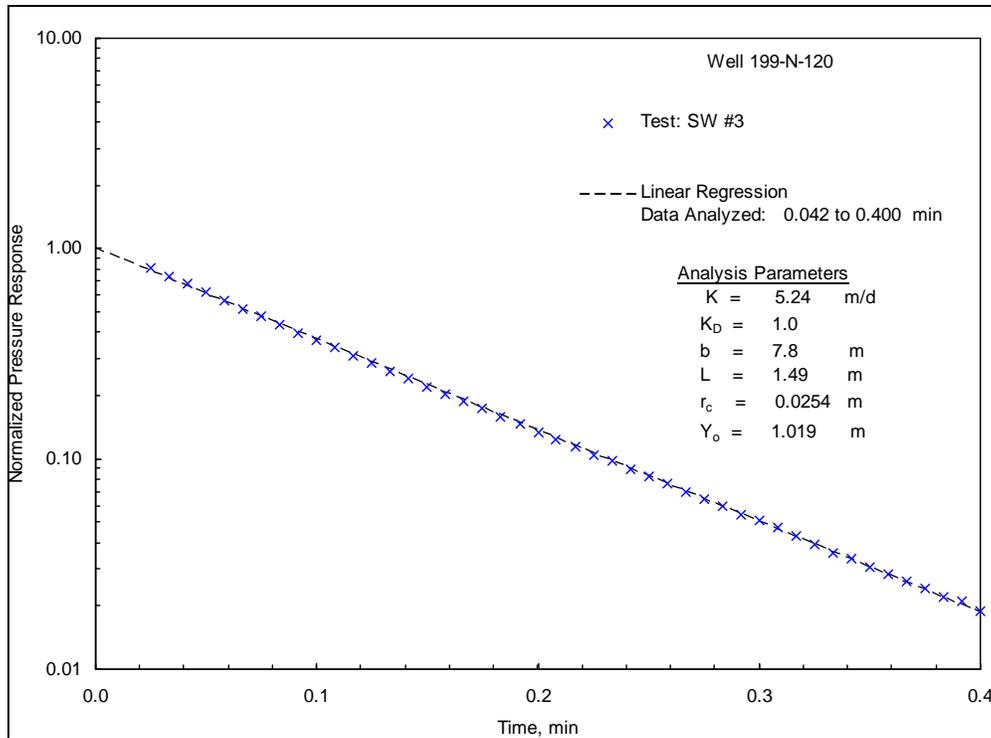
Figure A.6. Selected Slug-Test Analysis Plots for Well 199-N-120. Bouwer and Rice method (top) and type-curve method (bottom).
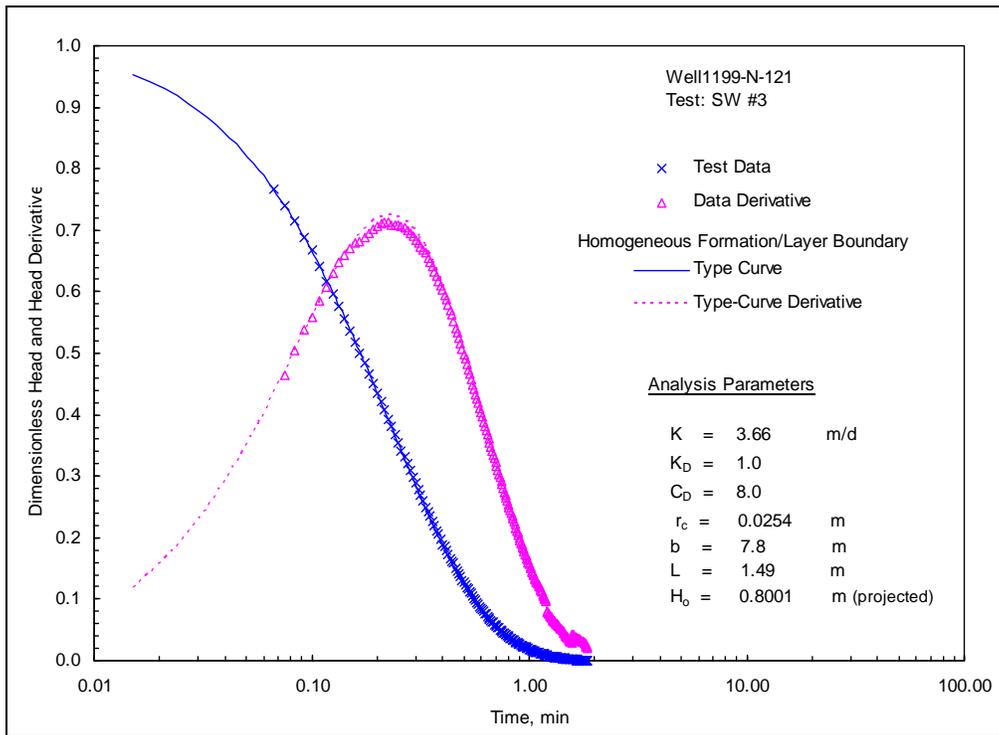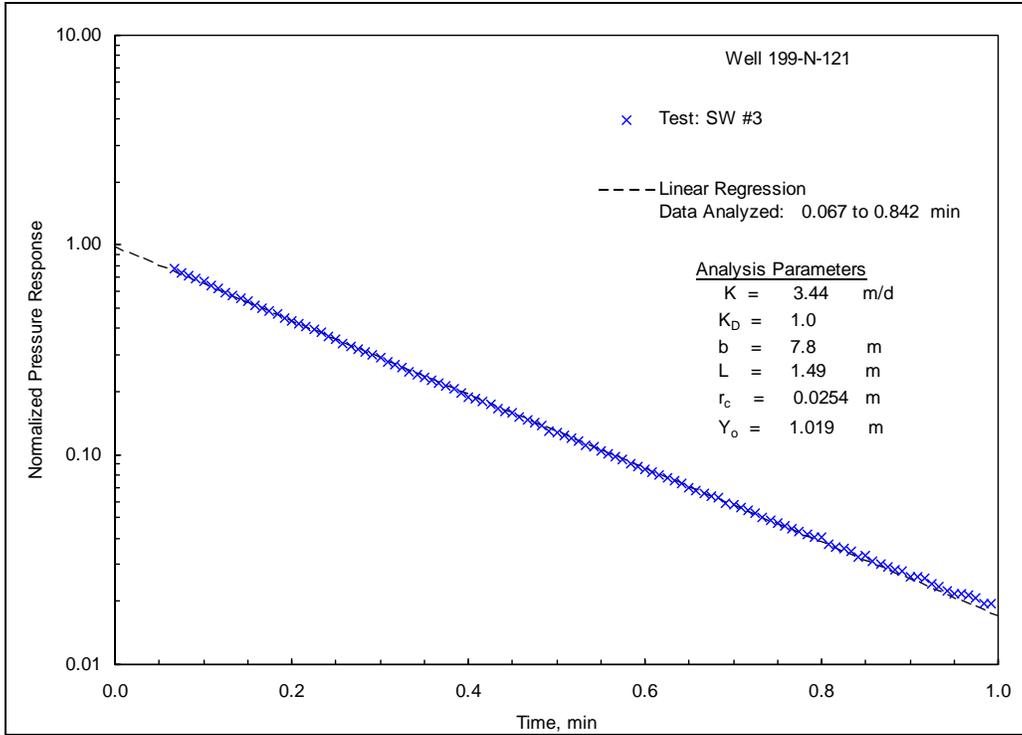
Figure A.7. Selected Slug-Test Analysis Plots for Well 199-N-121. Bouwer and Rice method (top) and type-curve method (bottom).

