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SUBSURFACE CONDITIONS DESCRIPTION OF THE B-BX-BY WASTE MANAGEMENT AREA

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Abstract: This document provides a discussion of the subsurface conditions relevant to the occurrence and migration of contaminants in the vadose zone and groundwater underlying the 241-B, -BX, and -BY tank farms. This document provides a concise summary of existing information in support of characterization planning. This document includes a description of the available environmental contamination data and a limited, qualitative interpretation of these data.

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Operating Specification	☐	Interface Control Drawing	☐	Spares Multiple Unit Listing	☐
Criticality Specification	☐	Calibration Procedure	☐	Test Procedures/Specification	☐
Conceptual Design Report	☐	Installation Procedure	☐	Component Index	☐
Equipment Spec.	☐	Maintenance Procedure	☐	ASME Coded Item	☐
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Environmental Impact Statement	☐	Fac. Proc. Samp. Schedule	☐	Tickler File	☐
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gravel sequence is interpreted to belonging to the gravel-dominated facies of the Hanford formation. Lenticular and discontinuous units of sand-dominated facies are sometimes interbedded with the gravel-dominated facies.

The H3 unit is not continuous beneath the B-BX-BY WMA; it generally is missing from the central portion of the waste site, where, in its place, lies the Hf/PPu(?). Where the Hf/PPu(?) silt layer is missing, the H3 and Hf/PPu(?) cannot be differentiated; these units are referred to collectively as the H3/Plio-Pleistocene unit (undifferentiated). A structure-contour map of the top of the Hanford formation lower gravel sequence (H3 unit) is shown in Appendix B, Figure B-12. The map shows approximately 20 m (70 ft) of relief on this surface beneath the WMA. The H3/Plio-Pleistocene unit (undifferentiated) averages about15 m (50 ft) thick over most of the waste site (Figure B-13), except to the northwest, where it is up to 30 m (100 ft) thick, and to the northeast, where it thins to about 10 m (30 ft).

2.2.8.2 Sand Sequence (H2 Unit). The Hanford formation sand sequence overlies the lower gravel sequence (H3 unit) and directly overlies the Hf/PPu(?) silt layer locally. The H2 unit is equivalent to the sandy sequence of the Hanford formation discussed in Last et al. (1989) and Lindsey et al. (1992), to the Hanford formation H2 sequence discussed in Lindsey et al. (1994), and to Qfs (Quaternary flood sands) documented in Reidel and Fecht (1994).

The H2 unit consists predominantly of the sand-dominated facies of the Hanford formation. Internally, this sequence probably contains multiple graded beds of plane- to foreset-bedded sand or gravelly sand several meters (feet) or more thick, which sometimes grade upward into silty sand or silt similar to that observed at the 218-E-12B Burial Ground (see Figure 2-8). Many more silt layers probably are present in the subsurface than are reported in driller's and geologist's logs and appear in the cross sections and fence diagram in Appendix A. This is because the drill method and/or the sampling interval (normally every 1.5 m [5 ft]) often cannot distinguish layers less than a few meters (feet) thick. Cementation is very minor or absent, and total calcium carbonate content generally is only a few weight percent or less.

The Hanford formation sand sequence (H2 unit) is ubiquitous beneath the B-BX-BY WMA. The base of the Hanford sand sequence lies at the top of the gravel-dominated sequence toward the bottom of the hole or at the top of the fine-grained Plio-Pleistocene unit, whichever is higher.

A structure-contour map of the top of the Hanford formation sand sequence is shown in Appendix B, Figure B-14. The map shows approximately 20 m (60 ft) of relief on the surface of the sand sequence beneath the B-BX-BY WMA. This sand sequence is thickest (60 m [200 ft]) in the central and southern portions of the WMA and thins to as little as 30 m (110 ft) to the north (Figure B-15).

2.2.8.3 Upper Gravel Sequence (H1 Unit). The Hanford formation upper gravel sequence overlies the Hanford formation sand sequence. This unit is equivalent to the upper gravel sequence of the Hanford formation discussed in Last et al. (1989) and Lindsey et al. (1992), to the Hanford formation H1 sequence discussed in Lindsey et al. (1994), and to Qfg documented in Reidel and Fecht (1994).

Based on observations of outcrop and intact core samples, the Hanford formation upper gravel sequence is interpreted to consist of the high-energy, gravel-dominated facies interbedded

with lenticular and discontinuous layers of the sand-dominated facies. Silt-dominated facies may also be present, though they probably constitute a relatively small percentage of the total.

The maximum thickness of the H1 unit reflects a north-south-trending trough (i.e., channel) that lies beneath the BX and BY tank farms. The maximum thickness of the H1 unit in this trough is about 20 m (60 ft) (Figure B-16).

2.2.8.4 Holocene Deposits. Locally up to 10 m (35 ft) of backfill material is present above the Hanford formation in many of the boreholes drilled in the B-BX-BY WMA.

2.2.9 Clastic Dikes

Clastic dikes are vertical to subvertical sedimentary structures that crosscut normal sedimentary layering. Clastic dikes are a common geologic feature of the Hanford formation in the 200 Areas, especially in the sand- and silt-dominated facies. Clastic dikes are much less common in the gravel-dominated facies of the Hanford formation. No clastic dikes were observed in the excavated walls of trench 94 in the 218-E-12B Burial Ground (see Figure 2-8), located about 1000 m (3,000 ft) east of the B-BX-BY WMA. However, they are occasionally observed elsewhere within the gravel-dominated facies of the Hanford formation.

Clastic dikes occur in swarms and form the following four types of networks (Fecht et al. 1999):

- Regular-shaped polygonal patterns
- Irregular-shaped polygonal patterns
- Preexisting fissure fillings
- Random occurrences.

Clastic dikes near the WMA probably occur randomly in the gravel-dominated facies (Hanford formation Units H1 and H3) and as regular-shaped polygons in the sand facies (Hanford formation unit H2). Regular-shaped polygonal networks resemble 4- to 8-sided polygons and typically range from 3 cm to 1 m (1 in. to 3 ft) wide, from 2 m to more than 20 m (6 to more than 65 ft) deep, and from 1.5 m to 100 m (5 to 325 ft) along their strike. Smaller dikelets, sills, and small-scale faults and shears are commonly associated with master dikes that form the polygons.

In general, a clastic dike has an outer skin of clay, with coarser in-filling material. Clay linings are commonly 0.03 mm to 1.0 mm (0.001 to 0.04 in.) thick, but linings up to about 10 mm (0.4 in.) thick are known. The width of individual in-filling layers ranges from as little as 0.01 cm to more than 30 cm (0.0004 to more than 12 in.) and their length can vary from about 0.2 m to more than 20 m (8 in. to more than 65 ft). In-filling sediments are typically poorly to well-sorted sand, but may contain clay, silt, and gravel (Johnson et al. 1999).

2.3 RECHARGE SOURCES AND EVENTS

The facility infrastructure, infiltration of water from natural and tank farm operation sources, and hydrologic properties of the stratigraphic units beneath the study area control the moisture and waste movement through the vadose zone to groundwater. This section summarizes available information on infiltration from natural resources, discharges caused by tank farm operations and observed spatial and temporal effects on subsurface hydrologic properties. Appendix C contains supporting data tables and figures.

Fluid infiltration into the soil column from the natural and tank operation sources, which are discussed in Sections 2.3.1 and 2.3.2, respectively, had a substantial effect on current environmental contamination conditions in the B-BX-BY WMA. Temporal changes in vadose zone moisture distribution and water table elevation in response to historical variations in natural and artificial recharge (Section 2.3.3), combined with aquifer properties, account for the rate and direction of contaminant dispersal in the aquifer.

2.3.1 Infiltration from Natural Sources

The tank farm surface characteristics and infrastructure create an environment conducive to enhanced general recharge and transient, high-intensity events. Natural infiltration, runoff events, and rapid snowmelt are discussed in Sections 2.3.1.1 through 2.3.1.3.

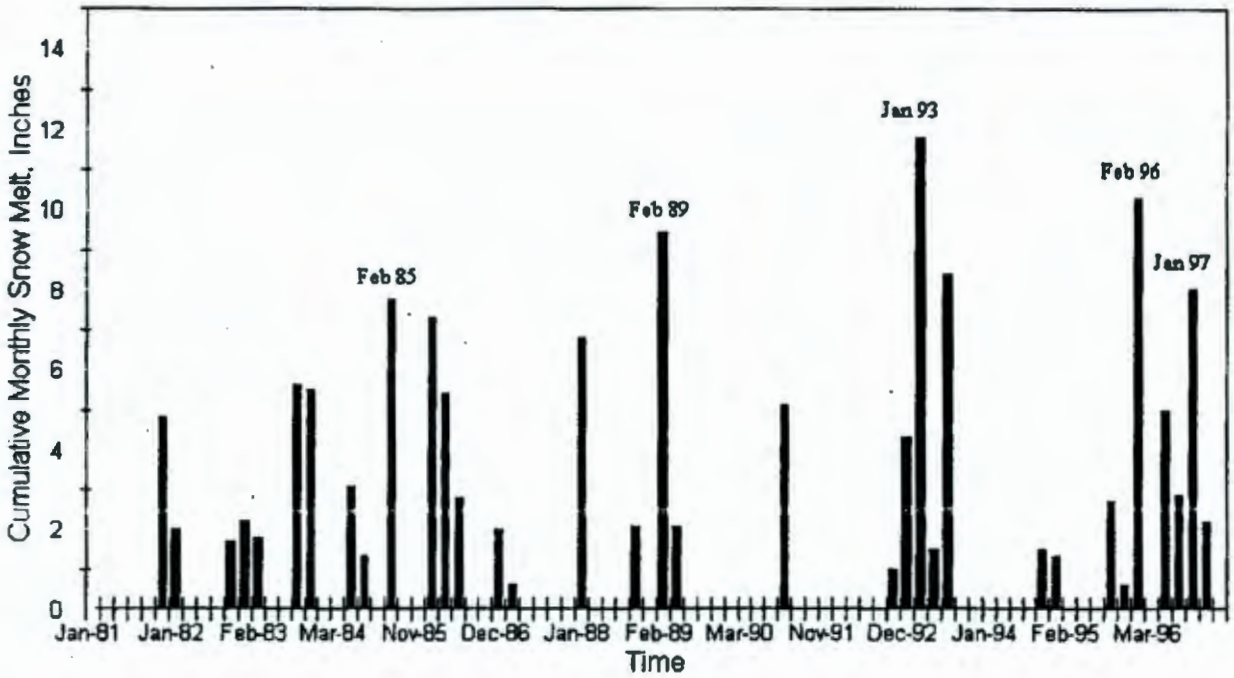
2.3.1.1 Infiltration. No direct measurements of the natural infiltration rate under the B-BX-BY WMA have been made. However, observations from similar, disturbed, gravel-covered areas at the Hanford Site indicate that as much as 10 cm/year (3.9 in./year) can infiltrate a vegetation-free coarse-gravel surface (Gee et al. 1992; Fayer and Walters 1995; Fayer et al. 1996). This represents about 60 percent of the average annual precipitation (rainfall plus snowmelt). Fayer and Walters (1995) indicate that the B-BX-BY WMA is in an area estimated to have about 2 cm/year to 5 cm/year (0.8 to 1.97 in./year) of infiltration based on soil type, vegetation, and land use and infiltration rates of 5 cm/year to 10 cm/year (1.97 to 3.9 in./year) immediately south of the tanks. Actual recharge is significantly different and not uniform because of the presence of the tanks and the disturbed soil surrounding the tanks. Recharge is blocked and "shed" by the tank domes and flows into the disturbed soil near the tanks. Thus, infiltration rates near tank edges and between rows of tanks are likely manifold higher than average areal infiltration rates.

2.3.1.2 Runoff Events. Transient saturation from collection of runoff in low spots may be more significant as a driving force than average annual infiltration. For example, rapidly melting snow is one natural event that can lead to surface flooding. This type of occurrence has been documented at other tank farms (e.g., T Tank Farm [Hodges 1998]), but no similar record is available for the B-BX-BY WMA. One topographical low at this WMA is located at the junction of the northwestern corner of the BY tank farm and the elevated soil barrier over crib 216-B-57. Within the boundaries of the tank farms, ponding can be controlled by the berms constructed over electrical lines. These barriers provide potential locations for water to collect during unusual runoff events.

2.3.1.3 Rapid Snowmelt. Records of snowmelt have been made since 1981 at the Hanford Meteorology Station, located between the 200 West and 200 East Areas. Figure 2-9 summarizes

the total snow melt per month for a 24-hour period. These records indicate likely periods when unusual accumulations or ponding of water may have resulted in transient saturation events, possibly leading to transport of contaminants through the vadose zone to groundwater. The snowmelt events, as well as maximum monthly precipitation since 1946 (Appendix B, Table B-1), are correlated with groundwater contamination occurrences in Figure 2-10.

Figure 2-9. Monthly Summaries of Rapid Snowmelt Events, 1981 Through 1997.



2.3.2 Fluid Discharges from Tank Farm Operations

Throughout the operational history of the B-BX-BY tank farms, fluids were discharged, both deliberately and inadvertently. To a large extent, the current state of environmental contamination has been caused by these discharges. Key characteristics include the location and time, volume, and contaminant inventory of these discharges. Where available, contaminant inventory information is summarized in Chapter 3. A more detailed discussion of these events is provided by Williams (1999). Data and narrative from Williams (1999) are provided in Appendix A.

Fluid discharge from the B-BX-BY tank farm complex occurred outside and inside the B-BX-BY WMA. Substantially greater volumes of waste fluids were deliberately discharged outside the B-BX-BY WMA. These releases occurred in four primary locations to support the major operations involving the B-BX-BY tank farm complex.

First, during the early stages of the bismuth phosphate operations, tank waste fluids were deliberately released to cribs and wells just north of the B tank farm. Cribs 216-B-7A and 216-B-7B received 4.3 x 10^7 L and Crib 216-B-8 received 2.7 x 10^7 L of waste fluids from 1946 to 1957. The majority of fluids were disposed of by 1953. Reverse wells 11A and 11B, which released fluids directly to the unconfined aquifer, received 2.96 x 10^7 L of waste from 1951 to 1954.

Second, in the final stages of the bismuth phosphate operations, waste was discharged to the BX trenches (216-B-35, -36, -37, -38, -39, -40, and –41). A total of 1.33 x 10^7 L of waste were discharged from February through November 1954.

Third, triutyl phosphate (TBP) waste from the uranium recovery program was discharged to the 216-B-42 BX trench (1.5 x 10^6 L) and the BY cribs (3.4 x 10^7 L) in 1954 and 1955.

Fourth, as part of tank stabilization, condensates from tank liquids were discharged into BY crib 216-B-50 (5.9 x 10^7 L) and 216-B-57 (8.4 x 10^7 L), just southwest of the BY cribs.

Discharges within the B-BX-BY WMA were unplanned releases. These are listed in Appendix A in the table captioned "Appendix 2: Unplanned Release Quantities." Quantities are not known for many of the identified releases. Reported releases are primarily leaks from transfer pipelines, diversion boxes, and tanks. The most significant release, in terms of quantity and degree of contamination is the loss of metal waste (MW) from BX-102 in 1951. MW was the initial waste stream produced in the plutonium extraction process and contained the highest concentrations of radionuclide constituents. Approximately 346,700 L of waste were released. The second largest reported release (265,000 L) is a tank leak from BX-102. However, evidence documenting this release is questionable. Smaller leaks from an above-ground pipe (87,000 L of first cycle bismuth phosphate waste), a flush tank overflow (41,600 L of TBP waste), another pipe leak (20,441 L), and leaks from various single shell and auxillary tanks (31,500 L or less) also are listed.

