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Hanford Site Ground-Water Monitoring for 1990

J. C. Evans
R. W. Bryce
D. J. Bates

June 1992

Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
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Pacific Northwest Laboratory
Richland, Washington 99352

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SUMMARY

The Pacific Northwest Laboratory monitors ground-water quality across the Hanford Site for the U.S. Department of Energy (DOE) to assess the impact of Site operations on the environment. Monitoring activities were conducted to determine the distribution of mobile radionuclides and identify chemicals present in ground water as a result of Site operations and whenever possible, relate the distribution of these constituents to Site operations. To comply with the Resource Conservation and Recovery Act, additional monitoring was conducted at individual waste sites by the Site Operating Contractor, Westinghouse Hanford Company (WHC), to assess the impact that specific facilities have had on ground-water quality. Six hundred and twenty-nine wells were sampled during 1990 by all Hanford ground-water monitoring activities.

Radiological monitoring results indicated that gross alpha, gross beta, tritium, cobalt-60, strontium-90, technetium-99, iodine-129, and cesium-137 concentrations in wells in or near operating areas were at levels above the drinking water standard (DWS). Concentrations of uranium in the 200-West Area were above the derived concentration guide (DCG). Concentrations of tritium in the 200 Areas and strontium-90 in the 100-N and 200-East areas were also above the DCG. Iodine-131, ruthenium-103, and other short-lived radionuclides remained below detectable levels in ground water as a direct consequence of the cessation of nuclear production operations on the Site.

Certain chemicals regulated by the U.S. Environmental Protection Agency and the State of Washington were also present in Hanford ground water near operating areas. Nitrate concentrations exceeded the DWS at isolated locations in the 100, 200, and 300 areas and in several 600 Area locations. Chromium concentrations were above the DWS at 100-D, 100-H, and 100-K areas, and the surrounding areas. Chromium concentrations above the DWS were also found in the 200-East and 200-West areas. High concentrations of carbon tetrachloride were found in wells in the 200-West Area. Trichloroethylene was found at levels exceeding the DWS at wells in and near the 100-F Area and

300 Area. Trichloroethylene concentrations dropped to just below the DWS at the Solid Waste Landfill; however, tetrachloroethylene levels remained slightly above the DWS at that location.

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ABBREVIATIONS

CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act of 1980
CFR	Code of Federal Regulations
DCE	dichloroethylene
DCG	derived concentration guide
DOE	U.S. Department of Energy
DWS	drinking water standard
EPA	U.S. Environmental Protection Agency
FFTF	Fast Flux Test Facility
ITC	International Technology Corporation
LWDF	liquid waste disposal facility
MCL	maximum contaminant level
NRDW	nonradioactive dangerous waste
PNL	Pacific Northwest Laboratory
PUREX	Plutonium-Uranium Extraction (Plant)
RCRA	Resource Conservation and Recovery Act
REDOX	Reduction/Oxidation (Plant)
SARA	Superfund Amendments and Reauthorization Act
SWL	Solid Waste Landfill
TCE	trichloroethylene
UST	United States Testing Company
WAC	Washington Administrative Code
WHC	Westinghouse Hanford Company

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1.0 INTRODUCTION

The Pacific Northwest Laboratory (PNL)[a] monitors the distribution of radionuclides and other hazardous substances in ground water at the Hanford Site (Figure 1.1) for the U.S. Department of Energy (DOE). This work is performed through the Ground-Water Surveillance Project and is designed to meet the requirements of DOE Order 5400.1 that apply to environmental surveillance and ground-water monitoring.

DOE Order 5400.1 was issued November 9, 1988, to establish direction for environmental protection programs at DOE facilities (DOE 1988b). This order requires the use of an environmental surveillance program at DOE facilities. Environmental surveillance activities are conducted to monitor the effects, if any, of DOE activities at Hanford to onsite and offsite environmental and natural resources. The Ground-Water Surveillance Project is designed to satisfy one or more of the following program objectives as identified in the DOE order:

- verify compliance with applicable environmental laws and regulations
- verify compliance with environmental commitments made in environmental impact statements, environmental assessments, safety analysis reports, or other official DOE documents
- characterize and define trends in the physical, chemical, and biological condition of the environment
- establish baselines of environmental quality
- provide a continuing assessment of pollution abatement programs
- identify and quantify new or existing environmental quality problems.

In addition to the Hanford Ground-Water Surveillance Project, which monitors contaminant distribution across the Site, two ground-water monitoring activities are being conducted at Hanford by Westinghouse Hanford Company

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(a) The Pacific Northwest Laboratory is operated for the U.S. Department of Energy by Battelle Memorial Institute.

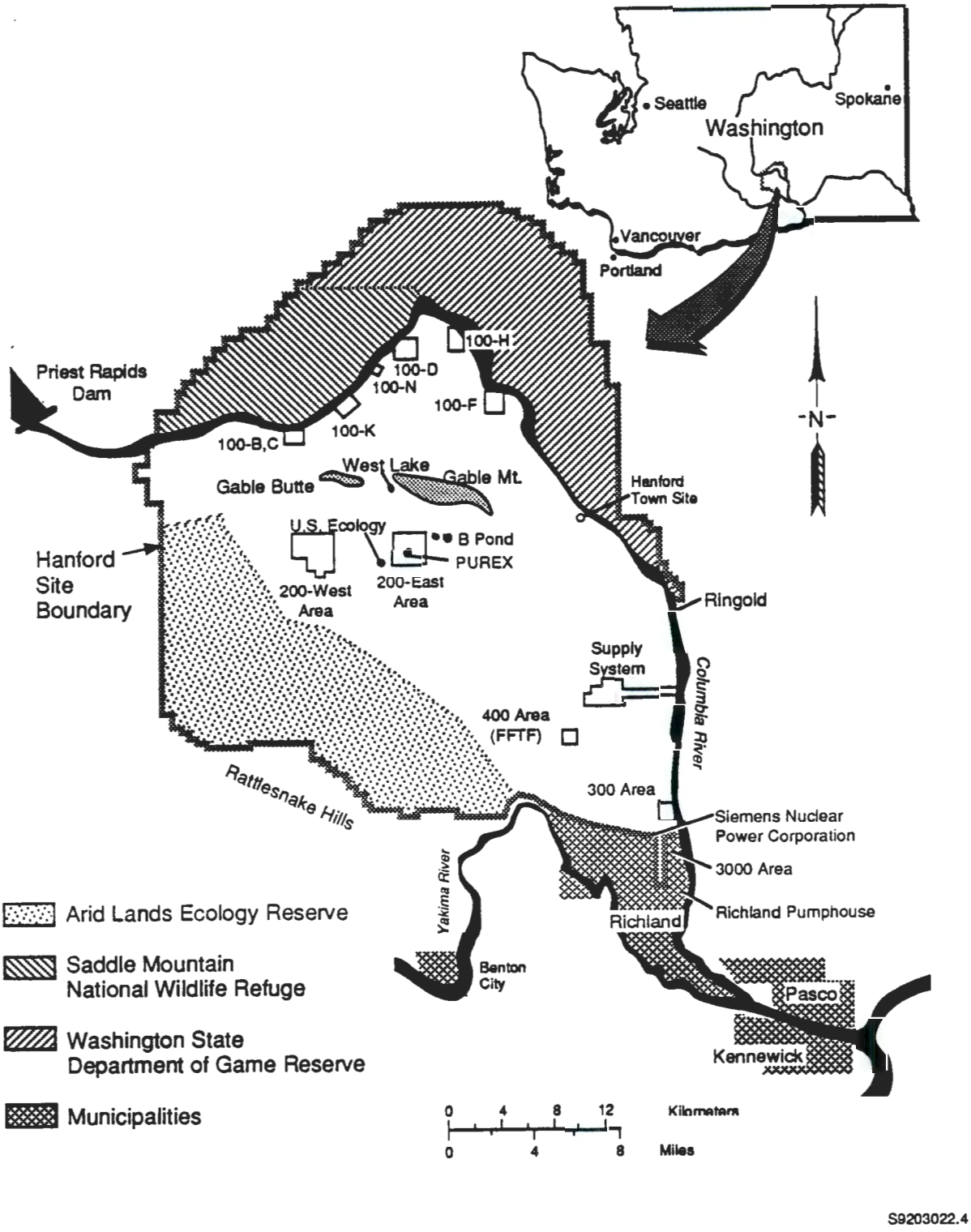

FIGURE 1.1. Hanford Site Location Map

(WHC). Ground-water samples are collected for operational monitoring in and around the 200 Areas for compliance with DOE orders and for facility-specific monitoring for compliance with the Resource Conservation and Recovery Act (RCRA) (40 CFR 265) and Washington Administrative Code (WAC 173-303 and -304). The facility-specific activities include sampling programs at facilities listed in Table 1.1. The results of some of these activities are discussed briefly in this report and are reported in more detail elsewhere (DOE 1991a). The compliance monitoring results (primarily for chemicals) are valuable in determining the total impact of Site operations on ground water and, therefore, are used by the Ground-Water Surveillance Project to meet its objectives.

This annual report discusses results of ground-water monitoring at the Hanford Site during 1990. In addition to the general discussion, the following topics are discussed in detail: 1) carbon tetrachloride in the 200-West Area; 2) cyanide in and north of the 200-East and the 200-West areas; 3) hexavalent chromium contamination in the 100, 200, and 600 areas; 4) trichloroethylene in the vicinity of the Solid Waste Landfill, 100-F Area, and 300 Area; 5) nitrate across the Site; 6) tritium across the Site; and 7) other radionuclide contamination throughout the Site, including gross alpha, gross beta, cobalt-60, strontium-90, technetium-99, iodine-129, cesium-137, uranium, and plutonium. Some of the figures in this report (i.e. plume maps) show data for a 24-month or 36-month period (January 1, 1988, to December 30, 1990) to adequately represent Site conditions. Water level monitoring results for 1990 are discussed in a separate report (Newcomer et al. 1991). Additional discussions of the hydrology and geology of the Site, operational activities, and sampling, analysis, and distributions of average constituent concentrations during 1990 are included in PNL's annual environmental report (Woodruff and Hanf 1991).

WHC reports operational monitoring results for the 200 Areas (e.g., WHC 1990a,b), and RCRA monitoring results are documented in annual reports (e.g., DOE 1991a).

TABLE 1.1. Waste Disposal Facilities with Ongoing Sampling Projects

100-D Pond
1301-N Crib
1324-N/NA Ponds
1325-N Crib
183-H Solar Evaporation Basins

216-A-10 Crib
216-A-29 Ditch
216-A-36B Crib
216-B-3 Pond
Grout Treatment Facility
Liquid Retention Facility (200 Area)

Solid Waste Landfill
Nonradioactive Dangerous Waste (NRDW) Landfill

216-B-63 Ditch
216-S-10 Pond
216-U-12 Crib
Single-Shell Tanks
200 Area Low-Level Burial Grounds
2101-M Pond

300 Area Process Trenches

2.0 RADIOLOGICAL AND CHEMICAL GROUND-WATER MONITORING

2.1 DATA COLLECTION

The well network used for the Ground-Water Surveillance Project is a combination of several networks that have been designed for facility-specific, operational, and site-wide environmental surveillance activities. The basis for selecting wells, the sampling frequencies, and the constituents analyzed is different for each of these projects and is based on the individual project objectives. The sampling schedules for the operational and facility-specific networks (RCRA monitoring) are reviewed in the context of environmental surveillance needs. A supplemental monitoring network is developed to meet the surveillance objectives (Bisping 1991).

The majority of radiological and chemical analysis data presented in this and all previous ground-water surveillance reports was produced by United States Testing Company (UST) in Richland, Washington. United States Testing Company performed analytical services for all Hanford Site contractors through a very comprehensive analytical services contract negotiated annually by PNL. In 1989 and 1990, the U.S. Environmental Protection Agency (EPA) conducted an investigation of UST associated with allegations of improper practices used in performance of Contractor Laboratory Services rendered for the EPA. The investigation was concerned primarily with organic analyses conducted in UST's Hoboken, New Jersey, facility; however, the Richland facility was also implicated. Because of the seriousness of the charges, which resulted in a temporary debarment of UST from award of new government contracts, the DOE also initiated a parallel investigation of their own focusing on the work performed in Richland for DOE needs. In response to these developments, PNL initiated a very comprehensive audit of UST, Richland in May 1990. The audit was designed to investigate integrity of past data through the use of vertical slice auditing techniques applied to inorganic, organic, and radiological data spanning the entire period of performance. A second PNL audit was performed in parallel aimed at current adherence to contractually specified procedures. Pacific Northwest Laboratory management terminated the analytical services contract with UST on June 1, 1990, citing irregularities in contractual performance

revealed by the audit. Several intensive reviews of data quality were initiated following the termination. An independent data quality study is being conducted by the University of Washington. Pacific Northwest Laboratory has completed a detailed study of ground-water data quality that will be published as a separate PNL report in early 1992. The conclusions from the PNL study are on the whole very reassuring. United States Testing Company data on blind interlaboratory comparison samples show excellent overall performance for organic, inorganic, and radiological analytes. Preliminary findings by the University of Washington group are reportedly favorable also; however, as the full report has not yet been received by PNL for review, that conclusion remains tentative.

Termination of analytical services in June 1990 resulted in major programmatic impact to all Hanford environmental monitoring activities including ground-water surveillance. The sampling program was temporarily halted and some samples collected to that point were archived. Numerous samples already submitted to UST but not yet analyzed up to the time of termination could not be retrieved in usable form. Starting in July 1990, some limited ground-water surveillance sampling was resumed. Samples collected for analysis of constituents with relatively nonrestrictive holding times were temporarily archived pending resumption of analytical services. Analytes with short holding times (i.e., nitrate and volatile organic compounds) were analyzed promptly by a PNL in-house laboratory. No further sampling for RCRA compliance was performed during the remainder of the calendar year. Negotiations for a temporary replacement contract with International Technology Corporation (ITC) were successfully concluded in October 1990; however, ITC was not ready to accept samples for radiochemical analysis until mid-February 1991 and until June 1991 for hazardous chemical analysis. Pacific Northwest Laboratory then began submitting archival samples as well as newly collected samples.

2.1.1 Facility-Specific Monitoring

Well networks have been established for WHC around specific waste-disposal facilities to comply with RCRA requirements. All facility-specific projects are listed in Table 1.1.

The requirements for monitoring-well design and location, constituents to be sampled, and sampling frequencies are specified in RCRA regulations (40 CFR 265) and by Washington Administration Code (WAC 173-303 and -304). Ground-water monitoring systems at each site must consist of at least one monitoring well hydraulically upgradient and at least three monitoring wells downgradient of the facility. The location, depth, and number of wells included in the network must ensure that results obtained to evaluate the migration of contaminants to the uppermost aquifer are statistically significant. The RCRA regulations require that ground water be sampled and analyzed for 1) drinking water parameters, 2) parameters that establish ground-water quality, and 3) parameters used as indicators of ground-water contamination. Samples are also analyzed for contaminants known to have been disposed of at the facility being monitored. The frequency of sampling for each parameter is also specified in the RCRA regulations, based on the status of permitting of the facility (e.g., interim status, permitted status). Annual reports (DOE 1991a) document monitoring networks and analytical plans for these RCRA sites.

2.1.2 Operational Monitoring

Operational monitoring near waste facilities in the 200 Areas is conducted by WHC to allow the performance of waste disposal and storage sites to be evaluated and to assess the impact of specific sites on ground water. The operational monitoring program was significantly redesigned in 1989 and 1990 to reflect the diminishing importance of Site production operations. A highly focused study entitled "Liquids Effluents Study" (WHC 1990a,b) was performed in 1989 and 1990, which aimed at very intensive characterization of ground water associated with key operational areas of remaining concern. The study involved 90 wells in both the 200 Areas. Some of the wells were specially remediated for the purposes of the study, thus providing new sampling locations not previously (or at least recently) sampled. All wells were sampled for a base set of EPA RCRA Appendix 9 chemical constituents as well as gross alpha, gross beta, and tritium. In addition, some selected radiological constituents such as technetium-99, uranium, and plutonium were included on a

discretionary basis if operational information suggested contamination potential by those species. Results of that study have been published in two reports by WHC (1990a,b).

2.1.3 Environmental Surveillance

The objective of environmental surveillance is to monitor the distribution and movement of radionuclides and other hazardous materials in ground water at the Hanford Site. The work is performed to satisfy the environmental surveillance requirements identified in DOE Order 5400.1 as it applies to ground water. The selection of wells, constituents for which samples are collected and analyzed, and sampling frequency are based on knowledge of waste disposal practices and inventories, regulatory requirements, contaminant mobility, and the site hydrogeology.

2.1.3.1 Radiological Monitoring

The radiological monitoring network was developed to monitor the extent of contamination, identify new instances of contaminant release to the ground water, and sample for selected radionuclides that may contribute to radiation dose. Wells and constituents near operational and facility-specific networks were selected to complement monitoring under these programs. For example, some wells in the 200 Areas monitored by WHC to evaluate facility operation are sampled for additional constituents to meet the objectives of ground-water surveillance.

Samples collected for radiological analysis are primarily analyzed for tritium and gross alpha, gross beta, gamma scans, and beta counting for radiochemical separates (i.e., strontium-90 and technetium-99). The maximum extent of radionuclide contamination in the ground water beneath the Hanford Site is defined using tritium because nearly all radioactive waste disposed of at Hanford contains tritium. Tritium exists as part of the water molecule and as such moves with the ground water relatively unretarded by chemical and physical interaction with dissolved constituents and aquifer materials. Tritium was also concentrated in certain large-volume wastes, such as reactor coolant in the 100 Areas and process condensates in the 200 Areas.

Gross alpha and gross beta analyses and gamma scans are used to identify potential new releases of radionuclides in a cost-effective manner at certain locations. These techniques are used to survey wells throughout the Site for a wide variety of alpha-, beta-, and gamma-emitting radionuclides. If measurable quantities of alpha, beta, or gamma radiation are found, samples may be collected and analyzed for individual radionuclides. Subsequent analyses are chosen on the basis of radionuclide inventories, radionuclide mobilities, and concern of the potential dose to humans.

Gross alpha concentrations above background may indicate the sample contains uranium or plutonium. Uranium is an alpha-emitting radionuclide that is mobile in ground water and is commonly the radionuclide responsible for elevated gross alpha concentrations at the Hanford Site. Uranium is also a potential concern in terms of its dose to man. Plutonium is another alpha emitter that may contribute to gross alpha activity. Past monitoring for plutonium suggests that it is highly immobile in ground water and hence has in past years been monitored in only a few wells near facilities suspected of receiving plutonium. These wells are all located within the 200 Areas. A major expansion of the plutonium monitoring effort in 1990 confirmed this assessment.

Elevated gross beta concentrations are more difficult to associate with individual radionuclides because of the relatively large number of beta-emitting radionuclides that have been discharged in Hanford liquid wastes. Of the beta-emitting radionuclides discharged on Site, strontium-90 has been a common contributor to elevated gross beta concentrations in ground water. Strontium-90 is monitored in ground-water samples collected throughout the Hanford Site, with emphasis on the operating areas. Other relatively mobile beta emitters of potential dose concern in the ground water are technetium-99 and iodine-129. Radioactive decay products of uranium also contribute to gross beta concentrations in areas with elevated uranium.

Gamma scans provide a quantitative assay for a large number of gamma-emitting isotopes with a range of half-lives. Because these assays are performed by high-resolution counting techniques, it is possible to identify isotopes of interest with a high degree of confidence. In addition, a

software library search can be used to identify unknowns. Isotopes routinely reported include cesium-137, cobalt-60, antimony-125, and numerous other short-lived fission and activation products, as well as some naturally occurring isotopes such as potassium-40.

2.1.3.2 Chemical Monitoring

A subset of both the PNL ground-water surveillance and the WHC operational radiological monitoring networks is used for environmental surveillance chemical sampling (in addition to nitrate) by PNL. Chemical sampling wells are selected primarily for their proximity to known active and inactive chemical disposal areas in the 100, 200, and 600 areas, and on the basis of the compiled waste inventories (Stenner et al. 1988). During 1990, 487 wells were sampled for selected chemical constituents (i.e., nitrate at a minimum) as part of the Hanford ground-water surveillance projects. This number represents a significant reduction from the number sampled in the previous 2 years because of programmatic interruptions (e.g., purge water disposal considerations, termination of analytical services).

Nitrate is monitored in most of the wells sampled. Nitrate, which is mobile in ground water, was present in many of the waste streams disposed of to the ground and, like tritium, can be used to help define the extent of contamination in Hanford aquifers. Extensive historical records also exist for nitrate. Other chemicals and radionuclides related to Site operations that are potential ground-water contaminants are listed in Table 2.1.

TABLE 2.1. Major Chemical and Radiological Ground-Water Contaminants and Their Link to Site Operations

Facilities Type	Area	Constituents
Reactor Operations	100	^{3}H, ^{60}Co, ^{90}Sr, Cr^{6+}, SO_4^{2-}
Irradiated Fuel Processing	200	^{3}H, ^{137}Cs, ^{90}Sr, ^{129}I, ^{99}Tc, NO_3^-, Cr^{6+}, CN^-, F^-, uranium, plutonium
Plutonium Purification	200	CCl_4, $CHCl_3$, plutonium
Uranium Recovery	200	uranium, ^{99}Tc, NO_3^-
Fuel Fabrication	300	uranium, ^{99}Tc, Cr^{6+}, NO_3^-, trichloroethylene

Ground-water samples collected from wells in areas where these constituents have been discharged are analyzed for the appropriate contaminant(s).

2.1.4 Sample Collection for 1990

During 1990, the PNL environmental surveillance radiological sampling network consisted of 629 wells including those cosampled with other projects. Wells were monitored with frequencies ranging from weekly to annually. The majority of the wells were monitored on a semiannual basis.

The unconfined aquifer ground-water surveillance network for 1990 is shown in Figure 2.1. Wells from which samples were collected from the uppermost confined aquifer are shown in Figure 2.2. Detailed maps of operational and facility-specific monitoring well networks for the 100-B, 100-D, 100-F, 100-H, 100-K, 100-N, 200-East, 200-West, 300, 400, and 1100 areas are included in Appendix A.

2.1.5 Monitoring Well Design

Most monitoring wells at the Hanford Site are 15 or 20 cm (6 or 8 in.) in diameter and are constructed of steel casing. Several small-diameter [5-cm (2-in.)] piezometers are sampled for radionuclides only. Monitoring wells for the unconfined aquifer are completed with well screens or perforated casing in the upper 3 to 6 m (10 to 20 ft) of the aquifer. Completion at the water table allows samples to be collected near the top of the aquifer where maximum concentrations for some radionuclides were measured at a few locations on the Hanford Site (Eddy et al. 1978). Confined aquifer monitoring wells have screens, perforated casing, or an open hole within the monitored horizon. Only wells containing submersible pumps were chosen for chemical sampling to allow sufficient purging of wells prior to sampling.

2.1.6 Sampling Methods

Samples are collected using internally documented sampling procedures (PNL 1989) that follow formal, established guidelines (EPA 1986). Wells fitted with submersible pumps are sampled after pumping for a sufficient time (at least 20 min) to allow ground-water temperature, pH, and specific conductivity to stabilize. The purging process removes any stagnant water in the

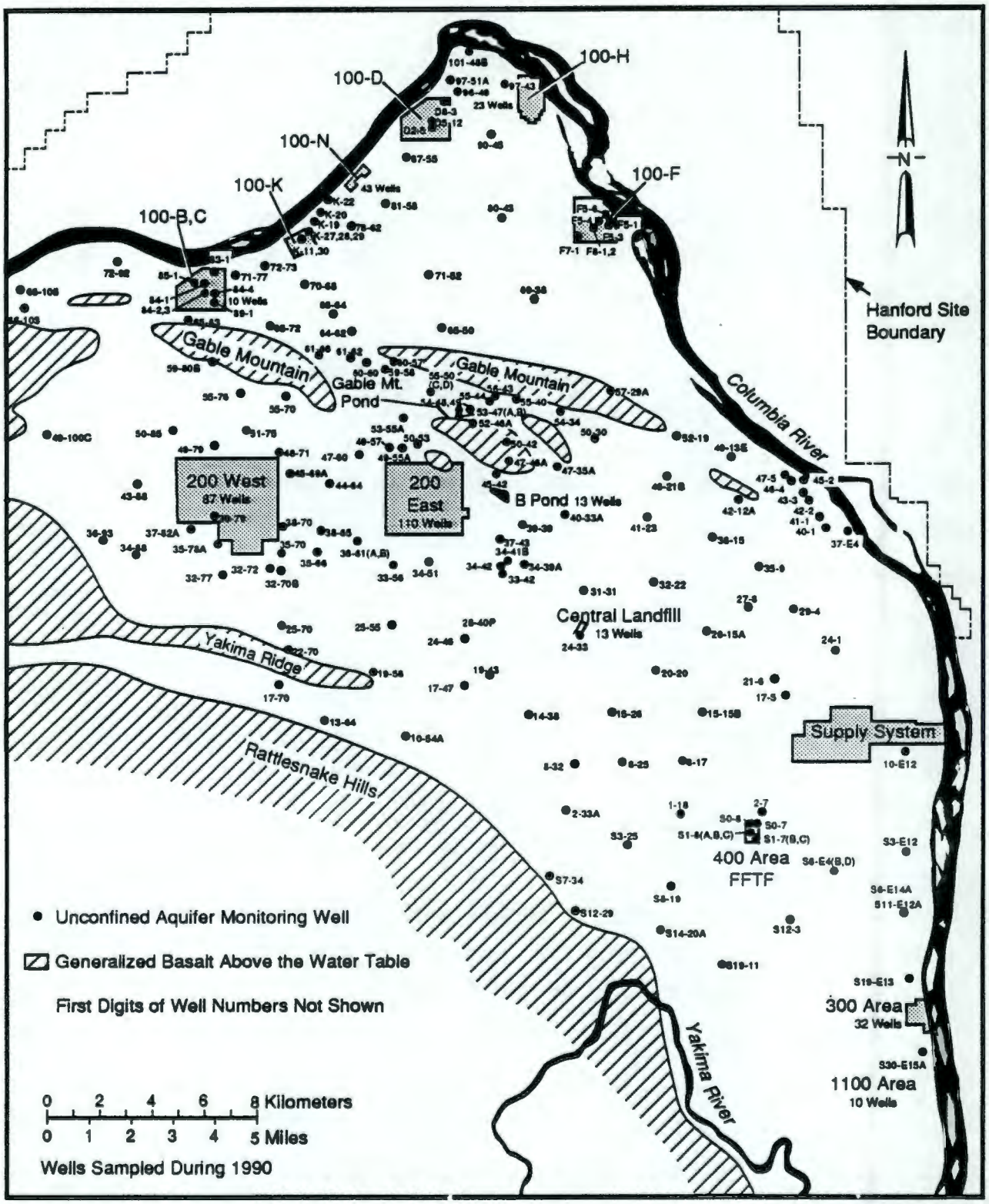

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FIGURE 2.1. Location of Hanford Site Unconfined Aquifer Ground-Water Monitoring Wells

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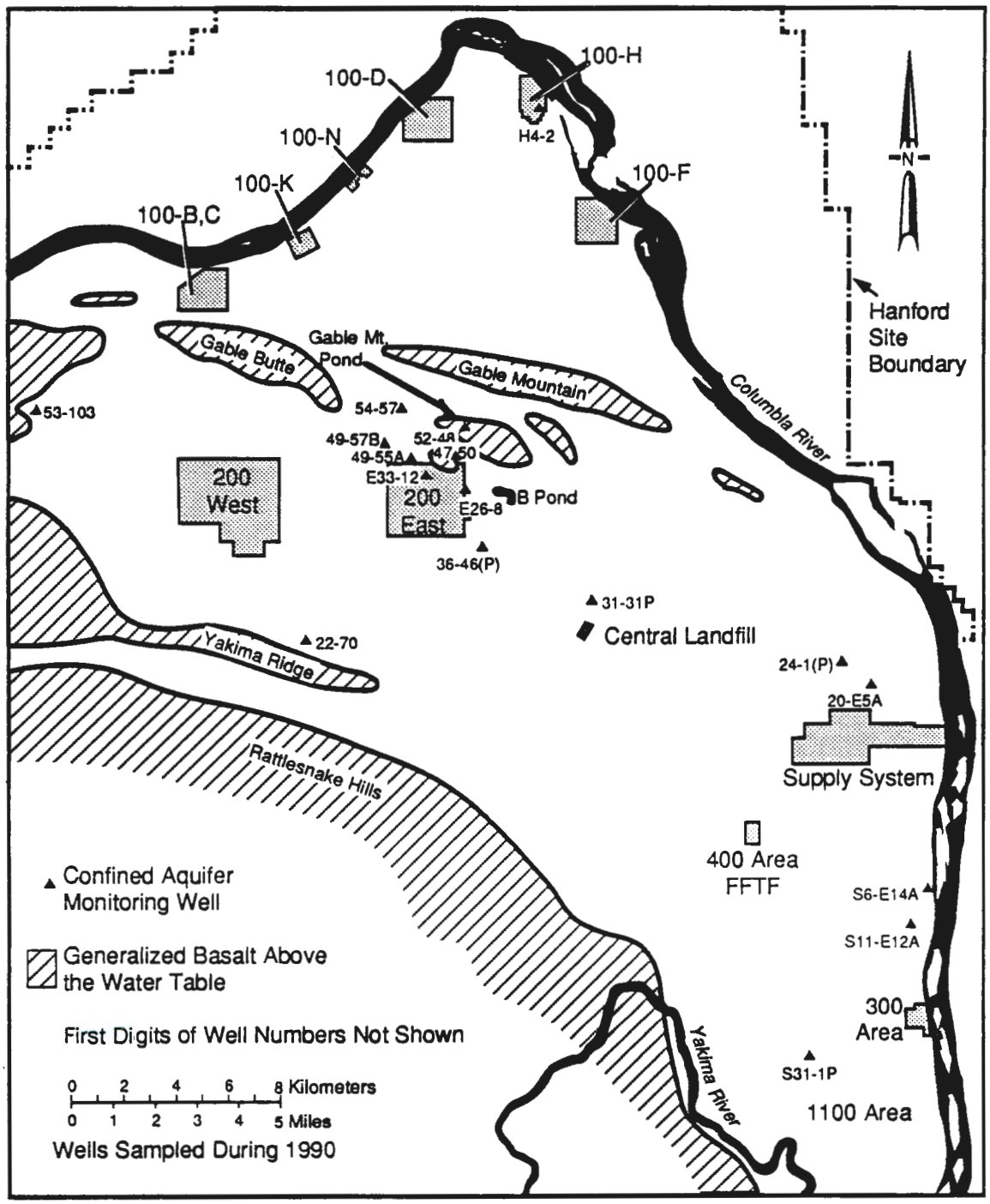

FIGURE 2.2. Location of Hanford Site Confined Aquifer Ground-Water Monitoring Wells

well, allowing collection of a sample that is representative of the ground water in the aquifer near the well.

