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Site Characterization Summary Report for Waste Area Grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee

Volume 2
Sections 4 Through 6

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Energy Systems Environmental Restoration Program
ORNL Environmental Restoration Program

Site Characterization Summary Report for Waste Area Grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee

Volume 2
Sections 4 Through 6

Date Issued—September 1992

Prepared by
Bechtel National, Inc./CH2M Hill/Ogden/PEER
Oak Ridge,Tennessee
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5.1.1 Microbiological degradation of TCE

6.6.1 WAG 1 operable units

ACRONYMS

BGS	below ground surface
BHTV	borehole televiewer
BMAP	biological monitoring and abatement program
BNAE	base/neutral/acid-extractable
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CRDL	contract-required detection limit
CSL	Close Support Laboratory
CSSS	Contaminated Site Summary Sheets
CWA	Clean Water Act
DOE	U. S. Department of Energy
EM	electromagnetic
EPA	U. S. Environmental Protection Agency
ER	Environmental Restoration
ES&H	environmental safety and health
FFA	Federal Facility Agreement
FOF	Field Operations Facility
GC	gas chromatograph
GM	Geiger-Mueller
ICAP	inductively coupled argon plasma
LITR	Low-Intensity Test Reactor
LLLW	liquid low-level waste
MCL	maximum contaminant level
MDA	minimum detectable activity
MDL	method detection limit
MSL	mean sea level
NEPA	National Environmental Policy Act
NPDES	National Pollutant Discharge Elimination System
NPL	National Priority List
NTF	North Tank Farm
OD	outside diameter
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OU	operable unit
OUSD	Operable Unit Strategy Document
PAH	polyaromatic hydrocarbon
PARCC	precision, accuracy, representativeness, completeness, and comparability
PCB	polychlorinated biphenyl
PMF	probable maximum flood
PRAR	Preliminary Risk Assessment Report
PVC	polyvinyl chloride
PWTP	Process Waste Treatment Plant

ACRONYMS (continued)

RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
SCSR	Site Characterization Summary Report
SDWA	Safe Drinking Water Act
SIA	structural integrity assessment
SQL	sample quantitation limit
STF	South Tank Farm
STP	Sewage Treatment Plant
SWMU	solid waste management unit
SWSA	solid waste storage area
TAL	Target Analyte List
TCE	trichloroethene
TCL	Target Compound List
TCMP	toxicity control and monitoring program
TDEC	Tennessee Department of Environment and Conservation
TDS	total dissolved solids
TIC	tentatively identified compound
TKN	total Kjeldahl nitrogen
TOC	total organic carbon
TOX	total organic halides
TRM	total recoverable metals
TSS	total suspended solids
USGS	U.S. Geological Survey
USRADS	ultrasonic ranging and data system
VOC	volatile organic compound
WAG	waste area grouping
WOC	White Oak Creek

EXECUTIVE SUMMARY (VOLUME 2)

ES.1 NATURE AND EXTENT OF CONTAMINATION

The nature and extent of contamination at Waste Area Grouping (WAG) 1 are described in this volume by media type—groundwater, soils, sediment, and surface water. Airborne contaminants were not investigated.

ES.1.1 Groundwater

Several areas of contamination were identified on the basis of groundwater sampling program results. Both radiological and chemical contaminants were identified; the primary man-made radiological contaminants are strontium-90 and tritium, and less frequently encountered radionuclides include technetium-99, cesium-137, cobalt-60, nickel-63, iron-55, and the transuranics americium-241, plutonium-238/239/240, and curium-244. The primary naturally occurring radionuclides detected were radium-228, thorium-228/230/232, and uranium 234. Most contaminants were within the range of reference levels, but radium-228 and uranium-234 exceeded reference concentrations in several areas and are probably site contaminants (see Sect. 4.3).

The most widespread organic compounds found in groundwater are trichloroethylene and its degradation products 1,2-dichloroethene and vinyl chloride (see Fig. ES.4.3). The metals silver, cadmium, chromium, lead, and mercury (one sample only) were detected in unfiltered samples at concentrations exceeding maximum contaminant levels (MCLs); cadmium, chromium, and lead, in excess of their respective MCLs, tend to occur together. Cadmium exceeded the MCL at the largest number of locations.

ES.1.2 Soils

Both man-made and naturally occurring alpha-emitting radionuclides were detected in soil. The primary man-made alpha-emitters detected include americium-241 and plutonium-238/239/240, and uranium-234/238 was found in concentrations above typical reference values. Most of the contamination is near Building 3019, North Tank Farm, South Tank Farm, isotope area, surface impoundments, Building 3503/3504 storage pad, floodplain soils, Solid Waste Storage Area (SWSA) 1, and the thorium tank farm.

Beta-emitting radionuclides commonly found in soils include cesium-137, strontium-90, and cobalt-60. Other man-made radionuclides such as technetium-99, europium-152/154/155, nickel-63, calcium-45, and tritium are found less often and usually at levels below reference values. Naturally-occurring beta emitting radionuclides detected above typical reference values include thorium-232/234 and radium-228.

A surface radiation survey was used to identify potential areas of radiological contamination; 42 soil sampling locations were selected using the survey data. Elevated exposure rates in four areas were determined to be caused by radiologically contaminated soils, and the exposure rates in seven other areas are probably attributable to skyshine from nearby structures or process operations.

Organic contaminants in [illegible] base/neutral/acid-extractable c[illegible] (PCBs), and cyanide (dioxins. [illegible] detected at a concentration gre[illegible] Approximately 75% of the BN[illegible] which are probably associated [illegible] past and present coal storage a[illegible]

All metals analyzed for we[illegible] possibly as the result of both na[illegible] in excess of reference levels in[illegible] mercury, silver, and zinc; past [illegible] have contributed to the eleva[illegible] were near Building 3592 at a [illegible] floodplain near the confluen[illegible]

ES.1.3 Surface Water

Both man-made and na[illegible] Creek, Fifth Creek, and N[illegible] radionuclide was strontium-[illegible]

The highest concentrati[illegible] indicate that during low ba[illegible] system above the 7500 brid[illegible] high base sampling, the co[illegible] The results of these samplin[illegible] that a strontium source disc[illegible] stormflow conditions than d[illegible] discharge to WOC from the [illegible]

Concentrations of tritiu[illegible] Act MCL (previous studies [illegible] cesium-137 in unfiltered sa[illegible] through absorption to susp[illegible] management units along WC[illegible] discharge from outfalls, an[illegible]

No metals were detecte[illegible] pesticides, dioxins/furans, [illegible] samples. Of the few VOC[illegible] may be of concern, althoug[illegible]

ES.1.4 Sediment

Both man-made and na[illegible] from WAG 1. The detected [illegible] americium-241 and curium-[illegible]

and therefore are site contaminants. Cesium-137 was the most frequently detected radionuclide. A decline in the maximum WOC cobalt-60 concentration from 250, 167, and 460 pCi/g in past studies to a current level of 12.6 pCi/g suggests that the cobalt-60 loading in surface water has declined.

VOC contamination in sediments was minimal. However, PAHs detected in samples throughout WOC and in Fifth Creek are probably the result of coal combustion and parking lot runoff. The metals cadmium, chromium, copper, lead, and mercury were detected above reference levels. Although mercury concentrations in WOC were comparable with those found in previous studies, the very high concentrations previously found below outfalls in Fifth Creek were not encountered. This difference is probably the result of the selection of sampling locations and should not be considered an indication that the high concentrations of mercury detected in previous studies have dissipated.

ES.2 FATE AND TRANSPORT

General information presented on the fate and transport processes at WAG 1 will be the basis for more detailed, operable unit-specific evaluations to be completed during future investigations. The discussion here is essentially a qualitative assessment and does not estimate exposure point contaminant concentrations.

The transport velocities of various contaminants identified during the Phase I investigation were calculated using average linear groundwater velocity and contaminant-specific distribution coefficients. The site-specific toxicity characteristic leaching procedure results indicate that most radionuclides (except for tritium and strontium-90) tend to adsorb to the soils. Site-specific distribution coefficient (K_d) tests verified a high K_d for cesium-137 and a relatively low K_d for strontium-90. Contaminant travel times from identified sources to surface waters are calculated for the primary radionuclides tritium, strontium-90, and radium-228 and for less common radionuclides. A qualitative assessment of the volatiles trichloroethylene, 1,2-dichloroethene, and vinyl chloride is also presented.

ES.3 ADDITIONAL INFORMATION NEEDS AND UNCERTAINTIES

Section 6.5 outlines investigation topics in need of additional data to clarify the nature and extent of contamination or the fate and transport of contaminants. Collection of this information will contribute to remedial action planning.

4. NATURE AND EXTENT OF CONTAMINATION

4.1 WAG 1 RI ENVIRONMENTAL DATA

4.1.1 Characterization Data Base

The WAG 1 characterization data base consists of analytical laboratory results from environmental sampling. These data are provided in Appendixes A and B of this report.

An analytical support level of III or higher was requested on all samples sent off site to the contracting laboratories. Most of the analytical data fell into the level IV category, but all radiological data were level V (special analytical services) as defined by the EPA data quality objective (DQO). More detail is provided in Appendix C.

The three categories of analytical data collected are radiological, chemical, and geotechnical. Radiological data include gross alpha and gross beta activity, tritium, and specific radionuclide isotopic analyses. Chemical data consist of analytical results for TCL organic compounds and TAL inorganic analytes; selected samples were analyzed for RCRA Appendix IX analytes. Geotechnical data consist of particle size distribution, specific moisture content, Atterberg limits, and wet and dry density.

Radiological data for liquid samples are reported in units of picocuries per liter (pCi/L); for solid samples, data are reported in units of picocuries per gram (pCi/g). Both units are measurements of the amount of radioactive material present. Radioactivity is defined as the rate at which a radionuclide decays (or disintegrates). One picocurie is generally equivalent to 2.22 disintegrations per minute (dpm). A direct equivalence between radioactivity and chemical concentration (i.e., the concentration of the radionuclide on a weight basis) can be calculated only on a radionuclide-specific basis.

Radiological results are generally reported with an accompanying error factor that represents a statistical value equal to two standard deviations of the sample's activity. Absence of an error term means that the reported result is the minimum detectable activity (MDA) for that analyte in that sample. The actual activity is some value less than the MDA. The MDA is a function of the measurement instrument background and varies from sample to sample. The best estimate of the radioactivity in a sample is the reported value. The range of what that value may be, with 95% confidence, can be estimated by adding the error factor to the reported value to obtain the upper limit and subtracting the error factor from the reported value to obtain the lower limit. For example, if the results are reported as 10 ± 5 pCi/g, the best estimate for the value is 10 pCi/g, and the range of what that value may actually be, with 95% confidence, is 5 to 15 pCi/g. If the error factor is greater than the reported value, the activity of that radionuclide is statistically indistinguishable from zero and the result is considered a nondetect. The actual result is used in reporting of radiological analyses at ORNL (i.e., if the sample activity is less than the background, a negative value is reported). This indicates that the sample in question may contain an amount of that radionuclide which is indistinguishable from background concentrations. Rather than reporting a negative value, the subcontract laboratories reported an MDA, or the smallest amount of activity that could be determined above the background for the sample under study.

Chemical data for liquid samples (e.g., groundwater or surface water) are presented in units of micrograms of the analyte per liter of liquid (μg/L). Chemical data for solid samples (e.g., soil or sediment) are presented in units of micrograms of the analyte per kilogram of solid (μg/kg) on a dry weight basis. Both one μg/L and one μg/kg are approximately equivalent to one part per billion (ppb) by weight.

Frequently, a concentration of an organic constituent is reported as a "less than" (<) value (e.g., <5 μg/L). This indicates that the constituent was not detected at or above its detection limit (in this case, 5 μg/L).

The analytical data presented herein have been qualified by the laboratory and by the project as part of the validation process. The qualifiers (flags) in the remaining chapters are the ones applied by the validators. An explanation of the flags is found in Appendix C, Table C4.1.

4.1.2 Data Quality Assessment

WAG 1 RI environmental data were assessed to determine their usefulness for describing the nature and extent of contamination and performing the preliminary risk assessment. Both chemical and radiological data were evaluated by assessing the following data quality indicators: precision, accuracy, representativeness, completeness, and comparability (PARCC) (EPA 1990a). Data generated by the ORNL RCRA Compliance Monitoring Program were evaluated only for comparability. Appendix C presents the detailed findings and conclusions of this data assessment.

After the validation and PARCC review of RI chemical and radiological data, limitations or uncertainties associated with the data were evaluated to determine whether deficiencies identified in the data would have the potential for either a negative or positive bias in the results. Deficiencies or uncertainties that could potentially affect the interpretation of environmental data for WAG 1 are identified below.

Deficiencies or uncertainties in chemical data include:

- Chemical analyses for liquid matrices that exceeded established holding time guidelines could lead to potential false negative detects. The potential for this negative bias has been reflected in the qualification of the data. This is discussed in more detail in Sect. C5.3.3, Appendix C.

- Lead and copper were detected in numerous field blanks and equipment rinsate samples; detection of these compounds in deionized water suggests the potential for a positive bias in regular samples. A detailed listing of these samples and the affected regular samples is given in Table C5.3.2, Appendix C.

- Spike recoveries for selenium and antimony in soil indicate a negative bias. Results for these analyses in soil matrices have been considered as biased low. This is discussed in more detail in Sect. C5.2.2, Appendix C.

- A reduced percentage of field blanks for surface water, soil, and sediment matrices introduces the potential for false positive chemical detects in associated regular samples collected for some sampling events. This is discussed in more detail in Sect. C5.3.2, Appendix C.

- The results for groundwater samples analyzed by the total recoverable metals (TRM) method exhibited a poor correlation with respect to the filtered and unfiltered metal analyses performed on the same sample. Results of these analyses should be considered of limited use. This issue is discussed in more detail in Sect. C5.4.3, Appendix C.

- Osmium was detected in numerous RI and reference soil and sediment samples. Attempts to confirm these results by resampling and subsequent reanalysis of the soils from these locations did not support the original analytical findings because no osmium was detected. Positive detects for osmium in soils and sediments should be viewed with caution. A discussion of this issue is presented in Sect. C5.4.3, Appendix C.

Deficiencies or uncertainties in radiological data include:

- A reduced percentage of field blanks for surface water, soil, and sediment matrices introduces the potential for false positive radiological detects in associated regular samples. This is discussed in more detail in Sect. C6.4.2, Appendix C.

- Several soil samples have a potential bias for certain radionuclides due to rinsate contamination (see Sect. C6.4.2.4). Samples 1315, 1316, 1324, 1325, 1336, 1328, 1334, and 1307 have the potential for a positive bias for strontium-90. Samples 1409, 1452, 1456, 1471, and 1464 have a potential positive bias for bismuth-212.

- Strontium-89 was reported to be present in two groundwater samples from the multiport well at CH008. The presence of strontium-89 in these samples is suspect and may be false positive detects. A detailed discussion of the uncertainties associated with the detection of strontium-89 in these samples is presented in Sect. C6.5.5.

- Promethium-147 was detected in some soil and groundwater samples. Because the separation technique used by the laboratory may not remove interfering beta-emitters (particularly yttrium-90, which is in equilibrium with strontium-90), the values reported by the laboratory are suspect and are probably false positives. This is discussed in detail in Sect. C6.5.5, Appendix C.

- Strontium-90 was detected in an equipment rinsate associated with background sample 0977 and surface water sample 1756. Results of these samples should be considered to be biased high. A detailed discussion of affected samples is presented in Sect. C6.4.2.2, Appendix C.

- Significant amounts of curium, a TRU, were detected in filtered and unfiltered reference groundwater samples collected from well 1250. The gross alpha determination did not substantiate the occurrence of alpha-emitting isotopes. These values are suspect and

should be considered of limited use. A discussion of gross measurements versus isotopic determination is in Sect. C6.6.1, Appendix C.

In addition, the reference network may not fully characterize the natural variability of groundwater quality. As discussed in Sect. 4.2.8, additional sampling locations and additional samples from the existing network should be considered to support groundwater operable unit-specific assessments.

Where appropriate, the effects of bias have been minimized by qualification of the data as estimated (J or UJ reviewer qualifier). When analysis problems were thought to have a significant impact on the data, the affected data were rejected.

Subsequent to validation, the total percentage of usable data was 97.5%, exceeding the DQO target outlined in Bechtel project procedures, which specify that valid analytical results will be obtained for 95% of the data collected.

4.2 REFERENCE SAMPLING

4.2.1 Purpose

Reference location samples were collected so that concentrations of chemical and radiological constituents detected in WAG 1 media (groundwater, surface water, soil, and sediment) could be compared with concentrations of the same constituents in media from locations believed to be unaffected by releases from WAG 1. All reference sampling locations are outside WAG 1. At the start of WAG 1 investigations, reference sample locations were considered equivalent to background sample locations on the assumption that both types of samples represent media uninfluenced by human activities and operations related to ORNL. The details of sample collection procedures and analyses are presented in Appendixes A and B. The following sections describe the approach of the reference sampling program and present analytical results.

4.2.2 Approach

In this study, the phrase "reference concentration" applies to the concentration of a chemical or radiological constituent detected in samples of groundwater, surface water, soil, or sediment from the ORR that have not been influenced by ORNL waste management practices or pilot plant and production activities. Various constituents analyzed during the WAG 1 RI can occur from sources other than waste management practices—automobile exhaust, surface water runoff from asphalt, cigarette smoke, insect repellents, analytical equipment, atmospheric fallout, and natural sources such as anaerobic degradation and volatile metabolites. Naturally occurring minerals containing metallic and nonmetallic elements (some of which are naturally radioactive) found in soil and sediments may also be dissolved in groundwater and surface water. In most instances, reference concentration is synonymous with "background concentration" (the naturally occurring concentration of a constituent uninfluenced by human activities). Thus, reference concentration includes the

RCRA definition of "background" used in 40 CFR 264.97(a)(1) concerning media that have not been affected by leakage from a regulated unit.

Reference sampling locations were chosen at hydrologically upgradient positions or in surface water drainage basins separate from WAG 1 and other known waste disposal sites. All reference sampling locations for WAG 1 are within Bethel Valley (Figs. 4.2.1 and 4.2.2). Table 4.2.1 presents a listing of reference sampling locations for all media and indicates the type of analysis performed for each sample collected at these locations.

Reference sample results were compared with environmental regulatory criteria [i.e., Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs), proposed RCRA Subpart S action levels], EPA guidance for water quality issued under the Clean Water Act (CWA), and concentrations reported for the ambient environment. The goal of this comparison was to identify reference sample results that may have been impacted by ORNL waste management activities or pilot plant operations. As discussed in Sect. 4.2.3, several locations were excluded based on this comparison.

A listing of suggested relevant chemical-specific criteria and guidelines is presented in Table 4.2.2. The proposed RCRA action levels are derived from those given in Appendix A of proposed RCRA Subpart S (EPA 1990). [The assumptions, methodology, and health-based criteria (e.g., slope factors, reference doses) used to derive the Appendix A values are given in Appendixes D, E, and F of proposed Subpart S.] These health-based criteria were compared with those published by ORNL, which contained updated toxicity data for various constituents (ORNL 1991). If the health-based criteria for an analyte differed, the RCRA action level was recalculated using the new toxicity criteria and the methodology from Appendixes D and E (BNI 1991).

Reference values were also compared with various types of detection limits including sample quantitation limits (SQLs), method detection limits (MDLs) for chemicals, and the minimum detectable activity (MDA) for radionuclides.

The SQL is generally the most useful description of the detection limit for chemical analysis. It reflects adjustments that might be made for analysis of individual samples such as dilution, percent moisture, or use of a smaller sample aliquot for analysis because of matrix effects or the high concentration of some analytes. For the same analyte, the SQL in one sample may be higher than, lower than, or equal to SQL values for other samples. Elevated SQLs for some analytes can occur when a sample is diluted to allow quantitation of an extremely high concentration of an analyte, which results in nondetect values being reported for other analytes that may have been present at low concentrations in the undiluted sample. The SQL is the detection limit used in reporting reference chemical results for soil, surface water, and sediment.

MDL is the minimum concentration of an analyte that can be identified by using a specific method. MDL values are used for determining whether elevated SQLs exist.

The MDA for radionuclides is analogous to the SQL for chemicals. Elevated MDAs can exist in situations that are similar to those that cause elevated SQLs. The contract-required

MDAs are used to determine whether elevated MDAs exist; the contract-required MDAs are specified by the ORNL RI/FS contract with the analytical laboratory.

4.2.3 Exclusion of Certain Locations

The WAG 1 reference groundwater sampling program was initially designed to include ten locations. Review of analytical data from five of these locations identified possible unknown influences on groundwater from sources outside WAG 1, resulting in the subsequent exclusion of these locations from the reference data set. The suspect locations consist of wells 1196, 1197, 1198, and 1199, which are approximately 1 mile east of WAG 1 on the eastern border of WAG 17, and well 1253 (soil boring 01.BV05), which is approximately 2.5 miles east of the WAG 1 boundary and south of Bethel Valley Road. Soil samples collected during installation of these wells were to be included in the data set defining reference soil conditions for Bethel Valley. Because groundwater at these locations is suspected to be contaminated, soil samples from these locations were not used to define reference conditions.

Tritium is the contaminant in the wells east of WAG 17; concentrations detected in samples from these wells ranged from 2610 pCi/L (in well 1197) to 30,800 pCi/L (in well 1198); this level is too high to attribute to contributions from atmospheric testing of nuclear weapons. The SDWA MCL for tritium is 20,000 pCi/L. Although the wells are topographically uphill from the WAG 17 complex, subsequent review indicated that the well screens may be completed in fractured bedrock along strike and potentially downgradient of WAG 17. Because the possibility of contamination from WAG 17 (which contains a tritium production facility in its eastern portion) could not be eliminated, these wells were deleted from the reference location data set although no documentation exists that identifies any releases from WAG 17. This provides for a conservative assessment of reference water quality used for comparison with WAG 1-related samples.

In well 1253, gross alpha levels range from 49.2 to 172 Pci/L—conspicuously higher than those in other reference wells. Gross alpha activity can be attributed primarily to higher concentrations of the naturally occurring uranium and thorium series radionuclides. Curium-242 and -243 were also detected in this well at 1.99 and 9.19 pCi/L, respectively, indicating the presence of man-made contaminants. Well 1253 is most likely completed in Unit E, or possibly in Unit D. Other reference wells located along bedrock strike from well 1253 in Units D and E do not exhibit the chemical characteristics of well 1253. Further investigation is needed to understand the presence of elevated gross alpha and curium in this well. This well will not be considered as part of the reference program for Bethel Valley, pending such an investigation.

4.2.4 Reference Soil Sampling

4.2.4.1 Reference soil sampling locations

Eighteen reference soil samples (not including associated QC samples) were collected from 16 locations within Bethel Valley (Fig. 4.2.1). Eleven of these locations are north of the WAG 1 boundary; the others are to the east and west at varying distances from WAG 1.

All 16 soil sampling locations were drilled and sampled along the same geologic units that lie within WAG 1. The sampling locations are not only representative as reference locations for WAG 1 but also represent the Bethel Valley reference soil data.

4.2.4.2 Reference soil analytical results

A summary of analytical results for the reference soil sampling program and detailed analytical results are given in Appendix A. All of the chemical results for reference soil samples have been reviewer-validated using the procedures contained in (EPA 1988a) and (EPA 1988b).

Volatile organic compounds. Ten VOCs were detected in reference soil samples: methylene chloride, acetone, methyl ethyl ketone (2-butanone), toluene, trichlorofluoromethane, chloroform, 2-hexanone, trichloroethene, 2-methyl-1-propanol (isobutanol), and methyl iodide. The first four compounds listed are common laboratory-induced contaminants. The maximum detected concentration of these four compounds was 260J μg/kg (methyl ethyl ketone). The minimum RCRA action level concentration for any of the common laboratory contaminants in soil is 90 mg/kg, which is more than two orders of magnitude above the highest concentration detected in reference samples for these compounds. Trichloroethene was detected in 2 of 22 samples at a level of 1J μg/kg. Both methyl iodide and 2-methyl-1-propanol were detected in one sample each at 3J and 10J μg/kg, respectively. Chloroform was detected four times at up to 9 μg/kg; 2-hexanone was detected once at 2J μg/kg. No RCRA Subpart S action levels were exceeded.

BNAE compounds. Fifteen BNAEs were detected, ten of which are polyaromatic hydrocarbons (the heavier-molecular-weight components of oil and diesel fuel and components of incomplete combustion of gasoline and diesel fuel). The polyaromatic compounds detected included benzo(a)pyrene, benzo(g,h,i)perylene, benzo(k)fluoranthene, benz(a)anthracene, benzo(b)fluoranthene, chrysene, fluoranthene, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene. The polyaromatic compounds were primarily detected at location 1.5CBG4 (near Fifth Creek) and 01.FCBG2 (near First Creek background) (see Fig. 4.2.1). Sampling locations adjacent to 01.5CBG4 and 01.FCBF2 had fewer polyaromatic compounds, which suggests localized introduction of these compounds and limited migration in the soil. All concentrations of detected polyaromatic compounds were less than the SQL and were, therefore, estimated values. The highest estimated concentration was 170J μg/kg. No RCRA Subpart S action levels were exceeded.

Two phthalate esters (diethyl phthalate and di-n-butyl phthalate) were detected. Concentrations were estimated values less than SQLs and did not exceed 150J μg/kg. Each compound was detected once at two separate locations. RCRA Subpart S action limits were not exceeded.

Benzoic acid, benzo(g,h,i)perylene, benzo(b)fluoranthene, and n-nitrosodiphenylamine were also detected at estimated concentrations below the SQL. The highest estimated concentration was 170J μg/kg. No RCRA Subpart S action levels were exceeded.

Metals. Metals occur naturally in soil and are an integral component of the minerals that comprise soil. Soil chemistry is indicative of both the parent material from which the soil was derived and the physical and chemical processes that formed it.

Twenty-five metals were analyzed in reference soil samples. With few exceptions (mentioned below), metal concentration ranges were similar to those detected in soil from Melton Valley to the south (BNI 1991). No RCRA Subpart S action levels were exceeded.

The more abundant metals detected include aluminum, calcium, iron, magnesium, manganese, and potassium. Concentrations of calcium and magnesium in soil from Bethel Valley are considerably higher than detected in soil from neighboring Melton Valley. Petrologic differences in parent material contribute to the higher concentrations; Melton Valley soil is developed from shales, sandstones, siltstones, and some carbonates, whereas soils in Bethel Valley are developed predominantly from carbonates. Other metals were detected at somewhat higher concentrations compared with reference samples from Melton Valley.

One occurrence of zinc from borehole 01.BV03 was, at 258,000J μg/kg, nearly 4.5 times greater than the next highest detected concentration (57,800 μg/kg). This value was estimated due to duplicate relative percent differences that were outside of control limits and to matrix interference in the analysis of the sample. This value is also considered an outlier because zinc concentrations in other samples from the same borehole were similar to those from other locations. The average zinc concentration among the remaining 2 samples from BV03 and 14 other reference samples was 37,400 μg/kg.

PCBs. There were no detectable concentrations of pesticides or PCBs in reference soil samples.

Organophosphorous pesticides. There were no detectable concentrations of organophosphorus pesticides in reference soil samples.

Herbicides. The herbicide 2,4,5-T was detected in sample BV03 at an estimated value of 22.7J μg/kg. This herbicide was used extensively before 1985; its use has since been prohibited or severely restricted. Whether this particular herbicide has been used at ORNL is unknown. The concentration of 22.75 μg/kg is below the RCRA action level in soil of 800,000 μg/kg, as shown in Table 4.2.2.

Dioxins/furans. There were no detectable concentrations of dioxins or furans in reference soil samples.

Radionuclides. Both naturally occurring and man-made radionuclides were detected in WAG 1 reference soil samples. In addition, measurements were made of gross alpha (an indication of the total concentration of alpha-emitting radionuclides) and gross beta (an indication of the total concentration of beta-emitting radionuclides) concentrations. Gross alpha concentrations ranged from 56 ± 17 to 12 ± 6 pCi/g and gross beta concentrations ranged from 34 ± 7.1 pCi/g to undetectable levels not exceeding 6 pCi/g. These ranges are generally comparable to those observed in Melton Valley reference soil samples, although some

measurements of gross alpha in Bethel Valley reference soil were over two times those detected in Melton Valley reference samples.

Radionuclides of the naturally occurring uranium and thorium series were detected in reference soil samples. The uranium decay series radionuclides detected include uranium-238, thorium-234, uranium-234, thorium-230, radium-226, and lead-214. Concentrations of uranium series radionuclides detected in soil from Melton Valley are similar to those detected in WAG 1 reference soil samples. The highest concentration of a uranium decay series radionuclide was 1.94 ± 0.41 pCi/g for thorium-234. The thorium decay series radionuclides detected include thorium-232, radium-228, actinium-228, thorium-228, radium-224, bismuth-212, and thallium-208. The highest concentration of a thorium decay series radionuclide was 19.9 ± 2.7 pCi/g for thorium-228, detected in a sample taken near Fifth Creek. Thorium-228 was detected at 11.4 ± 1.5 pCi/g in a second sample near Fifth Creek; the next highest concentration detected was 1.89 ± 0.44 pCi/g. Carbon-14, which is a nonseries, naturally occurring radionuclide that has also been produced by the nuclear industry and through atmospheric testing of nuclear weapons, was not detected in excess of the MDA of 10 pCi/g. Potassium-40, also a naturally occurring radionuclide, was detected in concentrations ranging from 2.42 to 29.6 pCi/g. Potassium-40 is analyzed principally to determine whether gross beta concentrations are related to its presence or to some other beta-emitting radionuclide that warrants further analysis.

Man-made radionuclides detected in WAG 1 reference soil samples include cesium-137, technetium-99, and tritium. These radionuclides have been released to the biosphere during atmospheric testing of nuclear weapons and are also products of nuclear reactor operations; the possibility of airborne transport and deposition cannot be ruled out. Cesium-137 was present at detectable levels in five samples; the highest detected concentration was 0.21 ± 0.05 pCi/g. Technetium-99 was detected above the MDA of 0.9 pCi/g in only one sample (5CBG, Fifth Creek background) at a concentration of 1.53 ± 0.52 pCi/g. Tritium (which is also produced naturally at a very low rate) was, for the most part, not detected. In the three instances when it was detected, it did not exceed 0.22 pCi/g. Total radioactive strontium was detected in one regular sample at $0.29J \pm 0.26$ pCi/g and in the duplicate sample at $0.43J \pm 0.25$ pCi/g. Other man-made radionuclides analyzed for but undetected above the MDA in selected soil samples include americium-241, curium-242, iron-55, iodine-129, nickel-63, promethium-147, plutonium-238, plutonium-239/240, and uranium-235/236.

4.2.5 Reference Groundwater Sampling

4.2.5.1 Sampling locations

The reference groundwater monitoring network for WAG 1 presently consists of five monitoring wells in Bethel Valley (see Fig. 4.2.1). Wells BV08 and BV09 are north of WAG 1 and adjacent to First Creek and Fifth Creek, respectively, outside the WAG 1 boundary. These two wells monitor groundwater in the unconsolidated zone. Well 1250 is approximately 1.5 miles southwest of the center of the WAG, well 1252 is approximately 2.5 miles to the northeast, and well 1251 is located approximately 1.25 miles to the east. These

wells monitor groundwater either in bedrock or across the bedrock/unconsolidated zone interface.

Wells BV08 (since renumbered as 4000) and BV09 (since renumbered as 4001) were installed on March 19, 1991. The 1200-series wells were installed between November 7, 1989, and May 8, 1990. Complete monitoring well construction details are provided in Appendix B.

4.2.5.2 Analytical results

A summary of analytical results for the reference groundwater sampling program and detailed analytical results are contained in Appendix B. The chemical results for reference groundwater samples have been reviewer-validated using the procedures contained in (EPA 1988a) and (EPA 1988b).

Volatile organic compounds. Carbon disulfide was detected at an estimated 2J μg/L in one sample from location BV08. The RCRA Subpart S action level for carbon disulfide is 4000 μg/L. Carbon disulfide can result naturally from anaerobic biodegradation and is released to the atmosphere from oceans and land masses (Howard 1990).

BNAE compounds. Two BNAEs were detected: bis(2-ethylhexyl)phthalate at 10 μg/L in well 1251, and di-n-butyl phthalate in one sample at an estimated concentration of 2J μg/L at location BVO9. No other BNAEs were detected greater than the respective SQL. Bis(2-ethylhexyl)phthalate is a common plasticizer for PVC and other polymeric materials. Bis(2-ethylhexyl)phthalate is known to be a common laboratory artifact and therefore may not represent actual site contamination. Di-n-butyl phthalate is a ubiquitous compound because of its widespread use, primarily as a plasticizer; it has also been used as an insect repellant and as a solvent in perfumes and inks (Howard 1990). Both of these compounds have been detected in other media from WAG 1 and WAG 6 (ORNL 1991) and in treated and untreated water supplies worldwide (Howard 1990).

Metals. Metals are a natural component of groundwater, and the types and concentrations present are dependent on site-specific geological and geochemical conditions. Unfiltered and filtered groundwater samples were analyzed for 25 different metals.

Not all metals analyzed were detected above the SQL. Metals not detected above SQLs in either filtered or unfiltered samples include antimony, beryllium, cobalt, mercury, osmium, selenium, silver, thallium, and tin. Metals detected in unfiltered groundwater but not in filtered groundwater include arsenic, copper, and vanadium.

Metals detected at the highest concentrations in unfiltered samples (detected at least once at the mg/L level) include calcium, magnesium, sodium, potassium, aluminum, and iron. None of the concentrations are believed to represent unnatural conditions. A summary of the minimum and maximum concentrations along with a complete data listing for each sample are found in the attachments to Appendix B.

Concentrations of metals detected in WAG 1 groundwater reference samples do not differ appreciably from those in samples from locations in Melton Valley. As compared with Melton Valley samples, somewhat higher concentrations (but less than an order of magnitude) of aluminum, chromium, manganese, nickel, potassium, and sodium have been detected in unfiltered groundwater samples from Bethel Valley reference locations. These differences could be attributable to contrasting lithologies in the valleys.

Pesticides/PCBs, herbicides, dioxins/furans, and organophosphorous pesticides. There were no detectable concentrations of PCBs, herbicides, dioxins/furans, or organophosphorous pesticides in reference groundwater samples. The pesticide DDD was detected in one sample at 1.2 μg/L.

Radionuclides. Analytical results for radiological analyses indicate that few radionuclides were present and concentration ranges were low. Unfiltered and filtered samples were analyzed. Gross alpha and gross beta results were suggestive of samples that have not been influenced by waste management activities; supplemental isotopic analyses of the samples confirmed this.

The maximum unfiltered gross alpha activity was 3.8 pCi/L, and the maximum unfiltered gross beta activity was 4.88 pCi/L. Of the uranium decay series radionuclides analyzed for in both filtered and unfiltered samples, none exceeded the MDA. Of the thorium decay series radionuclides analyzed for in both filtered and unfiltered samples, only thorium-228 exceeded the MDA. Tests for thorium-224 (uranium series) and radium-224 (thorium series) were not run.

Transuranic radionuclides were analyzed for in selected samples but were not detected at concentrations above the MDA. Other radionuclides analyzed for include nonseries radionuclides that are both naturally occurring and man-made. No specific radionuclide of this group was detected above the MDA except total radioactive strontium, which was present in two samples, at 0.99 pCi/L and 1.63 pCi/L.

Tritium was found in most samples; the highest concentration detected was 1940 ± 270 pCi/L from well 1250. This concentration was higher than might be expected from tritium introduced to the hydrologic cycle through nuclear weapons testing during the 1960s. At the end of large-scale atmospheric testing of nuclear weapons in 1963, the mean concentrations of tritium in surface streams in the United States were approximately 4000 pCi/L, about 400 times the concentration of naturally occurring tritium (Kathern 1984). Decay of this mean concentration of tritium over the years 1963 to 1992 would produce a concentration of approximately 715 pCi/L.

Curium was detected in samples from wells 1250 and 1252 at concentrations greater than would be predicted by the gross alpha activities in the samples. Thus, the presence of curium in the samples is considered suspect, and the curium values were not used to define background values for curium in WAG 1. Further support for the suggestion that curium is absent from reference wells is that curium-244 was detected in only four WAG 1 nonreference piezometers (598, 608, 590, and 593) near the isotope area and CH008. The

relatively few locations suggest that curium-244 is not widespread but related to specific areas within WAG 1.

4.2.6 Reference Sediment Sampling

4.2.6.1 Sampling locations

Four reference sediment samples (two regular and two duplicate) were collected from two locations during nonstorm, low base flow conditions on October 17 and 18, 1990. The sediments were collected from First Creek (location 01.CS009) and Fifth Creek (location 01.CS006) north of Bethel Valley Road, where surface water samples were also collected (see Fig. 4.2.2).

4.2.6.2 Analytical results

A summary of analytical results for the reference sediment sampling program and detailed analytical results are contained in Appendix B. All of the chemical results for reference sediment samples have been reviewer-validated using the procedures contained in (EPA 1988a) and (EPA 1988b).

Volatile organic compounds. Chloromethane, acetone, trichloroethene, and toluene were detected; the highest concentration was 76J μg/kg acetone. Concentrations of the other VOCs did not exceed 3J μg/kg.

Acetone and toluene are common laboratory-induced contaminants. The one occurrence of trichloroethene (estimated at 3J μg/kg) is not considered significant. Chloromethane has many different sources, both natural (combustion product of forest and brush fires, seawater, cedar and cypress trees) and man-made (cigarette smoke, manufacture of silicones, turbine exhaust, and propellants) (Howard 1990). In general, VOCs are considered absent from reference sediment samples.

BNAE compounds. Two BNAEs [4-methyl phenol and bis(2-ethylhexyl)phthalate] were detected in reference sediment samples. One sample showed 4-methyl phenol at an estimated concentration of 52J μg/kg; bis(2-ethylhexyl)phthalate was detected in all four samples at estimated concentrations of 67J to 93J μg/kg. Bis(2-ethylhexyl)phthalate, a common plasticizer and laboratory artifact, has been detected in various other media both at WAG 1 and WAG 6 (ORNL 1991). The compound 4-methyl phenol (4-cresol) has been detected in exhaust from gasoline and diesel engines, is a plant volatile, and has been detected in cigarette smoke (Howard 1990). Reference sediment samples were taken at locations that were not immune to the influences of automobile exhaust, which may be a source of the low concentration of 4-methyl phenol.

Metals. Metals occur naturally in the environment and are an important component of creek sediments. Of the 23 metals analyzed, 18 were present at detectable levels in reference sediment samples. Metals that were analyzed for but not detected in excess of the SQL include antimony, mercury, selenium, silver, and thallium. With the exception of calcium, concentrations detected in First Creek and Fifth Creek sediments are within the ranges

detected in stream sediments collected from Melton Valley that established reference concentrations for WAG 6 (ORNL 1991). The increase in range for calcium can be attributed to a greater abundance of limestone in Bethel Valley than in Melton Valley. Comparison of the detected concentration ranges with other published data indicates that the results are within or below these values.

Pesticides/PCBs. There were no detectable concentrations of pesticides or PCBs in WAG 1 reference sediment samples.

Herbicides and dioxins/furans. Reference sediment samples were not analyzed for herbicides, primarily because these constituents were absent from the reference soil samples, most of which were collected in the floodplain of the creeks.

Organophosphorous pesticides. Reference sediment samples were not analyzed for organophosphorous pesticides.

Radionuclides. Both man-made and naturally occurring radionuclides were detected in reference sediment samples. Gross alpha concentrations ranged from 6.99 to 12.9 pCi/g, and gross beta concentrations ranged from 5.75 to 15.5 pCi/g.

In analyses for the thorium decay series radionuclides, radium-228 (0.53 pCi/g) and thorium-228 (0.75 to 0.8 pCi/g) were detected. The uranium series radionuclides thorium-230 and radium-226 were detected at concentrations ranging from 0.604 to 1.2 pCi/g and 0.389 to 0.712 pCi/g, respectively.

Man-made radionuclides (fission products) detected include cesium-137 and strontium-90; both have been used extensively at ORNL and have also been released to the environment through atmospheric testing of nuclear weapons. Cesium-137 was detected in two of four samples in concentrations ranging from 0.237 to 1.13 pCi/g; the other two samples did not contain levels detectable above 0.2 pCi/g. Strontium-90 was detected in all four samples at concentrations ranging from 0.733 to 2.81 pCi/g. The concentration ranges of these radionuclides are slightly higher than detected in WAG 6 reference sediments (0.04 to 0.2U pCi/g of cesium-137, 0.52U to 0.92 pCi/g of strontium-90). Historic emissions from nearby stacks may influence concentrations detected in the WAG 1 samples.

4.2.7 Reference Surface Water Sampling

4.2.7.1 Sampling locations

Eleven reference surface water samples (eight regular and three duplicate) were collected from three locations near WAG 1 (see Fig. 4.2.2). Samples were collected on three separate occasions from First Creek and Fifth Creek at locations north of Bethel Valley Road. WOC was sampled twice, also at locations north of Bethel Valley Road. All three creeks were sampled under high base flow conditions and during a transitional period from high to low. First Creek and Fifth Creek were sampled during low base flow conditions. Low base flow samples were collected on October 17 and 18, 1990. One set of high base flow samples was collected on April 22, 1990; a second set was collected on March 12, 1991.

4.2.7.2 Analytical results

A summary of analytical results for the reference surface water sampling program and detailed analytical results are contained in Appendix B. All of the chemical results for reference surface samples have been reviewer-validated using the procedures contained in (EPA 1988a) and (EPA 1988b). The radiological data have been validated in accordance with appropriate project procedures.

Volatile organic compounds. Chloroform and toluene were detected in reference surface water samples: chloroform in 2 samples up to an estimated 4J μg/L, and toluene in 1 sample of 11 at an estimated value of 1J μg/L. Toluene and chloroform are found in the environment as a result of releases from various sources (e.g., automobile exhaust), and toluene is a common laboratory-induced contaminant. RCRA Subpart S action levels were not exceeded.

BNAE compounds. Three BNAE compounds [(n-nitrosodiphenylamine, bis(2-ethylhexyl)phthalate, and fluoranthene] were detected in reference surface water samples. Each compound, detected only once, was at an estimated concentration not exceeding 3J μg/L. RCRA Subpart S action levels and MCLs were not exceeded.

Metals. Metals occur naturally in unfiltered and filtered surface water; the types and concentrations of metals present are dependent on the geology of the watershed and the groundwater chemistry. Of the trace metals analyzed for, aluminum, barium, calcium, iron, magnesium, manganese, potassium, and sodium were detected most frequently. Calcium and magnesium, which are common metals present in carbonate rocks typical of Bethel Valley strata, were detected at higher concentrations than the other metals. Metals not detected above their respective SQLs include antimony, arsenic, beryllium, cadmium, chromium, cobalt, mercury, nickel, selenium, silver, thallium, tin, vanadium, and zinc. Copper was detected at location 01.FCBG at 12 μg/L. Lead was detected at locations 01.SW1 and 01.SW3 at 3.8 and 3.2 μg/L, respectively. These concentrations do not exceed the RCRA Subpart S action limits or MCLs.

Results for filtered samples, analyzed from location 01.CS006 (mercury only) and from a duplicate sample from location 01.CS009, indicated the presence of barium, cadmium, iron, magnesium, manganese, potassium, and sodium. Other metals were not detected above the SQL.

Pesticides/PCBs, organophosphorous pesticides, dioxins/furans, herbicides. There were no detectable concentrations of pesticides or PCBs, organophosphorous pesticides, dioxins/furans, or herbicides in reference surface water samples.

Radionuclides. Comparatively low levels of radioactivity were detected in reference surface water samples: the maximum detected gross alpha activity was 3.2 pCi/L, and the maximum detected gross beta activity was 5.4 pCi/L. The radionuclides detected and their concentrations do not suggest any external influences. The sample size is relatively small, however, and any statistical comparisons should be made with caution. Analyses were conducted for both man-made and naturally occurring radionuclides.

Radionuclides of the naturally occurring uranium and thorium decay series are not prevalent in reference surface water samples; however, this may be because of the small sample size. Of the uranium series, uranium-238 and uranium-234 were not detected above the MDA of 1 pCi/L. Thorium-234 results were rejected for QC reasons. Thorium-230 was detected in one sample below the MDA of 1 pCi/L at an estimated concentration of 0.25 ± 0.23 pCi/L. Radium-226 was detected at one location above the MDA of 1 pCi/L. The highest concentration of radium-226 was 4.57 ± 0.7 pCi/L, which approaches the 5 pCi/L MCL for drinking water.

In analyses for the thorium decay series radionuclides, thorium-232 and radium-228 were not detected above the MDAs of 1 pCi/L and 3 pCi/L, respectively. Thorium-228 was detected in one sample slightly above the MDA at $1.21J \pm 0.53$ pCi/L. Radium-224 concentrations are questionable because of higher concentrations of the radionuclide than suggested by the gross alpha concentrations and one rejected sample result. The detection levels for radium-224 were 16.7 ± 8.8 and 19.5 ± 8 pCi/L.

Potassium was detected at 110 ± 78 and 156 ± 91 pCi/L. A third result did not exceed the MDA of 11 pCi/L.

Man-made radionuclides analyzed for include cesium-137 and tritium. Cesium-137 was not detected above the MDA of 22.9 pCi/L. Tritium was detected in seven of the eight samples; the highest concentration was 1120 pCi/L, and the average was 840 pCi/L. This average level is close to the concentration that could be attributed to the introduction of tritium via nuclear weapons testing into the hydrologic cycle.

4.2.8 Conclusions

Various constituents have been detected in WAG 1 reference media from Bethel Valley. It is important to realize that many of the constituents detected occur naturally in the environment (especially metals and radionuclides). Others (such as VOCs and BNAEs), while usually not naturally occurring, may have been introduced to the various media by means other than waste management practices at ORNL. This may be particularly true of polyaromatic hydrocarbons detected in soil samples that may have been introduced from automobile emissions. Generally, the constituents of nonnatural origin were detected at low concentrations that are well below various regulatory action limits.

The reference network for WAG 1 may not be adequate to fully characterize the variability in groundwater quality identified during Phase I sampling and analysis. For example, concentrations of certain naturally occurring metals (e.g., aluminum, iron, potassium) vary significantly in samples from within WAG 1 but only within a very narrow range in the reference samples. This discrepancy may be due to contrasts in the geochemistry of the stratigraphic units between the reference well and WAG 1 well locations. Similarly, concentrations of naturally occurring radionuclides vary significantly, making it difficult to recognize with certainty where naturally occurring isotopes are present as contaminants (due to their concentration or enrichment through various plant operations). Presently, the reference groundwater network for WAG 1 consists of two locations at which two rounds of sampling have been conducted and three locations at which one round has been

completed. An expanded reference well network would be needed to support a more definitive interpretation of contamination in WAG 1 groundwater for an OU-specific analysis.

Generally, comparisons of constituent concentrations detected in Bethel Valley reference samples with background or reference concentrations of samples collected outside Bethel Valley indicate similarity in range. Some differences do exist between Bethel Valley and Melton Valley samples; however, these differences could be attributable to contrasting geologic conditions.

Statistics computed on reference sampling results should be interpreted with caution, especially in the case of reference sediments, surface water, and groundwater. Depending on the type of statistical analysis desired, the sample size may be insufficient for developing the appropriate degree of confidence for on-WAG versus off-WAG comparisons.

4.3 GROUNDWATER

Interpretations regarding the nature and extent of groundwater contamination at WAG 1 are based on samples collected from 109 wells and piezometers during the Phase I investigations (see Table 2.9.1). Four separate sampling events were conducted, though not all wells and piezometers were sampled during each event.

The first event involved sampling of 77 wells and piezometers during low base groundwater flow conditions (September and October 1990); the second included 18 wells and piezometers sampled during a prolonged storm and high base groundwater flow conditions (February 21–23, 1991); the third event involved 82 wells and piezometers sampled during normal (i.e., nonstorm) high base groundwater flow conditions (March and April 1991). Section 3.3 describes the site hydrogeology and the relationship among low, high, and storm events on groundwater levels and flow directions. See Figs. 3.3.2 and 3.3.3 for groundwater table maps for high and low base conditions, respectively. Figure 3.3.12 illustrates the maximum groundwater fluctuations observed during Phase I investigations.

The fourth groundwater sampling event was in response to the addition in 1991 of 33 SWMUs to the scope of the Phase I investigation and the discovery of radioactive contaminants in corehole CH008. This final event entailed sampling of 14 piezometers in the vicinity of the newly added SWMUs and CH008 during the period July through October 1991. In the same period, groundwater samples were also collected from discrete intervals in eight of the bedrock coreholes.

Groundwater sampling typically involved collection of both unfiltered and filtered samples for radiological and chemical analyses, as outlined in Sect. 2. Specific analytes varied, but the majority of the groundwater samples were analyzed for TCL organics, TAL metals, and radionuclides. Selected samples were also analyzed for Appendix IX constituents, general water quality constituents, and major ions. Detailed information related to the collection and analysis of the groundwater samples, including the complete results of all chemical and radiological analyses, is presented in Appendix B.

Samples were also collected from 25 monitoring wells installed by ORNL along the WAG 1 perimeter under the RCRA groundwater monitoring program. These wells were sampled during both low base and high base (nonstorm) groundwater flow conditions. The perimeter well samples were transferred to the ORNL Environmental Compliance Program for analysis at the ORNL analytical laboratory; results of these analyses were not available at the time this report was prepared.