The following occurrence reports and tank farm operations information are listed and briefly described for use in Figure 2-10, which describes the time line of hydrologic and tank farm operational events. These reports document that artificial water sources that existed in the past could have remobilized waste in the vadose zone associated with the 241-BX-102-tank leak. Furthermore, flooding occurred that might have caused the nearby vadose contamination observed during drilling to spread to the present location of well 299-E33-41. Several of the following occurrences describe water-line leaks and valve ruptures at the 244-BX receiving tank, located about 45.7 m (150 ft) south of well 299-E33-41 (see Figure 2-1). This water likely remobilized tank waste while well 299-E33-41 was being drilled.

- **Tank Farm-1990-0054, September 1990**. Raw water was found discharging from a 1.3 cm (0.5-in.) line onto the ground from the exterior wall of the 244-BX double-contained receiving tank (DCRT) located just south of well 299-E33-41 (see Figure 2-11). Although a leak-detection alarm sounded and the area was checked, the open line was not discovered. Approximately 4.5 hours later, an open valve was found in the DCRT building. How long the water flowed onto the ground before the alarm activated was not reported. A 5,678-L (1,500-gal) increase was observed in the DCRT, but no estimate was given on the total volume of liquid released to the soils. However, the open

valve reportedly finally was noticed because a pool of water was discovered adjacent to the 244-BX DCRT pump pit.

- **Tank Farm-1990-0373, December 1990**. Subzero weather conditions caused raw water piping in the 244-BX DCRT building to rupture several valves. No estimate was made of the amount of water discharge to the surrounding soil. Approximately 2082 L (550 gal) of water drained into the 244-BX DCRT via the 244-BX flush pit floor drain. Excess water also had to be removed from the flooded instrument building. It is important to note that drilling began in January 1991 for well 299-E33-41, located approximately 48.8 m (60 ft) north of 244-BX DCRT, where the terrain slopes slightly downward toward the north.

- **Tanks 241-BX-101 and 241 BX-103**. These two single-shell tanks, located near well 299-E33-41, were placed on the candidate intrusion list. indicating possible liquid intrusion into the tanks (Hanlon 1999). Both tanks 241-BX-101 and -103 have been interim stabilized. Both tanks are assumed leakers. These tanks were placed on the intrusion list because surveillance data show that the surface levels in the tanks have met or exceeded the increase criteria. Both tanks are on the east side of the BX tank farm, near well 299-E33-41. The source of the liquid that may be intruding into these tanks is unknown.

- **Raw and Sanitary Water Lines**. As-built diagrams show 10 and 15 cm (4- and 6-in.) raw water lines and 3.8 cm (1.5-in.) sanitary water lines running north and south along Baltimore Avenue and along the BY tank farm fence lines. These lines run past 244-BX-DCRT and next to well 299-E33-41. Also, until recently, the BY tank farm had pressurized water lines inside the tank farm fence lines. Near-surface concentrations of contaminants close to water line leaks could be another source of groundwater contamination. Although rarely documented as important events, water-line leaks have occurred, as is common with any water system. The lack of records makes determining or documenting any significant effect on contaminant mobilization or transport difficult.

2.3.3 Subsurface Discharge

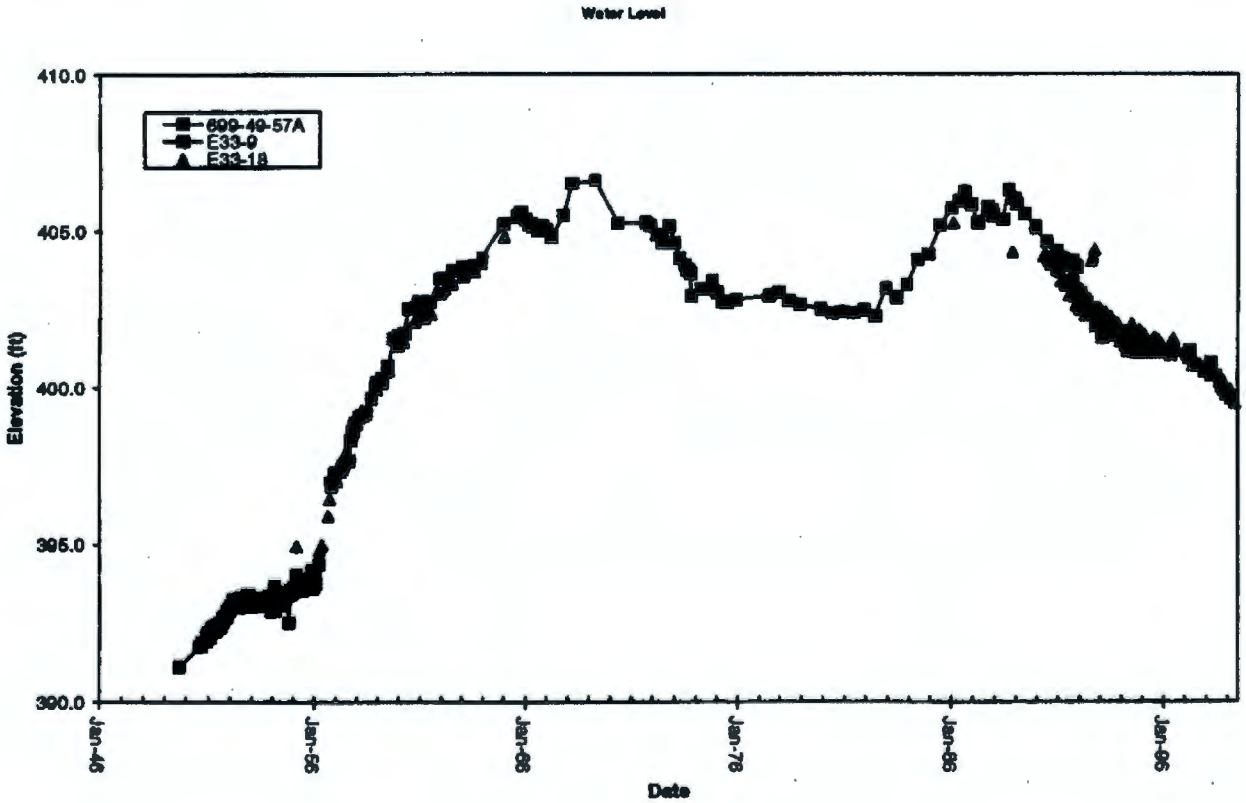
2.3.3.1 Vadose Zone Moisture Distribution. Substantial fluid volumes of tank waste and tank waste condensates were discharged into cribs and trenches adjacent to the B-BX-BY WMA. These fluids could have migrated into the vadose zone underneath the B-BX-BY WMA. However, no evidence exists to indicate that such events occurred. Given that more than 20 years have passed since crib and trench discharges adjacent to the B-BX-BY WMA occurred and the soils are highly permeable, any moisture from these sources is unlikely to be limited to silt-rich layers underlying the area. Based on a likely recharge scenario that 40 percent of the annual precipitation, which occurs almost exclusively during the winter, a flux rate of 70 mm/yr is estimated. Ten times the flux rate is reasonable as recharge or 0.7 meters per year penetration into the vadose zone. Over 20 years fluids may have migrated approximately 14 meters into the subsurface (Ward et al. 1997).

In the months before well 299-E33-41 was drilled, several flooding events occurred just south of this well's location at the 244-BX DCRT. The migration through the vadose zone of water from these floods while well 299-E33-41 was being drilled would explain the series of

high-radiation concentrations in a series of silt lenses from 22.3 m to 73.2 m (73 to 240 ft) and the contaminated perched water zone at 68.3 m (224 ft) below the ground surface. The actual water-table surface at this time was 75.3 m (247 ft) from the ground surface. Well 299-E33-41 is close to the site of the 113,562 L to 340,687 L (30,000- to 90,000-gal) overflow or spill between tanks 241-BX-103 and -102 in 1951 (DOE 1993). This tank leak is most likely the cause of the contamination and creation of the perched zone because it is only 11.3 m (37 ft) from the well. The nearest crib is 216 B-7B, 91.4 m (300 ft) from the well.

2.3.3.2 Water Table and Artificial Recharge. The water table has changed significantly since tank farm operations began in the early 1950s. The shift in discharge of large volumes of wastewater in the early 1950s raised the water table in the vicinity of the study area to over 4.9 m (16 ft) above the level before Hanford Site operations (Figure 2-11). The flow direction should be turning back to the original pre-Hanford direction, which is assumed to be to the southeast. This expected flow direction change would be in response to the diminishing B Pond mound located about 0.6 km (1 mi) east of the B-BX-BY WMA. Water levels are declining rapidly, as shown in Figure 2-11. As a result, in 5 to 8 years, some wells will contain little water. Given the transient hydrological conditions in this region, long-term water levels are difficult to predict.

Figure 2-11. Historical Water Levels Near the B-BX-BY WMA.



2.4 HYDROLOGIC PROPERTIES

2.4.1 Vadose Zone Properties

A summary of vadose zone hydrologic properties collected for Hanford Site sediments is provided in Khaleel and Freeman (1995). A subset of this database is included in Appendix C, Table C 1. The most pertinent data were collected on Hanford formation soils underlying the BY cribs during the remedial investigation of the 200-BP-1 operable unit. Given the proximity of the soil locations, these data are considered to be waste site-specific. The database includes the location of the sample, the depth at which the sample was collected, particle size distribution, moisture retention curve data, and saturated hydraulic conductivity values. Generally, the soils are variable mixtures of sands and gravels. Well-defined horizontal strata with distinctly different hydraulic properties favoring lateral movement in the vadose zone (e.g., silty sands) are probably present locally, but are not widespread.

2.4.2 Aquifer Properties

This section provides information on the current nature of the unconfined aquifer in the immediate region of the B-BX-BY WMA. Aquifer properties were determined from stratigraphic interpretations, current water elevations, and hydraulic conductivity values based on aquifer tests. Details are provided in Hartman (2000).

The water table lies in basal gravels interpreted as fluvial pre-Missoula sediments, extending upward at places into unit H3 of the Hanford formation. As explained in Section 2.2.7, the water table rests within these loose, sandy gravels, displaying primary grain sizes that range from cobble- to boulder-sized clasts. The aquifer thickness varies from 2.1 m to 4.3 m (7 to 14 ft) across the Site, depending on the location of local highs in the basalt surface. The aquifer appears to be thicker where the basalt surface is lower, correlating with the structure on the top of the basalt.

The hydraulic gradient is flat across the 200 East Area. With about 10 cm (4 in.) of change across the WMA, the use of discrete water elevations to determine flow direction is complicated. In this region, comparing data between individual wells to determine the upgradient versus downgradient locations is difficult. This difficulty is related to the fact that the total error in water elevations can be a significant portion of the actual differences in water elevation between two wells. Sources of vertical uncertainty that had to be addressed were the survey datum, survey loop or traverse errors, error caused by a well being out of plumb, and, occasionally, spurious water level errors. Barometric effects have been addressed in part by collecting contemporaneous water level measurements over a few hours or days for each data set. Barometric effects on water level elevation measurements at the Hanford Site are just beginning to be addressed (Spane 1999).

Part of this discrepancy in water levels is related to survey datum. In 1998, the Hanford Groundwater Monitoring Project changed the datum to which water levels are referenced (Hartman 1999). The geodetic elevation datum currently used is the NAVD88 protocol standard , which is the new minimum constraint adjustment of the North American Vertical Datum of 1988. This adjustment is referenced to the new International Great Lakes Datum of 1985

(IGLD85), local mean sea level height value, at Father Point/Rimouski, Quebec, Canada. The datum is not mean sea level, a geoid, or any other equipotential surface.

In the early 1990s, the U.S. Army Corps of Engineers adjusted both the NAVD88 and NAVD29 data for the environmental restoration contractor. Because the National Geodetic Survey no longer supports NAVD29, all actively monitored wells are now referenced to the vertical control datum NAVD88. However, doing this was not practical for the water-level data interpretation in the area of B-BX-BY, therefore, the NAVD29 was used. The NAVD88 elevations are about 1 m higher than NGVD29 elevations in the vicinity of the Hanford Site. Converting elevations to NAVD88, using a software package called Corpson (Version 5.11, U.S. Army Corps of Engineers 1997), which uses the VERTCON software program (Version 2.0) developed by NGS, can contribute errors of approximately 1 cm (0.4 in.).

More important to the amount of error between water levels in wells than the selection of the vertical control datum is the choice of the specific survey loop or traverse used to calculate water-level elevations. Vertical surveys of wells of variable accuracy have been conducted at the Hanford Site over the last 50 years. However, direct measurements between well pairs are rare. Consequently, errors between any two wells cannot be determined. Only errors between wells and their control point or network of survey points in the survey traverse from which the measurements were made can be determined. Therefore, the accuracy in well elevation or location is the amount of known error in the survey, which almost always is greater than the actual error between any two wells in the survey (Schalla et al. 1992). If separate vertical surveys are conducted on different groups of wells, the amount of estimated error would probably be at least equal to the composite error of all the surveys. A comparison of well elevations, based on different surveys in the B-BX-BY WMA, gives results that differed as much as 50 percent of the gradient across the Site. To avoid these errors the water elevations are referenced to a 1992 survey based on NGVD29. If a significant discrepancy was found, a newer survey based on NGVD29 was used for that well or the well's data were eliminated. Water level elevations are the most direct method to determine the direction of groundwater flow in the aquifer, but comparing water-level elevations from different surveys must be done with care to avoid confusion and incorrect conclusions.

A third source of error is vertical plumbness of the well. As part of the *Resource Conservation and Recovery Act of 1976* (RCRA) assessment work conducted by the Hanford Groundwater Monitoring Project, vertical plumbness was measured in several wells that appeared to complicate the interpretation of local flow. Well 299-E33-39 was surveyed in fiscal year (FY) 1999 because data from that well consistently displayed anomalous low water elevations. Based on deviations from vertical, determined with a downhole gyroscope, a 12 cm (0.4-ft) correction was added to the water levels in this well.

The total errors from all sources complicate the use of even a contemporaneous set of water level data to estimate flow direction. Besides survey errors (i.e., datum and loops), measurement error (e.g., tape accuracy limitations and well out of plumb), and storm effects (e.g., rapid barometric changes) can make accurate interpretation of certain data sets difficult and complicated. Therefore a series of contemporaneous sets is needed to establish a trend in the water table surface as shown in Figures 2-12 and 2-13.

The data from selected wells shown in Figure 2-12 depict the general local water-level trend. Spurious and outlying data were removed from the individual well trends to facilitate

interwell comparisons. All well water elevations decrease over time. Wells E-33-34, E-37-7, E-33-5, E-33-39, E-34-11, and E-32-8 show higher elevations than wells E-33-34, E-28-26, E-32-5, E-28-27, and E-32-4 at any given time. The location map in Figure 2-13 clearly shows that the upgradient water elevations are in the north. This indicates a southwest flow direction. Although data from a few wells in this are do not agree with the trend shown in Figure 2-12, the majority of wells for which consistent survey information is available appear to mirror this general southwest flow.

Figure 2-12. Hydrographs for 11 Wells Located North, East, West, and Southwest of the B-BX-BY WMA. (Wells E33-34, E33-7, E33-5, E33-39, E34-11, E32-8, and E33-34 are upgradiant; the rest are downgradient.)

