2.4 100-NR-2 Operable Unit

M. J. Hartman

This section describes groundwater flow and chemistry in the 100-NR-2 groundwater interest area, and focuses on the 100-N Area (Figure 1.0-1). The 100-NR-2 Operable Unit includes groundwater affected by contaminant releases from facilities and waste sites within the 100-N Area. Figure 2.4-1 shows facilities and wells in this region and Figure 2.4-2 shows shoreline monitoring sites and wells in an area of particular interest for monitoring.

Groundwater flows primarily to the north and northwest, toward the Columbia River (Figure 2.4-3). Typically, when river stage is high in late spring, the gradient is temporarily reversed and there is a potential for water to flow from the river into the aquifer.

A vertical gradient is not measurable within the unconfined aquifer. The difference in water levels in well pairs (199-N-81 and 199-N-70; 199-N-119 and 199-N-121) was only a few hundredths of a meter in FY 2008, within measurement error. The screen depths differ by ~5 to 6 m.

Some of the main concepts associated with the 100-NR-2 Operable Unit include the following.

- The major liquid waste disposal sites have been excavated and backfilled. Additional contamination remains in the vadose zone.
- Strontium-90 is the principal contaminant of concern in groundwater. The area of the plume has remained stable for many years.
- Strontium-90 tends to stick to sediment grains and is difficult to clean up by traditional methods like pump-and-treat. The U.S. Department of Energy (DOE) is applying an in situ technology, apatite sequestration, to immobilize strontium-90 before it reaches the Columbia River. Apatite-forming chemicals were injected into near-shore wells in 2006, 2007, and 2008. Strontium-90 concentrations initially rose after the injections, but then began to drop as chemical reactions progressed.
- Six new wells were installed to support expansion of the apatite barrier.
- Tritium, nitrate, sulfate, and petroleum hydrocarbons also are present in groundwater.
- Four *Resource Conservation and Recovery Act of 1976* (RCRA) units are located in the 100-N Area. During fiscal year (FY) 2008 the sites remained in detection monitoring programs. One new well was installed and will be monitored beginning in FY 2009.
- Most of the monitoring wells in the 100-N Area monitor the upper part of the unconfined aquifer, which is 10 m thick. Three wells monitor the base of the unconfined aquifer. Another well is screened in a fine-grained unit ~12 m below the water table. The deeper wells are essentially free of strontium-90 contamination. Nitrate concentrations are lower in the deep wells than in the shallow wells. Tritium concentrations are about the same or lower in the deep wells.

The following sections provide details about the operable unit activities. Section 2.4.1 describes contaminant plumes and concentration trends in the vicinity of the 100-N Area. Strontium-90 is the contaminant of concern for a *Comprehensive Environmental Response, Compensation, and Liability Act of 1980* (CERCLA) interim action (EPA/541/R-99/112, *Interim Remedial Action Record of Decision for the 100-NR-1 and 100-NR-2 Operable Units, Hanford Site, Benton County, Washington*). Section 2.4.2 provides information on operable unit activities during FY 2008. Section 2.4.3 discusses groundwater monitoring at four facilities monitored under RCRA and the *Atomic Energy Act of 1954* (AEA).

2.4.1 Groundwater Contaminants

Wells in the 100-NR-2 Operable Unit are sampled for constituents of concern provided in the interim action record of decision: strontium-90, tritium, nitrate, sulfate, petroleum hydrocarbons, manganese, iron, and chromium.

Plume areas (square kilometers) in the 100-NR-2 Operable Unit:

Nitrate, 45 mg/L — 0.54
Strontium-90, 8 pCi/L — 0.58
Tritium, 20,000 pCi/L — 0.06

2.4.1.1 Strontium-90

Strontium-90 was present in the liquid effluent discharged to the 116-N-1 Facility (1963 to 1985) and the 116-N-3 Facility (1983 to 1991). Both facilities were excavated to remove highly-contaminated soil, and backfilled with clean soil. The vadose zone and aquifer beneath the facilities remain contaminated with strontium-90, which binds to sediment grains and is moderately mobile in groundwater.

A record of decision stipulates interim remedial action for strontium-90 in the 100-N Area (EPA/541/R-99/112). From 1995 to March 2006, a pump-and-treat system operated between the 116-N-1 Facility and the Columbia River to reduce the amount of contamination entering the river. Because strontium-90 binds to sediment, the pump-and-treat system was not effective in cleaning up the aquifer. The DOE began to implement an in situ remedial action, apatite sequestration, in 2006. Apatite-forming chemicals were injected into the aquifer during the summers of 2006, 2007, and 2008 (Section 2.4.2.3).

Strontium-90 is the principal groundwater contaminant beneath the 100-NR-2 Operable Unit. The general shape of the plume has not changed in many years.

The size and shape of the strontium-90 plume changes very little from year to year. The plume extends from beneath the 116-N-1 and 116-N-3 Facilities to the Columbia River at levels above the drinking water standard (8 pCi/L) (Figure 2.4-4). Concentrations exceeding 100 pCi/L are limited to the top ~3 m of the aquifer (PNNL-16346). Concentrations in several wells and aquifer tubes exceeded the derived concentration guide (1,000 pCi/L).

The area where the highest concentrations of strontium-90 reach the Columbia River is of special concern for remediation and monitoring. Figure 2.4-5 shows details of the strontium-90 plume in this region in September 2008. The map shows that strontium-90 concentrations were substantially affected by the recent apatite injections. Strontium-90 concentrations declined in the wells within the barrier and some downgradient wells (199-N-122 and 199-N-147). Concentrations increased in some aquifer tubes. Section 2.4.2.3 explains these changes in more detail.

Strontium-90 trends in monitoring wells near the former 116-N-1 Facility show no obvious, long-term decline in concentrations, but significant variability related to water levels (Figure 2.4-6). When the water table rises beneath the former waste

facilities, strontium-90 from the vadose zone is mobilized and concentrations in groundwater increase. Water levels and strontium-90 concentrations in wells near the 116-N-1 Facility were high in the late 1980s, when liquid effluent was being discharged elsewhere in the 100-N Area, and declined after effluent discharges ceased in 1991. Concentrations rose again in the mid 1990s, which correlated with several years of relatively high river stage. Concentration peaks in each of the past three years were correlated with periods of high water table.

Figure 2.4-7 shows strontium-90 trend in well 199-N-81, near the 116-N-3 Facility. Many of the variations are correlated to water level. However, the concentration increased in September 2008, while the water level dropped.

The strontium-90 contamination is limited to the upper portion of the unconfined aquifer. Wells 199-N-69 and 199-N-70, which are screened at the bottom of the unconfined aquifer, have no detectable strontium-90, while adjacent, shallow wells 199-N-67 and 199-N-81 have high concentrations (Figure 2.4-6 and 2.4-7). Figure 2.4-8 shows the vertical distribution of gross beta[1] in the vertical profile aquifer tubes in June 2007 (high river stage), December 2007, and March 2008 (moderate river stage). The maximum concentrations were measured between 115.7 and 116.3 m elevation in the Ringold Formation, while the deeper tubes had lower concentrations. Concentrations also were much lower in the shallowest aquifer tubes, which monitor the Hanford formation (i.e., top two tubes in NVP1).

2.4.1.2 Tritium

The tritium plume has diminished since 1991 when effluent discharge to the 116-N-3 Facility ceased. In FY 2008, only one well had an average concentration exceeding the drinking water standard (20,000 pCi/L). The maximum concentration was 22,000 pCi/L in well 199-N-32, near the 116-N-3 Facility. The concentration in this well dropped below the standard in September 2008 (Figure 2.4-9). Concentrations near the river in well 199-N-14 also dropped below the drinking water standard in FY 2008.

Unlike strontium-90, tritium is present through the entire thickness of the unconfined aquifer. Concentrations in wells 199-N-69 and 199-N-70, completed at the base of the unconfined aquifer, are about the same as in nearby shallow wells. Tritium concentration in well 199-N-80, which monitors a confined aquifer in the Ringold Formation was, 15,000 pCi/L in FY 2008, continuing a declining trend.

2.4.1.3 Nitrate

Nitrate concentrations exceed the drinking water standard (45 mg/L) beneath a portion of the 100-N Area (Figure 2.4-10). Although the plume includes wells downgradient of all three of the RCRA units, it also includes upgradient and cross-gradient wells (e.g., 199-N-57 and 199-N-64). Historical nitrate trends in wells near the RCRA units do not indicate that discharges to these units created the nitrate plumes. However, the sources remain unknown.

Nitrate concentrations continued to exceed the drinking water standard in FY 2008.

Figure 2.4-11 shows nitrate trend plots for two wells near the 116-N-1 Facility for their entire recorded history. Figure 2.4-12 shows the nitrate trend in a well near the 116-N-3 Facility. At both sites, nitrate concentrations were high in the mid-1980s,

1 Gross beta values are equal to twice the strontium-90 concentration area in the 100-N Area (PNNL-16894).

declined sharply by 1990, and then began to increase again. Levels peaked in FY 2006 and remained high in FY 2008. The reason for the increase is unknown.

Near the 120-N-1 Percolation Pond in south 100-N Area, nitrate concentrations also increased in the 1990s (Figure 2.4-13). During the pond's period of use (1977 to 1990), only low levels of nitrate (~1 mg/L) were detected in effluent to the facility (DOE/RL-96-39, *100-NR-1 Treatment, Storage, and Disposal Units Corrective Measures Study/Closure Plan*, Appendix B). Monitoring began in 1987 and nitrate concentrations in groundwater also were low (1 to 4 mg/L). Nitrate levels have exceeded the drinking water standard in well 199-N-59 since 1998. Nitrate levels have increased in nearby well 199-N-72, and have exceeded the standard since 2005.

Anomalously low nitrate concentrations (undetected) continued to be observed in well 199-N-18. The low concentrations are believed to be caused by chemical reduction of the nitrate caused by biodegradation of hydrocarbons (Section 2.4.1.5). Other chemical constituents and parameters support the interpretation of chemical reduction around well 199-N-18: low dissolved oxygen, low pH, detectable nitrite, and high concentrations of metals (especially manganese and iron). Well 199-N-16 has a variable nitrate trend that also may be related to chemical reduction.

2.4.1.4 Sulfate

The former 120-N-1 Percolation Pond introduced sulfate and sodium to 100-N Area groundwater. The highest sulfate concentration in FY 2008 was 251 mg/L in well 199-N-59, adjacent to the 120-N-1 Percolation Pond. This was the only well with a concentration above the 250 mg/L secondary drinking water standard. Sulfate concentrations remain elevated in groundwater north and northwest of the 120-N-1 Percolation Pond. A second area of elevated sulfate concentrations underlies the 116-N-3 Trench. This contamination is residual from previous flow conditions that carried sulfate from the 120-N-1 Percolation Pond inland and then toward the north.

A thin layer of floating petroleum product continued to be found in one well. Traces of contamination were detected in two aquifer tubes.

2.4.1.5 Petroleum Hydrocarbons

Petroleum hydrocarbons from a 1960s diesel fuel leak (DOE/RL-95-111, *Corrective Measures Study for 100-NR-1 and 100-NR-2 Operable Units*) continued to be detected in 100-N Area groundwater. Of the affected wells, 199-N-18 is closest to the former leak site and had the highest levels of groundwater contamination. In April 2008, this well had 150 mg/L total petroleum hydrocarbons in the diesel range.

The DOE continued a remedial action to remove free product from well 199-N-18 in FY 2008. The passive remediation method employs a polymer that selectively absorbs petroleum products from the surface of the water like a sponge. Two cylinders of this material are lowered into the well, where the material absorbs the contamination. The cylinders are changed every two months when they are saturated with oil.

Evidence of low levels of hydrocarbon contamination has been observed in wells 199-N-3, 199-N-16, 199-N-19, and 199-N-96A in the past (PNNL-14187, *Hanford Site Groundwater Monitoring for Fiscal Year 2002*, Section 2.4), but not in FY 2008. Aquifer tubes 116mArray-0A and C6135 detected low levels of total petroleum hydrocarbons-diesel in FY 2008, up to 0.32 mg/L.

Total organic carbon concentrations were slightly elevated in a few shoreline wells and aquifer tubes near the area of contamination. Concentrations ranged from undetected to 6,060 µg/L in well 199-N-96A during FY 2008.