Data from earlier RCRA perimeter well sampling events conducted by ORNL were evaluated. These data are based on sampling of 24 wells (806 through 829) between December 1988 and September 1990. The perimeter well sample analyses included volatiles, semivolatiles, anions, unfiltered and filtered metals, and unfiltered and filtered radionuclides. Interpretations regarding potential contamination detected in the perimeter wells are included with descriptions of the nature and extent of contamination identified through the Phase I sampling program.

This section is organized into four subsections: Sect. 4.3.1 summarizes previous studies; Sect. 4.3.2 describes the nature and extent of radiological contamination; Sect. 4.3.3 describes the nature and extent of chemical contamination; and Sect. 4.3.4 presents a summary of overall contaminant trends in groundwater.

4.3.1 Previous Studies

Previous studies conducted to assess the nature and extent of groundwater contamination in the WAG 1 area have been limited in terms of both the number of studies and the scope of any individual study. One of the earliest studies that focused on groundwater contamination was conducted in 1973 using wells in the vicinity of SWSA 1 (Duguid et al. 1975); no additional investigations were conducted at WAG 1 until RCRA monitoring wells were installed around the 3500 series impoundments in 1985. These wells were sampled regularly beginning in 1986, and the resulting data were incorporated into several groundwater contamination studies [e.g., Stansfield and Francis (1986), Montford, Daniels, and Kitchings (1986), Solomon et al. (1989)].

Data from the vicinity of the impoundments and other areas in WAG 1 have also been generated through the annual sampling and analysis activities conducted in conjunction with the ORR environmental surveillance program, begun in 1985. Results from these earlier studies are discussed below and summarized in Table 4.3.1; no attempt has been made to reconcile the units reported in these earlier studies with those used in this report. The studies identified in Table 4.3.1 include a map reference number that can be correlated to Fig. 4.5.1.

Two wells and one seep near SWSA 1 were sampled for strontium-90 and cesium-137 in November 1973. No results exceeded the detection limits except for well 1-2, which contained 0.4 dpm/mL of strontium-90 (Duguid et al. 1975).

Sampling was conducted by Stansfield and Francis (1986) to investigate potential groundwater contamination associated with impoundment 3513. Groundwater collected from downgradient wells during the study was analyzed for EPA interim primary drinking water standards (40 CFR 265.92) as well as selected radionuclides. With the exception of the

radionuclides, most of the constituents were at or below detection limits. Maximum results for cesium-137, lead-214, radium-226, strontium-90, gross alpha, and gross beta were 1.04, 10.6, 0.14, 26, 3.9, and 54 Bq/L, respectively. Samples from other media were also obtained at that time.

Montford, Daniels, and Kitchings investigated groundwater in the vicinity of the impoundments in 1985 and summarized data collected quarterly during the first year of monitoring. Samples taken from wells around the 3524 and 3539/3540 impoundments were analyzed for 23 RCRA parameters. Quarterly values as well as annual average concentrations for several of the upgradient and downgradient wells exceeded EPA interim primary drinking water standards for gross alpha, radium, chromium, lead, and a few other constituents. Gross beta also exceeded the standards in most cases. No pesticides or PCBs were detected.

Solomon et al. (1989) also studied groundwater at the 3513 impoundment, with primary focus on a limited set of volatile and semivolatile organic compounds. The maximum detected concentrations for the VOCs under investigation were toluene, 8 mg/L; trichloroethene, 30 mg/L; vinyl chloride, 35 mg/L; and 1,2-dichloroethane, 472 mg/L.

A review of sampling results for the ORR environmental monitoring program from 1985 to 1988 indicates that although selected constituents were detected in many samples, most of these were indicator (water quality) parameters (e.g., TOX and TOC). Data for specific chemical contaminants were below detection limits.

4.3.2 Nature and Extent of Radiological Contamination

Radiological contamination in groundwater was measured through analyses for gross alpha and gross beta content as well as a variety of alpha- and beta-emitting radionuclides. Both man-made and naturally occurring radionuclides were detected in the Phase I groundwater samples collected from WAG 1 wells and coreholes (Table 4.3.2).

The most frequently detected man-made radionuclides include tritium and strontium-90. Other man-made radionuclides (less frequently detected) include technetium-99, cesium-137, promethium-147, cobalt-60, nickel-63, and iron-55, and the transuranics americium-241, plutonium-238/239/240, and curium-244. Naturally occurring radionuclides detected include potassium-40 and radionuclides belonging to the uranium decay series (uranium-238, thorium-234, uranium-234, thorium-230, radium-226) and the thorium decay series (thorium-232, radium-228, thorium-228, radium-224). The most frequently detected naturally occurring radionuclides were radium-226, radium-228, thorium-228, thorium-232, and uranium-234.

The evaluation of radiological contamination in this report serves primarily to provide an initial focus for data discussion; it is not intended to represent final interpretations regarding the nature and extent of groundwater contamination in WAG 1. The evaluation is based on a comparison with WAG 1-specific reference levels (discussed in Sect. 4.1) and established regulatory criteria for drinking water supplies (MCLs promulgated under the SDWA, including April 15, 1991, revisions). Although groundwater at WAG 1 is not a

current source of drinking water at ORNL, a comparison with the MCL criteria was conducted to identify the occurrence of site-related groundwater contamination that may be a source of potential concern for potential future users.

SDWA MCLs have been established for the following radiological constituents: tritium (20,000 pCi/L), strontium-90 (8 pCi/L), radium (5 pCi/L, taken as the sum of radium-226 and radium-228), gross alpha (15 pCi/L), gross beta (4 mrem/year), and all other man-made radionuclides (4 mrem/year). The MCLs focus on man-made constituents (e.g., tritium and strontium-90) but include gross alpha and radium, both of which may be present as naturally occurring constituents. Conversion of dosage factors (mrem/year) to activities (pCi/L), necessary to permit comparison of activity-based WAG 1 sampling results with the dosage-based MCLs, was accomplished using assumptions and methodology presented in the PRAR.

Comparison with MCLs does not imply that results exceeding MCLs necessarily pose a threat to human health or the environment under existing or future exposure scenarios. Nor should it be inferred that results below MCLs indicate the complete absence of any risk. A preliminary assessment of the risk associated with contaminant releases from WAG 1 to potential human and environmental receptors is presented in the WAG 1 PRAR.

The discussion of radiological contamination in groundwater is further subdivided by individual radionuclides or groups of related radionuclides (e.g., uranium series) as well as gross alpha and gross beta. Three figures are presented for each radiological parameter. One figure displays the maximum activities found at each well for all sampling events, regardless of whether the sample was filtered or unfiltered and regardless of sampling event. The second and third figures display individual radiological parameter results from unfiltered samples during the low and high base conditions, respectively. Comparisons of filtered and unfiltered sample results are discussed in the text for each parameter, as are results from the high base storm sampling event.

Information from the WAG 1 perimeter wells (Table 4.3.3) is not incorporated into figures depicting maximum detected activities for selected parameters or the high and low base figures because of uncertainty regarding groundwater flow conditions during these earlier sampling events.

In the following discussion, all references to frequency of detection, contaminant activities or ranges of activities, number of wells and piezometers, and other details about nature and extent are in reference to groundwater samples collected as part of the Phase I activities. References to or interpretations based on data from the WAG 1 perimeter monitoring wells (generated through ORNL's RCRA groundwater monitoring program) are specifically identified.

4.3.2.1 Nature and extent of individual radiological parameters

Strontium. Analysis for strontium-90 was performed on samples collected as part of the low base groundwater sampling event; samples collected for high base and storm event sampling were analyzed for total radioactive strontium (the sum of strontium-89 and strontium-90). Strontium was detected in samples from 72 wells, piezometers, and

coreholes; concentrations in 34 of these locations exceeded the SDWA MCL of 8 pCi/L. Table 4.3.4 presents the strontium-90 or total radioactive strontium detected at each location sampled. CH008 contained the highest activities of strontium detected in WAG 1 groundwater; the maximum activity of total strontium in CH008, 312,050 pCi/L, was measured in a sample collected from a depth of 40.9 to 42.9 ft BGS. Approximately 96% of the total strontium in this sample was strontium-90 (i.e., 298,780 pCi/L) and 2% strontium-89 (6690 pCi/L). The presence of strontium-89 (detected twice) in samples from CH008 is suspect and the detects may be false positive. A detailed discussion of this issue is presented in Sect. C6.5.4, Appendix C. Five additional samples from separate intervals in CH008 also contained elevated levels of strontium, ranging from 17,405 to 245,574 pCi/L. Radioactive strontium was detected in reference groundwater samples at a maximum concentration of 1.63 ± 1.29 pCi/L (total radioactive strontium).

Figure 4.3.1 presents the maximum detected activity of strontium, whether total radioactive strontium or strontium-90, at each well or piezometer sampled for the Phase I investigation. The majority of the locations where strontium exceeded the SDWA MCL of 8 pCi/L on at least one occasion were in the vicinity of the 3500 impoundments. Piezometers 539, 564, 589, 598, and 601 each had one or more occurrences of strontium in excess of 100 pCi/L.

During low base conditions, strontium-90 was not detected in unfiltered groundwater from 25 of 45 wells and piezometers sampled (Fig. 4.3.2 and Table 4.3.4); the remaining 20 contained strontium-90 in excess of the SDWA MCL of 8 pCi/L.

Figure 4.3.3 presents results for total strontium in unfiltered groundwater samples collected during the high base flow sampling event (more wells were sampled during high base than during low base). Nineteen wells and piezometers sampled during low base events contained strontium-90 greater than 8 pCi/L; unfiltered samples from 17 of these also exceeded 8 pCi/L when resampled at high base conditions. Nine of these wells and piezometers (539, 874, 564, 1100, 1102, 1104, 597, 882, and 875) exhibited higher strontium activities during low base conditions than during high base sampling. Wells 874 and 875 showed the most pronounced differences. Piezometer 601 showed a substantially higher activity of strontium during high base, and 1103, 885, 873, 566, 571, 589, and 877 showed marginally higher strontium levels during high base.

Activities of strontium were similar in 11 of 12 wells and piezometers sampled during both the high base and high base storm sampling events (see Table 4.3.4). Piezometer 598, however, had a total strontium activity of 1.49 pCi/L during the high base sampling and 108.24 pCi/L during the high base storm sampling.

The wells and piezometers sampled during the latter half of 1991 as part of the investigation of additional SWMUs revealed other locations with elevated strontium activity; those having total strontium above 8 pCi/L included 588, 593, 590, 596, 603, 608, and 613.

Groundwater samples from coreholes were analyzed for strontium; only CH11A and CH008 contained strontium above the SDWA MCL of 8 pCi/L. All groundwater samples from CH008 had very high concentrations.

Strontium in RCRA perimeter wells. ORNL sampling of the RCRA perimeter wells revealed total strontium activities above 8 pCi/L in wells 812, 825, 806, and 829; concentrations ranged from 13.5 to 7560 pCi/L. Wells 806 and 829 remained above 8 pCi/L for the 3-year duration (four samples). Four samples from well 812 contained total strontium greater than or equal to 3240 pCi/L, while one sample contained less than 8 pCi/L (October 1989).

Well 806 lies in the WOC floodplain in the water gap in Haw Ridge. Well 829 lies adjacent to and downgradient of SWSA 1. Piezometer 571 and well 946, also near SWSA 1, were sampled as part of Phase I. These locations exhibited strontium activities similar to that reported for well 829.

Tritium. Tritium was detected in nearly all of the samples analyzed; concentrations ranged from 290 to 912,000 pCi/L. The MCL for tritium, 20,000 pCi/L, was exceeded in samples from 14 wells and coreholes (Table 4.3.5). The maximum tritium concentration found in the reference wells was 1940 pCi/L.

Activities of tritium greater than 100,000 pCi/L were found in five wells (874, 875, 885, 876, and 1100) located between impoundments 3524 and 3513; two piezometers (564 and 566) near Building 2531; and one piezometer (608) in the isotope area south of Building 3033. Other locations with tritium in excess of 20,000 pCi/L include piezometers 603, 589, and 613 in the general vicinity of the isotope area; wells 1102 and 1104 on the southern and western perimeter of impoundment 3513; and well 590 east of NTF. Maximum tritium activities are plotted on Fig. 4.3.4.

Tritium was found in many of the locations where elevated strontium was detected. Strontium (i.e., strontium-90 or total radioactive strontium) exceeding 8 pCi/L was found in 13 of the 14 wells, piezometers, and coreholes that contained tritium above the MCL (i.e., 874, 608, 1104, 603, 589, 566, 875, 564, 1100, 1102, 885, 613, and 590). Well 876, which had tritium above 20,000 pCi/L, had detectable strontium below 8 pCi/L.

The distribution of maximum tritium activities detected during the low base and high base sampling events is presented in Figs. 4.3.5 and 4.3.6, respectively. Of the eight wells and piezometers sampled during both low and high base that contained tritium in excess of 20,000 pCi/L, well 874 and piezometers 566, 589, 1104, and 564 had low base activities nearly double the high base activities, while nearby wells 875, 1100, and 1102 had higher activities of tritium in high base samples than low base samples.

Tritium activities in 10 of the 12 wells and piezometers sampled during both the high base and high base storm events did not vary more than 10% (e.g., piezometer 566 had 133,000 pCi/L high base and 145,870 pCi/L high base storm activities). Piezometers 597 and 554 were the exception; they had levels of 510 and 2410 pCi/L, respectively, during high base conditions but were at 4980 and 1660 pCi/L, respectively, one month earlier during the high base storm sampling.

Tritium in RCRA perimeter wells. Tritium was not detected above 20,000 pCi/L in the perimeter wells sampled by ORNL. The maximum activity was 12,420 pCi/L in well 825,

located east of the 3500 series impoundments. An activity of 10,800 pCi/L was detected in wells 812 and 820, located on opposite sides of the northern portion of WAG 1. All other tritium activities in ORNL perimeter well samples were below 8000 pCi/L.

Gross alpha and gross beta. Detectable gross alpha and gross beta were present in most of the groundwater samples collected from WAG 1 wells and piezometers (Tables 4.3.6 and 4.3.7). Both naturally occurring and man-made radionuclides, including transuranic radionuclides, contribute to the gross alpha and/or gross beta activities. The range of detectable gross alpha and gross beta activity detected in unfiltered samples from reference wells were 3.5 to 3.8 pCi/L and 3.8 to 4.88 pCi/L, respectively.

The maximum gross alpha and beta activities (5093 and 585,497 pCi/L, respectively) were detected in samples collected from depths of 40.9 to 42.9 ft BGS in CH008. In some cases (i.e., samples from piezometers 598 and 541 and well 1101), naturally occurring radionuclides accounted for the majority of gross alpha activity in samples with gross alpha greater than 15 pCi/L. The majority of gross beta contamination can be attributed to elevated strontium and radium-228 activity.

Forty-three wells, piezometers, and coreholes sampled for gross alpha had activity greater than the SDWA MCL of 15 pCi/L (Fig. 4.3.7). These 43 wells, piezometers, and coreholes are distributed across WAG 1 and include areas to the west-northwest beyond the WAG boundary. Four locations with gross alpha above the MCL (piezometers 539 and 533 and coreholes CH008 and CH11A) contained elevated levels of radionuclides associated with uranium and thorium decay series, Including uranium-238, uranium-234, thorium-232, thorium-230, and thorium-228.

Figures 4.3.8 and 4.3.9 illustrate the gross alpha activity detected in unfiltered samples collected during low base and high base conditions, respectively. During low base sampling, 19 wells and piezometers contained gross alpha greater than the MCL; in the high base samples, 21 wells and piezometers and 1 corehole exceeded 15 pCi/L. The high base sampling locations containing gross alpha in excess of 15 pCi/L included five wells and piezometers that were not sampled during low base (i.e., piezometers 546, 550, 589, 563, and 611 and well 817). The data indicate that gross alpha activities are typically higher during low base conditions than during high base conditions.

The maximum tritium activity found in each well and piezometer during the Phase I investigation is The maximum gross beta activity detected in each well, piezometer, and corehole sampled as part of the Phase I RI is depicted on Fig. 4.3.10. Figures 4.3.11 and 4.3.12 illustrate the distribution of gross beta in groundwater during low base and high base sampling events, respectively. Gross beta activities were higher in approximately 60% of the unfiltered samples obtained from the wells and piezometers sampled during the low base event, compared with the high base event (see Table 4.3.7).

Radium-228 and strontium-90 were the major beta-emitting radionuclides identified in WAG 1 groundwater, and elevated gross beta activity in the majority of groundwater samples could be at least partially attributed to the presence of these constituents. Commonly observed discrepancies between the sum of reported activities for specific beta-emitting

radionuclides and gross beta content are probably the result of incomplete analyses for the full range of beta-emitting isotopes within the samples and the uncertainties related to low levels of activity.

Tables 4.3.6 and 4.3.7 do not list gross alpha and gross beta results for samples sent to the on-site CSL. Several samples collected as part of a supplemental investigation of a strontium-90 plume in the northwest portion of WAG 1 were analyzed at the CSL and were not sent to the contract laboratory for isotopic analysis. Analytical data for these samples are discussed in Sect. B6, Appendix B. Of particular significance are high gross beta (1,300,000 pCi/L) and gross alpha (1600 pCi/L) activities in a sample from piezometer 584, located on Central Avenue southeast of NTF. These high activities are possibly related to leaking pipelines in that area. Other piezometers that yielded samples with high gross beta activities include 550 (1200 pCi/L), 812 (8200 pCi/L), 539 (10,000 pCi/L), and 535 (320 pCi/L). These activities are believed to be reflective of a strontium-90 plume extending from corehole CH008 westward to First Creek and possibly beyond (see Sects. 3.3, 5.3, and Appendix B, Sect. B6 for additional information).

Gross alpha and beta in RCRA perimeter wells. Gross alpha activity was detected above the SDWA MCL in six samples from three wells (812, 825, and 829). Samples from three perimeter wells (wells 806, 812, and 825) contained gross beta activity greater than 50 pCi/L. The strontium activity in these wells is probably a principal component of the gross beta content; other components likely include radionuclides that were not analyzed for.

Radium. Total radium (i.e., radium-226 and radium-228) was found to exceed the SDWA MCL of 5 pCi/L in unfiltered samples collected from 15 wells and piezometers sampled during low base conditions (Table 4.3.8). Radium-228 had a detected range of 1.36 to 1980 pCi/L. In all but two locations (i.e., wells 1102 and 1103), radium-226 was not detected. Neither radium-226 nor radium-228 was detected in reference groundwater samples.

Figures 4.3.13 and 4.3.14 show the distribution of total radium in unfiltered samples collected during low base and high base conditions, respectively. Radium was not analyzed during the high base storm period except for a sample from piezometer 549. Radium-228 is a beta-emitter and therefore a contributor to the gross beta content described earlier.

Radium was most frequently detected in samples from the isotope and 3500 impoundment areas during both low and high base sampling events. A sample taken in September 1990 from piezometer 539, located just northwest of the WAG 1 boundary, had the highest concentration of radium detected of all samples collected during both high and low events (1980 pCi/L). However, ORNL results for RCRA perimeter well 812, located approximately 120 ft to the east of piezometer 539, showed a total radium activity of 2.16 pCi/L in December 1988. Total radium activities for samples collected from piezometers 588, 590, 593, 596, 603, 607, 608, and 613 and coreholes CH001 and CH11A between July and October 1991 exceeded 5 pCi/L.

Radium in RCRA perimeter wells. Samples collected and analyzed by ORNL were analyzed for total radium (the sum of radium-224 and radium-226); all results were below 5 pCi/L. Analyses were not conducted for radium-228.

Uranium and thorium series. Most of the naturally occurring radionuclides of the uranium and thorium decay series detected in many wells and piezometers are alpha-emitters; if present, they would contribute to the gross alpha activity detected in the samples. No correlation between the occurrence of naturally occurring alpha-emitters and gross alpha content was observed in wells and piezometers containing gross alpha greater than 15 to 20 pCi/L, indicating that other alpha-emitting (and most likely man-made) radionuclides are responsible for most of the gross alpha detected.

Thorium and uranium series radionuclides were generally detected at levels less than or approximately equal to the reference values. The highest activities were in samples from CH008 and piezometers 539 and 533. The uranium-234 activities in CH008 ranged from 631 to 4563 pCi/L in unfiltered samples from seven intervals. Samples from piezometers 539 and 533 had uranium-234 activities of 203 pCi/L (filtered, low base) and 84.5 pCi/L (unfiltered, high base).

Uranium and thorium decay series in RCRA perimeter wells. ORNL results for well 812 for October 1990 indicate an elevated level of uranium-234 (199.8 pCi/L). Uranium-235 and uranium-238 were detected in the same sample at 3.24 and 6.75 pCi/L, respectively. This was the only sample that included results of analyses for uranium and thorium isotopes. Piezometer 539, sampled approximately a week earlier than and located approximately 120 ft west of well 812, had a uranium-234 activity of 203 pCi/L.

Cesium. Analyses for cesium-137 were performed on most of the groundwater samples collected. Cesium-137 was not detected in filtered samples, but was detected in unfiltered samples ranging from 23.4 to 64.5 pCi/L in piezometers 571 and 589 during low base flow and from 32.9 to 67 pCi/L in piezometers 589, 571, and 541 during high base flow. Well 875 contained groundwater with 10.3 pCi/L cesium-137 during low base flow (see results in Appendix B). These activities do not exceed the annual dose equivalent (i.e., 109 pCi/L) equal to the SDWA MCL limit of 4 mrem/year dose for man-made beta. The reference level for cesium-137 was 11.8 pCi/L.

Cesium in RCRA perimeter wells. The maximum cesium-137 activity detected by ORNL in unfiltered samples collected between 1988 and 1990 was 32.4 pCi/L. Wells 812, 825, 810, and 811 had activities between 13.5 and 32.4 pCi/L; samples from the remaining wells contained less than 10 pCi/L. These activities do not exceed the dose-related MCL, although cesium-137 in samples from wells 810, 811, 812, and 825 exceeded the reference level of 11.8 pCi/L. Cesium-137 was not detected in filtered samples.

Well 810, which contained 21.6 pCi/L of cesium-137, is approximately 100 ft west of First Creek, which parallels the western boundary of the WAG. It is not known whether this occurrence is related to contaminant migration originating within WAG 1 or from an off-WAG source (e.g., WAG 3).

Transuranic radionuclides. The transuranic isotopes detected in WAG 1 groundwater include americium-241, curium-242/243/244, and plutonium-238/239/240. Analyses for transuranics were performed on only a limited number of samples, either as part of the scheduled analyses (see Sect. 2 for a discussion of rationale for sample analyses) or when the total activity in a sample, generally gross alpha, could not be accounted for by the results of an initial analysis for alpha-emitters. Table 4.3.9 presents the activities of all transuranic isotopes detected in the wells, piezometers, and coreholes.

The unfiltered sample collected from piezometer 596 during low base conditions while investigating additional SWMUs in 1991 contained the highest concentration of americium-241 (20.4 pCi/L). The maximum activity of americium-241 found elsewhere was 4.6 pCi/L. Curium-244 ranged from of 12.2 to 108 pCi/L in three different piezometers and CH008 (see Table 4.3.9). Plutonium-238/239/240 was found in only two piezometers, 571 and 590, at relatively low levels (between 0.3 and 0.64 pCi/L).

Other. Other man-made radionuclides detected in WAG 1 groundwater include technetium-99, calcium-45, promethium-147, cobalt-60, nickel-63, and iron-55. Technetium-99 was found in the filtered sample from piezometer 590 at an activity of 8214 pCi/L. Unfiltered samples obtained from two intervals in CH008 contained technetium-99 at 50.2 and 72.4 pCi/L. The unfiltered sample obtained from piezometer 593 contained technetium-99 at 22.6 pCi/L; the filtered sample contained 38.7 pCi/L. Technetium-99 was detected in an unfiltered sample from piezometer 598 at 8 pCi/L. Piezometers 596, 588, 563, 613, 549, 571, 885, 608, 597, 566, 603, 541, 564, and 607 and CH07A had detectable technetium less than 8 pCi/L.

Promethium-147 was detected in a well, two piezometers, and four coreholes. CH008 contained the greatest activity of promethium-147, which ranged from 2090 to 47,380 pCi/L in all seven intervals sampled; the maximum activity was detected in the sample collected from the 37-ft depth interval. The maximum concentrations outside of CH008 were 443 and 111 pCi/L in well 875 and CH11A, respectively. A range of 18.1 to 31 pCi/L was found in the other three locations. Promethium-147 was also detected in unfiltered samples from CH11A, CH07A, and CH001 and in samples from well 875 and piezometer 549. The presence of promethium-147 in groundwater samples is questionable due to limitations involved in the analytical method. A detailed description of limitations associated with the analysis of promethium-147 is presented in Sect. C6.5.4, Appendix C. As discussed in that section, promethium-147 and technetium-99 are difficult to distinguish in the laboratory. It is likely that some, if not all, of the activities reported as promethium-147 are actually attributable to technetium-99 or that the presence of radioactive strontium may be masking the analysis for promethium-147.

The unfiltered low base sample from piezometer 598 contained nickel-63 at 242 pCi/L, and the filtered sample contained 346 pCi/L. Iron-55 was encountered in well 875 at 330 pCi/L and in piezometer 549 at 68 pCi/L.

Calcium-45 was detected at high concentrations in unfiltered and filtered samples (i.e., 1860 and 465 pCi/L, respectively) in well 875, just south of impoundment 3524; piezometers

598 and 553 and well 1104 had calcium-45 concentrations between 27.4 and 68.2 pCi/L. All four locations were sampled during low base flow.

Cobalt-60 was found in groundwater from wells 877 and 885 during low base flow within a concentration range of 9 to 18.5 pCi/L.

Radionuclides found but not discussed here include bismuth-211/212, thallium-208, and cerium-141/144. Concentrations of these radionuclides were very close to their associated error and are thus considered suspect.

4.3.3 Chemical Contamination

Chemical contamination in groundwater was evaluated for the Phase I investigation through analyses for a full spectrum of organic and inorganic chemical constituents, including VOCs, BNAEs, and metals (Table 4.3.10). The samples were also analyzed for organochlorine pesticides/PCBs, organophosphorus pesticides, dioxins/furans, and chlorinated herbicides; however, none of these compounds were detected.

Among the VOCs, TCE, chloroform, 1,2-dichloroethene, vinyl chloride, and toluene were the most frequently detected compounds; TCE and other, less frequently detected VOCs were detected in concentrations above the applicable SDWA MCL. Phthalates and PAHs were the principal BNAE constituents detected; with few exceptions, these constituents were detected in low, estimated concentrations (i.e., qualified with a "J") between 1 and 5 μg/L. For the metals, silver, cadmium, chromium, and lead were detected at concentrations exceeding their respective MCLs.

The sampling results were compared with both reference data and the MCLs promulgated under the SDWA (revised April 15, 1991). The objective of this comparison was to identify occurrences of groundwater contamination that may be the result of releases from sources within WAG 1 and to provide an initial focus for data discussion.

4.3.3.1 Nature and extent of VOC contamination

Twenty-two VOCs were detected in 50 of the 72 locations sampled for VOCs during the four Phase I sampling events (Table 4.3.11). The majority were chlorinated alkanes and alkenes; a small number of aromatics and ketones were also detected. Maximum summed VOC concentration, per well, per sampling event did not exceed 530 μg/L (see Table 4.3.12). SDWA MCLs were exceeded for benzene, 1,2-dichloroethene, methylene chloride, tetrachloroethene, trichloroethene, and vinyl chloride. Carbon disulfide was the only VOC detected (2 J μg/L) in reference groundwater.

The distribution of VOCs detected in groundwater during the low base, high base, and high base storm sampling events is presented in Figs. 4.3.15 through 4.3.17. Detected concentrations of VOCs are listed in Table 4.3.13. Summed VOC concentrations in Table 4.3.12 were obtained from the samples that contained the highest summed concentrations of VOCs. Summed concentrations are presented as a means of highlighting the areas of

maximum VOC contamination. Results for other samples for the same event are presented in Appendix B.

The highest concentrations of VOCs were detected during low base sampling; the summed concentrations were less than 100 μg/L at 47 of the 50 wells for which low base VOC data are available. The summed concentrations exceeded 200 μg/L at the three remaining wells: 598, east of Building 3026 near the center of WAG 1; 553, west of Building 2519, also near the center of WAG 1; and 543, west of sewage lagoon 2544 in the western portion. The highest summed VOC concentration occurred in well 553 (530 μg/L).

Benzene, toluene, ethylbenzene, xylene (BTEX). In well 553, the predominant VOCs detected during low base sampling were the aromatic compounds xylene (190 μg/L), benzene (160 μg/L), ethylbenzene (120 μg/L), and toluene (41 μg/L) (see Table 4.3.13). The chlorinated alkanes 1,1,1-trichloroethane (30 μg/L) and its degradation product, 1,1-dichloroethane (42 μg/L), were also detected. This well is adjacent to an underground diesel storage tank that has been removed since sampling, and these aromatic VOCs may be evidence of a release from this tank. This was the only well sampled during high, low, and storm sampling that contained benzene.

BTEX compounds were not detected elsewhere during low base sampling, except for two occurrences of toluene [6 μg/L in well 587 (beyond the northern boundary of WAG 1) and 1 μg/L in well 533 west of First Creek outside of well 553] and one occurrence of xylene (23 μg/L) in well 618 (in the southeastern portion of WAG 1). BTEX compounds were not detected during high base or storm sampling events.

1,2-Dichloroethene. During low base flow conditions, 1,2-dichloroethene was detected at 13 locations, making it the most frequently detected VOC. Degradation of tetrachloroethene and trichloroethene, which were also detected during low base conditions, may be responsible for the presence of 1,2-dichloroethene in WAG 1 groundwater. The highest detected concentration (170 μg/L) was in a sample from well 543, approximately 100 ft west of the 2544 sewage impoundment (see Fig. 4.3.15). This concentration exceeds the MCLs of 70 μg/L for (cis)1,2-dichloroethene and 100 μg/L for (trans)1,2-dichloroethene. The cis and trans isomers were not differentiated. Additional locations where 1,2-dichloroethene was detected include wells south of the 3524 and 3513 surface impoundments and southwest of Building 3517 (Figs. 4.3.15 through 4.3.17).

Vinyl chloride. Vinyl chloride, the end product of the tetrachloroethane and trichloroethene degradation series, was detected at nine locations (see Table 4.3.13 and Fig. 4.3.15); the MCL of 2 μg/L was exceeded at all locations. Most occurrences of vinyl chloride were in samples from wells adjacent to the 3524 and 3513 surface impoundments. The highest concentration (43 μg/L) was in a sample from well 543, west of the sewage impoundments; this occurrence could be related to degradation of 1,2-dichloroethene. The nearest surface water sampling location, SW-7, is upgradient and approximately 100 ft to the northwest of well 543. Chloroform was the only VOC detected at SW-7 (2J μg/L). The nearest downgradient surface water sampling location at which VOCs were analyzed (SW-6) is over 1200 ft to the south, but none of the VOCs detected in well 543 were detected at this location. Therefore, if the suite of VOCs encountered at well 543 is entering First Creek in

the vicinity of the well, it is either volatilized and/or diluted below detection limits downstream before exiting WAG 1 boundaries.

Vinyl chloride was also detected at 3J μg/L in well 602, on the northeastern boundary of WAG 1, along with trichloroethene, 1,2-dichloroethene, 1,1-dichloroethane, and acetone.

Trichloroethene. TCE was found in samples from 15 locations; the highest concentration was in a sample collected from well 598 during the low base sampling event. TCE was also found in corehole CH07A, where concentrations ranged from 87 μg/L in a sample from 72 ft BGS (midpoint of sampling interval) to 180 μg/L in a sample from 90 ft BGS. TCE concentrations at all other locations were less than 30 μg/L. The majority of the samples containing TCE were collected from wells in the northwest portion of the WAG and in areas outside of the WAG boundary (wells 548, 660, 539, 538, and 546). Other areas where TCE was found include the Oak Ridge Research Reactor (wells 596, 588, and 589), the impoundments (wells 876 and 1103), the northeast corner of the WAG (well 602), and 564, southeast of STF.

Trichloroethene (210 μg/L) was the major contaminant in well 598 (see Table 4.3.13). Under anaerobic conditions, trichloroethene can degrade or undergo transformation to 1,2-dichloroethene, 1,1-dichloroethene, and eventually vinyl chloride, which have been detected in wells downgradient (to the south and to the southwest) of well 598 and at other locations at WAG 1. This suggests the possibility of a plume with an origin in the vicinity of well 598.

TCE concentrations in well 598 were highest during the low base sampling event (210 μg/L). Concentrations were 140 μg/L during high base storm conditions and 160 μg/L during high base conditions. A sample from well 896 exhibited a similar trend. These results may reflect dilution of TCE as water levels increase due to increased precipitation recharge. In other areas, TCE concentrations do not show consistent patterns of seasonal fluctuation. For example, samples from well 886 (south of STF) did not contain detectable concentrations during low base sampling, but a sample collected during high base conditions contained 15 μg/L of TCE. The pattern of TCE fluctuations observed in the well may reflect rewetting of TCE-contaminated soils as groundwater levels rise, or downward flushing of TCE from soils or other sources.

Tetrachloroethene. Tetrachloroethene was detected at four wells (886 and 873, southwest of Building 3517; 564, southwest of Building 2516; and well 554, east of sewage lagoon 2543), during low base flow conditions (see Fig. 4.3.15). The highest detected concentration in the low base samples was 22 μg/L in well 886; the maximum high base concentration, 39 μg/L, was also detected in well 886. The MCL for tetrachloroethene (5 μg/L) was exceeded at all locations where it was detected except well 564. Degradation of tetrachloroethene may be responsible for the trichloroethene, 1,2-dichloroethene, and vinyl chloride that were also detected in WAG 1 groundwater.

1,1,1-Trichloroethene. 1,1,1-Trichloroethene was detected in three wells in the west-southwestern portion of the WAG. The highest concentration (30 μg/L) was detected during the low base sampling event in well 553 located west of Building 2519. It was also detected

at well 553 during high base (9 μg/L) and high base storm sampling (16 μg/L). 1,1,1-Trichloroethene was also detected in well 564 (3J μg/L) and 566 (2J μg/L), which are northeast of well 553. Wells 546 and 566 showed low levels of 1,1,1-trichloroethene during the high base and high base storm events; it was not detected in these wells during low base events.

1,1-Dichloroethene. During low base conditions 1,1-dichloroethene was detected in four wells in the southwestern portion of WAG 1. The highest concentration was in well 553 (42 μg/L); lower levels were detected in wells 554 (1 μg/L), 564 (3 μg/L), and 602 (1 μg/L). 1,1-Dichloroethene was detected at well 555 during the high base and high base storm events at concentration of less than 20 μg/L, and trace levels were detected in well 564 (5 μg/L) during high base conditions.

Acetone. Acetone was detected at seven well locations at an average concentration of 17 μg/L. This compound was detected during low base, high base, and other miscellaneous sampling events.

Other. Other VOCs detected include 2-hexanone, chloroform, methylene chloride, carbon disulfide, 1,1-dichloroethene, carbon tetrachloride, 1,2-dichloroethane, 4-methyl-2-pentanone, bromodichloromethane, pyridine, and chloromethane. Of these, only chloroform, 1,1-dichoroethene, and bromodichloromethane were present in any individual well during more than one sampling event.

Chloroform. Chloroform was detected during low base sampling in six wells north of Central Avenue at concentrations ranging from 1 to 24 μg/L (see Table 4.3.13 and Fig. 4.3.15). Wells 589, 597, and 598 are within the WAG 1 boundary, and the others (539, 587, and 814) are just outside the northern boundary. Chloroform can be derived from bacterial action in chlorinated water (e.g., public water supplies); it may also form from the action of residual chlorine (used in water treatment) on native organic matter found in soil. Given these processes and the observed distribution and magnitude (low) of chloroform contamination in WAG 1 groundwater, the primary source of this contaminant may be leakage from the potable water lines that are present throughout the site.

1,1-Dichloroethene. This compound, an anaerobic breakdown product of trichloroethene, was detected in two wells in the western portion of the WAG. Well 543 near First Creek, had low levels (1 μg/kg) during the low base event. 1,1-Dichloroethene was detected twice in well 553, during low base and high base storm event, at levels less than 5 μg/kg.

Bromodichloromethane. Bromodichloromethane was detected (5 μg/L) at well 597, west of building 3029, during the low base and high base sampling events. The only other compound detected at this well location was chloroform, found during high base, low base, and the high base storm events.

Corehole sampling. VOCs detected in coreholes CH001, CH003, CH006, CH008, CH009, CH07A, and CH11A sampled from July to October 1991 are shown in Fig. 4.3.18. Samples from two intervals (51 to 63 ft and 164 to 176 ft) in CH001 and the 93- to 106-ft

depth interval in CH003 contained detectable concentrations of toluene (up to 8 μg/L); 1,2-dichloroethene was detected in samples from CH003 at 8 μg/L.

Samples from the 129- to 141-ft depth interval of CH009, located south and west of the 3513 and 3524 surface impoundments, contained vinyl chloride (18 μg/L), 1,2-dichloroethene (17 μg/L), and toluene (5 μg/L). Both vinyl chloride and 1,2-dichloroethene were detected in samples from other wells in the vicinity. A sample from the 315- to 330-ft depth interval contained acetone (180 μg/L), 1,2-dichloroethene (21 μg/L), and toluene (120 μg/L). This is the deepest groundwater sample in which VOC contamination was detected. Groundwater at this depth is characterized as a sodium-chloride type, which indicates that there is little direct communication with the shallow groundwater system (see Sect. 3.3 for discussion of groundwater geochemistry). Thus, the existence of VOC contamination at this depth is uncertain. There is a possibility that the contaminants were introduced to this depth as the packer test assembly was lowered through shallower contaminated zones; further sampling would clarify whether contamination is present at this depth.

Groundwater samples from the 86- to 93-ft and the 118.5- to 125.8-ft depth intervals of CH07A contained tetrachloroethene (2 and 6 μg/L, respectively), trichloroethene (180 and 87 μg/L, respectively), toluene (undetected and 2 μg/L, respectively), and chloroform (undetected and 2J μg/L, respectively). Samples from other wells in the northwestern portion of WAG 1 also contained trichloroethene (e.g., well 546 with 27 μg/L and well 539 with 6 μg/L), which supports the presence of this VOC in CH07A.

VOCs detected in groundwater samples from CH006, CH008, and CH11A were toluene (up to 62 μg/L), chloroform (up to 17 μg/L), and methylene chloride (up to 4J μg/L).

RCRA perimeter wells. VOCs were detected in samples from 11 of the 25 ORNL RCRA wells that were sampled and analyzed for VOCs (Table 4.3.14). The most commonly occurring VOCs were methylene chloride, acetone, and hexane, all of which were detected in the laboratory blanks. Because these data were not validated for blank contamination, it is difficult to determine whether these compounds are indicative of site-related contamination. Detected VOCs that are indicative of potential groundwater contamination are benzene, chloroform, trichloroethene, and vinyl chloride; reported concentrations ranged from less than 1 to 28 μg/L. All of these compounds were detected only during low base conditions, between June and October 1989 and the same period in 1990.

Benzene was detected in estimated concentrations near the detection limit in three wells around the southern and eastern perimeter of WAG 1: 808 (0.3 μg/L), 811 (0.5 μg/L), and 824 (2 μg/L). Trichloroethene was detected above the MCL of 5 μg/L in wells 812 (3 to 6 μg/L) and 813 (4 to 11 μg/L). Both of these wells are located in the northwestern portion of WAG 1. Chloroform was also detected in wells 812 (4 to 15 μg/L) and 813 (3 to 7 μg/L) and in a third well on the northern perimeter, 814 (14 μg/L). Vinyl chloride was detected in well 825, in the southern portion of WAG 1, at concentrations ranging from 18 to 28 μg/L, well above the 2 μg/L MCL.

4.3.3.2 Nature and extent of BNAE contamination

Ten BNAE compounds were detected in groundwater samples from 39 locations: acetophenone, N-nitroso-diphenylamine, bis(2-ethylhexyl)phthalate, butyl benzyl phthalate, carbolic acid, di-n-butyl phthalate, naphthalene, 2-methyl naphthalene, phenanthrene, and di-octylester phthalic acid (di-n-octyl phthalate). The majority of these constituents were detected in estimated concentrations (i.e., reported with a "J" qualifier) of 1 to 5 μg/L. Concentrations of this magnitude are only slightly above the method detection limits for these compounds and well below the RCRA action limits established for BNAE compounds.

Phthalate compounds. Phthalate compounds were the most frequently detected BNAEs and were detected from the largest number (29) of sampling locations. The maximum concentration detected for a phthalate compound was 75 μg/L, although in most cases, concentrations did not exceed 10J μg/L. Phthalate compounds are used as plasticizers and are common components of sampling equipment used in the field (gloves, tubing) and analytical equipment used in the laboratory. As a result, phthalate compounds are commonly detected in field and laboratory quality control samples. In addition, they are typically not mobile in soil due to a high affinity for absorption and susceptibility to biodegradation (Howard 1990).

Polynuclear aromatic hydrocarbons. Three PAH compounds were detected only in samples from well 553: naphthalene (10J to 14J μg/L), 2-methyl naphthalene (3J to 4J μg/L), and phenanthrene (2J μg/L). Well 553 is near the site of an underground diesel storage tank scheduled for removal because of indications that it has been leaking. Other petroleum components (benzene, toluene, ethylbenzene, and xylenes) were also detected in this well. Potential sources of PAHs, in addition to motor fuels, include asphalt pavement, waste oil and lubricants, and combustion residues from the coal-fired boilers.

N-nitrosodiphenylamine. This compound was detected at 14 locations in estimated concentrations not exceeding 6J μg/L. It was also detected at similar concentrations in four of the surface water reference samples (SW-4, SW-6, SW-7, and SW-8). Upon further investigation, it was determined that the occurrence of this compound in the reference samples was the result of laboratory contamination (BNI 1990). Although n-nitrosodiphenylamine was not found in laboratory blanks associated with groundwater samples, its occurrence in the groundwater is considered suspect.

Other compounds. Acetophenone (6J μg/L) and phenol (2J μg/L) were detected in the September–October 1990 samples from wells 818 and 541, respectively. These compounds were not detected in samples from these wells collected during other events. Acetophenone is commonly used in the perfumery industry; its presence in the groundwater at WAG 1 is suspect. Phenol may be related to ORNL activities, but its occurrence in only one well indicates that its impact on groundwater quality at WAG 1 is negligible.

In summary, most BNAE compounds present in WAG 1 groundwater samples were detected in estimated concentrations less than 10 μg/L. Many of these results should be discounted as representing laboratory artifacts or other forms of spurious contamination. The

presence of the polyaromatic compounds detected in well 553 is supported by the presence of VOCs also associated with a known source (a leaking diesel fuel tank).

RCRA perimeter wells. BNAEs were detected in the majority of these wells, primarily during low base groundwater conditions in the late summer/early fall of 1989 and 1990. Concentrations of individual compounds typically were in the range of 10 to 50 μg/L; maximum individual concentrations were 140 to 220 μg/L (Table 4.3.15). The reference levels for semivolatile organics were all at or below detection limits (typically 10 to 50 μg/L), with the exception of bis(2-ethylhexyl)phthalate and di-n-butyl phthalate, both of which were detected at estimated concentrations of 10 and 2 μg/L, respectively, in one of the reference wells.

The most frequently detected compounds (three to five occurrences) were a PAH (indeno [1,2,3-cd] pyrene), reported at 10J μg/L in five wells; two phthalate compounds [bis(2-ethyl hexyl) phthalate and diethylphthalate], ranging from 8J to 41 μg/L and 1J to 6JB μg/L, respectively; chlorinated benzenes, reported at 10 μg/L in five wells; hexachlorethane, also reported at 10 μg/L in three wells; and several phenolic compounds. The largest number of compounds were reported in samples from wells 816 and 818, both of which are in the northwest portion of WAG 1. Only bis(2-ethyl hexyl)phthalate was detected on more than one occasion in a given well (well 820). All other semivolatile compounds were only detected in one of the 1989 or 1990 sampling events for each well.

Twenty-five BNAE tentatively identified compounds (TICs) were reported. These compounds were detected only in wells in the eastern (820, 821, 824, 826) and southwestern (806, 808, 809) portions of WAG 1. Unknown BNAE compounds were detected on more than one occasion only in wells 824 and 826.

Total BNAE concentrations in each well ranged from 1 to 261 μg/L. The highest concentrations were detected in wells 816 (216 μg/L), 810 (244 μg/L), and 809 (261 μg/L) during low base conditions in September 1990. These wells are on the northeastern (816) and western (809 and 810) portions of WAG 1. Slightly lower concentrations of total BNAEs (100 to 200 μg/L) were detected in wells along the southeastern perimeter (806, 807, and 808) and in another well in the northeastern portion of the WAG (818).

Of note is the near absence of semivolatile organic compounds in perimeter wells near the 3513 and 3524 surface impoundments and SWSA 1. Of the five wells in this area (825 through 829), well 826 was the only one in which semivolatile organics (in this case unknowns) were detected.

4.3.3.3 Nature and extent of organochlorine pesticide/PCB contamination

Organochlorine pesticide and PCBs analyses were performed for the RCRA perimeter well samples. Two pesticides, beta-BHC and delta-BHC, were detected in well 814, located beyond the northern boundary of WAG 1. The maximum detected concentration of beta-BHC was 0.319 μg/L, while the maximum for delta-BHC was 0.667 μg/L. There were no detectable concentrations of PCBs in WAG 1 groundwater.

4.3.3.4 Nature and extent of other organic compound contamination

Organophosphorous pesticides, dioxins and furans, and chlorinated herbicides were included in the scope of Appendix IX analyses (see Sect. 2). There were no detectable concentrations of these compounds in groundwater samples from WAG 1.

4.3.3.5 Nature and extent of metal contamination

The results for metals are summarized in Table 4.3.16. In addition to being potential contaminants, many metals are natural constituents in groundwater and can be present in a wide range of concentrations. The variability in concentrations can depend on several factors, including seasonal variations in groundwater level, rate of groundwater flow, contaminant migration, contaminant release mechanisms, well construction, sample collection and preservation techniques, amount of suspended and dissolved solids present in the sample, and analytical techniques.

Filtered sample results were typically lower than unfiltered results, often by an order of magnitude or more (see Table 4.3.16). Metals that were found to exceed MCLs in the unfiltered samples were lead, chromium, cadmium, and mercury (Table 4.3.16). Filtered sample results did not exceed MCLs, except for two occurrences of cadmium (piezometers 572 and 879) and one occurrence of lead (piezometer 553).

Total recoverable metals (TRMs) were also analyzed in selected groundwater samples. However, a review of the analytical results for TRMs has revealed discrepancies in the data that possibly limit their usefulness. A detailed discussion of the TRM results is presented in Appendix C (Sect. C.5.4.3).

RCRA perimeter wells. Sample results reported by ORNL for the perimeter wells identified a number of metals present in concentrations that exceed reference levels (Table 4.3.17). In unfiltered samples, the 50 μg/L MCL for arsenic was exceeded in wells 807 and 809. Arsenic also exceeded the MCL in a filtered sample in well 807. The 5 μg/L MCL for cadmium was exceeded in unfiltered samples from all 15 wells in which it was detected; all of these samples were collected in June 1989. The MCL for cadmium was exceeded in filtered samples from seven wells; one of these samples was collected in September 1990, and the others were collected in June 1989.

The barium, chromium, and lead MCLs were exceeded in unfiltered samples from three wells; none of the filtered samples exceeded the MCL for any of these parameters. In each case, the MCLs were exceeded only once at a given location, most often in the June 1989 samples.

Nature and extent of individual metals. *Aluminum.* Aluminum was detected over a wide range of concentrations at WAG 1 and was found in nearly every well sampled. The highest concentration in an unfiltered sample was 176,000 μg/L (piezometer 553). The highest concentration in a filtered sample was 1830 μg/L (piezometer 538). Aluminum is an abundant metal in the clay minerals present in the overburden soils at WAG 1. The reference sample results ranged from 71.9 to 4400 μg/L.

Aluminum in RCRA perimeter wells. The unfiltered samples include only one well (816) in which aluminum was detected above the maximum reference value of 4400 μg/L. Aluminum is commonly associated with clay minerals that are often the components of suspended solids in a groundwater sample; the elevated concentrations detected in well 816 may be due to turbidity in the sample. Elsewhere, concentrations of aluminum ranged from 60 to 2700 μg/L.

This interpretation is supported by results from the filtered samples, in which the concentrations of aluminum were significantly lower. The high concentrations of aluminum observed in the unfiltered samples from well 816 (and other wells) were probably the result of suspended solids within the sample.

Antimony. Antimony was detected in 17 wells and coreholes; overall, however, it was infrequently detected above the SQL. Results ranged from nondetected to 49.1J μg/L (piezometer 553). The highest concentration in an unfiltered sample was 33.5 μg/L (piezometer 536). Antimony was not detected in any reference samples.

Arsenic. Arsenic did not exceed the SDWA MCL of 50 μg/L. The maximum concentration was 24.1J μg/L (CH006). The reference value of 2.6 μg/L in unfiltered samples was exceeded in samples from 29 additional wells. The highest concentration in unfiltered WAG 1 samples was 7.4 μg/L (piezometer 622).