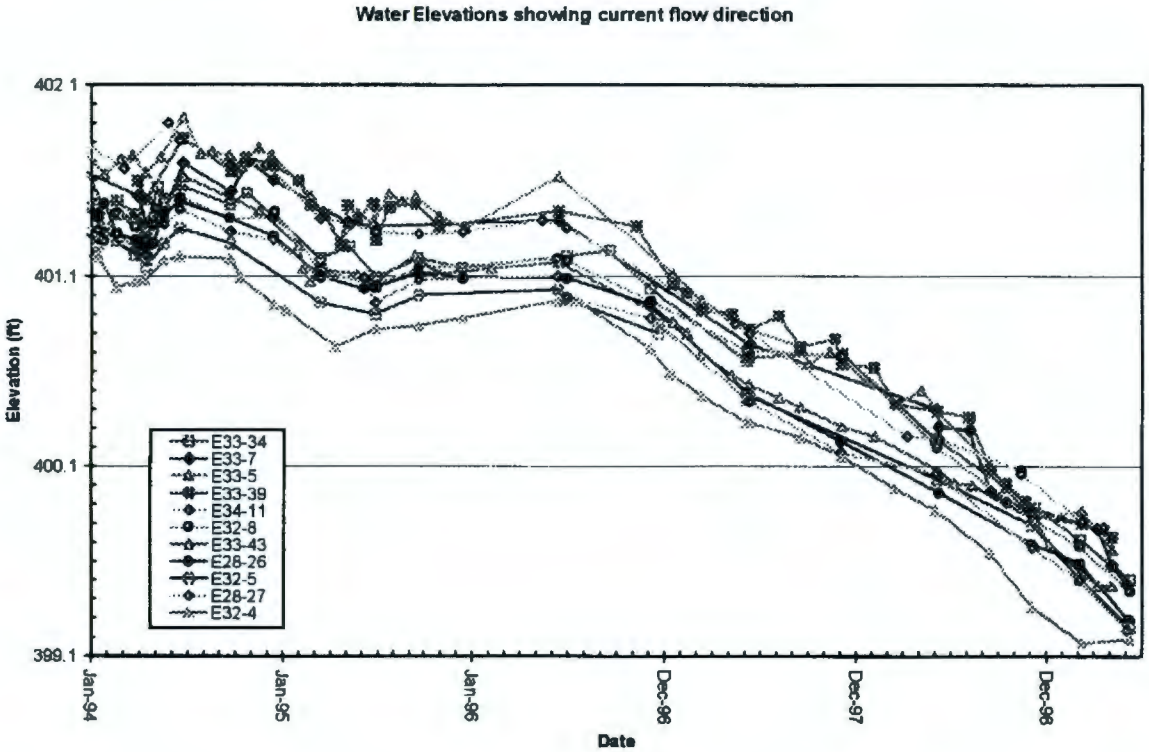
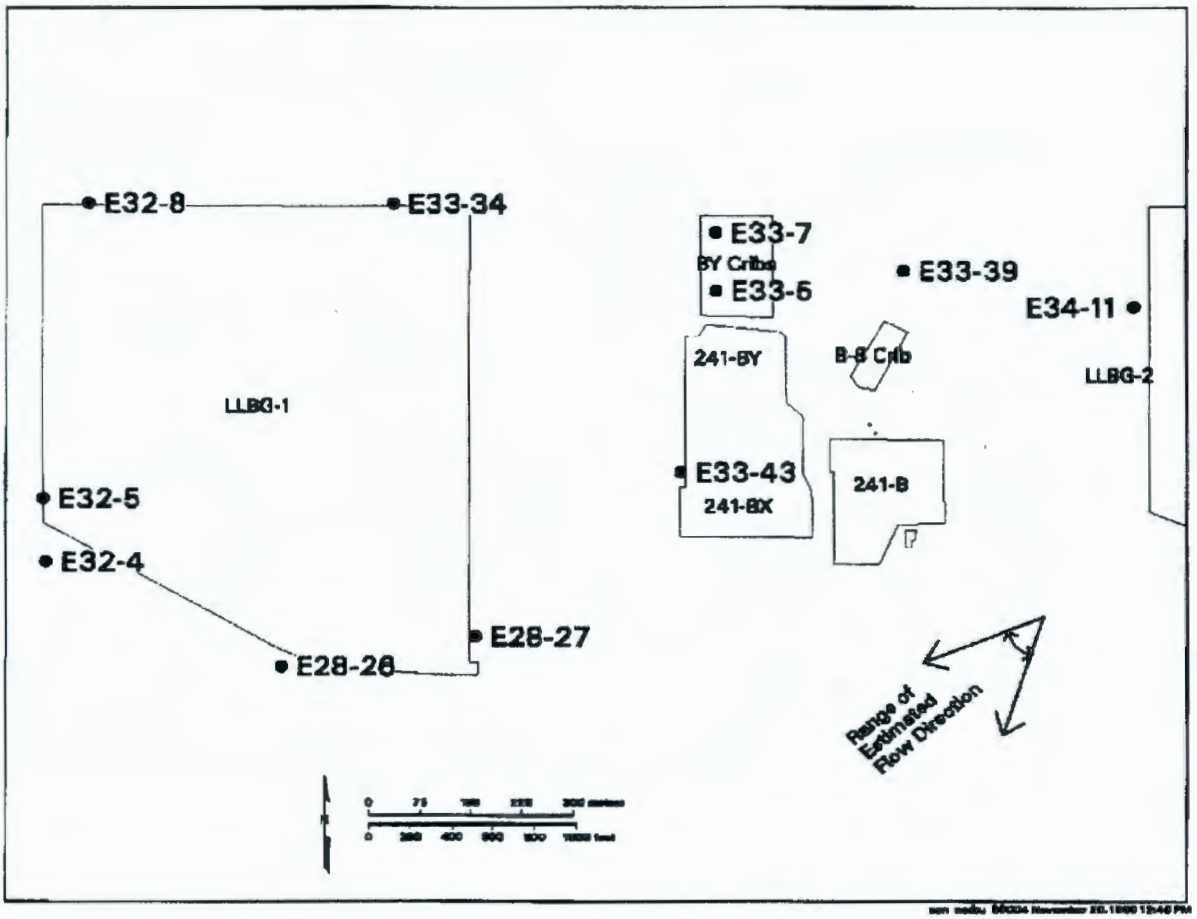


Figure 2-13. Location Map for Wells Shown in Figure 2-12.



As stated earlier and as can be seen in the hydrographs, determining flow using a selected contemporaneous data set to determine a single flow direction could be misleading. Consequently, it may not be appropriate to provide a three-point solution. However, based on observations of recent contaminant movement and on wells that consistently appear to be at the same relative elevations from 1996 to 1998, an estimated flow direction lies between 200° and 250° azimuth as shown in Figure 2-14.

The rate of groundwater flow for RCRA sites is calculated for a homogeneous, isotropic aquifer from the Darcy equation shown in Hartman (2000). This simple, one-dimensional equation incorporates the effective hydraulic conductivity, the local water-elevation gradient across the Site, and an estimated aquifer porosity. The local hydraulic conductivity of 1600 m/day (5,300 ft/day), based on aquifer test results, was reported in Newcomer et al. (1992) and Connelly et al. (1992). Porosity is estimated as 30 percent or greater for the unconsolidated gravels that made up the aquifer. Unfortunately, collecting enough intact core from the aquifer is difficult because of large grain size. Consequently, direct methods of determining porosity have not been used. Given the lack of direct measurements, combined with the cobble-to-boulder

nature of the aquifer, 30 percent may be a low estimate. The local hydraulic gradient across the B-BX-BY WMA is approximately 0.00017, based on September 1999 water levels.

The effective flow rate, using these parameters, is calculated to be 0.9 m/day (3 ft/day). This equates to 324 m (1,064 ft) of effective groundwater movement per year. If discrete, high-permeability flow channels are considered as the prime avenues of contaminant transport, a flow rate of 0.9 m/day (3 ft/day) may be low. This relatively high flow velocity has implications that relate to the optimal sampling frequency at which the groundwater is monitored. Because the WMA is approximately 400 m (1,300 ft) long from north to south and 300 m (985 ft) from east to west across the 241-BY tank farm, contamination related to leakage of tank waste might move through the area in less than 1 year. Given the pulse-type events seen in the past at well 299-E33-41 and the high frequency of contamination documented at the S-SX WMA, semiannual or even quarterly sampling may not be sufficient to clearly identify and differentiate tank-related waste from background contamination left from discharges to the surrounding cribs, trenches, and reverse wells (Johnson and Chou 1998; Narbutovskih 1998). As part of the RCRA B-BX-BY WMA assessment, a study is currently being conducted to determine the best sampling frequency for monitoring this WMA.

2.5 GEOCHEMISTRY

This section covers geochemical factors and material properties of the vadose zone and unconfined aquifer underlying the B-BX-BY WMA that control contaminant mobility in the soil column. Radionuclide and hazardous-constituent mobility can be substantially different depending on the innate characteristics of the contaminant and the geochemistry of the soil-water system. In these soils, both factors are expected to be important. Different contaminants present in the soils are variably mobile and, depending on interactions of tank fluids with the soil-water system, a given contaminant's mobility can be considerably different at different locations and times within the vadose zone and unconfined aquifer.

The geochemical characteristics and contaminant mobility are best considered in terms of behavior in relatively undisturbed soils versus soils that have interacted with tank waste fluids. In addition, tank fluid chemistry varies. Both types of soil conditions are expected in the vadose zone underlying the B-BX-BY WMA. For relatively undisturbed soils, a substantial Hanford Site-specific, but not B-BX-BY WMA-specific, database is available that quantifies geochemical characteristics and contaminant behavior, particularly for radionuclides (e.g., Ames and Rai 1978; Serne and Wood 1990; Serne et al. 1993; Kaplan, Parker, and Kutynakov 1998, and Kaplan and Serne 1999). Average soil properties are described in Section 2.2. Soil water in the vadose zone and groundwater in the unconfined aquifer have similar characteristics. They are moderately alkaline (pH about 8) and contain moderated concentrations of cations and anions. Dominant cations are calcium (about 50 mg/L), magnesium (about 14 mg/L), sodium (about 30 mg/L), and potassium (about 9 mg/L). Dominant anions are carbonate (about 70 mg/L) and sulfate (75 mg/L).

Within the B-BX-BY WMA, geochemical and related soil property data have not been collected. However, an extensive soil sample and analysis program was conducted in the soils underlying the BY cribs just north of the B-BX-BY WMA as part of the 200 BP-1 Operable Unit remediation investigation (DOE/RL 1993). At most depths in the undisturbed soils, the fraction of gravel-size particles (larger than 2 mm) dominates. The exceptions are a sand-dominated soil

at about 40 to 60 m below the surface and a silty sandy soil at about 95 m below the surface. The upper layer is more or less continuous at 58 m to 59 m throughout the BY crib area. A mineralogical analysis was not performed.

One Site-specific study of radionuclide sorption tendencies was completed as part of the remediation investigation (DOE/RL 1993). This report is provided in Appendix D. Batch sorption experiments were completed for ^{60}Co, ^{90}Sr, ^{99}Tc, plutonium, and cyanide using local soils and groundwater. Measured sorption coefficient values for ^{90}Sr, ^{99}Tc, and plutonium were in the expected range for standard undisturbed soils and groundwater chemistry (5 mL/g to 10 mL/g, 0 mL/g, and more than 1000 mL/g, respectively). As expected, cyanide sorption was very low. Cobalt-60 sorption also was very low (less than 1 mL/g) indicating the presence of a complexing agent acting to form anionic aqueous species with ^{60}Co. Additional tests were performed in the presence of various initial concentrations of cyanide and EDTA. Cyanide effectively reduced ^{60}Co sorption at both concentrations (150 and 2,000 ppb) used and EDTA also greatly reduced ^{60}Co sorption at the higher concentration (2,000 ppb).

These results are not definitive. The use of cyanide versus ferrocyanide in these experiments makes the relevance of the results ambiguous. The quantities of EDTA used experimentally are much greater than expected in the waste stream. Given the historical record of adding ferrocyanide during waste processing, a potential complexing agent may be cyanide if cobalt exchange with iron is favorable. However, the kinetics and mechanisms of this and other potential reactions that might lead to the formation of cobalt complexes are unknown. Other species known to be present in the waste, such as carbonate and ammonia, are potential complexing agents for cobalt.

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Figure 3-5. Historic Trend Plots of Nitrate Concentrations and ^{99}Tc Activities at Well 299-E33-16.

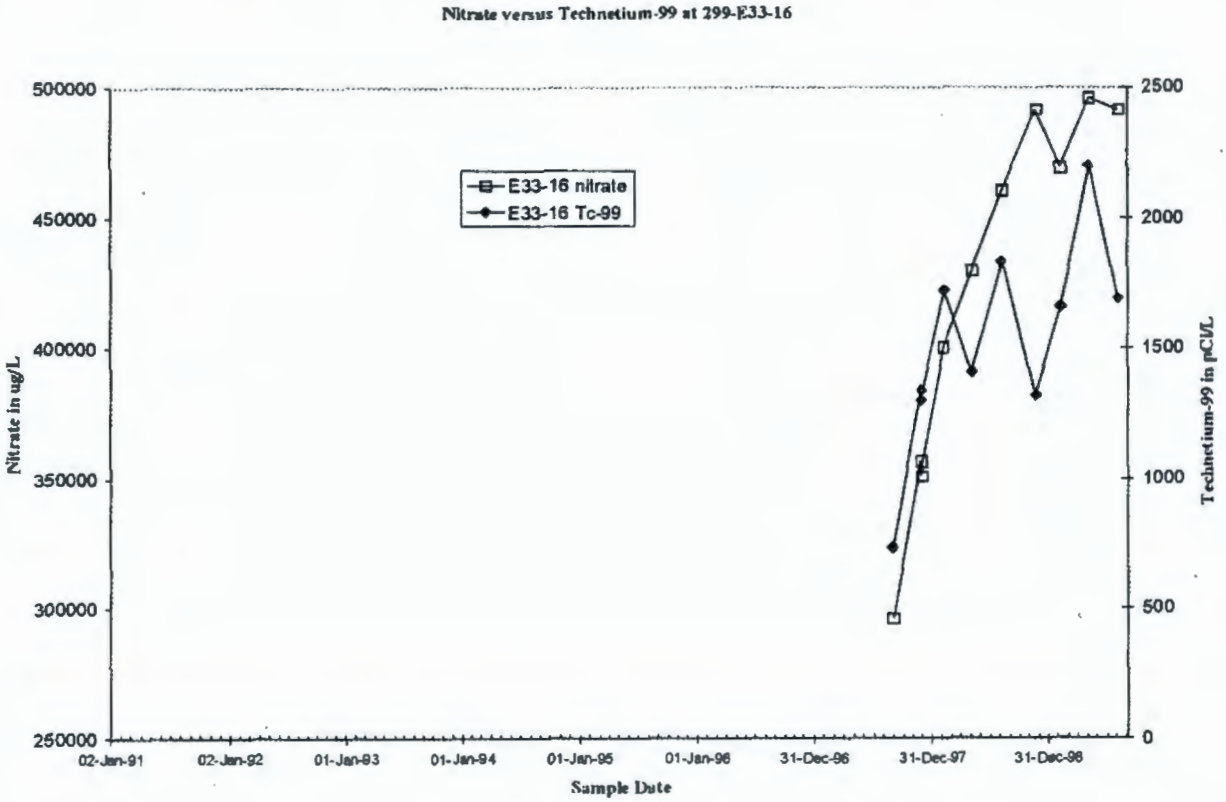


Figure 3-6. Historic Trends of ^{99}Tc and Uranium for Well 299-E33-41.