Samples for volatile organic analyses were taken with zero head space and sealed immediately with a septum-sealed cap. A disposable, 0.45-micron pore-sized filter pack was connected to the Teflon sampling line for sampling filtered trace metals. The filter was purged with 500 mL (0.13 gal) of well water, then a sample was collected in the appropriate sample bottle. Trace metal samples and some radiochemical samples were preserved by acidification at the time of collection. All samples were placed on ice in ice chests immediately after sampling for transport to the analytical laboratory or sample storage facility. Prior to June 1, samples were transferred the same day or early the next morning to UST for immediate analysis of nonconservative chemical species with short holding times (e.g., for nitrate and volatile organic analyses). Following June 1, samples for nitrate, metals, and volatile organic analyses were submitted to a PNL laboratory. Samples for radionuclide analyses were archived until a contract could be established to perform the analyses. Samples were stored at 4°C (39°F) from the time of sampling until they were analyzed. All samples were tracked using chain-of-custody procedures from sampling through analysis and disposal. Procedures for analyzing samples have been described elsewhere (Jaquish and Bryce 1990, Appendix B).

2.2 RADIOLOGICAL AND CHEMICAL MONITORING RESULTS FOR THE UNCONFINED AQUIFER

Results of the Ground-Water Surveillance, operational, and facility-specific ground-water monitoring projects are discussed in this section. Information on contaminants can be found in past environmental monitoring reports by PNL and the operating contractor (Westinghouse Hanford Company). The most recent reports are Woodruff and Hanf (1991); Evans et al. (1990); WHC (1990a,b). Evans et al. (1990) discussed in detail the following contaminants in Hanford Site ground water: 1) carbon tetrachloride in the 200-West Area; 2) cyanide in and north of the 200-East and 200-West areas; 3) hexavalent chromium in the 100 Areas and extended environs, 200-West Area, and 200-East Area; 4) chlorinated hydrocarbons near the Hanford Solid Waste Landfill, 300 Area, and 100-F Area; 5) nitrate across the Site; and 6) tritium

across the Site. This report will continue to update that information, including data that became available during 1990. Other observations of chemical and radiological contaminants are also briefly discussed.

Results are discussed relative to the maximum contaminant level (MCL), and/or derived concentration guide (DCG) appropriate for each constituent (Appendix B), and to background concentrations. The MCLs for radionuclides are more restrictive than the DCGs because the MCLs are based on an annual dose to the affected organ of 4 mrem/yr, while the DCGs are based on an effective whole body dose of 100 mrem/yr. The DCGs are only relevant to radionuclides. Derived concentration guides are presented in DOE Order 5400.5.

Plume maps are based on data extracted directly from the Hanford Ground Water Data Base or copies of that same data transferred to the Hanford Environmental Information System. Prior to plotting the data, the extracted data files were carefully examined. Data associated with wells completed in the deep unconfined aquifer and the confined aquifer or data that appeared to be anomalous relative to other related data points were removed with a text editor prior to further processing. Very minimal adjustments were required.

Tritium and nitrate plume maps were prepared by the same methodology used in previous years to provide continuity of interpretation. Data were plotted directly on translucent paper scaled to the same dimensions as a Hanford base map. Contours were drawn manually on the map by a hydrogeologist using a simple linear interpolation method. Knowledge of Site hydrology was used to guide preparation of plumes. Data collected between January 1, 1990, and December 31, 1990, were used where available. At some locations where comprehensive 1990 data were not available and concentrations have changed little in the past, data collected during 1989 were used. Those locations are indicated on the plume map. All other contaminant plume maps were drawn by a computer contouring package, SURFER (Golden Software, Golden, Colorado) using an inverse square interpolation algorithm. Contour plots were subsequently refined using graphics software and overlain on detailed base maps. The refinement process included some redrawing of lines to remove divergences at boundaries (such as the Columbia River, for example) and some smoothing of irregularities in the plots. The period covered by the computer generated

plots was January 1, 1988, to December 31, 1990, with the exception of the carbon tetrachloride and chloroform plots, which used all available data extending back to 1985. A relatively wide time window was used for these computer generated plots because the size of the data set collected during 1989 and 1990 was severely limited, particularly in areas of high contamination. Many key wells were not sampled or sampled infrequently because of restrictions on disposal of purge water and other sampling and analysis constraints. The 3-year period (1988, 1989, and 1990), therefore, formed a more representative data base from which to plot the concentration contours.

Plume maps included in the following sections are intended as visualization tools to provide the reader with a better understanding of the approximate areal distribution of contaminants. The plume maps are not comprehensive. Because of time constraints on report preparation or data base limitations, some contaminants were not addressed. Particular emphasis was placed on reevaluation of plumes in areas currently receiving major attention for Site remediation activities such as the 200-West Area and the 300 Area. A major effort was devoted to preparation of a strontium-90 plume map for the 100-N Area because of the perceived importance of that contaminant plume. The plume maps may not be absolutely accurate in some respects. While attempts were made to manually eliminate all computer generated graphical artifacts, it should be recognized that the process has inherent limitations. The most serious limitation comes from the nature of the well network itself, which is irregularly distributed and in general of insufficient spatial density to provide optimal contouring information. Areas with insufficient well density for accurate plume definition include 1) the area north of the BY Cribs in the 200-East Area; 2) the area south of the BC Cribs near the 200-East Area; 3) the area between the 200-East and 200-West areas; 4) the eastern portion of the plumes originating in the U1/U2 Cribs in the 200-West Area; 5) essentially all of the 100 Areas. Concerning the last point, 100-B, 100-D, 100-K, and 100-F Areas only have a few usable monitoring wells each. 100-H Area has a good well network close to the 183-H Solar Evaporation Basins, but little information is available for the rest of that site. Similarly, 100-N Area now has an extensive network of wells near compliance facilities, but has very limited well distribution in the area of maximum radiological contamination by

strontium-90. Since most of the existing ground-water contamination on the Site appears to be associated with past practices, well drilling activities that have targeted operating facilities have contributed only minimally to improving the situation in either the 100 Areas or other parts of the Site. With the recent onset of drilling activities associated with the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA), this situation is improving, and eventually sufficient wells will exist to characterize these areas.

2.2.1 Cyanide

Cyanide has been detected in four widely spaced wells in the 200-West Area; the highest level reported in 1988 was 69 μg/L in well 299-W14-2. No samples were taken from well 299-W14-2 in 1989 or 1990. A contour plot of the spatial distribution of cyanide in the 200-West Area ground water is presented in Figure 2.3. Two separate areas of concentration are shown on Figure 2.3. The northern lobe is centered near the 216-T-26 Crib, which received a total estimated inventory of 6000 kg of ferrocyanide in the period 1955 to 1956 (Stenner et al. 1988). The source of the other concentration maximum is not obvious.

Cyanide has been detected in samples collected from wells in and directly north of the 200-East Area. The cyanide source is believed to be wastes containing ferrocyanide disposed to the BY cribs. Samples taken in January 1989 had an average cyanide concentration of 580 ± 110 μg/L in well 699-50-53 (six replicate measurements). Lesser amounts of cyanide are present in four other wells in or near the northern side of the 200-East Area. Unfortunately, continuing purge water disposal problems prevented sampling of well 699-50-53 again until December 11, 1990; however, because of the lack of analytical support services at that time, cyanide was not measured. Wells containing cyanide also contain concentrations of several radionuclides, including cobalt-60. Although cobalt-60 is normally immobile in the subsurface, it appears to be chemically complexed and mobilized by cyanide or ferrocyanide.

The EPA has proposed a drinking water standard (DWS) for cyanide of 200 μg/L pending public review. Ferrocyanide is not explicitly regulated but

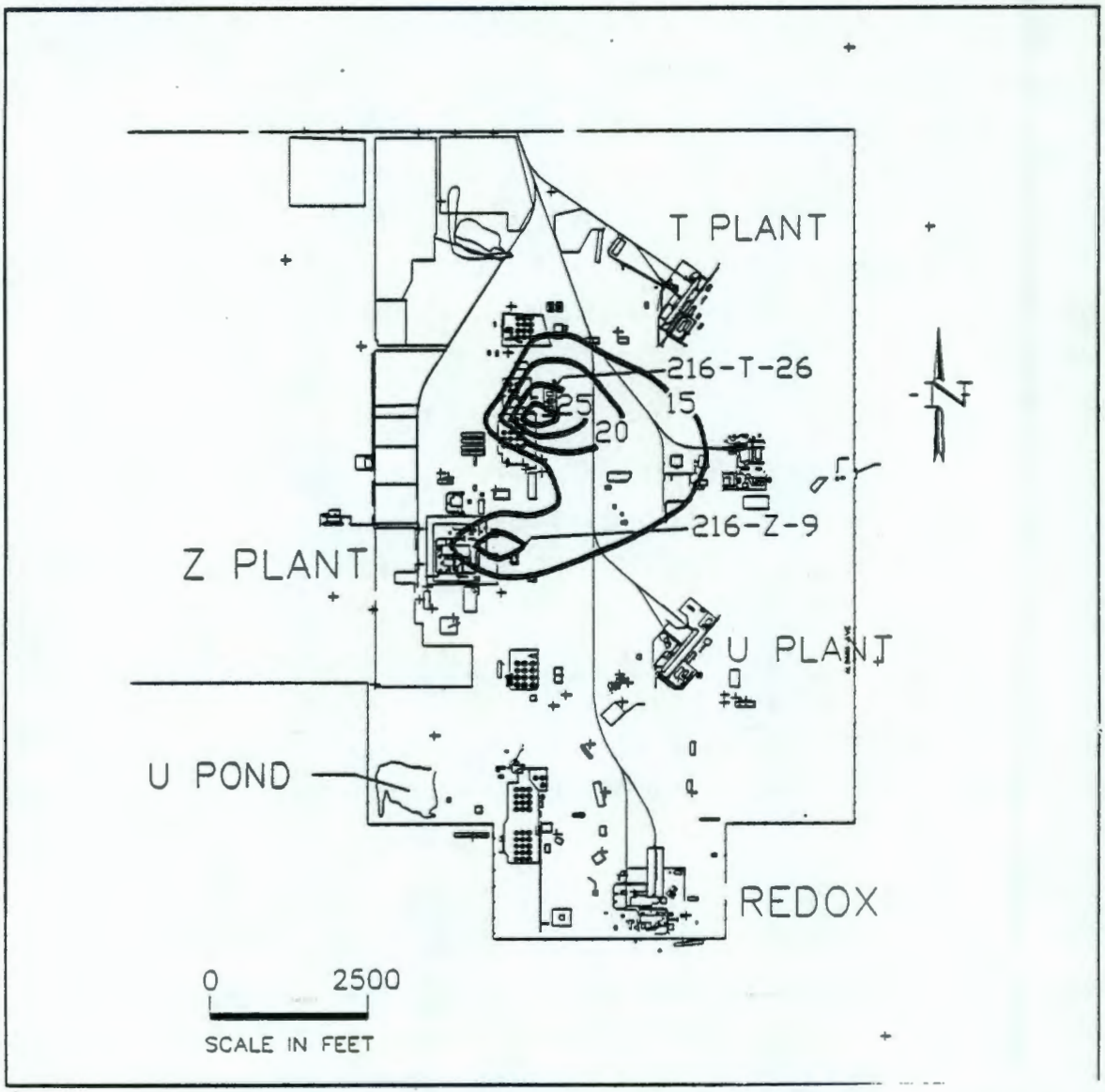

FIGURE 2.3. Cyanide Ground-Water Plume in the 200-West Area. Minimum contour is 15 μg/L. Contour intervals are 5 μg/L. + marks sampling locations.

is currently considered to be indistinguishable from cyanide because of the nature of the specified analytical test used, which responds equally to both free and complexed forms of cyanide.

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2.2.2 Fluoride

Fluoride concentrations above the DWS have been observed in a few wells in the 200-West Area between T Plant and Z Plant. The maximum concentration in 1988 was 12.8 mg/L in well 299-W15-4. None of the 200-West Area wells in the fluoride plume were sampled in 1989 or 1990. A contour plot of the areal extent of the fluoride plume in the 200-West Area is shown in Figure 2.4. Two areas of concentration are indicated; however, this may be an artifact of the well distribution. The source of fluoride is believed to be several liquid waste disposal facilities (LWDFs) associated with Z Plant. For example, the 216-Z-9 Crib received 210,000 kg of aluminum fluoride nitrate (Stenner et al. 1988) during the course of its operation from 1955 to 1962. A similar amount of aluminum fluoride nitrate was disposed to the 216-Z-18 Crib during its operation from 1969 to 1973. However, the fact that the plume is some distance from those two cribs makes identification of the source somewhat questionable. All wells sampled outside the 200-West Area contained fluoride levels below the DWS, which for fluoride is 2.0 mg/L.

2.2.3 Hexavalent Chromium

Chromium has been found in ground water from wells in the 100-B, 100-D, 100-H, and 100-K areas. In addition, at least one well in the 100-F Area had detectable hexavalent chromium.

The highest measured chromium concentrations on the Site in 1990 continued to be found in well 199-D5-12; however, the concentration of chromium in that well continued to drop reaching 464 μg/L in March 1990. A trend plot showing the concentration of chromium as a function of time in ground-water samples collected from well 199-D5-12 is shown in Figure 2.5. The chromium plume in the 100-D Area is centered near the reactor. The probable sources of the chromium contamination are the 116-D-1A and 116-D-1 Trenches, which received large inventories of chromium during the 1950s and 1960s (Stenner et al. 1988).

A sizable chromium ground-water plume is located in the 100-H Area. The center of the plume is located just south of the 183-H Solar Evaporation

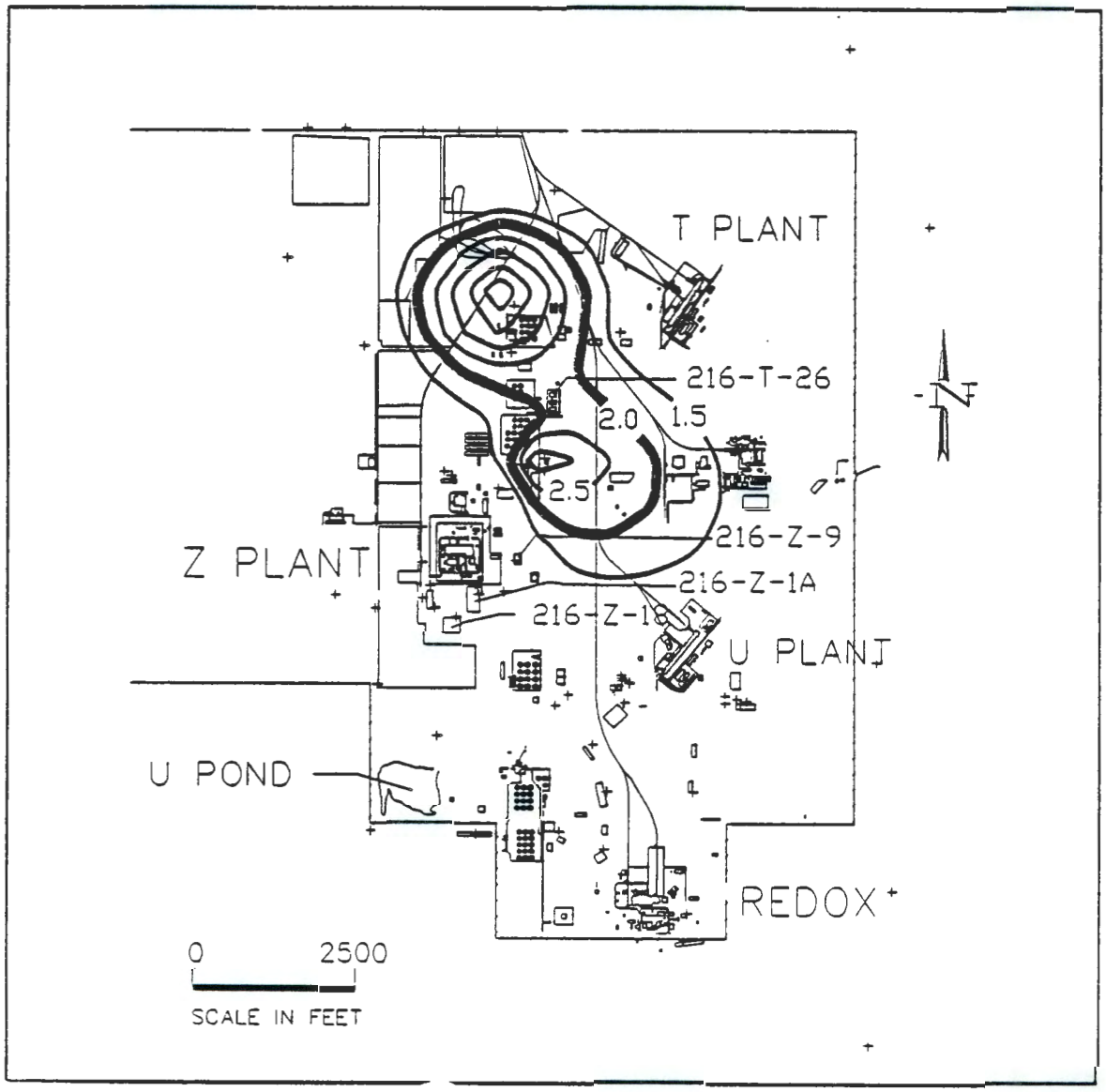

FIGURE 2.4. Fluoride Ground-Water Plume in the 200-West Area based on most recent data available (1988). Minimum contour is 1.5 mg/L. Contour intervals are 0.5 mg/L. Bold contour line indicates DWS + marks sampling locations.

Basins. The evaporator basins were used for volume reduction of decontamination wastes originating from the 300 Area Fuel Fabrications Facility. Leakage from at least one of the basins is believed to be the contamination source. A trend plot showing the concentration of chromium in two 100-H Area ground-water wells (199-H4-3 and 199-H4-4) as a function of time since mid-1985 is

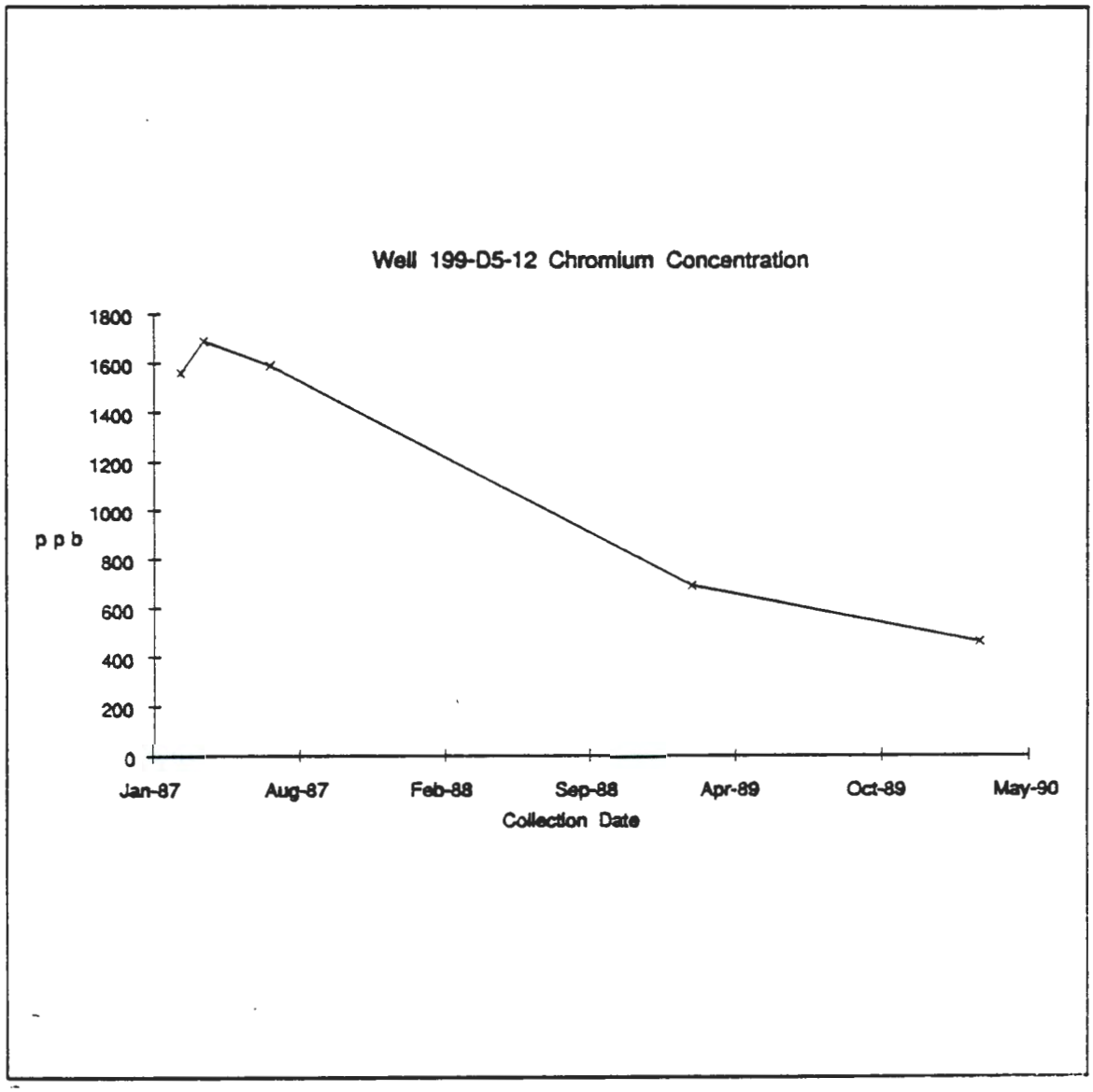

FIGURE 2.5. Trend Plot for Chromium in Well 199-D5-12

shown in Figure 2.6. Well 199-H4-4 is located near the bank of the Columbia River. The large cyclic variation visible in the data from the well is associated with river stage, which can cause dilution through bank storage. The overall trend in both this well and well 199-H4-3, which is further from the river and near the leaking basin, has been a continuous decrease that now appears to have leveled off.

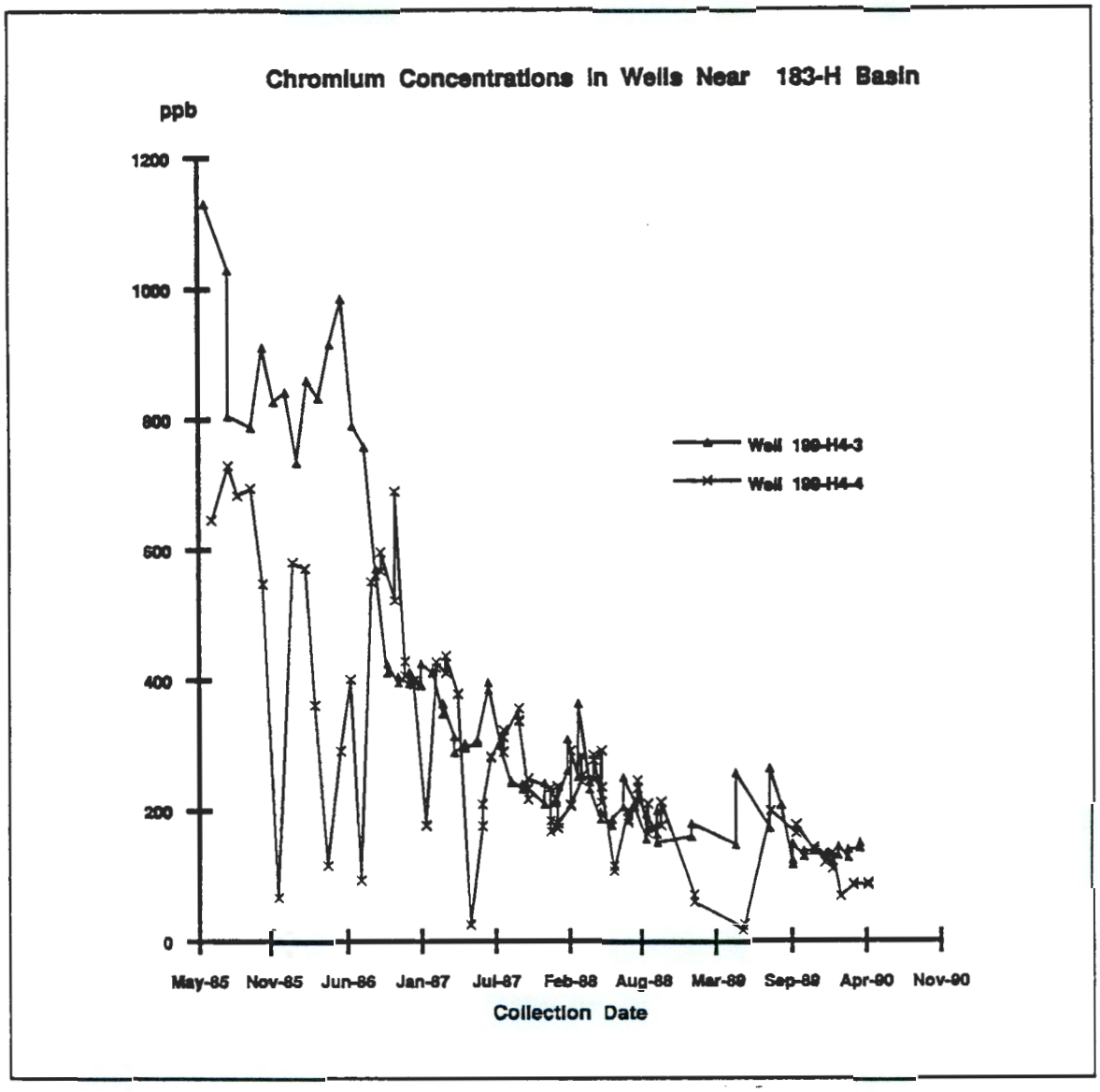

FIGURE 2.6. Trend Plots for Chromium Concentrations in Wells Near 183-H Solar Evaporation Basins

Detectable chromium was also found in various parts of the 600 Area, particularly near the 100-D and 100-H Areas. The highest concentration was found in well 699-97-43 (approximately 1 km west of the 100-H Area) at 170 μg/L, more than three times the DWS. Chromium concentrations in that area have remained relatively constant for the past 4 years.

Chromium contamination was previously found at several locations in the 200-West Area; however, only one of those wells (299-W6-2) was sampled since 1988. Chromium concentrations in well 299-W6-2 were similar to those observed in 1988. The maximum chromium concentration found in the 200-West Area during 1988 was 339 μg/L in well 299-W22-20. Ground-water samples from at least 12 other 200-West Area wells sampled in 1988 also had detectable chromium. A contour plot of the distribution of chromium concentrations in the 200-West Area is given in Figure 2.7. The origin of the plume at the southern end of the 200-West Area is attributed to past waste disposal at the 216-S-13 Crib, which was retired in July 1972 after receiving an estimated 10,000 kg of sodium dichromate over a 20-year period (Stenner et al. 1988). The origin of the chromium plume at the north end of the site is less obvious. The most likely candidate is the 216-T-28 Crib, which had been used for disposal of decontamination wastes from T Plant in the early 1960s. Chromium has commonly been associated with decontamination waste on the Site.

A few wells in the 200-East Area also showed evidence of minor chromium contamination. The highest level found was in well 299-E13-14, with a chromium concentration of 67 μg/L in November 1988. That well was not sampled in 1989 because of considerations associated with purge water disposal, and samples collected in May 1990 were not analyzed for chromium because of the UST contract termination.