Arsenic in RCRA perimeter wells. The MCL for arsenic was exceeded in wells 807 and 809 (74 and 65 μg/L, respectively) in samples collected in September 1990, and the concentration in well 811 was at the MCL of 50 μg/L. Arsenic was not detected in any of the other wells.

Barium. Barium was detected in samples from 79 locations, but no results exceeded the MCL of 2000 μg/L. The maximum detected concentration was 1450 μg/L in well 603, which is in the northwest portion of WAG 1. The maximum concentration in filtered samples was 375 μg/L (well 1102), which exceeds the maximum reference concentration of 148 μg/L.

Barium in RCRA perimeter wells. The MCL was exceeded in a sample collected in October 1989 from well 820 (2300 μg/L); however, the concentration of barium in the filtered sample from this well was 22 μg/L. Concentrations elsewhere ranged from 3 to 460 μg/L. Barium was detected above the range of reference levels (61 to 148 μg/L) in 13 wells; the majority of such occurrences were associated with samples collected in October 1989 and September 1990 (i.e., low base conditions).

Beryllium. Beryllium was detected in unfiltered samples from 44 locations at concentrations ranging from 1 to 21.3 μg/L, but it was not detected in reference samples. The highest concentration was detected at well 553. The maximum concentration detected in a filtered sample was 1.1J μg/L (CH009). The 1 μg/L MCL for beryllium was exceeded in the unfiltered samples from 68 locations; however, only one filtered sample exceeded the MCL.

Beryllium in RCRA perimeter wells. Beryllium was detected in 19 of the WAG 1 perimeter wells. The highest concentrations were in wells 829 (31 μg/L); 824, 812, 813, 827, and 829 (all 30 μg/L); and 806, 807, 808, 809, 810 and 811 at 29 μg/L. All of the elevated beryllium concentrations were associated with the June 1989 sampling event. Unfiltered samples from 27 wells contained beryllium exceeding the MCL. Concentrations in the filtered samples were comparable to those reported for the unfiltered samples, with maximum concentrations in the 30 μg/L range.

Wells 810 through 813 are along the western perimeter of the WAG, and 810 is approximately 100 ft west of First Creek. Well 824 is south of Building 4508 along the southeastern perimeter of the WAG, 827 and 829 are near SWSA 1, 807 and 808 are in the vicinity of the coal pile, and 806 is in the WOC floodplain in the Haw Ridge gap.

Because all beryllium detections were limited to one sampling event and were not observed in subsequent sampling events, a more detailed evaluation of the June 1989 analytical data (e.g., field and laboratory quality control data) would be necessary to support definitive conclusions regarding the presence of beryllium in the perimeter wells.

Boron. Boron was not analyzed during the Phase I investigation.

Boron in RCRA perimeter wells. No reference level or MCL is available for boron, which ranged in concentration from 80 to 1100 μg/L in these wells. The maximum concentrations were detected in well 808 (960 to 1100 μg/L) during low base conditions.

Concentrations of boron were similar in both filtered and unfiltered samples, indicating that the presence of boron is probably not attributable to suspended solids derived from the overburden soils or bedrock.

Cadmium. Cadmium was detected in concentrations exceeding the MCL of 5 μg/L at eight locations. The highest concentration detected was 26.9 μg/L in piezometer 553 (Fig. 4.3.19). The filtered results for only well 879 (9 μg/L) and piezometer 572 (6.3 μg/L) exceed the MCL. Cadmium was detected in the reference wells with a maximum concentration of 5.2 μg/L.

High base flow sample results for cadmium indicate no detectable concentrations, except for 3.7 μg/L detected in a filtered sample from piezometer 536. Cadmium was not detected in samples collected during the high base flow storm event. Cadmium was detected in CH003 at 6.3 μg/L.

Cadmium in RCRA perimeter wells. The 5 μg/L MCL was exceeded in the June 1989 samples from 15 wells. The highest concentrations were found in wells 820 (45 μg/L), 814 (11 μg/L), and 829 (11 μg/L). Concentrations of 10 μg/L were reported in wells 806, 809, 813, 824, 827, and 828. Concentrations between 8.6 and 9.9 μg/L were reported for wells 807, 812, 808, 811, 828, and 810. In the filtered samples, cadmium exceeded the MCL in six wells; concentrations ranged from 4.2 to 11 μg/L. With the exception of the unfiltered sample collected in October 1989 from well 828 (8.8 μg/L) and the September 1990 filtered

sample from well 809 (7.1 μg/L), all of the cadmium detects were associated with the June 1989 sampling round.

Calcium. Calcium was detected at a wide range of concentrations. The highest concentration detected in reference location samples (138,000 μg/L) is approximately one-tenth the highest concentration detected in an on-site sample (1,330,000 μg/L, piezometer 608). Calcium is a principal component of the bedrock at WAG 1 and it is unlikely that it is a contaminant.

Chromium. Chromium was detected at most locations; concentrations at 10 locations exceeded the MCL of 50 μg/L during low base flow sampling (Fig. 4.3.20). Chromium occurrence is widespread; 5 of the 10 locations with concentrations exceeding the MCL are outside of the west and northwest boundaries. The highest concentration (268J μg/L) was in an unfiltered sample from well 553, which also had the highest concentration of cadmium (26.9 μg/L) during the same sampling event. Filtered chromium results did not exceed 27.5 μg/L (well 541), which is below the MCL. The reference level for chromium ranged from 16 to 25.7 μg/L.

Chromium in RCRA perimeter wells. Chromium was widely detected in WAG 1 perimeter wells, and reference levels were exceeded in 11 wells. The MCL for chromium (50 μg/L) was exceeded in the June 1989 unfiltered sample from well 812 (110 μg/L), but the October 1990 sample showed a decline in concentration to 59 μg/L. Concentrations above the reference levels were detected in either June or October 1989, with the exception of the October 1990 results from well 812. Chromium concentrations in the remaining perimeter wells ranged from 5 to 25 μg/L.

Chromium was also widely detected in filtered samples; maximum concentrations were detected in the June 1989 samples from wells 809 and 828 (27 μg/L), 806 (25 μg/L), and 829 (24 μg/L). The concentration of chromium in the June 1989 filtered sample from well 812 was 20 μg/L.

Cobalt. Cobalt was not detected in any reference groundwater samples but was detected at 44 locations in WAG 1. The maximum concentration (267 μg/L) occurred in a sample from piezometer 553, located next to the diesel fuel tank at the steam plant. Samples from this piezometer also contained elevated concentrations of benzene, toluene, xylene, and ethylbenzene.

Two locations north of the WAG boundary (piezometers 538 and 549) also contained elevated concentrations of cobalt (138 μg/L and 62.2 μg/L, respectively). Five locations within the northern portion of the WAG 1 boundary yielded samples containing elevated concentrations. A sample from well 550, located north of Building 2013, contained 56.7 μg/L; a sample from well 602, north of Building 3010, contained 56 μg/L. Well 611, east of Building 3085, showed 124 μg/L; well 603, east of Building 3042, contained 88.9 μg/L; and well 608, in the isotopes area, contained 73.2 μg/L. Piezometer 592, southeast of STF, yielded a sample containing 58.5 μg/L. All other samples contained less than 50 μg/L. Concentrations were consistently higher in unfiltered samples than in filtered samples.

Filtered samples from seven locations had detected concentrations; the highest reported concentration of 14 μg/L was in a sample from well 880.

Cobalt in RCRA perimeter wells. Cobalt was detected in 13 wells at concentrations ranging between 3 and 14 μg/L in unfiltered samples; the maximum concentration was in the October 1989 sample from well 823. In the filtered samples, cobalt concentrations were lower (3 to 8 μg/L).

Copper. Copper was detected in reference samples at a maximum concentration of 9.3 μg/L in an unfiltered sample. It was detected in most unfiltered samples collected during the Phase I investigation at concentrations ranging from 2.3 to 267 μg/L but did not exceed the secondary MCL (1300 μg/L). Copper was detected in filtered samples from 30 locations, with a maximum concentration of 42.8 μg/L (piezometer 597).

Copper in RCRA perimeter wells. Copper was detected above the reference level in 15 wells at concentrations ranging from 8.6 to 600 μg/L. No samples exceeded to MCL. Samples collected in February 1989 from wells 816 and 819 contained the highest concentrations. Most of the samples containing copper above the reference levels were collected in October 1989.

Filtered results for copper were significantly lower than unfiltered results. Copper was detected in filtered samples collected in October 1989 in only six wells. The maximum concentration was 21 μg/L in the October 1989 sample from well 818; all other results ranged between 8.8 and 9.2 μg/L.

Iron. Iron was detected in all but a few samples; concentrations ranged between 13.4 and 437,000J μg/L. The highest concentration in a filtered sample was 17,400 μg/L (piezometer 610). Iron was detected in reference samples at a maximum concentration of 5100 μg/L. Iron is an abundant metal in the clay mineral component of the WAG 1 overburden; its presence in the WAG 1 groundwater samples is likely a reflection of this relationship.

Iron in RCRA perimeter wells. Iron was also detected in nearly every sample from perimeter wells at concentrations of 11 to 7000 μg/L. The reference level was exceeded in wells 806, 807, 809, 816, 819, and 826; the maximum concentration was detected in well 809. Well 809 also contained the maximum concentration of iron in the filtered samples (15,000 μg/L). Filtered sample concentrations above 1000 μg/L were detected in the same wells that exceeded reference levels.

Lead. Lead was detected at 39 locations above the 50 μg/L MCL during low base flow sampling (Fig. 4.3.21). The highest concentration (628 μg/L) was in a sample from well 587. However, this sample was subject to laboratory quality control problems and has been qualified as a result with limited use. A concentration of 52 μg/L was detected during high base flow from the same well. The reference level for lead (25.7 μg/L) is based on a single detection. Filtered results for lead did not exceed 25.9 μg/L, which is below the MCL.

Two samples collected during the high base flow storm event displayed higher concentrations than during high base flow. Although the MCL was not exceeded during either event, the concentration in one location (piezometer 553) increased from 11.7 to 40.2 μg/L. The MCL was, however, exceeded in piezometer 553 during low base flow sampling. In the second location (piezometer 602), an increase was also detected from high base (28.5 μg/L) to high base storm (94 μg/L). The MCL was also exceeded in well 602 during low base but not during high base nonstorm.

Lead in RCRA perimeter wells. Lead was detected in only one sample, collected in October 1989 from well 816. The concentration in this sample (40 μg/L) is below the MCL. Lead was not detected in any filtered samples collected from the ORNL perimeter wells during the period December 1988–September 1990.

Magnesium. Magnesium was detected in unfiltered samples at concentrations ranging between 6010 and 96,500 μg/L. The reference level (28,400 μg/L) was exceeded at 34 locations. The highest concentration in a filtered sample was 45,000 μg/L (well 879). Magnesium is a common metal in carbonate/dolomite terrains; therefore, it is unlikely that magnesium is a contaminant at WAG 1.

Magnesium in RCRA perimeter wells. Magnesium was detected in all of the RCRA perimeter wells, at concentrations ranging from 430 to 32,000 μg/L.

Manganese. Manganese was detected in samples from 80 locations; concentrations ranged between 1.2 and 14,400 μg/L. The maximum concentration in a filtered sample was 11,000 μg/L (well 877). Samples from 32 locations exceeded the maximum reference concentration of 1600 μg/L. Manganese is a common metal in clays and typically forms dendritic patterns of precipitation (pyrolusite) along planes of separation in the soil. It is unlikely that manganese is a contaminant at WAG 1.

Manganese in RCRA perimeter wells. Manganese was widely detected in these wells; the reference level was exceeded in eight wells. The highest concentrations were in wells 806 and 807 (>3500 μg/L). Elevated concentrations (>2000 μg/L) were also reported for wells 809, 826, and 829. Concentrations exceeding the reference levels were detected during both high and low base conditions. Manganese was also elevated in the filtered samples from wells 807 and 806. Concentrations of 4000 to 7000 μg/L were reported for the June and October 1989 samples, and the September 1990 sample for well 807 was 4000 μg/L.

Mercury. Most samples analyzed for mercury did not contain detectable levels of mercury. Mercury was detected in samples from 19 locations; the only location where it exceeded the MCL of 2 μg/L was piezometer 543, which yielded a sample containing 2.4J μg/L. Otherwise, the maximum detected concentration from on-site sampling did not exceed 1.2 μg/L, which is below the 2 μg/L MCL. Mercury was not detected in the two reference samples analyzed for mercury; the detection limit was 0.2 μg/L. Filtered results did not exceed 1.85 μg/L.

Mercury in RCRA perimeter wells. Mercury was detected in the January and February 1989 samples from wells 827 and 810, at concentrations of 1 and 0.1 μg/L, respectively. These concentrations are below the MCL of 2 μg/L.

Mercury was not detected in filtered samples from well 827, but was detected in well 810 at 0.1 μg/L. Wells 814, 828, 826, 813, 808, and 829 also contained mercury (0.1 to 0.2 μg/L). All of these concentration were detected in the June 1989 samples.

Nickel. Nickel was detected in concentrations ranging up to 304 μg/L; the highest was from piezometer 553. The maximum reference level was 38.6 μg/L. The MCL for nickel (100 μg/L) was exceeded in 11 wells. Detected concentrations of nickel in filtered samples ranged from 4.8 to 51.3 μg/L. The filtered sample from well 553 contained no detectable nickel at an SQL of 20 μg/L, in contrast to the 304 μg/L detected in the unfiltered sample.

Nickel in RCRA perimeter wells. The reference levels for nickel were slightly exceeded in wells 823 (52 μg/L) and 824 (42 μg/L). The concentration in filtered samples was similar in well 823 (36 μg/L) but was lower in 824 (8.9 μg/L).

Osmium. Osmium was found in seven samples but was not detected above the CRQL of 500 μg/L.

Osmium in RCRA perimeter wells. Osmium was not analyzed.

Potassium. Potassium was detected frequently in groundwater at WAG 1; the highest reference value of 3820 μg/L was exceeded in samples from 38 locations. Concentrations ranged to 25,000 μg/L; the highest was detected at piezometer 603. Potassium is a common metal in the clays found in overburden soils at WAG 1, and it is unlikely that it is a site contaminant.

Potassium in RCRA perimeter wells. Potassium was also frequently detected in the perimeter wells, at concentrations comparable to those detected in samples collected during Phase I.

Selenium. Selenium was detected in samples from nine locations; no concentration exceeded the SDWA MCL of 50 μg/L. No reference concentrations exceeded the SQL for selenium.

Selenium in RCRA perimeter wells. Selenium was not analyzed.

Silver. There is no SDWA MCL for silver; it was not detected in any samples above the RCRA MCL of 50 μg/L. Silver was detected in samples from 40 locations; the highest concentration (30.7 μg/L) was in a sample from piezometer 603. Silver was not detected in any of the reference wells, where the detection limits ranged from 5 to 10 μg/L. The reference level for filtered samples was also below the detection limits of 3 to 10 μg/L. Filtered results for silver did not exceed 20.3 μg/L in any sample.

Silver in RCRA perimeter wells. Silver was detected above reference levels in wells 806 (14 to 17 μg/L), 807 (14 to 16 μg/L), 809 (11 μg/L), 826 (11 μg/L), and 829 (12 μg/L). These concentrations are below the MCL for silver. All of the elevated concentrations were detected in samples collected during low base conditions in June or October 1989. Silver was detected in filtered samples in similar concentrations (11 to 16 μg/L) in the same wells that contained elevated silver in unfiltered samples (wells 806, 807, 809, and 829). A slight decline in concentrations over time was noted for many of the wells; for example, the concentration in the filtered sample collected in October 1989 in well 806 declined from 17 to 13 μg/L. As with the unfiltered samples, concentrations in the filtered samples were well below the MCL.

Sodium. Detected concentrations of sodium in unfiltered samples ranged up to 732,000 μg/L; unfiltered reference levels ranged up to 49,000 μg/L. Although the reference maximum was exceeded, this occurred in corehole samples taken from deep zones characteristic of sodium carbonate groundwater (see Sect. 3). The highest concentration of sodium from locations other than the coreholes was 91,400 μg/L (piezometer 548), which is similar in magnitude to the maximum reference concentration. Sodium is not considered to be a site contaminant.

Sodium in RCRA perimeter wells. The distribution of sodium in the perimeter wells was similar to that reported for samples collected during the Phase I investigation.

Strontium. Elemental (nonradioactive) strontium was not analyzed during Phase I.

Strontium in RCRA perimeter wells. Elemental strontium was detected in most samples; concentrations in unfiltered samples ranged from 56 to 2700 μg/L. The highest concentrations were detected in well 821 (2000 to 2700 μg/L). No reference levels are available for comparison. Concentrations in filtered samples were similar in magnitude and occurrence; the highest (2000 to 2600 μg/L) were detected in well 821. Because strontium was widely detected in the filtered samples, it is not associated with sediment particles larger than the filter pore diameter and is probably a dissolved constituent. Elemental strontium is a natural constituent of limestone, where it substitutes for calcium. Its presence in groundwater at WAG 1 is likely attributable to this factor.

Thallium. The highest concentration of thallium found was 5.6 μg/L in an unfiltered sample from piezometer 603. Thallium was not detected in reference samples at concentrations above the reference sample SQL of 2 μg/L. The highest concentration in a filtered sample was 3.3J (piezometer 588).

Thallium in RCRA perimeter wells. Thallium was detected in a large number of wells in the January and February 1989 samples; concentrations ranged from 20 to 86 μg/L. The maximum concentration was detected in the October 1989 sample from well 816, which is near the northeast perimeter of the WAG. Thallium was not detected in the filtered samples.

Tin. Tin was analyzed on a selective basis and was not detected.

Tin in RCRA perimeter wells. Tin was not analyzed.

Vanadium. Vanadium was detected frequently at concentrations ranging as high as 379J μg/L (piezometer 553) in unfiltered samples. The maximum reference level, based on analysis of two samples, was 5.8 μg/L; this concentration was exceeded in most samples in which vanadium concentration could be quantified. The highest concentration in a filtered sample (18.3 μg/L) was in a sample from piezometer 588.

Vanadium in RCRA perimeter wells. Vanadium was detected in unfiltered samples from nearly all of the perimeter wells in concentrations between 3 and 16 μg/L; most of these detections were in samples collected in December 1988, January 1989, and February 1989. Vanadium was detected in only four of the filtered samples (all collected in October 1989) at concentrations ranging from 3.2 to 3.9 μg/L. The maximum occurred in the sample from well 825.

Zinc. Zinc was detected in samples from 71 locations; concentrations in unfiltered samples ranged up to 57,200 μg/L. In filtered samples, concentrations ranged up to 745 μg/L (piezometer 548). Reference concentrations (based on four reference samples) ranged from 15.2 to 32.1 μg/L. It is unlikely that zinc is a contaminant on site because it is a common metal in carbonate/dolomite terrains.

Zinc in RCRA perimeter wells. Although zinc was detected in most unfiltered samples, only one, collected in well 813 (370 μg/L), exceeded reference levels. Zinc was also widely detected in filtered samples; concentrations were similar to those reported for unfiltered samples, with the maximum (52 μg/L) detected in the October 1990 sample from well 828.

Sources of variability and uncertainty in concentrations of metals. A source of uncertainty in the evaluation of metal contaminants is the varying quality of the monitoring wells. Piezometers at WAG 1 (i.e., the 500 and 600 series wells) were not constructed to RCRA groundwater quality monitoring well standards. Many of these piezometers are very low yielding and may not have been sufficiently developed. They produced water samples relatively high in suspended solids, which may result in elevated concentrations of metals when samples are preserved in the field with acid and further digested in the laboratory.

A comparison of site maximum concentrations of metals in unfiltered samples with site maximum concentrations in filtered samples suggests that suspended particles are contributing to elevated concentrations in unfiltered samples. In some instances, one to two orders of magnitude difference are observed.

4.3.4 General Observations

Radiological contamination. Figure 4.3.22 is a synthesis of the radiological contaminants observed in groundwater samples collected from WAG 1. The figure was generated by plotting locations where samples containing elevated concentrations of radionuclides were identified. For purposes of developing the figure, elevated concentrations were defined as those exceeding existing MCLs; if no MCLs existed, reference levels were used. For naturally occurring radionuclides such as uranium, thorium, and radium, some

judgment was also applied on the basis of the concentrations and on the presence or absence of man-made radionuclides in the vicinity. The presence of promethium-147 is shown on the figure, although the identification of this radionuclide is questionable because of analytical uncertainties (see Appendix C). Locations where promethium-147 is reported may actually contain other (unknown) beta-emitting radionuclides, such as technetium-99.

Hilltop area. Groundwater in this area is contaminated with americium-241, technetium-99, radium-228, and tritium. Hydraulic connection between groundwater in the 3019 area and the Building 3042 sump has been documented (see Sect. 3.3); contaminants from Building 3019 activities migrated quickly in the groundwater and were found in the Building 3042 sump.

Area northwest of WAG 1 boundary. Groundwater in this area is contaminated with radium-228, uranium-234, and thorium-228/230/232. This area of contamination overlaps the strontium plume that extends from corehole CH008 to First Creek (see below). In addition, piezometer 549 contains low levels of plutonium; the source is unknown, but may be in the northern 2000 area.

Isotope area. Groundwater in this area is contaminated with technetium-99, curium-244, nickel-63, tritium, radium-228, and strontium-90. Likely sources are past leaks from LLLW pipelines in this area. It is also possible that some of the contamination may have migrated from the area of Buildings 3019 and 3042.

NTF to First Creek. This area contains a strontium-90 plume that is strata-bound within Unit E and extends at least from corehole CH008 to First Creek, and possibly to piezometer 535, west of First Creek (see Sect. 3.3 for additional discussion of this plume). Other contaminants in the plume are americium-241, technetium-99, promethium-147, curium-244, radium-228, uranium-234/238, and thorium-228/230/232. Most of these isotopes were found in groundwater samples from CH008. The likely sources of contamination are NTF and past leaks in pipelines extending between the Building 3019 area and NTF.

Piezometer 584. This piezometer is situated near several waste transfer pipelines that are parallel to Central Avenue. Contamination at this location was identified on the basis of CSL results only; no samples were sent for laboratory analysis (see Appendix B for CSL results). High gross beta values in samples from this piezometer are probably related to historical leaks in the inactive pipelines.

Central 2000 area. Groundwater in the area near the 2000 block, west of STF, is contaminated with tritium, strontium-90, radium-228, and technetium-99. Possible sources may include past leaks in pipelines or contaminated pipeline trenches, which may be acting as a pathway for radionuclides from other areas inside WAG 1.

Impoundment area. Impoundment area groundwater contains elevated concentrations of tritium, strontium-90, uranium-234, and radium-228. As most of the tritium and all the promethium is found in samples from wells directly downgradient of impoundment 3524, that impoundment is the most likely source in the area. Strontium-90, uranium-234, and radium-

228 are more widespread and probably were derived from more than one impoundment. See Appendix C, Sect. C7 for discussion on uncertainties related to promethium-147.

Thorium tank farm. Piezometer 601 contains elevated concentrations of strontium-90 and radium-228.

SWSA 1. Groundwater in the area directly north and downgradient of SWSA 1 contains elevated concentrations of strontium-90 and radium-228 and very low levels of plutonium-238/239/240 (piezometer 571). Although it is not shown on Fig. 4.3.25, groundwater, surface water, and soil in this area also contained elevated concentrations of cesium-137. SWSA 1 and/or an inactive LLLW pipeline is the most likely source of this contamination, as indicated by the proximity of SWSA 1 to the contaminated areas.

Piezometer 593. This piezometer, located south of Central Avenue and southeast of the STF, contains elevated technetium-99 and slightly elevated thorium-228/230/232 and detected americium-241. The source is unknown, but there are many inactive and active pipelines are in this area, especially along Central Avenue.

Corehole CH07A. Corehole CH07A contains low levels of promethium-147. This contamination may have originated from the Building 3019 area (which is on a groundwater divide between First Creek and Fifth Creek and is now strata-bound in Unit D). Unit D contains numerous solution cavities that may provide groundwater transport pathways in the direction of geologic strike (see Sect. 3.2). A second possibility is that the contamination originated in the northwest part of the 2000 area. The presence of promethium-147 is suspect, as discussed in Sect. C7 of Appendix C, in addition to the fact that it is a relatively short-lived ($T_{1/2}$ = 2.64 years) fission product and relatively immobile.

Piezometer 533. This piezometer, located west of the WAG boundary, contains elevated concentrations of uranium-234. The contamination may have been derived from WAG 1 or from WAG 3, located west of WAG 1.

Well 806. Concentrations of strontium-90 were found to exceed MCLs at this location. The well is located in the major groundwater and surface water exit pathway from WAG 1; thus, the source is likely within WAG 1 or the numerous outfalls that may or may not be within the WAG 1 boundary but are related to ORNL plant activities.

VOC contamination. The pattern of VOC distribution found in the high base flow samples is similar to that observed during low base flow. No additional compounds were detected in the high base samples compared with those present in low base samples. 1,2-Dichloroethene was the most frequently detected VOC in samples from both events.

A trend toward lower concentrations with time was observed for selected constituents. This is most obvious in piezometers 543 and 553, where summed VOC concentrations decreased from 215 to 68 μg/L and 530 to 164 μg/L, respectively. Little change in total VOC content was detected in piezometer 598 (211 to 188 μg/L), which had the third highest summed VOC concentration detected during low base sampling.

No VOCs were detected in high base samples in several wells and piezometers that contained VOCs during the low base event; these are 533, 536, 545, 566, 587, 611, 618, 622, 814, and 879. The majority of these wells and piezometers are located along the perimeter of or beyond the WAG 1 boundary.

Only in wells 881 and 875, adjacent to the 3513 and 3524 surface impoundments, were VOCs (vinyl chloride and 1,2-dichloroethene) detected in high base samples and not in low base samples. In contrast, vinyl chloride was detected in low base samples from wells 885, 1103, and 1100 (which are also associated with the surface impoundments) but was not detected in these wells during high base flow.

High base flow storm event results are presented on Fig. 4.3.16. There appears to be no difference between VOC occurrence or concentration during storm and nonstorm high base flow conditions. Summed VOC concentrations and constituents detected are similar to those detected in the high base (nonstorm) samples (see Table 4.3.12). Two compounds (methylene chloride and chloroform) were detected in the high base storm samples in piezometers 566 and 596 but were not present in earlier sampling events. Because these compounds were reported as estimated concentrations below the CRQL and they are common laboratory contaminants, their presence in the samples may not be indicative of groundwater contamination.

Benzene, toluene, and xylene are also present at several locations at WAG 1. Their highest concentrations are associated with piezometer 553, located next to the former site of a diesel fuel tank.

VOCs in RCRA perimeter wells. VOCs were detected primarily in the northwestern and southern portions of the WAG 1 perimeter. Among the chlorinated VOCs, TCE and chloroform were detected in the northwestern portion of WAG 1; vinyl chloride was observed only in the southeastern portion. All three constituents were detected in multiple sampling rounds, and concentrations generally increased between the 1989 and 1990 sampling events. The absence of these chlorinated VOCs during high base conditions is probably the result of dilution associated with the greater flux of groundwater beneath the site.

Benzene was detected in scattered locations and in only one sampling round in each well (June 1989 or September 1990). This pattern of scattered, infrequent occurrence suggests that benzene is an occasional and transient contaminant, most likely related to infiltration of contaminated runoff from roadways, parking lots, and other areas associated with vehicular traffic.

The VOC data for these wells indicate minor contamination in localized areas in the northwest and southeastern portions of the WAG. The contamination detected in the southeastern portion is probably discharging into WOC; because the contaminant (vinyl chloride) is highly volatile, the resulting impact on surface water quality is likely to be negligible. This interpretation is supported by surface water sampling results from stations SW-5 and SW-6, at which vinyl chloride was not detected.

TCE and degradation products. The most widespread organic compounds found in groundwater at WAG 1 are TCE and its degradation products 1,2-DCE and vinyl chloride. Figure 4.3.23 shows the distribution of these contaminants; in general, they are widely scattered throughout the WAG. The highest concentration of TCE was found in a sample from piezometer 598; this TCE probably originated at a source within the isotope area. It is noteworthy that in areas downgradient (south and west) of piezometer 598, TCE concentrations decrease relative to the concentrations of 1,2-DCE and vinyl chloride. The occurrence of degradation products of TCE downgradient of a potential source area suggests the possibility that the contaminants in areas south and west of STF were derived from the same source as the TCE in piezometer 598. It is also possible that other sources exist near STF that have released TCE or its degradation products into the groundwater.

TCE and related VOCs were also found in the impoundment area. One well in this area contained TCE, and several wells contained 1,2-DCE and vinyl chloride. This contamination was probably released from the impoundments.

There is also a widely scattered area contaminated with TCE and its degradation products located in an east-west-trending band in the northern part of the WAG. This area extends from the vicinity of Building 3042 westward almost to First Creek. Several locations in this area contained elevated concentrations of TCE; the highest concentration was found in corehole CH007. The source of this contamination is not known, but there may have been one or more sources associated with Buildings 3019 and 3042. It is possible that contamination is strata-bound within Unit D and that it is migrating along bedrock strike.

BNAEs in RCRA perimeter wells. BNAE compounds were widely detected in the WAG 1 perimeter wells; the highest concentrations were in the wells along the western/southwestern and northwestern perimeter. In most wells, semivolatiles were detected during low base conditions and were not detected on more than one occasion. The episodic presence and generally low concentrations reported for these compounds suggest that semivolatile organic contaminants have a minor impact on groundwater quality in the vicinity of the perimeter wells and that off-WAG migration of these contaminants should not be a significant concern.

Metals. Silver, cadmium, chromium, and lead were detected in unfiltered samples at concentrations exceeding MCLs in groundwater samples taken in and adjacent to WAG 1. Cadmium, chromium, and lead, in excess of their respective MCLs, tend to occur in the same wells. Cadmium exceeded the MCL at the largest number of locations, followed by chromium, silver, and lead.

Metal concentrations were generally higher in samples collected during the low base event than those collected during high base. No appreciable differences between the concentrations detected in the high base and high base storm event samples were noted. In filtered samples, two results for cadmium exceeded the MCL; no other filtered results exceeded MCLs.

Concentrations of certain metals (e.g., aluminum, iron, potassium) vary widely in samples obtained from wells and piezometers within WAG 1 but only within a very narrow

range in the reference location samples. This difference may be due to contrasts in the geochemistry of the stratigraphic units between the reference well and WAG 1 well locations. Presently, the reference groundwater network for WAG 1 consists of two locations at which two rounds of sampling have been conducted and three locations at which one round of sampling has been completed. An expanded reference well network would be needed to support a more definitive interpretation of metals contamination in WAG 1 groundwater.

Metals in RCRA perimeter wells. With the exception of arsenic, concentrations of metals have generally declined over the period of record. Off-WAG migration is a potential concern in the southwestern corner of the WAG, where arsenic contamination above the MCL was detected in wells 807 and 809; the most likely mechanism for this migration in this area is via discharge into WOC.

4.4 SOILS

Samples for the characterization of WAG 1 soils were obtained from 286 soil borings completed during the Phase I investigation; the locations of these borings are shown on Plate I. All but 10 of these borings are located within the WAG boundary. Three of the 10 outside borings were drilled to investigate the waste pile area near SWSA 1; 4 were drilled adjacent to the northwest corner of the WAG; and 3 were completed in WOC floodplain soils south of Building 4500S. Fifty of the 276 on-site borings are in the floodplain of WOC and First Creek. Analytical results associated with these soil borings are discussed in Sects. 4.4.2 through 4.4.4. Results of the previous ORNL investigations are summarized in Sect. 4.4.1.

4.4.1 Previous Studies

Previous soil investigations conducted in the WAG 1 area were in response to waste line leaks, spills, or potential contamination associated with stack emissions or leakage from surface impoundments. A contamination assessment was also completed as part of a site suitability study for a new laboratory facility. The majority of these earlier investigations focused on radiological contamination in the soil.

The analytical component of these earlier investigations was generally limited to approximate estimations of alpha and beta activities. In some cases, a much broader spectrum of data was generated; for example, soil samples collected from NTF, the thorium tank farms, and tank WC-1 in the isotope area were analyzed by Huang et al. (1984a) for major radionuclide constituents of concern, including strontium-90, cesium-137, cobalt-60, and additional alpha- and beta-emitting radionuclides. Chemical analyses were also conducted, but on a more limited scale. Soils also have been sampled as part of the annual ORR environmental surveillance program, although no WAG 1-specific activities have occurred.

The first WAG 1-specific soil investigation for contaminants was conducted in 1976 near SWSA 2 to determine radioactivity levels near the foundation of the proposed Energy Systems Research Laboratory (Oakes and Shank 1977). Twenty-five borings were drilled,

ranging in depth from 4 to 9 ft, and the soil samples were analyzed for alpha-, beta-, and gamma-emitters. Water taken from the borings was analyzed to determine tritium, gross alpha, and gross beta levels. Concentrations in many of the samples ranged from below detection limits to slightly above background values for eastern and central Tennessee (Oakes and Shank 1977).

Soil contamination studies conducted in response to leaks, spills, and stack emissions include Oakes (1983a,b and 1985), Grimsby (1986), and Williams et al. (1987). In the Oakes (1983a) study, mercury concentrations in soil at Buildings 3503, 3592, and 4501 were examined through EPA's RCRA extraction procedure (EP) toxicity test method; results ranged from 0.8 to 320 ppm. Oakes also performed sampling to a depth of 40 ft in other WAG 1 areas and completed analyses for radioactive constituents such as gross alpha, gross beta, strontium-90, cesium-137, and cobalt-60. Activities for these constituents varied widely between locations, ranging from below detection limits at several locations to 467,619 pCi/g gross beta in the 3028/3047 area.

Grimsby (1986) presented analytical results from soil samples collected near the base of the 3019 stack in August 1985. Relatively higher levels of radioactivity were encountered in these samples, as evidenced by the maximum reported results for gross alpha (4595 pCi/g), gross beta (11,082 pCi/g), plutonium-238 (32.4 pCi/g), plutonium-239 (541 pCi/g), americium-241 (97.3 pCi/g), curium-244 (865 pCi/g), cesium-137 (17,029 pCi/g), and cobalt-60 (37.8 pCi/g). Williams, Clark, and Crutcher (1987) collected 69 surface and subsurface soil samples around the 3503 storage pad and analyzed them for an extensive list of radionuclides; EP toxicity tests were also performed on 7 of the samples. All concentrations were below detection limits.

Soils adjacent to inactive underground storage tanks at NTF and the thorium tank farms and above-ground tanks WC-1, WC-15, and WC-17 were investigated by Huang et al. (1984a). Samples from most tank locations were analyzed for cobalt-60, cesium-137, and strontium-90; soils from the vicinity of tanks WC-15 and WC-17 were also analyzed for other beta- and gamma-emitters. The results indicate that some of the tanks (or associated piping) have released radioactive contents into the surrounding soils. The highest activities for the primary radioactive constituents were detected in samples from NTF, near tanks W-1 through W-4, W-13, and W-14 (18,921 pCi/g cobalt-60; 459,510 pCi/g cesium-137; and 67,575 pCi/g strontium-90). Autrey (1989) collected soil samples around tanks WC-1 and WC-15; cobalt-60, cesium-137, potassium-40, gross alpha, and gross beta were the constituents of concern.

Huang et al. (1984b) investigated the soils around the 3513 impoundment. Both shallow and deep core samples were collected around the perimeter and analyzed for a variety of radionuclides. Cesium-137 and strontium-90 were consistently detected; maximum activities were 108,120 and 14,596 pCi/g, respectively. It was reported that the high activities may have been influenced by a ruptured LLLW pipeline that had been repaired just prior to the sampling event. Thirty impoundment soil samples were also collected during a study conducted by Uziel et al. (1989). Results were reported for gross alpha, gross beta, cobalt-60, potassium-40, and isotopes of uranium, plutonium, cesium, and europlum. The highest gross alpha and gross beta measurements were 240 and 2500 pCi/g, respectively. All of the

samples contained cesium-137; the maximum activity detected was 13,000 pCi/g. Cobalt-60 was found at up to 20 pCi/g in the samples. Additional results are presented in Table 4.4.1.

4.4.2 Radiation Survey and Relationship to Soil Contamination

A surface radiation survey of WAG 1 was performed in two phases during 1990 and 1991. Using USRADS, two radiation detection systems concurrently measured radiation fields. The first method was an NaI(Tl) detection system, that measured near-surface gamma radiation fields. The second method was an ionization chamber system positioned at a set distance above the ground (approximately 3 ft); this system measured direct exposure rates of the gamma radiation field. The USRADS methodology and a description of the walkover survey are explained in greater detail in Sect. 2.3 of this document. After validation, the digital data were gridded into intervals of 2 ft × 2 ft to allow efficient processing. Contour maps were generated from this gridded data set for each type of radiation measurement. Figure 4.4.1 presents the contoured results of the radiation field measurements, expressed as cpm; Fig. 4.4.2 presents the contoured results of the exposure rate measurements, expressed as μR/h.

As shown in Fig. 4.4.1, the radiation field ranged from less than 10,000 cpm to greater than 250,000 cpm. The highest levels were recorded at STF and the vicinity of Building 3515 and tank W-11. The WOC floodplain also exhibited elevated levels, ranging from 25,000 to greater than 250,000 cpm. Radiation levels at NTF ranged from approximately 50,000 to greater than 100,000 cpm. Other zones of elevated radiation levels were in the vicinity of the 3513/3524 surface impoundments, an area south of Building 3597, an area southeast of Building 3587, and several sections of the isotope area near Buildings 3029 and 3038. These zones exhibited readings from approximately 75,000 to greater than 100,000 cpm.

In most cases, the areas shown in Fig. 4.4.1 that exhibited elevated radiation fields also exhibited elevated exposure rate measurements. As shown in Fig. 4.4.2, exposure rates ranged from below 50 μR/h to greater than 2500 μR/h. Figure 4.4.2 shows 13 areas that exhibited exposure rates greater than or equal to 100 μR/h:

- reactor heat exchanger area near Building 3087,
- an area between Buildings 3019 and 3074,
- Building 3012/3112 area,
- isotope area,
- NTF,
- STF,
- radioactive waste evaporator and evaporator sump area (Building 2531 and vicinity),
- Fission Product Development Laboratory (Building 3517) and Metal Recovery Facility (Building 3505),
- area south of the high radiation examination lab (Building 3525),
- tank farm southeast of Building 3587,
- area south of Building 3597,
- 3513/3524 surface impoundments, and
- WOC floodplain area.

The highest exposure rate levels were measured in STF and the vicinity of tank W-11 (see Fig. 3.5.5); exposure rates ranged from approximately 50 to greater than 2500 μR/h. The area southeast of Building 3587 exhibited rates between approximately 50 and greater than 500 μR/h; exposure rates in the area south of Building 3597 ranged from approximately 50 to greater than 1000 μR/h. The WOC floodplain exhibited rates ranging from approximately 50 to greater than 1000 μR/h.

An area south of Building 3525 exhibited exposure rates ranging from approximately 50 to 1000 μR/h; however, this area did not exhibit elevated radiation field measurements (see Fig. 4.2.2).

The USRADS data cannot be interpreted as a direct indication of the extent of radiologically contaminated soils at WAG 1. Both measurement systems are omnidirectional and do not differentiate beta/gamma radiation emitted by radionuclide contaminants in soils from radiation emitted by surrounding structures (e.g., radiologically contaminated piping, tanks, buildings) or cosmic rays. Radiation from such sources, many of which may be above-ground, is referred to in this report as "shine."

To determine whether the elevated exposure rates identified for the 13 areas described earlier are caused by radiation from contaminated soil or shine, it was first necessary to model the exposure rates emitted by an idealized layer of contaminated soil. Cesium-137 and its daughter barium-137m were used in this model because cesium-137 was known to be a major radionuclide present in contaminated soils. The concentrations of cesium-137 detected in soil samples collected during the Phase I investigation were then used in this model to estimate the potential exposure rates that could be attributed to contaminated soils in these 13 areas. These results were then compared with the exposure rates measured in the USRADS survey to estimate whether the rates were attributable to contaminated soils or shine from other sources.

The radiation emitted by radionuclide contaminants in an idealized layer of soil was modeled using a gamma-shielding code named MICROSHIELD, developed by Grove Engineering Co. This model assumes a homogeneous and uniform infinite slab source approximately 1 ft thick with no clean soil above the contaminated soil zone. A density of 1.5 g/cm^3 and a shielding property of concrete was assumed for the contaminated soil. The radionuclide contaminant in the soil creating the gamma radiation field above the surface of the soil was assumed to be cesium-137 and its daughter barium-137m. The source strength was assumed to be 1 pCi/g of soil. Properties of the soil medium were used for gamma buildup factor calculations. The exposure location (receiver) was taken to be approximately 3 ft above the surface of the contaminated soil. A sensitivity analysis for the source region thickness revealed that the difference in exposure rate was insignificant below a depth of 1 ft due to the self-shielding properties of the soil layer. Therefore, for comparison of the estimated values predicted by the model with the USRADS instrument readings, only the concentrations of the radionuclides in the first sampling interval were considered. The predicted exposure rate from this model for this layer of soil contamination resulting from 1 pCi/g of cesium-137/barium-137m was estimated to be 7.71×10^{-1} μR/h.

The ranges of exposure rates within the 13 areas were compared with the modeled predictions using the concentrations of cesium-137 detected in soil samples collected within these areas. The results of these comparisons are summarized in Table 4.4.2.

A comparison within one order of magnitude is considered to be an indication that the exposure rates measured in the USRADS survey were most likely attributable to contaminated soils. A more precise comparison was not considered to be supported by the assumptions used in the model. A difference of more than one order of magnitude is probably an indication of the presence of shine during the survey from sources other than contaminated soils (e.g., contaminated above- and below-ground tanks, tank risers, contaminated buildings, exposed piping, contaminated equipment, or cosmic radiation). It is also possible that the radiation detected in the USRADS measurements was caused by localized, highly contaminated soil that was not sampled.

Beyond those attributable to soil contamination, areas 2, 3, 8, 9, 10, and 11 appear to exhibit elevated exposure rates due to shine from the surrounding environment. Areas in which the USRADS measurements appear to be attributable to soil contamination are areas 4, 5, 12, and 13. No soil sampling data were available from areas 1 and 7 to make a comparison; area 7 is paved.

This analysis supports the use of USRADS measurements to delineate areas of contaminated soils, but only where the contribution of shine from other sources is understood. For example, using the exposure rate data shown in Fig. 4.4.2, an approximation of the distribution of cesium-137 in the surficial soils of WOC floodplain can be formed.

4.4.3 Nature and Extent of Radiological Contamination in Soil

This section presents findings regarding the nature and extent of radiological contamination in WAG 1 soils as determined from the Phase I soil investigation and previous studies. The discussion is organized by type of principal decay process. Results of analyses for gross alpha and radionuclides that decay principally through alpha particle emission are presented in Sect. 4.4.3.1; results for gross beta and radionuclides that decay principally through beta particle or gamma ray emission are presented in Sect. 4.4.3.2. The data are summarized in Table 4.4.3.

Separate delineation of the nature and extent of alpha- and beta-contaminated soils is useful for several reasons. First, radionuclides that decay through alpha emission have, predominantly, very long decay half-lives (e.g., plutonium isotopes). Documenting the nature and extent of soils contaminated with such isotopes is relevant to evaluation of remedial action alternatives. Second, potential exposure to certain airborne alpha-decay isotopes is a particular concern. When these isotopes are present in surficial soils, where they might be mobilized by wind, runoff, or direct contact by site workers, interim remedial actions or administrative controls that limit release or exposure potential are routinely considered.

An assessment was also made regarding whether isotopes are present in the soil matrix in secular equilibrium. Isotopes and their daughters have well-defined decay patterns and ratios. Many isotopes, such as uranium-234, are both naturally occurring and man-made. Thus parent/daughter ratios can be used to assess whether such isotopes are present in expected natural decay patterns, or whether they have been released from a man-made source enriched in these isotopes.

The soils discussion is further subdivided by geographic areas:

- NTF,
- STF,
- SWSA 1 and vicinity,
- impoundments,
- Building 3019 area,
- isotope area,
- Building 3503/3504 area,
- miscellaneous leaks (additional locations), and
- floodplain soils.

4.4.3.1 Alpha-emitting radionuclides

Alpha-emitting radionuclide contamination is defined in this section as any activity exceeding the maximum detected reference activity (see Sect. 4.2.4.2 for soil reference results). For gross alpha, the maximum detected reference activity was 56 pCi/g.

Naturally occurring alpha-emitting radionuclides detected at WAG 1 include those from the thorium series [thorium-232, thorium-228, radium-224, and bismuth-212 (which emits both alpha and beta particles)]; the uranium series (uranium-238, uranium-234, thorium-230, and radium-226); and the actinium series (uranium-235 and bismuth 211). Man-made alpha-emitters detected include americium-241, plutonium-238, and plutonium-239/240.

In some instances, isotopic analyses for alpha-emitting radionuclides did not account for the reported gross alpha activities. This is particularly the case with low levels of contamination, where the limitations of the measurement processes and the random nature of radioactive decay cause difficulty in comparing isotopic and gross measurements. The presence of additional isotopes of plutonium, americium, curium, or other alpha-emitting radionuclides might also account for discrepancies with gross alpha results.

The distribution of gross alpha activities across WAG 1 is shown in Fig. 4.4.3. Figures 4.4.4 through 4.4.6 present specific results for gross alpha and alpha-emitting radionuclides from selected borings in WAG 1. The depth at which the maximum concentration was detected in each borehole is also presented.

Gross-alpha-contaminated soil was encountered in the central portion of WAG 1; suspected sources of the contamination are releases associated with the 3019 area complex of buildings and facilities (1959 hot cell explosion, historical pipeline leaks, 3019 stack), NTF, and STF. Scattered occurrences were encountered during investigations of suspected

mercury contamination and other minor operations at WAG 1. Other than thorium and radium, alpha-emitting radionuclides detected in excess of reference levels include americium-241, plutonium-238/239/240, and uranium-234/235/238.

Building 3019 area. In 1959, a tank within a shielded hot cell in Building 3019 exploded, resulting in the release of plutonium-239 to the environment. The area near Building 3019 has also been impacted by a release of condensation fluid from the stack on the north side of the building and past releases associated with an LLLW pipeline leak (the pipeline served Buildings 3074 and 3020). Previous soil samples in this area were determined to have elevated levels of gross alpha, gross beta, plutonium-239, americium-241, curium-244, cesium-137, and cobalt-60. Soil samples collected during Phase I confirmed alpha concentrations in excess of reference values (see Fig. 4.4.3). Maximum gross alpha activity detected in this area (and in WAG 1) was 3105±696 pCi/g from boring 01.SB130 at a depth of 10 to 12 ft. Plutonium-238/239/240 and americium-241 were detected above reference levels. The maximum activity of americium-241 was 71.1±4.2 pCi/g in the 4- to 6-ft sample from boring 01.SB126. The maximum activity of plutonium-238 in the area was 721±73 pCi/g in the 4- to 6-ft sample from boring 01.SB132. The maximum activity (41±6.6 pCi/g) of plutonium-239/240 was found the 0- to 2-ft sample from boring 01.SB244. Areas with elevated plutonium activities include the 3019 area north of the building and areas adjacent to the northern and southwestern parts of the building. Gross alpha concentrations elevated above reference values tend to persist below the interval where the highest activity was detected, which indicates mobility of some alpha-emitting radionuclides within the soil profile.

North Tank Farm. Three locations at NTF contained intervals of soil in which gross alpha activity exceeded reference (see Fig. 4.4.4). The highest gross alpha activity at NTF was 62,500±12,500 pCi/g, measured in the 15- to 17-ft sample from boring 01.SB026. Typically, radium-224/226 and thorium-228/230/232 isotopes were at or near reference values. The highest thorium-228 activity (7.87±1.04 pCi/g) was detected at 01.SB026 but is below reference (19.9±2.7). The maximum activity of uranium-234 at WAG 1 (591±115 pCi/g) was detected in the 15- to 17-ft sample from 01.SB026. Although gross alpha did not exceed reference levels at locations 01.SB032 and 01.SB033, uranium-238/234 were detected at activities exceeding reference. The uranium-238/234 activity ratios in samples from NTF are less than 1, ranging from 0.01 to 0.16. Activity ratios of less than 1 for uranium-238/234 indicate enrichment of uranium-234 at these locations, suggesting releases of enriched uranium-234 from former plant operations. Americium-241 was detected at 5.7±1.15 pCi/g (01.SB025). Plutonium-235 was identified in samples from one location directly north of the tank farm (4.13±0.78 pCi/g in the 4- to 6-ft sample from boring 01.SB221). No other transuranic radionuclides were included in the isotopic analyses; therefore, much of the gross alpha content was not accounted for with the given analyses. Alpha activities exceeding background in the NTF area were not encountered until at least 15 ft below the surface, possibly correlating with the bottoms of the tanks or fluid levels within the tanks.