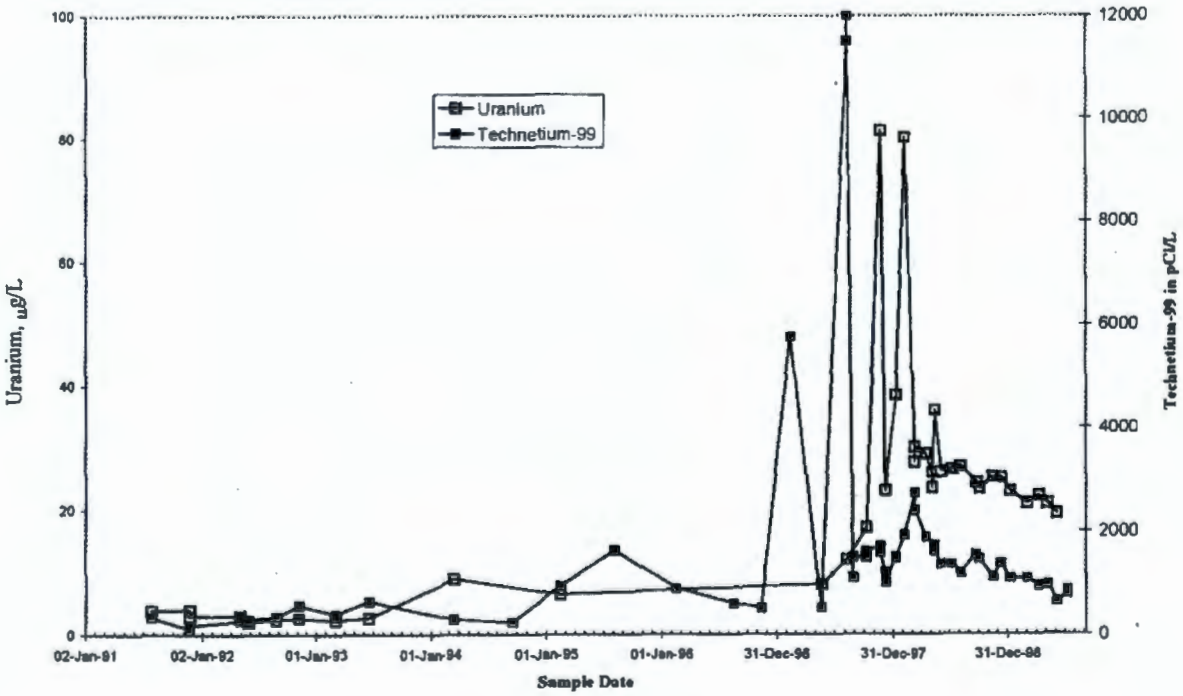
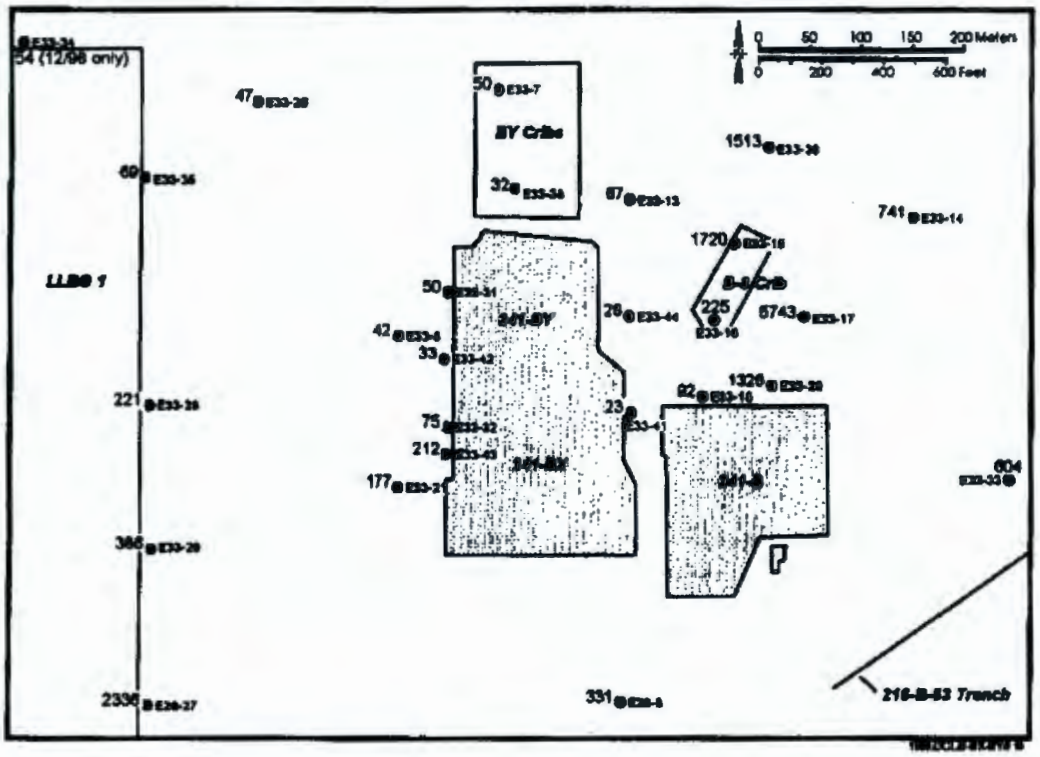


Figure 3-7. Ratio of Nitrate to ^{99}Tc (Second Quarter).



During the period of northward movement, probably before the early 1990's, the highest concentrations of ^{99}Tc and nitrate were found in well 699-50-53A, located north-northeast of the study area. The nitrate-to-^{99}Tc ratio from this well during the early 1990's is 42, for a ^{99}Tc value of 17,000 pCi/L and 716,000 µg/L of nitrate. This ratio is similar to that of the contamination currently moving through the northern part of this WMA.

The nitrate-to-^{99}Tc ratio at well 299-E33-16 is above 200 because of the very high levels of nitrate with lower ^{99}Tc values, less than half that observed at wells 299-E33-7 or -44. As can be seen in Figure 3-7, none of the surrounding wells have a similar ratio. Wells immediately to the north, east, and south have high nitrate values, but do not have ^{99}Tc above the DWS, which results in much higher ratios of nitrate to ^{99}Tc than at wells 299-E33-7 or -44. The contamination observed at this well appears to have a limited spatial extent. At least part of the aquifer at this site may be locally isolated by a depression on the basalt surface. The relief on the top of the basalt can be as much as 4.3 m (14 ft), which is more than the about 2.4 m (8-ft) thickness of the aquifer at this well. If the lower part of the aquifer is locally in a small depression, the contamination observed in the groundwater may be residual from liquid waste discharged to the 216-B-8 crib, which was used from the late 1940s to about 1952.

Finally, the ratios at wells 299-E33-41 and -44 are noticeably lower than at wells in the surrounding area. For example, the nitrate and ^{99}Tc levels at well 299-E33-41 are significantly low; both currently are below the DWS. If a groundwater sample can be collected from well 299-E33-9, located west of well 299-E33-44 but within the tank farm boundaries, further

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Figure B-7. Thickness of the Plio-Pleistocene Unit Silt Layer.

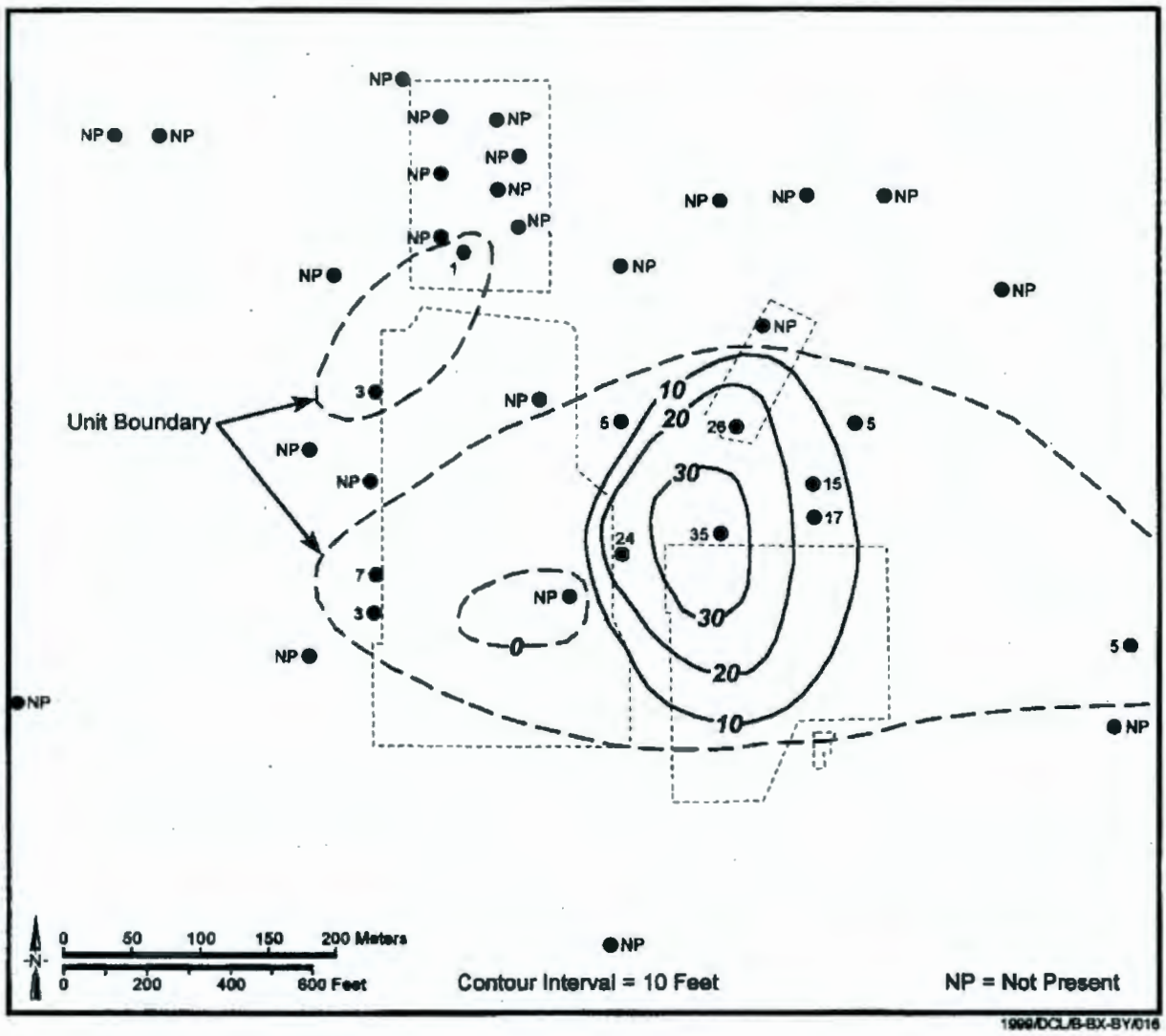

Figure B-8. Top of the Hanford Formation/Plio-Pleistocene Unit(?) Silt Layer.

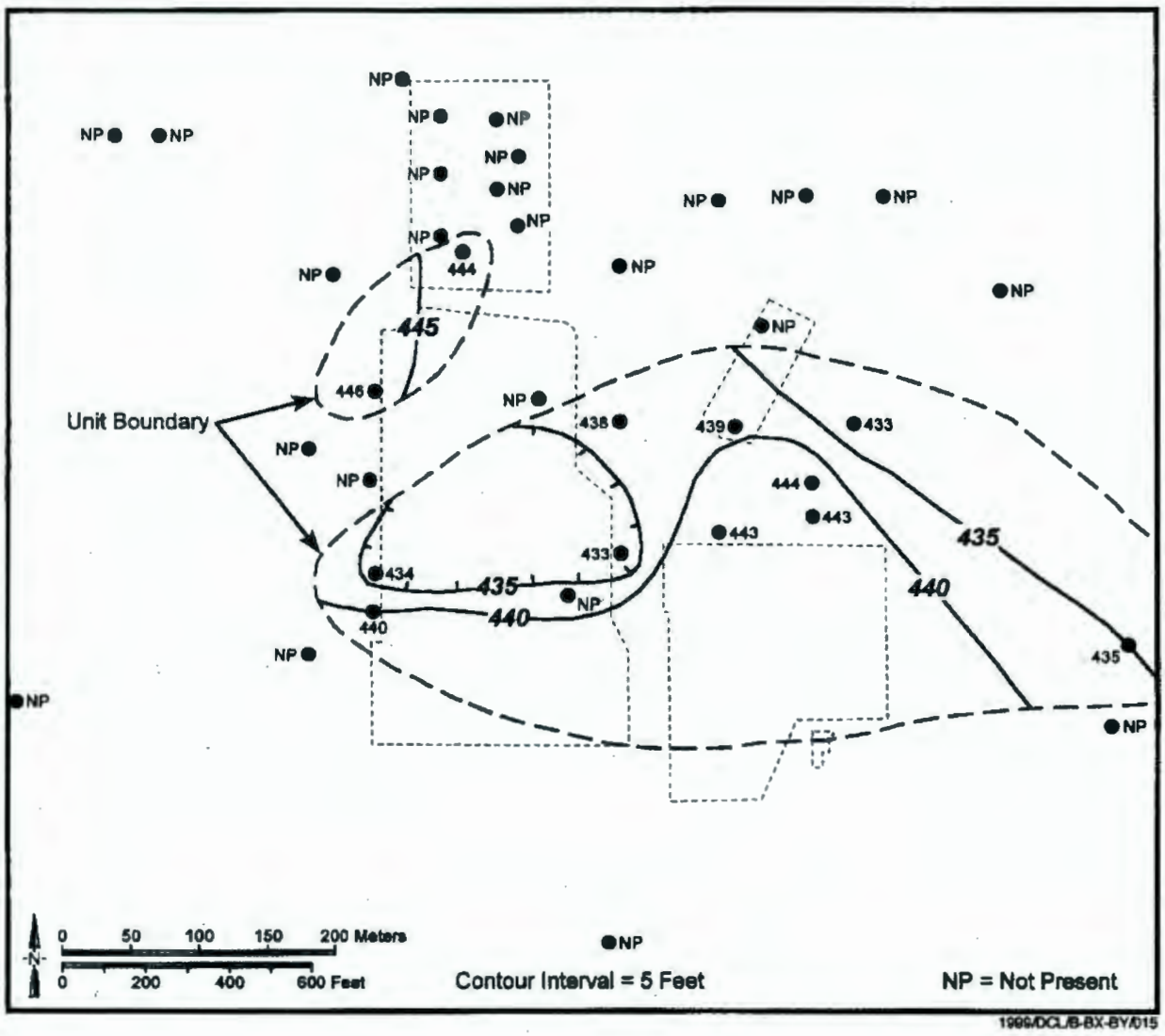

Figure B-9. Top of the Hanford Formation/Plio-Pleistocene Unit(?) Gravel.