2.2.4 Volatile Organic Compounds

2.2.4.1 Carbon Tetrachloride and Chloroform in the 200-West Area

Extensive carbon tetrachloride contamination has been found in the unconfined aquifer beneath much of the 200-West Area. The contamination is believed to be from waste disposal operations associated with Z Plant (particularly the 216-Z-18 Crib, 216-Z-1A Tile Field, and 216-Z-9 Trench) before 1973. A concentration of 8100 μg/L was found in a well near Z Plant first monitored in October 1988 (well 299-W15-16). Carbon tetrachloride concentrations in well 299-W15-16 were similar in 1989 and 1990, reaching a maximum of 8700 μg/L in March 1990. Remediation activities performed in the 200-West Area in 1990 added some additional wells to the network enabling a somewhat

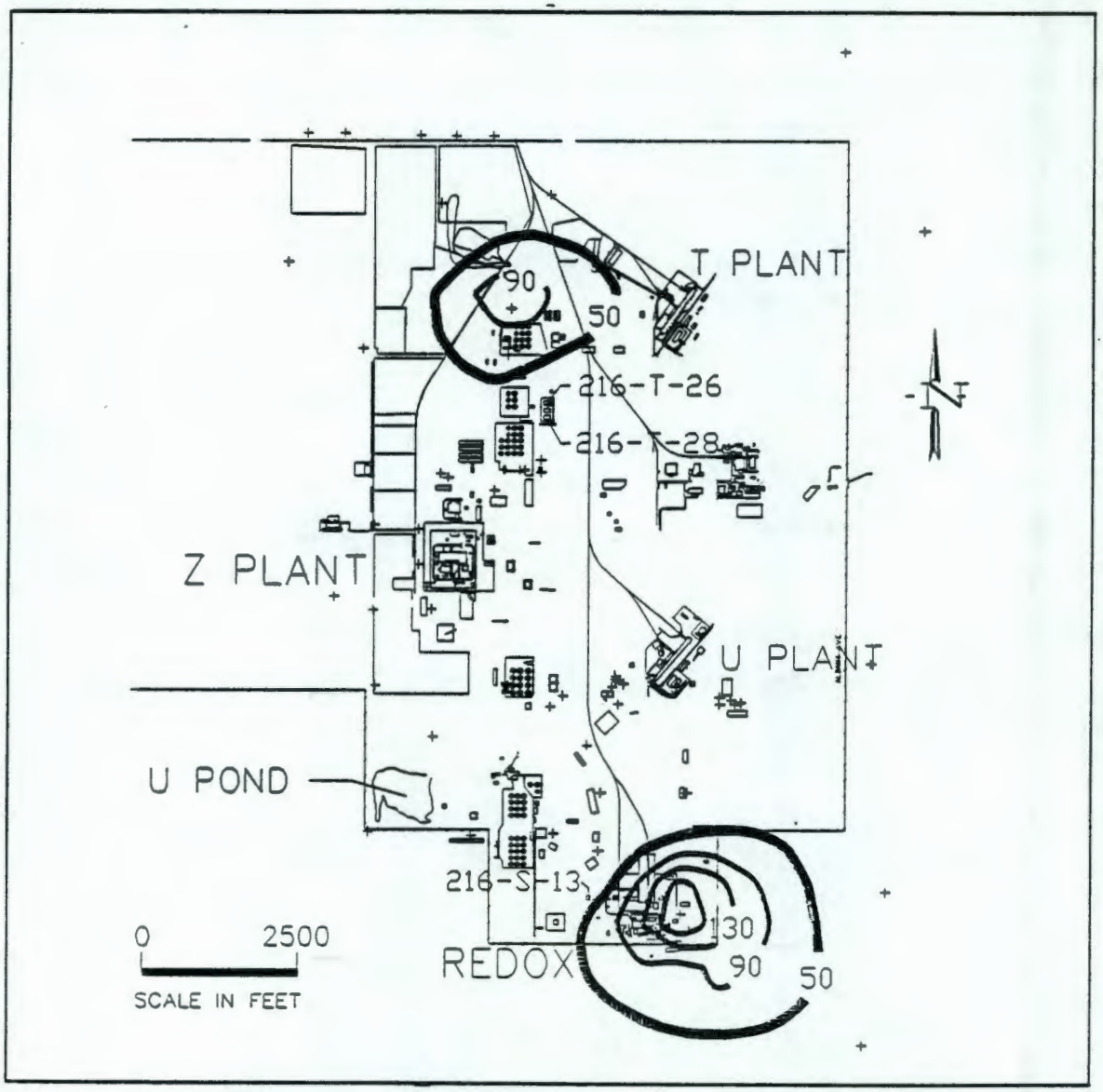

FIGURE 2.7. Chromium Ground-Water Plumes in the 200-West Area. Minimum contour is 50 μg/L. Contour intervals are 400 μg/L. Bold contour line indicates DWS. + marks sampling locations.

better definition of the ground-water plume. Trend plots of carbon tetrachloride concentrations as a function of time in wells with the highest carbon tetrachloride concentrations are shown in Figure 2.8. This figure shows relatively constant carbon tetrachloride concentrations in the well with the highest levels but a general dropoff in two other wells with high

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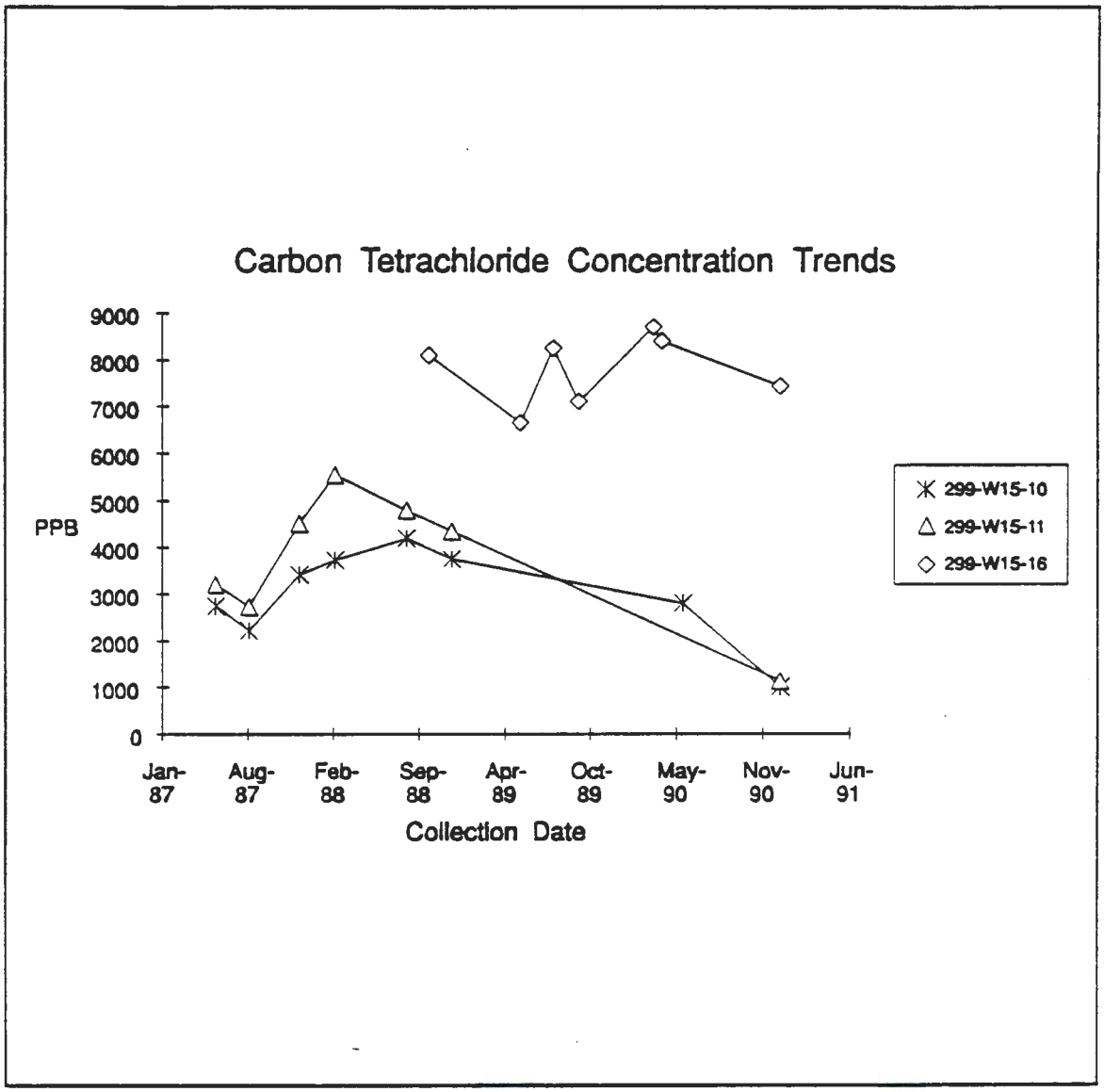

FIGURE 2.8. Carbon Tetrachloride Trends in Monitoring Wells Located Near the Center of the Z Plant Ground-Water Plume

concentrations. Figure 2.9 shows the carbon tetrachloride trends in wells at the east (699-38-70), west (699-39-79), north (299-W6-2) and south (299-W19-15) edges of the ground-water plume. The trends at the east, north, and south edges appear to indicate a relatively static, or at least a diffuse, nature of the plume at those locations, while the data from the western edge have shown a rapid increase since late 1985 followed by a leveling or slight

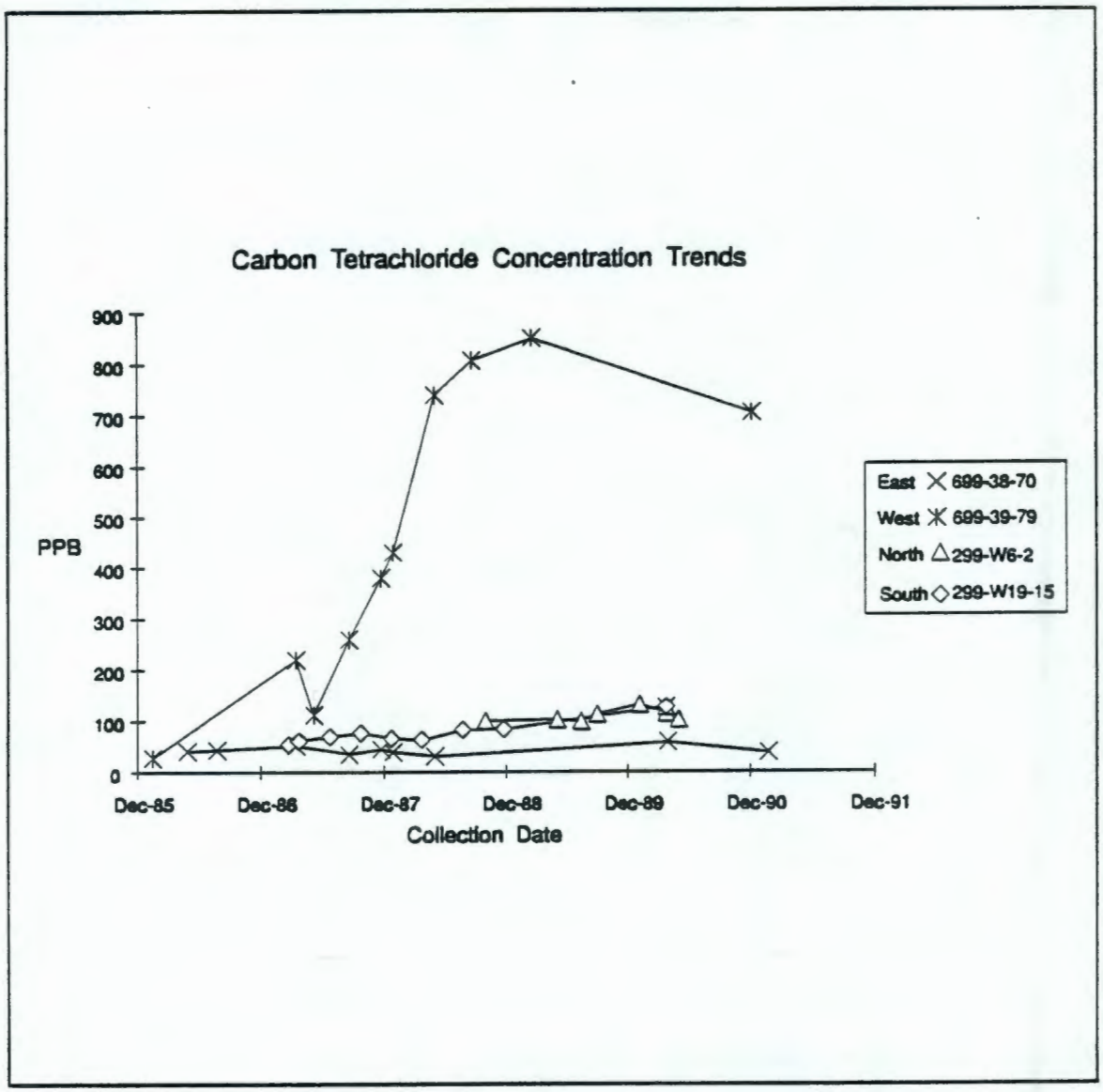

FIGURE 2.9. Carbon Tetrachloride Trends in Monitoring Wells Located Near the Margins of the Z Plant Ground-Water Plume

decrease in 1989 and 1990. This suggests there is some plume movement to the west with the leading edge of the plume now just past the well. Except for 699-39-79, wells in that area are rather sparse and represent a significant data gap. A contour plot of the carbon tetrachloride distribution in the 200-West Area is shown in Figure 2.10. The maximum contaminant level, or

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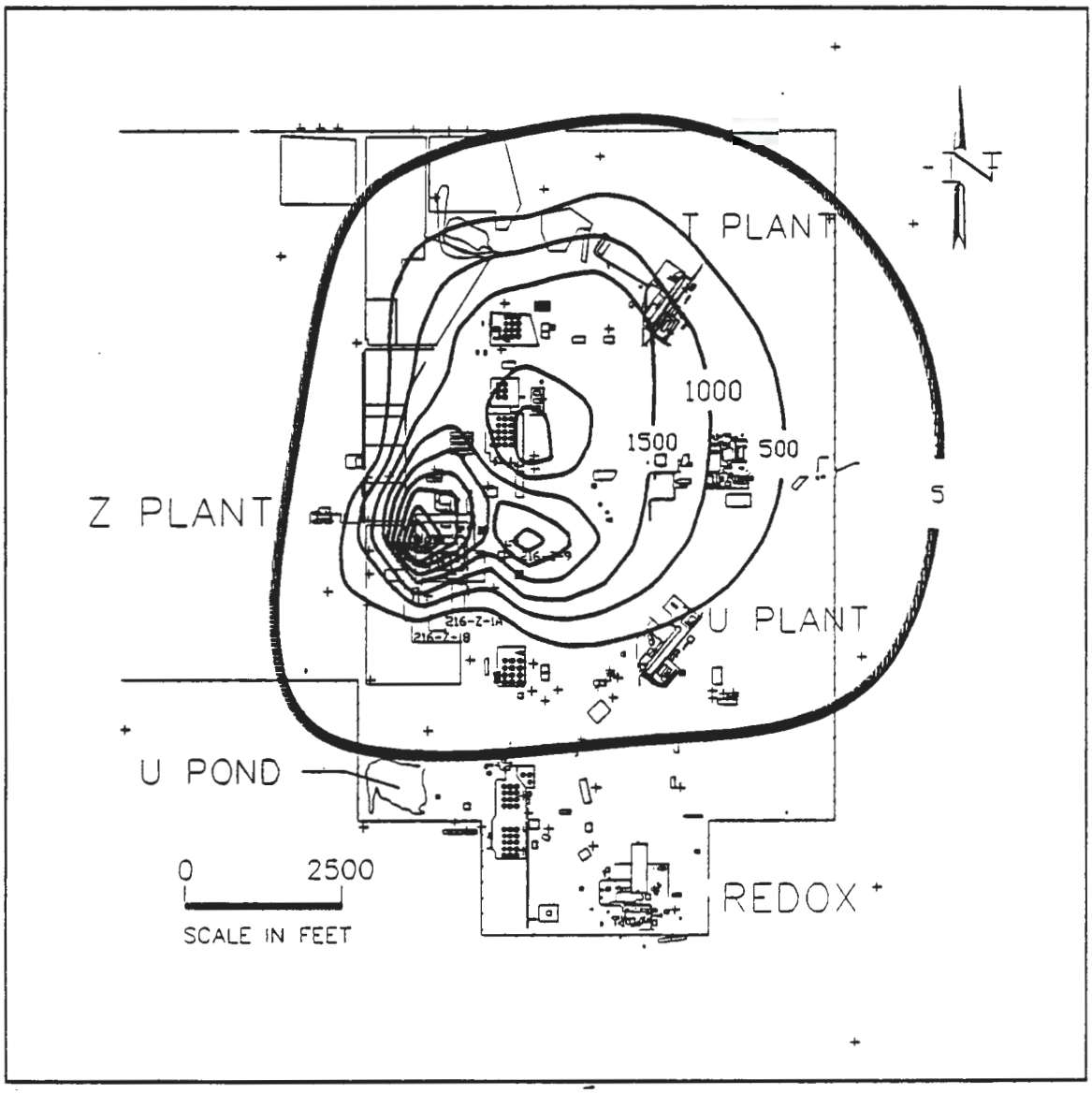

FIGURE 2.10. Carbon Tetrachloride Ground-Water Plume in the 200-West Area. Minimum contour is 5 μg/L. Contour intervals are 500 μg/L. Bold contour line indicates DWS. + marks sampling locations.

target concentration, of carbon tetrachloride for remediation under CERCLA and the Superfund Amendments and Reauthorization Act (SARA) of 1986 is 5 μg/L. The DWS is also 5 μg/L.

In addition to carbon tetrachloride, a chloroform plume of more limited extent was also observed in the 200-West Area near Z Plant. A contour plot of the chloroform plume is shown in Figure 2.11. The origin of the chloroform is

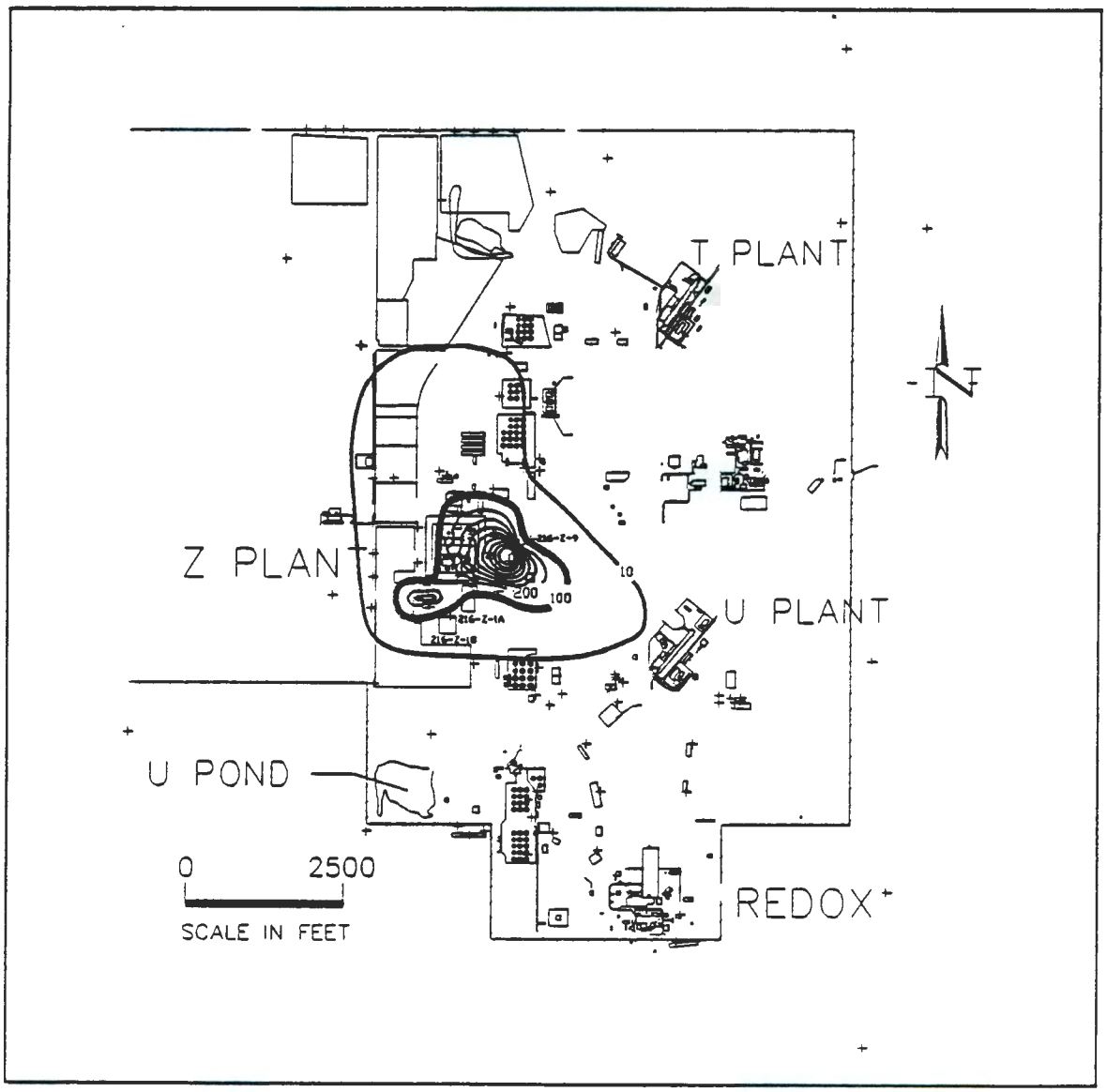

FIGURE 2.11. Chloroform Ground-Water Plume in the 200-West Area. Minimum contour is 10 μg/L. Contour intervals are 100 μg/L. Bold contour line indicates DWS. + marks sampling locations.

not entirely clear; however, it is probably a degradation product of carbon tetrachloride either through radiolytic processes prior to disposal or through natural transformation processes (i.e., microbial degradation) in the subsurface. The chloroform plume is more limited in extent than the carbon tetrachloride plume and is similar, but not identical, to it in location. The highest chloroform levels on the Site in the last year were found in wells 299-W15-9 and 299-W15-8 (1550 and 1540 μg/L respectively). Those wells are

located near the 216-Z-9 Trench and actually have higher levels of chloroform than carbon tetrachloride. A second high concentration of chloroform is associated with well 299-W18-4 (632 μg/L). The second concentration maximum appears to be distinct and is likely to be associated with one of the other LWDFs in that area, either 216-Z-1A or 216-Z-18. The DWS for chloroform is 100 μg/L (total trihalomethanes).

2.2.4.2 Trichloroethylene Contamination

Trichloroethylene (TCE) contamination in excess of the 5-μg/L DWS was found in ground water at several sites. Trichloroethylene was found in 600 Area wells on the west side of the 100-F Area. The highest level reported in 1989 was 32 μg/L in well 699-77-36. This well was not sampled in 1990; however, TCE concentrations in that well have been shown to be constant with time in 11 previous measurements. The concentration of TCE in well 199-F7-1, however, rose threefold to 35 μg/L early in 1990 after remaining relatively constant for several years. The source of the TCE at that location is not known.

Several wells at the Solid Waste Landfill (SWL) contained TCE close to but slightly below the DWS. Solid Waste Landfill wells had shown TCE concentrations above the DWS in 1987 and 1988. The highest level of TCE reported for any of the SWL monitoring wells during 1990 was 4.0 μg/L in well 699-24-34B. Trichloroethylene and several chlorinated hydrocarbon constituents are attributed to waste water from the vehicle maintenance area. The waste water contained small amounts of solvents and was discharged to three trenches on the west side of the SWL between January 1985 and January 1987. A soil gas survey of the landfill performed in 1989 (Evans et al. 1989) confirmed the presence and documented the distribution of TCE and other chlorinated hydrocarbons in the landfill. Other chlorinated hydrocarbons detected in the ground water and soil gas include 1,1,1 trichloroethane and perchloroethylene.

Trichloroethylene and some of its partial degradation products [i.e., cis-dichloroethylene (1,2-DCE)] were found in wells monitoring the lower portion of the unconfined aquifer in the 300 Area near the North Process Pond. Maximum concentrations in 1990 were 12 μg/L trichloroethylene and 77 μg/L DCE

in well 399-1-16B, similar to the levels observed in 1989. Similar levels were found in nearby well 399-1-16C, which monitors the upper portion of the confined aquifer. Trichloroethylene was not found in well 399-1-16A, which monitors the upper portion of the unconfined aquifer. Stenner et al. (1988) show large inventories of TCE disposed to both the North and South Process Ponds over the course of the project. These ponds are the likely source of the contamination. The vertical distribution of the TCE and DCE is consistent with its high density, which would tend to cause it to sink to the bottom of the aquifer. DCE is commonly found as a degradation product of TCE. The relatively high ratio of DCE to TCE suggests that the source is some distance from the monitoring well cluster.

Trichloroethylene contamination has been detected at levels exceeding the DWS in two locations inside the 200-West Area. A contour plot of the TCE distribution in the 200-West Area is shown in Figure 2.12. Two regions of minor TCE contamination are indicated, one near the Reduction/Oxidation (REDOX) facility and the other west of T Plant near the T Tank Farm. Neither areas are known sources of TCE discharge. Neither plume region showed any significant change during 1990. The highest TCE level measured in 1990 in the 200-West Area was 41 μg/L in well 299-W19-20.

Trichloroethylene contamination was found in several recently installed ground-water wells in the Horn Rapids Disposal located southeast of the 300 Area. The contamination was originally detected during a soil gas survey conducted during the preliminary phase of the 1100 EM-1 CERCLA investigation and was subsequently confirmed through well drilling. Concentrations range up to 84 μg/L in well 699-S31-E10. The source of the contamination is not clearly established at this time; however, the distribution of the soil gas plume combined with the best information currently available on ground-water flow direction at that site suggests that the contaminant plume may originate from outside the boundaries of the landfill and DOE controlled land.

2.2.5 Nitrate

Although NO_3^- is associated primarily with process condensate liquid wastes, other liquids discharged to ground also contain NO_3^-. Nitrate contamination in the unconfined aquifer reflects the extensive use of nitric acid in

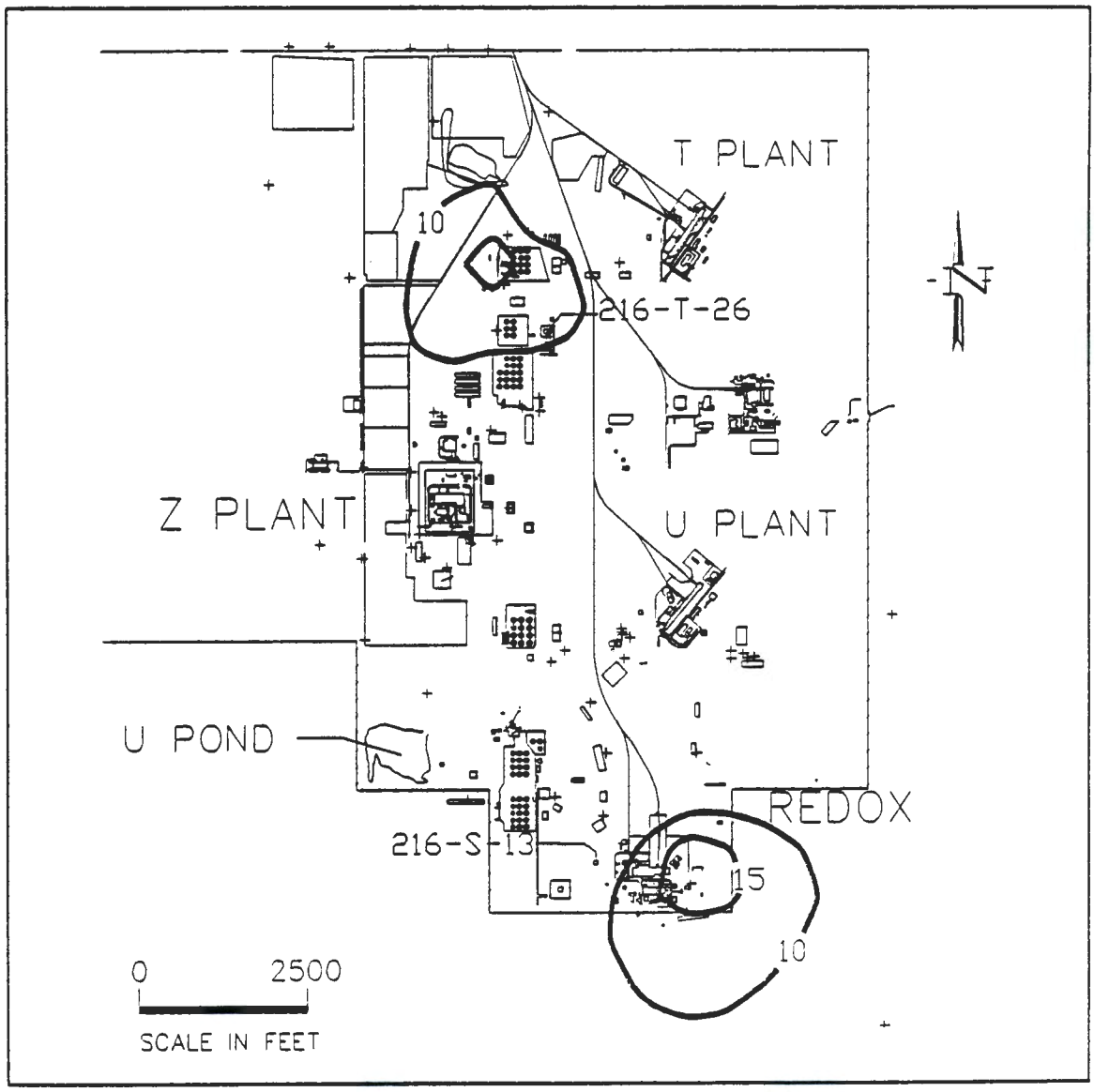

FIGURE 2.12. Trichloroethylene Ground-Water Plumes in the 200-West Area. Minimum contour is 10 μg/L. Contour intervals are 5 μg/L. + marks sampling locations.

decontamination and chemical reprocessing operations. Nitrate, like tritium, can be used to define the extent of contamination because NO_3^- is present in many waste streams and is mobile in ground water. The distribution of nitrate in Hanford Site ground water is similar but not identical to the tritium distribution. The distribution of NO_3^- on the Hanford Site is shown in

Figure 2.13. The nitrate distribution shown in the figure is similar to previous evaluations, with two notable exceptions, north of the 300 Area and west of 200-West Area.

Nitrate concentrations in well 699-S19-E13 have been increasing during the past few years and exceeded 20 μg/L in 1990. As a result, the nitrate plume north of the 300 Area is shown extending further to the south in Figure 2.13 than in previous years.