South Tank Farm. Soil samples from borings at STF and nearby tank locations (see Fig. 4.4.5) contained gross alpha, americium-241, plutonium-238, and plutonium-239/240 at activities exceeding background. The highest gross alpha activity in this area, 606±135

pCi/g, was detected in the 0- to 4-ft interval sampled from boring 01.SB020. Plutonium was detected in the same sample: plutonium-238 at 41.7±6.7 pCi/g and plutonium 239/240 at 29.4±4.7 pCi/g. Analyses for plutonium were not conducted on other STF samples. Americium-241 was detected at four locations, with a maximum activity (for STF and for WAG 1) of 171±14 pCi/g in the 2- to 4-ft duplicate sample from soil boring 01.SB213, which is a pipeline boring in the southeastern portion of STF. The regular sample from this interval contained 49±6.6 pCi/g of americium-241; this discrepancy between the regular and duplicate samples is outside of prescribed control limits (see Appendix C). This same duplicate sample also contained 206±30 pCi/g plutonium-239/240 and 3.02±1.46 pCi/g plutonium-238 (the regular sample contained 104±23 pCi/g plutonium-239/240 and 3.00±2.23 pCi/g plutonium-238). The maximum activities for uranium-238 and -234 were detected in 01.SB038: 54.08±7.63 pCi/g uranium-234 and 49.93±7.08 pCi/g uranium-238. In contrast to NTF, where activities of uranium-234 exceeded those of uranium-238, uranium-238 was more abundant in one of the STF samples (01.SB197) and approximately equal to uranium-234.

A contrast regarding the vertical distribution of alpha contamination at NTF and STF is apparent. Alpha contamination was not encountered within the first 15 ft at NTF, but it was detected in samples collected within the first 2 ft at STF. The shallow contamination at STF could have originated from past releases from the shallow pipelines that feed the tanks or from surface spills.

Surface impoundments. Soil borings in the vicinity of surface impoundments 3513 and 3524 encountered only limited alpha contamination (Fig. 4.4.5). Borings 01.SB189 and 01.SB102 encountered gross alpha activities of 216±55 pCi/g from the 2- to 4-ft interval and 296±79 pCi/g from 6 to 7.5 ft. No other borings in the vicinity encountered gross alpha activities exceeding background. The majority of the alpha activity found in 01.SB102 was uranium-238 and uranium-234 at concentrations of 141±18 and 19.2±2.7 pCi/g, respectively.

Buildings 3503 and 3504 and thorium tank farm. Borings 01.SB206 and 01.SB207 were sampled to investigate the storage pad at Buildings 3503 and 3504. Gross alpha activities exceeding background were encountered; however, not all of the isotopes were identified. Soil borings 01.SB173, 01.SB174, 01.SB175, and 01.SB176 were sampled for suspected mercury contamination in the vicinity of Buildings 3503 and 3592. The second highest gross alpha activity detected at WAG 1 (2839±639 pCi/g) was encountered at 2 to 3.3 ft in 01.SB174. Isotopes contributing to the high alpha were identified as uranium-238 (4260±976 pCi/g) and uranium-234 (514±124 pCi/g). The highest plutonium-238 concentration observed in the Building 3503 and 3504 area was at 01.SB206 from 0 to 1.3 ft.

Additional locations. Additional locations at which gross alpha activities exceeded reference include 01.SB160 (on Central Avenue on the eastern portion of WAG 1), sampled to investigate a potential pipeline leak; 01.SB258 (on the northwest corner of Building 3001), sampled to investigate contamination in the vicinity of the Graphite Reactor Building; and 01.SB140 (in the northeast portion of WAG 1), sampled to investigate a tank rupture. The gross alpha activities in these borings ranged from 54.7±24.3 to 386±99 pCi/g. No

additional isotopic analyses were conducted that would identify the alpha-emitting constituents responsible for the gross alpha activity.

Sampling point 01.SB095, selected based on USRADS information and located at the southern end of Third Street near WOC, contained elevated gross alpha in addition to americium-241, plutonium-238, and plutonium-239/240, in the 0- to 1-ft interval. The ratio of uranium-238 to uranium-234 in this interval was 0.16. Samples from 01.SB063 and 01.SB064 had plutonium-239/240 at 8.91±1.41 and 5.33±1.21 pCi/g, respectively (Fig. 4.4.6). Both of these sampling points were also selected based on USRADS information and are located northwest of SWSA 1. Gross alpha results did not exceed background at these locations. The fourth highest WAG 1 plutonium-239/240 activity of 70.2±15.1 pCi/g was detected at USRADS sampling location 01.SB106, near the western perimeter of WAG 1 and First Creek (Fig. 4.4.6). The sixth highest plutonium-239/240 activity of 44.5±10.6 pCi/g was measured at 01.SB112, which was drilled to investigate the 3524 impoundment.

Soil borings 01.SB177 and 01.SB179, south of Building 4501, contained soil with slightly elevated gross alpha (see Fig. 4.4.5).

As shown in Fig. 4.4.6, all gross alpha activity at SWSA 1 and vicinity was below reference values, although plutonium-239/240 was detected at 8.91±1.4 pCi/g at 01.SB063.

Concentrations of alpha emitters were not evident in the isotope area, as shown on Fig. 4.4.4.

Floodplain soils. Table 4.4.4 is a summary of the activity detected in WOC and First Creek floodplain soils. Results for samples from the WOC and First Creek floodplains have been highlighted because these soils are more susceptible than others to off-WAG release (through erosion/transport by surface water).

The presence of either gross alpha or naturally occurring and man-made alpha-emitting radionuclides above reference levels (56 pCi/g) was limited to samples obtained from WOC floodplain transects; none of the samples from First Creek floodplain soils contained alpha-related activity above the reference value. Within the floodplain soils of WOC, activities greater than reference were detected only in samples from locations downstream (west/southwest) of transect WOC4, which is opposite the southwest corner of the 3513 impoundment. Within the soil samples obtained from transects WOC5–WOC9, the highest alpha activities were typically associated with samples from the WOC5 and WOC6 transects as well as selected locations within the G-grid near the mouth of First Creek. The maximum activities for the floodplain soils were associated with samples from relatively shallow depths (<4 ft); however, the vertical extent of sampling did not extend beyond this depth in most of the borings.

Gross alpha activities above the reference level in the floodplain soils of WOC ranged from 57.3±16.9 pCi/g in the 0- to 2-ft sample from 01.WOC94 to 166±45 pCi/g in the 2- to 4-ft sample from 01.WOC63 (see Fig. 4.4.3). Location 01.WOC51 was sampled in both February and August 1990, and an increase was reported in the later sample (74.5±20.8 to 120±28 pCi/g); an increase was also noted for the individual alpha-emitting isotopes.

Interpretations regarding changes in gross alpha activity with depth were not possible given the limited number of locations with sampling below 4 ft.

Gross alpha activities in the floodplain soils of First Creek ranged from 10.8±7.6 to 46.7±14.7 pCi/g (see Fig. 4.4.3). All of these results are below the gross alpha reference value for WAG 1 soils. Similar to the trend observed in soil samples from elsewhere on WAG 1, the isotopic analyses for the alpha-emitting radionuclides rarely accounted for the gross alpha concentrations reported for the samples. As previously stated, the difference is likely attributable to comparing relatively low levels of contamination.

Numerous naturally occurring alpha-emitters were detected in the floodplain soils of WOC; these constituents include elements of the uranium-238 series [uranium-238, uranium-234, thorium-230, radium-226, and bismuth-214 (which emits both alpha and beta particles)], the thorium series [thorium-232, thorium-228, radium-224, and bismuth-212 (also an alpha- and beta-emitter)]; and one member of the actinium series (uranium-235). Man-made alpha-emitters detected in WOC floodplain soils include the transuranics americium-241, plutonium-238, and plutonium 239/240. Most of these constituents were detected at an activity level below or approximately equal (considering the error) to the reference levels for WAG 1 soils. The only naturally occurring alpha-emitting radionuclides that exceeded reference levels were uranium-234 and uranium-238. A maximum uranium-234 concentration of 16.4 pCi/g was found at location WOC64. No other floodplain soils contained uranium-234 or uranium-238 concentrations over 3.8 pCi/g.

The maximum activities for uranium-234 and thorium-228 in the floodplain soils were detected in the 2- to 4-ft sample from location 01.WOC63; the maximum for uranium-238 was detected in the 2- to 4-ft sample from 01.WOCG6. Uranium-234/238 activities exceeded reference values in samples from the upstream location (WOC-1) and in samples from transects WOC-4, WOC-5, WOC-6, and WOC-9. Some samples collected near the confluence of WOC and First Creek also exceeded the reference value.

Floodplain soils from First Creek contained selected isotopes of the uranium series (thorium-234 and radium-226) and thorium series (radium-228 and radium-224) in activities either below or approximately equal to the soil reference levels for these constituents. Uranium was not detected in any of the First Creek floodplain soil samples. The presence of thorium-234 (half-life of 24 days) but not uranium-238 or uranium-234 in samples collected from the FC1 and FC3 transects suggests either analytical problems (i.e., that the thorium-234 results are spurious) or the presence of a source of thorium-234 in the southern portion of First Creek, which is considered to be unlikely.

Among the man-made alpha-emitters, analyses were limited to the transuranics americium-241, plutonium-238, and plutonium-239/240. Americium-241 was analyzed for and detected at apparently elevated levels in 14 samples from WOC floodplain soils. All occurrences of plutonium were in samples collected downstream of transect WOC-5. The highest activities for both plutonium isotopes were found in the 2- to 4-ft sample from location WOC63. The activities were 1.1±1 pCi/g for plutonium-238 and 89.4±18.6 pCi/g for plutonium 239/240. Although reference levels for americium and plutonium were not

available, it is likely that activities above 1 to 2 pCi/g represent site-related contamination, based on the observed distribution of man-made radionuclides across WAG 1.

The 0- to 2-ft sample from 01.WOC51 and the 2- to 4-ft sample from 01.WOC63 were associated with the highest detected activities for americium-241 in floodplain soils (20.8±3 and 11.4±3.5 pCi/g, respectively). Americium was also reported for the 0- to 1.7-ft sample from 01.WOC61 (8.82±4.52 pCi/g), located on the opposite side of WOC from 01.WOC63. The 01.WOC63 sample also yielded the only detection of plutonium-238 (1.1±1 pCi/g) and a relatively significant detection of plutonium 239/240 (89.4±18.6 pCi/g). Plutonium-239/240 was also detected in the 4- to 5-ft sample from 01.WOC72 (downstream of 01.WOC63), but at a much lower activity (0.44±0.37 pCi/g).

The only man-made alpha-emitter detected in First Creek floodplain soils was the transuranic americium-241 (0.134 pCi/g). The occurrence of this radionuclide was limited to a single sample from the FC13 sampling location. No reference level for americium was available.

4.4.3.2 Beta-emitting radionuclides

Figure 4.4.7 shows the distribution of gross beta activities across the WAG. The highest activities (maximum of 62,500 pCi/g) were found in samples from NTF and STF and in the vicinity of the impoundments. The maximum detected gross beta activity in reference soils was 34 pCi/g. Although promethium-147 was detected in many soil samples, these results are suspect because of the potential laboratory misidentification of this isotope. As discussed in Appendix C, promethium-147 and technetium-99 are difficult to distinguish in the laboratory, and it is likely that some of the activities reported as promethium-147 are actually attributable to technetium-99 (see Sect. 4.1 and Appendix C for details).

North Tank Farm. Soil samples from NTF were found to contain the highest gross beta and strontium-90 activities detected on WAG 1. The distributions of maximum cesium-137, maximum cobalt-60, and maximum strontium activities detected above reference levels are presented in Figs. 4.4.8 through 4.4.10. The single detection of cesium-137 in NTF represented the maximum detected activity of cesium-137 on WAG 1 (outside of floodplain soils). Lead-212 and lead-214, as detected by gamma spectroscopy, were also found above reference levels in a limited number of samples.

The maximum gross beta activity of 62,500±12,500 pCi/g was measured in the 15- to 17-ft sample from boring 01.SB026. Other occurrences of high gross beta were also associated with relatively deep soil samples: 23,200±4,600 pCi/g from 18 to 19 ft in 01.SB029 and 21,100±4200 pCi/g from 18 to 20.5 ft in 01.SB032. All three of these samples also contained relatively high levels of strontium-90. The maximum strontium-90 (both within NTF and WAG 1) was measured in the 15- to 17-ft sample from 01.SB026 (35,300±3500 pCi/g); relatively high activities were also measured in 01.SB029 (8990±900 pCi/g) and 01.SB032 (12,000±1200 pCi/g). In most samples, only 50% or less of the gross beta could be attributed to specific beta-emitting radionuclides. The principal beta-emitter identified during the investigation is strontium-90.

South Tank Farm. STF also yielded a large number of samples with beta-emitting constituents exceeding reference levels. Soil samples from STF contained the WAG 1 maximum activities for europium-152 (274±18 pCi/g), europium-154 (171.7±15.1 pCi/g), technetium-99 (12.9±1.3 pCi/g), thorium-234 (34.1±6.4 pCi/g), and total strontium (47.2±5.3 pCi/g). Soil samples from STF also contained the second-highest WAG 1 gross beta (34,381±5159 pCi/g), cesium-137 (6213±360 pCi/g), and radium-228 (6.54±0.93 pCi/g). Samples from soil borings 01.SB182 (0- to 2-ft interval) and 01.SB183 (2-to 4-ft interval), located adjacent to Building 3515 in the eastern portion of STF, contained elevated activities of calcium-45 iron-55, nickel-63, promethium-147, and technetium-99. The maximum detected activities for these two borings were as follows: calcium-45, 87.3±6.8 pCi/g (01.SB183); iron-55, 66.7±50.7 pCi/g (01.SB182); nickel-63, 33,010±2369 pCi/g (01.SB183); promethium-147, 2286±241 pCi/g (01.SB183); technetium-99, 8±4.2 pCi/g (01.SB183).

The 2- to 4-ft sample from 01.SB183 yielded the highest gross beta activity within STF; this sample also had elevated activities of cesium-137 (1389±81 pCi/g) and europium isotopes. The 2- to 4-ft sample from 01.SB213 contained the highest cesium-137 activity in the STF as well as elevated gross beta (4672±702 pCi/g) and total strontium (848±94 pCi/g); however, activities for this sample are suspect because of inconsistencies between the regular and duplicate samples (see Appendix C, Sect. C6.3.3). The high europium activities were detected in the 0- to 4-ft sample from 01.SB020; this sample also contained the only occurrence in WAG 1 of yttrium-91 (543±486 pCi/g) and the highest activity of zirconium-95 (18.4±4 pCi/g), both of which are suspect due to their short half-lives of 59 and 65 days, respectively. A deeper sample from 01.SB020 (22 to 23.1 ft) contained 12.9±1.3 pCi/g of technetium-99. Technetium activities in shallower samples from this boring (0 to 4, 4 to 8, 16 to 18 ft) were less than 3.0 pCi/g.

Building 3019 area. Soil samples from the hot bank area immediately north of Building 3019 contained a relatively large number of beta-emitting radionuclides; however, the majority of these constituents were detected at activities within the range of reference levels. Activities greater than reference were reported for gross beta, actinium-228, calcium-45, cobalt-60, europium-152/154, iron-55, iodine-129, promethium-147, total strontium, and technetium-99. With the exception of samples from 01.SB126, which contained the only WAG 1 detection of iodine-129, all of these constituents were detected at levels below those reported for NTF and STF.

Samples from the 0- to 2-ft interval in 01.SB126 contained the largest number of and highest activities for beta-emitters from the 3019 hot bank area, including gross beta (6171±927 pCi/g), cesium-137 (3028±176 pCi/g), iodine-129 (689±44 pCi/g), and total radioactive strontium (2215±244 pCi/g). Samples from deeper intervals in 01.SB126 also contained elevated levels, but activities generally declined by 50% or more with each succeeding sample (e.g., cesium-137 and iodine-129 declined to 511 and 117 pCi/g, respectively, in the 4- to 6-ft sample). However, the sample from the 8- to 8.9-ft interval contained the highest activities (for the 3019 area and for WAG 1) of calcium-45 (1180±80 pCi/g) and iron-55 (118±5 pCi/g); this same sample also contained an elevated activity of promethium-147 (19.1±3.7 pCi/g). Neither calcium-45 nor promethium-147 was analyzed

in the samples from the shallower intervals from boring 01.SB126. As previously stated, the promethium-147 results are suspect (see Sects. 4.1 and Appendix C).

Soil boring 01.SB244 was the only other boring from the hot bank area to yield samples with beta-emitting radionuclide activities in relatively high levels, namely gross beta and total strontium. The activity for total strontium was observed to increase with depth, from 153±16.9 pCi/g in the 0- to 2-ft sample to 1162± 128 pCi/g in the 4- to 6-ft sample. Gross beta activity also increased, from 561±86 to 2619±394 in the same samples.

Samples collected at sites of suspected leaks in the vicinity of Building 3019 (01.SB128 through 01.SB134) contained elevated activities of gross beta, cesium-137, calcium-45, promethium-147, technetium-99, and total strontium down to 16 ft. The highest activities and deepest contamination were detected in samples from 01.SB132 at a past pipeline leak near the southwest corner of Building 3019. Samples from 01.SB128 and 01.SB130, on the north side of the building, showed similar types but smaller magnitudes of contamination.

Samples from 01.SB132 contained the maximum gross beta and total strontium detected in the vicinity of Building 3019; activities in this boring increased from essentially background conditions at the 0- to 2-ft interval to considerably higher activities at depths of 10 to 12 ft (16,005±2403 pCi/g for gross beta and 8621±948 pCi/g for total strontium). The vertical distributions of selected beta-emitting radionuclides measured in samples from 01.SB128, 01.SB130, and 01.SB132 are presented in Table 4.4.5.

Surface impoundments. Samples from boring 01.SB189, located near the western perimeter of the 3524 settling basin, contained the highest activities of any soil boring samples collected in the vicinity of the impoundments. Gross beta activity in the 4- to 4.3-ft sample from this boring was 21,382±3209 pCi/g, the fifth highest gross beta activity measured in WAG 1 soil samples. This sample also contained calcium-45 (19.7±1.8 pCi/g), nickel-63 (34,010±2440 pCi/g), and promethium-147 (677±72 pCi/g). The 2- to 4-ft sample from this boring contained 9871±1482 pCi/g gross beta, 53.1±3.1 pCi/g calcium-45, 14,400±2440 pCi/g nickel-63, 516±55 pCi/g promethium-147, 6±3.9 pCi/g technetium-99, and 137±8 pCi/g cesium-137.

Soil boring 01.SB103, located on the western perimeter of the 3513 settling basin, encountered elevated levels of gross beta (338±54 pCi/g), cesium-137 (361±21 pCi/g), and total radioactive strontium (51.8±5.8 pCi/g) in a shallow (0- to 2-ft) sample. Soil boring 01.SB104, located on the southern perimeter of the 3524 pond, encountered iron-55 (6.3±5.1 pCi/g), promethium-147 (676±72 pCi/g), cesium-137 (339±20 pCi/g), and technetium-99 (1.1±0.7 pCi/g) in the 2- to 4-ft interval.

Isotope area. Gross beta in soil samples from the isotope area exceeded reference in a number of samples; however, the highest activity (998±151 pCi/g) was well below the WAG 1 maximum of 62,500 pCi/g. Soil samples collected from the eastern portion of the area contained a relatively large number of beta-emitting radionuclides and included the maximum WAG 1 occurrence of cobalt-60 (99.5±9.6 pCi/g). Other beta-emitters detected above reference include cesium-137, strontium-90, thorium-234, calcium-45, iron-55, nickel-63, radium-228, potassium-40, thallium-208, and tritium.

The highest beta activities were associated with the 3028 leak area (sampled at borings 01.SB129, 01.SB148, and 01.SB149). Samples from these borings contained the maximum activities within the isotope area for radium-228 and thallium-208. The highest gross beta and tritium activities in these borings was detected in samples from the 6- to 8-ft interval; samples from shallower intervals were either within or slightly above reference ranges.

Soil borings 01.SB150, 01.SB152, and 01.SB153 also yielded samples from depths below 2 ft with elevated activities of gross beta (up to 1230±186 pCi/g), cobalt-60 (up to 41.9±3 pCi/g), and cesium-137 (up to 987±57 pCi/g). The 01.SB150, 01.SB152, and 01.SB153 samples were collected at sites of suspected or known past leaks; the depth at which elevated activities were detected indicates that the releases were most likely related to buried pipelines.

SWSA 1 and vicinity. Soil samples collected from within and in the immediate vicinity of SWSA 1 yielded only a limited number of samples with beta-related activities above background. In addition to gross beta, radionuclides detected above reference include cesium-137, potassium-40, and strontium-90. Among these constituents, only gross beta and cesium-137 were significantly elevated above reference (in this case greater than 100 times the reference level).

Soil samples collected from borings within or on the perimeter of SWSA 1 (01.SB009, 01.SB010, 01.SB064, and 01.SB215-218) contained only slightly elevated activities of beta-emitting radionuclides, typically potassium-40 and strontium-90. Gross beta activity was less than 50 pCi/g for these samples. These borings included samples collected at depths down to 12 ft.

Soil borings 01.SB005 through 01.SB008 were all drilled near the waste pile east-southeast of SWSA 1 and included sampling down to depths of almost 30 ft. Potassium-40 and strontium-90 were the only beta-emitting constituents detected above reference in samples from these borings; the maximum activities in these samples were 37.7±5.8 and 6.02±0.81 pCi/g, respectively.

Soil borings 01.SB060 through 01.SB064, completed west of SWSA 1 at USRADS sampling sites, contained the highest activities of gross beta and cesium-137 detected in this area. The maximum for gross beta was detected in the 0- to 1.8-ft sample from 01.SB063 (2166±326 pCi/g); this sample also contained the high for cesium-137 (2391±139 pCi/g). Samples from these borings did not extend below 6 ft.

3503/3504 area and thorium tank farm. Soil samples from the 3503/3504 area contained only a limited number of beta-emitters. In addition to gross beta, activities for cesium-137, radium-228, actinium-228, thorium-234, and thallium-208 were elevated above reference. The actinium-228 detected in this area (9.09±1.22 pCi/g) was the maximum activity detected on WAG 1.

Only one of the three borings completed around the thorium tank farm encountered any beta-related radiological soil contamination (01.SB047). The 0- to 5-ft sample from this boring contained gross beta of 2192±59 pCi/g and 123±17 pCi/g of cesium-137. The other

two borings near the thorium tanks did not contain beta-emitting radionuclides above reference levels. Boring 01.SB109, located in the northeast corner of the tank farm, encountered calcium-45 (41±5.4 pCi/g), promethium-147 (5.4±3.3 pCi/g), and technetium-99 (0.8±0.3 pCi/g) in the 0- to 1.9-ft interval.

Soil samples from 01.SB191 and 01.SB192 were collected to investigate a suspected leak site near Building 3503. High levels of gross beta (2260±342 pCi/g), cesium-137 (2873±167 pCi/g), and total radioactive strontium (26.3±3 pCi/g) were detected in the 4- to 4.8-ft sample from 01.SB191. The shallow sample from this location did not contain any beta-related activity above background.

Two of the samples from borings completed to investigate mercury contamination near Building 3504 (01.SB173 and 01.SB174) contained gross beta above reference. The maximum gross beta in these samples (2996±452 pCi/g) was measured in the sample from the 2- to 3.3-ft interval in 01.SB174. This same sample also contained calcium-45 (12.4±4.6 pCi/g), nickel-63 (462±31 pCi/g), and promethium-147 (1362±143 pCi/g). As previously mentioned, the promethium-147 detection is suspect.

Additional locations. The nature of beta-emitting radiological contamination at the multitude of suspected leak and USRADS sites around WAG 1 varies from location to location. Most of the leak sites with elevated gross beta activity also contained elevated levels of cesium-137 and/or total radioactive strontium. A small number of samples contained additional radionuclides, including calcium-45, thorium-234, lead-212, radium-228, and promethium-147. In most cases, these additional radionuclide levels were only slightly higher than the reported reference level.

Gross beta activity was elevated for a large number of the USRADS sampling sites. The most common beta-emitters identified in these samples were cesium-137, total radioactive strontium, and tritium. In the majority of the samples, cesium-137 accounted for more than 50% of the gross beta activity, and in two samples the cesium-137 activity exceeded the gross beta reference value.

The highest gross beta activity in an USRADS sample was detected in the 0- to 1-ft sample from 01.SB096 (4045±608 pCi/g), located west of the impoundments area. An elevated gross beta activity was also found in the sample from the 0- to 2-ft interval in 01.SB056 (2896±436 pCi/g), south of the sewage lagoons. Both of these samples also contained elevated cesium-137 activities, ranging from 3785±220 pCi/g in 01.SB096 to 3139±183 pCi/g in 01.SB096. The 0- to 0.8-ft sample from boring 01.SB106 (next to First Creek) contained 123.2±3.2 pCi/g of calcium-45.

Floodplain soils. A summary of the radiological data detected in these soils is included in Table 4.4.4. Figures 4.4.7 through 4.4.10 include the distribution of beta-related contamination in the floodplain soils along both First Creek and WOC. Within WOC floodplain soils, beta-emitters were more prevalent than alpha-emitters. Both naturally occurring (thorium-234, lead-214, and lead-210 of the uranium series; radium-228, actinium-228, and thallium-208 of the thorium series; and potassium-40) and man-made (cesium-137, technetium-99, sodium-22, and various isotopes of cobalt, europium, and

strontium) radionuclides were detected. Of this group, only the man-made constituents were detected above reference in the WOC floodplain soils. Potassium-40, thorium-234, and radium-228 were also detected in the floodplain soils along First Creek. The activities of the naturally occurring beta-emitters were within the reported reference levels for these constituents in WAG 1 soils.

Man-made beta-emitters detected in First Creek floodplain soils were limited to cesium-137 and cobalt-60. Cesium was detected in all of the samples in activities that generally exceeded the reported reference levels by 1 to 2 orders of magnitude. Cobalt-60 was detected in only three samples and in activities less than 0.2 pCi/g.

Within the WOC floodplain samples, activities per gram of cesium-137 and potassium-40 exceeded the reported reference levels in a large number of samples. Activities per gram of cesium exceeded reference by up to 5 orders of magnitude in several samples but were most commonly reported at levels 2 to 4 orders of magnitude greater than reference. The distribution of cesium above the reference level was more widespread than that observed for the alpha-emitting radionuclides and included locations in all nine of the WOC transects and all six of the G-grid locations. Activities were generally higher in samples downstream of the WOC4 transect. Potassium-40 activity levels were generally at or below the maximum reference value.

Gross beta results from First Creek floodplain soils were generally much higher than the sum of individual beta-emitting radionuclides. In most samples, approximately 50% of the gross beta could be accounted for by the potassium-40 and cesium-137 present in the sample; however, the remaining contributors were not determined. The absence of a correlation between the number and concentrations of individual beta-emitting radionuclides and the gross beta content for these samples likely is due to either inaccurate analyses or the omission of additional beta-emitting radionuclides from the list of analytes.

Gross beta activity in the soils along First Creek were generally within reference ranges (<30.5 pCi/g); 234 pCi/g was noted at one location and 57.1 pCi/g at a second location, both in the 0- to 2-ft interval. The presence of cesium-137 at activity levels greater than reference does not always correlate with elevated gross beta content, as evidenced by a comparison of the distribution of gross beta and total cesium activities in the soils along First Creek (see Figs. 4.4.7 and 4.4.8).

Gross beta activities above the reference level of 30.5 pCi/g were detected in 60 of the WOC floodplain samples (more than 60% of the total samples collected from the WOC floodplain). The reported activities for these samples ranged from 32.9 to 39,400 pCi/g, with the majority in the range of 100 to 700 pCi/g. The bulk of the gross beta activity could be attributed to the cesium-137 content in the samples.

The highest levels of cesium-137 in First Creek floodplain soils, up to slightly more than 100 times the reference activity of 0.21 pCi/g, were detected in samples from the lower (southern) portion of the creek. Similar levels were observed in terms of the maximum cesium activity detected in samples from each of the three transects (20 to 23.4 pCi/g).

The maximum cesium-137 activity (22,170±1286 pCi/g) in WOC floodplain soils was detected in the 2- to 4-ft sample from location 01.WOC63; activities greater than 1000 pCi/g were also reported for samples from 13 additional locations. All 13 of these samples were collected from the uppermost interval sampled, in most cases 0 to 2 ft. Cesium-137 activities between 100 and 1000 pCi/g were detected in 27 samples, only 7 of which were collected from a deeper sampling interval (i.e., depths below 2 ft).

Potassium-40 activity greater than reference was largely restricted to soil samples from the WOC8 transect; results varied from only slightly higher than the potassium-40 reference level of 18.7 pCi/g in samples 01.WOC81 through 83 (22 to 36 pCi/g) to a maximum of 39.4±4.3 pCi/g in sample 01.WOC84. This grouping included subsurface samples from depths of 6 to 8 ft (01.WOC83 and 01.WOC84).

Technetium-99, which was detected in only two samples, exceeded its reference level in the 2- to 4-ft sample from 01.WOC63 (5.8±3 pCi/g). Cobalt-60 was detected at apparently elevated levels (>2 pCi/g) in 12 samples (no reference level was available). All other beta-emitting radionuclides detected in WOC floodplain soils were within reported background ranges.

Total radioactive strontium exceeded the reference level (not detected) in all 12 WOC floodplain samples for which a positive result was reported; activities ranged from 1.88 to 192 pCi/g. Analyses for total radioactive strontium were not conducted on samples from First Creek.

Cobalt-60, technetium-99, radioactive strontium, americium-241, and gross beta exhibited a mode of occurrence similar to that noted for cesium-137—highest activity in the 01.WOC63 sample (except for americium-241) and a general distribution of the higher activities in samples downstream of transect WOC4. This similarity suggests a shared source(s) for these radionuclides, most likely in the vicinity of the WOC5 transect. Soil samples from the First Creek floodplain resulted in one americium-241 detection at 0.134±0.1 pCi/g in the 0- to 2-ft interval of 01.FC13.

4.4.4 Chemical Contamination in Soils

Analyses performed on soil samples collected during the Phase I RI included VOCs, BNAEs, chlorinated herbicides, pesticides/PCBs, dioxins/furans, metals, cyanides, and organophosphorous pesticides. The specific suite of analyses performed on each soil sample taken from the borings is identified in Table A4.1.6 in Appendix A. Twenty VOCs, 39 BNAEs, 7 pesticides, 2 PCBs, cyanide, and 22 metals were detected. No dioxins, furans, or herbicides were detected in soil samples.

The following is a discussion of the nonradiological chemicals detected during Phase I. The discussion is organized by the following contaminant grouping: VOCs, BNAEs, pesticides/PCBs, dioxins/furans/herbicides, cyanide, and metals. Proposed RCRA action levels for soil (54 FR 145) for specific contaminants, when available, are provided for comparison.

4.4.4.1 Nature and extent of VOC contamination

Twenty VOCs were detected in samples from 173 borings and soil sampling locations at WAG 1 (Table 4.4.6). Thirty-four of the borings are located in the WOC and First Creek floodplains. Acetone, 2-butanone, methylene chloride, and chloroform were found most often, typically with the highest concentrations among the VOCs.

Trichloroethylene, toluene, chloroform, 2-hexanone, acetone, trichlorofluoromethane, methylene chloride, and methyl ethyl ketone were found in the WAG 1 reference samples (Sect. 4.2).

The summed concentrations of VOCs per boring are presented in Table 4.4.7 and Fig 4.4.11. For each boring, the summed VOC concentration represents the sum of the maximum VOCs found in each depth interval (includes duplicate or regular sample) divided by the number of intervals sampled. As depicted on Fig 4.4.11, samples from only four borings (01.SB010, 01.SB011, 01.SB118, and 01.SB142) contained summed VOCs totaling greater than 1000 μg/kg. In these samples, 90% of the summed VOCs in boring 01.SB010 is methyl ethyl ketone, 87% of the summed VOCs in boring 01.SB011 is chloroform, and greater than 95% of the summed VOCs in borings 01.SB118 and 01.SB142 is acetone.

The majority of VOCs detected in WAG 1 were at levels below 100 μg/kg. The only ones detected at concentrations above 100 μg/kg were acetone, methylene chloride, methyl ethyl ketone, chloroform, and 1,2-dichloroethylene. The only VOC detected at a concentration greater than 1000 μg/kg was methyl ethyl ketone at 1100 μg/kg.

The following paragraphs summarize all 20 VOCs detected in WAG 1 soils. Concentration versus depth relationships were not evident and therefore are not addressed. VOCs were not analyzed at each interval in the borings, so comparisons among depths may be misleading. Each sample collected from the different intervals was screened at the on-site CSL using a gas chromatograph prior to selection and shipment of samples to the off-site laboratory. In most cases, the sample (or samples) in which the greatest concentrations of VOCs were found were sent to the off-site laboratory. Therefore, it may be assumed that concentrations elsewhere in the borehole would be equal to or less than those reported by the off-site laboratory. The sample intervals analyzed for VOCs are identified in Appendix A.

Acetone. Concentrations of acetone ranged from 2 to 880 μg/kg. Ninety-four samples from 58 borings contained detectable acetone; 69 of the 94 detected occurrences (73%) were at levels below 100 μg/kg. Acetone is commonly present as a laboratory or sampling contaminant, or it may have been introduced to soil from leaking pipelines, basements, or tanks. The borings with the highest acetone concentrations include 01.SB142 (east of Building 3002), 01.SB118 (north of impoundment 3517), 01.SB130 (north of Building 3019), and 01.SB124 (north of Building 3019 on the "3019 hot bank"). The high concentrations of VOCs in these borings were taken from intervals deeper than 2 ft. The RCRA soils action level of 8,000,000 μg/kg for acetone is greater than all measured soil concentrations in WAG 1.

Methylene chloride. Concentrations of methylene chloride ranged from 1 to 710 μg/kg. One hundred samples from 73 borings contained detectable quantities of methylene chloride; 89% of all methylene chloride detects were below 100 μg/kg. Methylene chloride can originate from a variety of sources including aerosols, paint removers, and metal degreasers. Its fate in soils is not completely understood, although it is expected to evaporate from near-surface soil because of its high vapor pressure. The three highest methylene chloride concentrations were found in samples from the top 2 ft of borings 01.5B114, 01.5B080, and 01.5B133. The RCRA action level for methylene chloride in soils is 90,000 μg/kg; all WAG 1 soil concentrations were below this action level.

Methyl ethyl ketone. Methyl ethyl ketone, a common solvent also known as 2-butanone, was detected at 260 μg/kg in WAG 1 reference soils. Its concentration in reference samples is questionable and may be an indication of contamination during sample container preparation or laboratory sample analysis. Samples from 25 borings contained detectable concentrations of methyl ethyl ketone, but only 01.SB010 yielded samples containing concentrations greater than the maximum reference concentration (260 μg/kg). The three samples from 01.SB010 (located between SWSA 1 and WOC) contained estimated concentrations ranging from 680 to 1100 μg/kg. The RCRA action level for methyl ethyl ketone in soils is 4,000,000 μg/kg, which is greater than all measured concentrations at WAG 1.

Chloroform. Chloroform was detected at concentrations from 1 to 770 μg/kg in 65 samples from 51 borings. Since chloroform has a high vapor pressure, it usually volatilizes rapidly and is poorly adsorbed to the soil; therefore, its occurrence in soil is questionable. Chloroform is commonly associated with use as an industrial solvent, extractant, and chemical intermediate; it was also indirectly produced in the chlorination of drinking waters, on-site sewage, and cooling waters. Twenty samples from 15 borings had chloroform concentrations above the maximum reference level of 9 μg/kg. The highest concentrations of chloroform were found in samples from 01.SB011 (770 μg/kg) and 01.SB014 (240 μg/kg), located northwest of Building 2013. The soils action level for chloroform is 100,000 μg/kg, which is greater than the measured concentrations detected.

Methylisobutyl ketone. Concentrations of methylisobutyl ketone ranged from 1 to 97 μg/kg in 58 samples from 34 borings. A variety of sources may be responsible, including vehicle exhaust, lacquers, varnishes, paints, or adhesives. If released to soil, methylisobutyl ketone is expected to be removed by direct photolysis on soil surfaces, volatilization, or aerobic biodegradation. The concentrations detected are not believed to indicate any substantial contamination in WAG 1 soils. The RCRA soils action level for methylisobutyl ketone is 4,000,000 μg/kg, which is greater than any concentration detected at WAG 1.

Carbon disulfide. Carbon disulfide was detected in 54 samples from 45 borings; the maximum concentration (65 μg/kg) was detected in a sample from 01.SB006 (southeast of SWSA 1). This concentration was almost double the next highest concentration (33 μg/kg). Carbon disulfide can be naturally occurring but is generally related to its use as a solvent or fumigant. The RCRA soils action level for carbon disulfide is 8,000,000 μg/kg, which is significantly higher than the maximum detected soil concentration at WAG 1.

1,2-Dichloroethylene/1,1-dichloroethylene. Both 1,2-dichloroethylene and 1,1-dichloroethylene are anaerobic transformation products of tetrachloroethylene and trichloroethylene, both of which were detected in several borings but at low concentrations. Six samples from six borings contained 1,2-dichlorethylene. The maximum concentration of 150 μg/kg was found in a sample from 01.SB133, which is located between Buildings 3001 and 3019 adjacent to the 3019 canal. The remaining five samples contained 1,2-dichloroethylene at or below 22 μg/kg. 1,1-Dichloroethylene was detected once in a sample from 01.SB010 (located north of SWSA 1 and south of WOC) at a concentration of 7 μg/kg (estimated). The action level for 1,1-dichloroethylene is 10,000 μg/kg, which is significantly greater than the concentrations measured at WAG 1.

Tetrachloroethylene and trichloroethylene. Tetrachloroethylene (PCE) was found in 12 samples at concentrations ranging from an estimated 1 μg/kg to 36 μg/kg. Trichloroethylene (TCE) was found in 21 samples from 20 borings and ranged in concentration from an estimated 0.8 μg/kg to 55 μg/kg. TCE was detected in one of five reference samples at an estimated 1 μg/kg. The RCRA action levels for PCE and TCE are 10,000 and 60,000 μg/kg, respectively; both PCE and TCE concentrations measured in WAG 1 soils are significantly lower.

Benzene/xylene/toluene/ethylbenzene. These aromatic compounds were detected in relatively minor amounts; toluene was detected the most frequently and at the highest concentration. All four were found in samples from depths greater than 2 ft, which suggests that the compounds have leached downward into the soil or have leaked from underground sources. In some cases, the concentrations found may originate from gasoline or exhaust fumes commonly present in WAG 1. Benzene was detected once at an estimated concentration of 3 μg/kg in a sample from 01.SB125, located on the 3019 hot bank. Ethylbenzene, a degradation product of benzene, was found only twice (borings 01.SB010 north of SWSA 1 and 01.WOC41 on the WOC floodplain) at depths between 2 to 4 ft and concentrations ranging from an estimated 6 μg/kg to 17 μg/kg. Toluene, detected in 45 samples from 42 borings, ranged from an estimated 0.6 μg/kg to 17 μg/kg. Toluene was detected at 4 μg/kg in reference soils. Total xylene was found in samples from four borings (i.e., 01.SB125 and 01.SB165 east of NTF and 01.WOC41 and 01.WOC72 in the WOC floodplain) at concentrations ranging from an estimated 1 μg/kg to 38 μg/kg. RCRA action levels for toluene (20,000,000 μg/kg), xylenes (200,000,000 μg/kg), and ethylbenzene (8,000,000 μg/kg) are much greater than the measured soil concentrations at WAG 1.

Others. The remaining five VOCs were detected in only a small number of borings and at concentrations that were often estimated values below the SQL. Of these VOCs, the highest concentration was 90 μg/kg of bromodichloromethane found in a sample from boring 01.SB011 (located northwest of Building 2525, at the northwestern boundary of the WAG). The RCRA soil action level for bromodichloromethane is 500 μg/kg, which is greater than the concentration measured in the sample from 01.SB011.

4.4.4.2 Nature and extent of BNAE contamination

Table 4.4.8 summarized BNAE analyses, and Table 4.4.9 lists summed BNAE concentrations for each borehole (normalized for the number of samples per borehole).

BNAE target compounds were detected 1286 times in numerous soil samples collected as part of the Phase I RI, although only a few borings contained soils with concentrations above 1000 μg/kg. Undetected values (CRQL) are not included but can be found in Appendix C.

Nine hundred sixty-nine of the detected occurrences of BNAEs (75.4% of 1286 BNAE detections) were attributed to 17 different polynuclear aromatic hydrocarbons (PAHs). Six different phthalates were detected 210 times (16.3% of 1286 BNAE detections). The remaining 107 detects (8.1%) were attributed to 16 different BNAEs that were neither PAHs nor phthalates.

Polynuclear aromatic hydrocarbons. PAHs exist in a variety of materials that are common at WAG 1, including fuel oil, gasoline, coal, and asphalt. PAHs were detected in WOC and First Creek floodplain soils 494 of the 969 times PAHs were identified. The PAHs in those samples are probably associated with the asphalt roadways and parking lots or with coal storage. Much of the on-site runoff that may carry PAHs to the creeks is derived from parking areas and roadways via storm drains.

PAH concentrations exceeded reference concentrations in 4 borings in the main plant area (01.SB097 north of SWSA 1, 01.SB141 in the northeast corner of WAG 1, 01.SB147 east of Building 3025, and 01.SB168 on Central Avenue between NTF and STF) and 13 borings in the WOC floodplain between the southwest corner of Building 4500S and a location downstream of Third Street.

Phthalates. Phthalates, common plasticizers, were the second most common type of BNAEs (behind PAHs) found in WAG 1 soil samples. Six phthalates [bis(2-ethylhexyl)phthalate, diethylphthalate, butyl benzyl phthalate, dimethyl phthalate, di-n-butyl phthalate, and di-n-octyl phthalate] were detected 210 times; approximately 31% of the detects were in the floodplain soils (12 in First Creek and 54 in WOC floodplain samples). The remaining 69% (144 detects) were from borings in the main plant area. The most common phthalates found were bis(2-ethylhexyl)phthalate, butyl benzyl phthalate, and di-n-butyl phthalate.

The four highest concentrations of bis(2-ethylhexyl)phthalate were found in samples from WOC floodplain locations 01.WOC52, 01.WOC32, 01.WOC51, and 01.WOC12. Unlike bis(2-ethylhexyl)phthalate, the highest concentrations of di-n-butyl phthalate were found in samples from borings in the main plant area. Only 2 of the 11 highest concentrations were found in samples of WOC floodplain soils. Di-n-butyl phthalate was the only phthalate found in reference soils, where it had a concentration of 150 μg/kg in one sample; this value was exceeded in 27 of the WAG 1 soil samples containing detectable concentrations.

Other BNAEs. Seventeen BNAEs that are neither PAHs nor phthalates were found in WAG 1 soils (Table 4.4.8). Most of these compounds were detected only once or twice except for n-nitroso-diphenylamine (34 detected occurrences), benzoic acid (28 detected occurrences), benzyl alcohol (3 detected occurrences), phenol (15 detected occurrences), and dibenzofuran (14 detected occurrences). The compounds detected only once or twice were all found in the floodplain soils, usually along WOC.

N-nitroso-diphenylamine was detected 34 times, although no sample concentration exceeded the maximum reference concentration of 150 μg/kg.

Benzoic acid was found in samples from boring 01.WOC52 at a concentration of 2400 μg/kg. Benzoic acid is a degradation product of benzene and toluene and also may be naturally occurring. Benzene and toluene were not found in the soil samples from 01.WOC52.

The three samples containing benzyl alcohol were collected along Third Street in borings 01.SB096, 01.SB097, and 01.SB098. The highest concentration was 130 μg/kg. Benzyl alcohol (phenol) typically biodegrades fairly rapidly under aerobic conditions in surficial soil. Possible sources of this compound include decomposition of organic and animal wastes, plastics, fibers, and adhesives.

Dibenzofuran was detected 14 times; the highest concentrations (6900 μg/kg estimated) were found in soil samples from borings 01.SB168 (between NTF and STF) and 01.SB141 (northeast portion of WAG 1) (1200 μg/kg). Dibenzofurans are typically associated with combustion products such as PAHs. Borings 01.SB168 and 01.SB141 contained the highest concentrations of PAHs found in WAG 1 soils.

4.4.4.3 Nature and extent of organochloride pesticides and PCB contamination

The locations and sample depth intervals of the seven detected pesticides are listed in Table 4.4.10. All of the pesticides were found in samples composited over the top 2 ft. Heptachlor (12J μg/kg), 4,4'-DDT (53 μg/kg), endrin (2.8J μg/kg), alpha-BHC (22J μg/kg), alpha-chlordane (100J μg/kg), gamma-chlordane (55J μg/kg), and 4,4' DDE (51 μg/kg) were each detected once. These compounds may be remnants of surface applications of pesticides.

Organophosphorous pesticides were not detected in any soil samples.

Two PCBs, Aroclor-1254 and Aroclor-1260, were detected in samples from 16 soil borings at concentrations ranging from 33 to 5800 μg/kg and 88 to 1900 μg/kg, respectively (Table 4.4.10). Only borings 01.SB052, 01.SB054, and 01.SB097 contained concentrations of Aroclor-1254 and Aroclor-1260 in the ppm range. Borings 01.SB052 (2300 μg/kg for Aroclor-1254) and 01.SB054 (5800 μg/kg for Aroclor-1254) are near First Creek away from the operations of WAG 1. The boring locations were initially chosen based on the USRADS survey. It is unclear what may be contributing PCBs to the surficial soils in this area. Boring 01.SB097 (1500J μg/kg for Aroclor-1254 and 1900J μg/kg for Aroclor-1260) is just north of WOC near Third Street in a marshy area that collects runoff from a ditch running north to south along Third Street from White Oak Avenue. Transformers near soil boring 01.SB097 are a possible source of the PCB contamination. The RCRA soils action level for PCBs is 90 μg/kg, which is less than concentrations measured in samples from the three soil borings described above. The other 13 borings are 01.SB035, 01.SB048, 01.SB049, 01.SB051, 01.SB060, 01.SB061, 01.SB063, 01.SB088, 01.SB108, 01.SB112, 01.SB114, 01.SB175, and 01.SB176.

4.4.4.4 Nature and extent of dioxin, furan, and herbicide contamination

No dioxins, furans, or herbicides were detected in any soil sample from WAG 1.

4.4.4.5 Nature and extent of cyanide contamination

Table 4.4.10 lists the 10 borings and the sample depths for samples in which cyanide was detected. The maximum concentration (5100 μg/kg) was found in a sample from 01.SB040, near tank WC-1 at the southern portion of the isotope area. The cyanide soil action level is 2,000,000 μg/kg, which is much greater than the maximum concentration measured at WAG 1.

4.4.4.6 Nature and extent of metal contamination

All metals analyzed for were detected in soil samples. The concentrations varied widely, possibly indicating both natural variability in the soils and the presence of contamination. Table 4.4.11 lists the maximum metal concentrations for Phase I soil samples; individual analytical data are presented in Appendix A.

Concentrations of individual metals in the main plant area and the floodplain soils varied by orders of magnitude; this variability may be influenced by several factors, including type of soil and presence of contamination. RCRA proposed soil action levels for metals (when available) or the reference sample metal concentrations were used to identify areas containing significant concentrations of metals.

When analyzed by the inductively coupled plasma argon spectrophotometry (ICAP) method, arsenic, lead, selenium, and thallium are subject to interferences from other metals and exhibit higher detection limits than when analyzed by the more conventional graphite furnace absorption spectrophotometry (GFAA) (see Sect. 4.1). Concentrations of these metals are presented whether or not the ICP method was used; analytical data presented in Appendix A identify which results came from ICAP analyses.

Each of the metals detected in WAG 1 main plant area soils and the floodplain soils is discussed below. Only those borings containing metal concentrations above the maximum reference level are discussed.

Aluminum. The maximum aluminum concentrations detected in individual boreholes ranged from 1,470,000 to 54,200,000 μg/kg. Approximately 55% of the borings did not yield samples containing aluminum above the maximum reference concentration of 14,000,000 μg/kg. The two samples containing the highest concentrations came from 01.SB175 and 01.SB176, which are about 15 ft apart and adjacent to Building 3592, where mercury spills have been documented. The highest concentrations of mercury (548,000 and 16,400 μg/kg) were also found in samples from these borings. The large range of aluminum concentrations likely reflects the natural diversity of soil material and is not believed to represent contamination.

Antimony. Figure 4.4.12 illustrates the distribution of maximum antimony concentrations (2400 to 37,600 μg/kg). Thirty of the 31 sampling locations having concentrations above the maximum reference value of 7600 μg/kg (undetected) were in the main plant area. The only floodplain location where antimony was detected above 7600 μg/kg was 01.WOC23. More than half of the borings showed no detectable concentrations of antimony. The RCRA soil action level for antimony is 30,000 μg/kg, which was exceeded in one sample from WAG 1 (i.e., boring 01.SB173).

Arsenic. The maximum concentrations detected in individual boreholes ranged from 1200 to 27,400 μg/kg; the maximum reference concentration was 4600 μg/kg. Figure 4.4.13 presents the distribution of maximum arsenic concentrations in boreholes; the highest concentrations are primarily restricted to areas along the First Creek and WOC floodplains and adjacent areas. This restricted geographic distribution suggests that the arsenic source is associated with plant activities rather than with natural variations in soil chemical composition. The RCRA soil action level for arsenic is 80,000 μg/kg, which is greater than the maximum arsenic concentration measured in soil samples.

Barium. Samples from 6 of 234 borings contained barium concentrations greater than the maximum reference concentration of 403,000 μg/kg. The highest concentration (1,940,000 μg/kg) was found in boring 01.SB090, located adjacent to tank 3013 (which contained effluent from the environmental processing laboratory in Building 3013). The RCRA soil action level for barium is 4,000,000 μg/kg, which is greater than the maximum concentration measured at WAG 1.