Appendix B – Sediment Sampling Results for Well 199-N-121

Appendix B

Sediment Sampling Results for Well 199-N-121

Tables B.1 through B.7 present results of analyses of split-spoon samples collected during drilling of well 199-N-121.

Table B.1. Soil Moisture

ID	Depth, ft	% Moisture
Core 2	10.0-10.5	5.31%
Core 3	10.5-11.0	2.95%
Core 4	11.0-11.5	1.61%
Core 5	11.5-12.0	3.72%
Core 6	12.0-12.5	3.66%
Core 8	13.0-13.5	4.68%
Core 11	14.5-15.0	2.65%
Core 14	16.0-16.5	12.59%
Core 17	17.5-18.0	10.81%
Core 22	20.0-20.5	16.97%
Core 27	22.5-23.0	10.95%
Core 32	25.0-25.5	16.22%
Core 37	27.5-28.0	14.48%
Core 42	30.0-30.5	15.92%
Core 52	35.0-35.5	13.33%
Core 65	41.5-42.0	25.43%
Core 65 Duplicate	41.5-42.0	26.24%

Table B.2. Strontium-90 Concentrations in Soil Samples

Sample ID	Depth, ft	pCi/kg dry soil
Core 2	10.0-10.5	(2.94E+03)[a]
Core 2 Dup	10.0-10.5	(1.25E+04)
Core 3	10.5-11.0	4.57E+04
Core 4	11.0-11.5	-(2.91E+04)
Core 4 Dup	11.0-11.5	-(1.49E+04)
Core 5 Rep 1	11.5-12.0	3.33E+04
Core 5 Rep 2	11.5-12.0	4.07E+04
Core 6	12.0-12.5	2.99E+04
Core 6 Dup	12.0-12.5	-(6.13E+04)
Core 8 Rep 1	13.0-13.5	7.97E+04
Core 8 Rep 2	13.0-13.5	3.98E+04
Core 11	14.5-15.0	5.59E+04
Core 14	16.0-16.5	5.44E+04
Core 17	17.5-18.0	(1.29E+04)
Core 22	20.0-20.5	(7.06E+03)
Core 27	22.5-23.0	-(3.35E+04)
Core 32	25.0-25.5	-(2.12E+04)
Core 37	27.5-28.0	-(4.10E+04)
Core 42	30.0-30.5	-(1.02E+04)
Core 52	35.0-35.5	-(3.84E+04)
Core 65	41.5-42.0	-(1.63E+04)
[a] Reported values in parentheses are below the estimated quantification limit (EQL)		

Table B.3. Concentrations of Anions in Soil

ID	Depth ft	Water Soil Ratio	Fluoride μg/g	Acetate μg/g	Chloride μg/g	Nitrite μg/g	Bromide μg/g	Nitrate μg/g	Carbonate μg/g	Sulfate μg/g	Oxalate μg/g	Phosphate μg/g
Core 2	10.0-10.5	1.00	0.29	<1.38	1.72	<0.453	<0.483	0.48	<50.19	2.09	<0.346	<0.507
Core 3	10.5-11.0	1.00	0.14	<1.37	0.59	<0.450	<0.480	0.60	<49.92	2.85	<0.344	<0.504
Core 4	11.0-11.5	1.00	0.28	<1.37	1.37	<0.450	<0.480	1.26	<49.93	2.14	<0.345	<0.504
Core 5	11.5-12.0	1.00	0.26	<1.37	0.96	<0.451	<0.481	7.81	<49.95	1.67	<0.345	<0.504
Core 6	12.0-12.5	1.00	0.24	<1.37	1.01	<0.451	<0.481	<0.433	<50.01	2.68	<0.345	<0.505
Core 8	13.0-13.5	1.00	0.36	<1.38	2.78	<0.453	<0.483	<0.435	<50.24	18.84	0.39	<0.507
Core 11	14.5-15.0	1.00	0.36	<1.37	1.77	<0.452	<0.482	<0.434	<50.11	4.32	<0.346	<0.506
Core 14	16.0-16.5	1.00	0.42	<1.37	1.61	<0.452	<0.482	<0.434	<50.06	6.19	<0.345	<0.506
Core 17	17.5-18.0	1.00	0.15	<1.37	1.33	<0.450	<0.480	<0.432	<49.89	3.54	<0.344	<0.504
Core 22	20.0-20.5	1.00	0.23	<1.37	0.92	<0.452	<0.482	0.81	<50.14	4.72	<0.346	<0.506
Core 22 DUP	20.0-20.5	1.00	0.16	<1.37	0.72	<0.452	<0.482	<0.434	<50.14	3.94	<0.346	<0.506
Core 27	22.5-23.0	1.00	0.24	<1.36	1.18	<0.449	<0.479	<0.431	<49.81	4.74	<0.344	<0.503
Core 32	25.0-25.5	1.01	0.18	<1.38	0.90	<0.453	<0.484	<0.435	<50.26	3.90	<0.347	<0.508
Core 37	27.5-28.0	0.99	0.19	<1.36	1.04	<0.449	<0.478	<0.431	<49.74	2.85	<0.343	<0.502
Core 42	30.0-30.5	1.00	0.19	<1.37	0.68	<0.450	<0.479	<0.432	<49.84	3.97	<0.344	<0.503
Core 52	35.0-35.5	1.00	0.29	<1.36	1.20	<0.449	<0.479	<0.431	<49.80	7.46	<0.344	<0.503
Core 52 DUP	35.0-35.5	1.00	0.27	<1.36	1.16	<0.449	<0.479	<0.431	<49.80	7.43	<0.344	<0.503
Core 65	41.5-42.0	1.00	0.30	2.13	0.46	<0.449	<0.479	1.61	61.89	5.46	<0.344	<0.503