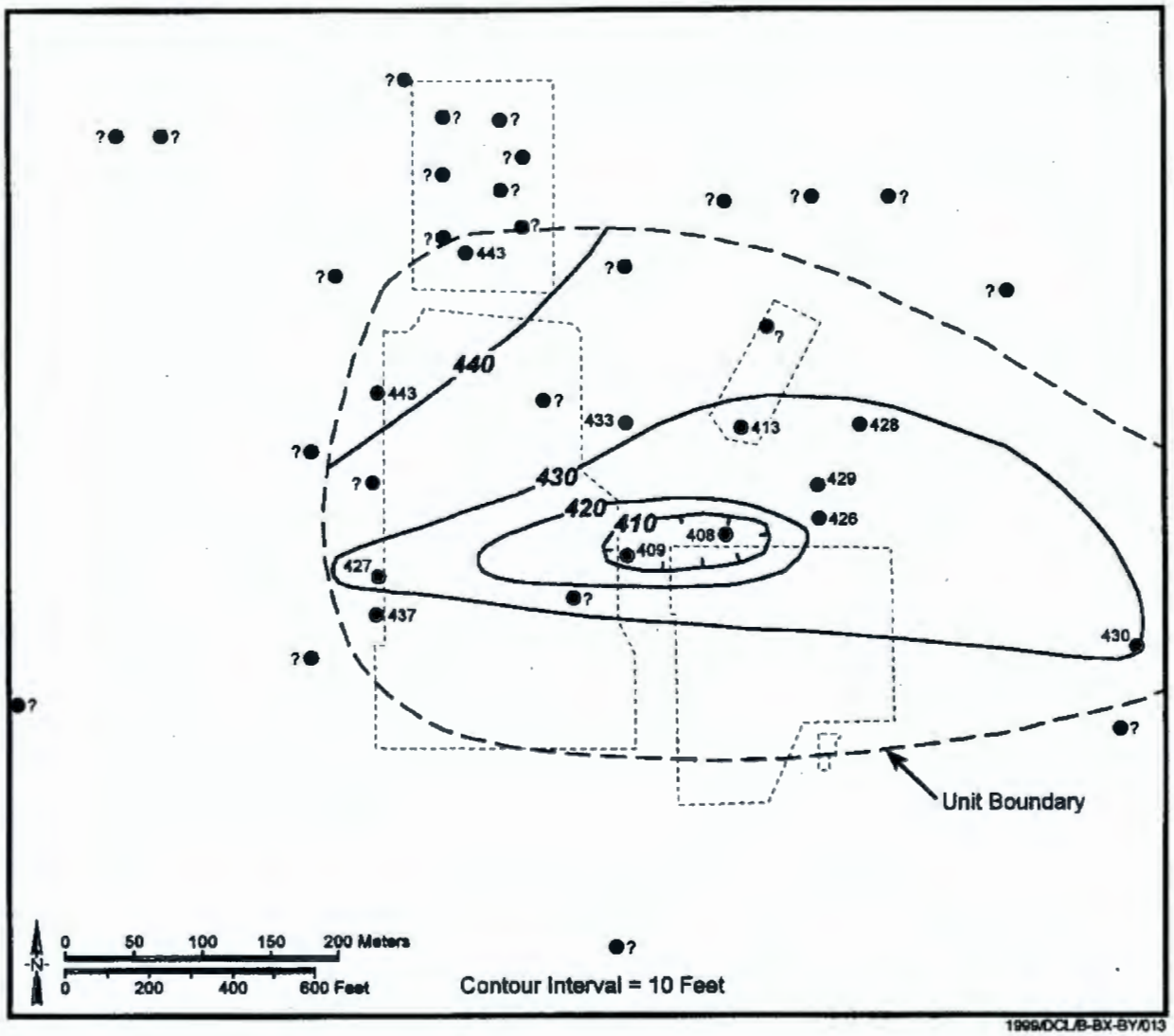

Figure B-10. Thickness of the Hanford Formation/Plio-Pleistocene Unit(?) Gravel.

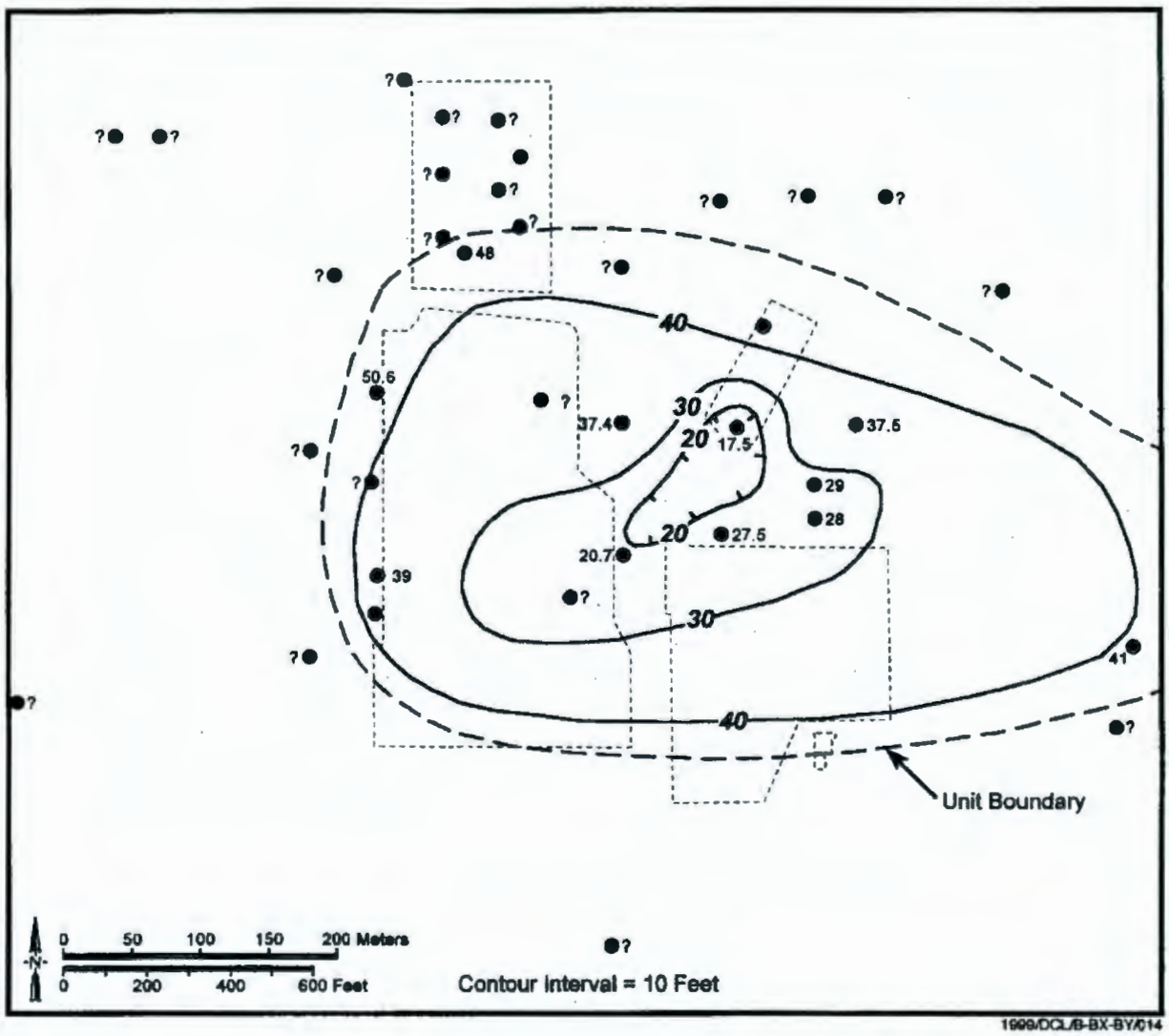

Figure B-11. Top of the Calcium Carbonate Marker Horizon within the Hanford Formation/Plio-Pleistocene Unit(?).

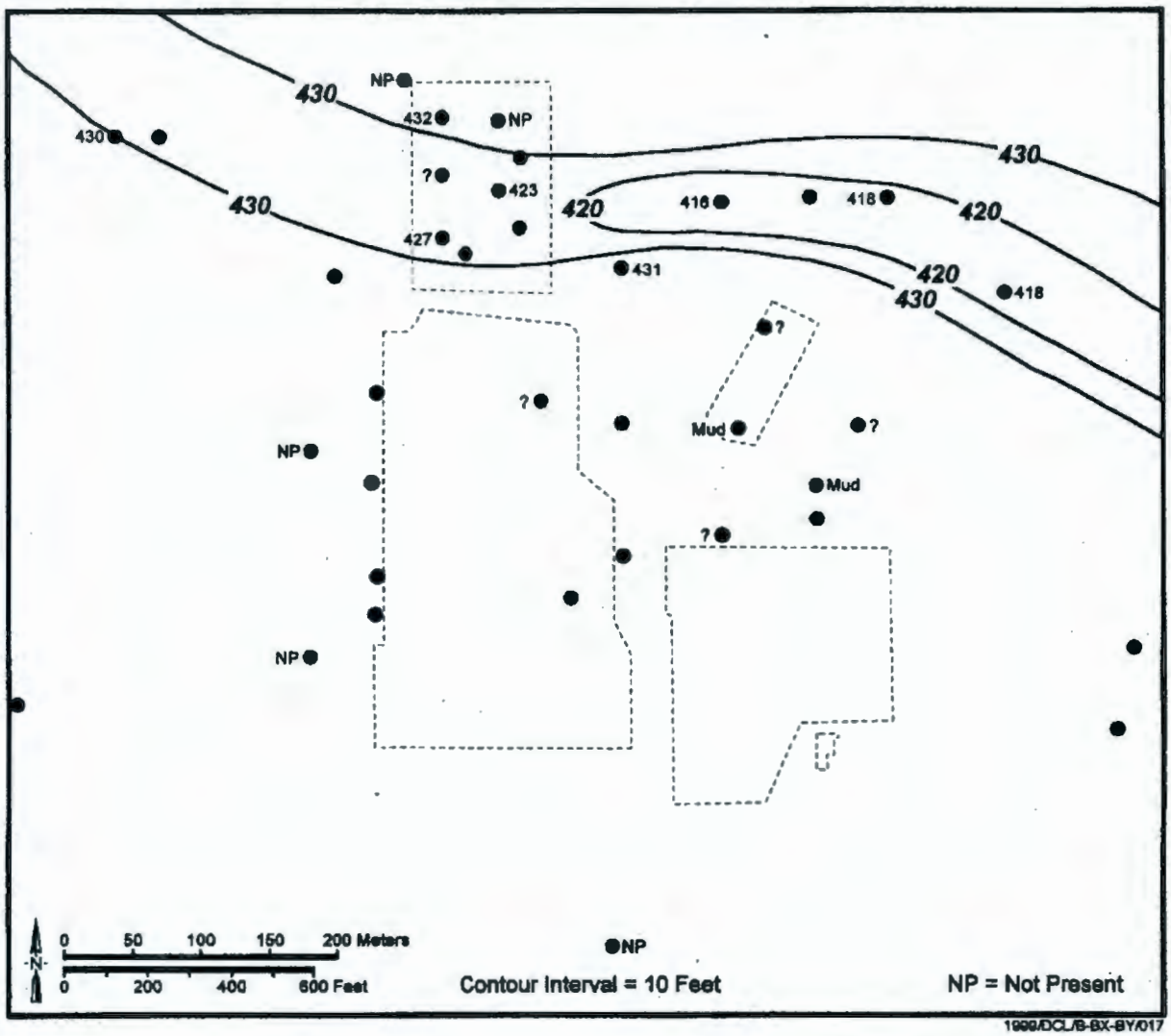

Figure B-12. Top of the Hanford Formation Lower Gravel Sequence/ Plio-Pleistocene (Undifferentiated) Units

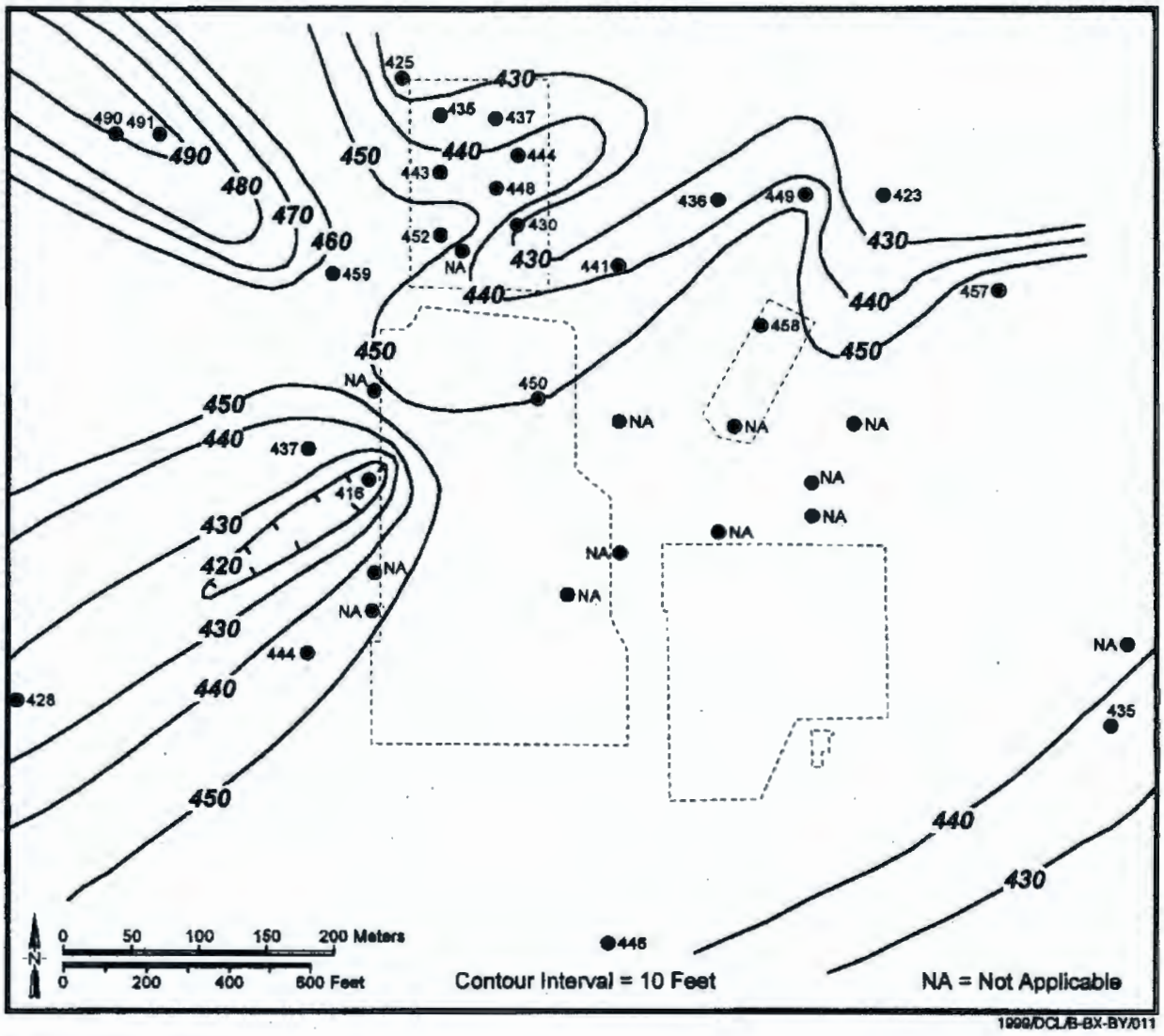

Figure B-13. Thickness of the Hanford Formation Lower Gravel Sequence/ Plio-Pleistocene (Undifferentiated) Units.