Beryllium. Samples from 35 borings contained beryllium concentrations above the maximum reference concentration of 1600 μg/kg. Samples from 180 borings had detectable beryllium below the maximum reference concentration, and samples from 17 borings had no detectable beryllium (Fig. 4.4.14). The highest concentration (212,000 μg/kg) was found in a sample from boring 01.SB026, located at NTF adjacent to Gunite tank W-1 (used to store highly radioactive waste from Building 3019). The RCRA soils action level for beryllium is 200 μg/kg, which was exceeded both by WAG 1 and 17 of 18 reference soil samples.

Boron. Boron was not among the 25 target metals of concern but was reported by the laboratory in soil borings 01.SB001, 01.SB002, 01.SB003 (located at the site of a former storage impoundment west of impoundment 3517) and 45 floodplain borings. No correlation is apparent within the floodplain samples, although the seven highest concentrations were in the First Creek area and at WOC where it crosses Haw Ridge.

Cadmium. Cadmium, detected in samples from 110 borings, was above the maximum reference concentration of 3800 μg/kg in samples from 15 borings (Fig. 4.4.15). The maximum concentration was 11,900 μg/kg, which is roughly 3 times greater than reference. The RCRA soils action level for cadmium is 40,000 μg/kg, which is greater than the maximum concentration measured in the soil samples.

Chromium. The highest level of chromium above the maximum reference concentration (41,000 μg/kg) was found in 34 borings from samples of First Creek and WOC floodplain

soils and in samples from the ditch that runs along the west side of Third Street between White Oak Avenue and WOC (Fig. 4.4.16). Samples from three locations near WOC (01.WOC32, 01.SB095, and 01.SB097) contained concentrations of chromium 3 to 4 times greater than reference, and 31 other borings contained between 41,000 and 99,000 μg/kg. The soils action level for hexavalent chromium (the most mobile species of chromium) is 400,000 μg/kg, which is greater than the maximum total chromium concentration measured in the soil samples.

Cobalt. Cobalt exceeded the maximum reference concentration of 28,600 μg/kg in samples from 11 borings containing detectable cobalt (Fig. 4.4.17). Detectable concentrations ranged from 590 to 143,000 μg/kg. The highest concentration was in the 22- to 24-ft interval in 01.SB135, at the south side of Building 3019. The second highest (98,800 μg/kg) was found in a sample from the 0- to 5-ft interval in 01.SB026, adjacent to tank W-1 (Fig. 4.4.17). Beryllium was also found in relatively high concentrations (212,000 μg/kg) in a sample from the same location. Samples from the remaining 10 borings that contained cobalt above reference values appear to reflect the natural concentration variability in the soils.

Copper. The maximum reference concentration of copper was 14,900 μg/kg, and concentrations in samples from nonreference boreholes ranged from 1100 to 394,000 μg/kg. The areal distribution of copper is shown in Fig. 4.4.18. The highest concentration occurred in a sample from 01.SB006, located in the waste pile area. Samples from boreholes 01.WOC12 and 01.WOC52 had maximum copper concentrations of 125,000 and 102,000 μg/kg, respectively. All other maximum concentrations were below 90,000 μg/kg. Copper was found in elevated concentrations in creek channel sediments (Sect. 4.6) and is believed to be related to ORNL operations, although specific sources could not be identified.

Iron. Maximum detectable iron in soil samples from individual borings ranged from 2,370,000 to 66,400,000 μg/kg. The maximum reference value was 38,400,000 μg/kg. These concentrations of iron may reflect the natural soil chemistry of WAG 1.

Lead. Lead was detected with a range in maximum concentration from 2600 to 337,000 μg/kg for individual borings. Samples from 37 of the borings contained lead above the maximum reference concentration of 49,600 μg/kg (Fig. 4.4.19).

Magnesium. Magnesium concentrations are presented in Fig. 4.4.20. The maximum concentration in reference soils was 17,100,000 μg/kg, which was exceeded in 18 borings. The maximum concentrations measured in individual boreholes, ranging from 386,000J to 60,500,000 μg/kg, and are probably related to the different soil types sampled throughout the WAG.

Manganese. The maximum manganese concentration (5,800,000 μg/kg) occurred in a sample from NTF soil boring 01.SB026, where elevated beryllium and cobalt were also found. The maximum reference concentration of manganese is 3,250,000 μg/kg. Manganese is not believed to be elevated due to plant operations and is probably a function of natural soil chemistry. Figure 4.4.21 shows the distribution of manganese in soils at WAG 1.

Mercury. Mercury was detected in six reference samples; the maximum reference concentration (150 μg/kg) was exceeded in samples from 64 borings in which mercury was detected (Fig 4.4.22). During sampling, elemental mercury was visible in the soil from boring 01.SB175, which had the highest concentration (548,000 μg/kg). Samples from 01.SB176, next to 01.SB175, had the second highest mercury concentration detected (16,400 μg/kg). Both borings were located adjacent to Building 3592 to investigate SWMU X01-0002, a mercury spill site. The third and fifth highest concentrations (16,000 and 12,300 μg/kg, respectively) were found in WOC floodplain soil near the Fifth Creek confluence with WOC (01.WOC21) and approximately 400 ft downstream at 01.WOC32 (see Fig. 4.4.22). Mercury from SWMU X01.0003 (Building 4501) may have entered Fifth Creek and subsequently been transported downstream to floodplain sampling locations 01.WOC21 and 01.WOC32. The fourth highest level (12,600 μg/kg) was detected in soil collected beneath the basement of Building 4501 (01.SB203); a spill from a lithium separation process involving elemental mercury was the source for mercury in this building. The RCRA soils action level for inorganic mercury is 20,000 μg/kg, which was exceeded at soil boring 01.SB175.

Nickel. Maximum detectable nickel concentrations per boring ranged from 4600 to 50,300 μg/kg, and the maximum reference concentration of 36,500 μg/kg was exceeded in samples from 41 borings. The concentrations found in all of the soils (Fig. 4.4.23) were evenly distributed through this range and are not considered to represent on-site contamination. The RCRA soils action level for nickel is 2,000,000 μg/kg, which is significantly greater than the maximum measured concentrations.

Osmium. Osmium was analyzed in samples from the majority of the WOC and First Creek floodplain borings, including 01.SB001 and 01.SB002. The maximum detected concentrations per borehole ranged from 93,900 to 587,000 μg/kg; the maximum reference concentration was 245,000 μg/kg. The unexpectedly high concentrations of osmium detected in soils and sediments warranted resampling of various locations. Subsequent reanalysis by another analytical subcontractor failed to confirm the original findings, and results for osmium detects are considered highly suspect. It is doubtful that osmium (results were nondetects), a platinum group metal, would be present at WAG 1 at the reported elevated concentrations.

Potassium. A large concentration range was noted for potassium (25,100J to 8,430,000 μg/kg), which is a common constituent of clay soils such as those found in WAG 1. The WAG 1 maximum reference level was 1,290,000 μg/kg (WAG 6 reference locations in Melton Valley had 4,570,000 μg/kg). Although samples from 10 borings contained potassium above 5,000,000 μg/kg, it is probable that the concentrations are related to differences in soil type.

Selenium. ICAP analyses were performed on roughly half of the samples, and ICAP samples had very high concentrations of selenium compared with those samples analyzed by GFAA. Of the 65 samples with detectable selenium, 43 were identified by ICAP analyses. Samples from four borings (01.SB160 along Central Avenue south of the isotope area, 01.SB111 west of the 3513 impoundment, 01.SB148 south of Building 3028, and 01.SB183

in STF) contained selenium as quantified using SW-846 methods. Selenium was not detected in reference samples.

Silver. Maximum silver concentrations in soil samples from individual boreholes ranged from 800 to 32,000 μg/kg; concentrations exceeded the maximum reference value (4400 μg/kg) in 43 borings. There was no identifiable pattern in the distribution of silver in floodplain soils. The highest concentration was found in a sample from boring 01.WOC12, which is in the WOC floodplain upstream of Fifth Creek just outside the WAG 1 boundary (see Fig. 4.4.24). The RCRA soils action level for silver is 200,000 μg/kg, which is significantly greater than the maximum measured silver concentration.

Sodium. Samples from 55 borings had sodium concentrations greater than the maximum reference level of 106,000 μg/kg. Sodium is not considered a contaminant at WAG 1, although the high concentration at boring 01.SB133 (1,540,000 μg/kg) may be related to plant operations (see Fig. 4.4.25).

Thallium. Thallium, like selenium, exhibits extremely high concentrations in samples for which the ICAP method was used. The concentrations in other samples analyzed by another method with a lower detection level were low, with a maximum of 3300 μg/kg (estimated). Thallium is not considered of significance.

Tin. Tin, analyzed only in floodplain soils, was detected in samples from 54 of the 55 floodplain borings in which it was analyzed. Samples from six borings contained concentrations above the maximum reference value of 72,000 μg/kg. Concentrations in samples from the six borings (01.SB003, 126,000 μg/kg; 01.WOC91, 83,900 μg/kg; 01.FC21, 82,200 μg/kg; 01.FC32, 73,900 μg/kg; 01.WOCG6, 73,500 μg/kg; and 01.SB001, 72,800 μg/kg) exceeded the maximum reference concentration.

Vanadium. Vanadium concentrations (46,600 to 64,600 μg/kg) in soil exceeded a maximum reference concentration of 44,400 μg/kg in samples from only 8 of 83 borings. The two highest concentrations occurred in samples from borings 01.SB176 and 01.SB175 (south of Building 3592), which is where the samples with the highest mercury concentrations were also found. Because concentrations of vanadium only slightly exceeded the maximum reference concentration, it is probably not related to contamination.

Zinc. The maximum concentration of zinc detected in individual boreholes ranged from 7800 to 514,000 μg/kg; the maximum reference concentration was 258,000 μg/kg. The highest concentrations were typically found in floodplain soil samples (see Fig. 4.4.26). No pattern of zinc distribution within the WOC floodplain could be seen except that all locations were below Fifth Creek. Zinc is likely a by-product of some of the operations in WAG 1 and may have been released via spills (e.g., pipeline leaks) or by releases directly into the surface water network.

4.5 SURFACE WATER

Surface drainage and point-source discharges from WAG 1 enter WOC, Fifth Creek, or First Creek. In addition, groundwater beneath WAG 1 is believed to discharge to these creeks. An evaluation of point- and nonpoint-source releases of contamination from WAG 1 can be made by evaluating water quality in the creeks. Although the watershed for Northwest Tributary is outside WAG 1 to the west and northwest, it will also be evaluated because it converges with First Creek. The exit point from the WAG for all releases to surface water is the WOC water gap through Haw Ridge, at the southwestern perimeter.

Phase I of the characterization of surface waters was conducted between October 1990 and March 1991; 30 surface water grab samples were collected from the major WAG 1 creeks during both low base and high base flow conditions, as well as during storms that occurred during low and high base conditions.

Table 2.5.4 lists surface water sampling locations and the nature of the sampling event (e.g., low base nonstorm flow). Three WOC locations were sampled: SW-5, downstream of Fifth Creek and upstream of the 3500 impoundment area; 01.CS003, just downstream of the 3500 impoundments; and SW-6, downstream of the First Creek confluence and below the 7500 bridge at the southern end of WAG 1.

Sampling sites SW-4 and 01.CS008 were south of Central Avenue in Fifth Creek. First Creek was sampled at locations 01.CS011 (approximately 200 ft above the confluence with Northwest Tributary), SW-7 (approximately 450 ft upstream of 01.CS011), and 01.CS010 (approximately 750 ft upstream of SW-7). Northwest Tributary was sampled at 01.CS012 (approximately 100 ft above the confluence with First Creek) and SW-8 (approximately 250 ft upstream of 01.CS012).

Sampling locations SW-5 through SW-8 coincide with flow gauging stations operated by the USGS on WOC, First Creek, and Northwest Tributary. These locations were sampled so that flow data could be used to calculate contaminant flux at the time of sampling. Because no gauging station was present in Fifth Creek, measurements of water level and velocity were obtained at SW-4 at the time of sample collection. Hydrographs created from data collected at each of the USGS flow measurement stations during the Phase I sampling periods are presented in Appendix B.

Twelve surface water samples (including one duplicate) were collected during low base flow from five locations in WOC, two in First Creek, one in Fifth Creek, and two in Northwest Tributary. Two locations in WOC and two in Fifth Creek were sampled during a low base storm event. During high base nonstorm flow conditions, five samples were collected from five locations (one each in First Creek, Fifth Creek, and Northwest Tributary, and two in WOC). During the high base storm event, five samples were collected from five locations (one each in Fifth Creek, First Creek, and Northwest Tributary, and two in WOC). Section 2 provides an overview of sampling activities.

Samples were analyzed for radionuclides, VOCs, BNAEs, metals, pesticides, PCBs, cyanide, and a variety of water quality parameters. Analyses for organophosphates,

herbicides, and dioxins/furans were conducted on one sample from WOC station SW-6. Appendix B contains detailed analytical data for each surface water sample.

An additional screening survey of First Creek was completed during September and October 1991 as part of the investigation into the nature and extent of the contamination encountered during the installation of corehole CH008 (see Appendix B). Because it was hypothesized that contaminated groundwater associated with that encountered in corehole CH008 might discharge to First Creek, samples were collected from the creek at intervals of approximately 50 ft between Bethel Valley Road and White Oak Avenue. Samples were also collected from four outfalls (ORNL numbers 341, 342, 250, and 249) and analyzed at the CSL for gross alpha, gross beta, gamma spectroscopy, and tritium. Appendix B presents the details of this survey.

This section is organized into four subsections. Section 4.5.1 summarizes the results of previous surface water quality investigations performed by ORNL. Sections 4.5.2 and 4.5.3 describe the nature and extent of radiological and chemical contamination in surface water, respectively, identified from the results of the Phase I investigation. Section 4.5.4 presents general observations concerning surface water contamination. Data from surface water reference location sampling are presented in Sect. 4.2.

4.5.1 Previous Studies

Surface water samples were collected in WOC and its major tributaries at various times between 1985 to 1989. Many of these samples were collected as part of a program designed to identify, monitor, and minimize ORNL point-source discharges to the aquatic environment. The samples were analyzed primarily for radionuclides (total strontium, cesium-137, cobalt-60, and tritium), mercury, and PCBs. Some studies also analyzed transuranics. Flow regimes during sampling events were not identified in most of the published reports of these analyses; therefore, sampling conditions (storms, low base, etc.) are not reported in this synopsis.

Most of the data obtained in these studies are published in the annual ORR Environmental Surveillance Program reports (Energy Systems 1985–1990). Other related data are available in reports written by F.G. Taylor, Jr. (Taylor 1989; 1990a,b). A summary of the data reported in these publications is presented in Table 4.5.1. Sampling locations are shown on Fig. 4.5.1.

This review of previous studies is organized into the following subsections: headwater areas, WOC within WAG 1, First Creek, Fifth Creek, Northwest Tributary, and surface waters downstream of the perimeter of WAG 1.

4.5.1.1 Headwater area surface water quality

The headwater area of WOC includes the headwaters of WOC above WAG 1 as well as sampling locations in First and Fifth Creeks north of Bethel Valley Road (upstream of the WAG 1 boundary). Radionuclides, mercury, and PCBs were the main constituents of concern.

Comparison of radionuclide sampling results shows that concentrations of most constituents have remained at relatively constant levels. Exceptions include cobalt-60, which increased from less than approximately 8 pCi/L (1986 and 1897) to 24 pCi/L and 49 pCi/L in 1988 and 1989, respectively; cesium-137, which increased from less than 8 pCi/L to 24 pCi/L in 1988 and 1989; a total strontium anomaly of 130 pCi/L in 1987 from less than 10 pCi/L; and tritium, which decreased through time from a maximum concentration of 70,000 pCi/L in 1986 to 620 pCi/L in 1989. Mercury results were at or below detection limits throughout the multiple sampling events conducted by Taylor (1989; 1990a). PCBs were also at or near detection limits (Taylor 1990b).

4.5.1.2 Fifth Creek surface water quality

Surface water sampling events were conducted at Fifth Creek under the ORR Environmental Surveillance Program. The primary constituents analyzed were cobalt-60, cesium-137, and total strontium; limited inorganic analyses were also performed (1986). Taylor also analyzed mercury and PCBs in samples collected in this creek and just below its confluence with WOC.

Results for cobalt-60 analyses were at or below detection limits until 1989, when levels increased to 51 pCi/L. Cesium results also increased from < 1.3 to < 8.1 pCi/L in 1986 and 1987 to 24 pCi/L and 14 pCi/L in 1988 and 1989, respectively. A total strontium anomaly (relatively low results overall with a "spike" in 1987) similar to the one found in the WOC headwaters was noted. The maximum concentration reported for surface water in Fifth Creek was 810 pCi/L. Mercury results also fluctuated through time, with a maximum concentration of 4.77 ng/mL (4.77 μg/L) in 1988 (Energy Systems 1989; Taylor 1989). Zinc, nitrate/nitrogen, chromium, and PCBs either were not present or were detected at background levels.

4.5.1.3 WOC surface water quality

Point-source discharges enter, or have entered in the past, WOC at various locations between Fifth Creek and First Creek. These discharges are (or were) from the 3500 series impoundments, the Process Waste Treatment Plant (PTWP) and Sewage Treatment Plant (STP), and the 2000 area. Additional information on point-source discharges permitted under NPDES and their influence on surface water hydrology is presented in Sect. 3.4 of this report.

The PWTP and STP discharges were sampled from 1979 through 1986 under the Environmental Surveillance Program and analyzed only for strontium-90. Strontium releases to WOC ranged from 0.3 to 33 pCi/L from PWTP and from 4 to 36 pCi/L from STP. Taylor collected a surface water sample at the confluence of the STP drainage area and WOC; Aroclor-1254 levels ranged from 0.3 to 1.1 μg/L.

The 2000 area surface water discharge (downstream of STP) to WOC was sampled in 1987 and analyzed for cobalt-60, cesium-137, total strontium, and gross beta. Results for cobalt-60 and cesium-137 were less than 5.9 and 5.4 pCi/L, respectively. Total strontium

and gross beta results ranged from 4.0 to 73 and 20 to 32 pCi/L, respectively (Energy Systems 1988).

4.5.1.4 First Creek surface water quality

The constituents analyzed in samples collected in First Creek were the same as those for the WOC samples. The results, however, do not follow a similar trend. Cobalt-60 and cesium-137 concentrations were both higher in 1986 than in 1987 and increased through 1988 and 1989 to levels greater than those detected in 1986. Total strontium levels decreased through the four years of surveillance sampling from a maximum of 1000 pCi/L in 1986 to a maximum of 510 pCi/L in 1989. Mercury and PCB results from the 1989 surveillance monitoring and Taylor studies were at or near detection limits.

The 1500 area is located between First Creek and Northwest Tributary. In 1987, the ORR Environmental Surveillance Program obtained samples from the discharge area to WOC. Gross alpha was detected between 1 and 32 pCi/L, and gross beta was detected between 8.1 and 310 pCi/L.

4.5.1.5 Northwest Tributary surface water quality

Surveillance sampling of Northwest Tributary above its confluence with WOC from 1986, 1988, and 1989 showed slightly increasing levels of cobalt-60, sporadic presence of cesium-137, and relatively consistent concentrations of total strontium. Maximum results for 1986, 1988, and 1989 for cobalt-60 were less than 11, 38, and 41 pCi/L, respectively. Cesium results ranged from less than 11 to 5.4 to 24 pCi/L, respectively, and total strontium maximums for these three years were 68, 62, and 78 pCi/L, respectively. No mercury was detected and PCBs were not analyzed.

4.5.1.6 Surface water quality downgradient of WAG 1 perimeter

WAG 1 downgradient sampling locations included the 7500 bridge, situated at the southern perimeter of WAG 1, locations in WOC, White Oak Dam, and the confluence of WOC and the Clinch River. All of these locations were investigated under the ORR Environmental Surveillance Program. Samples collected at the 7500 bridge were analyzed consistently through time for the same constituents.

The maximum concentrations of these constituents for all four years of monitoring were cobalt, 760 pCi/L (1986); cesium, 2200 pCi/L (1986); total strontium, 840 pCi/L (1986); tritium, 590,000 pCi/L (1987). No data trends by constituent are apparent in these results, although it appears that tritium levels decreased over time. The highest concentrations of radionuclides, with the exception of tritium, were reported in the 1986 samples (Energy Systems 1987).

Cobalt-60, cesium-137, and total strontium/strontium-90 results were highest at White Oak Dam: cobalt-60 was detected at 1900 pCi/L, cesium-137 at a maximum of 650 pCi/L, and strontium-90 at a maximum of 3500 pCi/L in samples collected in 1985 and 1986. Tritium was highest at the WOC locations upstream of the dam. Radionuclide results

decreased sharply between White Oak Dam and the WOC/Clinch River confluence locations. Zinc, nitrate/nitrogen, mercury, and chromium were at or near detection limits.

4.5.2 Radiological Contamination in Surface Water

Both man-made strontium-90 and cesium-137 and naturally occurring radionuclides were detected in surface water samples collected during the Phase I investigation. Radium-228 and uranium-234, which can be either naturally occurring or man-made, were detected above reference levels. The minimum and maximum concentrations and the number of occurrences for each radionuclide detected in WAG 1 surface water samples collected during Phase I are listed in Table 4.5.2. Figures 4.5.2 through 4.5.6 present the concentrations of selected radionuclides found in unfiltered samples; Figs. 4.5.7 through 4.5.9 show the concentrations in filtered samples. These figures illustrate seasonal fluctuations in the concentrations of the radionuclides. Figure 4.5.10 presents the flow rates at the time of sampling at locations SW-4 through SW-8, as well as the results of analyses for radiological parameters. These flow rates were calculated from USGS data and observations made at Fifth Creek, previously described.

Sampling results for man-made radionuclides have been compared with both reference data and the MCLs promulgated under the SDWA (revised April 15, 1991). This comparison identifies the occurrence of surface water contamination that may be the result of releases from sources within WAG 1 and provides an initial focus for data discussion. MCLs have been established for gross alpha (15 pCi/L), tritium (20,000 pCi/L), strontium-90 (8 pCi/L), radium (5 pCi/L, the sum of radium-226 and radium-228 concentrations), and man-made beta (4 mrem/year). For other man-made radionuclides, a 4-mrem/year MCL exists. Naturally occurring radionuclides that do not have MCLs are compared with reference levels to determine whether detected concentrations are indicative of contamination from sources within WAG 1.

It is not intended to imply that results exceeding MCLs necessarily pose a threat to human health or the environment under current-day exposure conditions. Nor is it intended to suggest that results below MCLs do not pose a potential threat. A preliminary assessment of the risk posed by contaminant releases from WAG 1 to potential human and environmental receptors is presented in the WAG 1 PRAR, which accompanies this SCSR.

4.5.2.1 Nature and extent of individual radionuclides

Strontium. In all but one sample (collected from SW-5 in WOC during the high base storm event), strontium concentrations in both unfiltered and filtered surface water samples exceeded the SDWA MCL of 8 pCi/L. Total radioactive strontium (which includes strontium-89 and strontium-90) was analyzed in all high base samples and in a sample from 01.CS011 collected during the low base nonstorm event. For clarity, the following discussion specifies the type of strontium analysis performed when reporting detected concentrations. Because the half-life of strontium-89 is short (52 days), it is likely that most, if not all, of the total radioactive strontium detected is attributable to strontium-90.

Total radioactive strontium and strontium-90 were detected in WOC, First Creek, Fifth Creek, and Northwest Tributary. Total radioactive strontium was also detected in reference location surface water; the maximum concentration was 1.11 pCi/L in an unfiltered sample.

The highest concentrations (544 pCi/L strontium-90 at SW-7 and 475 pCi/L total radioactive strontium at 01.CS011) were found in First Creek during the low base nonstorm sampling event (see Figs. 4.5.3 and 4.5.8). In all but one sample collected during Phase I (collected at location SW-5 in WOC during the high base storm event), strontium concentrations in both filtered and unfiltered samples exceeded the MCL of 8 pCi/L.

First Creek. Samples from First Creek station SW-7 contained the highest concentration of strontium-90 detected in WAG 1 surface water; the unfiltered sample collected during low base contained 544 pCi/L, and the filtered sample contained 489 pCi/L. The next highest concentrations were detected in samples collected several weeks later during the low base storm event in First Creek (01.CS011); the unfiltered sample contained 475 pCi/L total radioactive strontium, and the filtered sample contained 380 pCi/L total radioactive strontium.

The high base nonstorm event unfiltered sample collected at SW-7 contained total radioactive strontium at 142 pCi/L, and the high base storm sample contained 30.7 pCi/L of total radioactive strontium.

The results of a limited screening survey performed in October 1991 (Sect. 2) indicated that elevated gross beta activity, presumably strontium, enters First Creek via a seep near the contact between Chickamauga Units D and E and via two storm water outfalls (341 and 342) west of Building 2500. Sampling locations SW-7 and 01.CS011 are both downstream of these discharges.

The contaminant flux at SW-7 was calculated using flow rate measurement data (see Fig. 4.5.10 and Table 4.5.3) and the results for unfiltered samples for each sampling event. During the low base nonstorm flow condition, when the maximum concentration was measured, the flux of strontium-90 (or total radioactive strontium) in First Creek at SW-7 was approximately 2900 pCi/s. The flux of total radioactive strontium calculated for the high base nonstorm event was approximately 3200 pCi/s, and the flux of total radioactive strontium for the high base storm event was approximately 11,300 pCi/s. These calculations indicate that significantly more strontium is transported in First Creek during a storm event during high base conditions, even though concentrations are an order of magnitude less than those detected during low base conditions.

Northwest Tributary. Strontium-90 concentrations of 86.6 (unfiltered) and 83.8 (filtered) pCi/L were detected in Northwest Tributary in low base nonstorm samples from location SW-8; this unfiltered concentration corresponds to a strontium-90 flux of 1400 pCi/s, using the flow rate measured (16.1 L/s) at the time of sampling. Except for samples from First Creek (described earlier), these are the highest concentrations detected in surface water. The source of strontium contamination in Northwest Tributary may be WAG 3, approximately 3000 ft to the west. Strontium contamination has been identified in surface water and groundwater at WAG 3 (Webster 1976). It is also possible that a portion of the groundwater

contamination plume detected in CH008 underflows First Creek and discharges to Northwest Tributary.

White Oak Creek. The highest strontium concentration detected in samples from WOC (74.6 pCi/L) was in the unfiltered sample collected at SW-6 during the high base nonstorm event. SW-6 is downstream of the confluence of First Creek and WOC. Samples from SW-5, upstream of SW-6, contained the lowest concentrations of strontium detected in WOC, ranging from 4.88 pCi/L total radioactive strontium in the unfiltered sample collected during the high base storm event to 13.2 pCi/L strontium-90 in the unfiltered sample from the low base nonstorm event. The total radioactive strontium concentration of 4.88 pCi/L may be biased high; the associated rinsate contained a small percentage (i.e., 1.64 pCi/L) of radioactive strontium (see Appendix C, Sect. C7). The filtered portion of the low base nonstorm sample from SW-5 contained strontium-90 at a concentration of 11.8 pCi/L.

Although strontium concentrations in WOC are lower than those observed in First Creek, it appears that a greater flux of strontium is associated with WOC. Comparing the low base nonstorm strontium-90 flux in SW-7 of 2937 pCi/s with the low base flux of 9250 pCi/s in SW-6, it is apparent that approximately half of the strontium in WOC below its confluence with First Creek is attributable to First Creek and Northwest Tributary (Table 4.5.3). The other half (approximately 4900 pCi/s) is therefore attributable to WOC. Because the low base nonstorm flux of strontium-90 at SW-5 was only approximately 1083 pCi/s, a significant quantity of strontium must enter WOC between SW-6 and SW-5. Sources may include a number of outfalls, SWSA 1 runoff or leachate, leaking LLLW lines, contaminated groundwater discharge from the main plant area, or seepage from the 3513/3524 surface impoundments.

Fifth Creek. SW-4 was the only location in Fifth Creek from which surface water samples were collected for radiological analyses. Strontium concentrations in samples from SW-4 ranged from 17.09 pCi/L total radioactive strontium in an unfiltered sample collected during the high base storm event to 45 pCi/L strontium-90 in a filtered sample (40.1 pCi/L unfiltered) collected during the low base nonstorm period (see Figs. 4.5.3 and 4.5.8).

A concentration of strontium-90 of 40.1 pCi/L at SW-4 in low base nonstorm flow represents a flux of approximately 1042 pCi/s, calculated using the flow rate measured during sampling (26 L/s). This flux is similar to that calculated for downstream location SW-5 in WOC during low base nonstorm flow conditions (1083 pCi/s).

Tritium. Concentrations of tritium detected in WAG 1 surface water samples were below the SDWA MCL of 20,000 pCi/L (Fig. 4.5.4). The maximum of 5780 pCi/L was found in the unfiltered sample taken from SW-6 in WOC during the high base nonstorm flow event; a maximum of 1120 pCi/L was present in reference samples. Tritium was not analyzed in filtered samples. Previous studies (Sect. 4.5.1) reported significantly higher concentrations at the 7500 bridge (up to 590,000 pCi/L), approximately 100 ft upstream of SW-6. These earlier data indicate that there is a potential for high variability in the amount of tritium in WOC.

The highest concentration of tritium (1700 pCi/L) detected in samples from First Creek was from 01.CS011, collected during the low base nonstorm event. The next highest (1400 pCi/L) was detected in the low base nonstorm sample from SW-7. The high base nonstorm and storm samples from SW-7 contained 1360 and 790 pCi/L, respectively.

The highest concentration of tritium detected (1430 pCi/L) in Fifth Creek was from SW-4, collected during the high base storm event. Unlike First Creek, tritium concentrations in Fifth Creek were highest during the high base storm event and lowest during the low base nonstorm event.

The highest concentration of tritium detected (960 pCi/L) in samples from Northwest Tributary was from SW-8, collected during the high base storm event. The lowest concentration (490 pCi/L) was detected in the high base nonstorm sample.

Gross alpha and gross beta. Elevated alpha and beta activity was measured in samples from First Creek, Northwest Tributary, and WOC downstream of First Creek. Alpha activity was primarily attributable to naturally occurring radionuclides from the uranium and thorium series; most beta activity was attributable to strontium and, to a lesser degree, cesium-137, radium-228, and (possibly) potassium-40. The maximum gross alpha and beta values were 60.4 and 944 pCi/L, respectively, both from unfiltered samples collected in First Creek (location SW-7) during the low base nonstorm event. Maximum reference levels for gross alpha and gross beta were 1.6 pCi/L (unfiltered) and 2.2 pCi/L (filtered), respectively.

Gross alpha activity in 2 of 21 unfiltered samples collected during the Phase I investigation exceeded the SDWA MCL of 15 pCi/L (see Fig. 4.5.2). The filtered components from these samples were the only 2 of 11 filtered samples that exceeded the MCL. Both samples were taken from First Creek at locations SW-7 and 01.CS011 during low base nonstorm sampling (see Fig. 4.5.7).

First Creek. Samples from First Creek contained the highest concentrations of gross alpha and gross beta detected in WAG 1 surface water. Two samples exceeding the SDWA MCL of 15 pCi/L for alpha activity were taken from First Creek on two occasions (October and November 1990) under low base nonstorm flow conditions. A sample from SW-7 collected during low base nonstorm sampling had the highest gross alpha concentration (60.4 pCi/L) found among all surface water sampling locations in WAG 1. Uranium-234, an alpha-emitting radionuclide, was detected in the same sample at 22.7 pCi/L; this concentration accounted for approximately half of the gross alpha activity (see Fig. 4.5.5). Other alpha-emitters analyzed (thorium-232, thorium-230, thorium-228, and radium-226) did not account for the balance of this activity.

The gross beta activities of 944 and 824 pCi/L found in unfiltered samples collected during the low base nonstorm event from SW-7 and 01.CS011, respectively, can be attributed to strontium and radium-228 (see Figs. 4.5.3 and 4.5.4).

The gross alpha and beta concentrations detected at the groundwater seep near the Chickamauga Unit D/E contact during the First Creek screening survey in October 1991 were <898 and 4400 pCi/L (unfiltered) and <10 and <25 pCi/L (filtered). Concentrations

of gross alpha and gross beta in outfall 341, located in First Creek just north of White Oak Avenue, were <8.7 and 1400 pCi/L, respectively, in the unfiltered sample and 43 and 1800 pCi/L, respectively, in the filtered sample. The gross alpha and gross beta concentrations in the sample from outfall 342 were 200 and 13,000 pCi/L (unfiltered) and 180 and 10,000 pCi/L (filtered), respectively. Outfalls 341 and 342 are associated with the stormwater discharge system. The potential contaminated groundwater leakage to this system is discussed in Sect. 5.

White Oak Creek. No WOC surface water samples contained gross alpha contamination above the SDWA MCL limit of 15 pCi/L. The highest concentrations of gross beta (and strontium) in WOC were detected in unfiltered and filtered samples collected from SW-6 during high base nonstorm conditions. Gross beta values significantly exceeded the maximum reference activity of 2.2 pCi/L at downstream WOC locations 01.CS003 and SW-6. Gross beta activity ranged from 81.2 to 184.9 pCi/L in the unfiltered samples taken from SW-6 during the three sampling events. Location 01.CS003 was sampled for radionuclide analyses only during the low base nonstorm condition; this sample contained 131 pCi/L gross beta.

Fifth Creek. The gross alpha content in samples collected at SW-4 during all sampling events was at or below the maximum reference level of 2.2 pCi/L and the MCL of 15 pCi/L. Gross beta activity in samples from SW-4 ranged from 25.9 to 81.8 pCi/L; the highest concentration was detected in the low base nonstorm sample, and the lowest was detected in the high base storm sample. The gross beta concentration of 81.8 pCi/L can be attributed to a strontium-90 concentration of 40.1 pCi/L and equal amounts of yttrium-90, assuming that yttrium-90, a daughter product of strontium-90, is present in secular equilibrium.

Northwest Tributary. The concentration of gross alpha was below 15 pCi/L in all samples collected in Northwest Tributary. The maximum concentration of 8.09 pCi/L was detected in the filtered sample collected at SW-8 during low base nonstorm sampling.

Radium. Radium-228 only was analyzed in samples collected during low base nonstorm events. Samples collected during subsequent events were analyzed for total radium (the sum of radium-226 and radium-228).

Radium-228 activities ranged from 2.06 pCi/L (SW-5) to 152 pCi/L (SW-7) in unfiltered samples and from 2.61 pCi/L (SW-5) to 123 pCi/L (SW-7) in filtered samples (see Figs. 4.5.4 and 4.5.9). The maximum reference concentration of radium-228 was 1.77 pCi/L, detected in an unfiltered sample collected during low base nonstorm conditions. Samples from seven locations contained radium-228 in excess of this concentration.

All sampling locations except SW-5 in WOC and First Creek location 01.CS011 yielded samples with total radium concentrations in excess of the MCL of 5 pCi/L. The only detections of radium-226 were in samples from 01.CS011 collected during the low base nonstorm sampling event; the unfiltered sample from this location contained 0.18 pC/L, and the filtered sample contained 0.09 pCi/L.

The radium detected in samples from locations SW-4, SW-5, and 01.CS003 appears to be naturally occurring. The samples from SW-6, SW-7, and SW-8 may contain processed radium; concentrations are elevated compared with reference levels.

First Creek. The maximum WAG 1 concentration of radium-228 (152 pCi/L) was detected in an unfiltered sample collected at SW-7 during low base conditions. However, an unfiltered sample collected one month earlier at 01.CS011, located approximately 450 ft downstream, did not contain radium-228. The low base nonstorm sample collected at 01.CS011 contained 824 pCi/L gross beta and 475 pCi/L total radioactive strontium, and the sample from SW-7 contained 944 pCi/L gross beta and 544 pCi/L strontium-90.

The surface water flow rate at SW-7 during both sampling events was approximately 5.66 L/s. Consequently, it is likely that the flow rate at 01.CS011 was similar during both sampling events and that the difference in concentrations is not the result of dilution. There may be an intermittent source of radium that enters First Creek upstream of SW-7.

Uranium and thorium series. Thorium-228 and uranium-235, -236, and -238 concentrations detected in unfiltered and filtered samples (Table 4.5.2) were similar to those found in reference location samples. Other radionuclides associated with the natural thorium and uranium decay series were detected at concentrations well above levels found in reference location samples, suggesting that they are process-derived contaminants.

First Creek. A sample from SW-7 in First Creek contained the highest gross alpha activity (60.4 pCi/L) detected in WAG 1 surface water samples during the low base nonstorm sampling event. Uranium-234 (22.7 pCi/L) accounted for almost half of this activity; the uranium-238 concentration (1.2 pCi/L) was relatively low by comparison. Without the influence of uranium-238 enrichment processes, the two radionuclides should be found in similar concentrations in the environment. Other alpha-emitting radionuclides analyzed were not present at sufficient levels to account for the balance of this gross alpha activity. Uranium-234 was also detected in First Creek (location 01.CS011) at a concentration of 20.73 pCi/L during low base conditions (see Fig. 4.5.5).

Uranium-234 was detected at 8.9 pCi/L at SW-7 during the high base nonstorm sampling event and at 1.7 pCi/L at the same location during the high base storm event. The former concentration exceeds secular equilibrium with uranium-238, while the latter may not. The concentrations that exceed secular equilibrium levels may indicate the presence of man-made contamination.

White Oak Creek. Thorium-232 was detected at 10.2 pCi/L in a sample collected at location 01.CS003 during the low base nonstorm sampling event. The maximum concentration (7.25 pCi/L) of thorium-230 detected in WAG 1 surface water was also found in this sample.

Fifth Creek. Uranium-234 was detected 2.79 pCi/L in a sample collected during the low base nonstorm event (SW-4). A sample in which a concentration of thorium-232 was detected at 57±46.1 pCi/L (also collected at SW-4 during high base storm sampling) was considered suspect because the error term was 80% of the value. In addition, the gross alpha

for the same sample was 1.5±1.2 pCi/L, which suggests that thorium-232 was present closer to reference concentrations.

Cesium. *White Oak Creek.* Cesium-137 was detected only in unfiltered samples collected from WOC (see Fig. 4.5.6). The highest concentration (109 pCi/L) was detected in a low base nonstorm sample collected at location 01.CS003. All other cesium-137 concentrations were at or below 50.9 pCi/L. The MCL for cesium-137 is 119 pCi/L (based on a dosage rate of 4 mrem/year); this level was not exceeded in any samples. Cesium-137 was not detected in reference location samples.

The occurrence of cesium-137 in unfiltered samples and its absence in filtered samples indicates that the cesium-137 in surface water is probably related to sediment particles suspended in the sample. It is interesting to note that the cesium-137 concentration in WOC bottom sediments at 01.CS003 was 2480 pCi/g (see Sect. 4.6.2.1) and the floodplain soils in this area also contained elevated cesium-137 levels ranging from 333 to 22,170 pCi/g (see Sect. 4.4.2). The presence of cesium-137 in these sediments and soils supports the interpretation that cesium-137 in surface water is derived from erosion or suspension of contaminated soils and sediments.

Other locations. Cesium-137 was not detected in samples collected from First Creek, Fifth Creek, or Northwest Tributary.

Transuranics and other radionuclides. No transuranics or other radionuclides were detected in any of the surface water samples. Potassium-40 was not included in the laboratory reports; however, it is assumed to be present because it was found in Bethel Valley reference soils and in a reference surface water sample at 156±91 pCi/L.

4.5.3 Chemical Contamination in Surface Water

The following discussion of inorganic and organic compounds and elements detected in samples collected during the Phase I investigation is divided into separate sections: VOCs, BNAEs, metals, and other contaminants.

Thirty surface water samples were collected from 25 locations during this investigation. Twenty-five of these were regular samples, three were duplicates, and two resulted from a resampling for BNAEs (one regular and one duplicate). Only unfiltered samples were collected for organic chemical analyses; both filtered and unfiltered samples were collected for metal analyses.

Metals, BNAEs, VOCs, and cyanide were detected. No metals were detected at concentrations exceeding their MCLs. No organophosphorous pesticides, dioxins/furans, and chlorinated herbicides were detected in any surface water samples.

The sampling results have been compared with both reference data and the MCLs promulgated under the SDWA (revised April 15, 1991). This comparison identifies the occurrence of surface water contamination that may be the result of releases from sources within WAG 1 and provides an initial focus for data discussion.

The intent is not to imply that results exceeding MCLs necessarily pose a threat to human health or the environment under current-day exposure conditions. Nor is it intended to suggest that results below MCLs do not pose a potential threat. A preliminary assessment of the risk posed by contaminant releases from WAG 1 to potential human and environmental receptors is presented in the WAG 1 PRAR, which accompanies this SCSR.

4.5.3.1 Nature and extent of VOC contamination

Eight VOCs were detected in surface water samples collected from WAG 1 (see Fig. 4.5.11). Chloroform, the most frequently detected VOC, was encountered in seven samples from five different locations; the maximum concentration was 3J μg/L. Bromodichloromethane was detected in two samples from two locations, both at 1J μg/L.

Dichlorodifluoromethane, pyridine, trichlorofluoromethane, p-dioxane, TCE, and PCE were each detected once. The concentration of PCE detected in a sample from Northwest Tributary during low base conditions equaled the SDWA MCL of 5 μg/L.

Chloroform. Three samples from WOC contained chloroform in concentrations at or below 3 μg/L, which is below the maximum reference value of 4J μg/L. Chloroform was detected in one First Creek sample during low base nonstorm sampling at 2J μg/L; in a Fifth Creek sample at 1J μg/L; and in samples from Northwest Tributary during both high and low base nonstorm events (each at 2J μg/L).

The presence of chloroform in the reference samples and the narrow range of detected concentrations in surface water (i.e., 1J to 4J μg/L) indicates that chloroform may be a laboratory artifact. Another potential source of chloroform is STP, which discharges chlorinated effluent into WOC south of the sewage lagoons.

Dichlorodifluoromethane and trichlorofluoromethane. These compounds were each detected in the low base nonstorm sample from WOC (location SW-6) at 2J and 3J μg/L, respectively. Neither of these freon compounds was found in reference samples, and this was their only occurrence. Halogenated methanes are highly volatile and uncommon in surface water due to rapid evaporation [Howard (1990) reports a half-life of 4.3 h in surface water]. Consequently, these compounds probably represent laboratory artifacts rather than site-related contamination.

TCE and PCE. These chlorinated aliphatic compounds were detected only once each in surface water samples. TCE was detected (3J μg/L) in an unfiltered sample from Fifth Creek (location SW-4) collected during low base storm conditions. PCE was detected in the low base flow nonstorm sample from Northwest Tributary (location SW-8) at a concentration of 5 μg/L, which is equal to the SDWA MCL.

TCE was detected in a number of groundwater monitoring wells in the central and western portions of WAG 1. The general absence of these contaminants from the surface water bodies bordering WAG 1 suggests that either (1) any TCE discharged to surface water is lost through dilution, volatilization, or other mechanisms or (2) the TCE in contaminated groundwater is not discharging to the creek.

Pyridine and p-dioxane. Pyridine and p-dioxane were detected in samples from WOC in concentrations of 71J and 89J μg/L, respectively. These unfiltered samples were collected during the low base sampling event. These compounds were not detected in any of the reference location samples; neither has an MCL.

4.5.3.2 Nature and extent of BNAE contamination

Two BNAEs, N-nitroso-n-phenylbenzenamine and bis(2-ethylhexyl)phthalate, were detected in WAG 1 surface water at maximum concentrations of 3 μg/L each (see Fig. 4.5.11). In samples from WOC, both compounds were detected at or below 3J μg/L and did not exceed the maximum concentration found in reference location samples. Bis(2-ethylhexyl)phthalate is a common plasticizer, and N-nitroso-n-phenylbenzenamine has been identified as a probable laboratory contaminant.

The only BNAE detected in samples collected from Fifth Creek (location SW-4) was N-nitroso-n-phenylbenzenamine, detected once at 2J μg/L. No BNAEs were detected in samples from First Creek or Northwest Tributary.

4.5.3.3 Nature and extent of metals

Table 4.5.2 lists the minimum and maximum detected concentrations for each metal found in surface water. Many samples contained metals slightly in excess of reference values, but none of the concentrations exceeded MCLs.

Aluminum. Aluminum was detected in both filtered and unfiltered samples. The concentrations detected in unfiltered samples ranged from 88.9 to 2190 μg/L; the highest concentration was detected in a sample collected in Northwest Tributary (SW-8) during high base storm conditions. In filtered samples, aluminum concentrations ranged from 41 to 201 μg/L; the highest concentration was detected in a sample collected in Fifth Creek (SW-4) during low base nonstorm conditions.

Aluminum was detected in reference samples at a maximum concentration of 44 μg/L (unfiltered); it was not detected in the filtered reference samples. There is no MCL for aluminum.

Arsenic. Arsenic was detected in only one filtered sample at a concentration of 2.2 μg/L; this sample was collected in WOC (SW-6) during the high base nonstorm condition. Arsenic was not detected in the unfiltered portion of this sample at a detection level of 2 μg/L.

Arsenic was not detected in reference location samples. The MCL is 50 μg/L.

Barium. Barium was detected in both unfiltered and filtered samples. Concentrations in unfiltered samples ranged from 26.2 to 48.1 μg/L. The highest concentration was detected in a sample collected in Fifth Creek (SW-4) during the low base nonstorm condition. In filtered samples, barium concentrations ranged from 16.7 to 47.7 μg/L. The highest

concentration was detected in the same sample collected in Fifth Creek (SW-4) during the low base nonstorm condition.

Barium was detected in reference location samples at a maximum of 44 μg/L (unfiltered) and 78.4 μg/L (filtered). The MCL is 2000 μg/L.

Cadmium. Cadmium was detected in only one unfiltered sample (2.5 μg/L) from WOC location SW-6 during low base nonstorm conditions. It was detected in filtered samples at concentrations ranging from 2.2 to 2.5 μg/L; the highest concentration was in samples collected in WOC (SW-6) and First Creek (SW-7) during low base nonstorm conditions.

In reference samples, the maximum cadmium concentration was 2.8 μg/L (filtered); it was not detected in unfiltered samples. The MCL for cadmium is 5 μg/L.

Chromium. Chromium detected in unfiltered samples ranged from 10.7 to 13.6 μg/L; the highest concentration was in a sample collected in WOC (SW-6) during low base nonstorm conditions. In filtered samples, chromium ranged from 10.4 to 13.3 μg/L; the highest concentration was in a sample collected in First Creek (SW-7) during the same low base nonstorm event.

Chromium was not detected in reference samples. The MCL is 100 μg/L.

Copper. Copper concentrations detected in unfiltered samples ranged from 11.1 to 96.7 μg/L; the highest was in a sample collected in First Creek (SW-7) during low base nonstorm conditions. In filtered samples, concentrations ranged from 8.3 to 73.4 μg/L; the highest concentration was in a sample collected in First Creek (SW-7) during the same low base nonstorm event.

Copper was detected in reference location samples at a maximum of 12 μg/L (unfiltered); it was not detected in filtered reference samples. The EPA action level is 1300 μg/L.

Lead. Lead concentrations in unfiltered samples ranged from 2.1 to 13.9 μg/L; the highest concentration was in a sample collected in WOC (SW-5) during the high base storm event. In filtered samples, lead concentrations ranged from 2.8 to 3.6 μg/L; the highest concentration was in a sample collected in Northwest Tributary (SW-8) during the same low base nonstorm event.

Lead was detected in unfiltered reference samples at a maximum of 3.8 μg/L; it was not detected in filtered reference samples. The MCL is 15 μg/L.

Manganese. Manganese in unfiltered samples ranged from 14.5 to 143 μg/L; the highest concentration was in a sample collected in WOC (SW-6) during the high base storm event. In filtered samples, manganese ranged from 11.6 to 39.3 μg/L; the highest concentration was in a sample collected in WOC (SW-6) during the same high base storm event.

Manganese was detected in reference samples at a maximum concentration of 28 μg/L (unfiltered) and 16.6 μg/L (filtered). The secondary drinking water standard for manganese is 50 μg/L.

Nickel. Nickel was detected in three unfiltered samples and one filtered sample. In the unfiltered samples, concentrations ranged from 5.2 to 6.3 μg/L; the highest concentration was in a sample collected in WOC (SW-6) during the high base storm event. Nickel was detected in the filtered component of this same sample at 6.9 μg/L.

Nickel was not detected in reference samples. The EPA action level for nickel is 15 μg/L.

Selenium. Selenium was detected (2.4 μg/L) in only the unfiltered component of a sample collected in WOC (SW-6) during low base nonstorm conditions.

Selenium was not detected in reference samples, and there is no MCL.

Silver. Silver concentrations in unfiltered samples ranged from 10.2 to 12.3 μg/L; the highest concentration was in a sample collected in WOC (SW-6) during low base nonstorm conditions. In filtered samples, concentrations ranged from 10.7 to 12 μg/L, with the highest detected in a sample collected in First Creek (SW-7) during low base nonstorm conditions.

Silver was not detected in reference samples. The RCRA MCL for silver is 50 μg/L.

Vanadium. Vanadium was detected only in unfiltered samples at concentrations ranging from 3.1 to 5.1 μg/L; the highest concentration was in a sample collected in WOC (SW-6) during the high base storm event.

Vanadium was not detected in reference samples, and there is no MCL.

Zinc. Zinc concentrations in unfiltered samples ranged from 13.7 to 57.7 μg/L; the highest concentration was in a sample collected in WOC (SW-6) during the high base storm event. In filtered samples, concentrations ranged from 10.9 to 46.1 μg/L, with the highest concentration detected in a sample collected in First Creek (SW-7) during the low base nonstorm condition.