< = Instrument returned a zero or negative number. <Sample EQL is reported result

Table B.4. Calculated Concentrations of Anions in Pore Water

ID	Depth, ft	Dilution Factor	Fluoride µg/ml	Acetate µg/ml	Chloride µg/ml	Nitrite µg/ml	Bromide µg/ml	Nitrate µg/ml	Carbonate µg/ml	Sulfate µg/ml	Oxalate µg/ml	Phosphate µg/ml
Core 2	10.0-10.5	18.92	5.52	<25.91	32.35	<8.531	<9.099	9.13	<945.80	39.38	<6.526	<9.553
Core 3	10.5-11.0	33.81	4.71	<46.32	19.83	<15.248	<16.262	20.26	<1690.48	96.60	<11.664	<17.074
Core 4	11.0-11.5	62.21	17.66	<85.22	85.10	<28.055	<29.921	78.18	<3110.28	133.54	<21.461	<31.414
Core 5	11.5-12.0	26.87	6.90	<36.82	25.75	<12.119	<12.926	210.03	<1343.62	44.90	<9.271	<13.571
Core 6	12.0-12.5	27.30	6.53	<37.40	27.60	<12.312	<13.131	<11.821	<1364.96	73.12	<9.418	<13.786
Core 8	13.0-13.5	21.49	7.70	<29.44	59.38	<9.690	<10.335	<9.304	<1074.31	402.98	8.36	<10.851
Core 11	14.5-15.0	37.88	13.42	<51.89	66.92	<17.082	<18.218	<16.400	<1893.75	163.19	<13.067	<19.127
Core 14	16.0-16.5	7.95	3.31	<10.89	12.76	<3.586	<3.824	<3.442	<397.51	49.17	<2.743	<4.015
Core 17	17.5-18.0	9.23	1.40	<12.65	12.31	<4.164	<4.441	<3.998	<461.67	32.79	<3.186	<4.663
Core 22	20.0-20.5	5.91	1.37	<8.10	5.45	<2.666	<2.843	4.80	<295.54	27.80	<2.039	<2.985
Core 22 DUP	20.0-20.5	5.91	0.95	<8.10	4.27	<2.665	<2.843	<2.559	<295.50	23.19	<2.039	<2.985
Core 27	22.5-23.0	9.10	2.21	<12.47	10.75	<4.105	<4.378	<3.941	<455.05	43.26	<3.140	<4.596
Core 32	25.0-25.5	6.20	1.13	<8.49	5.56	<2.795	<2.980	<2.683	<309.81	24.06	<2.138	<3.129
Core 37	27.5-28.0	6.87	1.33	<9.41	7.19	<3.099	<3.305	<2.976	<343.60	19.72	<2.371	<3.470
Core 42	30.0-30.5	6.26	1.17	<8.58	4.24	<2.823	<3.011	<2.711	<312.99	24.96	<2.160	<3.161
Core 52	35.0-35.5	7.47	2.14	<10.24	8.98	<3.370	<3.594	<3.235	<373.60	55.99	<2.578	<3.773
Core 52 DUP	35.0-35.5	7.47	2.06	<10.23	8.74	<3.369	<3.593	<3.235	<373.50	55.71	<2.577	<3.772
Core 65	41.5-42.0	3.92	1.19	8.36	1.82	<1.767	<1.885	6.33	243.36	21.49	<1.352	<1.979

< = Instrument returned a zero or negative number. <Sample EQL is reported result