The high nitrate concentrations observed in wells located on the far west of the Site near the Yakima Ridge have long been regarded as unrelated to Site operations and most probably of agricultural origin. Nevertheless, past versions of the plume map have, for reasons of conservatism, assumed a Hanford origin and combined these measurements as part of a single plume emanating from the southwest corner of the 200-West Area. That interpretation is now believed to be inconsistent with the known hydrology of that part of the Site. In addition, no known source of nitrate in that area is associated with Site operations and intervening wells show no evidence of plume passage either with respect to nitrate or any other indicator species. Nitrate levels have fluctuated considerably in those wells during the past 30 years and again appear to be increasing particularly in well 699-36-93. A trend plot of nitrate data associated with wells near the Yakima Ridge is shown in Figure 2.14. The nitrate plume map (Figure 2.13) has been modified for 1990 to reflect this difference in interpretation.

Most ground-water samples collected in 1990 were analyzed for NO_3^-. Nitrate was measured at concentrations greater than the DWS (45 mg/L as NO_3^- ion) in wells in all operational areas, except the 400 Area.

The highest NO_3^- concentrations in the 200-East Area continued to be found near LWDFs that received effluent from Plutonium-Uranium Extraction (PUREX) Plant operations. Nitrate concentrations in wells near the 216-A-10 and 216-A-36B Cribs continued to decrease during 1990 but remained above the DWS even though these facilities were removed from service in 1987. There is also a large nitrate plume north of the 200-East Area. This plume is clearly

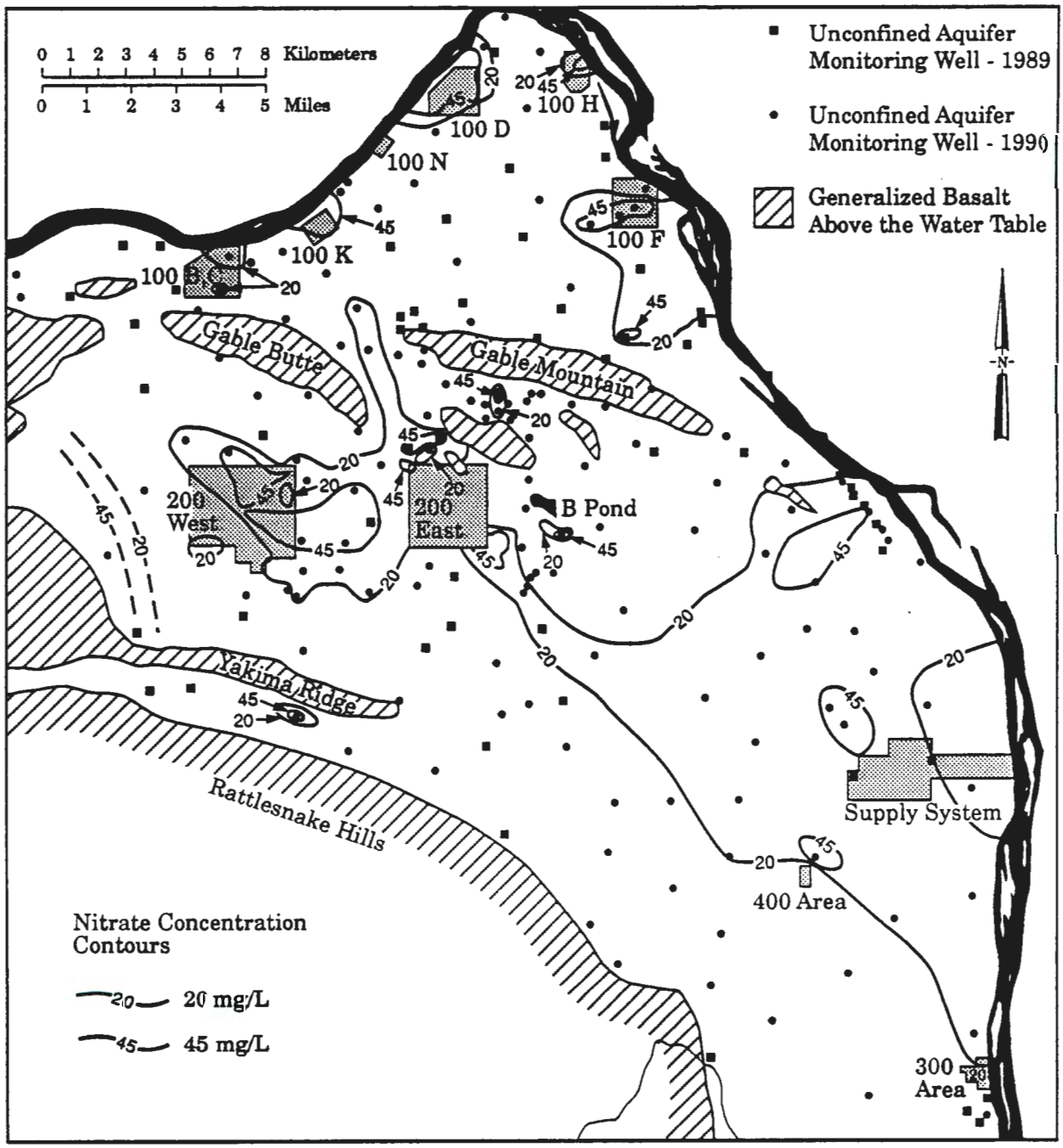

FIGURE 2.13. Distribution of Nitrate on the Hanford Site

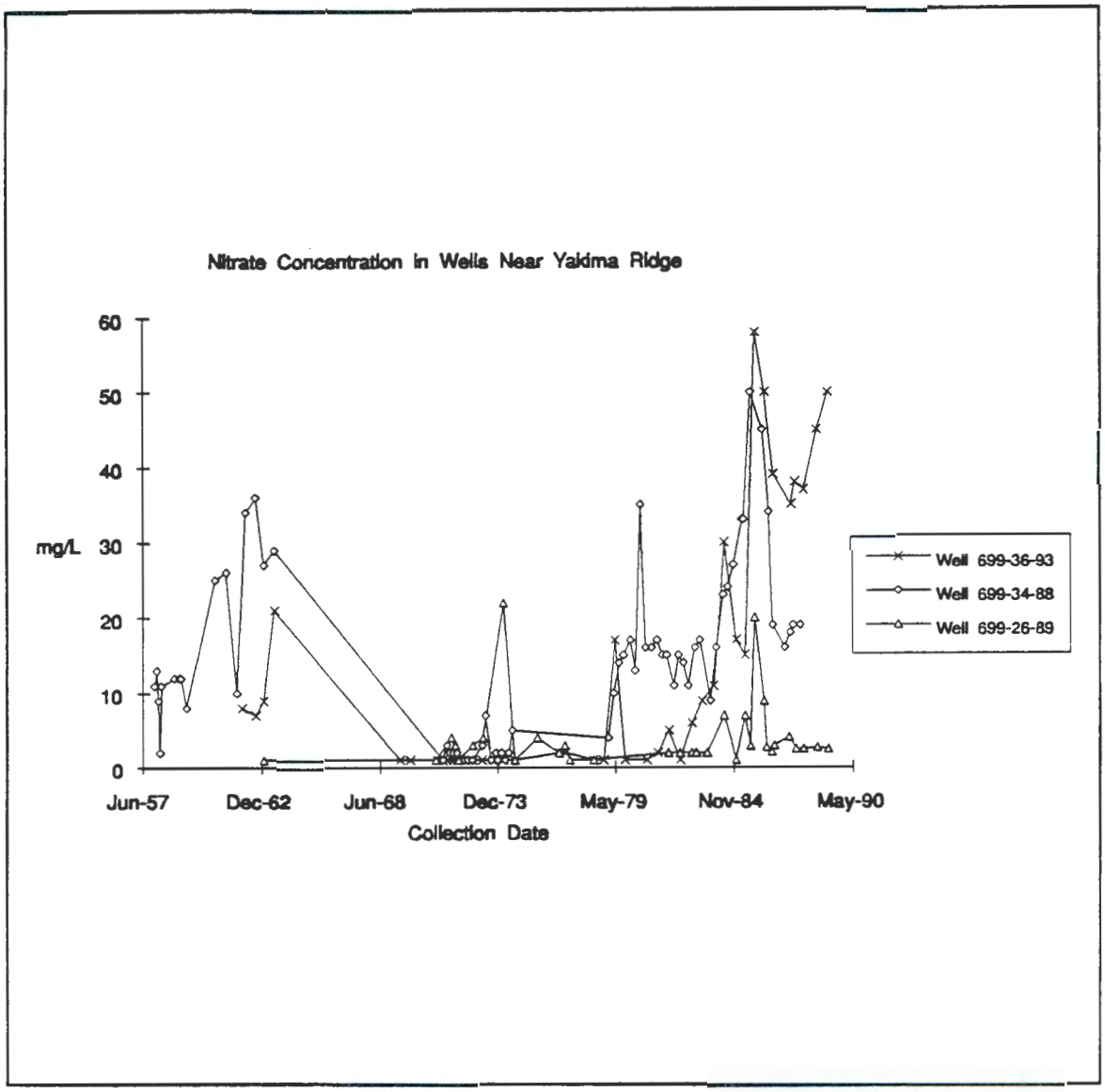

FIGURE 2.14. Trend Plot for Nitrate in Ground-Water Wells Located Near Western Margin of Hanford Site Near Yakima Ridge

associated with the BY Cribs waste disposal operation, which is evidenced by several other constituents in the same plume including cyanide, tritium, cobalt-60, and technetium-99.

The configuration of the NO_3^- plume emanating from the 200-East Area shows the influence of two periods of PUREX operation and recent changes in the operation of B Pond. The location of B Pond is shown in Figure 1.1.

Increases in the volume of process cooling water discharged to B Pond may have resulted in expanding the area of lower NO_3^- concentrations in ground water to the east and south of that facility (see Figure 2.13).

Nitrate concentrations above the DWS were widespread in ground water beneath the 200-West Area. Highest concentrations are centered in three locations: 1) wells near U Plant, 2) wells in the northwestern part of the 200-West Area, and 3) wells near the 216-S-25 Crib. The highest NO_3^- concentrations across the Site continued to be found in wells east of U Plant near the 216-U-17 Crib. The presence of nitrate in wells near this crib was observed before February 1988 when the crib went into operation. The source of NO_3 is believed to be wastes disposed of in the 216-U-1 and 216-U-2 cribs. These cribs received over 1 million kg of NO_3^- during their operation from 1951 to 1967 (Stenner et al. 1988). A maximum NO_3^- concentration of 1360 mg/L was measured in 1989 in a recently installed well (299-W19-26) and similar concentrations were seen in other nearby wells. No new nitrate measurements were available in that well in 1990; however, other nearby wells showed no significant change from 1989. Nitrate concentrations in wells located near the 216-U-1 and 216-U-2 cribs west of U Plant continued to decrease in 1990, with concentrations in most of the wells below the DWS. Several wells in the northwestern part of the 200-West Area continued to contain NO_3^- at concentrations greater than the DWS. These wells are located near several inactive LWDFs that received waste from early T Plant operations. Maximum concentrations in these wells in 1988 ranged up to 699 mg/L in well 299-W15-4. The pattern in that area was similar in 1989 and 1990; however, less information was available because of the programmatic restrictions on sampling and analysis discussed earlier. A contour plot of the nitrate distribution in the 200-West Area ground water is shown in Figure 2.15.

2.2.6 *Tritium*

Tritium is present in many waste streams discharged to the soil column and is the most mobile radionuclide on Site. As a result, tritium reflects the extent of contamination in the ground water from Site operations and is the radionuclide most frequently monitored at the Hanford Site. Figure 2.16

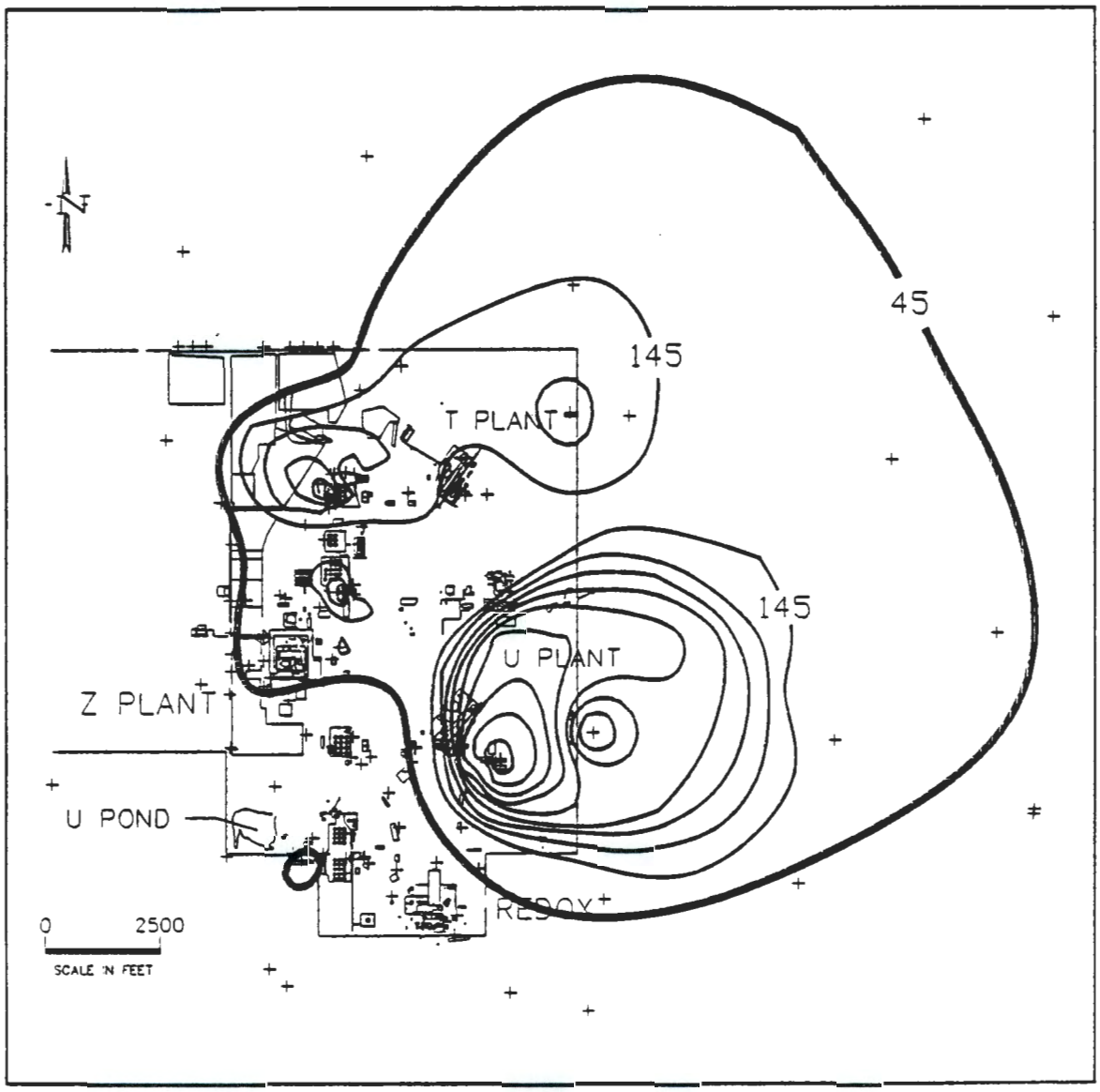

FIGURE 2.15. Nitrate Ground-Water Plume in the 200-West Area. Minimum contour is 45 μg/L. Contour intervals are 100 mg/L. Bold contour line indicates DWS. + marks sampling locations.

shows the current distribution of tritium in the unconfined aquifer resulting from over 45 years of Site operations. An average of tritium measurements for 1990 were used for each well.

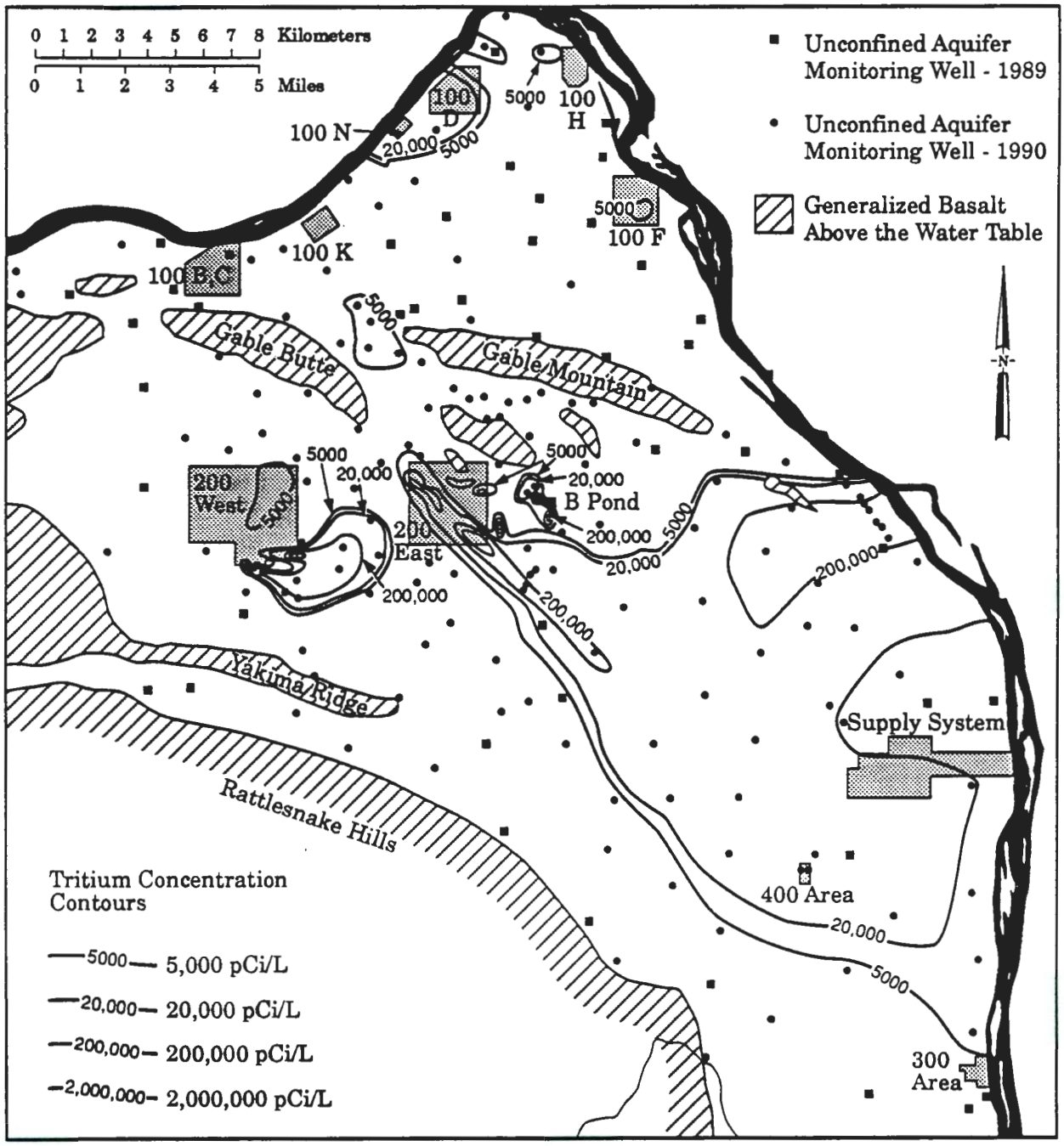

FIGURE 2.16. Distribution of Tritium on the Hanford Site

In some areas, where 1990 data were not available and concentrations have changed little in the recent past, data collected during 1989 were used. Those locations are indicated on the plume map.

Tritium concentrations greater than the 20,000-pCi/L DWS were detected in portions of the 100-B, 100-D, 100-K, 100-N, 200-East, 200-West, 400, and 600 areas. Well 199-K-30 continued to contain the highest tritium concentration within the 100 Areas with a maximum concentration of 823,000 pCi/L, similar to the high for 1989, but lower than the maximum of 1,220,000 pCi/L in 1988. Well 199-K-27 continued to show a large increase in tritium concentrations relative to most of its past history with a maximum of 134,000 pCi/L in 1990. Wells 199-K-28 and 199-K-29, located between and in proximity to the other two wells, continued to contain relatively low tritium concentrations (1869 and 9739 pCi/L, respectively). The reason for the changes in tritium concentration in ground water is not known. The nearby K-East Basins contain irradiated fuel elements and, as a result, water in the basins contains tritium at a concentration of 3,700,000 pCi/L. DOE (1991b) indicates this basin has leaked in the past and that there may be several unidentified tritium sources in the area. A trend plot illustrating these changes with time is shown in Figure 2.17.

Concentrations greater than the 2,000,000-pCi/L DCG were detected in eight wells in the 200-East Area. Tritium concentrations in one well, 299-E17-13, dropped from a high of 3,340,000 pCi/L in 1989 to 751,000 pCi/L in 1990; however, the tritium concentrations in two other wells (299-E17-12 and 299-E25-19) rose to above the DCG in 1990. The highest tritium concentrations in the 200-East Area, and throughout the Hanford Site, continued to be in wells near cribs that have received effluents from the PUREX Plant. Tritium concentrations greater than the DCG were present in wells near the 216-A-10, 216-A-36B, 216-A-37-1, and 216-A-45 cribs. The highest ground-water tritium concentration measured in 200-East Area in 1990 was 4,170,000 pCi/L in well 299-E25-19 (January 1990). Tritium concentrations exceeding the DWS continued to occur in most other wells affected by these cribs.

The movement of the widespread tritium plume (see Figure 2.16) extending from the southeastern portion of the 200-East Area to the Columbia River was consistent with patterns noted earlier (Jaquish and Bryce 1990; Evans et al. 1990). Separate tritium pulses associated with the two episodes of PUREX operations can be distinguished in the plume. The 200,000- to 2,000,000-pCi/L

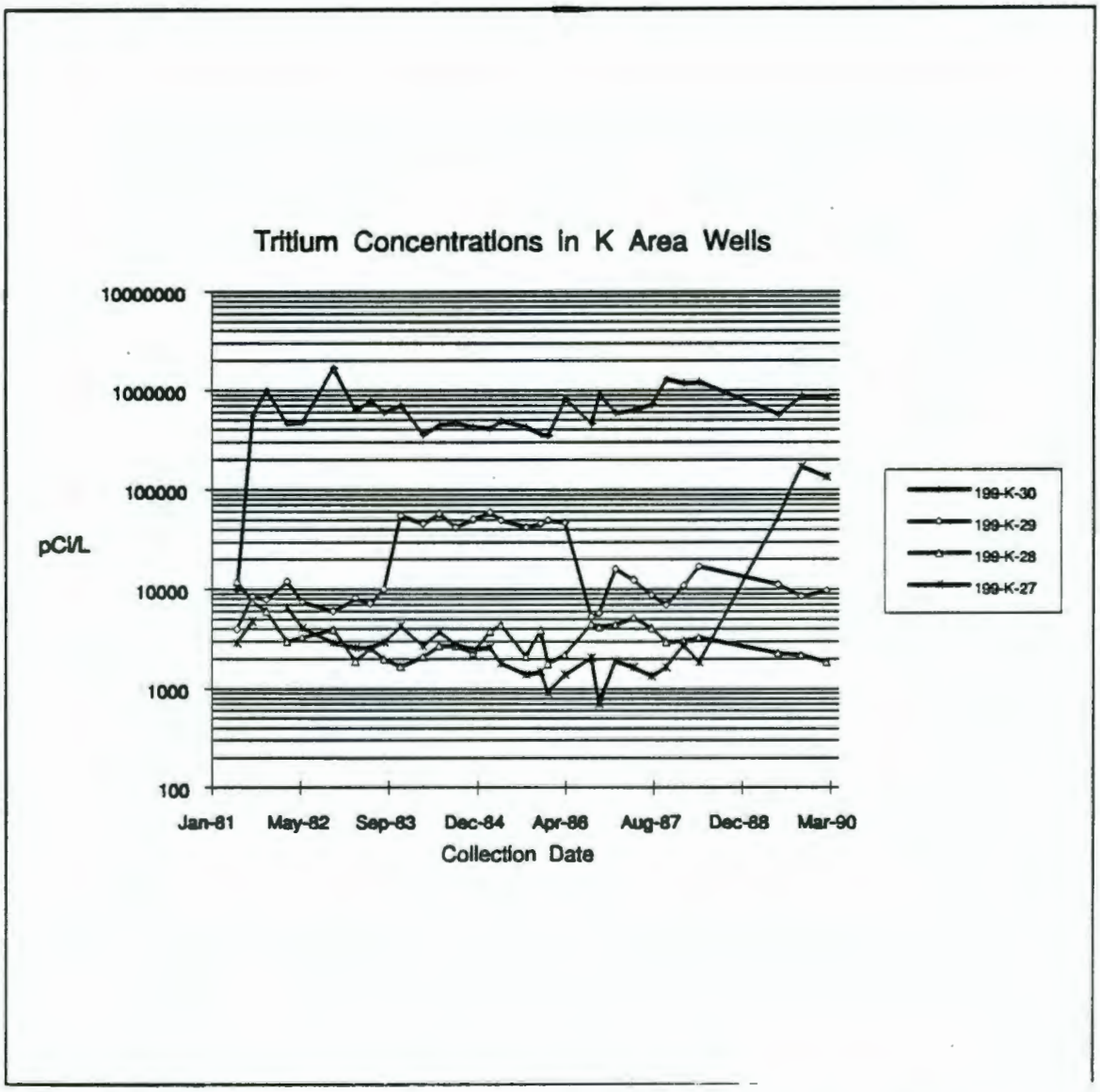

FIGURE 2.17. Tritium Concentrations in 100-K Area Wells

lobe east of the 200-East Area near the Columbia River is a result of discharges to ground water during the operation of the PUREX Plant from 1956 to 1972. Following an 11-year shutdown, plant operation began again in 1983. Elevated tritium concentrations measured in several wells (e.g., wells 699-32-43, 699-33-42, 699-36-46 and 699-24-33) downgradient from the 200-East Area represent the formation of a second pulse of tritium moving away from PUREX waste disposal facilities. Large-scale movement of the leading edge of

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this plume is best observed in well 699-24-33 (Figure 2.18), which clearly shows the arrival of the plume in early 1987 followed by passage of the plume from the earlier campaign that had reached much higher levels in the mid 1960s. A trend plot of the tritium concentrations in well 699-40-1 located

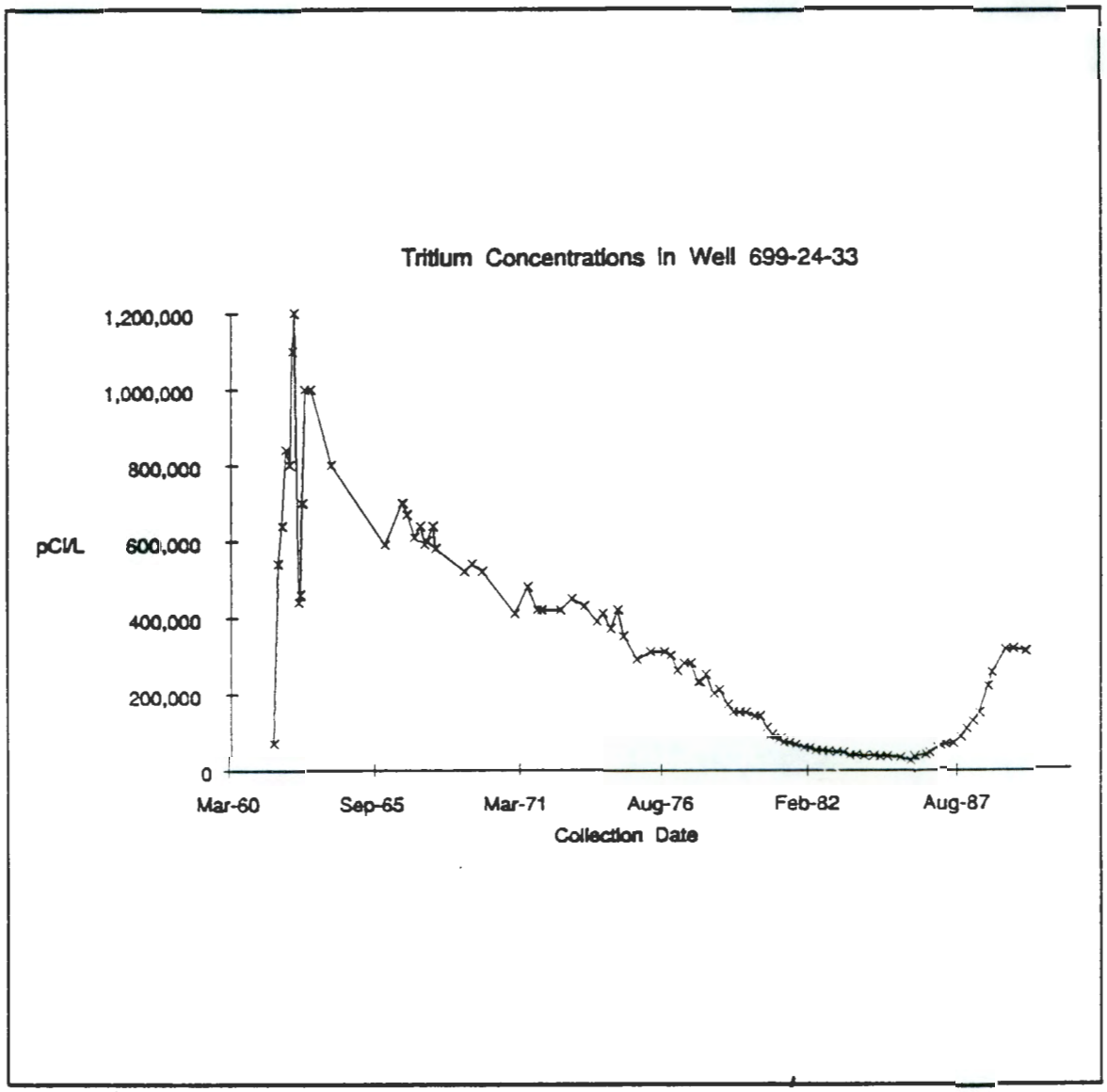


FIGURE 2.18. Trend Plot for Tritium in Well 699-24-33

near the shore of the Columbia River, shows the arrival in the early 1970s of the plume from the first campaign with no discernable effect as yet from the second plume (Figure 2.19).