Zinc was not detected in reference samples, and there is no MCL.

Other metals. Antimony, arsenic, beryllium, cobalt, mercury, osmium, thallium, and tin were not detected in unfiltered samples. In filtered samples, antimony, beryllium, cobalt, mercury, osmium, selenium, thallium, tin, and vanadium were not detected. However, other metals common to surface waters were also detected. Calcium ranged from 445.2 to 51,600 μg/L in unfiltered samples and 25,400 to 52,200 μg/L in filtered samples. Iron ranged between 70 and 2600 μg/L in unfiltered samples and 11.4 and 27.4 μg/L in filtered samples. Magnesium ranged from 113.8 to 12,500 μg/L in unfiltered samples and 3660 to 12,600 μg/L in filtered samples. Potassium ranged between 599 and 1710 μg/L in unfiltered

samples and 956 and 1710 μg/L in filtered samples. Sodium ranged from 40.6 to 12,300 μg/L in unfiltered samples and 2410 to 12,500 μg/L in filtered samples.

4.5.3.4 Nature and extent of other contaminants

Cyanide was detected in a sample collected in WOC (location SW-5) during the low base nonstorm condition at 1.2 μg/L, which is below the SDWA MCL of 50 μg/L. No pesticides, PCBs, herbicides, dioxins/furans, or organophosphates were detected in any of the surface water samples.

4.5.4 General Observations

4.5.4.1 Radionuclides

Both man-made and naturally occurring radionuclides were detected during the Phase I RI in WOC, First Creek, Fifth Creek, and Northwest Tributary. The most frequently detected were strontium-90 and cesium-137, which are man-made. Radium-228 and uranium-234 were also detected above reference levels, but less frequently and at lower concentrations than strontium and cesium. While radium-228 and uranium-234 can be naturally occurring, it is believed that the amounts detected in samples from First Creek are man-made or enriched from on-site processes.

Although strontium concentrations in surface water were highest during low base flow, the flux of strontium (expressed in pCi/s passing through the creek at a given point) was greatest during the high base storm event. The flux of strontium-90 in WOC at the Haw Ridge water gap was estimated to be 9250 pCi/s during low base, 20,067 pCi/s total radioactive strontium during high base, and 85,550 pCi/s total radioactive strontium during the high base storm (see Table 4.5.3).

Approximately 50% of this flux is estimated to be contributed by First Creek and Northwest Tributary during low base nonstorm flow, and the nonstorm balance is estimated to be contributed by WOC. During high base conditions, however, First Creek and Northwest Tributary contribute only approximately 25% of this flux. This indicates that there is a strontium source that discharges greater quantities to WOC during high base and high base storm flow conditions than during low base conditions.

The known or potential sources of radiological contamination within these creeks include ORNL outfalls, groundwater discharge seeps, and resuspension/desorption of previously deposited contaminated sediment. Tentatively identified pathways through which contamination enters First Creek include a seep located near the geologic contact between Chickamauga Units D and E, approximately 350 ft northwest of Building 2069, and two storm drain outfalls (341 and 342), approximately 150 ft west of Building 2500. Both of the outfalls and the seep are sources of beta-emitting contamination, which is probably strontium-90, although the samples were not analyzed for strontium.

Strontium is entering WOC between the 3513/3524 impoundments and the confluence of WOC and First Creek. Phase I samples from groundwater monitoring wells located

adjacent to these impoundments (wells 874, 875, 1100, 1102, and 1104) contained elevated concentrations of strontium-90 (see Sect. 4.3.2). A sample from well 875 contained the second highest concentration of strontium-90 detected in groundwater during Phase I; the filtered component contained 12,000 pCi/L and the unfiltered component contained 10,300 pCi/L. There may be additional sources of strontium contamination, such as SWSA 1 and other ORNL outfalls (e.g., radiological process waste system), although sampling data obtained during the Phase I investigation are not adequate to identify these additional sources. The surface impoundments and the radiological process waste system outfall are the most probable sources of strontium-90 contamination to the surface water.

In most instances, radionuclide concentrations were slightly lower in filtered than in unfiltered samples. Gross alpha activities in surface water were near background levels and below the SDWA MCL of 15 pCi/L, except for two samples from First Creek. High gross alpha concentrations in First Creek may be partially attributable to uranium-234; other naturally occurring radionuclides were not present in sufficient quantities to account for the remaining alpha activity, suggesting that additional man-made radionuclides were present.

The data indicate that the presence of cesium-137 is limited to the portion of WOC downstream of the 3500 impoundment area. The highest concentrations of cesium-137 were found in samples collected during low base nonstorm conditions. Cesium-137 was not detected in filtered samples, suggesting that it is transported through adsorption to suspended sediments. Potential sources of cesium-137 include seepage from waste management units along WOC, discharge from outfalls, and erosion/suspension from bottom sediments and floodplain soils.

Uranium-234 and radium-228 are predominantly associated with First Creek. Their presence may be related to the groundwater and storm drain discharge associated with the contamination encountered at corehole CH008.

Tritium was also widely detected in WAG 1 surface water; in contrast with previous investigations, however, the detected concentrations were generally below reference levels and well below the MCL. The maximum concentration of tritium (5780 pCi/L) was detected in WOC near the Haw Ridge water gap during high base (nonstorm) flow conditions. Tritium concentrations else where in WOC and other creeks were generally similar between high and low base flow. The increased tritium detected in the downstream portion of WOC during high base flow therefore reflects increased input below WOC location SW-5 and may indicate greater discharge (or leakage) of tritium-contaminated water from the impoundments.

4.5.4.2 Chemicals

Of the few VOCs and BNAEs detected, only the VOCs pyridine and p-dioxane may be of concern, although they were not widely or routinely detected. Metal concentrations in all samples were well below MCLs, although aluminum, arsenic, chromium, copper, lead, manganese, nickel, selenium, silver, vanadium, and zinc were detected above reference levels. Cadmium was detected below reference levels.

4.6 SEDIMENTS

Surface drainage and point-source discharges from WAG 1 enter WOC, Fifth Creek, or First Creek. In addition, groundwater within WAG 1 discharges to these creeks. Therefore an evaluation of point- and non-point-source releases of contamination from WAG 1 can be made by evaluating sediment from the creeks. Northwest Tributary was included in the evaluation because it converges with First Creek.

Creek channel bottom sediment samples were collected concurrently with surface water samples during the low base nonstorm flow sampling event between October 16 and 22, 1990. Ten samples were collected: five from WOC (01.CS001 through 01.CS005), two from Fifth Creek (01.CS007 and 01.CS008), two from First Creek (01.CS010 and 01.CS011), and one from Northwest Tributary (01.CS012).

Most samples were analyzed for radionuclides, metals, VOCs, BNAEs, cyanide, pesticides, PCBs, and sulfides. The sample from 01.CS003 also underwent Appendix IX analyses, which included herbicides and organophosphate. Samples from Fifth Creek locations 01.CS007 and 01.CS008 and WOC location 01.CS001 were not analyzed for radionuclides. Samples from WOC location 01.CS004 and Fifth Creek location 01.CS008 were not analyzed for VOCs, and BNAEs were not analyzed in the sample collected from WOC location 01.CS003.

Section 4.6.1 summarizes the results of previous studies of sediment contamination. An assessment of the nature and extent of sediment contamination from the results of the Phase I sampling program are presented in Sects. 4.6.2 (radiological) and 4.6.3 (chemical). General observations are presented in Section 4.6.4. Analytical results for samples collected at reference locations in Fifth Creek (01.CS006) and First Creek (01.CS009) are presented in Sect. 4.2.

The sampling results were compared with reference location results; this comparison identifies the occurrence of sediment contamination that may be the result of releases from sources within WAG 1 and provides a focus for data discussion. Regulatory standards for sediment quality, such as MCLs, have not been promulgated.

4.6.1 Previous Studies

Table 4.6.1 provides a summary of the results of previous studies of contaminants in sediments in WOC and its tributaries in the area of WAG 1. The sampling locations cited in this table are shown in Fig. 4.5.1.

4.6.1.1 Headwater area sediment quality

Spalding and Cerling (1979) examined WOC sediments at its headwaters in 1978 to assess levels of strontium-90, cesium-137, and cobalt-60. Sediments in the headwaters were also analyzed for mercury (Oakes 1983a; Taylor 1990a) and total organic carbon (Taylor 1990b). Of the radioactive constituents analyzed, only strontium-90 was found above detection limits (nondetect to 0.7 dpm/g). Mercury was detected at levels of 0.08 ppm

(Oakes 1983a) to 0.063 μg/g (Taylor 1990a). At locations farther downstream (but upstream of the confluence with Fifth Creek), mercury levels remained relatively constant (5.3 to 5.04 μg/g) through time (Taylor 1989; 1990a). TOC in headwater area sediments ranged from 2.5 to 4.3% (Taylor 1990b).

4.6.1.2 Fifth Creek sediment quality

Analyses of mercury levels in Fifth Creek sediments were performed by Taylor (1989; 1990a), who sampled sediments at locations at or below NPDES outfalls. Mercury concentrations were the highest near three outfalls; concentrations ranged from 21.1 to 155.81 μg/g in samples from a containment box at outfall No. 362, 67.5 to 112.43 μg/g in sediment samples collected below outfall No. 362, and 4874 to 7427 μg/g near outfall No. 261.

4.6.1.3 White Oak Creek sediment quality

Cerling and Spalding (1979, 1981), Taylor (1989; 1990a), and Oakes (1983a) collected sediment samples in WOC between its confluences with Fifth and First Creeks. Spalding and Cerling analyzed strontium-90, cesium-137, and cobalt-60, whereas Taylor and Oakes investigated mercury levels. Radionuclide concentrations in sediments collected in 1978 below the Fifth Creek confluence ranged from below detection limits to 0.7 dpm/g strontium-90, 9 to 3409 dpm/g cesium-137, and 3 to 554 dpm/g cobalt-60. Results for these constituents in samples collected in 1980 above the First Creek confluence were slightly higher for strontium-90 (below detection limits to 22.4 dpm/g) and cesium-137 (below detection limit to 23,200 dpm/g). However, cobalt-60 levels were lower in the sample from this location (370 dpm/g). Mercury concentrations in sediment samples collected along this section of WOC ranged from 0.4 to 19 ppm (Oakes 1983a).

4.6.1.4 First Creek sediment quality

Cerling and Spalding (1981) analyzed sediment samples from First Creek; they noted only strontium-90 and cesium-137 in the sediment at maximum concentrations of 5.5 dpm/g and 272 dpm/g respectively. Mercury was detected at a maximum concentration of 1.37 μg/g (Taylor 1990a). In samples collected in Northwest Tributary near its junction with First Creek, the maximum concentration of mercury detected was 0.17 μg/g (Taylor 1989).

4.6.1.5 Sediment quality downgradient of WAG 1 perimeter

In a study of sediment quality in WOC at the 7500 bridge, Daniels (1989) reported that cesium-137 ranged from 2300 to 290,000 Bq/kg; strontium-90 ranged from 37 to 1100 Bq/kg; cobalt-60 ranged from 11 to 17,000 Bq/kg; and plutonium-239 ranged from 110 to 160 Bq/kg.

Sediments were also collected within the Clinch River below the WOC confluence; the samples contained 5.7 pCi/g of cesium-137, 0.7 pCi/g of strontium-90, 0.49 pCi/g of cobalt-60, and 0.022 pCi/g of plutonium-239 (Energy Systems 1989).

4.6.2 Radiological Contamination in Sediments

Both naturally occurring and man-made radionuclides were detected in seven sediment samples collected from seven locations (01.CS002, 01.CS003, 01.CS004, 01.CS005, 01.CS010, 01.CS011, and 01.CS012) at WAG 1 during the Phase I investigation (Figs. 4.6.1 through 4.6.3). Naturally occurring radionuclides include those belonging to the uranium series (uranium-238, uranium-234, thorium-230, radium-226) and the thorium series (thorium-232, radium-228, thorium-228). The concentrations of radium-226 and -228, and thorium-228, -230, and -232 were near or below the maximum concentrations detected in reference location samples. Concentrations of uranium-238 and uranium-234 ranged from 0.77 to 3.52 pCi/g and 0.96 to 4.47 pCi/g, respectively; neither radionuclide was detected in reference location samples.

Man-made radionuclides detected in sediment samples include cobalt-60, sodium-22, europium-154, europium-152, iodine-129, cesium-134, cesium-137, strontium-90, calcium-45, and iron-55. Cobalt-60 was detected in four samples; the maximum concentration was 12.6 pCi/g in the sample collected in WOC (location 01.CS005). The transuranic radionuclides detected in sediments were americium-241, curium-242, and curium-243/244.

The maximum detected concentration of strontium-90 was 67 pCi/g, and the maximum detected concentration of cesium-137 was 2480 pCi/g. Strontium-90 and cesium-137 were the only man-made radionuclides detected in reference samples, where their maximum concentrations were 2.81 and 1.13 pCi/g, respectively. Seven samples contained concentrations of strontium-90 in excess of reference levels; only the sample collected at WOC location 01.CS002 contained strontium-90 below reference levels. Eight samples contained concentrations of cesium-137 in excess of reference levels.

The minimum and maximum concentrations, number of samples, and associated detects and nondetects for the radiological constituents are presented in Table 4.6.2.

4.6.2.1 Nature and extent of individual radiological parameters

Strontium. The concentrations of strontium-90 detected in sediment samples are shown in Fig. 4.6.2. The highest concentration was in samples collected in WOC; samples from locations 01.CS004 and 01.CS005 contained 46.2 and 67 pCi/g, respectively. The sample from WOC location 01.CS002 contained strontium-90 at 1.2 pCi/g, which was below the maximum reference level. Strontium-90 was detected in First Creek sediment at locations 01.CS010 and 01.CS011 at 16.7 and 18 pCi/g, respectively. In a sample collected at Northwest Tributary location 01.CS012, strontium-90 was detected in a concentration of 4.08 pCi/g.

Tritium. Tritium was not detected in any WAG 1 or reference sediment samples.

Gross alpha and gross beta. The activities associated with gross alpha and gross beta detected in sediment samples are shown in Fig. 4.6.1. Samples from WOC locations 01.CS003, 01.CS004, and 01.CS005 contained the highest gross alpha and gross beta

activities among all sediment samples. Gross alpha ranged from 76.6 to 135 pCi/g in the samples from these three locations; the sample from 01.CS004 contained the highest activity. Gross beta ranged from 896 to 1910 pCi/g; the highest was in the sample from location 01.CS003.

The sum of the concentrations of beta-emitters (i.e., cesium-137, radium-228, and strontium-90) detected in the samples collected at location 01.CS005 was 1913 pCi/g; this exceeds the gross beta activity (1110 pCi/g) detected in this sample. Otherwise, the sum of beta-emitting radionuclides detected in samples from other locations is within the reported uncertainty range of gross beta measurements.

The majority of the gross alpha activities in the samples collected at locations 01.CS002 through 01.CS005 cannot be accounted for by the detected concentrations of americium-241, curium-234/244, and naturally occurring radionuclides (radium-226, thorium-228/230/232, and uranium-234/238). This indicates that one or more additional alpha-emitting radionuclides were present in these samples.

Gross alpha and gross beta activities in samples from First Creek ranged from undetected to 22.3 pCi/g and 13.5 to 72 pCi/g, respectively. The sample from location 01.CS010 contained the highest gross alpha, and the sample from location 01.CS011 contained the highest gross beta. In the sample from 01.CS011, cesium-137 was detected in a concentration of 66.6 pCi/g, which accounted for the majority of the gross beta activity. However, the majority of gross alpha activity detected in the sample from 01.CS010 (22.3 pCi/g) was not accounted for by the detected concentrations of alpha-emitting radionuclides. No transuranic radionuclides were detected in sediment samples collected in First Creek.

Gross alpha and gross beta activities in Northwest Tributary location 01.CS012 were 13.3 and 20.5 pCi/g, respectively. Transuranics were absent from this sediment sample.

Radium. The maximum concentrations of radium-226 and radium-228 detected in WAG 1 sediment were in samples collected from WOC. Radium-226 was detected at a maximum concentration of 0.66 pCi/g (location 01.CS002), and radium-228 was detected at 1.41 pCi/g (location 01.CS005). These levels are likely attributable to the presence of naturally occurring radionuclides, because the concentrations of radium-226/228 are both comparable to reference levels and are in secular equilibrium with uranium-238 and thorium-230. The maximum reference location levels for these radionuclides were 0.71 pCi/g (radium-226) and 0.53 pCi/g (radium-228).

Cesium. The concentrations of cesium-137 detected in WAG 1 sediment samples are shown in Fig. 4.6.3. In WOC, cesium-137 ranged from 923 to 2480 pCi/g at locations 01.CS003, 01.CS004, and 01.CS005. The maximum concentration found outside of WOC (66.6 pCi/g) was in a sample from First Creek (location 01.CS011).

Cesium-137 was detected at 1.73 and 66.6 pCi/g in samples collected at First Creek locations 01.CS010 and 01.CS011, respectively. The concentration of cesium-137 detected at Northwest Tributary location 01.CS012 was 1.45 pCi/g, which is comparable to the maximum reference level detected (1.13 pCi/g).

Cesium-134 was detected in one sample from WOC location 01.CS004 at a concentration of 0.608 pCi/g.

Transuranic radionuclides. Americium-241, curium-242, and curium-243/244 were detected only in WOC sediments. The maximum concentration of curium-242 was 12.5 pCi/g in a sample from 01.CS003; this sample also contained the maximum detected concentration of curium-243 and/or 244 (15.1 pCi/g). Americium-241 was detected at a maximum concentration of 5.1 pCi/g in a sample from 01.CS005.

Other radionuclides. Seven additional man-made radionuclides were detected in sediments collected in WOC; none were detected in reference location samples. Cobalt-60 was detected at concentrations of 1.05 pCi/g at 01.CS002, 8.71 pCi/g at 01.CS004, and a maximum of 12.6 pCi/g at 01.CS005. It was not detected at 01.CS003.

Sodium-22 was detected in concentrations ranging from 0.14 to 0.815 pCi/g in samples from three locations in WOC (01.CS002, 01.CS004, and 01.CS005). Iron-55 was detected once in a sample from WOC location 01.CS003 at 26 pCi/g; iodine-129 and calcium-45 were detected in this same sample at 0.202 pCi/g and 5.2 pCi/g, respectively.

Europium-152 and -154 were detected in samples from two locations; the sample collected at 01.CS004 contained 4.81 and 2.16 pCi/g, and the sample collected at 01.CS005 contained 2.57 and 2.04 pCi/g, respectively.

4.6.3 Chemical Contamination in Sediments

Few TCL VOCs and BNAEs were detected in sediment samples (Fig. 4.6.4). Eight VOCs were detected in concentrations ranging from 1 to 30 μg/kg; the VOC with the highest concentration was acetone, detected in a sample from First Creek at 30 μg/kg. Fourteen BNAEs were detected; most were PAHs, with concentrations between 200J and 12,000 μg/kg. The PAH with the maximum concentration was benz(e)acephenanthrylene, detected in a sample from WOC (location 01.CS002) at 12,000 μg/kg. One or more PCBs (Aroclor-1260, -1254, or -1248) were found in eight sediment samples at concentrations ranging from 410 to 12,000 μg/kg. The herbicide HxCDF was found in a WOC sediment sample at a concentration of 0.93 μg/kg. Organophosphates and cyanide were not detected. Chromium, copper, lead, and mercury were detected at concentrations over twice those detected in reference location samples. The minimum and maximum concentrations, number of samples, and associated detects for the chemical constituents are presented in Table 4.6.2.

4.6.3.1 Nature and extent of VOC contamination

VOCs were encountered in six of the eight samples analyzed for VOCs. Of the eight VOCs detected, only two had concentrations greater than 8 μg/kg. Acetone was detected twice, in concentrations of 17 and 30 μg/kg. Tetrachloroethylene (PCE) was detected in a sample from First Creek (location 01.CS010) at 18 μg/kg. VOCs detected at concentrations below 8 μg/kg were toluene, methylene chloride, methylisobutylketone, chlorobenzene, and carbon disulfide.

4.6.3.2 Nature and extent of BNAE contamination

Fourteen BNAEs were identified in samples collected from six locations. BNAEs were not detected at two locations (01.CS010 and 01.CS011), and the sample from 01.CS003 was not analyzed for BNAEs. Three of the detected BNAEs, all phthalates, [i.e., bis(2-ethylhexyl)phthalate, di-n-butyl phthalate, and dioctyl ester phthalic acid] are common plasticizers. Only bis(2-ethylhexyl)phthalate was detected in the reference samples at a maximum concentration of 93J μg/kg.

Bis(2-ethylhexyl)phthalate was detected in samples from three locations in concentrations that exceeded reference levels: WOC locations 01.CS001 (200J μg/kg) and 01.CS002 (930J μg/kg) and Northwest Tributary location 01.CS012 (1300 μg/kg). Di-n-butyl phthalate was detected in only one sample (WOC location 01.CS004), at 630J μg/kg, and dioctyl ester phthalic acid was also detected in only one sample (Northwest Tributary location 01.CS012), at 83J μg/kg.

The remaining 11 BNAEs were PAHs ranging in concentration from 130 to 9800 μg/kg, with most values estimated. None of the PAHs were found in the reference samples.

The PAHs are present in all WOC samples and one Fifth Creek sample, but are notably absent in First Creek and Northwest Tributary samples. The sample collected from WOC location 01.CS001, which is approximately 75 ft upstream of the WAG 1 boundary, contains PAH concentrations comparable to those in downstream samples. This pattern suggests that PAHs have accumulated in creek sediments through stormwater runoff from multiple source areas within the WOC and Fifth Creek watershed. Many of these compounds are by-products from coal combustion or are associated with vehicle parking lot and asphalt surface runoff. Their absence in samples from First Creek and Northwest Tributary might be related to a lower density of asphalt in the area that drains to First Creek and Northwest Tributary.

4.6.3.3 Nature and extent of other organic contamination

The PCB Aroclor-1260 was detected in four of the nine samples analyzed for this compound; concentrations ranged from 570J to 3100J μg/kg. The maximum concentration was detected in a sample from WOC location 01.CS002. Aroclor-1254 was detected at 2100J and 460J μg/kg in two WOC sediment samples, at 410J and 630J μg/kg in samples from Fifth Creek, and at 12,000J and 1800J in samples from First Creek. Aroclor-1248 was detected in one sample from Fifth Creek in a concentration of 620J μg/kg. No PCBs were detected in reference samples.

The pesticide HxCDF was detected at a concentration of 0.93J μg/kg in the only sample collected for Appendix IX analysis; this sample was from WOC at location 01.CS003.

4.6.3.4 Nature and extent of metal contamination

Figures 4.6.5 through 4.6.8 present the concentrations of the six metals most frequently detected in WAG 1 sediments. Cadmium, chromium, copper, lead, mercury, and silver were frequently detected at concentrations above reference location levels.

Cadmium was detected in reference location samples at a maximum concentration of 2000 μg/kg (see Fig. 4.6.5). This level was exceeded in all sediment samples collected in WOC, First Creek, Fifth Creek, and Northwest Tributary. The maximum concentration (4300 μg/kg) was detected in a sample from Fifth Creek location 01.CS008.

The maximum concentration of chromium detected in sediment samples (see Fig. 4.6.5) was 145,000 μg/kg in a sample from WOC; another sample from WOC had a concentration of 94,200 μg/kg. Chromium was also elevated in a sample from Fifth Creek (96,000 μg/kg). Chromium in the sample from Northwest Tributary was below the maximum reference level of 40,200 μg/kg.

Copper concentrations varied widely (see Fig. 4.6.6), although all samples exceeded the maximum reference concentration of 4500 μg/kg. The maximum (107,000 μg/kg) was detected in a sample from First Creek location 01.CS010. Samples from WOC were also significantly above the maximum reference level.

Lead was also detected in sediment samples in excess of reference levels. A maximum concentration of 103,000 μg/kg was detected in sediment from Fifth Creek location 01.CS008 (see Fig. 4.6.6). Concentrations of 88,600 and 71,700 μg/kg were found in samples from First Creek location 01.CS010 and WOC location 01.CS002, respectively.

Mercury was detected in all WOC sampling sites downstream of the Fifth Creek confluence; concentrations ranged from 3800 to 7900 μg/kg (see Fig. 4.6.7). The reference location level of 120J μg/kg was also exceeded at WOC location 01.CS001 (140 μg/kg) and in one sample from Fifth Creek (170 μg/kg).

Silver was detected in all WAG 1 samples but was not detected in reference samples. The maximum concentration detected was 197,000 μg/kg at location 01.CS004 in WOC (Fig. 4.6.7).

4.6.4 General Observations

Both man-made and naturally occurring radionuclides were detected in sediment samples from WAG 1. Radionuclides associated with the natural uranium and thorium decay series were detected at concentrations within reference ranges and are not considered site contaminants.

Of the man-made radionuclides detected (cesium-137, cobalt-60, and strontium-90), cesium-137 was detected most frequently. All man-made radionuclides, including the transuranics americium-241, curium-242, and curium-243/244, were detected at concentrations exceeding reference levels, indicating that these are site contaminants.

The maximum concentration of cesium-137 detected (2489 pCi/g) was lower than the maximum concentration reported in previous studies [10,000 pCi/g, reported in Cerling and Spalding (1981)], although the sampling locations were not coincident. However, the concentrations of cesium-137 and strontium-90 detected in samples from each creek, including reference locations, are generally within the same order of magnitude as the results

from previous studies. One exception is First Creek, were strontium-90 was detected at 16 and 18 pCi/g in two samples, whereas Cerling and Spalding (1981) reported concentrations ranging from nondetect to 5.5 dpm/g (2.48 pCi/g). While this is not clear evidence of an increase in strontium-90 contamination, its presence in sediment samples is consistent with the pattern of strontium-90 contamination found in First Creek surface water and related groundwater sampling (see Sects. 4.3 and 4.5).

A greater difference is seen in the concentrations of cobalt-60 detected in sediments collected during the Phase I investigation compared with those reported in previous studies. The maximum cobalt-60 concentration detected in samples from WOC was 12.6 pCi/g, whereas in previous studies, cobalt-60 was detected at 250, 167, and 460 pCi/g. This suggests either that the cobalt-60 loading in surface water has declined or that the contaminated sediments have been transported farther downstream or covered with less-contaminated sediment.

A number of man-made radionuclides were detected in samples collected during Phase I that were not reported in previous studies of sediment quality: sodium-22, iron-55, iodine-129, and calcium-45. These radionuclides were only detected in samples collected from WOC. Iron-55, iodine-129, and calcium-45 were detected in the sample collected at location 01.CS003, while sodium-22 was detected in samples collected both upstream and downstream of this location. Calcium-45 has the shortest half-life (165 days) of these radionuclides; its presence in sediments suggests that there is a new or chronic release of this radionuclide. Additional analysis of potential source areas for calcium-45 would aid in determining whether there is a chronic release point.

VOC compounds detected were at concentrations near detection limits; however, PAHs were detected in samples throughout WOC and in Fifth Creek. Six metals (i.e., cadmium, chromium, copper, lead, mercury, and silver) were detected above reference levels.

The concentrations of mercury detected were comparable to those reported in previous studies, although the maximum concentrations found in previous studies at locations associated with outfalls into Fifth Creek were not encountered. This difference is likely due to the selection of sampling locations and should not be viewed as an indication that the high concentrations of mercury detected in previous studies [e.g., 4874 to 7427 μg/kg near outfall 261 (Taylor 1990a)] have dissipated.

The absence of mercury in sediment samples collected in WOC above the confluence with Fifth Creek indicates that discharge or groundwater seepage into Fifth Creek is the major pathway for mercury contamination of WOC. However, previous studies (see Sect. 4.6.1) found mercury in the portion of WOC above its confluence with Fifth Creek.

Because data from previous studies on cadmium, chromium, copper, and lead were not available, it is not possible to comment on trends in metal contamination of sediments. Sediments from First Creek contained the greatest concentration of copper, and sediments from Fifth Creek contained the greatest concentration of cadmium.

With the exception of PAHs, it appears that organic contamination is not present in the sediments at WAG 1. Concentrations of PAHs, which ranged from 200J to 12,000 μg/kg, may be attributable to parking lot and asphalt surface runoff (e.g., oils) or the accumulation of by-products from coal combustion.

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Table 4.2.1. Reference groundwater, surface water, sediment, and soil sampling locations

Location*	Sample No.	TCL VOC	TCL BNAE	TAL metals	App. IX VOC	App. IX BNAE	App. IX metals	Herb.	Pest./ PCBs	OPP	Diox/ furans	Rad.	Cyanide	Sulfide	Anions	Carb.	Bicarb.	TDS	TSS	TOC	TOX	TKN
Groundwater																						
01.1250	0976				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
01.1250	1821	X	X	X					X			X		X	X					X	X	X
01.1251	0978				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
01.1251	1844	X	X	X					X			X		X	X					X	X	X
01.1252	0975				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
01.1252	1834	X	X	X					X			X		X	X					X	X	X
01.BV08	1868	X	X	X					X			X	X	X	X					X	X	X
01.BV09	1869	X	X						X													
Surface water																						
01.5CBG	0555	X	X	X					X	X												
01.CS006	1078	X	X	X					X				X	X	X	X	X	X		X		X
01.CS006	1082	X	X	X					X				X	X	X	X	X	X		X		X
01.CS009	1080	X	X	X					X			X	X	X	X	X	X	X		X		X
01.CS009	1081	X	X	X					X				X	X	X	X	X	X		X		X
01.FCBG	0552	X	X	X					X			X	X									
01.FCBG	0554	X	X	X					X			X	X									
SW-1	1599	X	X	X					X			X	X	X	X					X		X
SW-2	1602	X	X	X					X			X	X	X	X					X		X
SW-3	1603	X	X	X					X			X	X	X	X					X		X
WOCBG	0550				X	X	X	X	X	X	X	X	X	X								
Sediment																						
01.CS006	1084	X	X	X					X			X	X	X								
01.CS006	1086	X	X	X					X			X	X	X								
01.CS009	1075	X	X	X					X			X	X	X								
01.CS009	1076	X	X	X					X			X	X	X								

Table 4.2.1 (continued)

Location[a]	Sample No.	TCL VOC	TCL BNAE	TAL metals	App. IX VOC	App. IX BNAE	App. IX metals	Herb.	Pest./PCBs	OPP	Diox/ furans	Rad.	Cyanide	Sulfide	Anions	Carb.	Bicarb.	TDS	TSS	TOC	TOX	TKN
Soil																						
01.5CBG1	0048	X	X	X								X										
01.5CBG2	0050	X	X	X								X										
01.5CBG3	0124				X	X	X	X	X	X	X	X	X	X								
01.5CBG4	0123				X	X	X	X	X	X	X	X	X	X								
01.BV01	0029				X	X	X	X	X	X	X	X	X	X								
01.BV02	0030				X	X	X	X	X	X	X	X	X	X								
01.BV03	0059				X	X	X	X	X	X	X	X	X	X								
01.BV03	0060				X	X	X	X	X	X	X	X	X	X								
01.BV03	0061	X	X	X					X			X	X	X								
01.BV04	0042				X	X	X	X	X	X	X	X	X	X								
01.BV08	1683	X	X	X					X			X	X									
01.BV09	1684	X	X	X					X			X	X									
01.BV09	1685[b]	X	X	X					X			X	X									
01.FCBG1	0053	X	X	X								X										
01.FCBG2	0126				X	X	X	X	X	X	X	X	X	X								
01.FCBG3	0125				X	X	X		X	X			X	X								
01.WCBG1	0054	X	X	X								X										
01.WCBG3	0055	X	X	X								X										
01.WCBG4	0040	X	X									X										

[a]Locations are shown on Figs. 4.2.1 and 4.2.2.
[b]Duplicate sample.

NOTE: This table was created manually. The table was then verified against printouts of the RI/FS data tables to verify which analyses were performed on each sample.

Table 4.2.2. Regulations and guidelines specific to water and soil

	SDWA MCL (μg/L)	*RCRA limits (μg/kg)
1,1-Dichloroethane		
1,1-Dichloroethene	7[a]	10,000
1,1-Dichloroethene (cis)		
1,1,1-Trichloroethane	200[a]	7,000,000
1,1,2-Trichloroethane	5[c]	
1,1,2,2-Tetrachloroethane		40,000
1,2-Dibromo-3-Chloropropane	0.2[b]	
1,2-Dichlorobenzene	600[b]	
1,2-Dichloroethane	5[a]	8,000
1,2-Dichloroethylene (cis)	70[b]	
1,2-Dichloroethylene (trans)	100[b]	
1,2-Dichloropropane	5[b]	
1,2-Diphenylhydrazine		900
1,2,4-Trichlorobenzene	9[c]	2,000,000
1,2,4,5-Tetrachlorobenzene		20,000
1,3-Dichlorobenzene		
1,3-Dichloropropane (cis)		
1,3-Dichloropropane (trans)		
1,3-Dichloropropene (cis)		20,000
1,3-Dichloropropene (trans)		20,000
1,4-Dichlorobenzene	75[a]	
2-Butanone (Methylethylkeytone)		4,000,000
2-Chloronapthalene		
2-Chlorophenol		400,000
2-Hexanone		
2-Methyl-4,6-Dinitrophenol		
2-Methylnaphthalene		0.065
2-Methylphenol		
2-Nitroaniline		
2-Nitrophenol		
2,3,7,8-Tetrachlorodibenzo-p-dioxin	0.00005	
2,4-Dichlorophenol		200,000
2,4-Dichlorophenoxyacetic acid (2,4-d)	70[d]	800,000
2,4-Dimethylphenol		
2,4-Dinitrophenol		200,000
2,4-Dinitrotoluene		
2,4,5-Trichlorophenol		8,000,000
2,4,5-Trichlorophenoxypropionic acid	50[d]	
2,4,6-Trichlorophenol		40,000
2,6-Dinitrotoluene		1,000
3-Methyl-4-chlorophenol		
3-Nitroaniline		
3,3-Dichlorobenzidine		2,000
3,4-Benzofluoranthene		
4-Bromophenyl-phenylether		
4-Chloro- 3-methylphenol		
4-Chloroaniline		
4-Chlorophenyl-phenylether		
4-Methyl- 2-pentanone		
4-Methylphenol		

Table 4.2.2 (continued)

	SDWA MCL (μg/L)	*RCRA limits (μg/kg)
2,4,5-Trichlorophenoxyacetic acid	10	800,000
4-Nitroaniline		
4-Nitrophenol		
4,4'-DDD		3,000
4,4'-DDE		2,000
4,4'-DDT		2,000
4,6-Dinitro- 2-methylphenol		
Acenaphthene		0.15
Acenaphthylene		
Acetone		8,000,000
Acrolein		
Acrylamide	TT[e,f]	200
Acrylonitrile		1,000
Adipates	500	
Alachlor	2[b]	
Aldicarb	3[g]	100,000
Aldicarb Sulfanone	2[g]	
Aldicarb Sulfoxide	4[g]	
Aldrin		40
Aluminum	87	
Ammonia	(pH dependent)	(pH dependent)
Anthracene		0.085
Antimony	10/5[c]	30,000
Arsenic	50[h]	80,000
Asbestos	7 Mfig/L[b]	
Atrazine	3[b]	
Barium	2,000[g]	4,000,000
Benzene	5[a]	
Benzidine		3
Benzyl alcohol		
Benzoic acid		
Benzo(a)anthracene	0.1[c,f]	
Benzo(a)pyrene	0.2[c]	
Benzo(b)fluoranthene	0.2[c,f]	
Benzo(g,h,i)perylene		
Benzo(k)fluoranthene	0.2[c,f]	
Beryllium	1[c]	200
BHC-alpha		
BHC-beta		
BHC-delta		
BHC-gamma (Lindane)	0.2[b]	500
Bis(2-Chloroisopropyl)ether		
Bis(2-Chloroethoxy)methane		
Bis(2-Chloroethyl)ether		600
Bis(2-Ethylhexyl)phthalate	4[c]	50,000
bis-(Chloromethyl) ether		
Bromodichloromethane		500
Bromoform		2,000,000
Bromomethane		100,000
Butybenzylphthalate	1[c]	20,000,000

Table 4.2.2 (continued)

	SDWA MCL (μg/L)	[a]RCRA limits (μg/kg)
Cadmium	5	40,000
Carbofuran	40[b]	
Carbon tetrachloride	5[a]	5,000
Chlordane-alpha (total)	2[b]	500[l]
Chlordane-gamma (total)	2[b]	500[l]
Chlorine		
Chlorobenzene	100[b]	2,000,000
Chloroethane		
Chloroform (Trichloromethane)		100,000
Chloromethane (Methyl chloride)		
Chlorpyrifos	0.041	
Chlorodibromomethane		
Chromium (III)	100[m]	
Chromium (IV)		400,000[n]
Chrysene	0.2[c,j]	
Cobalt		
Copper	1,300	
Cyanide	200[l]	2,000,000
Dalapon	200	
Demeton		0.1
Dibenzofuran		
Dibenzo(a,h)anthracene	0.3[c]	
Dibromochloromethane		
Dichlorodifluoromethane		20,000,000
Dieldrin		40
Diethylphthalate		60,000,000
Dimethylphthalate		
Di-n-Butylphthalate	4[c]	8,000,000
Di-n-Octylphthalate	4[c]	
Dinoseb	7	
Diquat	20	
Endosulfan I		4,000[o]
Endosulfan II		4,000[o]
Endosulfan sulfate		4,000[o]
Endothall	100	2,000,000
Endrin	2μ[c,h] 0.2	20,000
Endrin ketone		
Epichlorohydrin	TT[b]	70,000
Ethyl benzene	700[b]	8,000,000
Ethylene dibromide	0.05[b]	8.0
Fluoranthene		
Fluorene		
Fluoride	4,000[l]	
Glyphosate	700	
Halomethanes		
Heptachlor	0.4[b]	200
Heptachlor epoxide	0.2[b]	80
Hexachlorobenzene	1[c]	
Hexachlorobutadiene		90,000
Hexachlorocyclohexanes-alpha		100

Table 4.2.2 (continued)

	SDWA MCL (μg/L)	*RCRA limits (μg/kg)
Hexachlorocyclohexanes-beta		4,000
Hexachlorocyclohexanes-gamma	0.2[d]	
Hexachlorocyclopentadiene	50[c]	
Hexachloroethane		80,000
Hydrogen Sulfite		200,000
Indeno(1,2,3-cd)pyrene	0.4[c,f]	
Iron		
Isophorone		2,000,000
Lead	15	
Magnesium		
Mercury (inorganic)	2[b,d]	20,000
Methyl Bromine		
Methyl Chloride		
Methylene chloride	5	90,000
Monochlorobenzene	2,000,000	2,000,000
Naphthalene		
Nickel		2,000,000[c]
Nitrate	10,000 (as N)[b,d]	
Nitrate + Nitrite	10,000 (as N)[b]	
Nitrite	10,000 (as N)[b]	
Nitrobenzene		
Nitrogen Dioxide		80,000,000
n-Nitrosodimethylamine		
n-Nitroso-di-n-propylamine		
n-Nitrosodiphenylamine		100,000
n-Nitrosopyrrolidine		300
o-Dichlorobenzene	600[b]	
Oxamyl (Vydate)	200	
PAH's		
Parathion		500,000
PCBs	0.5[a,b]	90
p-dichlorobenzene	75	
Pentachlorobenzene		60,000
Pentachlorophenol	1.0	2,000,000
Phenanthrene		
Phenol		50,000,000
Phthalates	4	
Picloram	500	
Pyrene		
Selenium	50[b,d]	
Silver		200,000
Styrene	100[b]	20,000,000
Sulfides		
Tetrachloroethene	5[b]	10,000
Thallium	2/1[c]	
Toluene (Methyl benzene)	1,000[b]	20,000,000
Toxaphene	3[b,d]	600
Trichloroethylene	5[b]	60,000
Trichlorofluoromethane		20,000,000
Trihalomehtanes (total)	100[h,k]	

Table 4.2.2 (continued)

	SDWA MCL (μg/L)	[e]RCRA limits (μg/kg)
Vanadium		
Vinyl Acetate		
Vinyl chloride	2[a]	
Xylenes (total)	10,000[b]	2,000,000,000
Zinc		

[e]55 FR 30865-30867 (July 27, 1990). Appendix A of proposed RCRA Part 264, Subpart S.

[a]52 FR 25690 (July 8, 1987).

[b]56 FR 3526 (January 30, 1991), effective July 30, 1992.

[c]55 FR 30370 (July 25, 1990), proposed. Two MCLs are based on two practical quantitation limits.

[d]The final MCL/MCLG was set for this chemical (56 FR 3526, January 30, 1991) and supercedes the orignal interim SDWA MCL. Effective July 30, 1992; interim MCLs remain in effect until that time.

[e]Treatment technology.

[f]In addition to an MCL/MCLG for benzo(a)pyrene, EPA proposes, as a second option for public comment, MCL/MCLGs for these PAHs.

[g]56 FR 30266 (July 1, 1991). Effective January 1, 1993.

[h]40 FR 59570 (December 24, 1975).

[i]The interim MCL was revoked for this chemical (56 FR 3526, January 30, 1991).

[j]MCL-51 FR 11396 (April 2, 1986); applies to community water systems only. MCLG-50 FR 47141 (November 14, 1985).

[k]Total trihalomethanes refers to the sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane.

[l]RCRA action levels do not differentiate alpha and gamma chlordane.

[m]MCL listed in for total chromium.

[n]RCRA action level for chromium (VI) only.

[o]RCRA action levels do not differentiate endosulfan I, endosulfan II, and endosulfan sulfate.

[p]55 FR 30865-30867 Appendix A of proposed RCRA Part 264 Subpart S, July 27, 1990.