The DOE recently began work to characterize petroleum contamination in the 100-N Area subsurface (Section 2.4.2.6).

2.4.1.6 Manganese and Iron

Manganese concentrations continued to exceed the secondary drinking water standard (50 µg/L) in samples from two wells affected by petroleum contamination: 199-N-16 (371 µg/L filtered; 281 µg/L unfiltered) and 199-N-18 (2,810 µg/L filtered; 7,210 µg/L unfiltered). Iron concentrations also exceeded the secondary drinking water standard (300 µg/L) in well 199-N-18 (16,900 µg/L filtered; 37,000 µg/L unfiltered). Natural biodegradation of the hydrocarbons creates reducing conditions, which increases the solubility of metals, such as manganese and iron, from the well casing or aquifer sediment. The dissolved oxygen content in well 199-N-18 in FY 2008 was 2.4 mg/L, much lower than ambient groundwater (typically ~8 mg/L). Unfiltered samples contained higher levels of metals because the samples from these wells were turbid. During sampling, turbidity ranged from 10 to 56 NTU in well 199-N-16 and from 2.6 to 81 NTU in 199-N-18, which is sampled with a bailer.

Manganese and iron in 100-N Area groundwater are associated with biodegradation of petroleum hydrocarbons.

Concentrations of manganese, iron, and other metals increased sharply in shoreline wells and aquifer tubes following injections of apatite-forming chemicals in summer 2008. This effect is described in Section 2.4.3.2.

2.4.1.7 Chromium

Only one well in the 100-N Area has dissolved chromium concentrations above the drinking water standard (100 µg/L). Well 199-N-80, which is completed in a thin, confined aquifer in the Ringold Formation, had a chromium concentration in FY 2008 of 172 µg/L in a field-filtered sample, a typical level for this well. Chromium was present in the effluent discharged to the 116-N-1 Facility, but levels in wells monitoring the unconfined aquifer were low while the facility was in use, and remained low through FY 2008. Thus, it is unlikely that the chromium seen in deep well 199-N-80 originated at the 116-N-1 Facility. A down-hole video survey of this well in 2001 observed corrosion of the screen, which could affect chromium levels.

Well 199-N-18 had a high FY 2008 chromium result from an unfiltered sample (493 µg/L). The filtered result was just 13.5 µg/L, indicating the high result was associated with particles and not dissolved chromium (Section 2.4.1.6).

2.4.2 Operable Unit Activities

This section summarizes activities related to groundwater in the 100-NR-2 Operable Unit. The principal contaminant of concern is strontium-90. Operable unit activities in FY 2008 included interim action monitoring, and emplacement of a permeable reactive barrier, apatite infiltration tests, phytoremediation studies, and planning for characterization of petroleum hydrocarbon contamination.

2.4.2.1 Status of Five-Year Review Action Items

The second CERCLA five-year review was published in November 2006 (DOE/RL-2006-20). The review identified two actions pertaining to the 100-N Area. In FY 2008, the DOE made progress on both actions.

- **Action 6-1.** Implement the treatability test plan for permeable reactive barrier using apatite sequestration (DOE/RL-2005-96, *Strontium-90 Treatability Test Plan for 100-NR-2 Groundwater Operable Unit*) and issue treatability test report (September 1, 2008). This action was completed with the installation of the barrier via low-concentration injections in FY 2007 and high-concentration injections in FY 2008. An interim report was completed in June 2008 (PNNL-17429, *Interim Report: 100-NR-2 Apatite Treatability Test: Low-Concentration Calcium-Citrate-Phosphate Solution Injections for In Situ Strontium-90 Immobilization*) and a final report will be issued in September 2009. Section 2.4.2.3 discusses the apatite barrier.
- **Action 7-1.** Perform additional data collection to support risk assessment, provide previously collected data, and collect additional pore water data from new and existing aquifer tubes. Samplers continued to collect water from aquifer tubes in FY 2008. Section 2.4.1 discusses significant results. Data are included in electronic files accompanying this report. Monitoring will continue in FY 2009 and results will be reported to the Washington State Department of Ecology (Ecology).

2.4.2.2 Interim Action Monitoring

A pump-and-treat system operated from 1995 until March 2006 in the 100-N Area as part of a CERCLA interim action (EPA/541/R-99/112). The system removed ~1.8 Ci of strontium-90 from the aquifer. Because strontium-90 binds to sediment grains, the pump-and-treat system was not effective in cleaning the aquifer. One of the requirements of the interim action record of decision was to evaluate technologies to clean up the groundwater. Therefore, Ecology, the U.S. Environmental Protection Agency (EPA), and DOE approved Tri-Party Agreement Change Control Form M-16-06-01 in 2006 requiring the pump-and-treat system be put on cold standby and a permeable reactive barrier be constructed. The interim action record of decision allowed the pump-and-treat system to be shut down with Ecology approval; therefore, no explanation of significant difference to the 1999 interim action record of decision was needed to place the system on cold standby.

The groundwater monitoring requirements for the 100-NR-2 Operable Unit interim action are specified by Tri-Party Agreement Change Control Form M-15-96-08. These requirements remain in effect even though the pump-and-treat system is on standby, because the change control form has not been superseded. This monitoring also supports requirements of the AEA for site-wide groundwater monitoring. Wells,

The remedial action objectives in the 100-NR-2 Operable Unit (EPA/541/R-99/112) are as follows.

- ***Protect the Columbia River from the adverse impact of groundwater contamination by limiting exposure pathways, reducing or removing sources, controlling groundwater movement, or reducing the concentration of contaminants.***
- ***Protect the unconfined aquifer by implementing remedial actions that reduce the concentration of contaminants.***
- ***Obtain information to evaluate technologies to remove strontium-90 and evaluate the impact to ecological receptors.***
- ***Prevent destruction of sensitive wildlife habitat and minimize the disruption of cultural resources.***

In 2006, Ecology added a requirement for the pump-and-treat system to be put on standby, and an alternative, in situ treatment technology to be tested.

constituents, and sampling frequencies for interim action monitoring are shown in Appendix A. During FY 2008, three wells were not sampled as scheduled. Well 199-N-21 was not sampled, pending repair of the pump. Well 199-N-26 is located in a dig site and samplers could not access the well. The planned September sampling of well 199-N-18 was delayed until early FY 2009. Additional details on interim action monitoring for calendar year 2007 are available in DOE/RL-2008-05. Results for calendar year 2008 will be published in an upcoming report.

The DOE continued to perform supplemental monitoring of the shoreline area (PNNL-15798, *100-N Shoreline Groundwater Monitoring Plan*). For two years after the pump-and-treat system went on standby, this included rebound monitoring of former extraction wells and nearby monitoring wells. That period concluded in March 2008 and sampling frequency of some wells decreased (Appendix A). The shoreline plan also includes monitoring of aquifer tubes and shoreline wells, which continued in FY 2008 and was coordinated with monitoring for the apatite barrier.

2.4.2.3 Permeable Reactive Barrier

D. J. Alexander

The DOE has agreed to construct and evaluate the effectiveness of a permeable reactive barrier, using apatite sequestration technology, as part of the CERCLA remedial investigation/feasibility study process and consistent with the interim remedial action record of decision for the 100-NR-1 and 100-NR-2 Operable Units (EPA/541/R-99/112; Tri-Party Agreement Change Control Form M-16-06-01). Strontium-90 sequestration by this technology occurs through the injection of a calcium citrate phosphate solution. Once injected, biodegradation of the citrate results in apatite precipitation and strontium-90 substitutes for calcium in the mineral matrix when apatite crystallization occurs.

The apatite treatability test site extends ~90 m along the 100-N Area shoreline (Figure 2.4-2). Forty-five monitoring points are associated with this site, including injection/barrier wells, monitoring wells, and aquifer tubes (Appendix A). Sixteen wells comprise the permeable reactive barrier. Six new apatite injection wells (199-N-159, 199-N-160, 199-N-161, 199-N-162, 199-N-163, and 199-N-164) were installed in FY 2008. Four monitoring wells are located between the river and the barrier. The injection/barrier wells at each end of the barrier (wells 199-N-137 and 199-N-138) were used for pilot tests during FY 2006 and FY 2007. The pilot test sites include additional, smaller-diameter monitoring wells surrounding the injection/barrier wells. Results of low-concentration injections conducted in FY 2006 and 2007 were published in PNNL-17429, *Interim Report: 100-NR-2 Apatite Treatability Test: Low-Concentration Calcium-Citrate-Phosphate Solution Injections for In Situ Strontium-90 Immobilization*. Final results, including the high-concentration injections of FY 2008, will be published in September 2009.

Groundwater project staff injected apatite-forming chemicals into the aquifer to reduce movement of strontium-90 into the Columbia River.

Strontium-90 contamination in the 100-N Area is primarily absorbed to sediment grains by ion exchange in the upper portion of the unconfined aquifer and lower vadose zone. Scientists estimate that 99% of the contamination is absorbed and only 1% is in solution in the groundwater. Although primarily absorbed, strontium-90 is mobilized by seasonal river stage increases and by plumes of higher ionic strength water (PNNL-16891, *Hanford 100-N Area Apatite Emplacement: Laboratory Results of Ca-Citrate-PO4 Solution Injection and Sr-90 Immobilization in 100-N Sediments*).

Field testing during FY 2007 showed that the test site can be categorized by two general hydrologic conceptual models based on the specific capacity[2] and the contrast between the hydraulic conductivities of the Hanford and Ringold Formations. The southwestern portion of the barrier, between injection wells 199-N-138 and 199-N-141, has relatively low specific capacity and a lower contrast in hydraulic conductivity. The northeastern portion of the barrier, between injection wells 199-N-142 and 199-N-137, has generally higher specific capacity and a larger contrast in hydraulic conductivity. The Hanford formation has higher hydraulic conductivity in the northeastern portion than in the southwestern portion of the barrier. The injections conducted in FY 2008 were modified to account for these differences in hydraulic properties. The southwestern portion achieved adequate treatment by injecting wells screened across both formations. Northeastern wells had to be injected in two phases, one to treat the Ringold Formation and one to treat the Hanford formation.

Staff conducted five injection phases in FY 2008: the first at wells 199-N-137 and 199-N-138 in June, and four more along the length of the barrier from late June until late July. Injections were timed to correspond with high flow periods of the Columbia River, which enabled a better injection of the Hanford formation.

Information provided in 0078408, "100/300 Area Unit Managers Meeting Minutes," Attachment 2, describes monitoring requirements for the treatability test. Post-injections samples were collected starting the day the injection ceased. Specific monitoring points for each injection were sampled daily the first week, every other day the second week, and weekly for four more weeks. Samples were analyzed for gross beta (for strontium-90 determinations), metals, and anions (Appendix A). Citrate samples were collected for the first two weeks following an injection to track biodegradation of the citrate due to interaction with in-situ soil microbes.

Most of the wells and aquifer tubes showed a significant increase in cations and anions in solution following an injection, because of the higher ionic strength solution that was injected. Cation and anion concentrations generally decreased over time following an injection. There was some variability on how the different monitoring points reacted over the length of the barrier based on hydrologic conditions discussed above.

Gross beta concentrations temporarily increased in response to injections to the apatite barrier. Levels subsequently dropped, and are expected to continue to decline as the remediation takes effect.

High levels of total dissolved solids in injected solutions temporarily mobilized strontium-90 by ion exchange. The highest concentration of gross beta was seen in aquifer tube NVP2-116.0 (Figure 2.4-14). The maximum gross beta concentration was 150,000 pCi/L on July 24, equating to 75,000 pCi/L strontium-90. Gross-beta concentrations dropped from their peak by early September (5,100 pCi/L) but remained higher than levels before injections. The spikes in gross-beta concentration were a result of injections in nearby wells.

The highest gross beta level in a well was 51,000 pCi/L in well 199-N-162 on July 15 (Figure 2.4-15). The concentration had declined to 86 pCi/L by early September.

Figure 2.4-16 shows trends of gross beta for two pairs of injection/barrier wells and the nearest downgradient monitoring well for each pair. Concentrations initially increased in all the wells because of the high ionic strength injections. All wells showed a general decrease in gross beta concentrations following the injection, except well 199-N-159. Many factors affect the chemistry of the soil and water interaction,

2 Specific capacity is a measure of pumping rate per unit drawdown and relates to hydraulic conductivity of the aquifer.

including changes in river level and differences in hydraulic conductivity and soil matrix.