Table B.5 (sheet 1). Concentrations of Metals in Soil

ID	Depth, ft	Al µg/g soil	B µg/g soil	Ba µg/g soil	Be µg/g soil	Ca µg/g soil	Cd µg/g soil	Cr µg/g soil	Cu µg/g soil	Fe µg/g soil	K µg/g soil	Li µg/g soil	Mg µg/g soil	Mn µg/g soil	Mo µg/g soil
Core-2	10.0-10.5	5,037	6.76	53	0.19	1,782	0.51	6.62	11.99	10,684	827	8.27	2,831	151	ND
Core-2 dup	10.0-10.5	4,828	4.78	45	0.16	1,515	0.44	7.12	9.90	8,744	913	8.68	2,815	149	ND
Core-3	10.5-11.0	4,123	3.76	47	0.12	1,282	0.34	5.72	10.77	6,267	1,096	7.22	2,486	92	ND
Core-4	11.0-11.5	8,783	3.47	45	0.14	2,685	0.66	26.82	9.01	13,242	948	15.27	6,360	177	ND
Core-4 dup	11.0-11.5	7,068	3.20	40	0.12	2,021	0.55	22.84	8.76	10,623	862	12.44	4,985	152	ND
Core-5	11.5-12.0	5,101	2.13	69	0.14	1,541	0.42	6.00	17.77	7,579	1,150	7.66	2,947	151	ND
Core-6	12.0-12.5	3,931	4.67	44	0.13	1,319	0.35	7.31	8.51	7,095	835	6.17	2,298	148	ND
Core-6 dup	12.0-12.5	3,880	4.03	45	0.13	1,349	0.33	5.65	7.62	6,160	777	6.23	2,255	149	ND
Core-8	13.0-13.5	6,744	2.50	84	0.20	2,354	0.60	6.74	11.11	11,853	941	8.63	3,200	197	0.05
Core-11	14.5-15.0	4,353	4.08	43	0.09	1,975	0.32	4.58	8.61	6,002	941	6.35	2,240	115	ND
Core-14	16.0-16.5	5,084	3.97	58	0.16	2,301	0.46	9.16	9.58	8,850	866	7.75	2,951	152	0.69
Core-17	17.5-18.0	3,666	4.20	47	0.14	1,841	0.35	4.89	12.83	6,958	724	5.45	2,236	137	ND
Core-22	20.0-20.5	2,195	3.82	26	0.08	1,117	0.21	4.68	4.97	4,252	391	3.09	1,363	64	0.33
Core-27	22.5-23.0	3,204	3.42	48	0.10	1,710	0.32	4.77	15.33	6,486	513	4.13	2,156	104	ND
Core-32	25.0-25.5	2,887	4.17	57	0.16	1,923	0.35	5.65	11.15	6,366	447	3.74	1,825	181	ND
Core-37	27.5-28.0	4,207	2.82	43	0.16	5,026	0.40	7.28	10.22	7,504	654	6.33	2,753	215	ND
Core-42	30.0-30.5	2,497	4.16	31	0.11	3,909	0.24	5.15	6.87	4,702	455	3.79	1,728	114	ND
Core-52	35.0-35.5	4,232	2.98	42	0.16	5,301	0.43	7.63	8.03	8,838	625	6.60	2,827	160	ND
Core-65	41.5-42.0	9,495	ND	103	0.99	36,898	0.83	8.10	11.21	8,052	1,503	0.17	6,164	346	ND

Table B.5 (sheet 2). Concentrations of Metals in Soil

ID	Depth, ft	Ni µg/g soil	P µg/g soil	Pb µg/g soil	Sr µg/g soil	V µg/g soil	Zn µg/g soil	Na µg/g soil	Si µg/g soil	S µg/g soil	Ti µg/g soil	Zr µg/g soil
Core-2	10.0-10.5	7.23	344	1.99	12.50	13.99	22.67	319	34.53	44.61	368	4.18
Core-2 dup	10.0-10.5	7.25	275	1.63	11.09	12.04	22.12	291	29.20	40.20	327	2.52
Core-3	10.5-11.0	5.79	219	1.82	9.58	8.97	19.10	234	34.16	38.37	339	1.17
Core-4	11.0-11.5	8.45	350	2.80	12.96	18.35	30.26	379	28.99	40.81	423	1.59
Core-4 dup	11.0-11.5	7.40	351	2.84	10.81	14.08	32.80	318	33.68	39.78	277	1.42
Core-5	11.5-12.0	6.49	266	1.63	12.94	12.33	20.02	242	32.31	34.85	383	4.18
Core-6	12.0-12.5	6.72	219	2.35	11.75	8.74	18.67	249	27.48	38.56	258	1.86
Core-6 dup	12.0-12.5	6.52	276	2.09	11.30	7.77	18.23	237	35.49	41.01	250	1.69
Core-8	13.0-13.5	7.01	392	1.62	18.80	17.07	25.96	356	45.58	72.74	543	8.34
Core-11	14.5-15.0	4.80	285	0.92	12.61	8.61	19.08	305	38.98	53.03	214	1.82
Core-14	16.0-16.5	7.95	497	2.32	16.22	11.03	24.27	336	37.40	53.97	308	4.94
Core-17	17.5-18.0	6.72	412	2.63	11.55	8.90	21.42	230	35.40	41.73	237	5.00
Core-22	20.0-20.5	5.04	208	0.80	10.23	6.36	10.25	228	45.50	41.04	152	2.16
Core-27	22.5-23.0	6.61	301	1.54	10.15	8.34	14.60	268	41.20	52.68	217	4.17
Core-32	25.0-25.5	8.28	399	2.24	11.37	7.80	17.21	210	41.35	43.88	266	6.50
Core-37	27.5-28.0	11.52	334	1.69	16.25	8.77	19.02	230	43.26	64.42	245	5.45
Core-42	30.0-30.5	8.29	276	1.30	13.77	5.45	13.02	195	47.32	55.50	125	3.64
Core-52	35.0-35.5	7.88	287	1.34	14.90	11.21	18.80	227	42.32	70.47	235	5.42
Core-65	41.5-42.0	8.14	250	8.10	79.49	11.41	31.70	231	29.24	285.59	5	3.13

Calculated concentrations in soil based on ICP-OES analysis of contact acid.

As, Bi, Co, Se all less than detection or quantification limits.

ND = undetected

Table B.6. Technetium-99 Concentrations Calculated in Pore Water Samples

Sample ID	Depth, ft	μg/l	pCi/l
Core 2	10.0-10.5	(3.97E-02) [a]	(6.74E+02)
Core 3	10.5-11.0	(4.06E-02)	(6.88E+02)
Core 4	11.0-11.5	(1.31E-01)	(2.22E+03)
Core 5	11.5-12.0	<8.06E-02	<1.37E+03
Core 6	12.0-12.5	(3.28E-02)	(5.56E+02)
Core 8	13.0-13.5	(5.48E-02)	(9.29E+02)
Core 11	14.5-15.0	(7.95E-02)	(1.35E+03)
Core 14	16.0-16.5	4.77E-02	8.09E+02
Core 17	17.5-18.0	(1.66E-02)	(2.82E+02)
Core 22	20.0-20.5	(1.42E-02)	(2.41E+02)
Core 27	22.5-23.0	(1.37E-02)	(2.32E+02)
Core 32	25.0-25.5	(1.67E-02)	(2.84E+02)
Core 37	27.5-28.0	(1.86E-02)	(3.15E+02)
Core 42	30.0-30.5	(1.50E-02)	(2.55E+02)
Core 52	35.0-35.5	(1.34E-02)	(2.28E+02)
Core 65	41.5-42.0	<1.18E-02	<1.99E+02

[a] Reported values in parentheses are below the estimated quantification limit (EQL)
< = Undetected (instrument returned a zero or negative number. Sample EQL is reported result.)
Sample EQL = instrument EQL x dilution factor.