Table 4.3.1. Previous groundwater studies at WAG 1

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
Duguid 1975	SWSA 1, Well 1-1	Sr-90	≤0.5	dpm/mL	24
		Cs-137	≤2.1 E-02	dpm/mL	
	SWSA 1, Well 1-2	Sr-90	0.4	dpm/mL	
		Cs-137	≤2.7 E-02	dpm/mL	
	SWSA 1, Seep 1-1	Sr-90	≤4.6 E-02	dpm/mL	
		Cs-137	≤1.9 E-02	dpm/mL	
Stansfield and Francis 1986	Downgradient Wells at Impoundment 3513	As	0.001-0.004	mg/L	25
		Ba	0.059-0.52	mg/L	
		Cd	0.001-0.002	mg/L	
		Cl	6-35	mg/L	
		Cr	0.016-1.2	mg/L	
		Endrin	0.0001	mg/L	
		F	1	mg/L	
		Gross Alpha	0.03-3.9	Bq/L	
		Gross Beta	1.4-54	Bq/L	
		Fe	5.6-72	mg/L	
		Pb	0.003-1.4	mg/L	
		Lindane	0.0001-0.001	mg/L	
		Mn	2.7-5	mg/L	
		Hg	0.0001-0.0005	mg/L	
		Methoxychlor	0.0002	mg/L	
		NO_3	2-5	mg/L	
		PCBs	0.0001	mg/L	
		Phenol	0.001-0.007	mg/L	
		Se	0.005	mg/L	
		Ag	0.07	mg/L	
		Na	25-37	mg/L	
		SO_4	5-22	mg/L	
		TOC	1.46-10	mg/L	
		TOX	0.022-0.08	mg/L	
		Toxaphene	0.002	mg/L	
		H3	2200-3600	Bq/L	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
		2,4,5-TP (Silvex)	0.005-0.01	mg/L	
		2,4-D	0.005-0.009	mg/L	
		Cs-137	0.0001-1.04	Bq/L	
		Pb-214	3.51-10.6	Bq/L	
		Ra-226	0.008-0.14	Bq/L	
		Sr-90	0.4-26	Bq/L	
Energy Systems 1986	Impoundment 3524	2,4,5-TP (Silvex)	<0.01	mg/L	16
		2,4-D	<0.01	mg/L	
		Ag	<0.005	mg/L	
		As	<0.01	mg/L	
		Ba	<1.0	mg/L	
		Cd	<0.002	mg/L	
		Cl	4.7-12	mg/L	
		Co-60	<0.01-0.013	pCi/mL	
		Cr	<0.02	mg/L	
		Cs-137	<0.008-0.013	pCi/mL	
		Endrin	<0.0002	mg/L	
		F	<1.0	mg/L	
		Fe	0.09-2.1	mg/L	
		Gross Alpha	0.0016-1.4	pCi/mL	
		Gross Beta	<0.0027-5.1	pCi/mL	
		Hg	<0.0001	mg/L	
		Lindane	<0.002	mg/L	
		Methoxychlor	<0.008	mg/L	
		Mn	0.22-3.5	mg/L	
		Na	15-22	mg/L	
		NO_3	<5.0	mg/L	
		Pb	<0.02-0.053	mg/L	
		Phenols	<0.001	mg/L	
		Ra (total)	<0.0001-0.0008	pCi/mL	
		Se	<0.005	mg/L	
		SO_4	14-110	mg/L	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
		TOC	1.3-4.1	mg/L	
		TOX	0.013-0.052	mg/L	
		Toxaphene	<0.005	mg/L	
	Impoundments 3539 and 3540	2,4,5-TP (Silvex)	<0.01	mg/L	
		2,4-D	<0.01	mg/L	
		Ag	<0.005	mg/L	
		As	<0.01	mg/L	
		Ba	<1.0	mg/L	
		Cd	<0.002	mg/L	
		Cl	5.2-13	mg/L	
		Co-60	<0.011-0.017	pCi/mL	
		Cr	<0.02	mg/L	
		Cs-137	<0.008-0.016	pCi/mL	
		Endrin	<0.0002	mg/L	
		F	<1.0	mg/L	
		Fe	0.052-8.7	mg/L	
		Gross Alpha	0.0011-0.013	pCi/mL	
		Gross Beta	0.0022-0.07	pCi/mL	
		Hg	<0.0001	mg/L	
		Lindane	<0.002-0.04	mg/L	
		Methoxychlor	<0.008	mg/L	
		Mn	0.65-8.9	mg/L	
		Na	4.6-37	mg/L	
		NO_3	<5.0	mg/L	
		Pb	<0.02-0.034	mg/L	
		pH	6.5-7.5	mg/L	
		Phenols	0.0–0.002	mg/L	
		Ra (total)	<0.0003-0.0008	pCi/mL	
		Se	<0.005	mg/L	
		SO_4	<5.0-210	mg/L	
		TOC	2.3-6.6	mg/L	
		TOX	0.009-0.062	mg/L	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
		Toxaphene	<0.005-<0.05	mg/L	
Montford, Daniels, Kitchings, 1986	Impoundment 3524, Well 31-001 (upgradient)	Cl	5.3	mg/L	22
		Fe	1.0	mg/L	
		Gross Alpha	0.36	Bq/L	
		Gross Beta	3.2	Bq/L	
		Mn	0.26	mg/L	
		Na	22	mg/L	
		Pb	0.02	mg/L	
		SO_4	97	mg/L	
		TOC	1.6	mg/L	
		TOX	0.03	mg/L	
		Fe (dissolved)	0.050	mg/L	
		Mn (dissolved)	0.23	mg/L	
		Na (dissolved)	22	mg/L	
	Impoundments 3539/3540, Wells 31-007, -009 (upgradient)	Cl	8.8-14	mg/L	
		Fe	0.38-1.3	mg/L	
		Gross Beta	0.27-0.47	Bq/L	
		Mn	2.1-1.2	mg/L	
		Na	11-31	mg/L	
		Pb	0.020	mg/L	
		Ra (total)	0.014-0.055	Bq/L	
		SO_4	41-220	mg/L	
		TOC	4.1-4.3	mg/L	
		TOX	0.021-0.060	mg/L	
		Fe (dissolved)	0.32-0.49	mg/L	
		Mn (dissolved)	0.89-1.7	mg/L	
		Na (dissolved)	12-31	mg/L	
	Impoundment 3524, Wells 31-002, -003, -004 (downgradient)	Cl	6.7-9.9	mg/L	
		Fe	0.095-1.2	mg/L	
		Gross Alpha	0.24-13	Bq/L	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.[m]
		Gross Beta	0.56-123	Bq/L	
		Mn	0.28-2.8	mg/L	
		Na	15-22	mg/L	
		Pb	0.020-0.040	mg/L	
		SO_4	16-56	mg/L	
		TOC	1.8-2.8	mg/L	
		TOX	0.027-0.065	mg/L	
		Fe (dissolved)	0.053-1.4	mg/L	
		Mn (dissolved)	0.21-3.6	mg/L	
		Na (dissolved)	15-21	mg/L	
	Impoundment 3539/3540, Wells 31-005, -006, -008, -010, -012 (downgradient)	Cl	6.4-7.4	mg/L	
		Fe	1.0-5.1	mg/L	
		Gross Beta	0.21-2.5	Bq/L	
		Mn	0.65-8.6	mg/L	
		Na	4.7-9.4	mg/L	
		Pb	0.020-0.025	mg/L	
		Ra (total)	0.013-0.38	Bq/L	
		SO_4	5.0-67	mg/L	
		TOC	2.3-4.0	mg/L	
		TOX	0.021-0.027	mg/L	
		Fe (dissolved)	0.44-4.2	mg/L	
		Mn (dissolved)	0.64-8.5	mg/L	
		Na (dissolved)	4.7-9.2	mg/L	
Energy Systems 1987	Impoundment 3524 Wells[f,s]	2,4,5-TP (Silvex)	<0.01	mg/L	
		2,4-D	<0.01	mg/L	
		Ag	<0.005	mg/L	
		As	<0.01	mg/L	
		Ba	<1	mg/L	
		Cd	<0.002	mg/L	
		Cl	4.8-11	mg/L	
		Cr	<0.02	mg/L	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.[m]
		Endrin	<0.0002	mg/L	
		F	<1.0	mg/L	
		Fe	0.08-1.7	mg/L	
		Gross Beta[h,i]	0.0092-5.9	pCi/mL	
		Gross Alpha[h,i]	0.00027-0.16	pCi/mL	
		Hg	<0.0001	mg/L	
		Lindane	<0.002	mg/L	
		Methoxychlor	<0.008	mg/L	
		Mn	0.01-4.1	mg/L	
		Na	14-30	mg/L	
		NO_3	<5.0	mg/L	
		Pb	<0.02-0.04	mg/L	
		Phenols	<0.001-0.0020	mg/L	
		Ra (total)	0.00011-0.0057	pCi/mL	
		Se	<0.005	mg/L	
		SO_4	11-250	mg/L	
		TOC	0.76-3.6	mg/L	
		TOX	<0.01-0.20	mg/L	
		Toxaphene	<0.005	mg/L	
	Impoundments 3539 and 3540 Wells[f,g]	2,4,5-TP (Silvex)	<0.01	mg/L	
		2,4-D	<0.01-0.60	mg/L	
		Ag	<0.005	mg/L	
		As	<0.01	mg/L	
		Ba	<1-1.3	mg/L	
		Cd	<0.002	mg/L	
		Cl	2.7-17	mg/L	
		Cr	<0.02-0.050	mg/L	
		Endrin	<0.0002	mg/L	
		F	<1	mg/L	
		Fe	0.050-10	mg/L	
		Gross Alpha	0.00081-0.025	pCi/mL	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.[m]
		Gross Beta	0.0035-0.35	pCi/mL	
		Hg	<0.0001	mg/L	
		Lindane	<0.002	mg/L	
		Methoxychlor	<0.008	mg/L	
		Mn	0.010-10	mg/L	
		Na	4.6-220	mg/L	
		NO_3	<5	mg/L	
		Pb	<0.020-1.2	mg/L	
		Phenols	<0.001-0.003	mg/L	
		Ra (total)[h,i,k]	0.00027-0.038	pCi/mL	
		Se	<0.005	mg/L	
		SO_4	5.0-250	mg/L	
		TOC	1.6-23	mg/L	
		TOX	<0.005-0.093	mg/L	
		Toxaphene	<0.005	mg/L	
Boegley, et al. 1987	Impoundments 3539 and 3540 Wells	2,4,5-TP (Silvex)	<0.01	mg/L	29
		2,4-D	<0.01-0.06	mg/L	
		Ag	<0.005	mg/L	
		As	<0.01	mg/L	
		Ba	<1.0	mg/L	
		Cd	<0.002	mg/L	
		Cl	2.7-17	mg/L	
		Cr (total)	<0.02-0.032	mg/L	
		Endrin	<0.0002	mg/L	
		F	<1.0	mg/L	
		Fe	0.052-5.9	mg/L	
		Gross Alpha	0.03-0.52	pCi/L	
		Gross Beta	0.081-2.0	pCi/L	
		Hg	<0.0001	μg/mL	
		Lindane	<0.002	μg/mL	
		Methoxychlor	<0.008	μg/mL	
		Mn	0.01-10	μg/mL	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.[m]
		Na	4.8-220	μg/mL	
		NO_3	<5.0	μg/mL	
		Pb	0.02-1.2	μg/mL	
		Phenols	<0.001-0.003	mg/L	
		Ra (total)	0.011-0.17	pCi/mL	
		Se	<0.005	mg/L	
		SO_4	<5.0-250	mg/L	
		TOC	1.6-23	mg/L	
		TOX	<0.005-0.093	mg/L	
		Toxaphene	<0.005	mg/L	
	Impoundment 3524 Wells	2,4,5-TP (Silvex)	<0.01	mg/L	
		2,4-D	<0.01	mg/L	
		Ag	<0.005	mg/L	
		As	<0.01	mg/L	
		Ba	<1.0	mg/L	
		Cd	<0.002	mg/L	
		Cl	4.7-11	mg/L	
		Cr (total)	<0.02-0.02	mg/L	
		Endrin	<0.0002	mg/L	
		F	<1.0	mg/L	
		Fe	0.08-1.5	mg/L	
		Gross Alpha[c]	0.011-52	pCi/L	
		Gross Beta[d]	0.30-220	pCi/L	
		Hg	<0.0001	μg/mL	
		Lindane	<0.002	μg/mL	
		Methoxychlor	<0.01	μg/mL	
		Mn	0.07-4.0	μg/mL	
		Na	14-30	μg/mL	
		NO_3[a]	<5.0	μg/mL	
		Pb	<0.02-0.05	μg/mL	
		Phenols	<0.001-0.002	μg/mL	
		Ra (total)[l]	<0.011-0.037	pCi/mL	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
		Se	<0.005	mg/L	
		SO_4	19-100	mg/L	
		TOC	1.1-3.8	mg/L	
		TOX	0.01-0.07	mg/L	
		Toxaphene	<0.005	mg/L	
Energy Systems 1989	Perimeter Wells	F	<1.0-3.8	mg/L	11
		Al	0.095-2.1	mg/L	
		Ar	<0.01-0.05	mg/L	
		Be	<0.0003-0.003	mg/L	
		B	<0.08-0.77	mg/L	
		Ca	1.2-200	mg/L	
		Co (total)	<0.003-0.0034	mg/L	
		Fe	<0.050-15	mg/L	
		Mg	0.43-26	mg/L	
		Mn	<0.010-6.5	mg/L	
		Ni	<0.005-0.026	mg/L	
		Si	3.4-6.9	mg/L	
		Na	3.5-260	mg/L	
		Sr	0.056-2.5	mg/L	
		Ti	<0.020-0.045	mg/L	
		V	<0.004-0.014	mg/L	
		Co-60	-5.9-6.5	pCi/L	
		Cs-137	-3.8-5.9	pCi/L	
		Gross Alpha	0-230	pCi/L	
		Gross Beta	0-18,000	pCi/L	
		Radioactive Strontium	0.54-7,600	pCi/L	
		Ra	0-2.4	pCi/L	
		H-3	-430-54,000	pCi/L	
		TOC	0.6-4.4	mg/L	
		TOX	0.0009-0.16	mg/L	
	Upgradient wells	Al	0.26-2.1	mg/L	
		Be	<0.0003-0.0028	mg/L	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
		B	<0.08-0.31	mg/L	
		Ca	44-130	mg/L	
		Fe	0.08-1.4	mg/L	
		Mg	10-29	mg/L	
		Mn	0.01-0.06	mg/L	
		Ni	<0.005-0.0091	mg/L	
		Si	3.6-6.8	mg/L	
		Na	4.0-26	mg/L	
		Sr	0.13-1.7	mg/L	
		Ti	<0.02-0.056	mg/L	
		V	0.0084-0.016	mg/L	
		Co-60	-4.9-4.1	pCi/L	
		Cs-137	-2.2-1.6	pCi/L	
		Gross Alpha	0-4.6	pCi/L	
		Gross Beta	0-4.9	pCi/L	
		Radioactive Strontium	-1.4-6.8	pCi/L	
		Ra	0.27-2.2	pCi/L	
		H-3	-650-2,200	pCi/L	
		TOC	0.8-1.3	mg/L	
		TOX	<0.005-0.094	mg/L	
Solomon et al. 1989	Impoundment 3513 Wells	Ag (dissolved)	0.007	mg/L	23
		Ag (total)	0.006	mg/L	
		Al (dissolved)	0.355-0.54	mg/L	
		Al (total)	0.380-0.49	mg/L	
		B (dissolved)	0.145	mg/L	
		B (total)	0.140	mg/L	
		Ba (dissolved)	0.075-0.39	mg/L	
		Ba (total)	0.083-0.375	mg/L	
		Be (dissolved)	0.002-0.003	mg/L	
		Be (total)	0.002-0.003	mg/L	
		Ca (dissolved)	88.0 -170.0	mg/L	
		Ca (total)	82.5-150.0	mg/L	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
		Co (dissolved)	0.003	mg/L	
		Co (total)	0.003	mg/L	
		Cr (total)	0.008	mg/L	
		Cu (total)	0.016-0.026	mg/L	
		Fe (dissolved)	0.029-6.90	mg/L	
		Fe (total)	0.073-6.7	mg/L	
		K (dissolved)	1.8-3.4	mg/L	
		Mg (dissolved)	9.0-26.0	mg/L	
		Mg (total)	8.7-23.0	mg/L	
		Mn (dissolved)	0.28-4.4	mg/L	
		Mn (total)	0.26-4.15	mg/L	
		Na (dissolved)	19-43	mg/L	
		Na (total)	12-40	mg/L	
		Ni (total)	0.008	mg/L	
		Si (dissolved)	4.1-6.6	mg/L	
		Si (total)	3.6-5.8	mg/L	
		Sr (dissolved)	0.250-0.990	mg/L	
		Sr (total)	0.230-0.975	mg/L	
		V (dissolved)	0.008-0.011	mg/L	
		V (total)	0.008-0.011	mg/L	
		Zn (dissolved)	0.130	mg/L	
		Zn (total)	0.015	mg/L	
		Br	0.5	mg/L	
		Cl	5.6-50.5	mg/L	
		F	0.5	mg/L	
		NO_3	0.5	mg/L	
		PO_4	0.5	mg/L	
		SO_4	8.1-87.0	mg/L	
		Toluene	8.0	mg/L	
		Trichloroethene	30.0	mg/L	
		Vinyl Chloride	24.0-35.0	mg/L	
		1,2-Dichlorethene (Total)	14.0-459.5	mg/L	

Table 4.3.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.[m]
		C-14	710.0-2,400.0	Bq/L	
		-Co-60	1.0-0.1	Bq/L	
		-Cs-137	0.2-0.07	Bq/L	
		Gross Alpha	0.0-0.4	Bq/L	
		Gross Beta	26-79.0	Bq/L	
		H-3	1,300-4,200	Bq/L	
		Sr-90	2.4-31.0	Bq/L	
		Tc-99	0.3-1.2	Bq/L	

[a]Nitrate as nitrogen.
[b]Average annual concentration in water assumed to produce total dose to bone marrow of 4 mrem/year.
[c]Includes Ra-226, but excludes radon and uranium.
[d]Chapter 1200-5-1-1.06 (TDHE) specifies that if two or more radionuclides are present, the sum of their annual dose to the total body or to any organ shall not exceed 4 mrem/year.
[e]Total trihalomethanes.
[f]Includes well numbers 31-001, -002, -003, -004, -013, and -015.
[g]During 1986, detection limit for several parameters varied.
[h]Summary of March 1986 and June 1986 data.
[i]Concentration exceeded standards in groundwater.
[j]Includes well numbers 31-005, -006, -007, -008, -009, and -019.
[k]Includes well numbers 31-005 through 31-012.
[l]Combined Ra-226 and Ra-228.
[m]Map reference number refers to the location identified on Fig. 4.5.1.

Table 4.3.2. Summary of radiological contaminants detected in WAG 1 groundwater

CAS No.	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
Unfiltered analyses											
12587-46-1	Alpha particle	pCi/L	-1.7	4.5		5093	1124.1		238.64127	119	191
14596-10-2	Am-241	pCi/L	0.24	0.17	J	20.4	7.9		3.111667	13	36
12587-47-2	Beta particle	pCi/L	0.2	3.5		585497.1	87826		11781.535	170	191
01-00022	Bi-211	pCi/L	72.2	64.7		75.8	66.8		73.5	3	3
14913-49-6	Bi-212	pCi/L	123.4	114.8		366	310		244.7	2	2
01-00020	Bi-214	pCi/L	73.3	49.2		73.3	49.2		73.3	1	1
14762-75-5	C-14	pCi/L	118	48		118	48		118	1	7
13966-05-7	Ca-45	pCi/L	27.4	3.2		1860	190		495.1	4	5
01-00012	Ce-144	pCi/L	41.3	36.3		41.3	36.3		41.3	1	1
7440-45-1	Cerium	pCi/L	36	25.3		36	25.3		36	1	1
0-190	Cm-234/244	pCi/L	1			1			1	2	3
15510-73-3	Cm-242	pCi/L	1			1			1	2	8
10198-40-0	Co-60	pCi/L	9.06	4.53		328	66		93.29	4	4
10045-97-3	Cs-137	pCi/L	10.3	6.3		67	33.6		28.404091	30	183
14681-59-5	Fe-55	pCi/L	67.9	40.1	J	67.9	40.1	J	67.9	1	9
13966-00-2	K-40	pCi/L	385	361		1629.1	476.6		959.7	3	31
13981-37-8	Ni-63	pCi/L	168	34		242	40		205	2	6
14255-04-0	Pb-210	pCi/L	443.1	376.9		443.1	376.9		443.1	1	1
15092-94-1	Pb-212	pCi/L	30.2	29.2		71.4	49.3		49.242857	7	7
01-00002	Pb-214	pCi/L	23.7	18.9		23.7	18.9		23.7	1	1
14380-75-7	Pm-147	pCi/L	15.7	12.2	J	47380	5031	J	9178.0929	14	21
13981-16-3	Pu-238	pCi/L	0.12	0.14		1			0.508	6	38
0-013	Pu-239/240	pCi/L	0.14			1.11	0.69	J	0.62	6	37
13982-63-3	Ra-226	pCi/L	0.3	0.2		73.3	49.3		4.162	45	108
15262-20-1	Ra-228	pCi/L	0.61	0.83		1980	280		126.02845	59	110
13967-48-1	Ru-106	pCi/L	150			150			150	2	9
14158-27-1	Sr-89	pCi/L	6690	1365	J	6690	1365	J	6690	1	1
10098-97-2	Sr-90	pCi/L	5			298780	32880		10621.678	32	70
14133-76-7	Tc-99	pCi/L	1.8	1.6	J	5017	398		275.32	19	48
14274-82-9	Th-228	pCi/L	0.25	0.22		114	85		4.9833824	74	118
14269-63-7	Th-230	pCi/L	0.13	0.42		42.11	13.15		3.7681579	44	119
7440-29-1	Th-232	pCi/L	0.18	0.17		210	119		15.836316	44	123
01-00004	Tl-208	pCi/L	65.4	39.8		106	79		83.8	3	3
01-00018	Total radioactive strontium	pCi/L	0.02	0.89		312050	34338		9303.9832	100	117
10028-17-8	Tritium	pCi/L	290	250		897000	90000		25621.580	189	194
13966-29-5	U-234	pCi/L	0.36	0.25		4563	453		240.33571	73	115
15117-96-1	U-235	pCi/L	0.13	0.08		11.7	7.4		4.075	6	47
0-012	U-235/236	pCi/L	1			3.29	0.51		2.145	7	68
7440-61-1	U-238	pCi/L	0.28	0.21		43.23	17.34		6.4419231	57	116

Table 4.3.2 (continued)

CAS No.	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
01-00014	Zn-65	pCi/L	53.4	45.8		53.4	45.8		53.4	1	1
Filtered analyses											
12587-46-1	Alpha Particle	pCi/L	0.1	1.5		1150	170		36.609194	63	137
14596-10-2	Am-241	pCi/L	0.19	0.18		1			0.44	5	14
12587-47-2	Beta Particle	pCi/L	-1.4	3.6		12100	1200		285.1671	100	136
01-00020	Bi-214	pCi/L	36.3	32		52.97	37.63		44.635	2	2
14762-75-5	C-14	pCi/L	311	51		311	51		311	1	4
13966-05-7	Ca-45	pCi/L	31.1	3.8		465	47		134.16	5	8
0-190	Cm-234/244	pCi/L	1			1			1	1	2
15510-73-3	Cm-242	pCi/L	1			1			1	1	6
13981-15-2	Cm-244	pCi/L	12.2	2		12.2	2		12.2	1	1
10045-97-3	Cs-137	pCi/L	13.6			28.7	20.1		19.852941	23	134
14681-59-5	Fe-55	pCi/L	110			330	77		220	2	7
13981-37-8	Ni-63	pCi/L	195	36		346	49		270.5	2	8
14255-04-0	Pb-210	pCi/L	43.31	42.59		43.31	42.59		43.31	1	1
15092-94-1	Pb-212	pCi/L	43.3	40.2		70.4	52.3		56.85	2	2
01-00002	Pb-214	pCi/L	17.1	15		117	52		42.65	4	4
14380-75-7	Pm-147	pCi/L	50			443	45		246.5	2	8
13981-16-3	Pu-238	pCi/L	0.64	0.42		1			0.82	3	16
0-013	Pu-239/240	pCi/L	1			1			1	2	16
13982-63-3	Ra-226	pCi/L	0.2	0.1		2.2	0.4		0.7525	12	50
15262-20-1	Ra-228	pCi/L	3			1500	210		164.65167	30	52
13967-48-1	Ru-106	pCi/L	150			150			150	2	9
10098-97-2	Sr-90	pCi/L	5			12000	1200	J	1193.8	18	42
14133-76-7	Tc-99	pCi/L	0.8	0.7	J	8214	646		920.1	10	19
14274-82-9	Th-228	pCi/L	0.56	0.71		15.71	4.05		2.7063636	14	48
14269-63-7	Th-230	pCi/L	1			11.22	3.28		3.9928571	10	48
7440-29-1	Th-232	pCi/L	1			96.2	74.2		34.4475	9	51
01-00004	Tl-208	pCi/L	22.6	20.1		95	72.2		67.066667	3	3
01-00018	Total radioactive strontium	pCi/L	0.27	0.67		4713	520		125.83949	80	93
10028-17-8	Tritium	pCi/L	941	219		912000	91000		40419.375	48	48
13966-29-5	U-234	pCi/L	0.25	0.25		203	22		10.906957	24	50
15117-96-1	U-235	pCi/L	0.41	0.38		.41	0.38		0.41	1	10
0-012	U-235/236	pCi/L	1			4.78	0.65		2.89	6	40
7440-61-1	U-238	pCi/L	0.48	0.38		427	308	J	30.597333	20	52
13967-71-0	Zr-95	pCi/L	232	220		232	220		232	1	1

Table 4.3.3. Summary of radionuclides in perimeter wells, November 1988–October 1990

Constituent	Frequency	Detected concentrations (pCi/L)				Location of maximum	Date of maximum
		Minimum	Error	Maximum	Error		
^{60}Co	92/113	0.27	6.48	40.5	40.5	821	Feb-89
^{137}Cs	93/114	0.27	3.51	32.4	43.2	812	Jan-89
Gross alpha	109/113	0.108	0.432	232.2	10.8	812	Dec-88
Gross beta	112/113	0.027	1.323	17820	270	812	Dec-88
Total rad strontium	93/93	0.27	3.24	7560	270	812	Jun-02
Total radium	44/44	0.027	0.459	2.43	2.16	813	Dec-88
^{3}H	103/107	135	1323	12420	1350	825	Oct-89
^{234}U	1/1			199.8	5.4	812	Oct-90
^{235}U	1/1			3.24	0.54	812	Oct-90
^{238}U	1/1			6.75	0.81	812	Oct-90

NOTE: This table was created manually using listings of the Energy Systems perimeter well chemical data tables.

Table 4.3.4. Strontium detected in Phase I groundwater samples (pCi/L)

	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
Location[b]	Unfilt ^{90}Sr	Filt ^{90}Sr	Unfilt Tot Sr	Filt Tot Sr	Unfilt Tot Sr	Filt Tot Sr	Unfilt Tot Sr	Filt Tot Sr
01.0533	ND	ND			ND	2.91		
01.0536	ND	ND			3.32	1.84		
01.0538	ND	ND			2.17			
01.0539	5670	5880			3783	4713		
01.0540	ND	ND			1.73	ND		
01.0541	ND	ND						
01.0543	ND	ND			2.95	1.51		
01.0545	ND	ND	1.57	1.58	4.98	2.61		
01.0546					ND	ND		
01.0548					ND			
01.0549	ND	ND	2.42	ND	1.75	ND		
01.0550					ND	ND		
01.0553	5.33	ND	0.39	0.85	1.53	ND		
01.0554	ND	ND	2.13	1.99	3.52	2.69		
01.0563					31.55	32.28		
01.0564	363	374			190.6	216.3		
01.0566	20.9	17.3	19.09	16.8	21.1	18.8		
01.0571	15.2	16.3			39.15	26.19		
01.0572		ND			4.55	ND		
01.0579	ND	ND	6.61	4.86	4.28	5.22		
01.0587	ND				10.23	1.29		
01.0588							58.8	61.5
01.0589	203	174			284	180		
01.0590							40.4	842
01.0593							39.4	36.8
01.0596							2.91	8.63
01.0597	50.9	86.9	41.92	31.71	34.23	38.31		
01.0598	82.1	106	108.24	123.96	7.87	17.2		
01.0599	ND	ND			1.41	ND		
01.0601	477	466			894	973		
01.0602	ND	ND	2.48	2.79	3.66	3.56		
01.0603							7.6	19.9
01.0604	ND	ND			1.63	1.55		
01.0607							3.5	2.1
01.0608							4.6	12
01.0610	ND				4.43	3		

Table 4.3.4 (continued)

	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
Location[b]	Unfilt ^{90}Sr	Filt ^{90}Sr	Unfilt Tot Sr	Filt Tot Sr	Unfilt Tot Sr	Filt Tot Sr	Unfilt Tot Sr	Filt Tot Sr
01.0611					5.45	9.17		
01.0613							45.1	
01.0618	ND	ND			2.03	ND		
01.0620	ND	ND			13.8	ND		
01.0621	ND	ND			ND	ND		
01.0622	ND	ND			ND	ND		
01.0623	ND		1.22	0.89	ND	ND		
01.0634	12.1	13			3.28	4.4		
01.0814			3.23	4.9				
01.0820			2.12	3.36				
01.0824			2.46	ND				
01.0826			4.92	3.3				
01.0827			2.93	2.99				
01.0828			ND	1.55				
01.0873	12.6	17.7	16.13	21.16	13.2	9.8		
01.0874	1100	1120			647.7	676.9		
01.0875	10300	12000			21.61	16.25		
01.0876					4.4	ND		
01.0877	14.9	14.2			23.76	27.92		
01.0878	ND	ND			ND	ND		
01.0879	ND	ND			0.76			
01.0880	ND	ND			1.63	1.84		
01.0881	ND	ND			2.88	ND		
01.0882	20.3	19.2			17.83	19.45		
01.0884	ND	ND			ND	ND		
01.0885	27.1	30.3			33.11	27.87		
01.0886					3.3			
01.0946			15.26	14.97	11.29	13.49		
01.1100	101	111			56.3	72.3		
01.1101					114.7	108.1		
01.1102	1020	990			948	960		
01.1103	34.9	26.6			37.6	34.2		
01.1104	90	82.6			78.3	78.1		
01.CH11A					24.45			
01.CH001-2							1.9	
01.CH003-1							7.49	

Table 4.3.4 (continued)

	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
Location[b]	Unfilt ^{90}Sr	Filt ^{90}Sr	Unfilt Tot Sr	Filt Tot Sr	Unfilt Tot Sr	Filt Tot Sr	Unfilt Tot Sr	Filt Tot Sr
01.CH006-1							4.19	
01.CH006-2							ND	
01.CH006-4							ND	
01.CH008-2							312050	
01.CH008-2							298780[c]	
01.CH008-2							6690[d]	
01.CH008-3							245574	
01.CH008-1							103238	
01.CH008-4							81372	
01.CH008-5							56851	
01.CH008-6							16520[c]	
01.CH008-6							1190[d]	
01.CH008-7							17405	
01.CH009-2							3.95	
01.CH009-4							3.89	
01.CH07A-1							5.12	
01.CH07A-2							3.82	
01.CH11A-2							1.74	

[a]The value reported is the maximum activity found at the specified location, whether a regular or duplicate sample.
[b]Refer to Table 3.3.5 for further details on the intervals sampled within the coreholes.
[c]Strontium-90 concentration.
[d]Strontium-89 concentration.

Table 4.3.5. Tritium detected in Phase I groundwater samples (pCi/L)

Location[b]	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991	High base[a] March–April 1991	Other[a] July–October 1991
	Unfiltered	Filtered	Unfiltered	Unfiltered	Unfiltered
01.0533	1740	1690		2190	
01.0536	2460	2420		2190	
01.0538	1210	1400		1780	
01.0539	13500	13400		11990	
01.0540	1960	1100		1310	
01.0541	1030	941	1660	1660	
01.0543	17000	17700		11150	
01.0545	3700	3700	3080	3200	
01.0546				2500	
01.0548				3050	
01.0549	3550	3600	3710	3640	
01.0550				2750	
01.0553	2110	1920	2060	2240	
01.0554	927	949	1660	2410	
01.0563				4260	
01.0564	108000	102000		63070	
01.0566	231000	233000	145870	133000	
01.0571	1560	1730		1810	
01.0572	2340	2760		2150	
01.0579	3490	7280	3060	3330	
01.0587	1360	1150		1570	
01.0588					1460
01.0589	35600	34800		17600	
01.0590					22530
01.0593					730
01.0596					1140
01.0597	ND	4600	4980	510	
01.0598	7250	7200	6840	6460	
01.0599	5800	5550		5130	
01.0601	3470	3520		1620	
01.0602	10600	9530	9660	9000	
01.0603					61750

Table 4.3.5 (continued)

Location[b]	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991	High base[a] March–April 1991	Other[a] July–October 1991
	Unfiltered	Filtered	Unfiltered	Unfiltered	Unfiltered
01.0604	4850	ND		4800	
01.0607					3550
01.0608					181650
01.0610	1600	1720		1310	
01.0611				7330	
01.0613					54180
01.0618	3240	3310		3290	
01.0620	4150	4330		3060	
01.0621	4810	4870		5050	
01.0622	6250	6360		5770	
01.0623	5160	5050	3950	3990	
01.0634	2710	2920		2920	
01.0814	3590		2780		
01.0818	4720				
01.0819	1440				
01.0820			5610		
01.0824			2430		
01.0826			2890		
01.0827			1500		
01.0828			2090		
01.0873	7760	7560	9710	9070	
01.0874	404000	359000		275100	
01.0875	185000	165000		827670	
01.0876				338800	
01.0877	2560	2540		2340	
01.0878	2590	2660		2320	
01.0879	3000	3020		2830	
01.0880	2760	2760		2860	
01.0881	2420	2560		2240	
01.0882	2180	2150		10400	
01.0884	1630	1560		1710	
01.0885	897000	912000		838200	

Table 4.3.5 (continued)

Location[b]	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991	High base[a] March–April 1991	Other[a] July–October 1991
	Unfiltered	Filtered	Unfiltered	Unfiltered	Unfiltered
01.0886	8920	8420		11620	
01.0946			1790	1680	
01.1100	101000	104000		168530	
01.1101				2540	
01.1102	24900	24200		42370	
01.1103	19900	19100		16140	
01.1104	79500	77600		50950	
01.CH001-2					1870
01.CH001-3					900
01.CH001-1					670
01.CH003-1					1940
01.CH006-1					2040
01.CH006-2					290
01.CH006-4					ND
01.CH008-2					3780
01.CH008-3					3580
01.CH008-1					3470
01.CH008-5					3170
01.CH008-4					2670
01.CH008-6					660
01.CH008-7					450
01.CH009-2					29980
01.CH009-4					18220

Table 4.3.5 (continued)

Location[b]	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991	High base[a] March–April 1991	Other[a] July–October 1991
	Unfiltered	Filtered	Unfiltered	Unfiltered	Unfiltered
01.CH07A-1					3180
01.CH07A-2					2370
01.CH11A-1					880
01.CH11A-3					ND
01.CH012					310

[a]The value reported is the maximum activity found at the specified location, whether a regular or duplicate sample.
[b]Refer to Table 3.3.5 for further details on the intervals sampled within the coreholes.

Table 4.3.6. Gross alpha activity in Phase I groundwater samples (pCi/L)

	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
Location[b]	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered
01.0533	ND				32.1	ND		
01.0536	68.4	4.98			15	ND		
01.0538	136	ND			247	ND		
01.0539	1080	1150			200	210		
01.0540	ND	ND			ND	ND		
01.0541	17.9	ND			47.8	ND		
01.0543	47.8	ND			32.9	ND		
01.0545	37.7	ND	35.1	12.3	56.3	ND		
01.0546					19	ND		
01.0548						25.8		
01.0549	118	ND	125.9	ND	38.2	ND		
01.0550					1684	ND		
01.0553	ND	ND	15.6	ND	ND	1.5		
01.0554	24	ND	26.4	ND	ND	8.6		
01.563					32.7	ND		
01.0564	27.9	12			7.6	ND		
01.0566	212	165	34.9	1.7	25.2	2.3		
01.0571	81.5	ND			61.6	ND		
01.0572		ND			5.6	ND		
01.0579	ND	ND	22.1	ND	5.4	3.3		
01.0587		9.89			ND	2.8		
01.0588							48.9	ND
01.0589					76.9	2.8		
01.0590							87.9	8.1
01.0593							114	3.7
01.0596							125	1.7
01.0597	4.34		47.2	2.1	12.3	2.5		
01.0598	25.7	15.2	ND	6.1	15	ND		
01.0599	ND	ND			3	ND		

Table 4.3.6 (continued)

Location[b]	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered
01.0601	117	35.4			32.2	ND		
01.0602		ND	37.1	ND	12.5	ND		
01.0603							54.5	6.9
01.0604	ND	ND			24.2	ND		
01.0607							ND	2.3
01.0608						ND	177	2.3
01.0610	ND				14.9	ND		
01.0611					19.7	ND		
01.0613							ND	
01.0618	ND	ND			24.4	ND		
01.0620	7.76	ND			12.8	ND		
01.0621	ND				2.9	ND		
01.0622	29.9	8.3			22.1	ND		
01.0623	ND	ND	ND	ND	ND	5.7		
01.0634	6.75				9.7	ND		
01.0814		11.8	ND	ND				
01.0819	ND	2.94						
01.0820			2.5	ND				
01.0824			8.3	14				
01.0826			8.1	6.4				
01.0827			ND	ND				
01.0828			ND	12.6				
01.0873	7.67	6.36	ND	ND	18.9	ND		
01.0874	73.7	28.3			4.4	ND		
01.0875	160	287			ND	4		
01.0876					ND	ND		
01.0877	ND	11.8			58.4	ND		
01.0878	ND	ND			5.1	ND		
01.0879	ND	ND			ND	5		

Table 4.3.6 (continued)

Location[b]	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered
01.0880	ND	ND			ND	ND		
01.0881	ND	5.53			3.1	ND		
01.0882	ND	ND			ND	ND		
01.0884	ND	ND			ND	ND		
01.0885	9.41				ND	ND		
01.0886					ND	ND		
01.0946			11.1	ND	4.9	ND		
01.1100	7.46	12			2.5	ND		
01.1101	16.6				ND	ND		
01.1102	91.6	120			4.7	8.8		
01.1103					ND	ND		
01.1104	18.6	7.24			5.6	ND		
01.CH001-1							3.1	
01.CH001-2							2.2	
01.CH001-3							ND	
01.CH003-1							13.5	
01.CH006-2							10.8	
01.CH006-4							ND	
01.CH006-1							ND	
01.CH008-2							5093	
01.CH008-4							4263.3	
01.CH008-3							3775	
01.CH008-5							2516.6	
01.CH008-1							1461.4	
01.CH008-6							1295	
01.CH008-7							697	
01.CH009-2							4.3	
01.CH009-4							ND	
01.CH07A-2							4.1	

Table 4.3.6 (continued)

	Low base[a] September–October 1990		High base storm[a] February 21–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
Location[b]	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered
01.CH07A-1							ND	
01.CH11A-3							16.1	
01.CH11A-1							ND	

[a]The value reported is the maximum activity found at the specified location, whether a regular or duplicate sample.
[b]Refer to Table 3.3.5 for further details on the intervals sampled within the coreholes.

Table 4.3.7. Gross beta activity in Phase I groundwater samples (pCi/L)

	Low base[a] September–October 1990		High base storm[a] February 22–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
Location[b]	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered
01.0533	71.4	5.05			675	26.1		
01.0536	97	ND			24.8	19.5		
01.0538	162	ND			118	ND		
01.0539	12900	12100			10638	10729		
01.0540	71.3	4.65			ND	5.8		
01.0541	20.8	3.31			41.5	4.7		
01.0543	41.2	ND			37	ND		
01.0545	40.8	4.24	40.8	ND	48.6	4.3		
01.0546					12.9	ND		
01.0548					17.4	ND		
01.0549	155	ND	170.6	ND	131.5	ND		
01.0550					3476	6		
01.0553	23.2	ND	52.5	ND	ND	4.9		
01.0554	39.4	4.32	47.4	7.2	8.3	8.6		
01.0563					195.2	85.9		
01.0564	805	783			753.4	657.1		
01.0566	154	439	109	47.2	97.2	58.8		
01.0571	227	37.5			218	60.3		
01.0572	114	4.05			2.7	ND		
01.0579	79.2	8.22	35.3	8.6	114	93.2		
01.0587	9.32	5.08			7.4	ND		
01.0588							335	140.1
01.0589	520	338			552	343		
01.0590							5278	3852
01.0593							128	15.3
01.0597	118	208	182.3	66.6	130.1	101.1		
01.0598	251	222	484.5	298	267	157		
01.0599	11.7	ND			7.3	ND		
01.0601	1040	873			2999	2231		

Table 4.3.7 (continued)

Location[b]	Low base[a] September–October 1990		High base storm[a] February 22–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered
01.0602		ND	68.3	ND	25.5	ND		
01.0603							203	33.4
01.0604	43.9	6.1			50.2	ND		
01.0607							9.5	18.9
01.0608							307	65.1
01.0610	14.6	13.8			16.4	4.7		
01.0611					108	6.6		
01.0613							151	
01.0618	46.4	ND			26.2	ND		
01.0620	5.29	ND			14.8	ND		
01.0621	6.96				6.8	ND		
01.0622	28.6	15.7			31.3	ND		
01.0623	18.7	7.71	7.4	ND	ND	ND		
01.0634	13.2				7.6	6.7		
01.0814		ND	ND	ND				
01.0819	ND	61.5						
01.0820			ND	ND				
01.0824			ND	ND				
01.0826			15.2	11.5				
01.0827			10.1	12.9				
01.0828			4.6	9.7				
01.0873	28.7	30.4	39.5	41.6	165	31.9		
01.0874	2710	1570			1049	1083		
01.0875	4650	5710			44	48.2		
01.0876					7.7	ND		
01.0877	32.7	32.6			56	60.5		
01.0878	ND	ND			ND	ND		
01.0879	ND	ND			ND	ND		
01.0880	ND	8.26			ND	ND		

Table 4.3.7 (continued)

Location[b]	Low base[a] September–October 1990		High base storm[a] February 22–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered
01.0881	ND	ND			ND	ND		
01.0882	34.9	56.2			40.5	43.2		
01.0884	4.07	ND			ND	ND		
01.0885	93.6	71.7			65.6	76.6		
01.0886	ND	ND			13.6	6.4		
01.0946			35.2	31.7	29.4	26		
01.1100	215	178			90.7	118		
01.1101	191				173	188		
01.1102	2010	2040			2200	1840		
01.1103	78.4	68.9			66.9	64.6		
01.1104	205	164			145	155		
01.CH001-2							5.4	
01.CH001-3							3.7	
01.CH001-1							2.8	
01.CH003-1							21	
01.CH006-1							11.2	
01.CH006-2							5.9	
01.CH006-4							ND	
01.CH008-2							585497.1	
01.CH008-3							487093.5	
01.CH008-1							215495.3	
01.CH008-4							156799.7	
01.CH008-6							118960	
01.CH008-5							113545	
01.CH008-7							32080	
01.CH009-4							17.5	
01.CH009-2							12.3	
01.CH07A-2							23.4	
01.CH07A-1							6.3	

Table 4.3.7 (continued)

Location[b]	Low base[a] September–October 1990		High base storm[a] February 22–23, 1991		High base[a] March–April 1991		Other[a] July–October 1991	
	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered	Unfiltered	Filtered
01.CH11A-1							105	
01.CH11A-3							26	
01.CH012							3.2	

[a]The value reported is the maximum activity found at the specified location, whether a regular or duplicate sample.
[b]Refer to Table 3.3.5 for further details on the intervals sampled within the coreholes.

Table 4.3.8. Radium detected in Phase I groundwater samples (pCi/L)

Location[b]	Low base unfiltered[a]		Filtered[a]		High base unfiltered[a]		Filtered[a]		Other unfiltered[a]		Filtered[a]	
	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra
01.0533	ND	ND	ND		ND	1						
01.0536	ND	ND	4.12	ND								
01.0538	ND	ND	ND	ND	9.6	5.84						
01.0539	1980	ND	1500	ND								
01.0540	ND	ND	ND	ND								
01.0541	ND	ND	ND	ND	ND	2.9	96.1					
01.0543	ND	ND	ND	ND								
01.0545	ND	ND	5.19	ND			59.2					
01.0546					4.1	3.54						
01.0549[c]	ND	ND	ND	ND	3.8	4.02						
01.0553	ND	ND	ND	ND								
01.0554	ND	ND	ND	ND								
01.0563					28.89	2.1	31.34	0.62				
01.0564	75.8	ND	87.6	ND								
01.0566	8.66	ND	ND	ND	43	1.92						
01.0571	9.3	ND	5.04	ND	30.39	2.68		52.97				
01.0572	ND	ND	ND	ND	101.9							
01.0579	ND	ND	140	ND								
01.0587	5.47	ND	ND	ND								
01.0588									193	2.1	140	0.81
01.0589	43.8	ND	91.5		84.1	6.75						
01.0590									938	ND	820	0.4
01.0593									26.3	3.7	4.2	0.2
01.0596									210	3.7	4.5	2.2
01.0597	10.3	ND	4.67	ND								
01.0598	27.1	ND	31.7	ND	111.7							
01.0599	ND	ND	ND	ND								
01.0601	127	ND	92.5	ND								
01.0602	ND	ND	ND	ND								
01.0603									47.4	5.7	96.2	0.31

Table 4.3.8 (continued)

Location[b]	Low base unfiltered[a]		Filtered[a]		High base unfiltered[a]		Filtered[a]		Other unfiltered[a]		Filtered[a]	
	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra
01.0604	3.46	ND	ND	ND	4.9	3.06						
01.0607									8	0.54	11	0.56
01.0608										1.06	23.9	0.54
01.0610	ND	ND	ND									
01.0611					6.09	1.33						
01.0613									126	1.7		
01.0618	ND	ND	ND	ND	2.3	1.18						
01.0620	ND	ND	ND	ND								
01.0621	ND	ND	ND	ND								
01.0622	3.13	ND	ND	ND	1.3	0.45						
01.0623	ND	ND	ND									
01.0634	ND	ND	ND	ND								
01.0873	ND	ND	ND	ND								
01.0874	316	ND	229	ND								
01.0875	1870	ND	1160	ND								
01.0877	4.54	ND	4.03	ND	10.1							
01.0878	ND	ND	ND	ND								
01.0879	ND	ND										
01.0880	ND	ND	ND	ND								
01.0881	ND	ND										
01.0882	3.75	ND	3.45	ND								
01.0884	ND	ND	ND	ND			93.3					
01.0885	1.36	ND	5.89									
01.0886	ND	ND	3									
01.1100	16.5	ND	17.5	ND								
01.1101								140				
01.1102	207	1.34	308	ND								
01.1103	17.2	2.43	11.8					69.3				
01.1104	15.3	ND	9.55	ND								
01.CH001-1									17.1	2		

Table 4.3.8 (continued)

Location[b]	Low base unfiltered[a]		Filtered[a]		High base unfiltered[a]		Filtered[a]		Other unfiltered[a]		Filtered[a]	
	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra	^{228}Ra	^{226}Ra
01.CH001-3									28.4	2		
01.CH008-6									ND	13.3		
01.CH008-4									ND	0.7		
01.CH008-1									ND	1.4		
01.CH008-2									ND	3.9		
01.CH008-7									ND	4.7		
01.CH008-5									ND	ND		
01.CH008-3									ND	1		
01.CH11A-1									138	0.9		
01.CH11A-3									ND	0.3		

[a]The value reported is the maximum activity found at the specified location, whether a regular or duplicate sample.
[b]Refer to Table 3.3.5 for further details ou the intervals sampled withiu the coreholes.
[c]Also sampled during storm event. Result = 66.3 pCi/L ± 57.5 in filtered sample.

Table 4.3.9. Transuranics detected in Phase I groundwater samples

Location	Compound	Filtered/ unfiltered	Result	Error	Sample type	Sampling date
01.0596	Am-241	U	20.4	7.9	RG	08-OCT-91
01.CH008	Am-241	U	4.6	3.3	RG	03-SEP-91
01.CH008	Am-241	U	3.86	1.96	RG	19-AUG-91
01.0593	Am-241	U	1.69	1.11	RG	17-OCT-91
01.CH008	Am-241	U	1.68	1.57	RG	21-AUG-91
01.CH008	Am-241	U	1.48	1.09	RG	27-AUG-91
01.CH008	Am-241	U	1.23	0.93	DU	21-AUG-91
01.0571	Am-241	U	0.46	0.29	RG	21-MAR-91
01.0603	Am-241	F	0.43	0.25	RG	15-OCT-91
01.0603	Am-241	U	0.41	0.3	RG	15-OCT-91
01.0608	Am-241	U	0.29	0.22	RG	17-OCT-91
01.0571	Am-241	U	0.24	0.17	DU	21-MAR-91
01.0608	Am-241	F	0.21	0.18	RG	17-OCT-91
01.0607	Am-241	F	0.19	0.18	RG	15-OCT-91
01.0608	Cm-244	U	108	44	RG	
01.CH008	Cm-244	U	87.6	40.9	DU	21-AUG-91
01.0590	Cm-244	U	44.7	22.6	RG	
01.0593	Cm-244	U	34.2	17.9	RG	
01.0598	Cm-244	F	12.2	2	RG	28-SEP-90
01.0590	Pu-238	F	0.64	0.42	RG	11-OCT-91
01.0571	Pu-238	U	0.52	0.45	DU	21-MAR-91
01.0571	Pu-238	U	0.5	0.46	RG	21-MAR-91
01.0590	Pu-238	U	0.4	0.34	RG	11-OCT-91
01.0571	Pu-239/240	U	1.11	0.69	RG	21-MAR-91
01.0571	Pu-239/240	U	0.55	0.46	DU	21-MAR-91
01.0590	Pu-239/240	U	0.3	0.27	RG	11-OCT-91

Table 4.3.10. Summary of chemical contamination detected in WAG 1 groundwater

CAS No.	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
BNAE											
98-86-2	Acetophenone	µg/L	6		J	6	J		6	1	8
86-30-6	Benzenamine, N-Nitroso-N-	µg/L	2		J	6	J		3.75	15	163
117-81-7	Bis(2-Ethylhexyl) Pthala	µg/L	2		J	44	J		16.17	28	163
85-68-7	Butyl Benzyl Pthalate	µg/L	13			13			13	1	163
108-95-2	Carbolic Acid	µg/L	2		J	2	J		2	1	151
84-74-2	Di-n-butyl Phthalate	µg/L	1		J	75			14.29	10	163
91-20-3	Naphthalene	µg/L	10		J	14	J		12.00	2	163
91-57-6	Napthalene, 2-Methyl	µg/L	3		J	4	J		3.5	2	163
85-01-8	Phenathrene	µg/L	2		J	2	J		2	1	163
117-84-0	Phthalic Acid, Dioctyl Ester	µg/L	1		J	2	J		1.5	2	163
CYANIDE											
57-12-5	Cyanide	µg/L	100			100			100	1	138
METALS (UNFILTERED)											
7429-90-5	Aluminum	µg/L	18			180000			25666.06	162	206
7440-36-0	Antimony	µg/L	26.2			162			56.85	20	202
7440-38-2	Arsenic	µg/L	2		J	282			21.35	43	202
7440-39-3	Barium	µg/L	14.2			1450			201.2	204	206
7440-41-7	Beryllium	µg/L	1			21.3			4.48	77	206
7440-43-9	Cadmium	µg/L	2			29.9			7.64	60	206
7440-70-2	Calcium	µg/L	16900			1330000			223020.59	206	206
7440-47-3	Chromium	µg/L	4.1			282			45.09	152	206
7440-48-4	Cobalt	µg/L	4.2			267			30.93	97	206
7440-50-8	Copper	µg/L	4.4		J	224			36.31	104	206
7439-89-6	Iron	µg/L	13.4			437000		J	29070.84	197	206

Table 4.3.10 (continued)

CAS No.	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
7439-92-1	Lead	µg/L	1.1			628		J	44.38	137	206
7439-95-4	Magnesium	µg/L	496			104000			24295.99	206	206
7439-96-5	Manganese	µg/L	1.8			14400			1603.2	202	206
7439-97-6	Mercury	µg/L	0.24			2.4		J	0.76	15	174
7440-09-7	Nickel	µg/L	4.4			304			52.44	113	206
7440-09-7	Potassium	µg/L	313			51600			5405.32	193	206
7782-49-2	Selenium	µg/L	3.2		J	5.8		J	4.78	4	161
7440-22-4	Silver	µg/L	2.6		J	132			20.92	70	206
7440-23-5	Sodium	µg/L	2210			691000			25440.51	204	206
7440-28-0	Thalium	µg/L	5.6			2470			1353.15	4	201
7440-62-2	Vanadium	µg/L	3.2			379		J	48.87	129	206
7440-66-6	Zinc	µg/L	5			57200			1082.76	164	206
METALS—FILTERED											
7429-90-5	Aluminum	µg/L	17.6			1830			196.72	57	175
7440-36-0	Antimony	µg/L	13.2			33.5			20.95	15	174
7440-38-2	Arsenic	µg/L	2.1			7.4			3.64	20	170
7440-39-3	Barium	µg/L	3.9			375			83.78	175	175
7440-41-7	Beryllium	µg/L	1			1.1		J	1.05	4	175
7440-43-9	Cadmium	µg/L	2			9			3.86	24	175
7440-70-2	Calcium	µg/L	1300			203000			89246.34	175	175
7440-47-3	Chromium	µg/L	3.4			27.5			17.11	35	175
7440-48-4	Cobalt	µg/L	5.1			14			8.56	9	175
7440-50-8	Copper	µg/L	3.8			42.8			12.84	41	175
7439-89-6	Iron	µg/L	10.2			17400			1406.68	135	175
7439-92-1	Lead	µg/L	1.2			25.9			4.13	56	175
7439-95-4	Magnesium	µg/L	636			45000			14709.78	175	175

Table 4.3.10 (continued)

CAS No.	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
7439-96-5	Manganese	µg/L	1.2			11000			1053.48	154	175
7439-97-6	Mercury	µg/L	0.24			1.8		J	0.92	7	174
7440-02-0	Nickel	µg/L	4.2			51.3			18.19	28	175
7440-09-7	Potassium	µg/L	306		J	147000			2127.08	158	175
7782-49-2	Selenium	µg/L	2.2		J	18.9			6.42	5	155
7440-22-4	Silver	µg/L	3.9			20.3			13.53	27	174
7440-23-5	Sodium	µg/L	1810			732000			27496.82	174	175
7440-28-0	Thallium	µg/L	3.3		J	3.3		J	3.3	1	174
7440-62-2	Vanadium	µg/L	3.1			18.3			10.22	15	175
7440-66-6	Zinc	µg/L	2.2			745			62.25	90	175
PEST/PCB											
319-85-7	Beta-BHC	µg/L	0.1		J	0.32			0.18	3	140
319-86-8	Delta-BHC	µg/L	0.67			0.67			0.67	1	142
VOC											
71-55-6	1,1,1-Trichloroethane	µg/L	2		J	30			13.14	7	171
79-34-3	1,1-Dichloroethane	µg/L	1		J	42			20.14	8	171
75-35-4	1,1-Dichloroethylene	µg/L	1		J	4			2.67	3	171
107-06-2	1,2-Dichloroethane	µg/L	2		J	2		J	2	1	171
540-59-0	1,2-Dichloroethylene	µg/L	1		J	170			22.82	36	166
591-78-6	2-Hexanone	µg/L	2		J	13		J	6.33	3	171
67-64-1	Acetone	µg/L	4		J	180		J	40.63	9	170
71-43-2	Benzene	µg/L	51		J	160		J	108.5	4	171
75-15-0	Carbon Disulfide	µg/L	1		J	7			3.8	8	169
56-23-5	Carbon Tetrachloride	µg/L	2		J	19		J	9.25	4	171
67-66-3	Chloroform	µg/L	1		J	32			14.33	31	171
100-41-4	Ethylbenzene	µg/L	25		J	120		J	62.5	4	171

Table 4.3.10 (continued)

CAS No.	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
75-27-4	Methane, bromodichloro	µg/L	5			5			5	2	171
74-87-3	Methyl Chloride	µg/L	18			18			18	1	171
75-09-2	Methylene Chloride	µg/L	1		J	74			15.17	11	171
108-10-1	Methylisobutylketone	µg/L	14			31		J	22.5	2	171
110-86-1	Pyridine	µg/L	26		J	26		J	26	1	3
127-18-4	Tetrachloroethylene	µg/L	1		J	39			12.09	13	171
108-88-3	Toluene	µg/L	1		J	150			31.19	19	171
79-01-6	Trichloroethylene	µg/L	2		J	210			59.67	24	170
75-01-4	Vinyl Chloride	µg/L	3		J	43			12.36	12	171
1330-20-7	Xylene (Total)	µg/L	23		J	190			83.5	4	170

Table 4.3.11. Maximum concentrations of VOCs detected in Phase I groundwater samples from WAG 1

Volatile organic compound (μg/L)	MCL	RCRA action limit[a]	Low base maximum	High base maximum	Storm maximum	Miscellaneous sampling
1,1-Dichloroethane			42J	18	32	
1,1-Dichloroethene	7	7 (MCL)	4J		3J	
1,1,1-Trichloroethane	200	3000	30	9	16	4J
1,2-Dichloroethene (cis)	70[c]		170[d]	55	32J	21
1,2-Dichloroethene (trans)	100[c]				13J	
1,2-Dichloroethane				2J		
2-Hexanone			4J			
Acetone		4000	19J	33	37J	180
Benzene	5		160	51J	93J	
Bromodichloromethane		0.03	5	5		
Carbon disulfide		4000	7	5		
Carbon tetrachloride	5	0.3	3J		19J	
Chloroform		6	24	23	32	17
Ethylbenzene	700[c]	4000	120J	25J	30J	
Methyl chloride (chloromethane)			18			
Methyl isobutyl ketone			31J			
Methylene chloride	5	5		74	7J	4J
Pyridine			26J			
Tetrachloroethene	5f	0.7	22	39	9	6
Toluene	1000[c]	10,000	41J	10	11	150
Trichloroethene	5	5 (MCL)	210	160	140J	180
Vinyl chloride	2		43	12	7J	18
Xylene	10,000[c]	70,000	190	51J	70J	

[a]See Figs. 4.3.15 through 4.3.18 for locations of the listed maximum concentrations.
[b]Proposed RCRA corrective action for SWMUs at hazardous waste sites, 55 FR 30798 (July 27, 1990).
[c]MCL effective July 30, 1992, 56 FR 3526 (January 30, 1991).
[d]1988 SOW for Organic Analyses does not require that the isomers of 1,2-Dichloroethene be differentiated.