Barrier injections completed prior to spring 2008 used lower concentrations of the calcium-citrate-phosphate solution. To determine if apatite was forming in the soil matrix from the 2007 injections, tests were conducted on sediment collected when six additional injection/barrier wells were installed in spring 2008. Samples were taken at 0.3 m intervals from 2.1 to 7.6 m below ground surface in each well, for a total of 120 samples. Phosphate profiles with depth in all six wells clearly showed much more apatite in the Hanford formation than the Ringold Formation. This was likely because of the larger volume of solution that permeated this formation during injections in the fully screened wells. Phosphate extraction data from these tests indicated that at a radial distance of ~4.6 m from the adjacent injection wells, the Hanford formation received an average treatment of 110% and the Ringold Formation an average treatment of 30% of the targeted apatite content (PNNL-17429). Further study is ongoing to determine the progress and mechanisms of strontium-90 attenuation.

Monitoring at the apatite barrier will be performed bimonthly through the fall, winter, and early spring of 2008 and 2009. All forty-five monitoring points listed in Appendix A will be sampled, weather and river level permitting. The wells completed only in the Hanford formation are dry at low river stages. Aquifer tubes may not produce water during the winter because of freezing conditions. Sampling will be scheduled during periods of warmer weather whenever possible to ensure the best sample set is collected.

2.4.2.4 Apatite Infiltration Tests

Apatite injections treat the strontium-90 contamination in the aquifer, but much of the contamination is in the vadose zone. Pacific Northwest National Laboratory is conducting a study of apatite infiltration to treat vadose zone contamination under an Environmental Management Technology (EM-22) program. The study will investigate whether it is viable to emplace apatite precipitate in the lower half of the vadose zone with surface infiltration of a calcium-citrate-phosphate solution. Results of the study will be used to design an efficient and effective infiltration strategy that will be tested at a field scale.

Researchers are testing surface infiltration to emplace apatite in the lower vadose zone and immobilize strontium-90 above the water table.

In FY 2008, researchers built a large, two-dimensional apparatus for simulating infiltration in the laboratory. The apparatus is 2.4 m high, 1.2 m wide, and 1.1 cm thick. This apparatus was packed with Hanford formation material with a matrix of less than 4 mm sediment interspersed with five layers of finer and coarser grained sediment. Testing results from the large two-dimensional system will be used to evaluate and modify an infiltration strategy developed in earlier, smaller scale experiments.

A series of five two-dimensional infiltration experiments were conducted in FY 2008 to test whether sequential infiltration events (with a week reaction time before the subsequent event) will efficiently increase the mass of apatite precipitate. Preliminary analysis showed that the apatite mass increased with each subsequent infiltration event. However, while the apatite mass increased at all depths, the zone of greatest increase was nearest the water table. The researchers are constructing two-dimensional maps of the apatite distribution, which will be used to determine the efficiency of subsequent injections. Results will be reported during FY 2009.

Field testing is planned for FY 2009. An infiltration gallery of shallow piezometers will be installed ~3 m northeast of well 199-N-153 to facilitate infiltration testing. Initial tests will be conducted with plain water.

2.4.2.5 Phytoremediation

Phytoremediation has been identified as a potential technology for the removal of strontium-90 from the soil as a filter for groundwater along the Columbia River at the 100-N Area. Phytoremediation is a remediation technology in which plants are used to extract or sequester contaminants. Greenhouse studies have demonstrated the viability of phytoremediation to remove strontium-90 from soil and water in the 100-N Area. The technology would be used in conjunction with the apatite barrier.

Pacific Northwest National Laboratory is conducting a study of phytoremediation, under the EM-22 program. A demonstration plot of coyote willow plants was established in March 2007 along the banks of the Columbia River at the 100-K Area. The area chosen for the test was not contaminated by strontium-90 or any other radionuclide. Objectives of the initial testing phase include determining how much biomass is produced, how strontium and calcium are partitioned in the plant, and the extent of leaf litter. The test plot was maintained in FY 2008 and the leaf-bearing branches were harvested. Researchers will conduct tests on the harvested vegetation and evaluate results in FY 2009.

2.4.2.6 Characterization of Petroleum Contamination

D. J. Alexander

The continuing presence of petroleum hydrocarbons in 100-N Area groundwater indicates that contamination from old diesel leaks remains in the vadose zone. The potential behavior of this contamination in response to river/groundwater dynamics is an important aspect of the conceptual model of the 100-NR-2 Operable Unit. This type of floating source will tend to be retained in the top of the aquifer and the capillary fringe above the water table. The hydrocarbons are relatively insoluble in water and are unlikely to be found in biota; however, they may accumulate in sediment and soil.

The DOE has begun work to characterize the subsurface petroleum contamination in the 100-N Area. The results will support ecological risk assessments and relate to an item in the interim action record of decision, which states, “remove petroleum hydrocarbons from any monitoring well.”

The DOE has begun work to characterize the subsurface petroleum contamination in the 100-N Area.

As discussed in Section 2.4.1.5, hydrocarbon contamination is still seen in monitoring wells, and traces are detected at the shoreline in aquifer tubes. Other evidence of contamination includes observations of rust-like deposits (i.e., iron oxide) along the shoreline that indicated potential anoxic conditions, and observations of a dark soil layer that smelled of diesel in shallow shoreline excavations. Diesel product also was recovered during drilling of wells 199-N-122 and 199-N-123, and examination of borehole material revealed accumulation of iron oxide, again indicative of anoxic conditions.

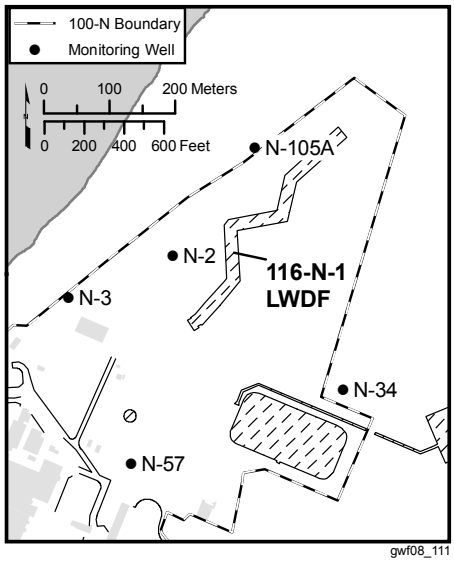
Characterization work planned for FY 2009 includes installation of a well located ~120 m southwest (upriver) of the apatite barrier. The well will be located between the known diesel spill area (located near monitoring well 199-N-18) and the aquifer tubes where low levels of total petroleum hydrocarbons, dissolved iron and manganese have been detected. Samples will be collected to determine levels of contamination and to evaluate existing cleanup technologies, create a treatability test plan, and deploy the selected technology.

2.4.3 Facility Monitoring

This section describes results of monitoring individual facilities: the 116-N-1 and 116-N-3 Facilities, 120-N-1 Percolation Pond, and 120-N-2 Surface Impoundment. Groundwater is monitored at these facilities to meet the requirements of RCRA for hazardous waste constituents and AEA for source, special nuclear, and by-product materials. Data from facility-specific monitoring also are integrated into the CERCLA groundwater investigations. Hazardous constituents and radionuclides are discussed jointly in this section to provide comprehensive interpretations for each facility. Groundwater data for these facilities are available in the Hanford Environmental Information System database and in the data files accompanying this report. Appendix B includes well and constituent lists, maps, flow rates, and statistical tables for the 100-N RCRA units.

2.4.3.1 116-N-1 (1301-N) Liquid Waste Disposal Facility

This facility contaminated groundwater with radionuclides during its period of use in the 1960s through 1985. Strontium-90 and nitrate concentrations in groundwater exceed drinking water standards. Results of monitoring were discussed in Section 2.4.1. The facility has been excavated to remove shallow vadose zone sediment, where most of the radionuclide contamination resided, and was backfilled. Wells downgradient of the 116-N-1 Facility are sampled quarterly to annually for strontium-90 and gamma activity. No gamma-emitters were detected in FY 2008.



This facility is included in the Hanford Facility RCRA Permit (WA7890008967). The Permit states that RCRA monitoring during closure activities will follow the requirements of BHI-00725, *100-N Pilot Project: Proposed Consolidated Groundwater Monitoring Program*. That plan and a supplemental plan (PNNL-13914, *Groundwater Monitoring Plan for the 1301-N, 1324-N/NA, and 1325-N RCRA Facilities*) are similar to an interim status indicator evaluation program (40 CFR 265.93(b), as referenced by WAC 173-303-400).

Groundwater flows to the northwest beneath the 116-N-1 Facility, discharging to the Columbia River. The hydraulic gradient in March 2008 was 0.0014, and flow rate was estimated to be between 0.03 to 0.53 m/day (Appendix B).

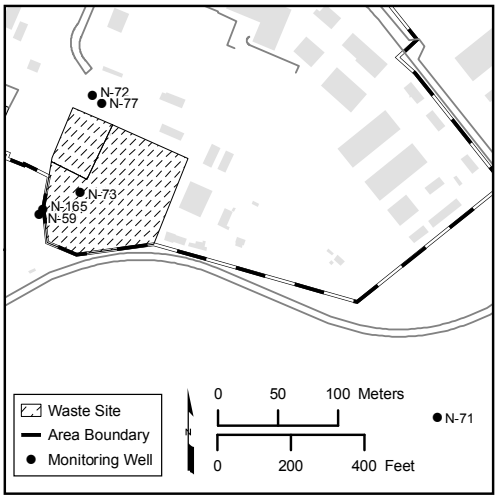
Upgradient and downgradient wells are scheduled for sampling twice each year for RCRA contamination indicator parameters (pH, specific conductance, total organic carbon, and total organic halides) and once for groundwater quality and site-specific parameters. The wells were sampled as scheduled in FY 2008.

Average specific conductance in downgradient well 199-N-3 continued to exceed the critical mean value (1,333 µS/cm) in March 2008. This was a continuation of previous exceedances, and prior assessment results (WHC-SD-EN-EV-003, *Results of Groundwater Quality Assessment Monitoring at the 1301-N and 1324-N/NA Facilities*) indicated the elevated specific conductance is related to constituents from the 120-N-1 Percolation Pond. Recent data indicate this conclusion remains valid (DOE/RL-2008-01, Appendix B). The average specific conductance dropped below the critical mean value in September 2008.

In March 2008, well 199-N-3 exceeded the critical mean value for total organic carbon (1,816 µg/L). The well was resampled in July 2008, and split sample sets were sent to two laboratories. The average result was below the critical mean value.

Upgradient/downgradient comparison values for indicator parameters have been revised based on recent data for use in FY 2009 comparisons (Appendix B).

2.4.3.2 120-N-1 (1324-NA) Percolation Pond and 120-N-2 (1324-N) Surface Impoundment



These facilities were used to treat and dispose of corrosive, nonradioactive waste from 1977 to 1990. They have been remediated and backfilled.

These facilities are included in the Hanford Facility RCRA Permit. The Permit states that RCRA monitoring during closure activities will follow the requirements of BHI-00725. That plan, and a supplemental plan (PNNL-13914), are similar to an interim status indicator evaluation program (40 CFR 265.93(b), as referenced by WAC-173-303-400). The two units are monitored as a single site (waste management area) because of their proximity and similar waste type.

Groundwater flows to the northwest beneath the 120-N-1 and 120-N-2 Facilities, discharging to the Columbia River. The hydraulic gradient in March 2008 was 0.0022, and flow rate was estimated to be between 0.05 to 0.82 m/day (Appendix B).

During FY 2008, four of the five monitoring wells for this site were sampled twice for RCRA contamination indicator parameters and groundwater quality and once for site-specific parameters, as planned (Appendix B). Downgradient well 199-N-59 contained too little water to sample in December 2007, but was successfully sampled in June 2008. A replacement well, 199-N-165, was installed in FY 2008, and will be sampled in FY 2009.