Approximate travel times have been calculated from an analysis of tritium arrival at well 699-40-1. Utilizing tritium data for this well, Freshley and Graham (1988) calculated an average travel time from PUREX cribs

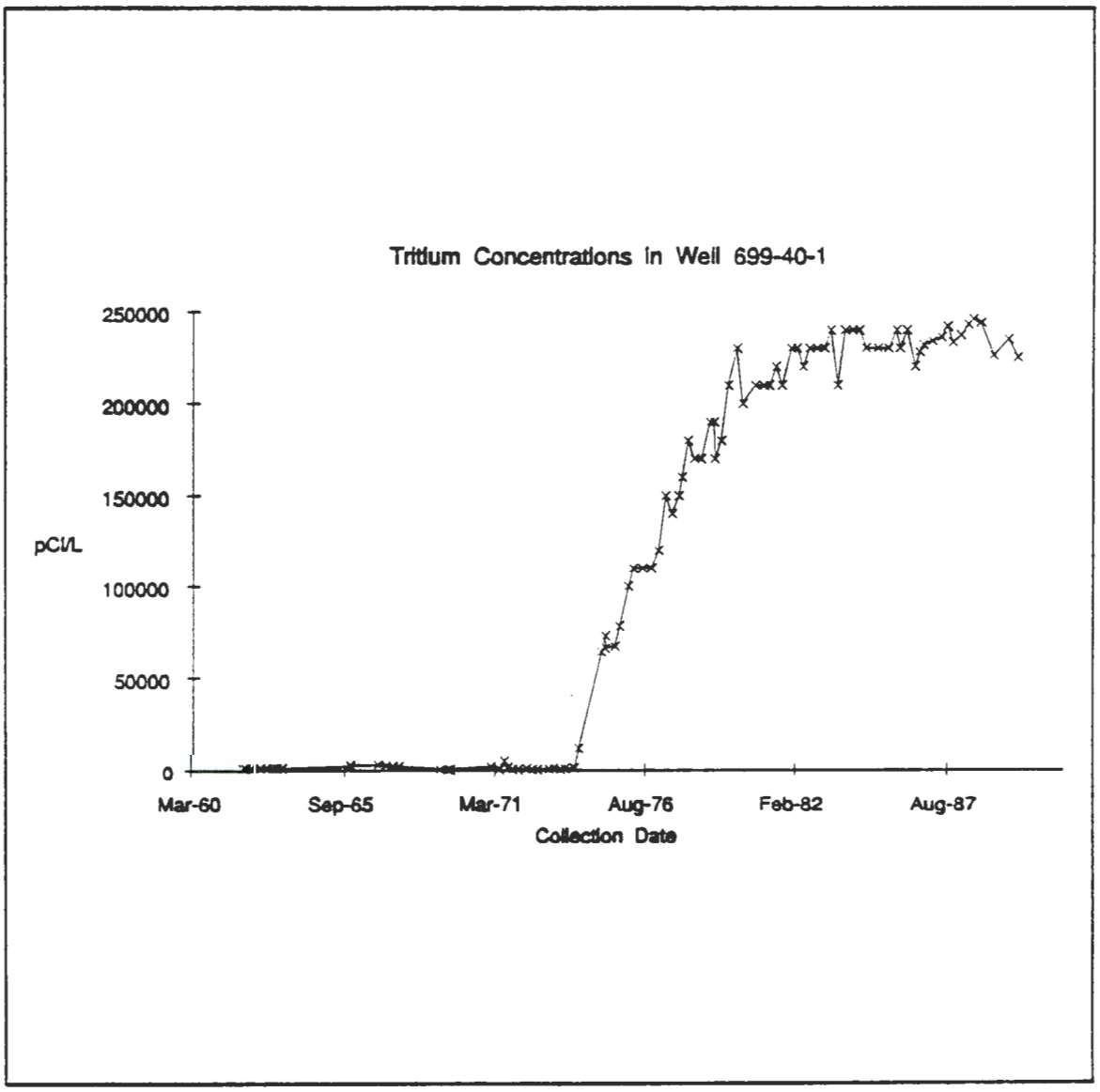


FIGURE 2.19. Trend Plot for Tritium in Well 699-40-1

to the river of 20 to 23 years. It is difficult to calculate a ground-water velocity from this information because the length of the path taken from the disposal sites to this well is unknown.

At the time of the restart of PUREX, monitoring wells had been installed in sufficient density to monitor the development of the contaminant plume. Under these conditions, the tritium data can be used to calculate an average velocity for ground water between the facilities receiving waste and well 699-24-33. The distance of approximately 8.4 km was traveled in 4 years, yielding a velocity of approximately 2.1 km per year in the portion of the Site under the conditions that existed when PUREX was operating.

The eastern portion of the plume continues to move to the east-southeast and discharge into the Columbia River. Migration of the plume continued farther to the south, as indicated by increased tritium concentrations in wells near the 300 Area (e.g., 699-S19-E13). Figure 2.20 shows the trend of tritium concentrations in well 699-S19-E13. In recent years, this well has shown a steady increase in tritium, having reached a new maximum value of 8480 pCi/L in April 1990. The configuration of the western portion of the plume closely matches previous predictions of the direction of contaminant movement from the 200-East Area (Freshley and Graham 1988). Movement to the south may be enhanced by the spreading ground-water mound beneath B Pond. This mound is spreading as a result of increased discharge of steam condensate and process cooling water to B Pond since 1984 when Gable Mountain Pond was deactivated. However, the plume is not expected to move much farther south because of the influence of the Yakima River on ground-water flow in this area. The Yakima River is at a higher elevation than that of ground water in this area, which is at a higher elevation than the Columbia River. As a result, ground water flows from west to east, preventing the contaminant plume from spreading farther south. In addition, plume spread is also balanced to some extent by radioactive decay of the tritium, which has a half-life of 12.3 years.

The movement of tritium plumes in the 200-West Area was also consistent with previous observations. The plume extending from near the REDOX Plant in the southern part of the 200-West Area continued to move slowly to the east and north. Only one well in the 200-West Area (299-W22-9) continued to show

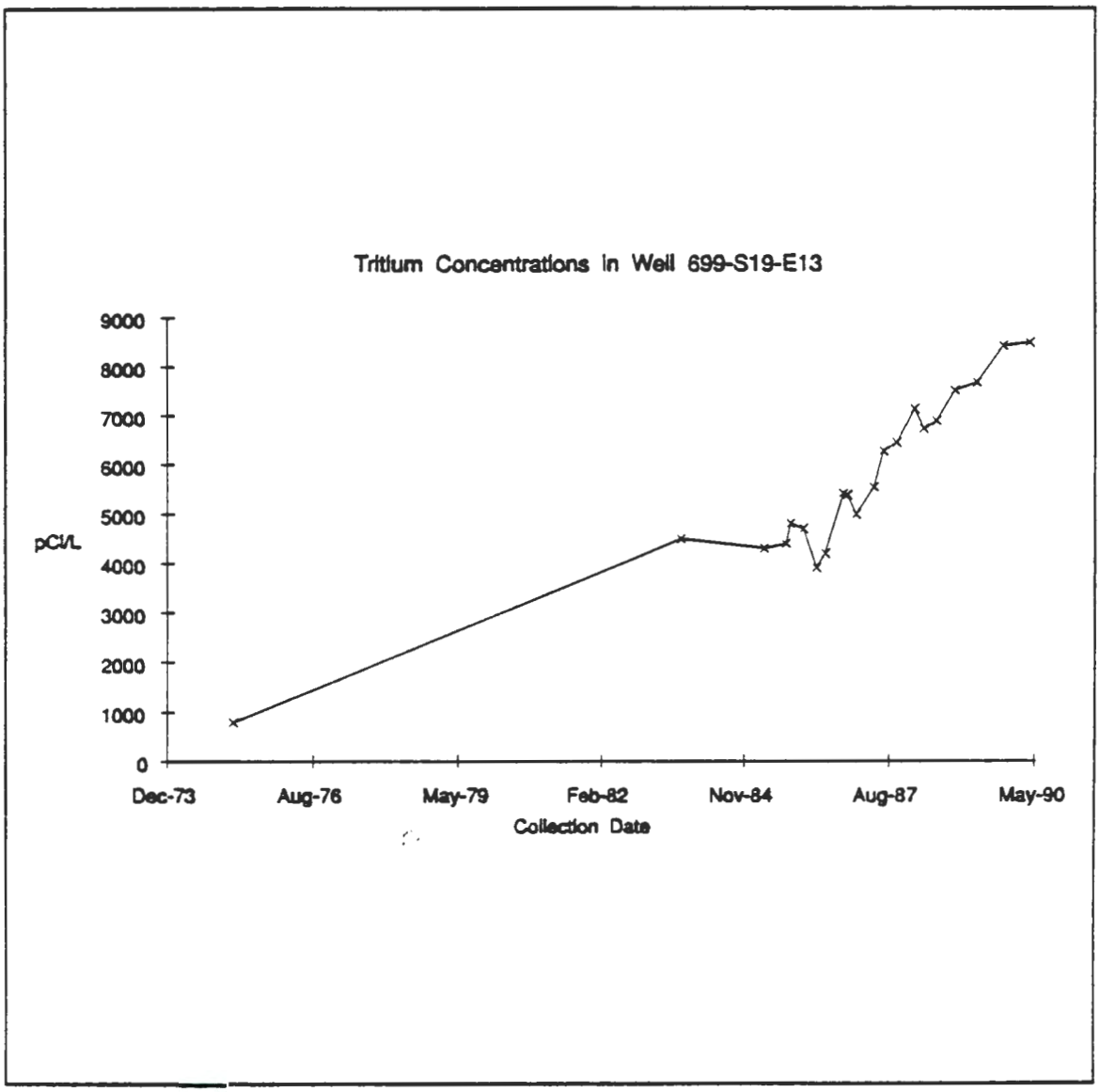


FIGURE 2.20. Tritium Concentrations in Well 699-S19-E13

tritium levels in excess of the DCG during 1990; however, that well contained the highest tritium levels of any ground-water wells on the Hanford Site (5,880,000 pCi/L). Tritium concentrations in well 299-W23-4 increased rapidly, reaching a maximum of 5,450,000 pCi/L in February 1988, followed by a rapid decrease to below the DCG during the remainder of the year. That trend continued during 1990, with the level down to 8510 pCi/L by April 1990. The explanation of this rapid decrease in tritium concentration remains unclear.

Well 299-W23-4 had shown negligible tritium levels during 1987. Tritium concentrations in nearby wells within the 200-West Area and in the adjacent 600 Area remained above the DWS and were relatively constant throughout 1990 with the exception of tritium concentrations in well 299-W23-9, which dropped by nearly an order of magnitude in 1990 after remaining nearly constant for several years. Movement of the tritium plume extending north and east from the REDOX Plant was indicated by changes in the tritium concentrations in several wells in the plume. Concentrations in well 699-35-70 continued to decrease slightly, suggesting that peak concentrations may have moved beyond this well, although at least part of the decrease seen in this well during the past several years can be accounted for by radioactive decay. Plume movement in that area is very slow because of low hydraulic conductivity of middle Ringold Formation sediments at the water table in this region. Concentrations in wells near the center of the plume remained relatively constant. The northernmost extent of the plume appeared to be near well 699-40-62, which was not monitored during 1990. Well 699-44-64, north of well 699-40-62, has shown a small but steady increase over the last 24 months, reaching a new high of 814 pCi/L in April 1990. A contour plot of the tritium plume in the 200-West Area is shown in Figure 2.21. Figure 2.17 provides considerably more detail concerning the higher tritium concentrations found in localized areas near sources (i.e., LWDFs) than does Figure 2.16, which is intended to address large-scale movement of the dilute portion of the plume.

2.2.7 Gross Alpha Activity

Relatively few gross alpha measurements were made in 1990. In general, the Ground-Water Surveillance Project has, in recent years, opted to use more specific analytical techniques rather than the relatively nonspecific gross alpha method. Gross alpha measurements have thus been made primarily by the operational and compliance monitoring projects, which were less active in 1990. A total of 100 gross alpha measurement were made during the year primarily in uncontaminated areas of the Site. In past years, elevated gross alpha concentrations have been detected in ground water from wells in several areas and may be attributable to the presence of isotopes of plutonium and/or uranium; however, plutonium (and other transuranic isotopes) concentrations in

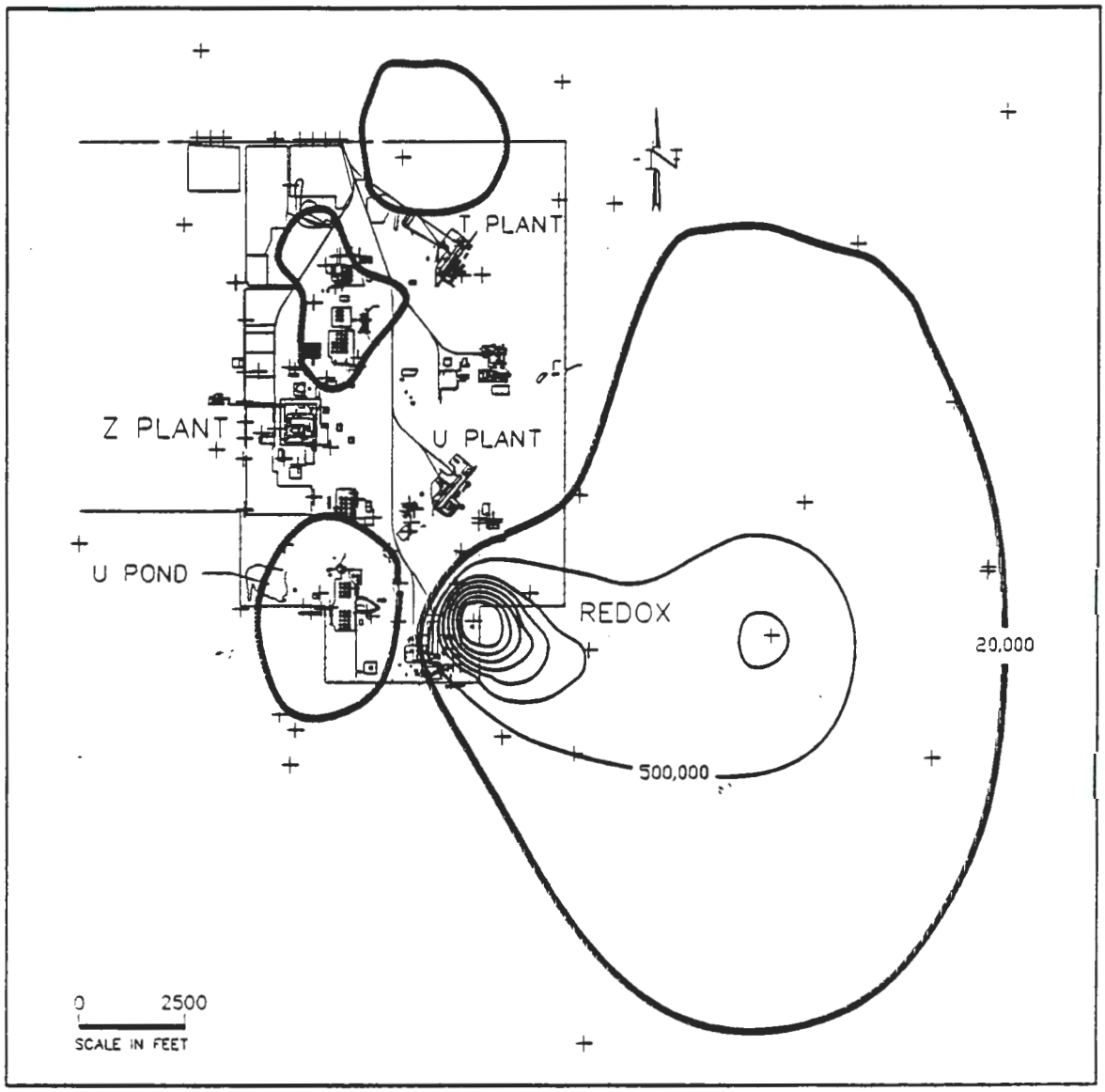


FIGURE 2.21. Tritium Ground-Water Plume in the 200-West Area. Minimum contour is 20,000 pCi/L. Contour intervals are 500,000 pCi/L. Bold contour line indicates DWS. + marks sampling locations.

all but four wells were below the detection limit attainable by the analytical laboratory. The DWS for gross alpha is 15 pCi/L, not including uranium. Wells in the 100-F, 200, and 300 areas where gross alpha has routinely exceeded 15 pCi/L have been shown to contain uranium at levels that would account for the gross alpha level detected. Several wells in the 100-H Area

also contained gross alpha levels exceeding the DWS. Although levels in a few wells in the 200-East Area have been somewhat above the DWS, gross alpha levels in most wells in the 200-East Area were low. The highest gross alpha levels measured on Site were found in wells adjacent to the inactive 216-U-1 and 216-U-2 cribs. Wells adjacent to these cribs contained uranium levels that would account for the gross alpha levels detected.

2.2.8 Gross Beta Activity

Gross beta concentrations greater than the 50-pCi/L DWS have been found in wells throughout the Site. Gross beta levels can be attributed to one or more of the following radionuclides in ground water: potassium-40 (naturally occurring); cobalt-60, strontium-90, technetium-99, ruthenium-106, antimony-125, cesium-137, thorium-234, and proctactinium-234 (uranium radioactive decay products); and to a lesser extent iodine-129. During past Site operations, some shorter-lived beta emitters (such as ruthenium-103, ruthenium-106, or iodine-131) were also occasionally present. Tritium is not detected by the method used for assay of gross beta. Gross beta activity above natural background in most cases derives from a combination of uranium and technetium-99 activity. Known exceptions include some wells in the 100-N Area and a few wells in the 200-East Area that contain strontium-90 at concentrations high enough to be detected with the gross beta technique.

More than 500 gross beta measurements were made in 1990. Although gross beta levels greater than the DWS were widespread, the highest levels were in wells near several waste disposal facilities in the 100-N, 200-East, and 200-West areas, and in the 600 Area adjacent to the 200 Areas. Wells in the 200-East Area with the highest gross beta levels in 1990 reflect past disposal of liquid waste to the inactive 216-B-5 Reverse Injection Well, BY Cribs, and cribs near the PUREX Plant. Gross beta levels in wells 299-E28-23 (12,900 pCi/L) and 299-E28-25 (12,000 pCi/L) near the 216-B-5 Reverse Injection Well were some of the highest measured on Site in 1989. All wells near this reverse injection well contained elevated levels of strontium-90, and three wells also contained measurable cesium-137. The 216-B-5 reverse injection well received an estimated 27.9 Ci of strontium-90 and 31.8 Ci of cesium-137 (both values decayed through April 1, 1986) when used from 1945 to

1947 (Stenner et al. 1988). The BY Cribs received waste scavenged from U Plant. Wells monitoring the BY Cribs (located at the north end of the 200-East Area) showed gross beta levels greater than the DWS, ranging up to 1440 pCi/L (well 699-50-53) in 1989; however, those wells were not monitored in 1990. The BY Crib monitoring wells showed the presence of cobalt-60 and technetium-99 accounting for the majority of the gross beta activity.

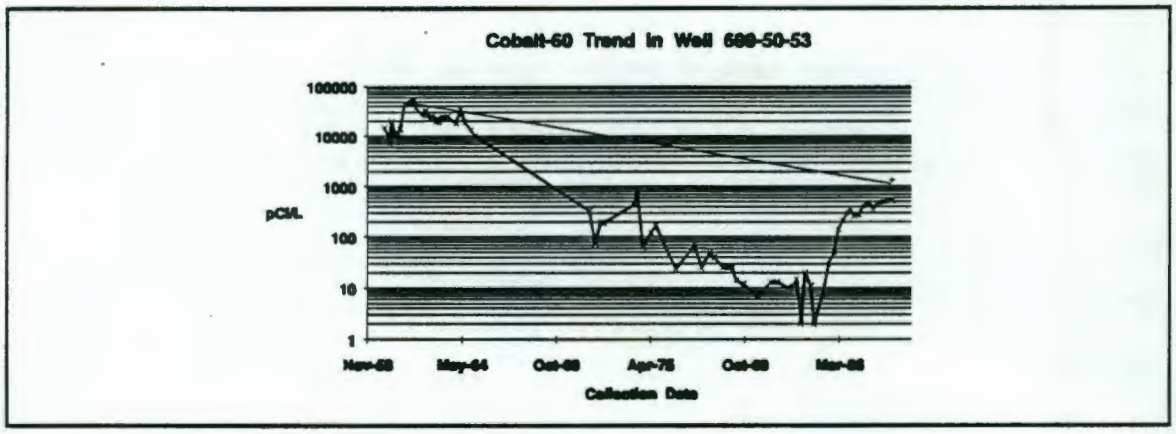
The highest gross beta levels in the 200-West Area were found in wells near U Plant. Gross beta levels in wells near the 216-U-1 and 216-U-2 cribs remained above the DWS but are generally decreasing. Gross beta levels in these wells are dominated by uranium radioactive decay products.

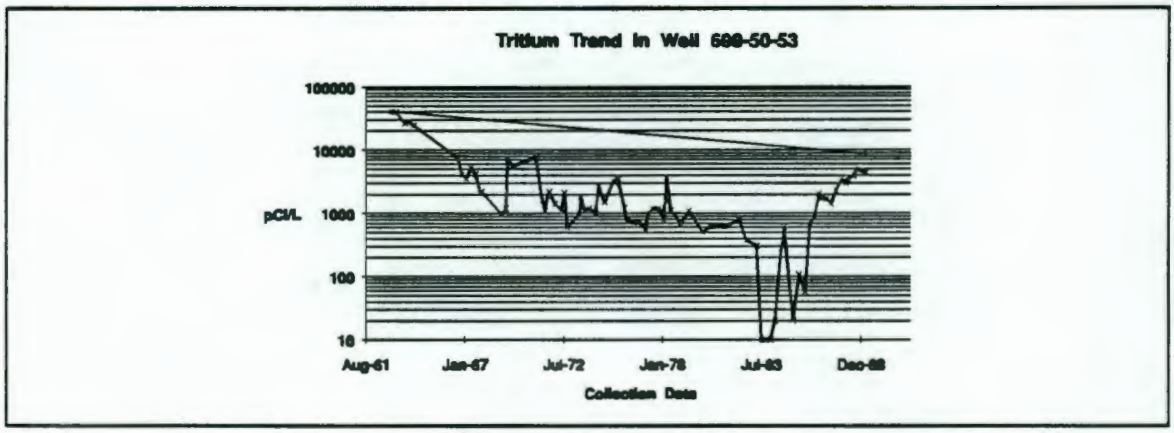
Gross beta levels remained above the DWS in several wells near Gable Mountain Pond. These wells contain relatively high concentrations of strontium-90, which would account for the gross beta levels measured.

The highest gross beta levels on Site in 1990 were found in wells monitoring the 1301-N LWDF. Well 199-N-67 showed a gross beta concentration of 16,500 pCi/L in February 1990. The observed concentrations at this location are primarily due to strontium-90.

2.2.9 Cobalt-60

Most cobalt-60 concentrations were consistently near or below the detection limit (20 pCi/L) for wells monitored in 1990. Concentrations of cobalt-60 were above detection in a number of 100-N Area wells near the 1325-N LWDF, but have dropped below detection in the past year. The highest concentrations of cobalt-60 in Hanford Site ground water during 1989 were in well 699-50-53 (532 pCi/L), directly north of 200-East Area. No additional monitoring was performed on that well in 1990. Cobalt-60 in this well appears to be highly mobile, probably because of the presence of a soluble cobalt-cyanide (or ferrocyanide) complex associated with the plume originating from the BY Cribs. This effect was first observed as far back as the late 1950s and was the main reason that disposal to the BY Cribs was discontinued. Figure 2.22 shows a trend plot for cobalt-60 in well 699-50-53 extending back to 1960. The figure shows very elevated levels of cobalt-60 in the ground water at that time, dropping off through the 1960s and 1970 largely as a result of changing





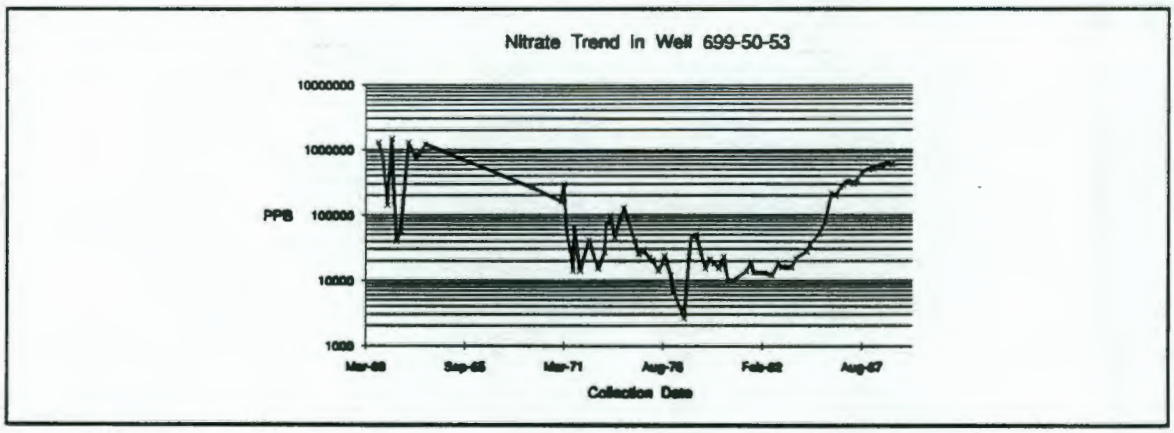


FIGURE 2.22. Long-Term Concentration Trends for Radionuclides and Nitrate Monitored in Ground-Water Samples from Well 699-50-53 Associated with Plume Originating from BY Cribs in Late 1950s. Upper line on each graph denotes decay correction from initial peak concentration.

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ground-water flow patterns associated with the discontinuation of the use of the BY Cribs and the increased disposal to Gable Mountain pond. As Gable Mountain Pond was phased out and replaced by disposal of large volumes of cooling water to B Pond, the situation appears to have reversed. Figure 2.22 shows a return to a level only slightly less than that explained by simple radioactive decay. Tritium and nitrate trends shown in the same plot show a similar effect as do the more recently available chemical data (calcium, strontium, and sulfate) shown in Figure 2.23. Nitrate is plotted in both figures for intercomparison of time scales. These two plots suggest that cobalt-60 is moving essentially unretarded with the local ground-water flow.

2.2.10 Strontium-90

Concentrations of strontium-90 were above the 8-pCi/L DWS in wells in the 100-B, 100-D, 100-F, 100-K, 100-N, 200-East, 200-West, and 600 areas. Concentrations of strontium-90 were greater than the 1000-pCi/L DCG in the 100-N and 200-East areas, ranging up to 8980 pCi/L in the 100-N Area near the 1301-N LWDF (well 199-N-67) significantly reduced from the maximum of 23,400 pCi/L reached in March of 1989. A trend plot of strontium-90 concentrations in two of the 100-N Area wells is given in Figure 2.24. A contour plot of the strontium-90 ground-water plume distribution is given in Figure 2.25. The plot is based on ground-water well data collected in 1989 and 1990. Also included on the plot are data from spring sampling locations near the shoreline (Craig Perkins, Environmental Engineer, WHC, personal communication, 1992). These measurements were all made in September 1990 at relatively low river stage in order to minimize the effect of bank storage.

Concentrations of strontium-90 ranged up to 6200 pCi/L in the 200-East Area near the 216-B-5 Reverse Injection Well (see Figure 2.20). Concentrations of strontium-90 above the DWS (maximum of 240 pCi/L in well 699-53-48B) but less than the DCG were detected in several wells near Gable Mountain Pond.