Table B.7. Tritium Concentrations in Pore Water and Soil Samples

Sample ID	Depth, ft	Pore water pCi/L	Dry soil pCi/kg
Core 2	10.0-10.5	(1.91E+05) [a]	(1.07E+04)
Core 3	10.5-11.0	(1.64E+05)	(5.00E+03)
Core 4	11.0-11.5	(6.53E+05)	(1.06E+04)
Core 5	11.5-12.0	(2.75E+05)	(1.06E+04)
Core 6	12.0-12.5	(4.19E+05)	(1.59E+04)
Core 8	13.0-13.5	(1.39E+05)	(6.78E+03)
Core 8 DUP	13.0-13.5	(3.04E+05)	(1.49E+04)
Core 11	14.5-15.0	(2.10E+05)	(5.70E+03)
Core 11 DUP	14.5-15.0	(1.11E+05)	(3.01E+03)
Core 14	16.0-16.5	(5.39E+03)	(7.61E+02)
Core 14 DUP	16.0-16.5	(3.08E+04)	(4.32E+03)
Core 17	17.5-18.0	(3.96E+04)	(4.78E+03)
Core 22	20.0-20.5	(3.88E+04)	(7.49E+03)
Core 27	22.5-23.0	(1.14E+04)	(1.38E+03)
Core 32	25.0-25.5	(7.20E+04)	(1.34E+04)
Core 37	27.5-28.0	(9.56E+04)	(1.55E+04)
Core 42	30.0-30.5	(5.19E+04)	(9.41E+03)
Core 52	35.0-35.5	(5.02E+04)	(7.49E+03)
Core 65	41.5-42.0	(4.08E+04)	(1.25E+04)

[a] Reported values in parentheses are below the estimated quantification limit (EQL)

Appendix C – Well Summary Sheets

Appendix C – Well Summary Sheets

The following three well summary sheets document construction and geologic/hydrologic data from wells 119-N-119, 119-N-120, and 119-N-121.

WELL SUMMARY SHEET		Start Date 3/17/04	Page _1_ of _1_
		Finish Date 4/2/04	

Well ID	C4471	Well Name	199-N-119
Location NW of 100 N Pump & Treat (100-NR-2)		Project 100-NR-2 Apatite Study	
Prepared By L.D. Walker	Date 4/6/04	Reviewed By G. S Thomas	Date 4/6/04
Signature L.D. Walker		Signature Doug Thomas	

CONSTRUCTION DATA

Description · Diagram

- 8" dia threaded carbon steel Temporary Casing

- 4" ID SS protective casing set at +1.00' above permanent

- 2" ID SS 304 riser: +2.5' → 23.00' 15.00'

- Portland Cement: 0 → 9.93'

- Bentonite Crumbles: 9.93' → 10.58'

- 10-20 mesh Silica Sand 10.58' → 23.81'

- 2" ID SS 316 screen 0.020 slot: 15.00' → 21.90'

- 2" ID SS 304 sump w/ centralizer: 21.90' → 23.00'

- All depths are in feet below ground Surface

- All Temporary Casing removed from ground

Depth in Feet: 0', 10', 20', 30'

GEOLOGIC/HYDROLOGIC DATA

Graphic Log · Lithologic Description

0' → 4': Silty Sandy GRAVEL (msG)

4' → 24': Sandy GRAVEL (sG)

TD = 24'

DTW = 15.05' bgs (4-2-04)

A-6003-643 (03/03)

WELL SUMMARY SHEET		Start Date 3/16/04	Page _1_ of _1_
		Finish Date 4-2-04	

Well ID	C 4472	Well Name	199-N-120
Location	NW of 100N Pump & Treat (100-NR-2)	Project	100-NR-2 Apatite Study
Prepared By	L.D. Walker	Date 4/2/04	Reviewed By G.S. Thomas	Date 4/7/04
Signature	AWalker		Signature

CONSTRUCTION DATA

GEOLOGIC/HYDROLOGIC DATA

Description	Diagram	Depth in Feet	Graphic Log	Lithologic Description

Construction Data Descriptions:

- 8" dia threaded carbon Steel Temporary Casing

- 4" ID SS protective casing set at +1.00' above Permanent.

- 2" ID SS 304 riser: +2.02' → 24.50"

- Portland Cement: 0' → 9.86'

- Bentonite Pellets: 9.86' → 23.90'

- 10-20 mesh Silica Sand 23.90' → 32.26"

- 2" ID SS 316 Screen 0.020" slot: 24.50' → 29.40"

- 2" ID SS 304 Sump w/ centralizer: 29.40' → 30.50

- All depths are in feet below ground surface

- All Temporary Casing removed from ground

Depth markers: 0, 10, 15.42', 20, 30, 40

Lithologic Description:

0' → 32': Silty Sandy GRAVEL

T.D. = 32.0'

W.L. = 15.42' (3/31/04)

A-6003-643 (03/03)

| WELL SUMMARY SHEET | | Start Date 03/10/04 | Page 1 of 1 |
| | | Finish Date 4/2/04 | |

Well ID C4473   Well Name. 199-N-121

Location NW of 100N Pump+Treat (100-NR-2)   Project 100-NR-2 Apatite Study

Prepared By EJ Jensen   Date 03/29/04   Reviewed By L.D. Walker   Date 4/6/04

Signature   Signature

| CONSTRUCTION DATA | | | Depth in Feet | GEOLOGIC/HYDROLOGIC DATA | |
Description	Diagram			Graphic Log	Lithologic Description

CONSTRUCTION DATA – Description:

8" dia threaded carbon steel Temporary casing

4" ID SS protective casing Set + 1.00' above Permanent

2" ID SS 304 riser: +1.52 → 36.00'

Portland Cement: 0' → 10.10'

Granular Bentonite: 12.72' → 15.16'

Bentonite slurry: 15.50' → 32.31'

20-40 mesh Silica Sand/Bentonite slurry 25.31' → 32.31'

1/4" coated Bentonite Pellets: 10.10' → 12.72', 15.16 → 25.31' 32.31' → 34.56'

10-20 mesh Silica sand: 34.56' → 42.5/46' EST

2" ID SS 316 Screen 0.020' slot 40.90' → 36.00'

2" ID SS 316 304 sump w/centra. 40.90' → 42.00'

All depths are in feet below ground surface

All Temporary casing removed from ground

GEOLOGIC/HYDROLOGIC DATA – Lithologic Description:

0'-1.0' Silty Sandy GRAVEL (msG)

1.0-5' Sandy GRAVEL (gS) EST (gG)

5-33' gravely SAND (gS)

24'-25' SAND (S) ?