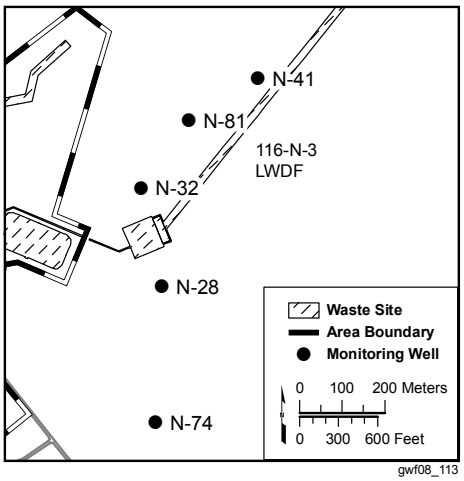
Average specific conductance values in wells downgradient of the facilities continued to exceed the critical mean value in FY 2008. A previous groundwater quality assessment indicated that the high specific conductance is caused by sulfate and sodium (WHC-SD-EN-EV-003), which are not listed hazardous waste constituents. Recent data indicate this conclusion remains valid (DOE/RL-2008-01, Appendix B).

The average of total organic halides results from upgradient well 199-N-71 and downgradient well 199-N-72 exceeded the critical mean value of 26.3 µg/L in December 2007. The data had poor precision. The wells were resampled and results indicated the initial results were erroneous.

Total organic carbon data from downgradient well 199-N-72 were anomalous in June 2008. Quadruplicates from one laboratory ranged from 2,200 to 23,000 µg/L, while split results from another laboratory were in the hundreds of micrograms per liter. The anomalous samples were reanalyzed and results came back much lower (less than 400 to 480 µg/L). Staff are continuing to investigate what caused the recent anomalies.

Upgradient/downgradient comparison values for indicator parameters were revised based on recent data for use in FY 2009 comparisons (Appendix B). Wells in this RCRA network have been sampled in December and June for the past several years. The schedule was chosen because it increased the chance of sampling nearly-dry well 199-N-59 during high water-table conditions (June). A replacement well (199-N-165) was installed in early FY 2009. Well 199-N-165 is deeper, so beginning in FY 2009 the network will be sampled in March and September like the other 100-N Area wells.

2.4.3.3 116-N-3 (1325-N) Liquid Waste Disposal Facility



This facility contaminated groundwater with radionuclides during its period of use from 1983 to 1991. Nitrate, strontium-90, and tritium concentrations in groundwater downgradient of the facility exceed drinking water standards. Section 2.4.1 discusses monitoring results. The facility was excavated to remove the shallow vadose zone material, which contained the highest concentrations of radionuclides, and backfilled.

This facility is included in the Hanford Facility RCRA Permit. The Permit states that RCRA monitoring during closure activities will follow the requirements of BHI-00725. That plan, and a supplemental plan (PNNL-13914), are similar to an interim status indicator evaluation program (40 CFR 265.93(b), as referenced by WAC 173-303-400).

Groundwater flows to the north beneath the 116-N-3 Facility, then turns to the northwest and discharges to the Columbia River. The hydraulic gradient in March 2008 was 0.0010, and the groundwater flow rate was estimated to be between 0.02 to 0.38 m/day (Appendix B).

All five wells were sampled twice for RCRA contamination indicator parameters (pH, specific conductance, total organic carbon, and total organic halides) and once for groundwater quality and site-specific parameters, as planned. However, samplers neglected to take quadruplicate field readings in one well in March (Appendix B).

Average specific conductance values in downgradient wells 199-N-32 and 199-N-41 continued to exceed the critical mean value at least once in FY 2008. These were continuations of previous exceedances noted in 1999 through 2007. The DOE notified Ecology of the original exceedance and submitted an assessment report (00-GWVZ-054, “Results of Assessment at the 1325-N Facility”) that concluded the exceedance was caused by past discharges to the 120-N-1 Percolation Pond. Recent data indicate this conclusion remains valid (DOE/RL-2008-01, Appendix B).

Detection monitoring will continue in FY 2009. Upgradient/downgradient comparison values for indicator parameters were revised based on recent data for use in FY 2009 (Appendix B).

Groundwater monitoring in the 100-NR-2 groundwater interest area includes the following monitoring activities.

CERCLA and AEA Monitoring (Appendix A)

- ***Twenty-nine wells are scheduled for monthly to annual sampling for purposes of the original interim action. Three wells were not sampled as planned.***
- ***Thirty-seven wells and eight aquifer tubes were sampled daily following the injection of apatite-forming chemicals, and at lower frequencies thereafter.***
- ***The DOE installed six new wells to support expansion of the apatite barrier and 19 new aquifer tubes to help define plumes.***
- ***Twenty wells and twenty-eight aquifer tubes are scheduled for monthly to annual sampling under a shoreline groundwater-monitoring plan, coordinated with apatite barrier monitoring.***

Facility Monitoring (Appendix B)

- ***Five wells are scheduled for semiannual sampling for the 116-N-1 Liquid Waste Disposal Facility for requirements of RCRA and AEA. The wells were sampled as planned.***
- ***Five wells are scheduled for semiannual sampling for the 120-N-1 Percolation Pond and 120-N-2 Surface Impoundment for requirements of RCRA and AEA. One well was sampled only once because of low water levels. A replacement well was installed and will be sampled beginning in FY 2009.***
- ***Five wells are scheduled for semiannual sampling for the 116-N-3 Liquid Waste Disposal Facility for requirements of RCRA. The wells were sampled as planned.***

Figure 2.4-1. Facilities and Groundwater Monitoring Wells in 100-N Area.

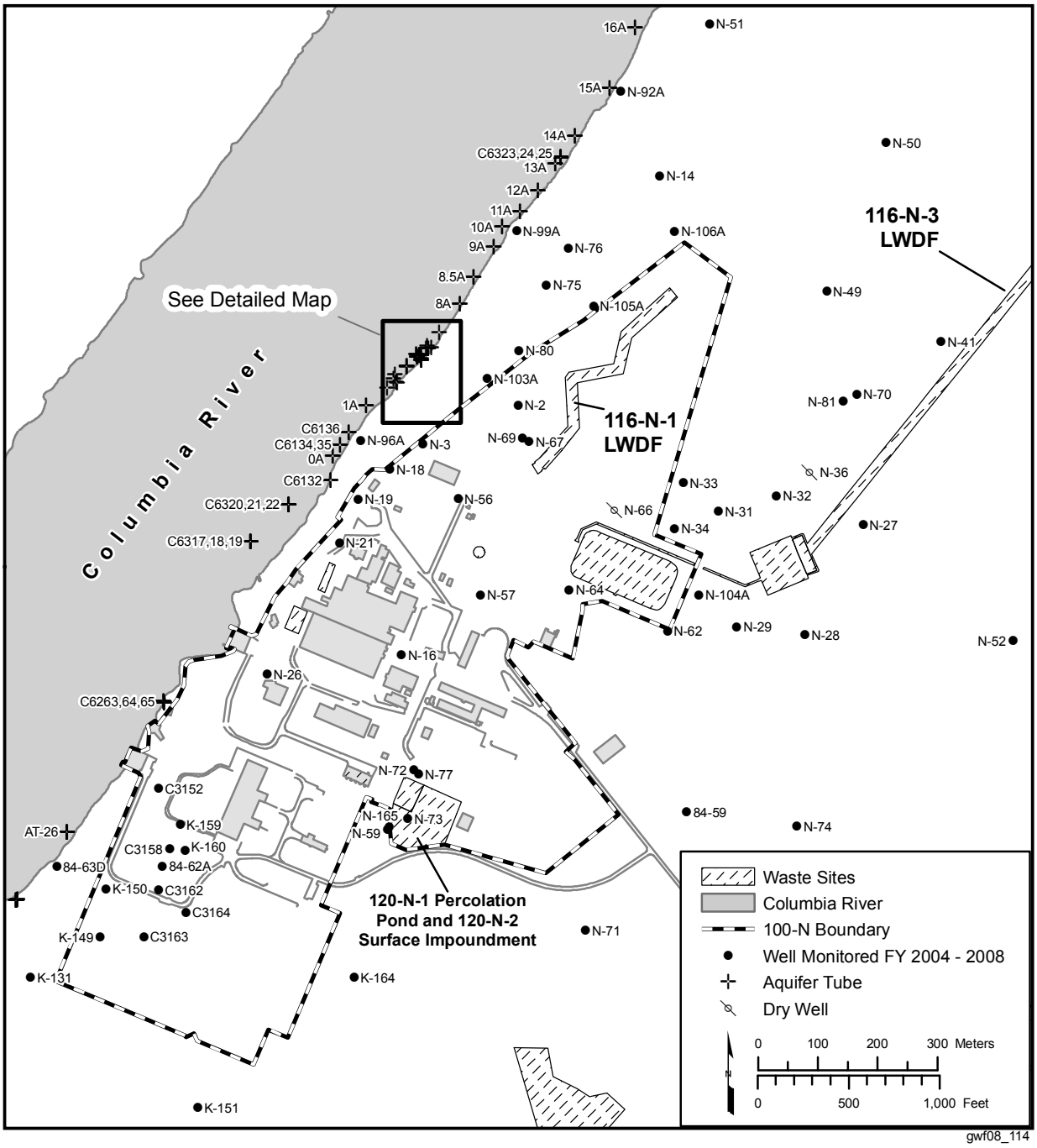


Figure 2.4-2. Aquifer Tubes and Monitoring Wells on the 100-N Area Shoreline.

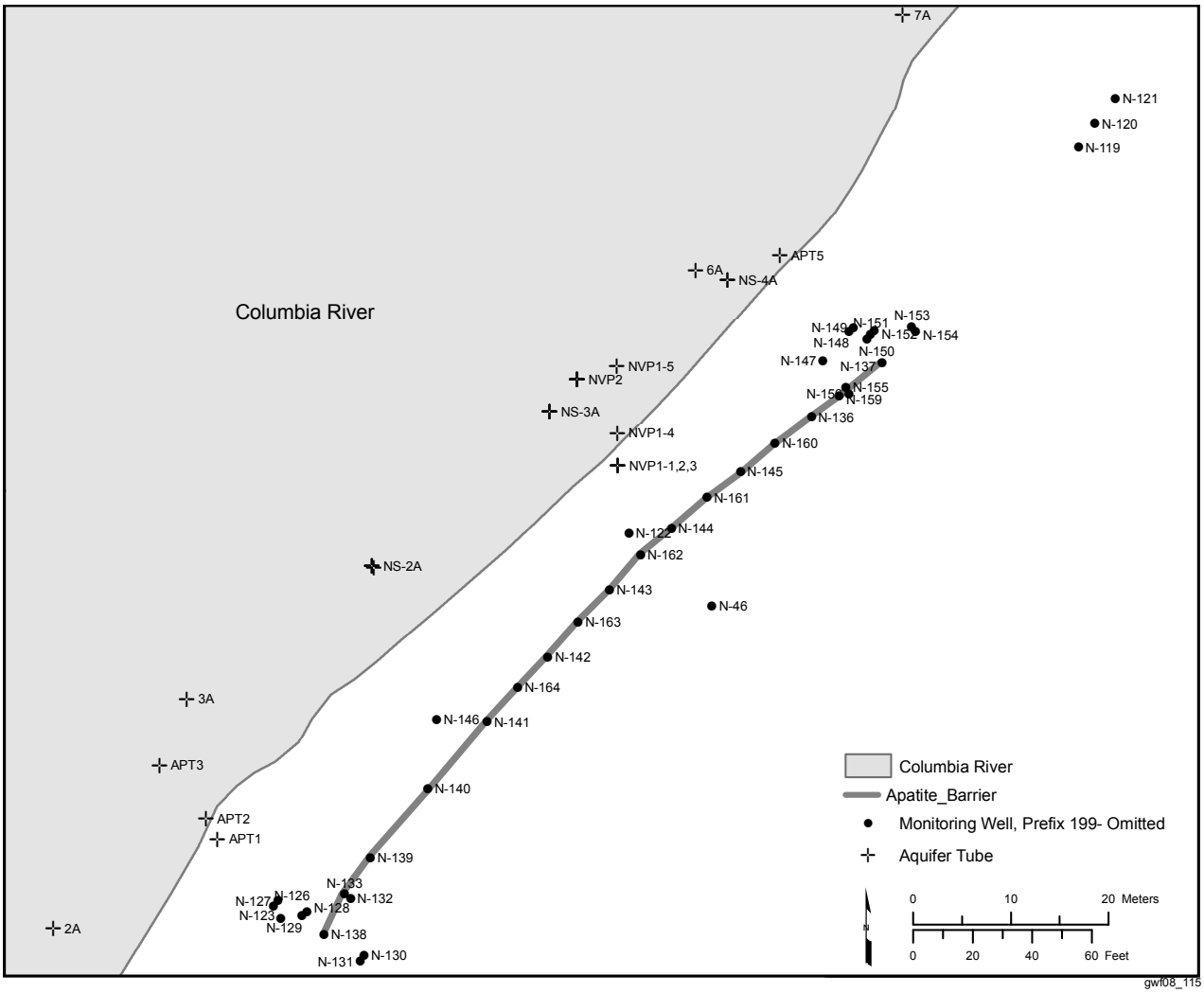


Figure 2.4-3. 100-N Area Water-Table Map, March 2008.