2.2.11 Technetium-99

Concentrations of technetium-99 greater than the 900-pCi/L DWS have been detected in past years (through 1989) in wells in the 100-H, 200-East, and 200-West areas and in portions of the 600 Area. None of the wells had

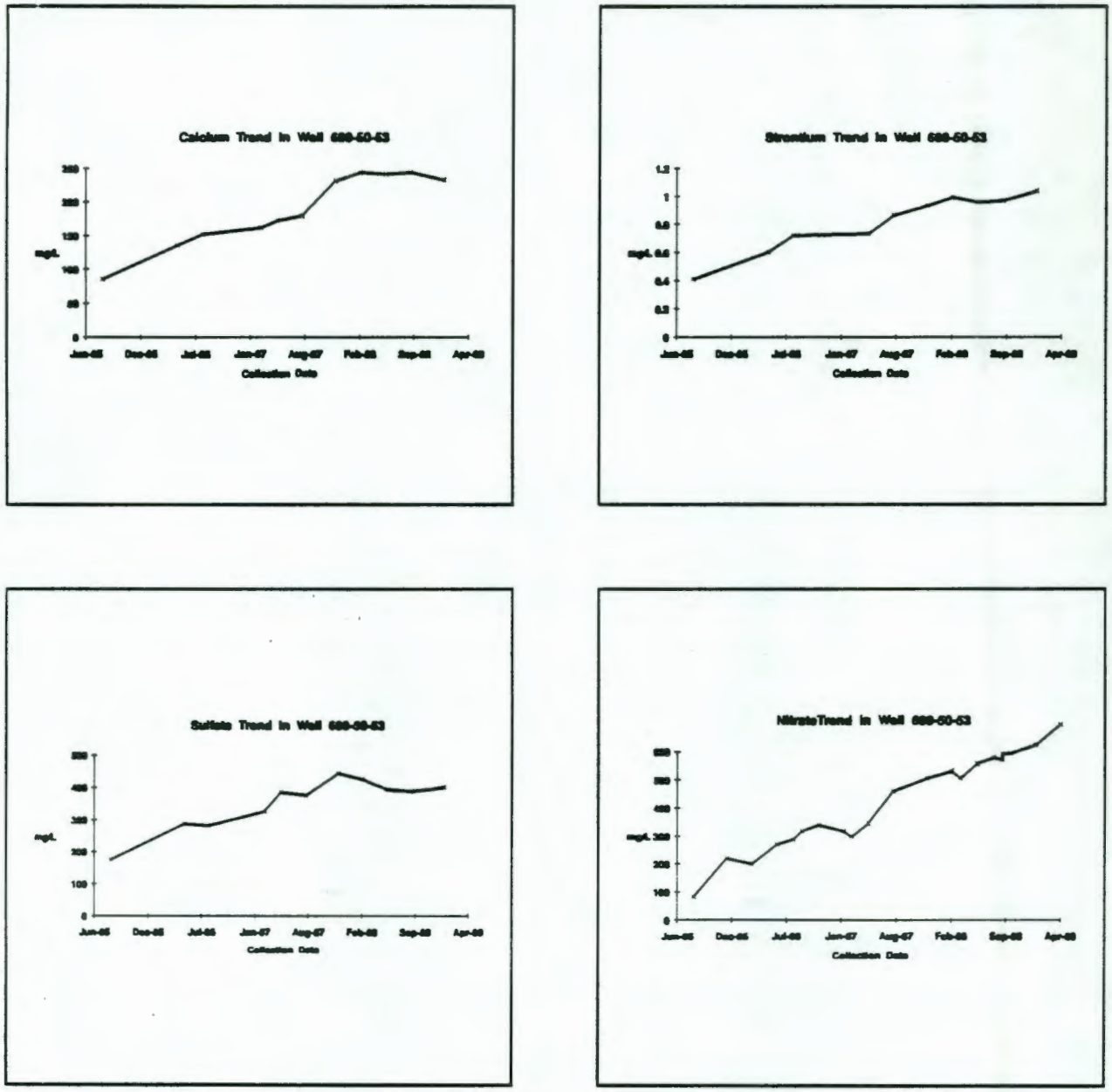

FIGURE 2.23. Recent Concentration Trends for Chemicals Monitored in Ground Water from Well 699-50-53 Associated with Contaminant Plume Originating from BY Cribs in Late 1950s

concentrations exceeding the 100,000-pCi/L DCG. None of the wells showing the highest technetium-99 levels during past years were monitored for that parameter in 1990; however, some reanalysis of past data was performed. The

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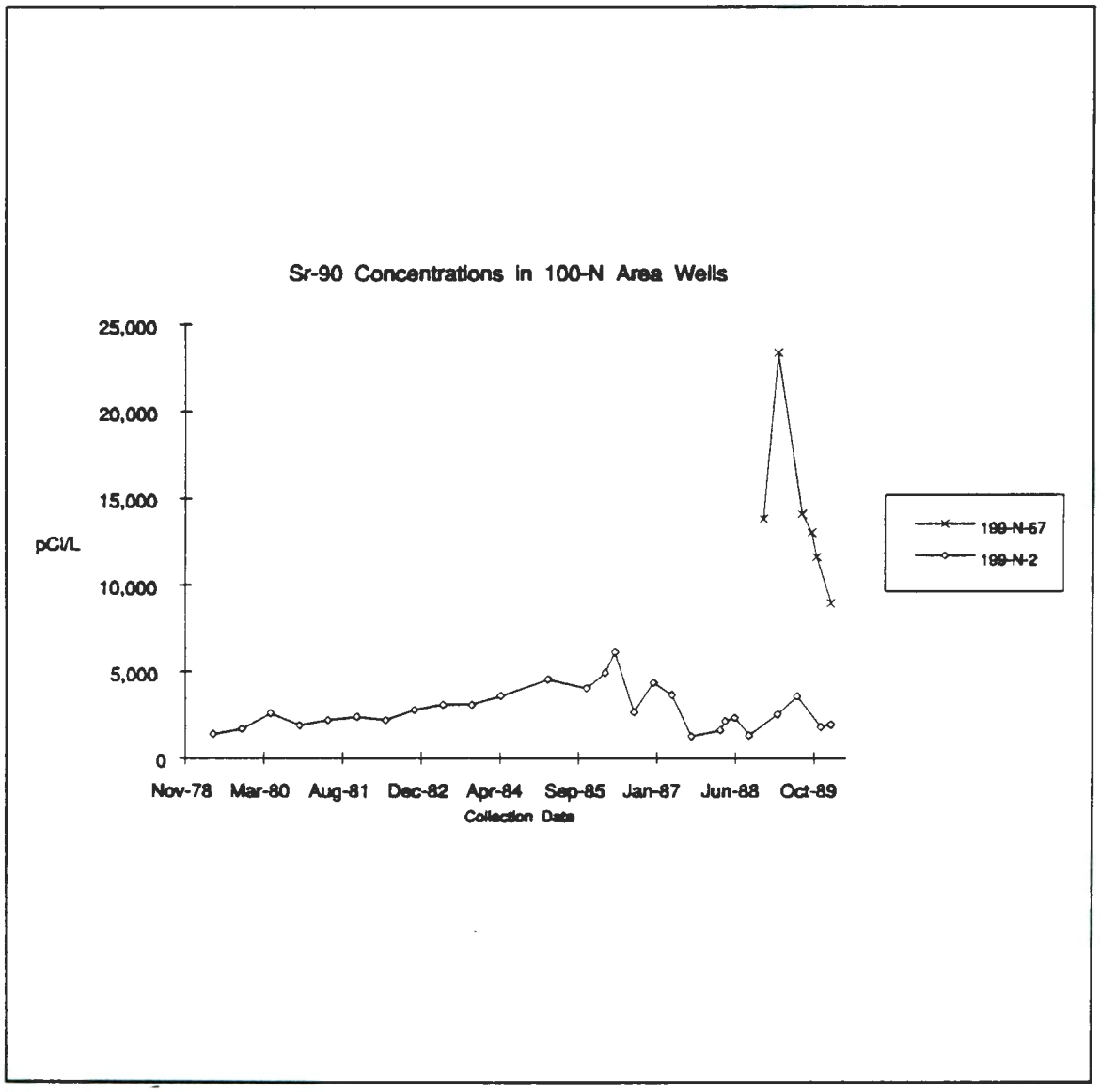

FIGURE 2.24. Trend Plot for Strontium-90 in 100-N Area Ground-Water Wells Between 1301-N LWDF and the Shoreline of the Columbia River

spatial distribution of technetium-99 in the 200-West Area is shown in Figure 2.26. The technetium-99 plume in the 200-West Area appears to have originated from the 216-U-1 and 216-U-2 cribs, which had received a large amount of uranium recovery waste in the past. Technetium has generally been observed to follow uranium throughout the uranium recovery and recycling process.

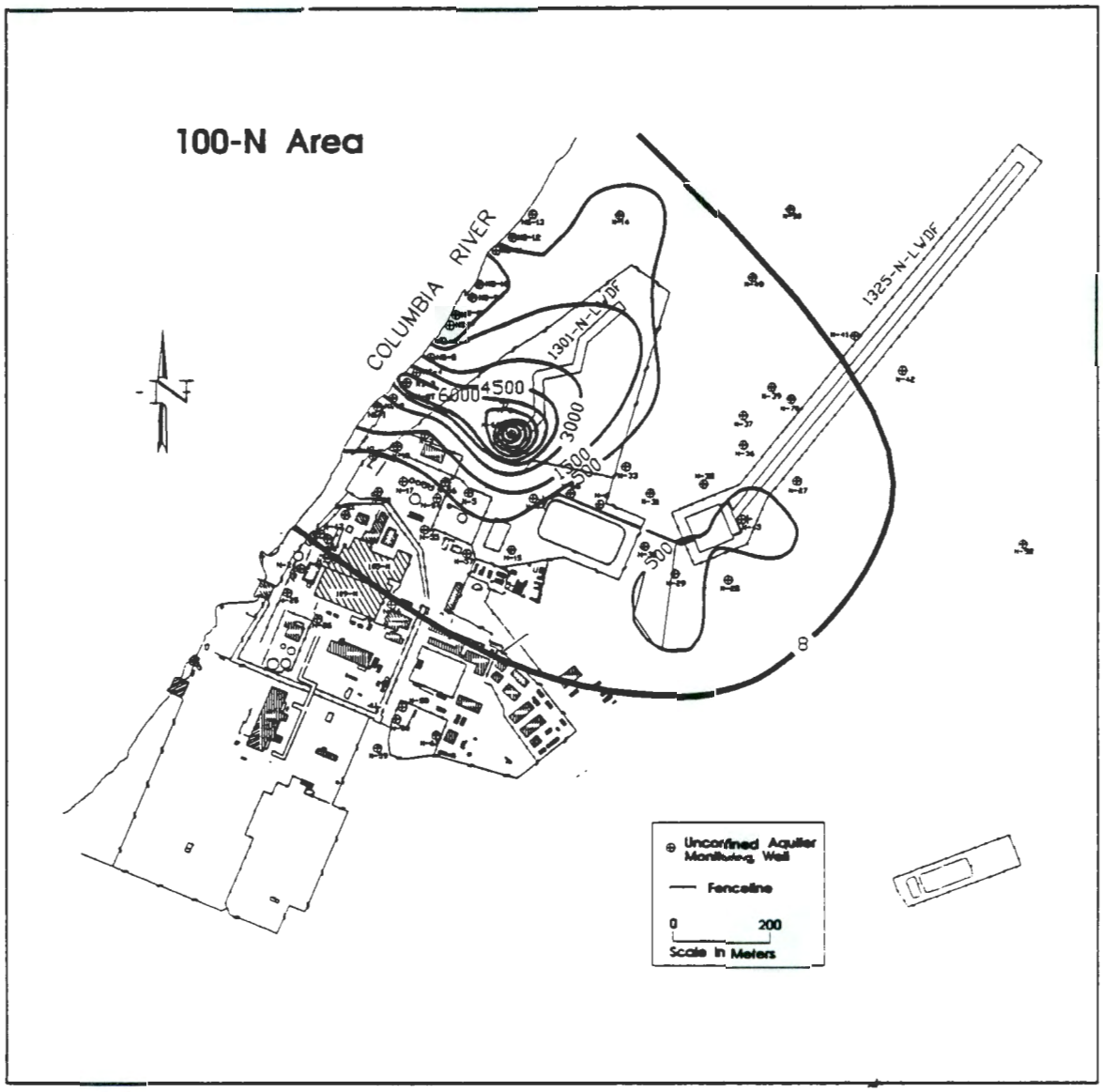

FIGURE 2.25. Contour Plot of Strontium-90 in 100-N Area Ground Water. 1989-1990 data. Minimum contour is set at DWS (8 pCi/L). Maximum contour is 14,000 pCi/L.

Technetium has also been observed in ground water several wells north of the 200-East Area. The distribution is similar in size, shape, and location to cyanide, nitrate, and cobalt-60 found in the same area resulting from waste disposed to the BY Cribs.

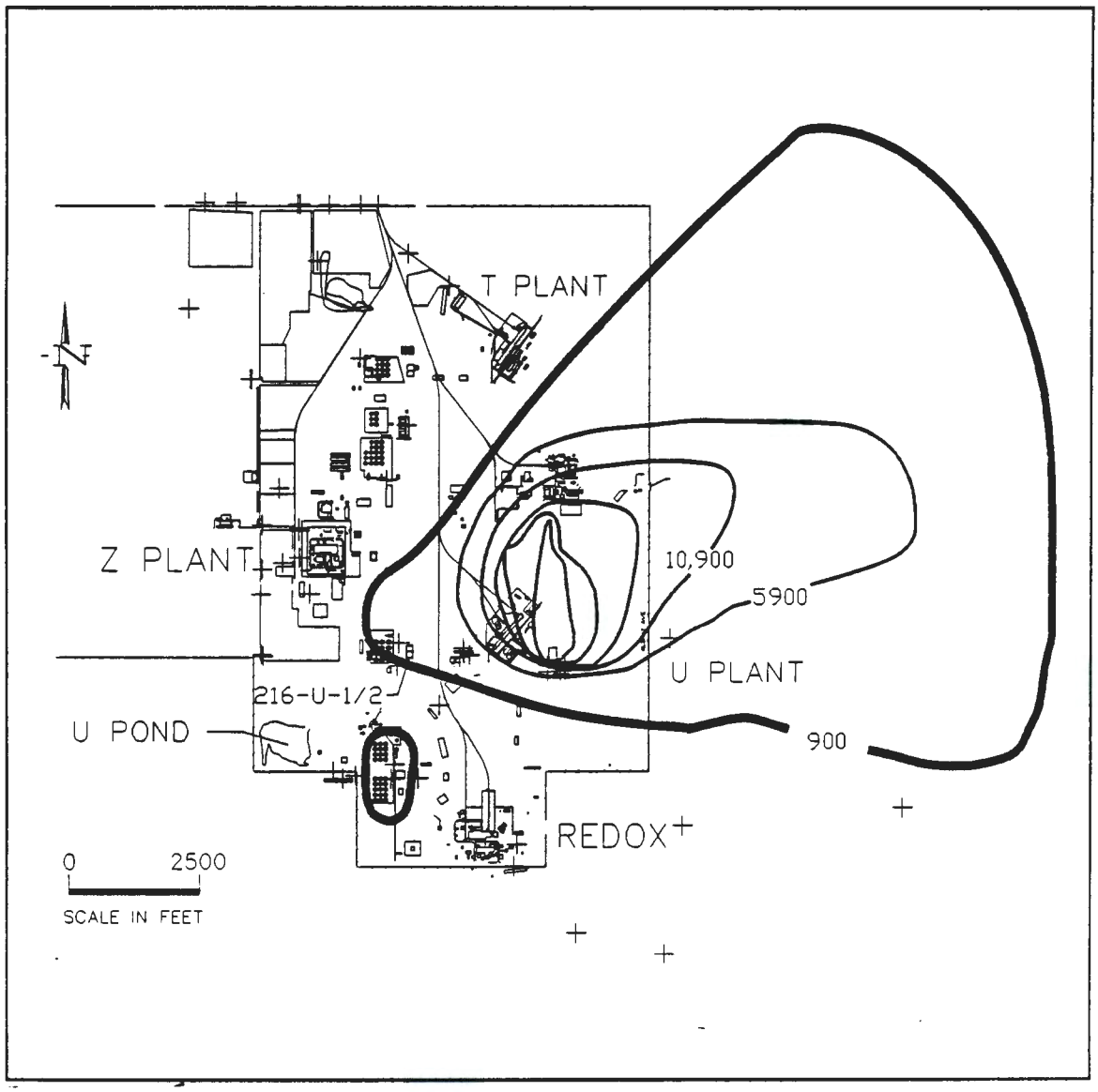

FIGURE 2.26. Technetium-99 Ground-Water Plume in the 200-West Area. Minimum contour is 900 pCi/L. Contour intervals are 5000 pCi/L. Bold contour line indicates DWS. + marks sampling locations.

2.2.12 Ruthenium-106

Because of its short half-life (367 days), ruthenium-106 was detected in the past principally in wells located in areas near operating reactors and active fuel reprocessing facilities. Past examples have included the 100-N Area and the 200-East Area near the PUREX Plant. Concentrations in wells in

the 100-N Area were at most marginally detectable in 1987 and continued to decline in 1988 because the N Reactor was in cold standby and discharges to ground were significantly reduced. Ruthenium-106 was undetectable by routine methods in the 100-N Area in 1989. Concentrations of ruthenium-106 in wells near LWDFs receiving effluents from the PUREX Plant generally increased in 1988, with well 299-E24-12 reaching a maximum of 547 pCi/L (DWS is 200 pCi/L) in April 1988. That trend reversed in 1989 as a result of interruption in the operation of PUREX, with the ruthenium-106 concentrations in well 299-E24-12 dropping to below detectable levels. A ruthenium-106 concentration of 257 pCi/L was found in well 299-E17-15 in September 1989. The concentration of ruthenium-106 dropped to below the detection limit in that well in 1990. Ruthenium-106 has, thus, not been detectable by routine methods in any Hanford ground-water wells sampled after 1989.

2.2.13 Antimony-125

Antimony-125, a gamma emitter, was measured in the past in only a few 100-N Area wells near the 1325-N LWDF. Results ranged up to 93.6 pCi/L in well 199-N-32 in 1989. Well 199-N-45, which had the highest antimony-125 in 1988, was not assayed for that radionuclide in 1989 or 1990. No positive detection of antimony-125 was reported in 1990. The DWS for antimony-125 is 300 pCi/L, and the DCG is 60,000 pCi/L.

2.2.14 Iodine-129

The presence of iodine-129 in ground water is significant because of the radionuclide's relatively low DWS (1 pCi/L), relatively long half-life (16,000,000 years), and its potential for accumulation in the environment as a result of long-term releases from nuclear fuel reprocessing facilities (Soldat 1976). At Hanford, the main contributor of iodine-129 to ground water has been liquid discharges to cribs in the 200 Areas. The expanded iodine-129 monitoring effort that began in 1988 was continued through 1990 with many new wells sampled. The highest concentration reported in 1990 was 10.7 pCi/L in well 699-35-70, located just outside the 200-West Area boundary and down-gradient from the REDOX Plant. The concentration in January 1991 was 33.4 pCi/L. A contour map of the iodine-129 distribution in 200-West Area ground water is shown in Figure 2.27 (January 1991 data for 699-35-70 was used

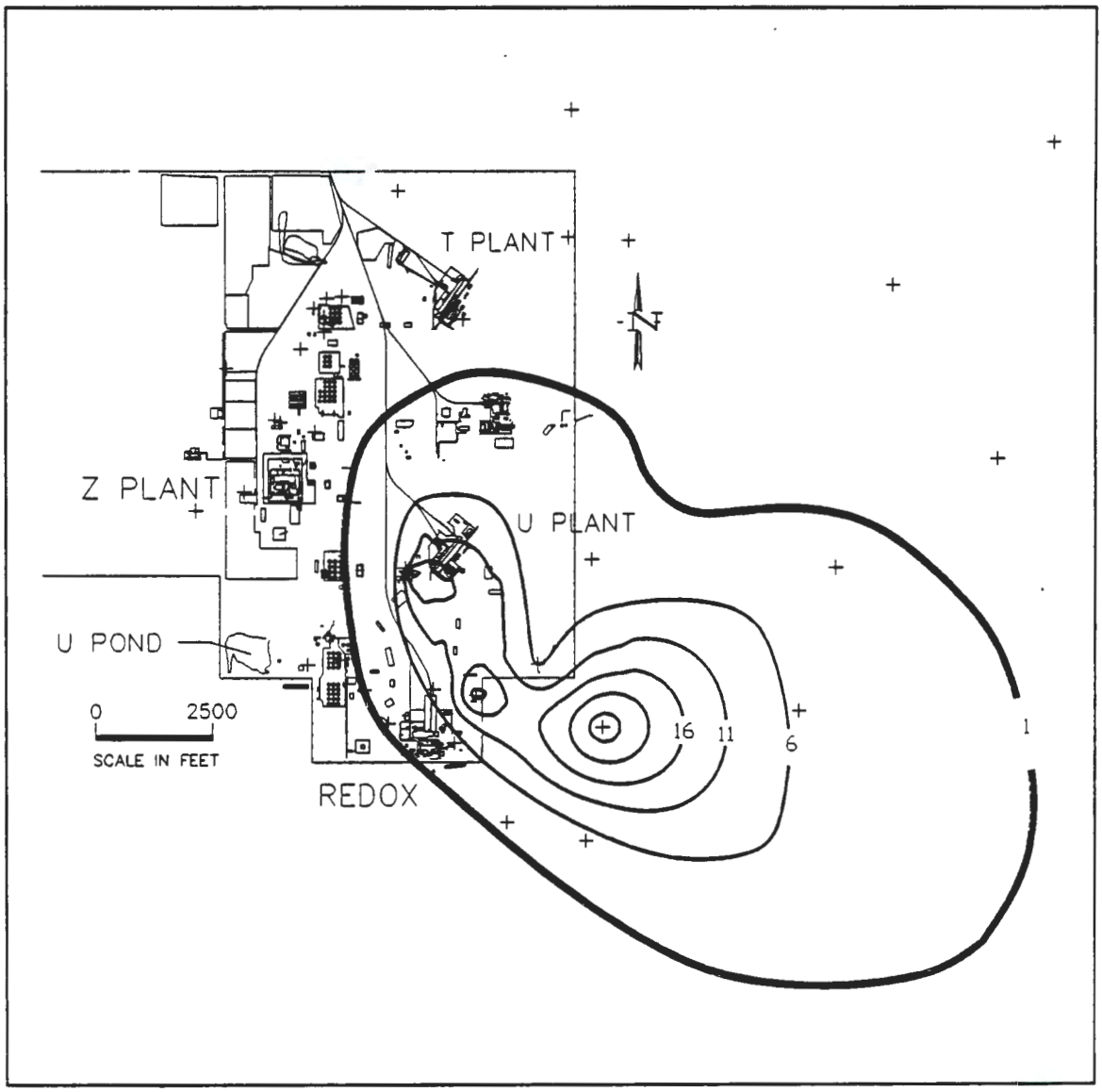

FIGURE 2.27. Iodine-129 Ground-Water Plume in the 200-West Area. Minimum contour is 1 pCi/L. Contour intervals are 5 pCi/L. Bold contour line indicates DWS. + marks sampling locations.

when creating this map). At least two or more major sources are indicated associated with both the U Plant and REDOX facilities. Wells sampled in the 200-West, 200-East, and 600 areas had concentrations somewhat above the DWS; however, none was above the DCG (500 pCi/L). Assay of iodine-129 by high-sensitivity, direct-counting methods requires long counting times with correspondingly low analytical throughput. Unfortunately, the unexpected

termination of the analytical contract at midyear severely limited the number of available measurements, and many samples that had already been submitted to the laboratory could not be retrieved in usable form.

2.2.15 Iodine-131

Because iodine-131 has a short half-life (8.04 days), it typically has been detected only in ground water near known waste water discharge facilities (100-N Area wells). Iodine-131 was not detected in any Hanford Site wells during 1990 because the N Reactor was in cold standby and iodine-131 was not discharged to ground water.

2.2.16 Cesium-137

Concentrations of cesium-137 were below the detection limit (23 pCi/L) except in three wells located near the 216-B-5 Reverse Injection Well. Ground water sampled at well 299-E28-23 contained 1450 pCi/L; ground water at well 299-E28-25 contained 166 pCi/L. The concentration in well 299-E28-25 represents a small increase over the previous trend but is significantly less than the single measurement of 1070 pCi/L reported for 1989, which may have been an analytical artifact or reporting error. In addition to concentrations in these wells, cesium-137 was also detected for the first time in nearby well 299-E28-24 in 1989. Cesium-137 continued to increase in that well reaching a new high of 633 pCi/L in April 1990. The 216-B-5 Reverse Injection Well received an estimated 31.8 Ci of cesium-137 (decayed through April 1, 1986) during its operation from 1945 to 1947 (Stenner et al. 1988). The DWS for cesium-137 is 200 pCi/L and the DCG is 3000 pCi/L.

2.2.17 Uranium

The highest uranium levels in Hanford ground water occur in wells adjacent to the inactive 216-U-1 and 216-U-2 cribs. Uranium concentrations in these wells have been decreasing over the last 4 years following uranium recovery activities associated with those cribs. The total uranium concentration in well 299-W19-3 dropped from 16,000 pCi/L in January 1987 to 2000 pCi/L in March 1989. No uranium measurements were available for that well in 1990, but the gross alpha measurement suggests that the uranium level has not changed significantly from 1989. Uranium concentrations in other

nearby wells also tended to decrease over the past 4 years and now appear to have stabilized. A contour plot of the uranium distribution in the 200-West Area ground water is shown in Figure 2.28.

There is a small uranium plume in the northwest corner of the 200-East Area downgradient of B Plant. The source of the plume is believed to be the

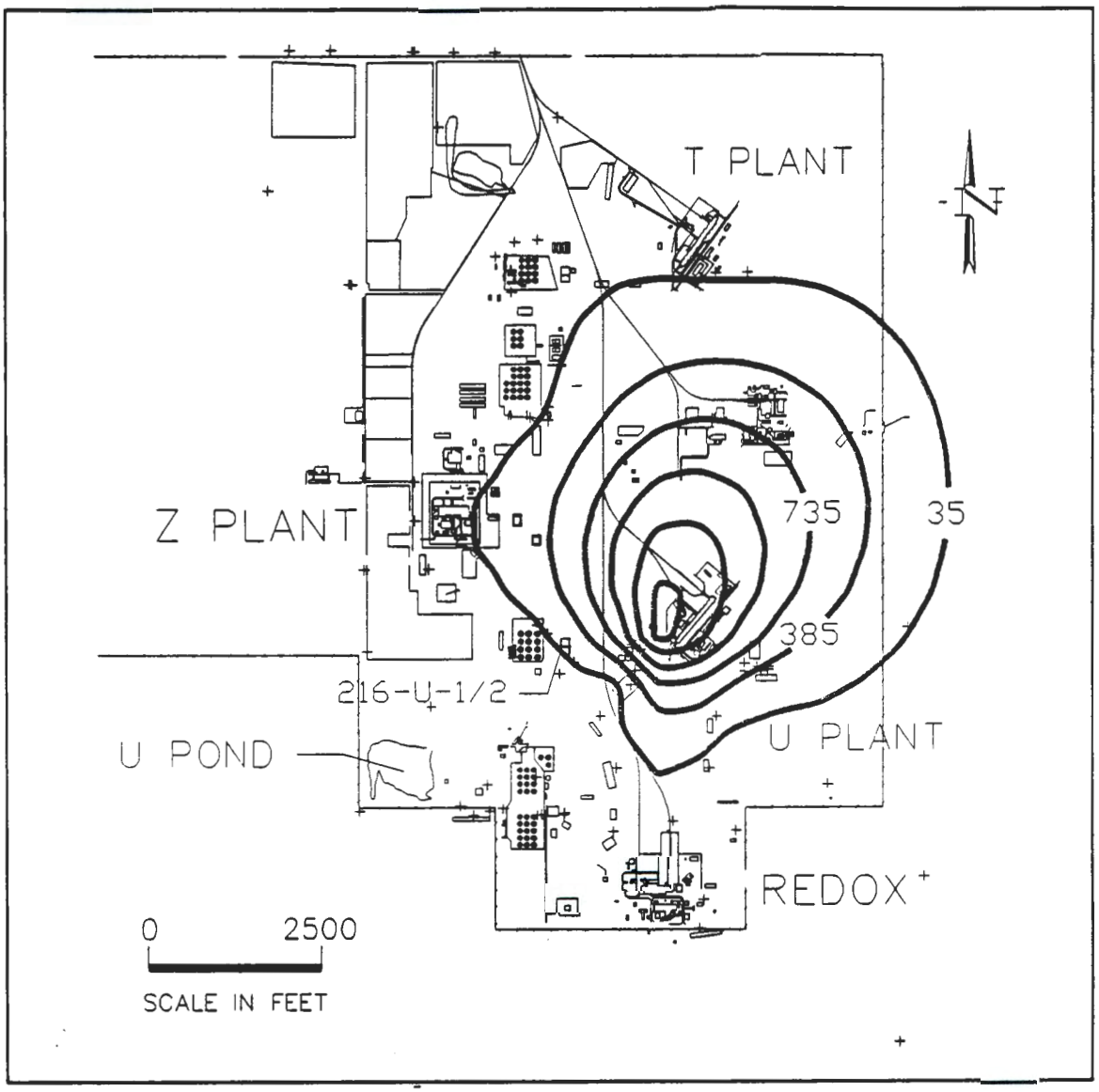

FIGURE 2.28. Uranium Ground-Water Plume in the 200-West Area. Minimum contour is 35 pCi/L. Contour intervals are 350 pCi/L. + marks sampling locations.

216-B-12 Crib, which received an estimated 7 Ci or 20,700 kg of uranium (Stenner et al. 1988) during its operation between 1957 and 1973. Uranium levels in this well have been decreasing slowly over the past few years. For example, the uranium concentration in well 299-E28-21 decreased from 52.1 pCi/L in 1987 to 19.1 pCi/L[(a)] in early 1990.

Uranium levels increased sharply in two 100-F Area wells in 1987. Levels in well 199-F8-1 reached a maximum of 414 pCi/L in January 1988 and generally have decreased thereafter, dropping to a low of 72 pCi/L in April 1990. A similar trend occurred in well 199-F8-2. A trend plot showing uranium concentrations in those two wells as a function of time is given in Figure 2.29.

A uranium plume exists in the 100-H Area near the 183-H Solar Evaporation Basins. The maximum uranium concentration during 1990 in the 100-H Area ground water was 44.8 pCi/L in well 199-H4-4.

A plume of uranium also exists in the unconfined aquifer beneath the 300 Area in the vicinity of uranium fuel fabrication facilities and inactive waste sites known to have received uranium waste. The extent of the plume was limited to an area downgradient from active and inactive LWDFs. Uranium concentrations in wells in and adjacent to the 300 Area ranged up to 334 pCi/L during 1990. These maximum concentrations were similar to maximums measured in previous years, although temporal variability continues to be large. This variability can be seen in the trend plots for uranium concentration in two key 300 Area wells shown in Figure 2.30. The observed variability appears to be associated with river stage fluctuations in the nearby Columbia River. A contour plot of the uranium concentrations in 300 Area ground water is given in Figure 2.31.

(a) Uranium concentration is determined by fluorometric determination of total elemental uranium. These values (μg/L) are converted to activity units (pCi/L) using a factor of 0.6905 pCi/μg. This value is calculated assuming secular equilibrium between U-234 and U-235 and normal isotopic abundance of U-235. It also agrees with isotopic ratios observed on site.