33'-41' Silty Sandy GRAVEL (msG)

41'-42.5' SILT (RUM)

42.5' TD

W.L = 15.50' bgs. (3/29/04)

Depth markers: 0', 10', 15.50', 20', 30', 40', 50'

A-6003-643 (03/03)

C.3

Appendix D – Diesel Assessment Along the 100-N Area Shoreline

Total Petroleum Hydrocarbons in Water Samples from Aquifer Tubes Along the 100-N Area Shoreline

Remediation Task of the Remediation and Closure Science Project
Work Conducted by Pacific Northwest National Laboratory for Fluor Hanford Incorporated
DP Mendoza and BG Fritz (Technical Leads for 100-NR-2)
April 17, 2007

Background

A portion of the groundwater in the 100-NR-2 operable area is contaminated with diesel fuel from a leak in the 1960s (DOE 1997). This diesel plume has generally been monitored by analyzing water samples for total petroleum hydrocarbons (TPH) at groundwater monitoring wells. The highest concentrations of TPH in groundwater samples have been found in well 199-N-18, which is the closest well to the diesel leak area. TPH concentrations of 6.7, 9.2, and 22 mg/L were observed from well water samples collected in 2006. In 2003 this well contained ~2 cm of floating product, and water samples from this well had a TPH-diesel concentration of 6,100 mg/L. This well is located on the plateau of the 100-N Area. Water samples from a monitoring well closer to the river, 199-N-96A had TPH concentrations ranging from 0.5-1.5 mg/L over the past five years. Elevated concentrations of TPH have been measured for other wells in this area (Hartman et al. 2006). To date, only limited sampling has been conducted along the river shoreline to look for TPH. The recent PNNL 100-NR-2 riparian assessment conducted limited sampling of sediment for hydrocarbons with no detected values. This effort was led by Janelle Downs, a PNNL research scientist.

As part of the Remediation Task of the Remediation and Closure Science Project, aquifer tubes were installed along the river shoreline to assess for contaminant discharge into the river. In particular, a set of aquifer tubes (referred to as the "Horizontal Array") were installed along the shoreline of the 100-N Area to evaluate the discharge of strontium-90 into the river at an elevation of approximately 116.0 m (Figure 1). Horizontal Array aquifer tubes 0A and 1A were installed adjacent to groundwater well 199-N-96A, which is in the suspected pathway of the diesel plume. It was noted during the installation that the sediment along the shoreline appeared discolored in certain areas. Therefore, on January 10, 2007 samples were collected from Horizontal Array- 0A and Horizontal Array-1A and analyzed for TPH. The sample from Horizontal Array-1A was below the detection limit for TPH; however, a concentration of 0.97 mg/L was measured in the initial sample collected from Horizontal Array-0A. Because detectable TPH was found, six additional aquifer tubes were installed along the 100-N Area shoreline to assess potential TPH concentrations discharging into the Columbia River.
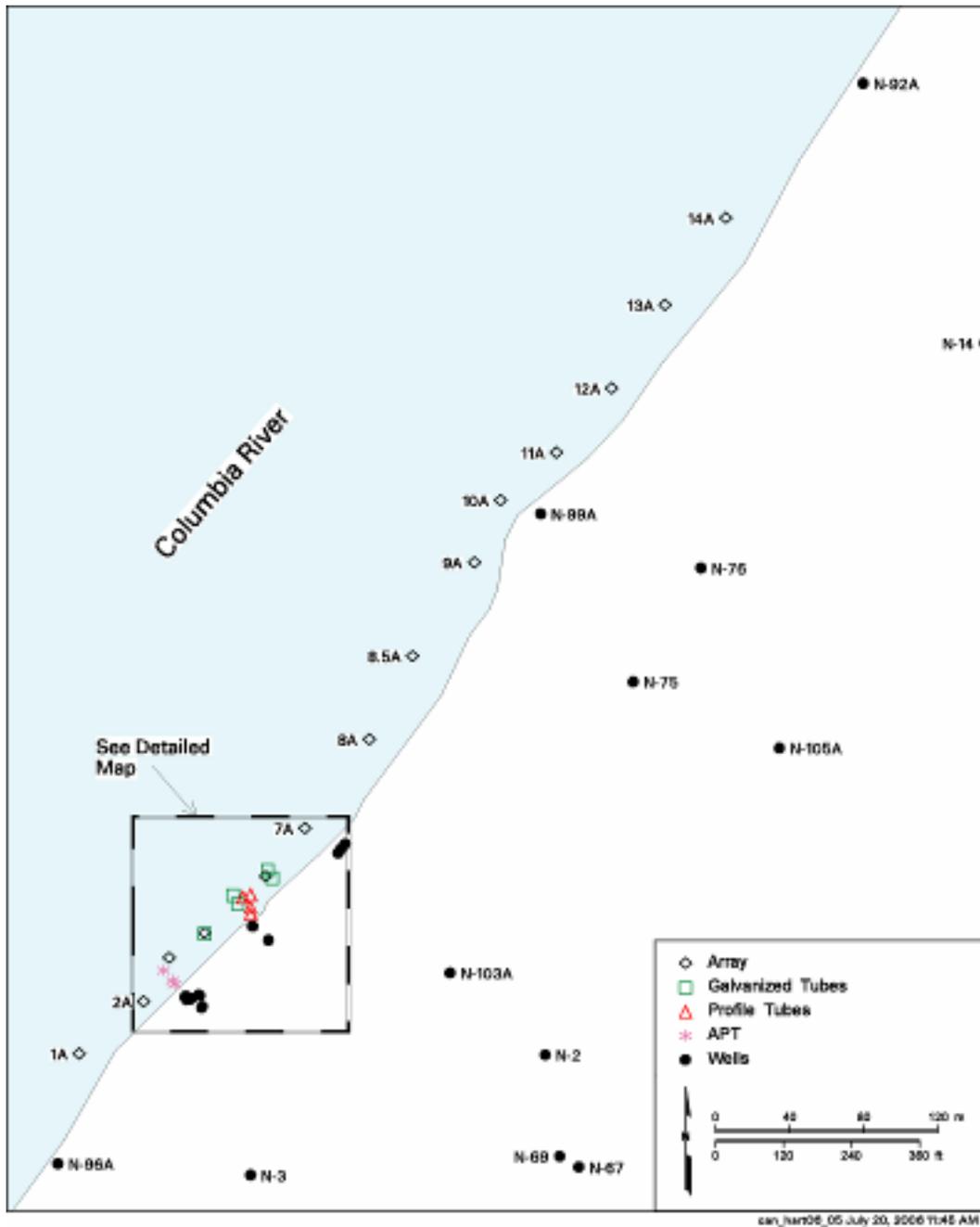
Figure 1: Location of Horizontal Array Aquifer Tube Installations.