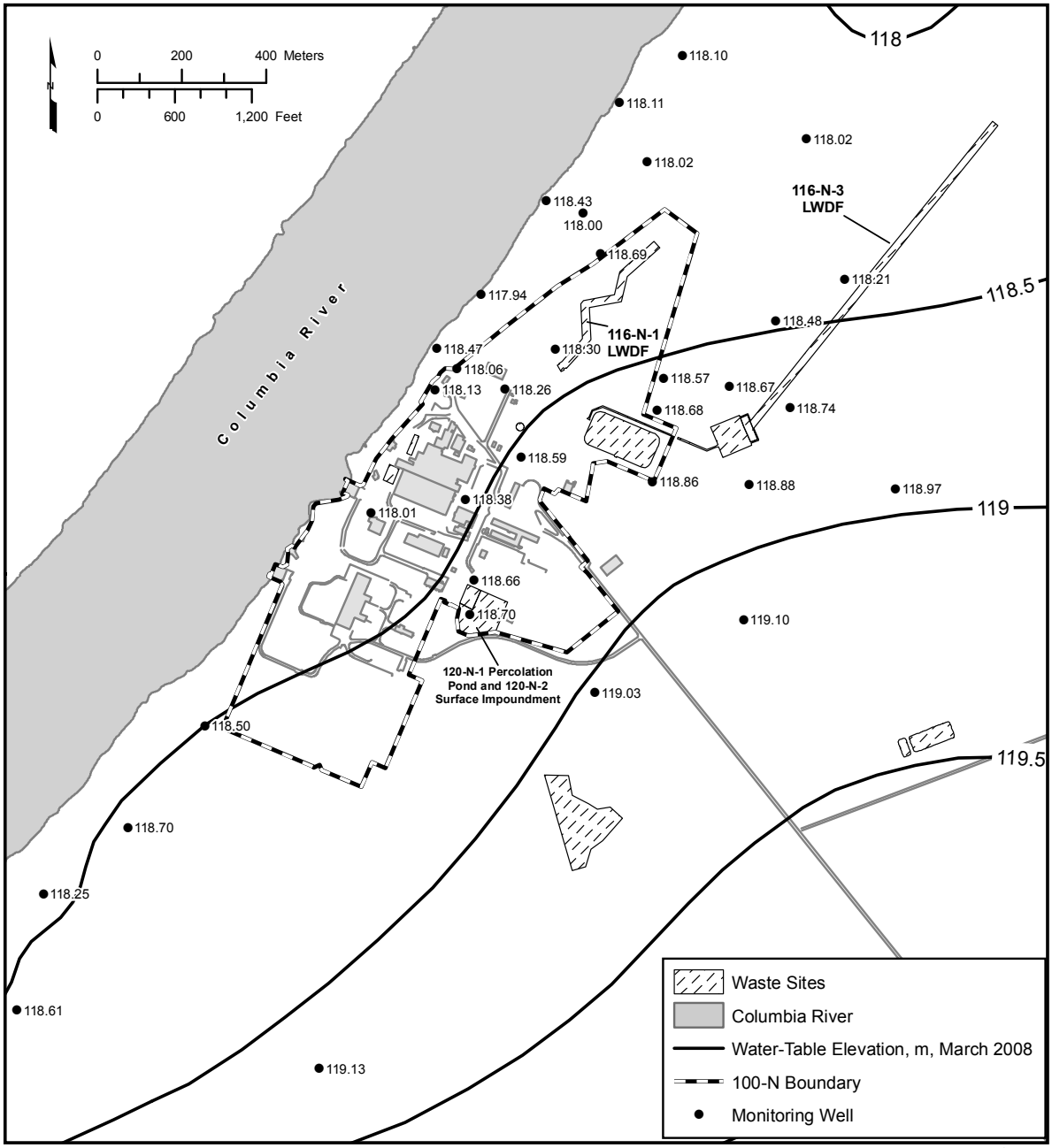


Figure 2.4-4. Average Strontium-90 Concentrations in the 100-N Area, Upper Part of Unconfined Aquifer.

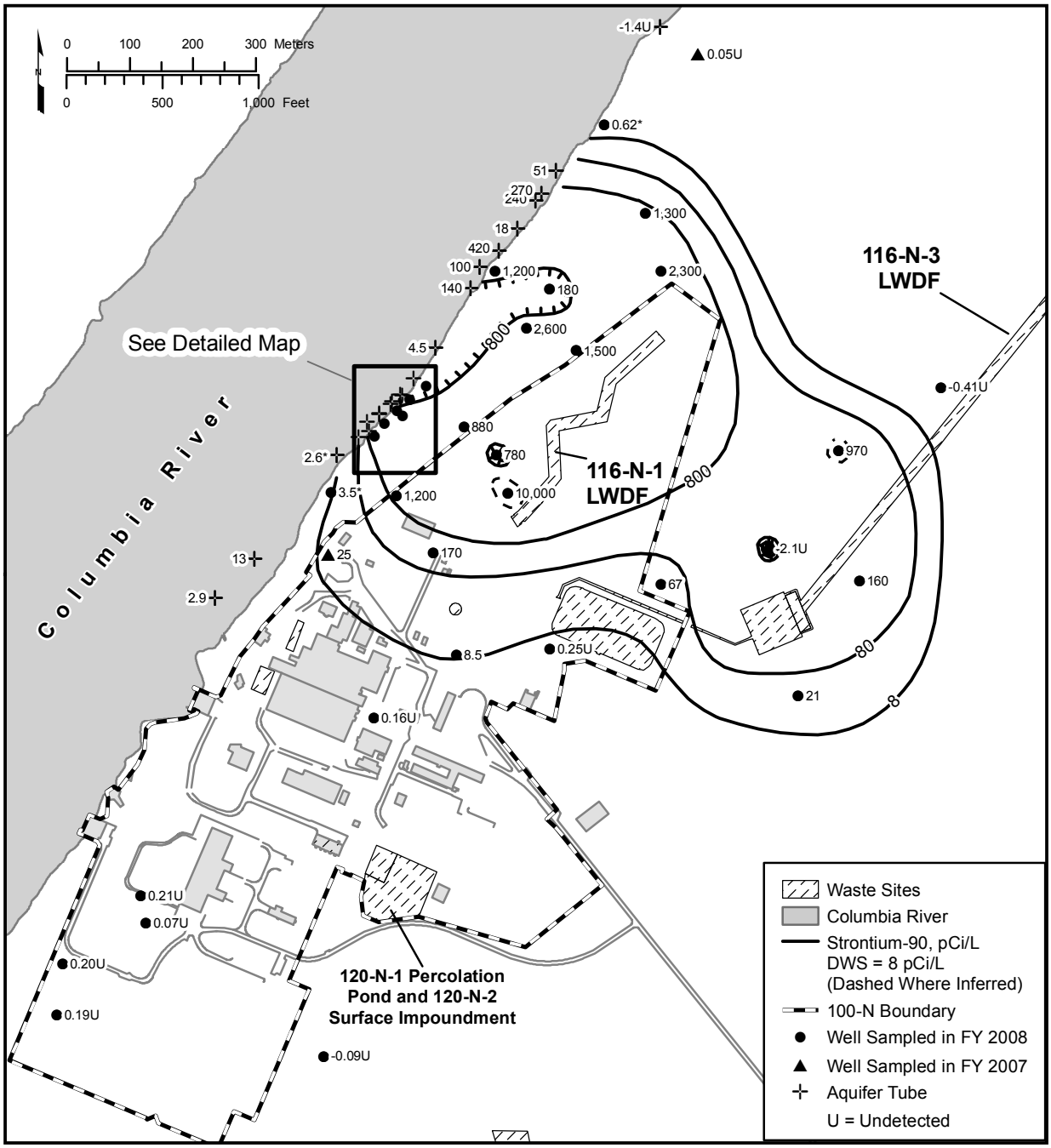


Figure 2.4-5. Strontium-90 in Groundwater at the Shoreline Study Area, September 2008, Upper Part of Unconfined Aquifer.

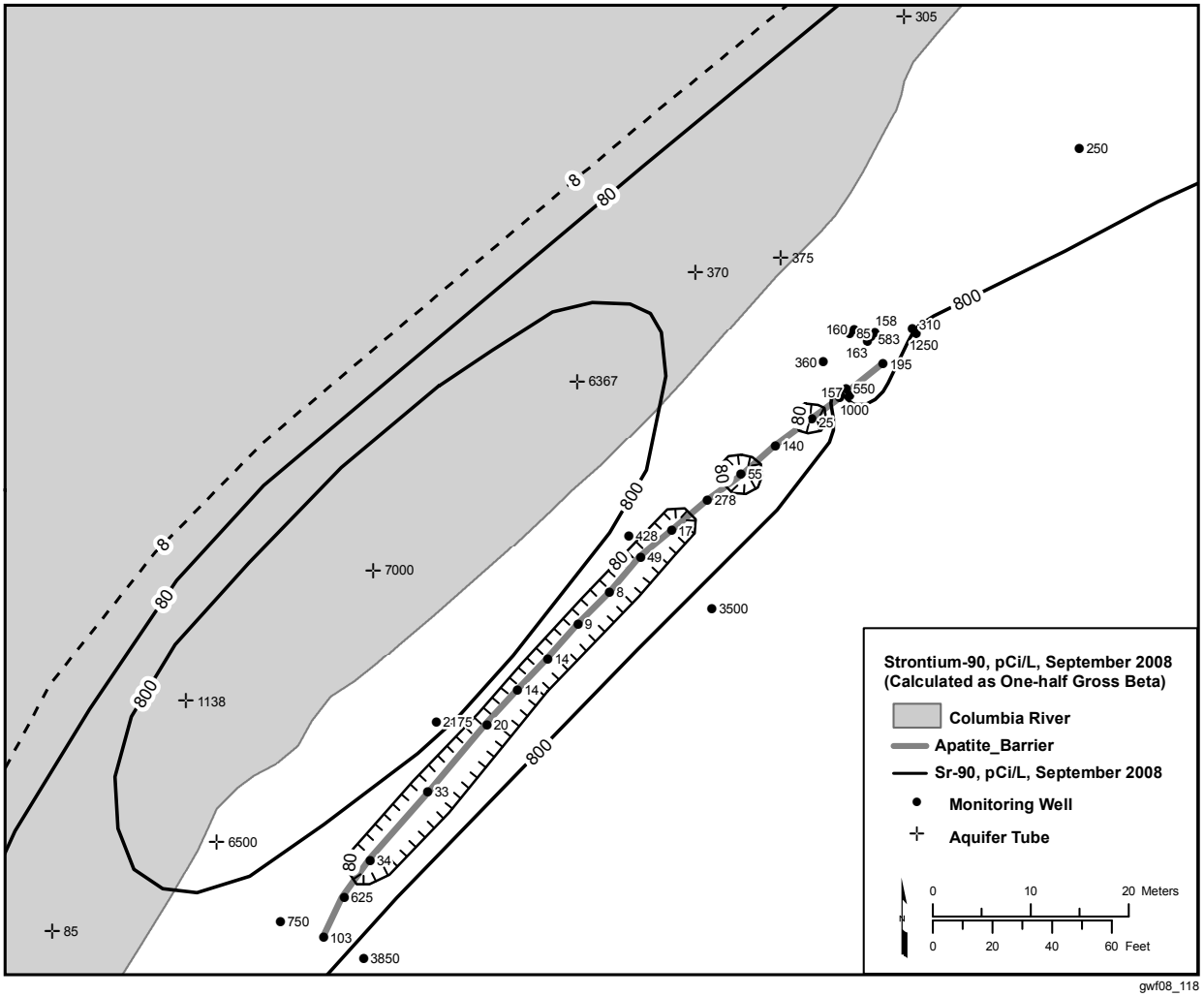


Figure 2.4-6. Strontium-90 Concentrations and Water Levels near the 116-N-1 Facility.