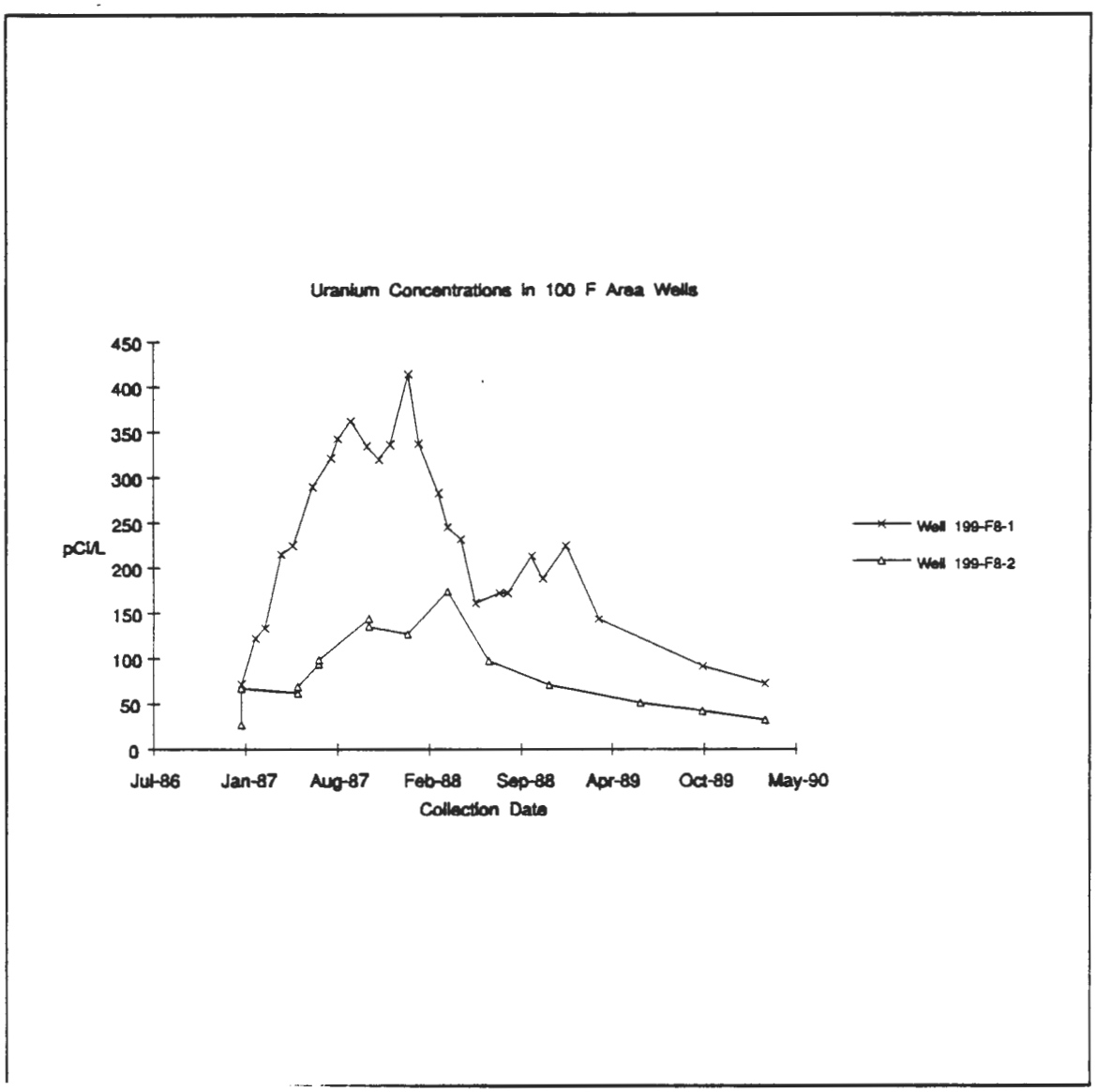

FIGURE 2.29. Uranium Concentrations in Wells on the West Side of the 100-F Area

2.2.18 Plutonium

Concentrations of plutonium-239/240 were below the detection limit in all wells except three located near the 216-B-5 Reverse Injection Well and one in the 200-West Area. Plutonium is generally considered to bind strongly to sediments and thus have limited mobility in the aquifer. Ground water sampled at well 299-E28-23 contained 21.7 pCi/L of plutonium-239/240; ground water at

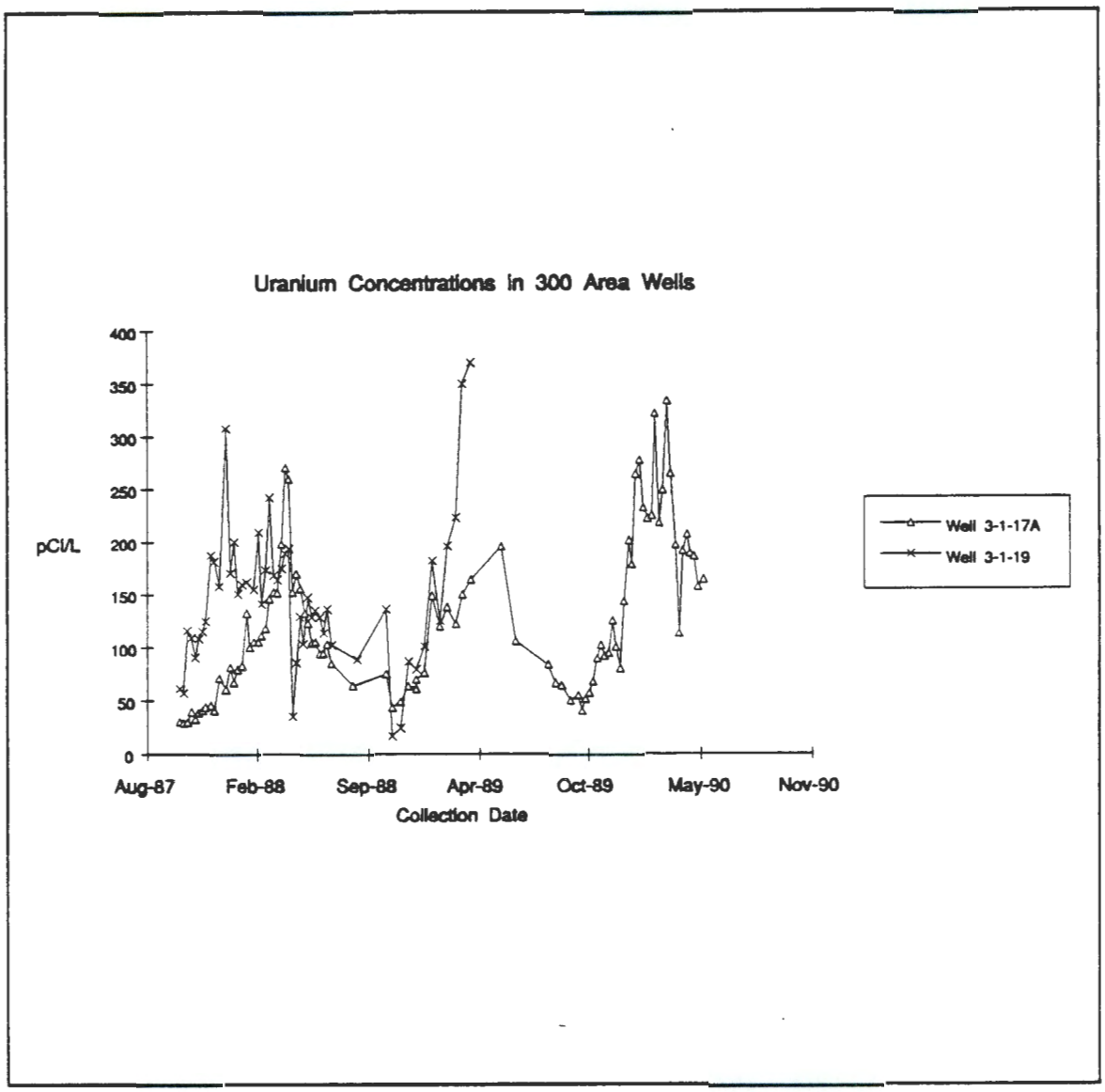

FIGURE 2.30. Trend Plot for Uranium in Wells Near South End of 300 Area Process Trench

well 299-E28-25 contained 19.3 pCi/L. The measurement in well 299-E28-25 represents a confirmation of the observation made in 1989 that the plutonium concentrations in the ground water near the 216-B-5 Reverse Injection Well have dramatically increased. In addition, plutonium-239/240 was detected for the first time in 1989 in nearby well 299-E28-24 (72 pCi/L). Plutonium-239/240 has increased to 144 pCi/L in that well in 1990. Plutonium-238 is

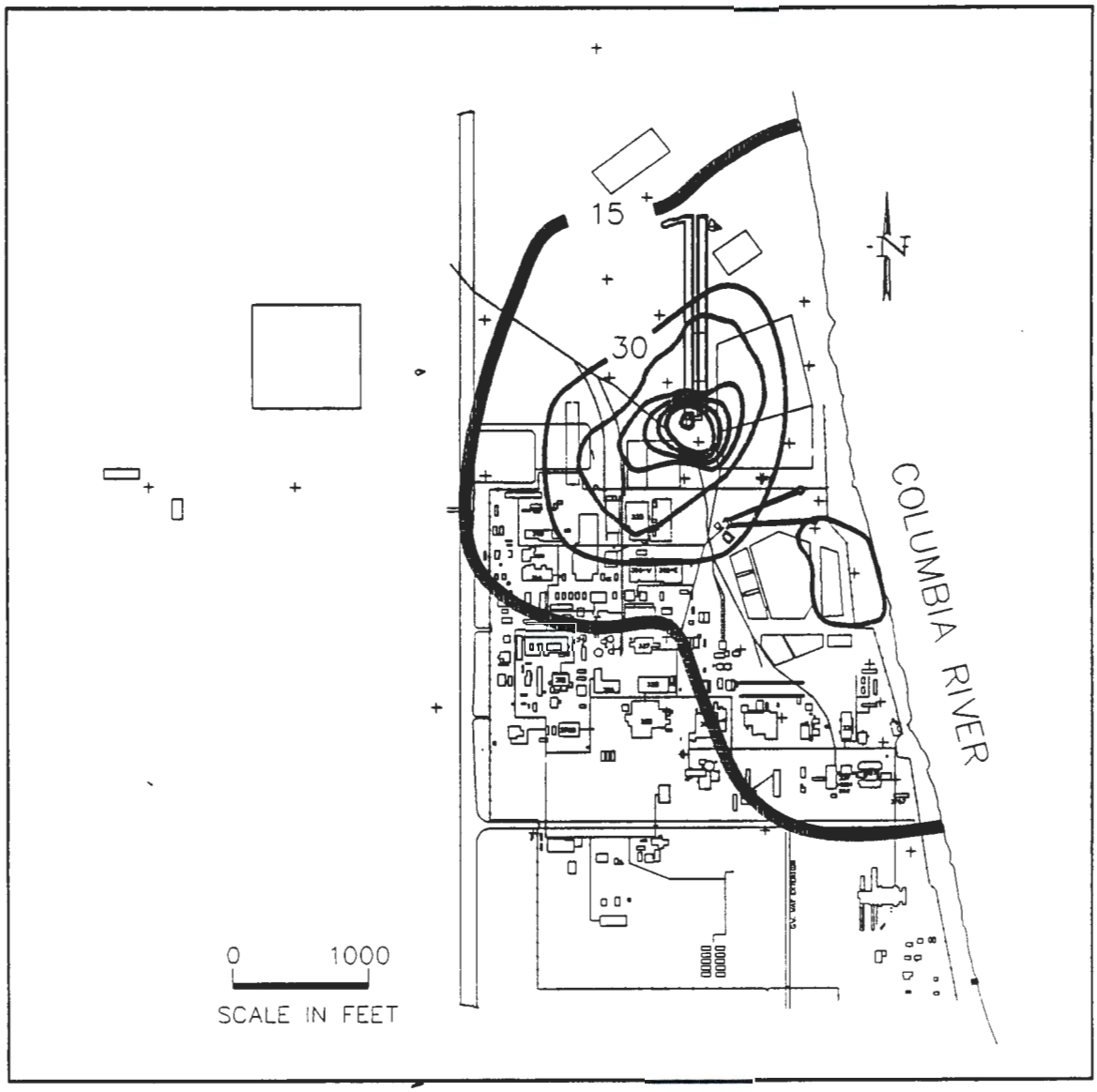

FIGURE 2.31. Uranium Ground-Water Plume in the 300 Area. Minimum contour is 15 pCi/L. Contour interval is 15 pCi/L. Sampling locations are marked with + symbols.

also detectable at much lower levels in the three wells. A trend plot of the plutonium-239/240 concentrations in the three wells is shown in Figure 2.32. The 216-B-5 Reverse Injection Well received an estimated 244 Ci of plutonium during its operation from 1945 to 1947 (Stenner et al. 1988). The DCG of 300 pCi/L for plutonium has been reduced to 30 pCi/L effective February 1990.

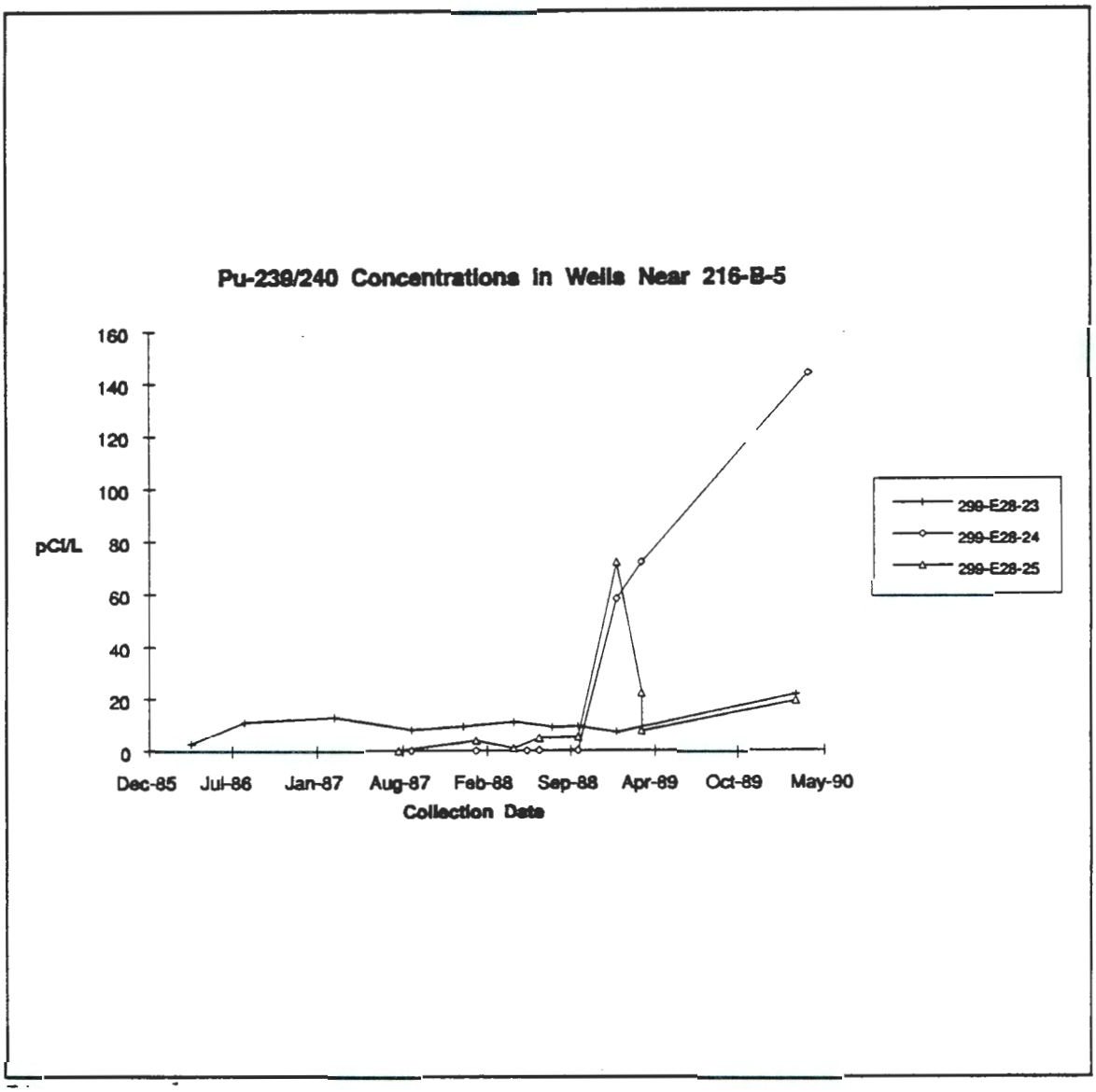

FIGURE 2.32. Trend Plot for Plutonium Isotopes in Wells Located Close to 216-B-5 Reverse Injection Well in 200-East Area

There is no explicit DWS for plutonium; however, the gross alpha DWS of 15 pCi/L is applicable. Alternately, if the DCG (which is based on a 100-mrem dose standard) is converted to the 4-mrem dose equivalent used for the DWS, 1.2 pCi/L would be the relevant guideline.

Plutonium-239/240 was detected for the first time in a well located in the 200-West Area (299-W15-8). That well monitors the 216-Z-9 Crib, which

received a large amount of plutonium from the Z Plant liquid effluent streams. No previous plutonium measurements are available for this well. Because the data were received just before termination of the analytical contract, verification of the data's validity was not possible during 1990. The measured concentration of plutonium-239/240 was 8.3 pCi/L in May 1990. Plutonium-238 was also detected in the same sample (0.14 pCi/L). The presence of plutonium (and americium) in this well has been confirmed by sampling conducted in 1991.

2.3 RADIOLOGICAL AND CHEMICAL MONITORING RESULTS FOR THE CONFINED AQUIFER

The uppermost (Rattlesnake Ridge interbed) confined aquifer is monitored to determine the extent of ground-water interaction between the confined and unconfined aquifers. Intercommunication between the aquifer systems was identified previously by a number of investigators (e.g., Gephart et al. 1979; Graham et al. 1984). Based on available hydrologic information, contamination of the uppermost confined aquifer through intercommunication with the overlying unconfined aquifer appears to be limited primarily to areas in and around the 200-East Area - Gable Mountain region, where favorable hydrogeologic conditions are present. Favorable hydrogeologic conditions contributing to direct hydraulic intercommunication between the aquifer systems include the absence of intervening low-permeability formations (i.e., resulting from the presence of subsurface erosional paleostream channels), enhanced vertical hydraulic communication resulting from structural deformation, and downward vertical hydraulic head gradients.

Because of the upward vertical hydraulic head gradient that exists in this region (Gephart et al. 1979; DOE 1988a), no direct or really pervasive transference of contaminated ground water from the unconfined aquifer to the underlying upper-confined aquifer system is possible in the eastern section of the Hanford Site (i.e., from east of the 200-East Area/B Pond area to the Columbia River).

To assess the extent of contamination within the upper-confined aquifer system, ground-water samples were collected from selected wells completed in the Rattlesnake Ridge interbed, as shown in Figure 2.2. Ground-water samples from the confined aquifer were analyzed for tritium, nitrate, iodine-129, and

gamma-emitting radionuclides. In most cases, background levels of these constituents were detected in wells sampled during 1990. Detection of radionuclides in well 299-E33-12 in the past has been attributed to contamination by high-salt waste that migrated by density flow into the borehole when it was open to both the unconfined and the confined aquifer during drilling (Graham et al. 1984). Samples were not collected from this well during 1990 because of the loss of analytical services with the termination of the UST analytical contract.

Intercommunication between the Rattlesnake Ridge confined aquifer and the unconfined aquifer north of the 200-East Area has also been indicated in the past by the presence of nitrate in well 699-47-50. This well is located near an erosional window (i.e., near an area where the confining layer is absent) in the confining basalt flow (Graham et al. 1984). Elevated levels of tritium (3830 pCi/L) have been measured in ground water from the Rattlesnake Ridge interbed in well 699-42-40C. Elevated levels of iodine-129 (0.15 pCi/L) have been observed previously in the same well. Wells 699-47-50 and 699-42-40C were not sampled in 1990 because of the termination of the UST analytical contract.

2.4 GROUND-WATER QUALITY NEAR RICHLAND WATER SUPPLY WELLS

During 1990, ground water from 31 monitoring wells in the southern portion of the Hanford Site was sampled and analyzed for hazardous chemicals and radiological constituents. This region currently is being characterized through a remedial investigation under the Comprehensive Environmental Response, Compensation, and Liability Act. Tetrachloroethane was detected at low concentrations in ground water is a well near one of the sites being investigated. In the vicinity of the Horn Rapids Landfill elevated levels of nitrate, trichloroethane (TCE) and radioactivity have been observed in ground-water samples. Data collected indicates that the presence of these contaminants cannot be attributed to the Horn Rapids Landfill (DOE 1991c). Details of this study are provided in DOE (1990a). No contaminants were observed in concentrations above the DWS in the vicinity of the Richland Water Supply Wells.

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APPENDIX A

MONITORING WELL NETWORKS WITHIN OPERATING AREAS

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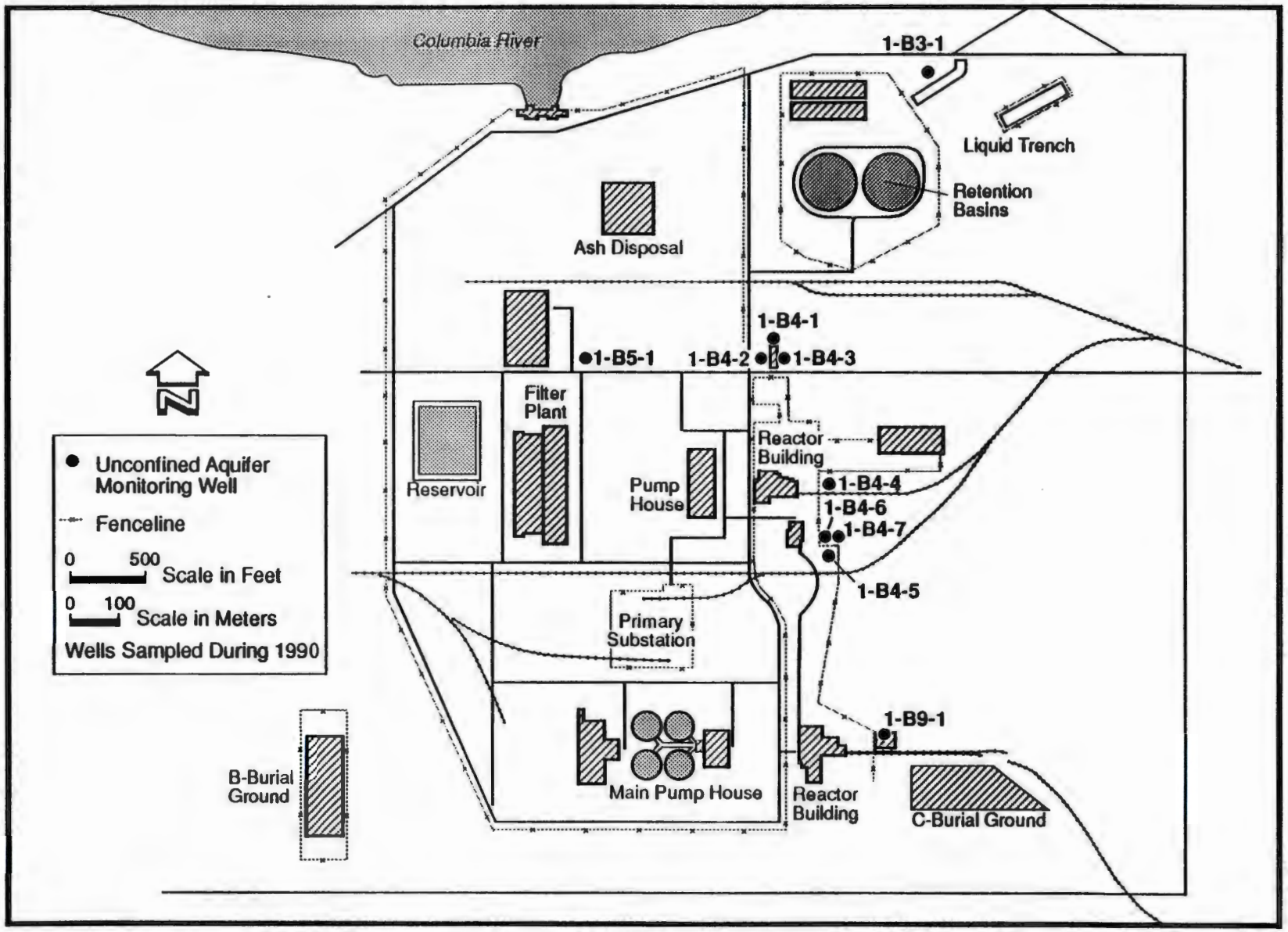