Methods

Six aquifer tubes were installed upstream and downstream of Horizontal Array 0A at 25 m increments. The aquifer tubes were installed using a portable jackhammer and manual pounding to insert a hollow, 2.5-cm outer diameter, hardened-steel drive rod with a stainless steel tip attached to the end into the ground. Drive rod sections were added as needed to reach the targeted depth. Once the desired depth was reached, the aquifer tube (consisting of a 6-in. stainless steel screen and ¼-in. polyethylene tubing) was attached and fed into the hollow drive rod and threaded onto the drive tip (Figure 2). Once the aquifer tube was successfully attached to the drive point, the drive rod was extracted leaving the drive tip, screened portion of the aquifer tube, and polyethylene sampling tubing in place. The tubing was then run up the shoreline for future sampling. A peristaltic pump was attached to the tubing immediately after installation to develop the aquifer tube.

The aquifer tubes were installed on February 16, 2007, and water samples were collected three days later. The samples were collected in clean 500-mL amber glass jars.
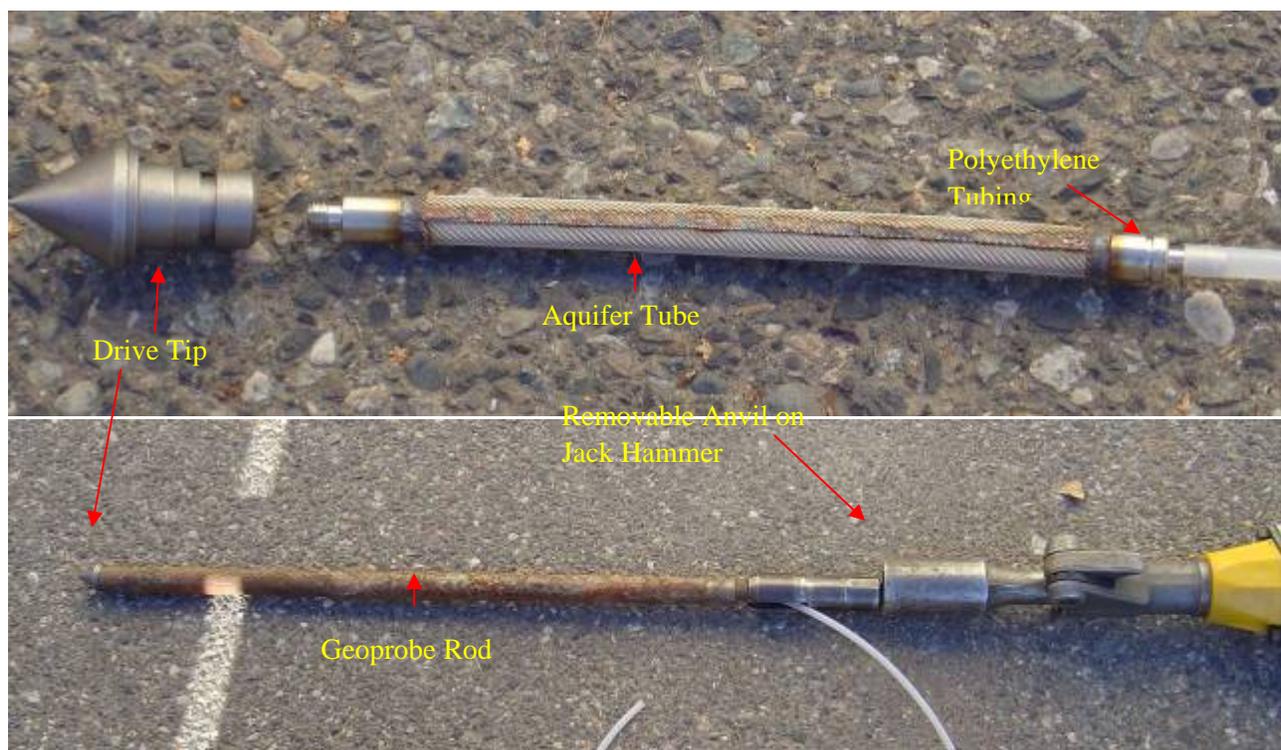
Figure 2: Components used in Aquifer Tube Installation.

Results

The objective of collecting water samples from aquifer tubes along the 100-N river shoreline was to determine if there were any locations where groundwater contaminated with diesel was being released into the river. Therefore, the samples analysis was limited to specific conductance (field parameter measured using a hand-held meter) and TPH.