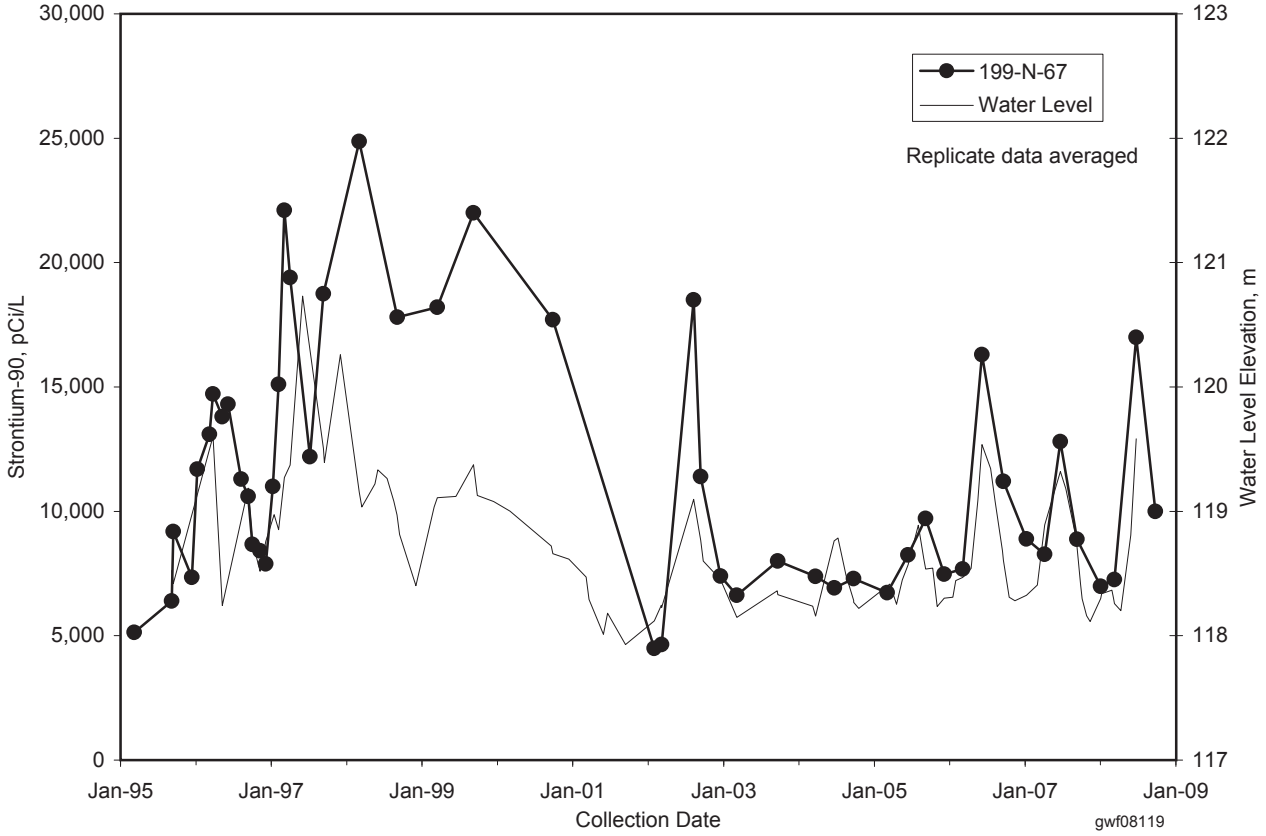


Figure 2.4-7. Strontium-90 Concentrations and Water Levels near the 116-N-3 Facility.

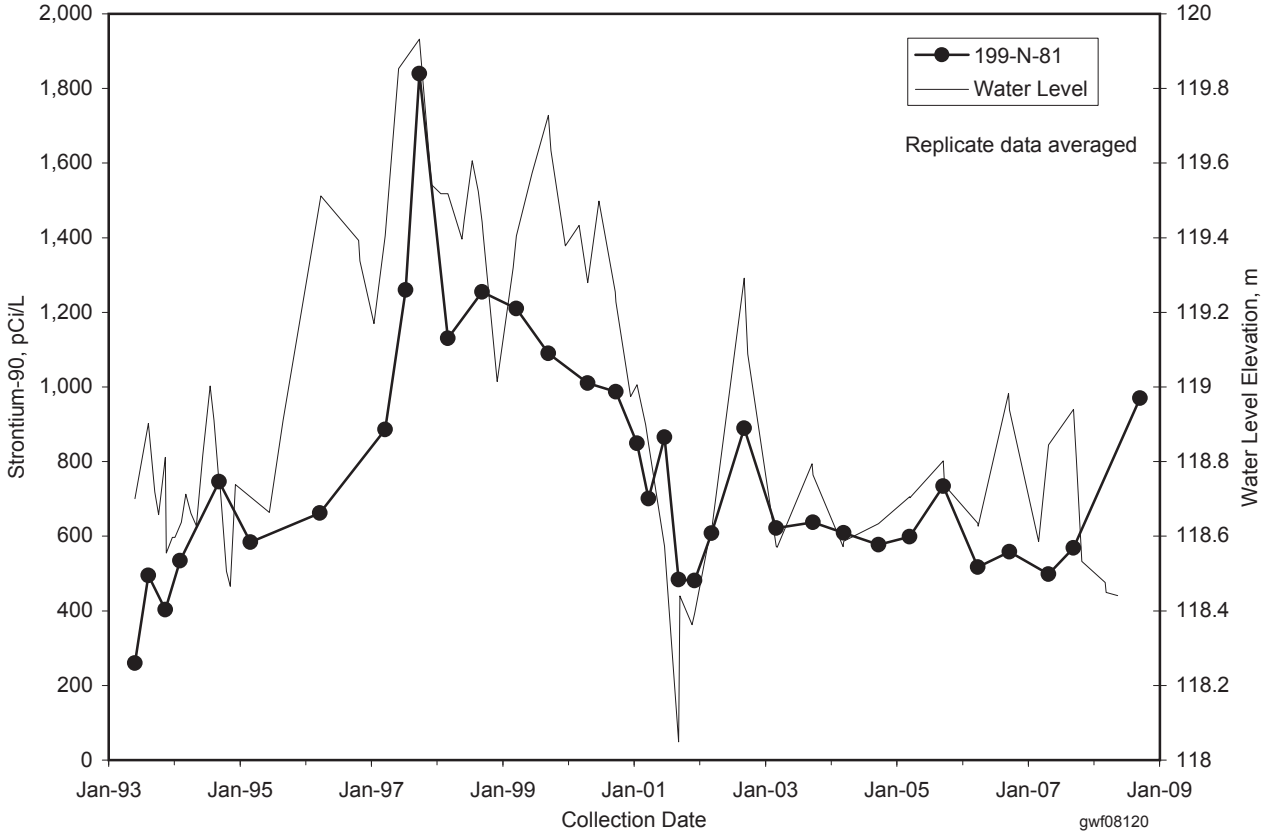


Figure 2.4-8. Gross Beta Vertical Profile in 100-N Area Aquifer Tubes.

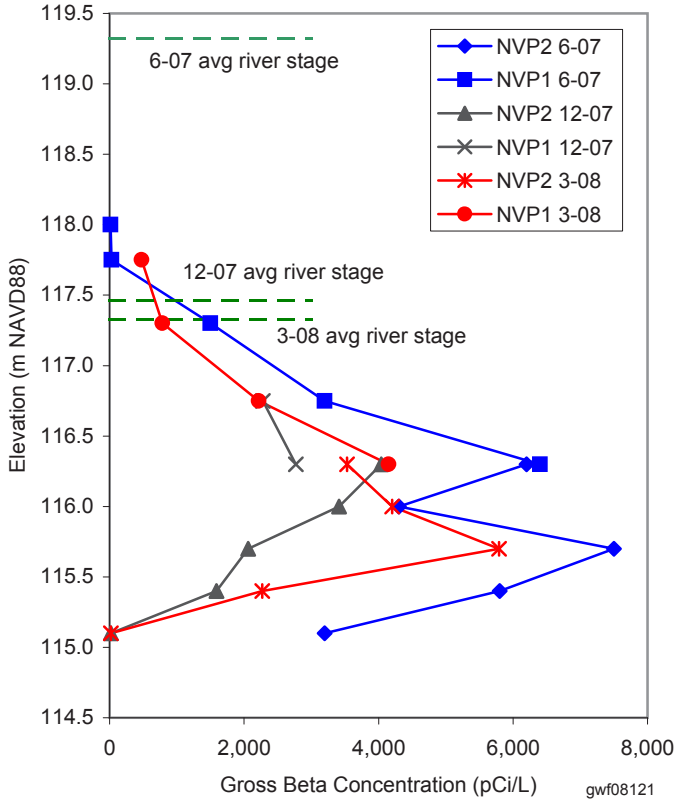


Figure 2.4-9. Tritium Concentrations near the 116-N-1 and 116-N-3 Facilities.

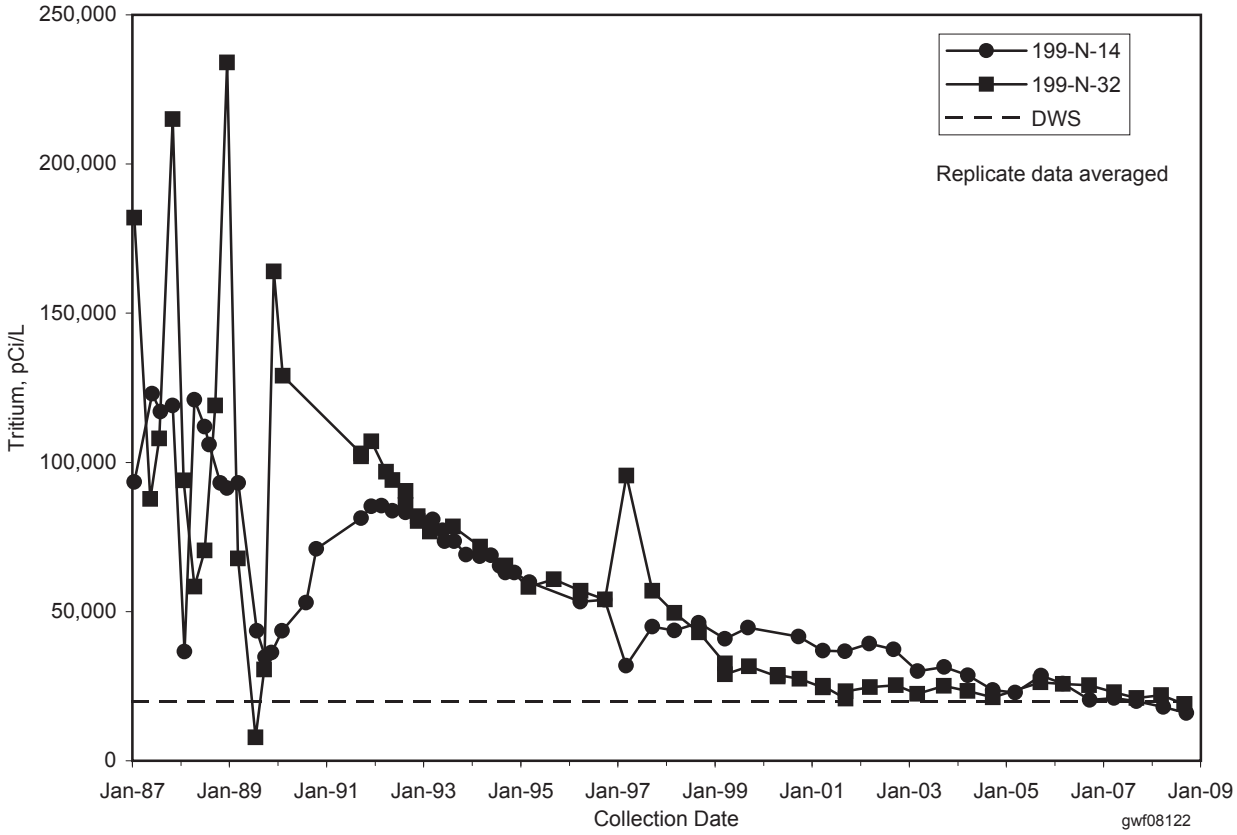


Figure 2.4-10. Average Nitrate Concentrations in the 100-N Area, Upper Part of Unconfined Aquifer.