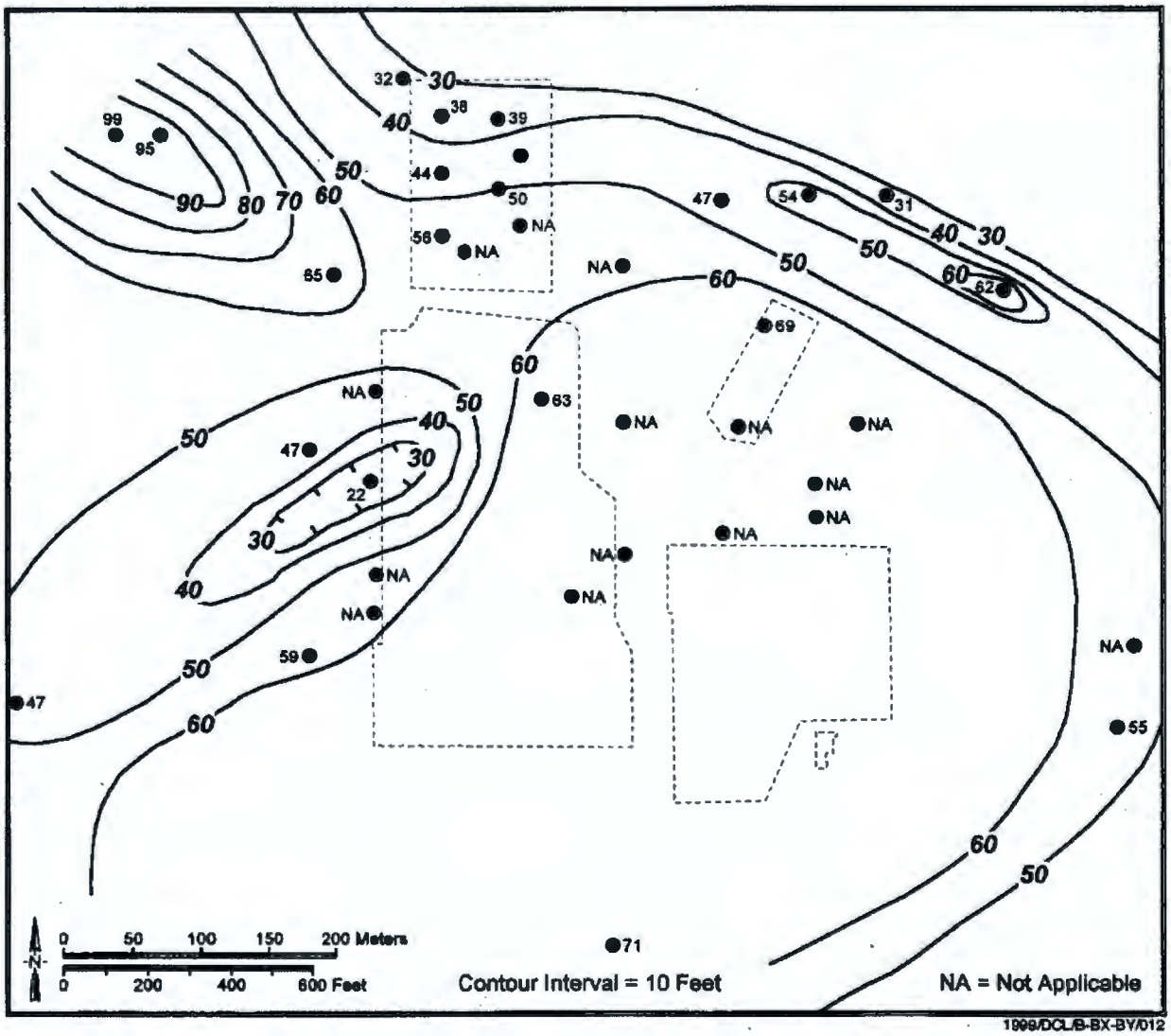

Figure B-14. Top of the Hanford Formation Sand Sequence (H2 unit).

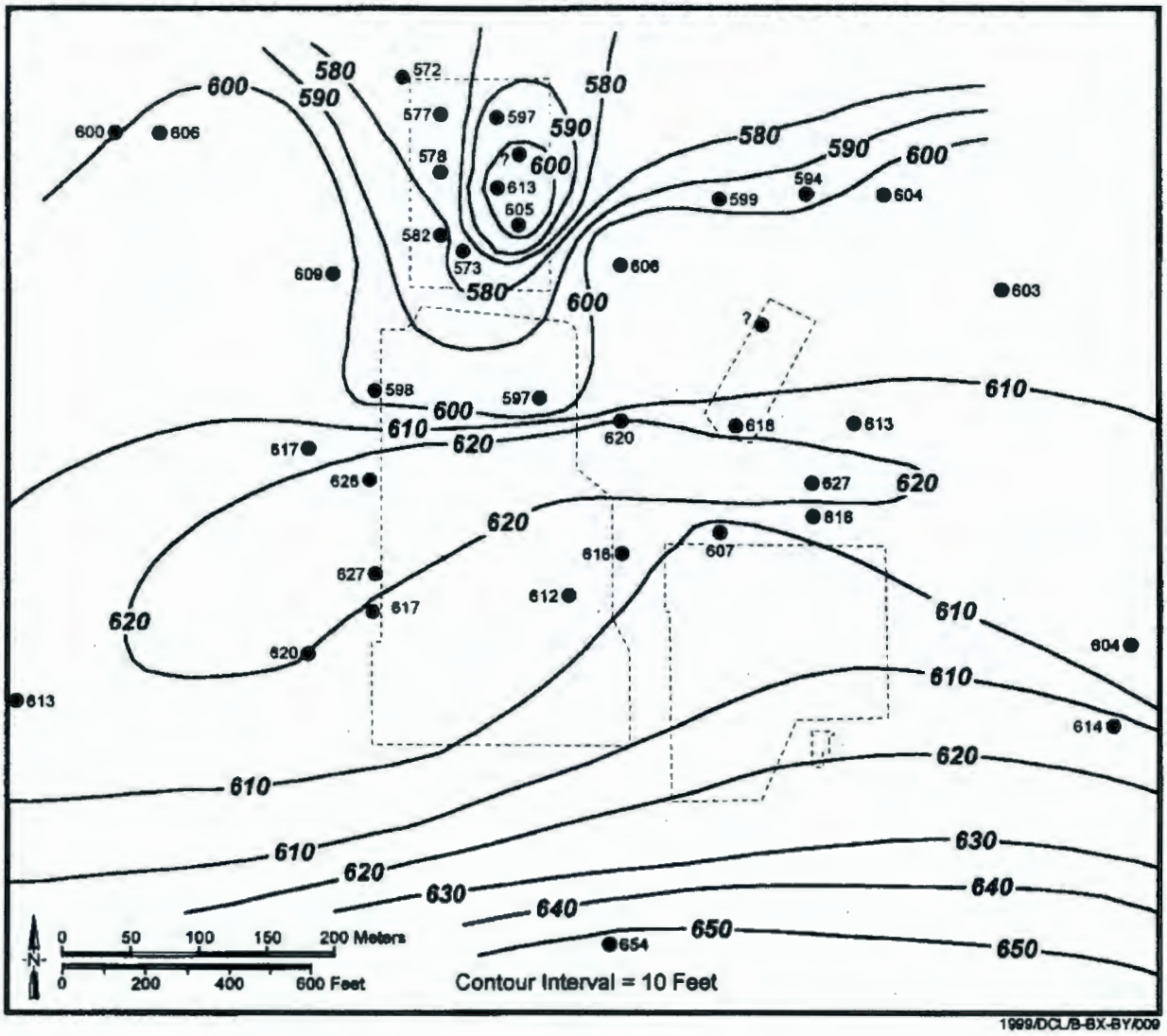

Figure B-15. Thickness of the Hanford Formation Sand Sequence (H2 unit).

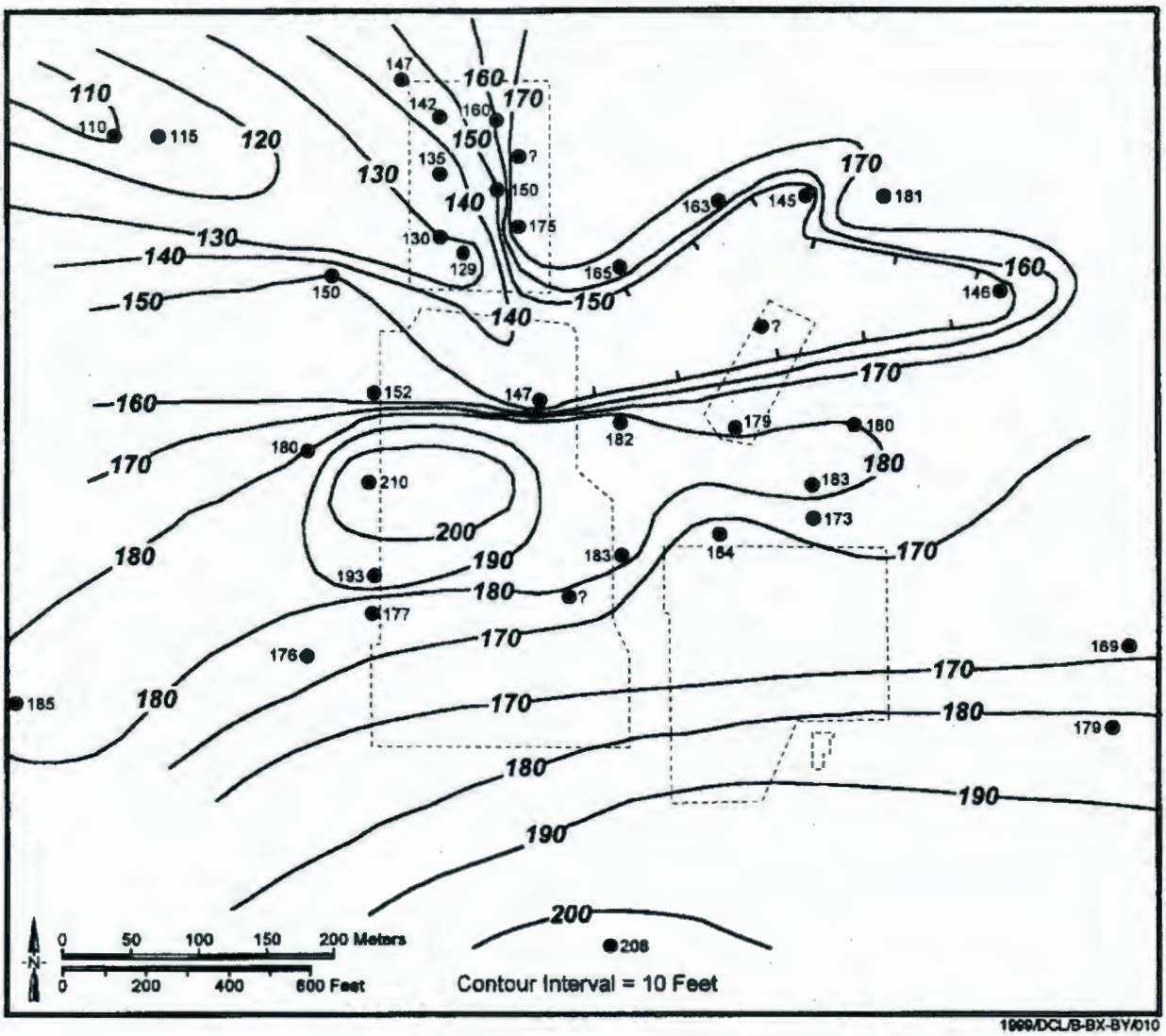

Figure B-16. Thickness of the Hanford Formation Upper Gravel Sequence (H1 unit).

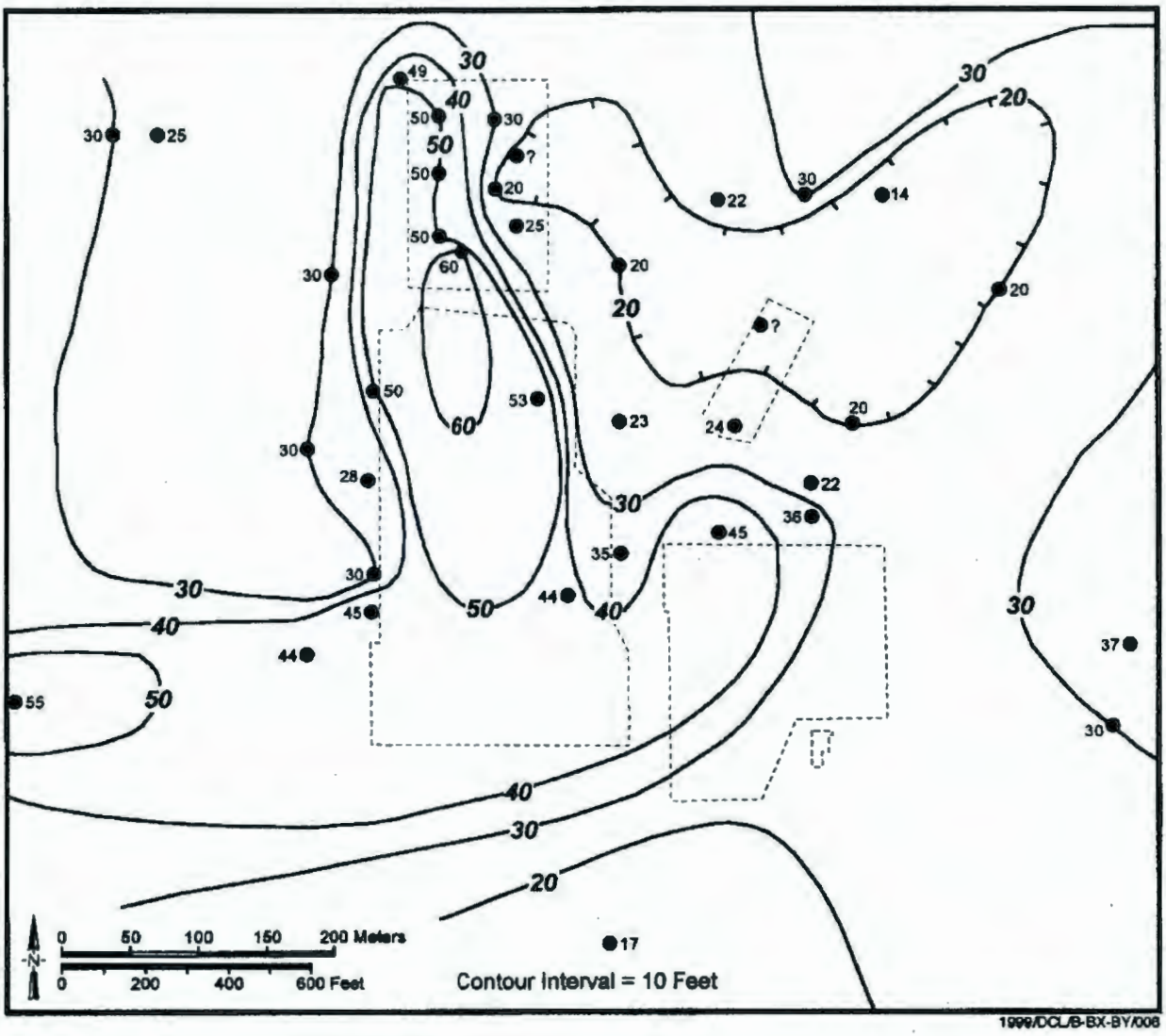

Figure B-17. Regional Groundwater Plume of Hazardous Constituents.