FIGURE A.1. Well Location Map for the 100-B Area

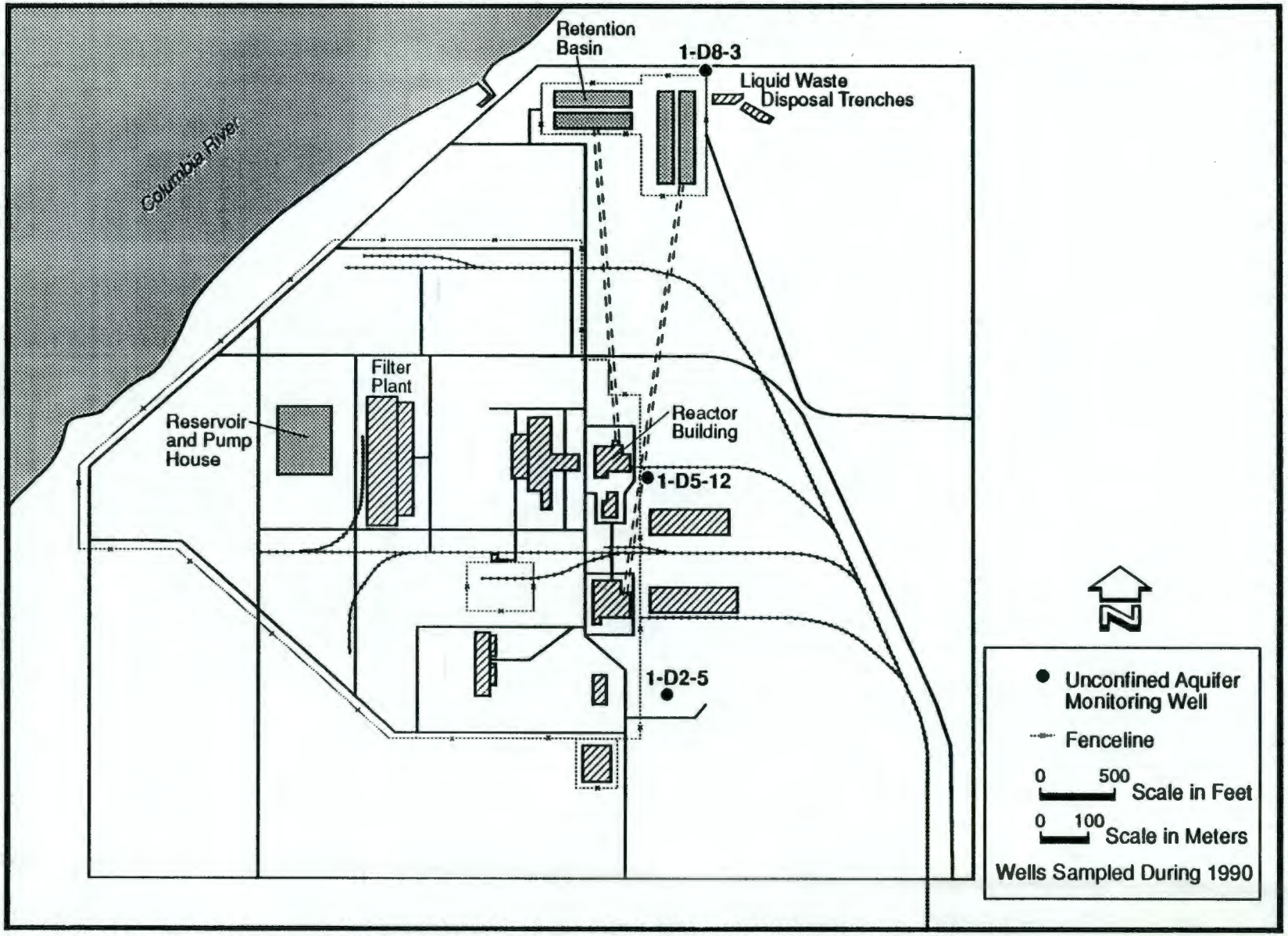

FIGURE A.2. Well Location Map for the 100-D Area

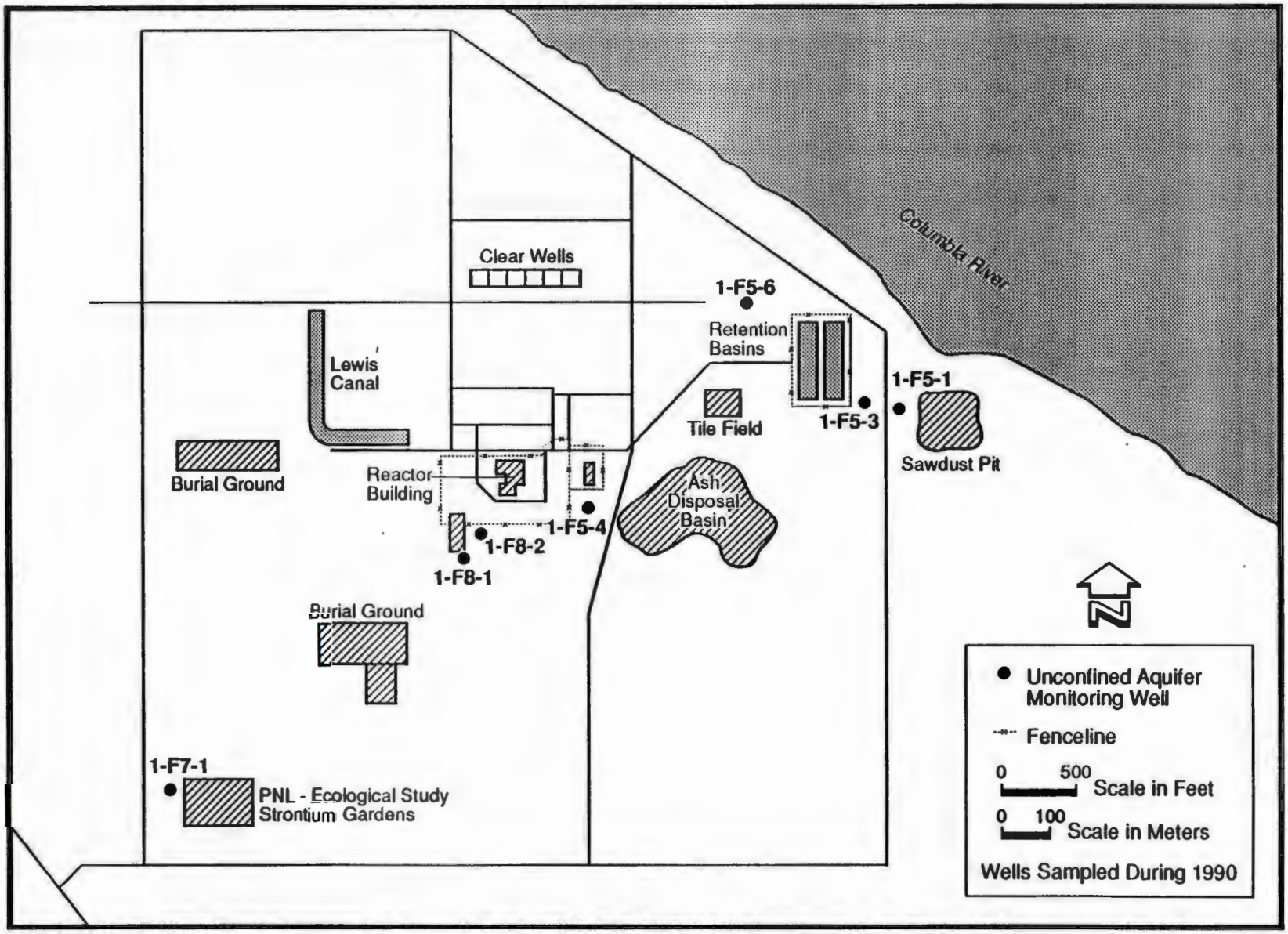

FIGURE A.3. Well Location Map for the 100-F Area

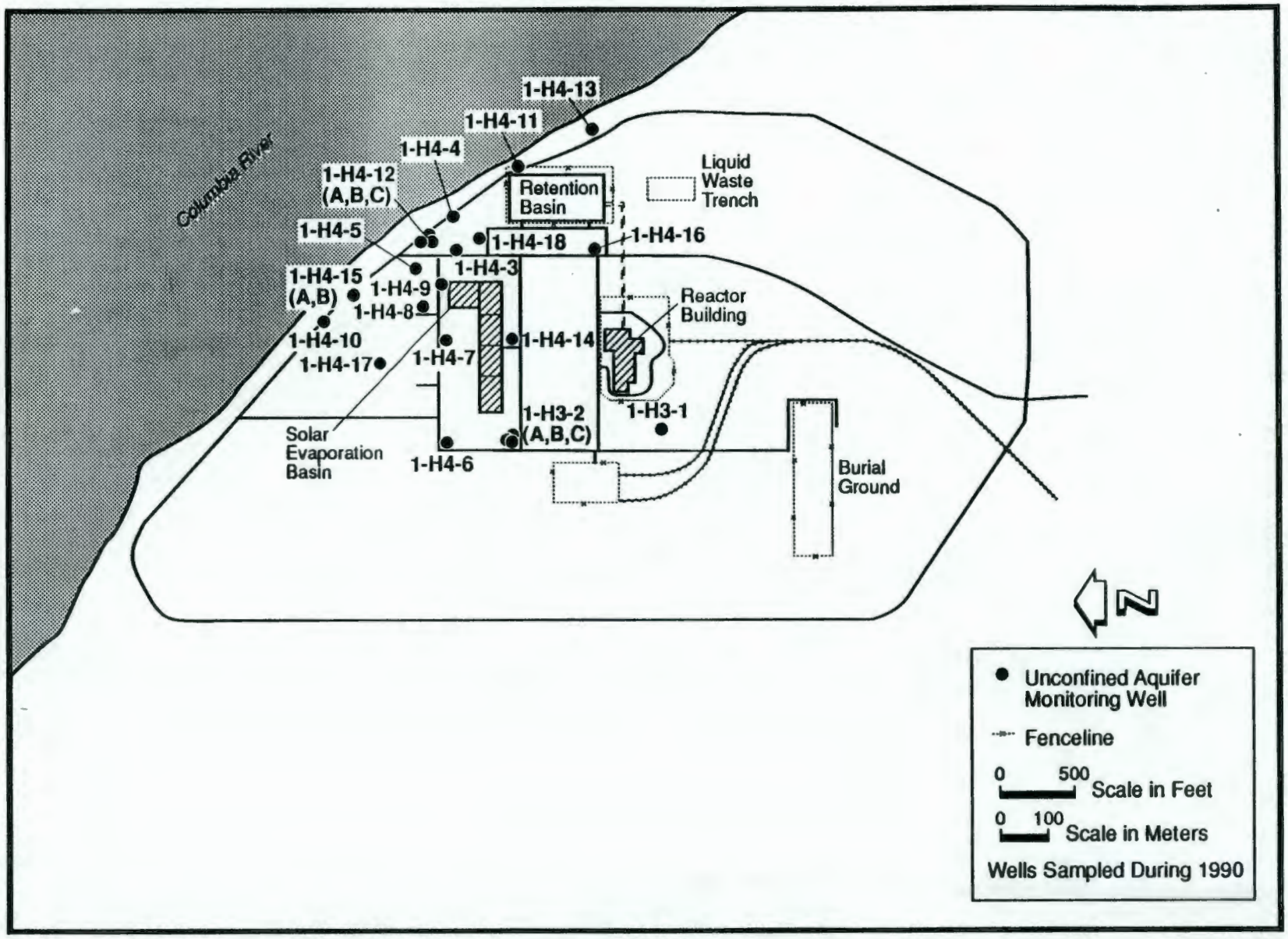

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FIGURE A.4. Well Location Map for the 100-H Area

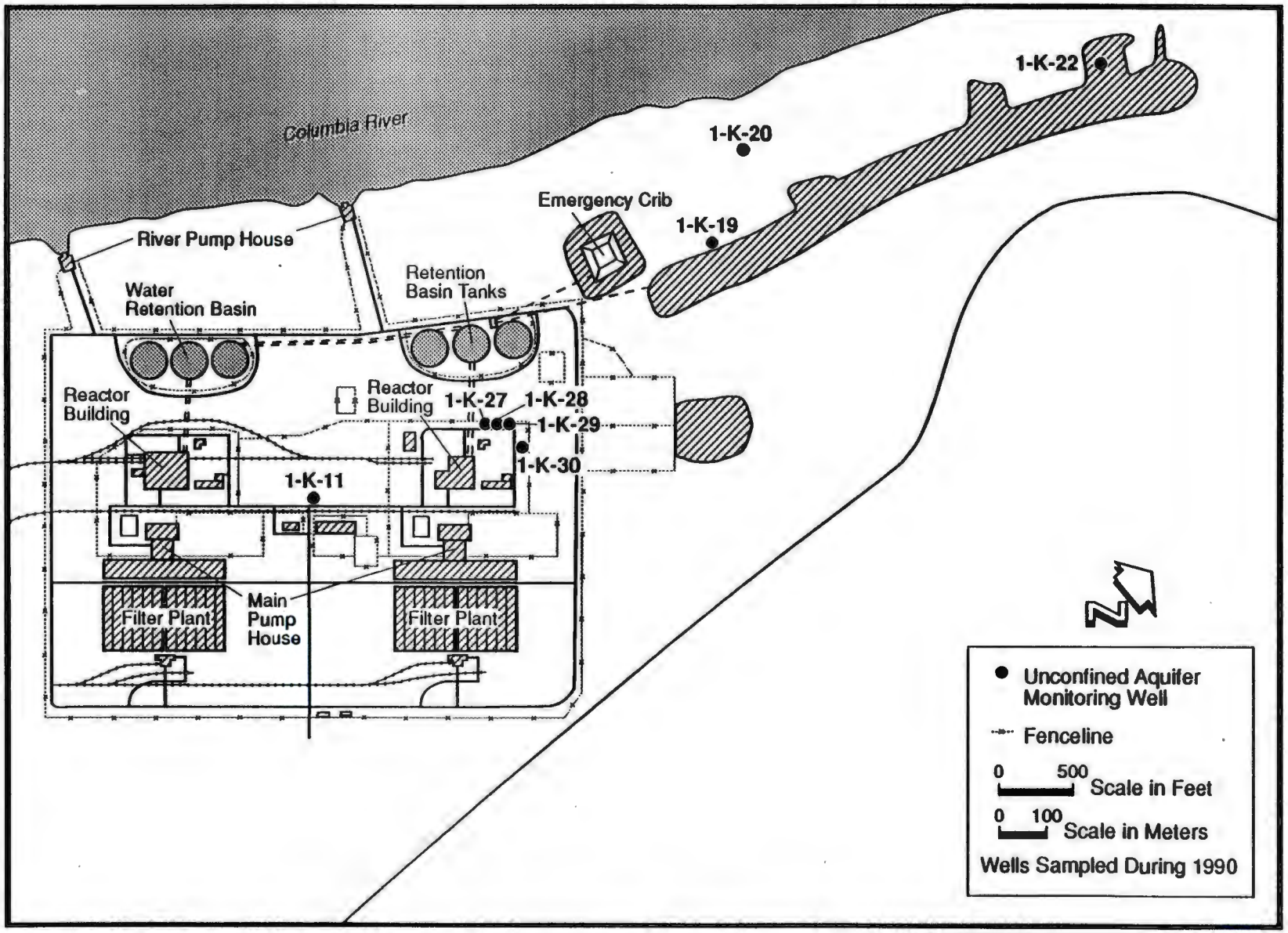

FIGURE A.5. Well Location Map for the 100-K Area

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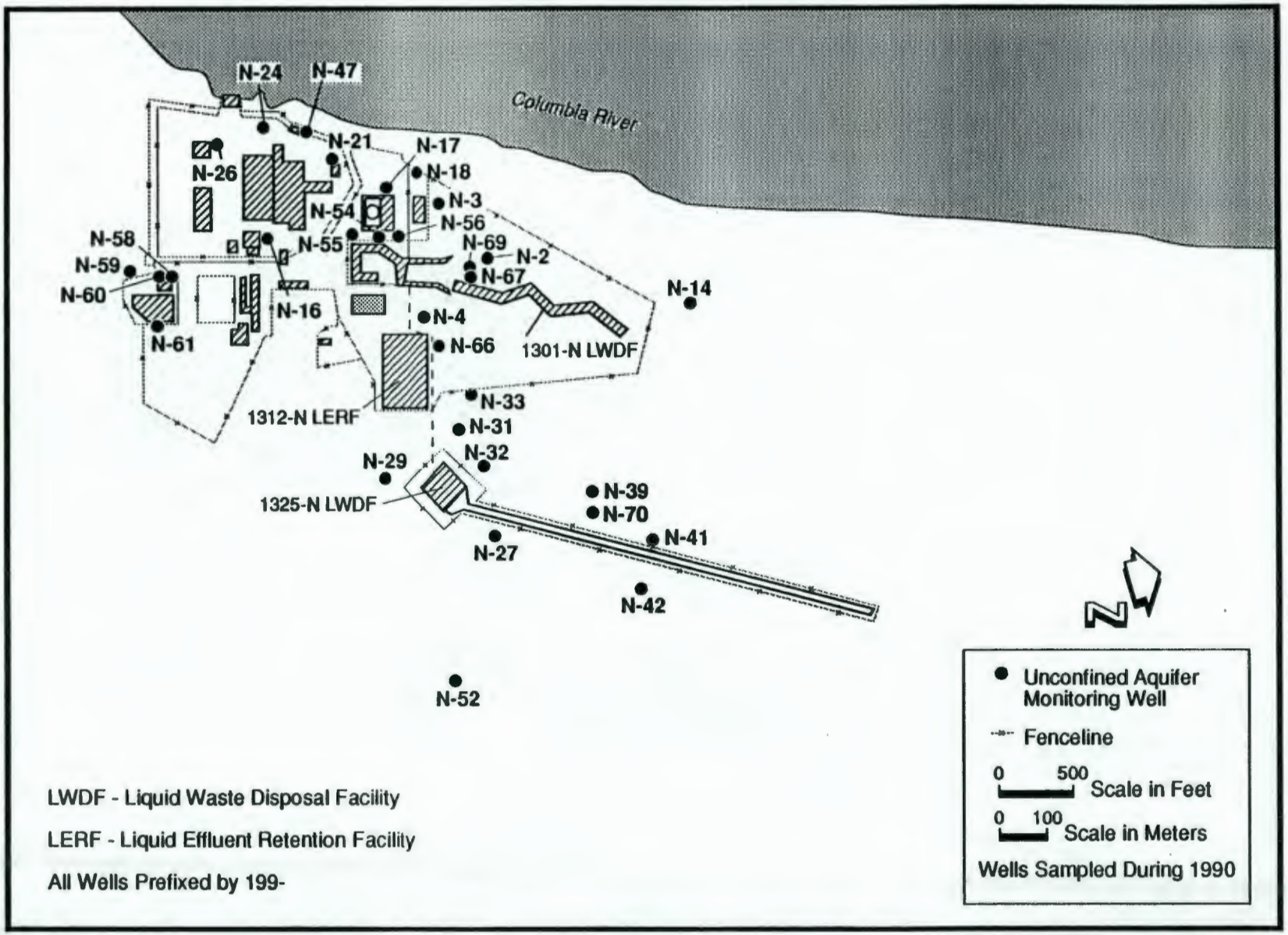

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FIGURE A.6. Well Location Map for the 100-N Area

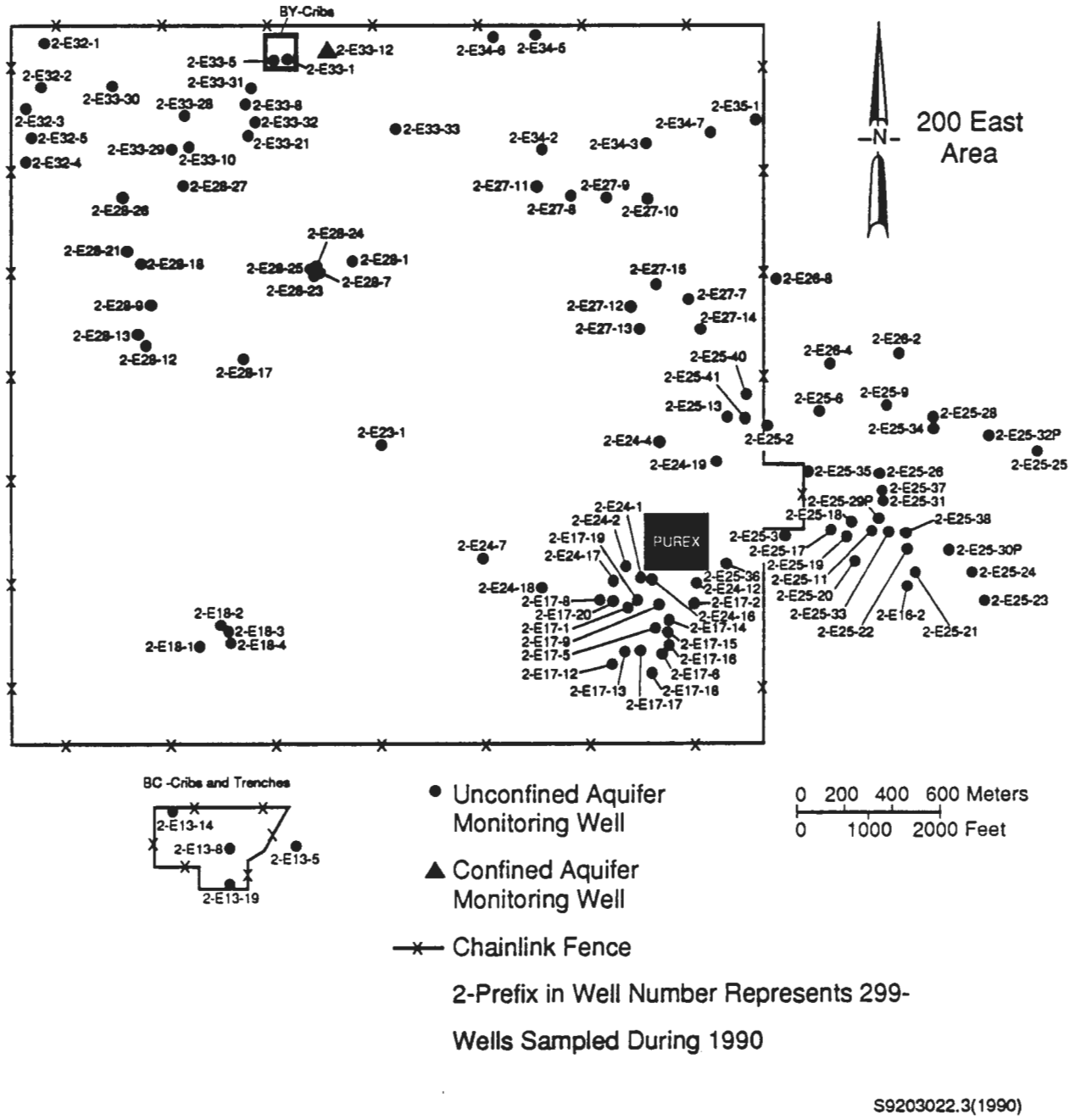

FIGURE A.7. Well Location Map for the 200 East Area

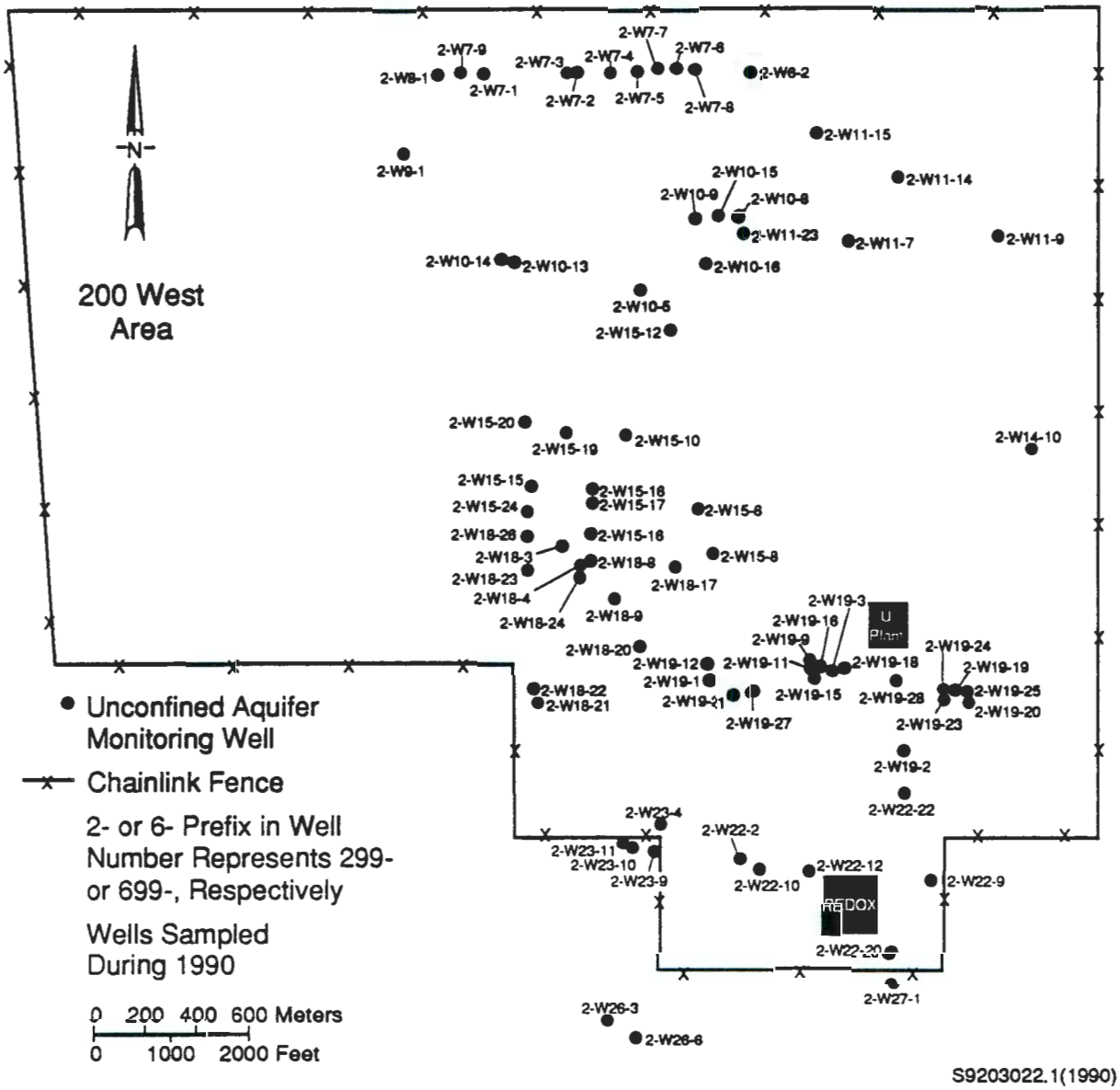

FIGURE A.8. Well Location Map for the 200 West Area

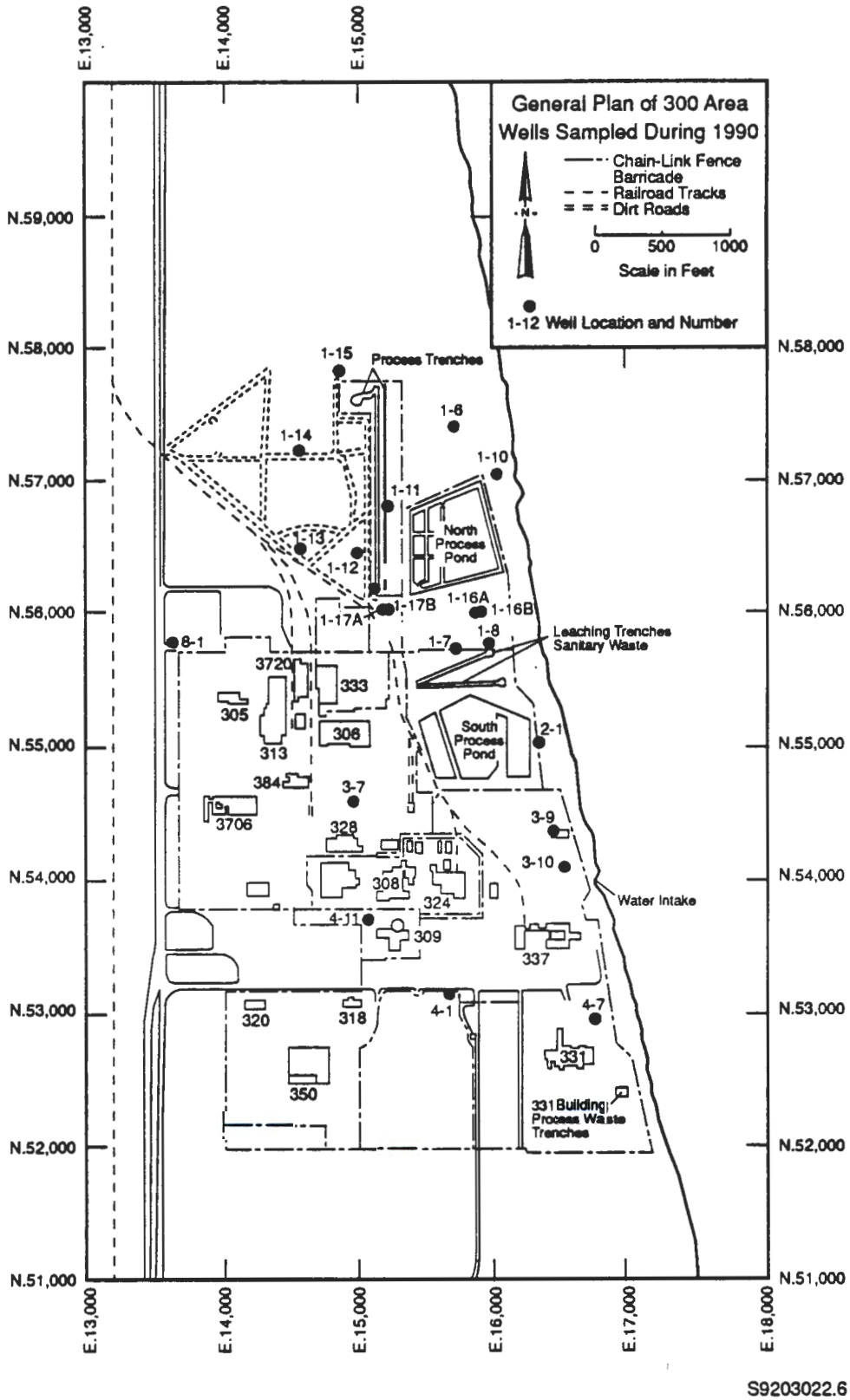

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FIGURE A.9. General Plan of 300 Area

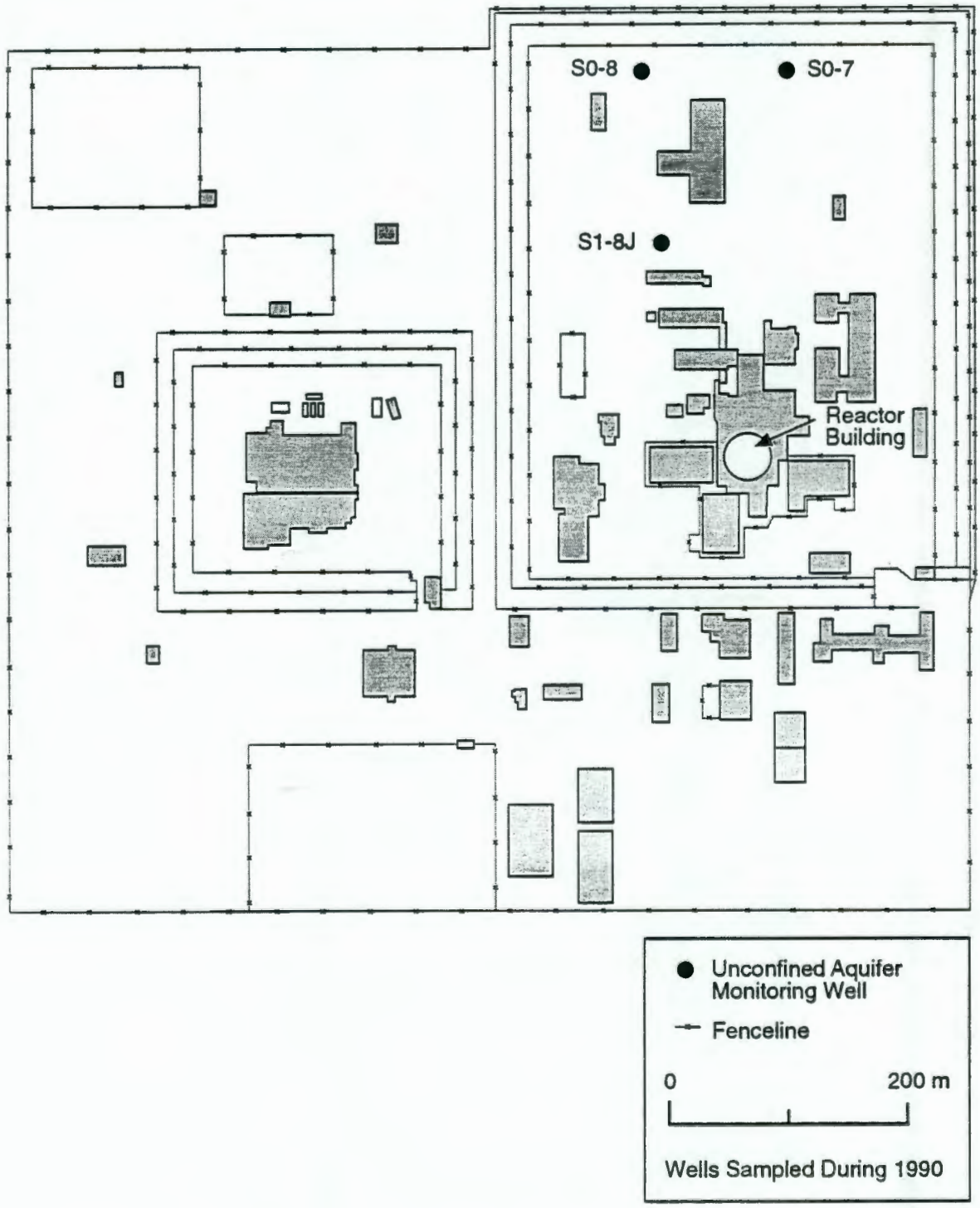

FIGURE A.10. Well Location Map for the 400 Area

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