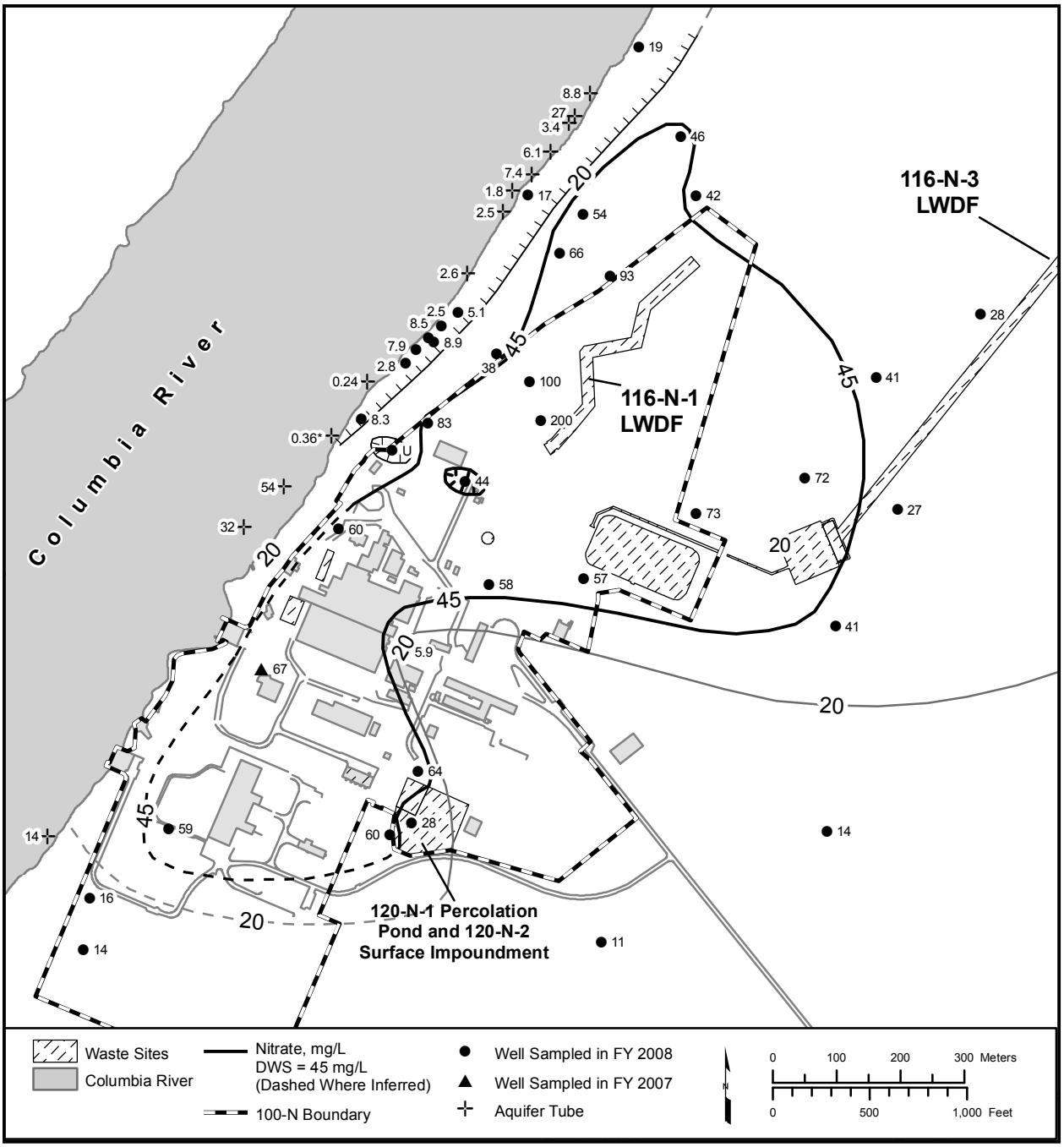


Figure 2.4-11. Nitrate Concentrations near the 116-N-1 Facility.

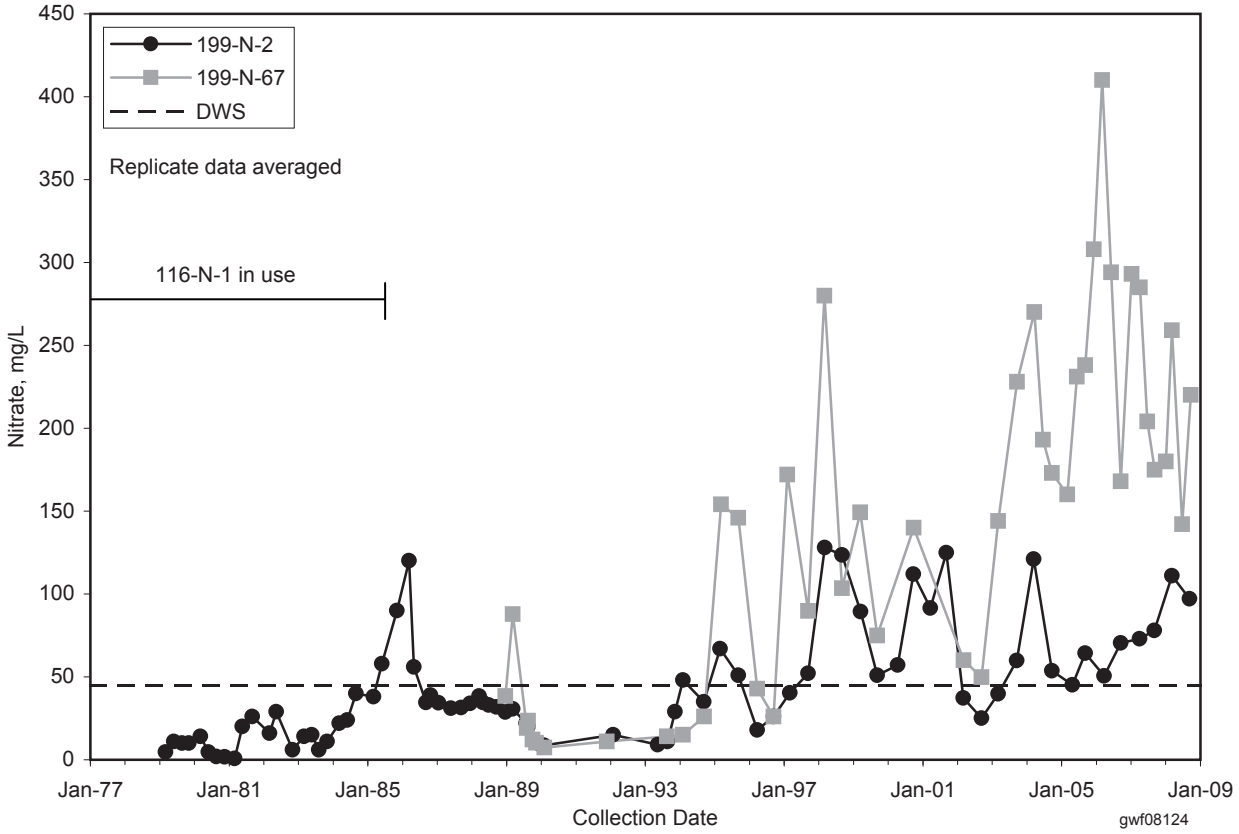


Figure 2.4-12. Nitrate Concentrations near the 116-N-3 Facility.

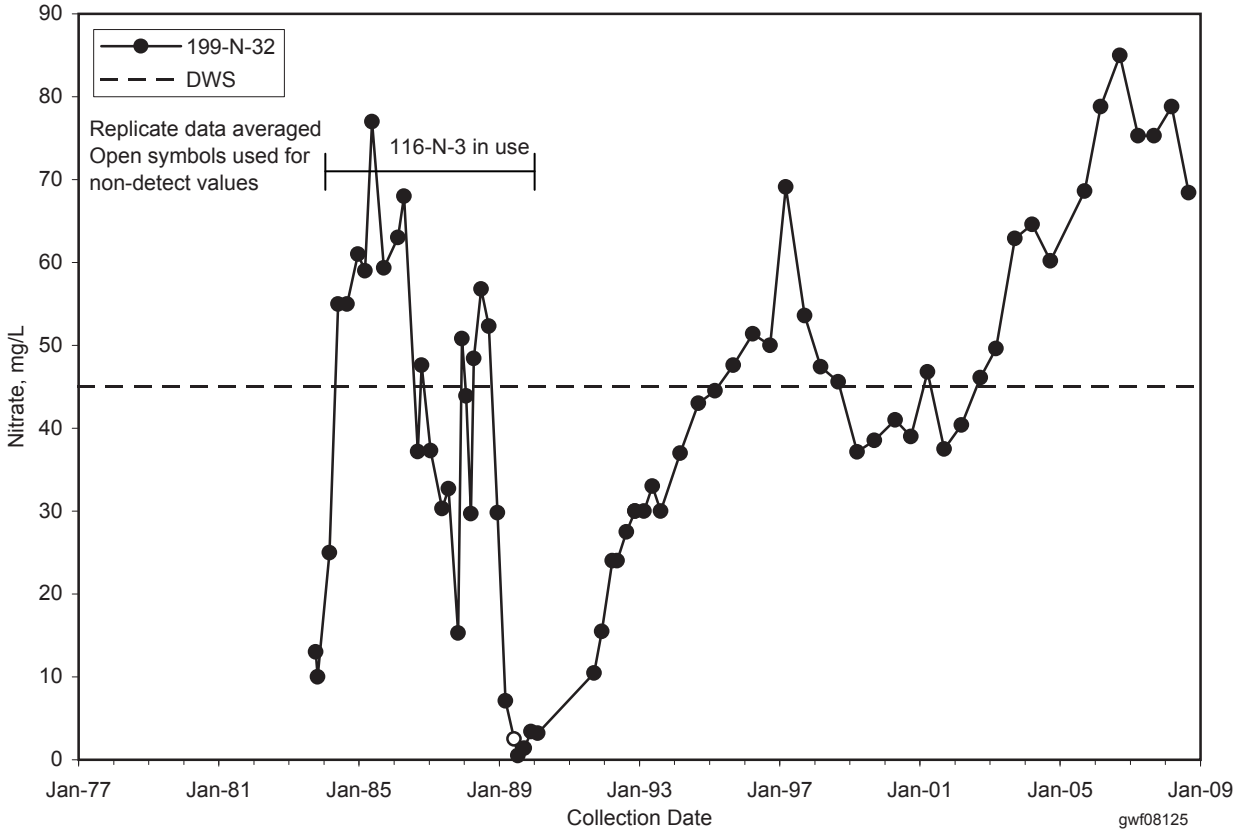


Figure 2.4-13. Nitrate Concentrations near the 120-N-1 Percolation Pond.