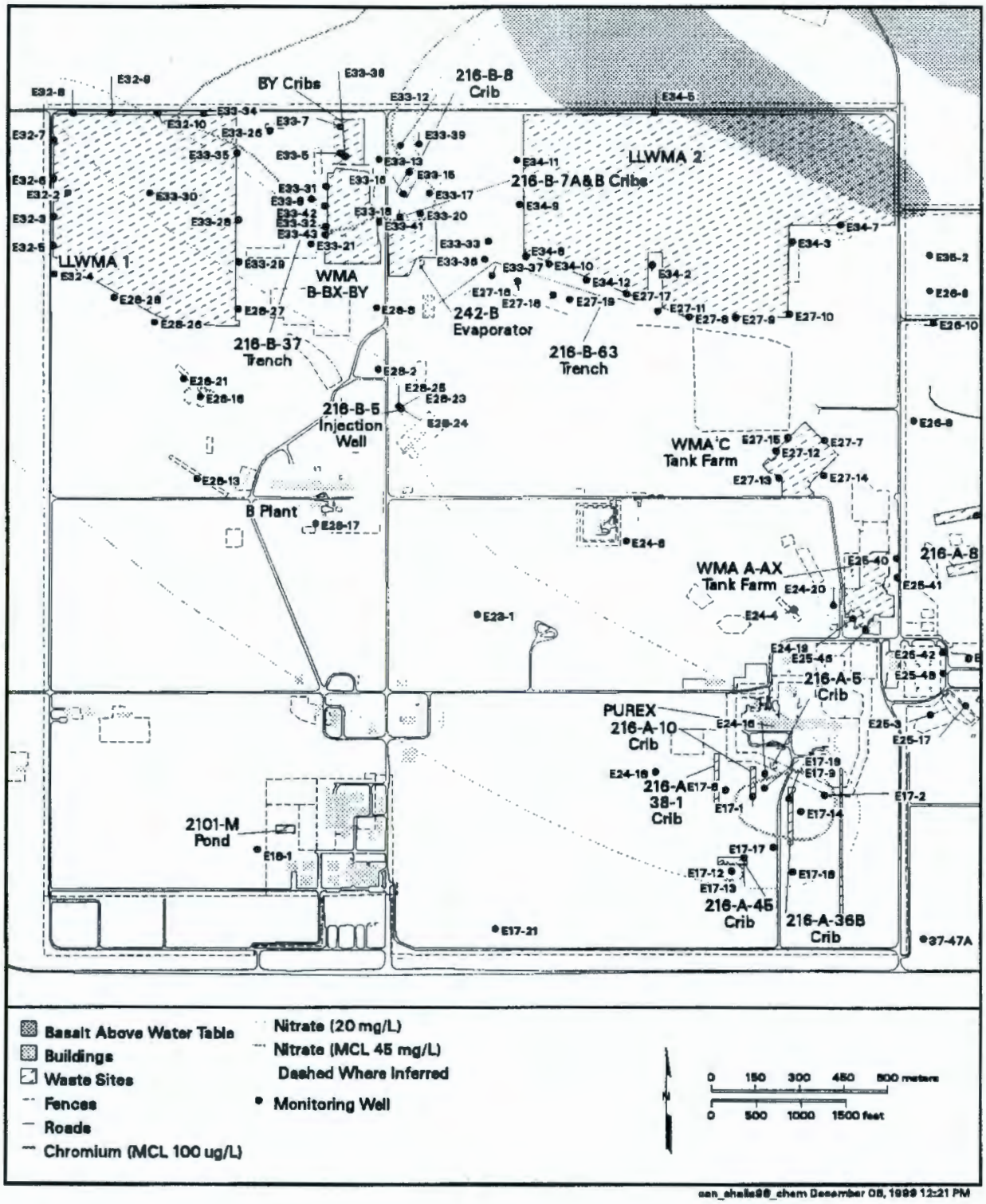

Figure B-18. Regional Groundwater Plume of Radioactive Constituents.

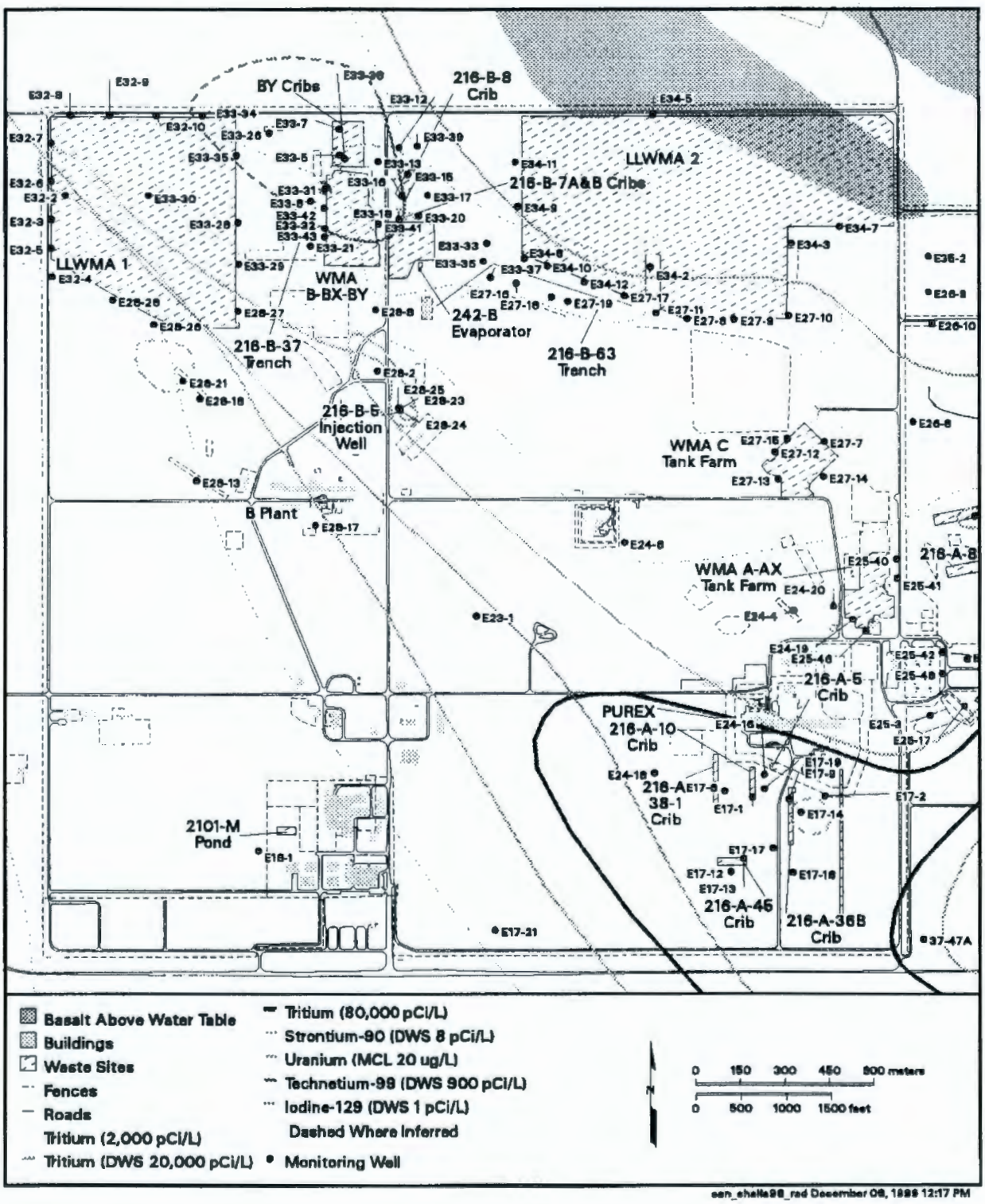

Figure E-3.1 Correlation Plot of Concentrations of Synthetic Radionuclides in Boreholes Surrounding Tank B-103.

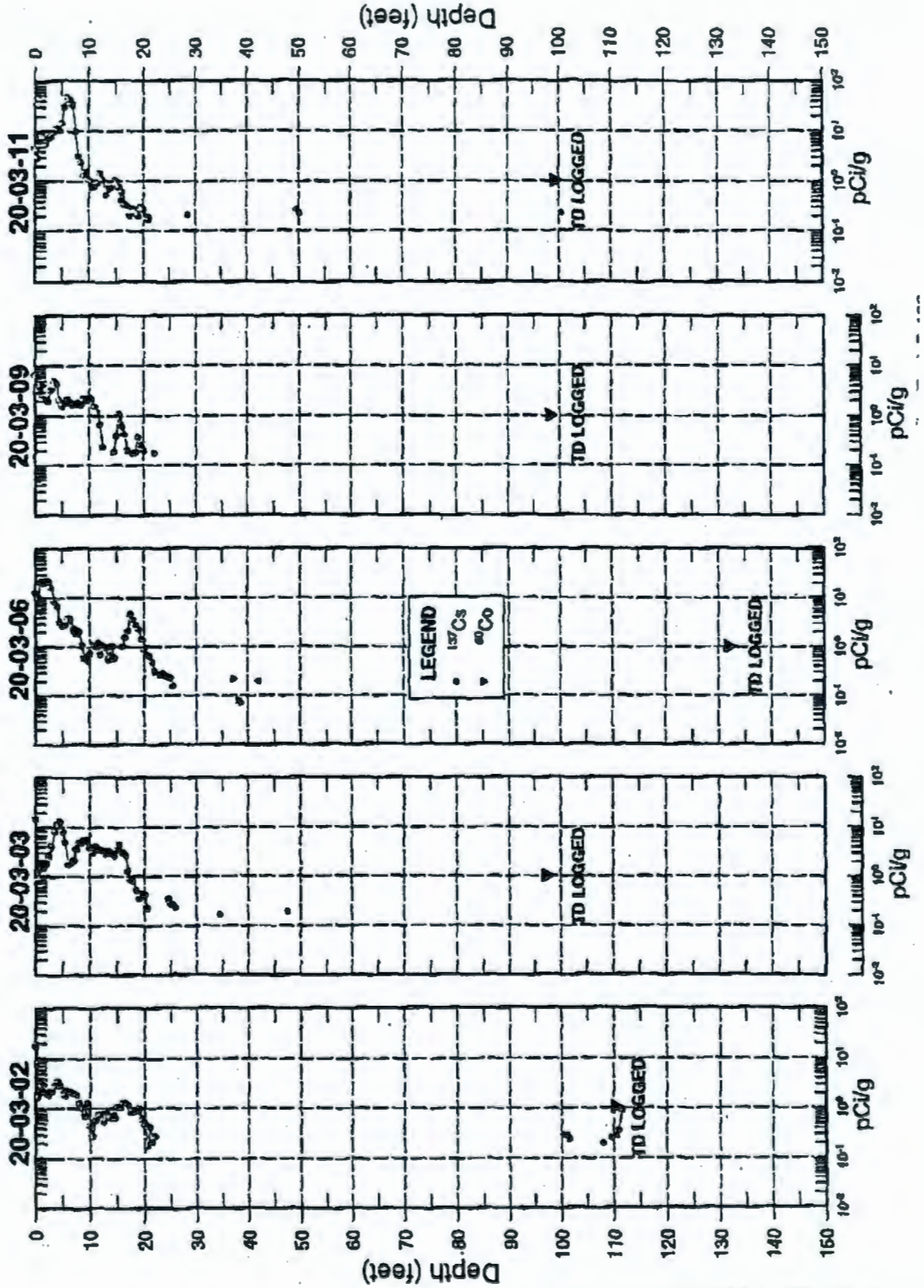

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Table 6. BY Unstable Zones

Borehole Number	Total Depth feet	Subsurface Condition Category	Zone Depth feet	Max. GTP ft*c/s	Year Max. GTP	Isotopes Identified	Comment
22-00-02	100	Unstable	64-96	1,800	1975	^{60}Co	Downward movement at low levels
22-00-03	145	Unstable early	80-117	12,000	1975	^{60}Co	
22-03-09	100	Unstable early	24-52	29,000	1976	^{60}Co; $^{*125}Sb$; $^{*106}Ru$	
		Unstable	48-95	16,000	1976	^{60}Co; $^{*125}Sb$	Downward movement below bottom of well in 1993. Appears to be moving at an estimated rate of 2 feet per year
22-04-09	100-125	Unstable early	75-95	1,800	1980	^{60}Co	
22-05-09	100	Unstable early; undetermined late	55-90	1,000	1975	^{60}Co	Downward movement
22-06-05	100	Unstable	40-84	10,000	1984	^{60}Co; $^{*125}Sb$	Downward movement
22-06-07	140	Unstable early	40-52	300	1975	^{137}Cs	
		Unstable early	52-80	1,100	1979	^{60}Co	Downward and lateral movement
22-06-09	100	Unstable early	70-90	650	1975	$^{*106}Ru$	
22-07-01	100	Unstable early	40-52	800	1976	^{137}Cs	
22-07-02	100	Unstable early	42-95	2,800	1976	^{60}Co	May be downward movement along casing; contaminant may be below bottom of well
22-07-05	100	Unstable early	40-78	3,800	1975	^{60}Co	Downward movement within the zone from 42 to 65 feet
22-07-07	100	Unstable early	30-54	2,500	1975	^{137}Cs; $^{*125}Sb$; $^{*106}Ru$	
		Unstable	80-98	1,800	1976	^{60}Co; ^{125}Sb	Stable since 1983 or 1990
22-07-09	100	Unstable	62-100	2,200	1976	^{137}Cs; ^{60}Co	Downward movement to below well bottom in 1990
22-08-01	100	Unstable	59-95	12,000	1975	^{60}Co; $^{*125}Sb$	Movement of isotopes is unclear; stable from 1985 to 1994
22-08-02	100	Unstable	44-100	15,000	1975	^{60}Co; $^{*125}Sb$	Downward movement, possibly below bottom of borehole
22-08-05	100	Unstable early	63-84	900	1975	^{60}Co	Downward movement
22-08-06	100	Unstable early	73-83	450	1975	^{60}Co	Levels too low to identify downward movement
22-08-09	100	Unstable early	72-84	150	1975	^{137}Cs; $^{*106}Ru$	
22-08-12	105	Unstable early	25-40	300	1980	^{137}Cs	^{137}Cs decay curve does not fit GTP plot
		Unstable early	40-51	3,000	1975	^{60}Co; $^{*125}Sb$	
		Unstable early	51-60	3,000	1975	^{60}Co	Possible downward movement
		Unstable early	60-82	1,000	1976	^{60}Co	Downward movement within the zone
22-09-07	100	Unstable early	20-40	12,000	1975	$^{*106}Ru$	
		Unstable early	40-50	9,000	1976	$^{*106}Ru$	
		Unstable early	50-64	2,700	1976	$^{*125}Sb$; $^{*106}Ru$	
22-09-11	100	Unstable early	38-52	3,500	1975	$^{*106}Ru$	
22-10-05	100	Unstable early	55-75	300	1979	^{60}Co	
22-10-07	100	Unstable early	45-65	200	1983	^{60}Co	
22-10-10	100	Unstable early	58-76	1,500	1975	^{60}Co	
22-11-01	100	Unstable	19-28	4,000	1984	^{137}Cs	
22-11-09	100	Unstable early	34-46	250	1975	^{60}Co	

*Currently, isotopes cannot be identified from gross gamma ray data alone; therefore, isotopes with a rapid rate of decay, such as Ru-106, or at low enough levels to decay below detection limits, may not be identified if the period of instability is prior to the collection of SGLS data.