The February 2007 results indicated that near shore groundwater with elevated TPH concentrations was found along a 25-m stretch of shore. Table 1 shows TPH values for water samples from the Horizontal Array 0A and N0A-DS25m locations. Two aquifer tubes were installed at each of these locations at different elevations. TPH results indicated that concentrations were elevated at the lower elevation aquifer tuber at N0A-DS25m, while at Horizontal Array 0A similar concentrations were measure at both elevations. At the time of sample collection, the Columbia River was at a moderate river elevation.

Table 1: Results of Water Samples Analyzed for TPH for the Six Additional Aquifer Tubes Installed to Assess Potential Diesel Releases into the Columbia River (February 2007).

Sample ID	Specific Conductance (μS/cm)	TPH values (mg/L)	Elevation of screen (m)
N0A-DS50-149cm	268	ND	116.0
N0A-DS25-149cm	208	0.63	116.1
N0A-DS25-76cm	156	0.17	116.8
N116mArray0A	200	0.57	116.0
N116mArray0A-81cm	160	0.56	116.8
N0A-US25-167cm	260	ND	116
N0A-US50-137cm	127	ND	116.3
ND-Sample results below detection limit			

During the installation of aquifer tubes at both elevations at N0A-DS25, when the drive rod was extracted, a petroleum hydrocarbon sheen was observed on the water surface when sediment that was adhered onto the side of the rod contacted the river (Figure 3). This oil sheen was observed at both points at N0A-DS25. The sediment that was adhered onto the drive rod also appeared discolored compared to the other installation points.

Figure 3. Petroleum Hydrocarbon Sheen Observed After the Drive Rod Used for Installing Aquifer Tubes was Extracted (100-N Area, February 2007). Note: the drive rod is visible along the left border of the figure.

Recommendations

The visual observations and analytical data from aquifer tube water samples collected during this sampling event indicate that there is a release of petroleum hydrocarbons (most likely from the 1960s diesel spill) along the shoreline of the 100-N Area in the groundwater pathway of wells 199-N-96A and 199-N-18. Visual observations of the shoreline substrate show a discolored area along the shoreline in this same area and a petroleum hydrocarbon sheen coming off the sediment, as seen in Figure 3. Based on the preliminary results of one sampling event, it is recommended that an additional round of sampling be conducted on these same set of aquifer tubes. Two to three additional tubes should be added at different elevations to obtain a vertical profile of the TPH plume with measurements of field parameters (specific conductivity, pH, and dissolved oxygen). The effect of changing river stage on the release of the TPH should also to be evaluated.
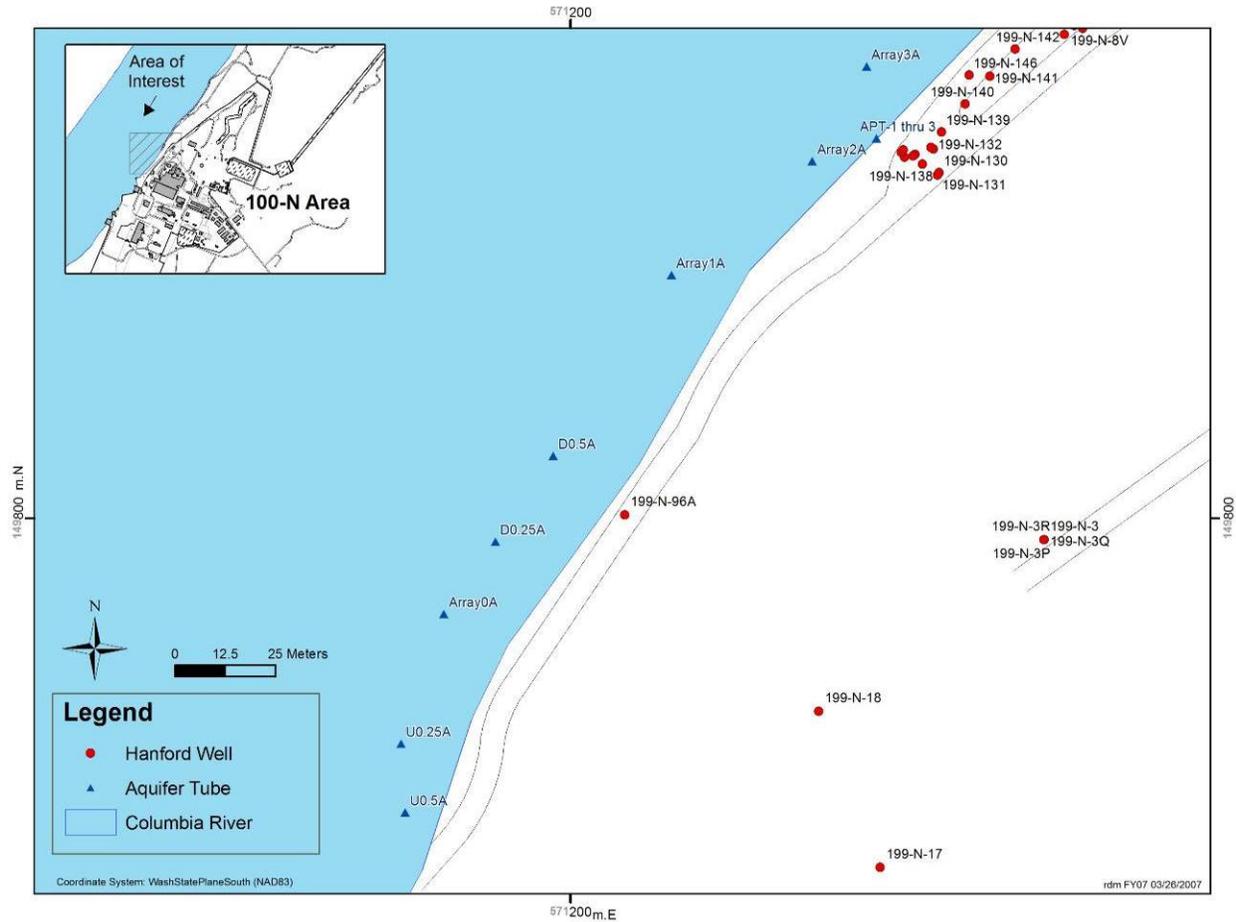
Figure 4: Location of additional aquifer tubes used for TPH sampling

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