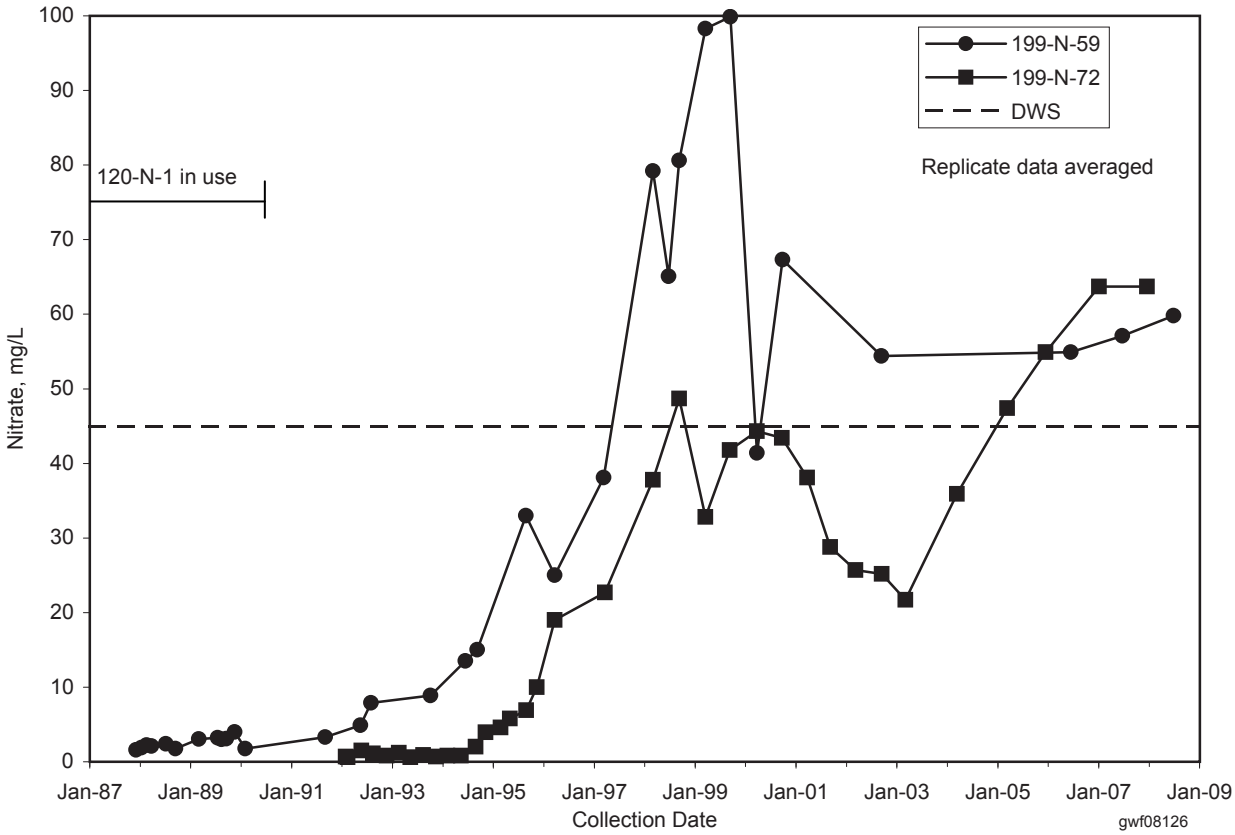


Figure 2.4-14. Gross Beta (and Equivalent Strontium-90) Concentrations in Aquifer Tube NVP2-116.0.

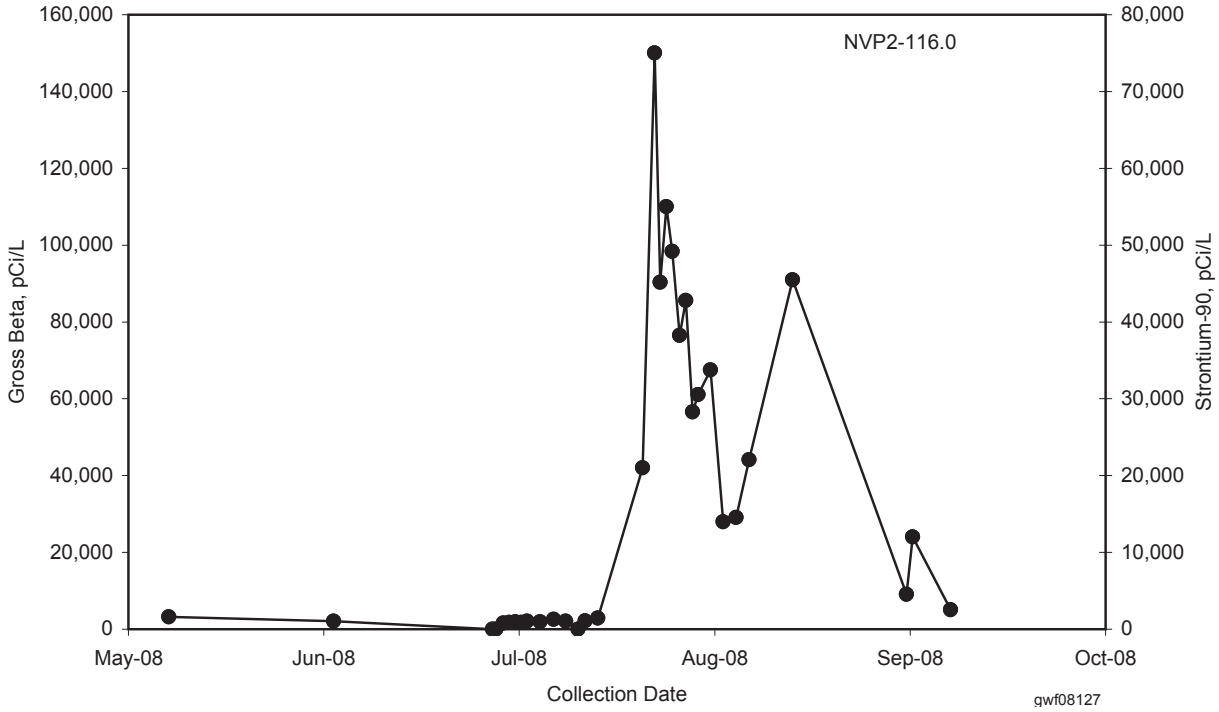


Figure 2.4-15. Gross Beta (and Equivalent Srontium-90) Concentrations in Apatite Injection/Barrier Well 199-N-162.

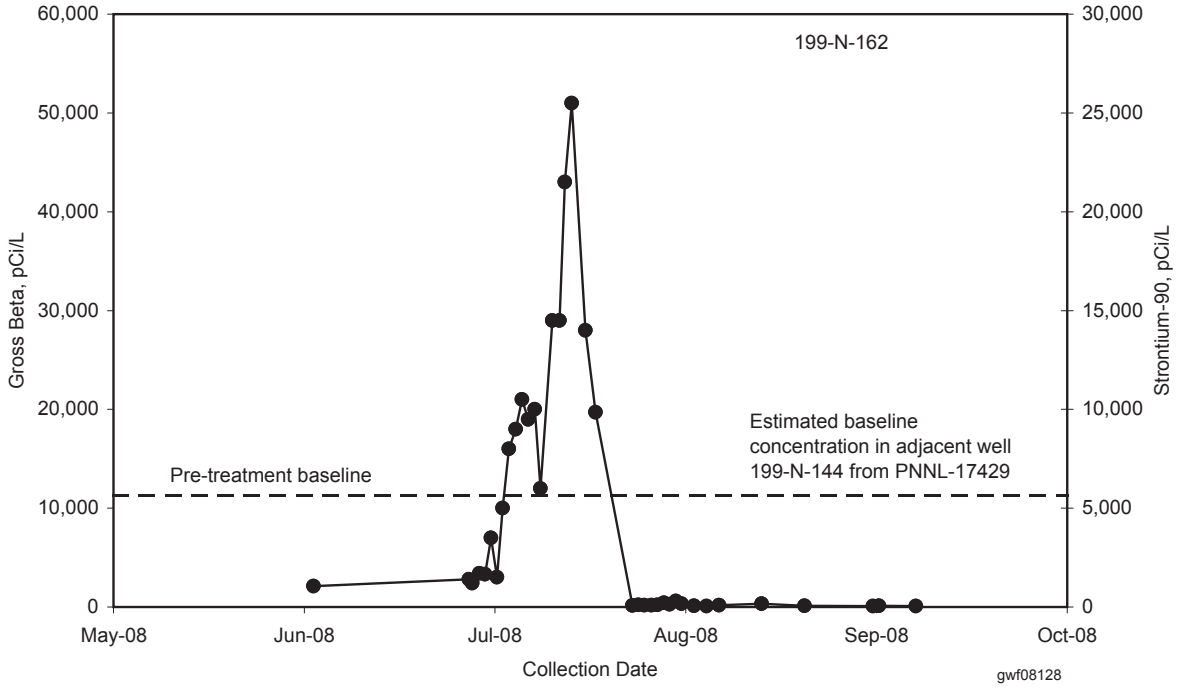
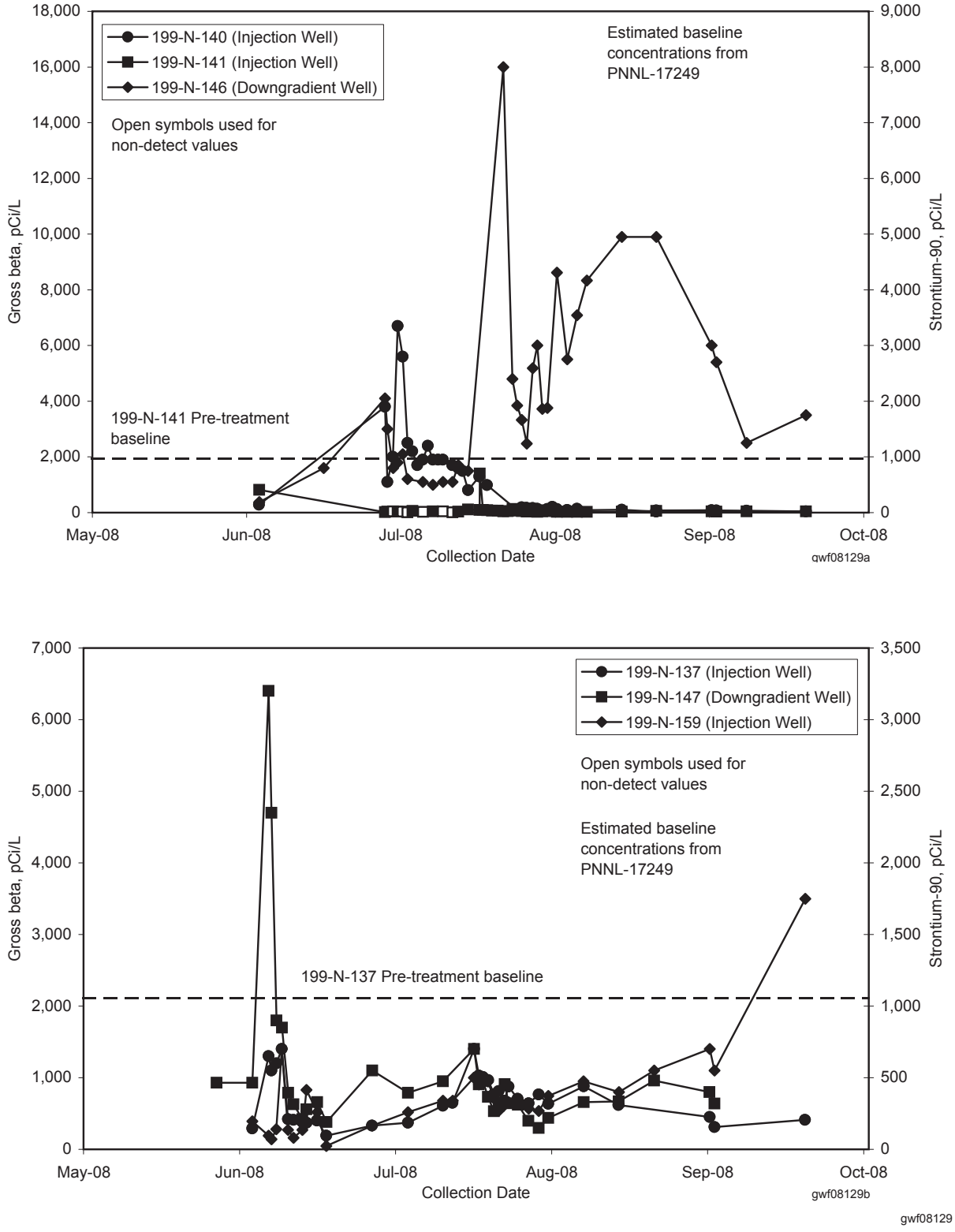



Figure 2.4-16. Gross Beta (and Equivalent Strontium-90) Concentrations in Apatite Injection/Barrier Wells and Downgradient Monitoring Wells.