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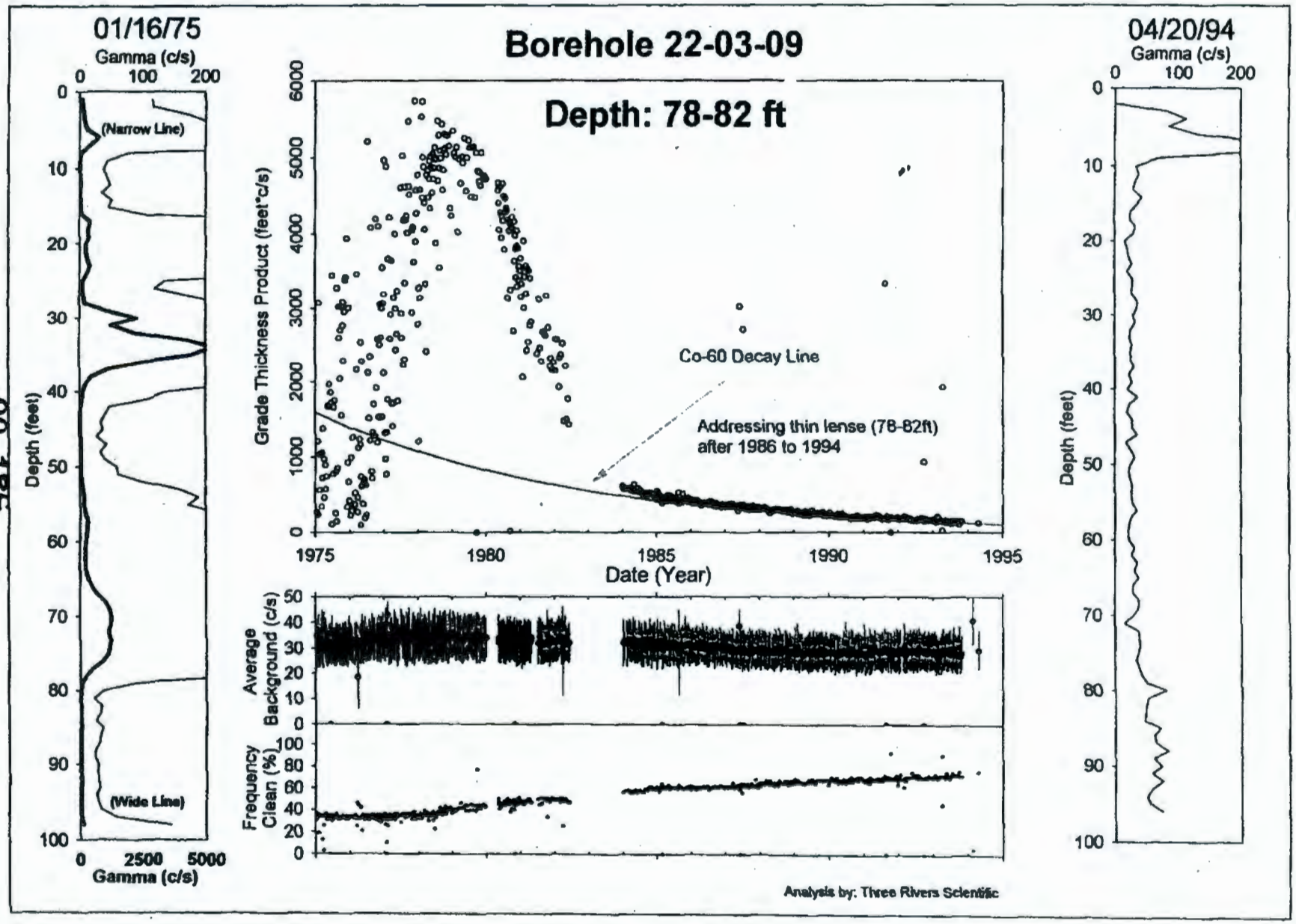
Table 10. BY Tank Farm Unstable Zone Parameters

Borehole Number	Total Depth feet	Subsurface Condition Category	Zone Depth feet	Interval of Instability	Isotopes Identified	**Comment
22-00-02	100	Unstable	64-96	1979-1994	^{60}Co	^{137}Cs decay curve fits, but was not used as ^{137}Cs was not id'd by the SGLS
22-00-03	145	Unstable early	80-117	1975-1976	^{60}Co	
22-03-09	100	Unstable early	24-52	1975-1977	^{60}Co; $^{*125}Sb$; $^{*106}Ru$	Incr. 1975-1976; decr. 1976-1977
		Unstable early	44-52	1975-1984	$^{*106}Ru$	Incr. 1975-1980; sharp incr. 1980-mid 1982
		Unstable	78-92	1975-1985	^{60}Co; $^{*125}Sb$	Incr. 1975-1979; decr. 1979-1985
		Unstable	48-95	1975-1990	^{60}Co	Incr. 1975-1976; stable 1976-1978; unstable decr. 1978-1990; stable 1990-1994
22-04-09	100-125	Unstable early	75-95	1974-1984	^{60}Co	Incr. 1979-1980; decr. 1980-0982; decr. 1982-1984
22-05-09	100	Unstable	55-90	1975-1985	^{60}Co	Decr.
22-06-05	100	Unstable	36-50	1978-1981	^{60}Co; $^{*125}Sb$	Decr.
		Unstable	62-84	1986-mid1991	^{60}Co	Decr.
		Unstable	28-84	1975-mid1975	^{60}Co; $^{*125}Sb$	Incr.
		Unstable	40-84	1979-1994		Decr. mid 1975-1976; decr. 1979-1994
22-06-07	140	Unstable early	40-52	1975-mid1982	^{137}Cs	Decr.
		Unstable early	52-64	1975-1985	^{60}Co	Incr. 1975-1977; decr. 1977-mid1977; incr. mid1977-1979; decr. 1979-1985
		Unstable early	64-80	1975-1984	^{60}Co	Incr. 1975-1981; decr. 1981-1984
		Unstable early	52-80	1975-mid1979	^{60}Co	Incr. 1975-1977; decr. 1977-mid1977; incr. mid1977-1979
22-06-09	100	Unstable early	70-90	1976-1976	$^{*106}Ru$	Incr. 1975-mid1975; decr. mid1975-1976
22-07-01	100	Unstable early	40-52	1975-1981	^{137}Cs	Incr. 1975-1976; decr. 1976-1981
22-07-02	100	Unstable early	42-53	1975-1994	^{60}Co	Incr. 1975-mid1975; decr. mid1975-1984; decr. 1981-1994
		Unstable early	53-70	1975-1994	^{60}Co	Incr. 1975-1979; rapid incr. 1979-early 1979; decr. early 1979-1981; decr. 1981-1994
		Unstable early	70-82	1980-mid1987	^{60}Co	Incr. 1980-1981; decr. 1981-1987
		Unstable early	82-95	1975-1987	^{60}Co	Decr. 1975-1980; incr. 1982-mid1983; decr. mid1983-1987
22-07-05	100	Unstable early	40-57	1975-1994	^{60}Co	Incr. 1975-mid1975; decr. mid1975-mid1978; incr. mid1978-1979; decr. 1979-1985
		Unstable early	57-65	mid1978-mid1986	^{60}Co	Incr. mid1978-mid1983; decr. mid1983-mid1986
		Unstable early	65-78	1981-mid1987	^{60}Co	Incr.
22-07-07	100	Unstable early	30-54	1980-1994	^{137}Cs; $^{*125}Sb$; $^{*106}Ru$	Step decr. 1980-1981; flat near 0 to 1994
		Unstable	80-98	1975-1985	^{60}Co; ^{125}Sb	Incr. 1975-1976; decr. 1976-1981; incr. 1981-mid1981; decr. mid1981-1985
22-07-09	100	Unstable	62-74	1975-1986	^{137}Cs	Incr. 1975-mid1976; decr. m1976-1986
		Unstable	74-84	1975-mid1988	^{60}Co	Incr. 1975-1979; decr. 1979-mid1980; incr. mid1980-1982; decr. 1982-mid1988
		Unstable	84-94	1982-1989	^{60}Co	Incr. 1982-1986; decr. mid1981-1985; decr. 1985-1994
		Unstable	94-100	1981-1990	^{60}Co	Incr. 1981-mid1981; decr. mid1981-mid1982; incr. 1984-mid1986; decr. mid1986-1990
22-08-01	100	Unstable	59-95	1975-1986	^{60}Co; $^{*125}Sb$	Decr.

22-08-02	100	Unstable	44-62	1975-1994	^{60}Co; $^{*125}Sb$	Decr. 1975-1982 flat near 0 1982-1994
		Unstable	62-72	1975-1994	$^{*125}Sb$	Incr. 1975-1977; decr. 1977-1994
		Unstable	72-84	1975-1994	$^{*125}Sb$	Decr. 1975-1981; incr. 1981-1985; decr. 1985-1994
		Unstable	84-100	1975-1994	$^{*125}Sb$	Decr. 1975-1988; incr. 1988-1991; decr. 1991-1994
22-08-05	100	Unstable early	63-74	1975-1986	^{60}Co	Decr.
		Unstable early	74-84	mid1984-1990	^{60}Co	Incr.
22-08-06	100	Unstable early	73-83	1975-1977	^{60}Co	Flat
22-08-09	100	Unstable early	72-84	1975-1976	^{137}Cs; $^{*106}Ru$	Incr.
22-08-12	105	Unstable early	25-40	1975-1994	^{137}Cs	Incr. 1975-mid1976; decr. mid1976-1978; incr. 1978-mid1980; decr. mid1980-1983; flat near 0 1983-1994
		Unstable early	40-51	1975-1989	^{60}Co; $^{*125}Sb$	Decr.
		Unstable early	51-60	1975-1983	^{60}Co	Decr. 1975-1979; incr. 1979-mid1983
		Unstable early	60-70	1975-1987	^{60}Co	Decr.
		Unstable early	70-82	1975-1983	^{60}Co	Incr.
22-09-07	100	Unstable early	20-40	mid1978-1982	$^{*106}Ru$	Decr.
		Unstable early	40-50	1975-1984	$^{*106}Ru$	Incr. 1975-1976; decr. 1980-1984
		Unstable early	50-64	1980-1990	$^{*125}Sb$; $^{*106}Ru$	Decr.
22-09-11	100	Unstable early	38-52	1975-1976	$^{*106}Ru$	Decr.
22-10-05	100	Unstable early	55-75	1975-1979	^{60}Co	Incr.
22-10-07	100	Unstable early	45-65	1980-1994	^{60}Co	Incr. 1980-1983; decr. 1983-1985; flat near 0 1985-1994
22-10-10	100	Unstable early	58-76	1975-1980	^{60}Co	Decr.
22-11-01	100	Unstable	19-28	1982-1994	^{137}Cs	Incr. 1982-1984; decr. 1984-1994
22-11-09	100	Unstable early	34-46	1975-mid1978	^{60}Co	Flat

*Currently, isotopes cannot be identified from gross gamma ray data alone; therefore, isotopes with a rapid rate of decay, such as Ru-106, or at low enough levels to decay below detection limits, may not be identified if the period of instability is prior to the collection of SGLS data.

**Unless otherwise noted, the GTP plot decreases consistent with the decay curve of known isotopes.


Borehole 22-03-09
Depth: 78-82 ft
01/16/75
Gamma (c/s)
0 100 200
(Narrow Line)
(Wide Line)
Depth (feet)
0 2500 5000
Gamma (c/s)
Grade Thickness Product (feet*c/s)
Co-60 Decay Line
Addressing thin lense (78-82ft)
after 1986 to 1994
1975 1980 1985 1990 1995
Date (Year)
Average Background (c/s)
Frequency Clean (%)
04/20/94
Gamma (c/s)
0 100 200
Depth (feet)
Analysis by: Three Rivers Scientific

HNF-3532 -REVO

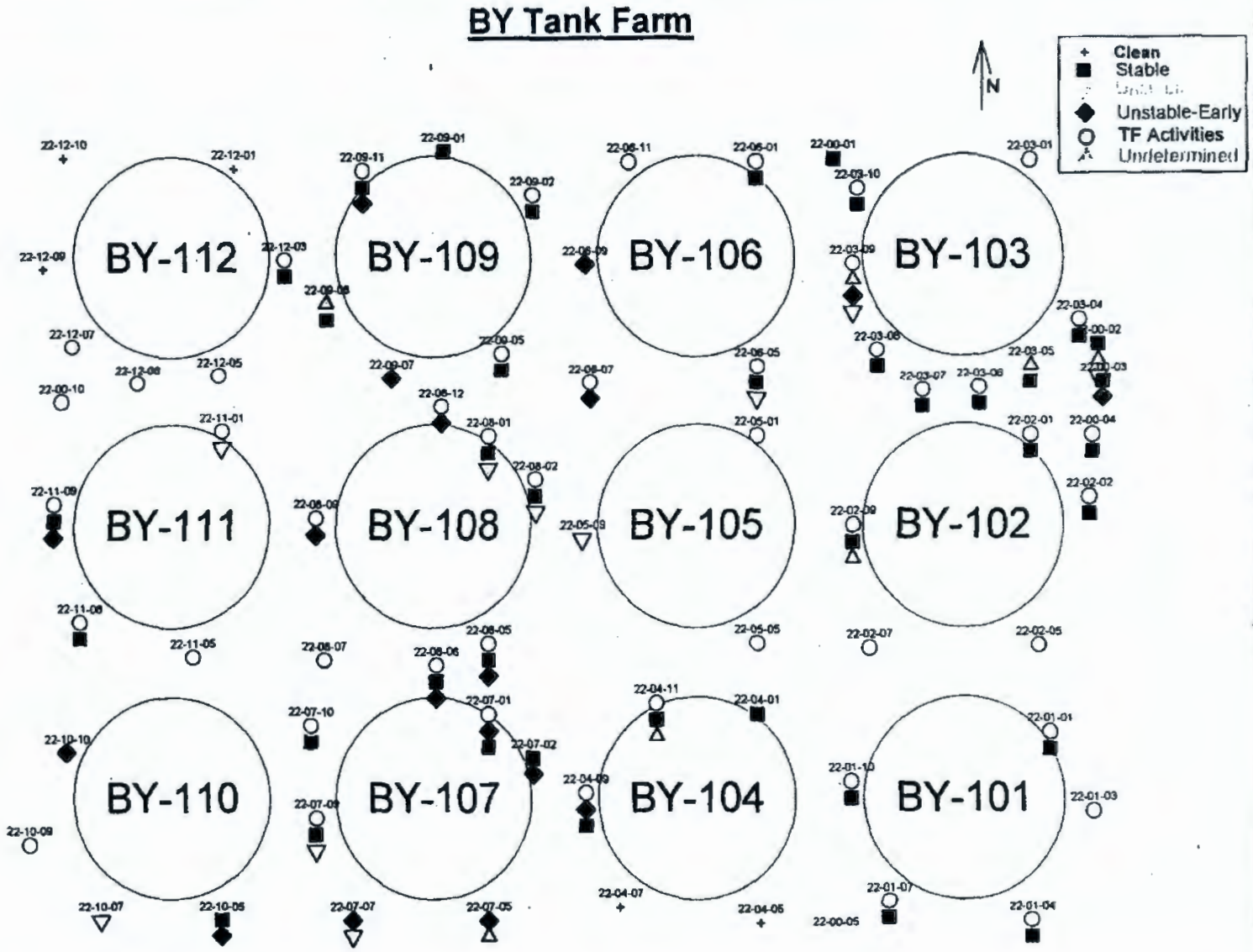


Figure 2. BY Tank Farm Radiation Zone Conditions