Table 4.3.12. Total VOC concentrations detected in Phase I groundwater samples from WAG 1

Location	Low base (μg/L)	High base (μg/L)	High base storm (μg/L)	Miscellaneous sampling (μg/L)
01.0533	1J	0		
01.0536	2	0		
01.0538	7	0		
01.0539	24	8		
01.0540	0	0		
01.0541	8	5		
01.0543	215	68		
01.0545	3	0	0	
01.0546	NS	28		
01.0548	NS	19		
01.0549	0	0	0	
01.0550	NS	7		
01.0553	530 (412)[a]	164		442
01.0554	20	12	12	
01.0558	NS	2		
01.0563	NS	8		
01.0564	7	11		
01.0566	21	0	4	
01.0571	0	0		
01.0572	2	4		
01.0579	0	0	0	
01.0584	0	0	0	
01.0587	12	0		
01.0588				99
01.0589	10	4		
01.0596				55
01.0597	29	28	32	
01.0598	211	190	172	
01.0599	0	112		
01.0601	1	1		
01.0602	37	22	10	
01.0604	0	6		
01.0610	0	0		
01.0611	11	0		
01.0614	NS	0		
01.0618	60	0		
01.0620	0	0		
01.0621	0	0		
01.0622	5	0		
01.0623	0	0	0	
01.0624	0	0		
01.0814	29	NS	7	
01.0818	0	NS		

Table 4.3.12 (continued)

Location	Low base (μg/L)	High base (μg/L)	High base storm (μg/L)	Miscellaneous sampling (μg/L)
01.0819	0	NS		
01.0820	NS	NS	4	
01.0828	NS	NS	3	
01.0873	28	37		
01.0874	0	0		
01.0875	0	5		
01.0876	41	14		
01.0877	0	0		
01.0878	0	0		
01.0879	4	0		
01.0880	0	NA		
01.0881	0	38		
01.0882	0	0		
01.0884	0	0		
01.0885	23	9		
01.0886	36	72		
01.0946	NS	0	3	
01.0987	NS	0		
01.0988	NS	0		
01.1100	57	2		
01.1101	0	35		
01.1102	6	8		
01.1103	33	3		
01.1104	0	0		
CH001-1				2J
CH001-3				2J
CH003-1				43
CH006-1				165
CH006-2				38
CH006-4				62
CH008-6				17
CH008-7				19
CH009-2				40
CH009-4				321
CH07A-1				182J
CH07A-2				97
CH11A-1				4J
CH11A-3				4J
CH012				2J

[a]Value in parenthesis indicates 2 sampling events at that well location.
NS = not sampled.
NA = not analyzed for.

NOTE: This table was generated by extracting maximum values from report used in Table 4.3.14.

Table 4.3.13. Sample-specific VOCs detected in Phase I groundwater samples from WAG 1[a]

Location	Compound	Low base (μg/L)	High base (μg/L)	High base storm (μg/L)	Miscellaneous (μg/L)
533	Toluene	1J	ND	NS	
536	2-Hexanone	2J	ND	NS	
538	Trichloroethylene	3J	ND	NS	
	2-Hexanone	4J	ND		
539	1,2-Dichloroethylene	2J	ND	NS	
	Chloroform	16	8		
	Trichloroethylene	6	ND		
541	1,2-Dichloroethylene	8	4J	NS	
	Methylene chloride	ND	1J		
543	1,2-Dichloroethylene	170	55	NS	
	Carbon disulfide	1J	ND		
	1,1-Dichloroethylene	1J	ND		
	Vinyl chloride	43	11		
	Methylene chloride	ND	2J		
545	Carbon tetrachloride	3J	ND	ND	
546	Trichloroethylene	NS	27	NS	
	Chloroform		1J		
548	1,2-Dichloroethylene	NS	15	NS	
	Trichloroethylene	ND	4J	ND	
550	Chloroform	NS	4J	NS	
	Trichloroethylene		3J		
	1,2-Dichloroethane	2J	ND		
553	Vinyl chloride	ND ND	ND	7J	
	1,1-Dichloroethane	40 42J	18	32	
	Benzene	160 130J	51J	93J	
	4-Methyl-2-pentanone	ND 31J	ND		
	Toluene	35 41J	10J	11J	
	Xylene (total)	190 ND	51J	70J	
	Ethylbenzene	75 120J	25J	30J	
	1,1,1-Trichloroethane	30 28J	9	16	
	1,1-Dichloroethylene	ND 4J	ND	3J	
	Acetone	ND 14J	ND	ND	
554	Tetrachloroethylene	17	9	9	
	1,1-Dichloroethane	1J	ND	ND	
	Carbon disulfide	2J	ND	ND	
	Chloroform	ND	3J	3J	
558	Chloroform	ND	2J	ND	
563	1,2-Dichloroethylene	NS	6	NS	
	Carbon disulfide	NS	2J	NS	
564	1,1-Dichloroethane	3J	5	NS	

Table 4.3.13 (continued)

Location	Compound	Low base (μg/L)	High base (μg/L)	High base storm (μg/L)	Miscellaneous (μg/L)
	Trichloroethylene	2J	2J		
	1,2-Dichloroethylene	1J	ND		
	Tetrachloroethylene	1J	1J		
	1,1,1-Trichloroethane	ND	3J		
566	Carbon disulfide	7	ND		
	4-Methyl-2-pentanone	14	ND		
	1,1,1-Trichloroethane			2J	
	Chloroform			2J	
572	Carbon disulfide	2J	ND	NS	
	Acetone	ND	4J		
587	Toluene	6	ND	NS	
	Chloroform	6	ND		
588	2-Hexanone			13J	
	Trichloroethene			16J	
	Carbon tetrachloride			19J	
	Acetone			37J	
	Chloroform			14J	
589	Chloroform	8	4J	NS	
	Trichloroethylene	2J	ND		
596	Chloroform			22J	
	Carbon Tetrachloride			13J	
	Trichloroethene			20	
597	Bromodichloromethane	5	5	ND	
	Chloroform	24	23	32	
598	Chloroform	1J	ND	ND	
	Trichloroethylene	210	160	140J	
	1,2-Dichloroethylene	ND	30	32J	
599	Acetone	ND	33	NS	
	Carbon disulfide		5		
	Methylene chloride		74		
601	1,2-Dichloroethylene	1J	ND	NS	
	Methylene chloride	ND	1J		
602	Trichloroethylene	23	18	10	
	1,2-Dichloroethylene	6	3J	ND	
	1,1-Dichloroethane	1J	ND	ND	
	Vinyl chloride	3J	ND	ND	
	Acetone	4J	ND	ND	
	Chloroform	ND	1J	ND	
604	Carbon disulfide	ND	2J	NS	
	Chloroform		4J		

Table 4.3.13 (continued)

Location	Compound	Low base (μg/L)	High base (μg/L)	High base storm (μg/L)	Miscellaneous (μg/L)
611	Acetone	11	ND	NS	
618	Methyl chloride	18	ND	NS	
	Xylene (total)	23	ND		
	Acetone	19J			
622	1,2-Dichloroethylene	5J	ND	NS	
814	Chloroform	3J	ND	ND	
	Methylene chloride			7J	
	Pyridine	26J			
820	Methylene chloride	A	A	4J	
828	Methylene chloride	ND		3J	
873	1,2-Dichloroethylene	16J	16	?	
	Tetrachloroethylene	12	14		
	Trichloroethylene	ND	7		
875	1,2-Dichloroethylene		5	NS	
876	1,2-Dichloroethylene	17J	14	NS	
	Trichloroethylene	24	ND	ND	
879	Carbon disulfide	4J	ND	NS	
881	1,2-Dichloroethylene	ND	26	NS	
	Vinyl chloride	ND	12		
885	Vinyl chloride	5J	ND	NS	
	1,2-Dichloroethylene	18J	9		
886	1,2-Dichloroethylene	14J	18	NS	
	Tetrachloroethylene	22	39		
	Trichloroethylene	ND	15		
946	Methylene chloride	A		3J	
1100	1,2-Dichloroethylene	46	2J	NS	
	Vinyl chloride	11	ND		
1101	1,2-Dichloroethylene		35		
1102	Vinyl chloride	6J	8J	NS	
1103	1,2-Dichloroethylene	8J	3J	NS	
	Trichloroethylene	6J	ND		
	Vinyl chloride	19	ND		
CH001-1	Toluene				2J
CH001-3	Toluene				2J
CH003-1	1,2-Dichloroethylene				8
	Toluene				8
	Acetone				27
CH006-1	1,1,1-Trichloroethylene				4J
	Methylene chloride				3J
	Toluene				150

Table 4.3.13 (continued)

Location	Compound	Low base (μg/L)	High base (μg/L)	High base storm (μg/L)	Miscellaneous (μg/L)
	Chloroform				8
CH006-2	Chloroform				4J
	Toluene				34
CH006-4	Toluene				62
CH008-6	Chloroform				17
CH008-7	Chloroform				12
	Methylene chloride				4J
	Toluene				3J
CH009-2	1,2-Dichloroethylene				17
	Vinyl chloride				18
	Toluene				5
CH009-4	Acetone				180
	Toluene				120
	1,2-Dichloroethylene				21
CH07A-1	Tetrachloroethylene				2J
	Trichloroethylene				180
CH07A-2	Trichloroethylene				87
	Chloroform				2J
	Tetrachloroethylene				6
	Toluene				2
CH11A-1	Toluene				4J
CH11A-3	Toluene				4J
CH012	Chloroform				2J

[a]At locations where field duplicate samples were collected, the maximum detected value is listed.

Notes:
- A - sampled by RI/FS Team, analyzed by ORNL (results not available).
- J - estimated concentration.
- ND - not detected.
- NS - not sampled.
- B - also in associated method blank.
- D - value obtained by dilution.

NOTE: This table was generated by extracting summed values from report used in Table 4.3.14.

Table 4.3.14. Summary of VOCs detected in perimeter wells, November 1988–October 1990

Compound	Frequency of detect range (μg/L)			Prefix	Location of maximum	Date of maximum
	Detection	Minimum	Maximum			
Acetone	16/46[a]	2	5	JB	808	Jun-89
Benzene	3/43	0.3	2	J	824	Sep-90
Chloroform	6/48	3	15		812	Oct-90
Hexane-20.1	16/16[a]	15	16	JB	807	Sep-90
Methylene chloride	3/65	1	3	J	813,816	Sep-90
Trichloroethene	5/47	3	11		813	Jun-89
1,1,1-trichloroethane	1/42		3	J	823	Oct-89
Vinyl chloride	2/42	18	28		825	Jun-89

[a]All positive detections qualified with "JB."

Table 4.3.15. Summary of BNAE compounds in perimeter wells

Compound	No. of detects	Detected range Min		Max		Location of maximum	Date of maximum
1,13-TETRADECADIENE	4	130	B	220	B	809	Sep-90
1,2-DICHLOROBENZENE	1			10		819	Oct-90
1,2,4-TRICHLOROBENZENE	2			10	B	819	Oct-90
1,3-DICHLOROBENZENE	1			10		819	Oct-90
1,4-DICHLOROBENZENE	1			10		819	Oct-90
2-CHLORONAPHTHALENE	1			10		819	Oct-90
2-CHLOROPHENOL	2			10		816, 819	Sep-90
2-NITROANILINE	1			50		816	Sep-90
2-NITROPHENOL	1			10		816	Sep-90
2,4-DICHLOROPHENOL	1			10		816	Sep-90
2,4-DIMETHYLPHENOL	2			10		816, 818	Sep-90
2,4-DINITROPHENOL	2			50		816, 818	Sep-90
2,4-DINITROTOLUENE	1			10		818	Sep-90
2,4,5-TRICHLOROPHENOL	1			50		818	Sep-90
2,4,6-TRICHLOROPHENOL	1			10		818	Sep-90
2,6-DINITROTOLUENE	1			10		818	Sep-90
4-BROMOPHENYL-PHENYLETHER	1			10		819	Sep-90
4-CHLORO-3-METHYLPHENOL	1			10		819	Sep-90
4-CHLOROPHENYL-PHENYLETHER	2	10		11	J	814	Oct-89
ANTHRACENE	1			11	J	813	Oct-89
BENZYL ALCOHOL	1			10	J B	818	Sep-90
BIS(2-CHLOROISOPROPYL)ETHER	2	3	J	6	J	807	Jun-89
BIS(2-ETHYLHEXYL)PHTHALATE	4	8		41		809	Sep-90
DIBENZOFURAN	1			10		816	Sep-90
DIETHYLPHTHALATE	3	10	J B	6	J B	816	Sep-90
DIMETHYLPHTHALATE	1			10		816	Sep-90
DI-N-OCTYLPHTHALATE	2	10		220		810	Sep-90
FLUORANTHENE	1			10		816	Sep-90
FLUORENE	1			10		816	Sep-90
HEXACHLOROBENZENE	1			10		816	Sep-90
HEXACHLOROBUTADIENE	1			10	J B	816	Sep-90
HEXACHLOROETHANE	3			10	J	813, 814, 818	Oct-89
INDENO(1,2,3-CD)PYRENE	4			10	J	813	Oct-89
ISOPHORONE	1			10		818	Sep-90
N-NITROSO-DI-N-PROPYLAMINE	1			10		818	Sep-90
PHENANTHRENE	1			10	J	818	Sep-90
PHENOL	1			10		819	Oct-90
PYRENE	1			10		819	Oct-90
UNKNOWN BNAE COMPOUNDS	30	0.9	J	27	J	824	Sep-90

NOTE: This table was generated manually using data from ORNL data base tables TOT8890 and DID8890.

Table 4.3.16. Summary of results for metals analyses of groundwater samples

Metal	SDWA MCLs[a]	Maximum reference Value (μg/L)	Maximum reference Type	No. of detect locations	Above max. ref.	Above MCL	Maximum concentration (μg/L) Value	Maximum concentration (μg/L) Location	Filtered (μg/L) Type	Filtered (μg/L) Value	Filtered (μg/L) Location
Aluminum	NA	4400	U	69	45	NA	176000	553	U	1830	538
Antimony	NA	ND		17	17	NA	49.1J	553	U	33.5	536
Arsenic	50	2.6	U	36	25	0	24.1	CH006	U	7.4	622
Barium	2000	148	U	79	43	0	1450	603	U	375	1102
Beryllium	NA	ND		44	44	NA	21.3	553	U	1.1J	CH009
Cadmium	5	5.2	U	32	8	8	26.9	553	U	9	879
Calcium	NA	138000	U	80	44	NA	1330000	608	U	203000	543
Chromium	100	25.7	U	63	37	17	268J	553	U	27.5	541
Cobalt	NA	ND		44	44	NA	267	553	U	14	880
Copper	1300	9.3	U	51	44	0	224	553	U	42.8	597
Iron	NA	5100	U	78	50	NA	437000J	553	U	17400	610
Lead	15	25.7	U	73	30	39	628J	587	U	25.9	553
Magnesium	NA	28400	F	79	26	NA	96500	549	U	45000	879
Manganese	NA	1600	U	80	32	NA	14400	593	U	11000	877
Mercury	2	ND		19	19	1	2.4J	543	U	1.8J	CH006
Nickel	NA	38.6	U	53	26	NA	304	553	U	51.3	536
Potassium	NA	3830	F	80	38	NA	25000	603	U	14700	590
Selenium	50	ND		9	9	0	5.8	CH008	U	18.9	814
Silver	NA	ND		40	40	NA	30.7	553	U	20.3	879
Sodium	NA	49000	F	79	7	NA	732000	CH006	U	732000	CH006
Thallium	NA	ND		2	2	NA	5.6	603	U	3.3J	588
Vanadium	NA	5.8	U	54	49	NA	379J	553	U	18.3	536
Zinc	NA	32.1	U	71	53	NA	57200	608	U	745	548

[a]MCL taken from "Applicable or Relevant and Appropriate Requirements (ARARs) and To-Be-Considered (TBC) Guidance", May 1992, U.S. DOE Contract No. DE-AC05-84OR21400.

NA - No applicable SDWA MCL found.

ND - Not detected.

U - Unfiltered sample.

F - Filtered sample.

J - Estimated cocentration.

NOTE: This table was generated manually using data from ORNL data base tables TOT8890 and DIS8890.

Table 4.3.17. Summary of metals detected in perimeter wells, November 1988–October 1990

Compound	Frequency of detection	Detected range (mg/L) Minimum	Detected range (mg/L) Maximum	Location of maximum	Date of Maximum	Frequency of detection	Detected range (mg/L) Detected minimum	Detected range (mg/L) Maximum	Location of maximum	Data of maximum
Silver	22/114	0.005	0.017	806	12-Oct-89	21/69	0.016	0.005	815	30-May-89
Aluminum	75/113	0.062	12	816	02-Oct-89	32/69	0.059	0.65	809	16-Oct-89
Arsenic	3/137	0.05	0.074	807	07-Sep-90	2/92	0.01	0.064	807	07-Sep-90
Boron	31/113	0.08	1.1	808	10-Sep-90	20/69	0.082	1.1	808	10-Sep-90
Barium	70/114	0.0033	2.3	820	01-Jun-89	69/69	0.003	0.34	809	14-Jun-89
Beryllium	29/113	0.00032	0.031	828	15-Jun-89	6/69	0.029	0.03	829	15-Jun-89
Calcium	113/113	0.54	160	809	14-Jun-89	69/69	0.96	170	809	14-Jun-89
Cadmium	15/114	0.0086	0.045	820	01-Jun-89	8/69	0.0042	0.011	809	14-Jun-89
Cobalt	18/113	0.003	0.014	823	18-Oct-89	14/69	0.003	0.0084	828	17-Oct-89
Chromium	57/114	0.005	0.11	812	20-Jun-89	51/69	0.0042	0.027	809	14-Jun-89
Copper	18/113	0.0086	0.6	816	16-Feb-89	6/69	0.0088	0.021	818	03-Oct-89
Iron	105/113	0.011	17	809	10-Sep-90	38/69	0.011	15	809	10-Sep-90
Mercury	3/113	0.0001	0.001	827	03-Feb-89	7/69	0.0001	0.0002	814	06-Jun-89
Potassium	23/23	0.68	6	808	10-Sep-90	23/23	0.7	6.3	808	10-Sep-90
Lithium	2/109	0.24	0.32	811	26-Jan-89	0/65				
Magnesium	113/113	0.43	32	826	24-Sep-90	69/69	0.46	32	815	30-May-89
Manganese	106/113	0.0012	6.7	807	13-Jun-89	49/69	0.0024	7	807	13-Jun-89
Sodium	99/113	2	340	811	12-Jun-89	56/69	2.4	310	811	10-Oct-89
Nickel	41/113	0.0041	0.052	823	18-Oct-89	13/69	0.0042	0.036	823	18-Oct-89
Lead	1/114		0.04	816	02-Oct-89	0/69				
Antimony	1/136		0.17	828	17-Oct-89	8/94	0.01	0.11	829	13-Oct-89
Silicon	113/113	0.99	8.9	816	20-Sep-90	69/69	2.2	8.8	807	12-Oct-89
Strontium	91/91	0.056	2.7	821	04-Oct-89	69/69	0.075	2.6	821	01-Jun-89
Titanium	31/113	0.02	0.086	816	02-Oct-89	0/69				
Vanadium	49/113	0.0033	0.016	816	30-Nov-88	3/69	0.0032	0.0039	825	19-Oct-89
Zinc	76/113	0.0062	0.37	813	12-Dec-88	29/69	0.0051	0.052	828	01-Oct-90

NOTE: This table was created manually using listings of the Energy Systems perimeter well chemical data tables.

Table 4.4.1. Previous soils investigations at WAG 1

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
Oakes and Shank 1977	SWSA 2	U	ND-1.1	pCi/g	1
		Th	0.093-0.88	pCi/g	
		Sr-90	0.27-1.7	pCi/g	
		Pu	0.020-0.14	pCi/g	
		Cs-137	ND-1.9	pCi/g	
		K-40	ND-16	pCi/g	
		Ra-226	0.4-1.1	pCi/g	
		Th-232	0.60-1.5	pCi/g	
		Pu-239	<0.00045-0.22	pCi/g	
		Pu-238	<0.00045-0.0059	pCi/g	
Oakes 1983a	Building 3503	Hg	0.8-25	ppm	7
	Building 3592	Hg	4.1-320	ppm	
	Building 4501	Hg	0.12-465	μg/g	
Oakes 1983b	Bank of Fifth Creek-31	Hg	465	ppm	8
	Building 4501-20	Hg	0.05	ppm	
Huang et al. 1984a	North Tank Farm Tanks W-1 W-4 W-13 W-15	Co-60	0.01-700	Bq/gm	14
		Cs-137	0.01-17,000	Bq/gm	
		Sr-90	0.09-2,500	Bq/gm	
	Tank TH-4	Co-60	0.002-0.01	Bq/gm	
		Cs-137	0.01-1.1	Bq/gm	
		Sr-90	0.11-0.36	Bq/gm	
	Tanks TH-1, 2, 3	Co-60	0.01-0.31	Bq/gm	
		Cs-137	0.03-280	Bq/gm	
		Sr-90	0.02-170	Bq/gm	
	Tank W-11	Co-60	0.01-0.44	Bq/gm	
		Cs-137	0.01-110	Bq/gm	
		Sr-90	0.20-54	Bq/gm	
	Tank WC-1	Co-60	0.02-22	Bq/gm	
		Cs-137	0.02-44	Bq/gm	

Table 4.4.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
		Sr-90	0.14-200	Bq/gm	
	Tanks WC-15, 17	Am-241	0.0008-3.9	Bq/gm	
		Cm-244	0.0009-2.7	Bq/gm	
		Cs-134	0.074-0.33	Bq/gm	
		Cs-137	0.015-11	Bq/gm	
		Eu-154	0.037-4.8	Bq/gm	
		Pu-238	0.0002-4.2	Bq/gm	
	Tanks WC-15, 17	Pu-239	0.0003-0.90	Bq/gm	
		Sr-90	0.035-11	Bq/gm	
Huang et al. 1984b	Impoundment 3513	Gross Gamma[a]	77-4,600	cps/kg	15
		Cs-137[a]	0.25-48	Bq/g	
		Sr-90[a]	0.05-74	Bq/g	
		Gross Gamma[b]	12-49	cps/kg	
		Cs-137[b]	<0.01-0.12	Bq/g	
		Sr-90[b]	0.03-0.82	Bq/g	
		Pu-239	<0.1-500	Bq/kg	
		Pu-238	<0.1-10	Bq/kg	
		Am-241	0.4-100	Bq/kg	
		Cm-244	0.3-10	Bq/kg	
		Cs-137	800-4,000	Bq/g	
		Co-60	10-40	Bq/g	
		Eu-154	4	Bq/g	
		Pu-239	20-80	Bq/g	
		Pu-238	1.0-2.8	Bq/g	
		Am-241	5-14	Bq/g	
		Cm-244	1.1-3.6	Bq/g	
		Sr-90	200-540	Bq/g	
	3074 Area	Gross Alpha	0.16-9.8	Bq/kg	
		Gross Beta	0.58-14	Bq/kg	
		Sr-90	0.9	Bq/kg	

Table 4.4.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
	3019-West End	Gross Alpha	0.30-2.2	Bq/kg	
		Gross Beta	0.39-7.7	Bq/kg	
		Sr-90	0.01-4.0	Bq/kg	
	3019 Manholes	Gross Alpha	0.15-2.1	Bq/kg	
		Gross Beta	<0.02-4.8	Bq/kg	
		Cs-137	0.02-0.04	Bq/kg	
		Co-60	0.00-0.02	Bq/kg	
	3001 Area	Gross Alpha	0.17-3.8	Bq/kg	
		Gross Beta	0.27-74	Bq/kg	
		Sr-90	4.2	Bq/kg	
	3028 Area	Gross Alpha	13-338	Bq/kg	
		Gross Beta	1,600-17,300	Bq/kg	
		Sr-90	50-771	Bq/kg	
		Cs-137	63	Bq/kg	
		Co-60	340 - 2.0 E+5	Bq/kg	
	3028/3047 Area	Gross Beta	1.6 E+6 - 1.73 E+7	Bq/kg	
		Gross Alpha	1.3 E+4 - 3.38 E+5	Bq/kg	
		Sr-90	5 E+4 - 7.71 E+5	Bq/kg	
		Co-60	3.4 E+5 - 1.97 E+8	Bq/kg	
		Eu-152	3.1 E+5 - 2.41 E+7	Bq/kg	
		Eu-154	200 E+5 - 1.6 E+7	Bq/kg	
		Eu-155	Trace - 3.59 E+6	Bq/kg	
		Cs-137	6.3 E+4	Bq/kg	
Oakes 1985	3028/3047 Area	Co-57	1.59 E+7	Bq/kg	
		Zr-95	6.82 E+5	Bq/kg	
	3019/3028 Leak Areas	Gross Alpha	150 - 3.38 E+5	Bq/kg	
		Gross Beta	<20 - 17.3 E+6	Bq/kg	
		Sr-90	10 - 7.71 E+5	Bq/kg	
		Cs-137	20 - 6.3 E+4	Bq/kg	
		Co-60	<1 - 2.0 E+8	Bq/kg	

Table 4.4.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
	Background	Gross Alpha	0.5	Bq/kg	
		Gross Beta	0.5	Bq/kg	
		Sr-90	6 E-03	Bq/kg	
		Cs-137	60 E-03	Bq/kg	
		Co-60	<5 E-03	Bq/kg	
Energy Systems 1985	HP-34	Sr-90	0.12	pCi/g	3
		Cs-137	0.62	pCi/g	
		Pu-239	0.005	pCi/g	
		Pu-238	0.001	pCi/g	
		U-238	0.17	pCi/g	
		U-235	0.05	pCi/g	
		U-234	0.28	pCi/g	
Grimsby 1986	3019 Bank Area	Gross Alpha	1.0 E+3 - 1.7 E+5	Bq/kg	13
		Gross Beta	1.6 E+3 - 4.1 E+5	Bq/kg	
		Pu-239	13 - 2.0 E+4	Bq/kg	
		Pu-238	1.2 - 1.2 E+3	Bq/kg	
		Am-241	23 - 3.6 E+3	Bq/kg	
		Cm-244	27 - 3.2 E+4	Bq/kg	
		Cs-137	640 - 6.3 E+5	Bq/kg	
		Co-60	3.1 - 1.4 E+3	Bq/kg	
Williams, Clark, and Crutcher 1987	3503 Storage Pad Area	Am-241	0.11-0.58	pCi/g	4
		Co-57	0.055	pCi/g	
		Co-60	0.077-30	pCi/g	
		Cr-51	3.0-34	pCi/g	
		Cs-134	9.4-230	pCi/g	
		Cs-137	1.6 - 1.8 E+5	pCi/g	
		Eu-152	0.34-71	pCi/g	
		K-40	1.2-280	pCi/g	
		Mn-54	0.023-5.9	pCi/g	
		Ra-226	0.48-1.5	pCi/g	

Table 4.4.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
		Ra-228	0.85-3,800	pCi/g	
		Th-232	0.81-3,800	pCi/g	
		Th-234	0.61-750	pCi/g	
		Cm-244	0.00054-1.1	pCi/g	
		Pu-238	0.13-700	pCi/g	
		Pu-239	0.54-68	pCi/g	
		Sr-90	1.9-110	pCi/g	
		U-235	0.035-37.0	pCi/g	
		U-238	<1.8-930	pCi/g	
Energy Systems 1987a	S3 Perimeter Station	U-234	410-510	pCi/kg	9
		U-235	25-73	pCi/kg	
		U-238	320-410	pCi/kg	
		Pu-238	1.0-6.8	pCi/kg	
		Pu-239	7.6-78	pCi/kg	
		Sr-90	110-210	pCi/kg	
		Cs-137	380-2,500	pCi/kg	
Energy Systems 1988	ORNL Perimeter Stations	Co-60	<0-73	pCi/kg	10
		Cs-137	110-2,300	pCi/kg	
		U-238	-25 - 4.1	pCi/kg	
		Pu-239	0.92-35	pCi/kg	
		Total Sr	46-760	pCi/kg	
		U-235	-3.8 - 210	pCi/kg	
		U-238	220-1,500	pCi/kg	
		U-234	240-1,100	pCi/kg	
Energy Systems 1989	ORNL Perimeter Stations	Co-60	-0.035 - 0.41	pCi/g	11
		Cs-137	0.027-30	pCi/g	
		Pu-238	-0.0019 - 0.012	pCi/g	
		Pu-239	-0.0027 - 0.73	pCi/g	
		Total Sr	-0.024 - 10	pCi/g	
		U-234	0.21-0.95	pCi/g	

Table 4.4.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*
		U-235	0.010-0.035	pCi/g	
		U-238	0.14-0.57	pCi/g	
Uziel Williams Tiner (1989)	Impoundment 3524 Area	Gross Alpha	180 - 19,000	Bq/kg	5
		Gross Beta	830 - 930,000	Bq/kg	
		Co-60	<2 - 2,800	Bq/kg	
		Cs-137	9.1 - 470,000	Bq/kg	
		Cs-134	14 - 40	Bq/kg	
		Eu-152	50 - 870	Bq/kg	
		Eu-154	65 - 270	Bq/kg	
		Eu-155	17 - 93	Bq/kg	
Autrey 1989	Tank WC-1 Area	Gross Alpha	270 - 300	Bq/kg	6
		Gross Beta	110 - 4,400	Bq/kg	
		Co-60	<2 - 54	Bq/kg	
		Cs-137	3.4 - 1,100	Bq/kg	
	Tank WC-1 Area	K-40	190 - 340	Bq/kg	
	Tank WC-15 Area	Gross Alpha	230 - 830	Bq/kg	
		Gross Beta	1,000 - 1,600	Bq/kg	
		Co-60	<2	Bq/kg	
		Cs-137	<2 - 5	Bq/kg	
		K-40	680 - 880	Bq/kg	
Energy Systems 1990	ORNL Perimeter Stations	Co-60	-0.035 - 0.057	pCi/g	12
		Cs-137	0.051-1.5	pCi/g	
		Pu-238	-0.00070 - 0.0035	pCi/g	
		Pu-239	-0.000027 - 0.049	pCi/g	
		Total Sr	0.014-0.78	pCi/g	
		U-234	0.20-0.97	pCi/g	
		U-235	0.0057-0.041	pCi/g	
		U-238	0.14-0.62	pCi/g	

Table 4.4.1 (continued)

Source	Sample location	Parameter	Concentration	Units	Map Ref. No.*

*Map reference number refers to the location identified on Fig. 4.5.1.
[a]Hand cores ND = Not detected
[b]Deep cores N/A = Not available

Table 4.4.2. Comparison of USRADS exposure rates and modeled exposure rates

Area	USRADS exposure rate range (μR/h)	Range of cesium-137/barium-137 concentration in soil (pCi/g)	Modeled exposure rate range (μR/h)
Reactor heat exchanger area (Building 3087)	50-100	No soil data	NA
Building 3019/3074	50-500	8.91	6.8
Building 3012/3112 Area	50-500	<1	<1
Isotope production area	50-1000	1-987	1-761
North Tank Farm	50-250	3-163	2-130
South Tank Farm	50->2500	2-762	2-588
Rad. waste evaporator area	50-100	No soil data (area paved)	NA
Fission Product Development Lab.	50-5000	103-429	79-339
Area south of Building 3525	50-1000	<1	<1
Tank Farm southeast of Building 3587	50-500	<1	<1
Area south of Building 3597	50-1000	4-123	3-95
3513/3524 impoundments	50-1000	4-1520	3-1172
WOC floodplain	50-1000	6-6000	5-4600

NA - not applicable

Table 4.4.3. Summary of radiological contaminants detected in WAG soils

Test group	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
RAD	Ac-228	pCi/G	.5	.48		9.09	1.22		1.53	160	160
	Alpha particle	pCi/G	3.9	7.4		3104.9	696		73.31	465	503
	Am-241	pCi/G	.06	.06		171	14		8.76	67	105
	Be-7	pCi/g	1.43	1.4		3.91	3.77		2.67	2	2
	Beta particle	pCi/g	8.1	4.4		62500	12500		871.44	500	503
	Bi-211	pCi/g	.81	.65		1.18	1.12		1	2	2
	Bi-212	pCi/g	.87	.76		10.1	2.8		2.49	68	69
	Bi-214	pCi/g	.37	.36		1.41	.29		.86	82	82
	Bismuth	pCi/g	.42	.23		.7	.29		.56	2	2
	Ca-45	pCi/g	12.4	4.6	J	1470	90	J	204.25	19	19
	Cd-109	pCi/g	4.87	2.5		4.87	2.5		4.87	1	1
	Ce-144	pCi/g	2.09	1.74		2.09	1.74		2.09	1	1
	Cm-244	pCi/g	1.3	.5	J	453	89	J	108.39	9	10
	Co-57	pCi/g	.06	.03		2.03	.29		.85	8	8
	Co-58	pCi/g	.25	.15		2.19	1.41		1.22	2	2
	Co-60	pCi/g	.04	.02		99.5	9.6		5.1	106	106
	Cs-134	pCi/g	.43	.32		70.85	4.86		12.89	6	6
	Cs-137	pCi/g	.06	.05		22170	1286		398.02	347	471
	Eu-152	pCi/g	.81	.47		274.2	18.2		28.19	20	20
	Eu-154	pCi/g	.73	.38		171.7	15.1		16.04	16	16
	Eu-155	pCi/g	1.18	.61		5.9	2.4		2.59	4	4
	Fe-55	pCi/g	6.3	5.1	J	118	5	J	46.65	6	22
	I-129	pCi/g	17.5	4.6		689	44		274.5	3	3
	K-40	pCi/g	1.55	1.21		39.92	6.49		14.51	415	416
	Mn-54	pCi/g	.03	.03		.13	.1		.08	3	3
	Na-22	pCi/g	.05	.04		1.68	.31		.44	13	13
	Nb-95	pCi/g	.13	.11		.13	.11		.13	1	2
	Nd-147	pCi/g	.68	.65		.79	.41		.74	2	2
	Ni-63	pCi/g	92.2	8.9	J	34010	2440	J	13435.31	7	7
	Pb-210	pCi/g	.92	.53		319	33		24.05	18	18
	Pb-212	pCi/g	.12	.09		9.13	.74		1.23	213	214
	Pb-214	pCi/g	.2	.12		1.95	.54		.87	250	251

Table 4.4.3 (continued)

Test group	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
	Pm-147	pCi/g	3.31	2.24		6650	734	J	509.51	29	51
	Pu-238	pCi/g	.04	.03	J	721	73		16.67	50	121
	Pu-239/240	pCi/g	.01	.02		206	30	J	10.37	78	122
	Ra-224	pCi/g	.14	.11		13	1.8		1.36	110	121
	Ra-226	pCi/g	.09	.05	J	1.4	.74		.76	404	440
	Ra-228	pCi/g	.2	.05		9.09	1.22		1.24	420	452
	Ru-106	pCi/g	.16	.14		1.13	.79		.65	2	32
	Sr-90	pCi/g	.5	.19		35300	3500		810.31	83	89
	Tc-99	pCi/g	.2	.3	J	210	28	J	5.95	51	104
	Th-228	pCi/g	.23	.13	J	18.6	3.2	J	1.44	424	434
	Th-230	pCi/g	.18	.09	J	4.8	1	J	1.01	286	306
RAD	Th-232	pCi/g	.14	.08	J	27.1	4.2	J	1.35	412	434
	Th-234	pCi/g	.75	.34		34.11	6.38		2.71	82	83
	Thallium	pCi/g	1.03	.41		1.16	.42		1.1	2	2
	Tl-208	pCi/g	.23	.19		7.89	.84		1.13	242	244
	Total radioactive strontium	pCi/g	.11	.07		8621	948		104.42	299	321
	Tritium	pCi/g	.03	.02		8.24	.43		.71	253	435
	U-234	pCi/g	.31	.13	J	591	115		6.9	384	392
	U-235	pCi/g	.04	.03	J	34	13.1	J	1.07	136	277
	U-235/236	pCi/g	.28	.17		1.93	1.28		1.11	21	20
	U-238	pCi/g	.06	.62		4260	976	J	21.18	387	399
	Y-91	pCi/g	543	486.3		543	486.3		543	1	1
	Zr-95	pCi/g	.23	.21		18.4	4		4.85	4	4

Table 4.4.4. Summary of radiological data for WAG 1 floodplain soils

		Detected range (pCi/g)									Location of maximum (depth, ft)	
		White Oak Creek				First Creek						
Constituent	Reference	Minimum	Error	Maximum	Error	Minimum	Error	Maximum	Error	Number above ref	WOC	First Creek
^{228}Ac		0.84	0.79	1.2	0.76	ND		ND		None	WOC 94 (4-6)	N/A
Gross alpha	56	7.75	4.26	166	45	10.8	7.6	46.7	14.7	7	WOC63 (2-4)	FC22 (0-2)
^{241}Am	NA	0.22	0.116	20.8	3	0.134	0.1	0.134	0.1	8	WOC51 (0-2)	FC13 (0-2)
Gross beta	30.5	12	4.6	39400	5916	17.2	5.1	234	48	63	WOC63 (2-4)	FC13 (0-2)
$^{212/214}Bi$	NA	1.32	1.02	2.44	1.33	ND		ND			WOC81 (6-7.1)	N/A
^{57}Co	NA	0.06	0.03	2.03	0.29	ND		ND			WOC51 (0-2)	N/A
^{60}Co	0	0.0433	0.021	28.9	2.4	0.0497	0.02	0.176	0.058		WOC63 (2-4)	FC21 (0-2)
^{137}Cs	0.21	0.304	0.072	22170	1286	0.977	0.153	23.4	2.4	80	WOC63 (2-4)	FC13 (0-2)
^{152}Eu	NA	3.46	0.38	6.21	0.55	ND		ND			WOC51 (0-2)	None
^{40}K	1.53	1.66	0.2	39400	4.3	6.16	1.02	14.8	2.7	14	WOC84 (0-6)	FC21 (0-2)
^{210}Pb	0.63	7.99	2.75	7.99	2.75	ND		ND		3	WOC51 (0-2)	N/A
^{238}Pu		1.1	1	1.1	1	ND		ND			WOC63 (2-4)	N/A
$^{239/240}Pu$	NA	0.44	0.37	89.4	18.6	ND		ND		1	WOC63(2-4)	N/A
^{224}Ra	1.5	0.407	0.131	1.67	0.6	0.487	0.092	1.18	0.23		WOCG1 (0-2)	FC21 (0-2)
^{226}Ra	0.37	0.35	0.157	1.33	0.69	0.545	0.077	0.859	0.094		WOC62 (0-1.7)	FC34 (0-2)
^{228}Ra	1.58	0.394	0.087	1.43	0.79	0.46	0.092	1.21	0.16		WOC94 (4-6)	FC31 (0-2)
^{99}Tc	1.53	0.61	0.3	5.8	3	ND		ND		1	WOC81(6-7.1)	N/A
^{228}Th	19.9	0.694	0.155	4.28	1.84	ND		ND		None	WOC63 (2-4)	N/A
^{230}Th	1.87	0.58	0.2	1.12	0.46	ND		ND		None	WOC94 (2-4)	N/A
^{232}Th	1.83	0.51	0.21	4.42	1.82	ND		ND		1	WOC63 (2-4)	N/A
^{234}Th	1.21	0.746	0.344	7.05	4.35	1.26	0.31	1.61	0.54	13	WOC94 (2-4)	FC13 (0-2)
Tot Rad Sr	0.29	1.88	0.29	192	26	ND		ND		12 (all)	WOC63 (2-4)	N/A
^{3}H	0.22	0.16	0.03	0.63	0.13	ND		ND		2(all)	WOC72 (4-5)	N/A
^{234}U	1.29	0.72	0.17	16.4	2.7	ND		ND		22	WOC63 (2-4)	
^{235}U	0.15	0.07	0.06	0.5	0.4	ND		ND		2	WOC63 (2-4)	N/A
^{238}U	1.2	0.648	0.159	3.63	0.53	ND		ND		14	WOCG6 (2-4)	N/A
^{95}Zr	0	0.42	0.25	0.42	0.25						WOC62 (0-1.7)	
^{208}Tl	0	1.25	0.69	1.3	0.83						WOC61 (6-7.2)	
^{147}Pm	0	15.1	2.8	6650	734						WOC63 (2-4)	
^{214}Pb	0	0.72	0.57	0.95	0.53						WOC83 (6-8)	
^{22}Na	0	0.05	0.04	1.68	0.31						WOC51 (0-2)	

Table 4.4.4 (continued)

		Detected range (pCi/g)									Location of maximum (depth, ft)	
		White Oak Creek				First Creek						
Constituent	Reference	Minimum	Error	Maximum	Error	Minimum	Error	Maximum	Error	Number above ref	WOC	First Creek
^{55}Fe	0	56.3	4.6	56.3	4.6						WOC63 (2-4)	
^{155}Eu	0	1.36	0.45	0.36	0.45						WOC51 (0-2)	
^{154}Eu	0	2.02	0.31	3.96	0.35						WOC62 (0-1.7)	
^{134}Cs	0	0.76	0.14	0.76	0.14						WOC62 (0-1.7)	
^{58}Co	0	0.25	0.15	0.25	0.15						WOC66 (2-4)	
^{45}Ca	0	1470	90	1470	90						WOC 63 (2-4)	

Table 4.4.5. Vertical distribution of beta contamination near Building 3019

Depth (ft)	Boring 01.SB128			Boring 01.SB130			Boring 01.SB132		
	Gross beta	^{137}Cs	Total rad Sr	Gross beta	^{137}Cs	Total rad Sr	Gross beta	^{137}Cs	Total rad Sr
0-2	NS	NS	NS	NS	NS	NS	24.2±7.1	NA	2.87±0.39
2-4	48±10.9	8.91±0.64	8.7±1.1	NS	NS	NS	44.7±10.2	0.62±0.26	19.7±2.2
4-6	542.7±84	73±4.4	77.4±8.6	NS	NS	NS	3028±457	50.4±3	758±83
6-7	985±150	83.4±5	236±26	102±18	61.4±3.8	4.7±0.6	381±60	NA	83.2±9.3
7-8	1380±209.6	111.3±6.6	164±18	102±18	61.4±3.8	4.7±0.6	381±60	NA	83.2±9.3
8-10	NS	NS	NS	95.4±16.7	81.9±5	19.2±2.2	378±59	0.76±0.29	188±21
10-12	NS	NS	NS	1855±280	1148±67	360±40	16005±2403	1.7±0.28	8621±948
12-13	NS	NS	NS	1354±206	74.1±4.5	784±86	NS	NS	NS
14-16	NS	NS	NS	NS	NS	NS	1031±156	1.59±0.34	531±58

Table 4.4.6. Summary of VOCs detected in WAG 1 soil

CAS No.	Compound	Units	Minimum	Flag	Maximum	Flag	Average	Hits	Count
VOC									
71-55-6	1,1,1-Trichloroethane	µg/kg	1	J	28	J	8	20	475
75-35-4	1,1-Dichloroethylene	µg/kg	7	J	7	J	5	2	474
540-59-0	1,2-Dichloroethylene	µg/kg	2	J	150		36.33	6	475
78-87-5	1,2-Dichloropropane	µg/kg	1	J	1	J	1	1	475
591-78-6	2-Hexanone	µg/kg	1	J	5	J	3	4	475
67-64-1	Acetone	µg/kg	2	J	880	J	130.42	97	474
71-43-2	Benzene	µg/kg	3	J	3	J	3	1	475
75-15-0	Carbon Disulfide	µg/kg	1	J	65		14.57	54	475
108-90-7	Chlorobenzene	µg/kg	1	J	8	J	3.67	3	475
67-66-3	Chloroform	µg/kg	1	J	770		61.70	65	475
100-41-4	Ethylbenzene	µg/kg	6	J	17		11.5	2	475
75-27-4	Methane, bromodichloro	µg/kg	7		90		33.50	4	475
74-83-9	Methyl Bromide	µg/kg	1	J	2	J	1.5	8	475
78-93-3	Methyl Ethyl Ketone	µg/kg	1	J	1100	J	137.32	38	297
75-09-2	Methylene Chloride	µg/kg	1	J	710		76.24	101	474
108-10-1	Methylisobutylketone	µg/kg	1	J	97		24.79	58	475
127-18-4	Tetrachloroethylene	µg/kg	1	J	36		10.44	12	475
108-88-3	Toluene	µg/kg	.6	J	17		6.51	45	475
79-01-6	Trichloroethylene	µg/kg	.8	J	55		11.18	22	475
1330-20-7	Xylene (total)	µg/kg	1	J	38		16.25	4	474

NOTE: This table was created manually using a listing of soil contamination data for WAG 1.

Table 4.4.7. Summed VOCs in boreholes where VOCs detected

Boring	Total VOCs (µg/kg)	Boring	Total VOCs (µg/kg)	Boring	Total VOCs (µg/kg)	Boring	Total VOCs (µg/kg)
01.SB010	774	01.SB187	65	01.SB135	23	01.SB063	7
01.SB118	552	01.SB221	126	01.SB175	22	01.SB157	7
01.SB011	299	01.SB232	124	01.SB017	22	01.SB120	6
01.SB142	282	FC12	120	01.SB213	11	WOC22	6
01.SB133	270	01.SB056	117	01.SB188	22	01.SB043	6
01.SB124	454	01.SB022	58	01.SB220	20	01.SB059	3
01.SB126	224	01.SB095	109	01.SB078	19	01.SB040	3
01.SB146	203	WOC43	52	01.SB241	19	01.SB026	6
01.SB114	782	WOC74	99	WOC72	9	01.SB154	6
01.SB007	140	FC35	99	01.SB197	16	01.SB246	6
01.SB014	402	WOC14	32	01.SB111	50	01.SB067	5
01.SB140	405	WOC84	95	01.SB199	15	01.SB103	5
01.SB006	382	01.SB005	29	01.SB097	15	01.SB145	5
01.SB113	369	01.SB198	88	WOC33	14	01.SB144	5
01.SB080	365	01.SB104	88	01.SB089	14	01.SB262	4
01.SB127	174	01.SB215	86	01.SB185	6	01.SB100	4
WOC11	124	01.SB038	38	WOC21	32	01.SB030	4
01.SB130	318	01.SB141	40	01.SB211	13	01.SB045	4
01.SB132	128	WOC23	40	01.SB072	6	01.SB102	4
WOC64	118	01.SB192	78	01.SB175	17	01.SB171	3
WOC41	117	01.SB174	76	01.SB025	12	01.SB042	3
WOC93	233	01.SB261	68	01.SB263	12	01.SB061	3
WOC12	210	WOC94	65	01.SB173	12	01.SB021	3
01.SB016	41	01.SB121	59	01.SB150	6	01.SB077	3
01.SB191A	81	01.SB176	58	01.SB190	11	01.SB031	2
01.SB191B	120						
WOC32	192	WOC91	55	01.SB060	11	01.SB195	2
01.SB094	184	WOC31	54	01.SB162	10	01.SB189	2
01.SB214	180	WOC13	27	01.SB160	10	01.SB164	2
01.SB128	83	01.SB125	28	01.SB075	5	01.SB088	2
WOC52	4	01.SB165	8	01.SB032	8	01.SB083	2
01.SB008	50	01.SB069	8	01.SB052	8	WOCG5	2
01.SB147	48	01.SB138	24	01.SB217	8	WOC42	2
WOC53	68	01.SB064	23	01.SB247	7	01.SB084	1.6
FC33	137	01.SB243	38	01.SB048	1	01.SB054	1
01.CH006	26	01.SB082	51	01.SB168	22		
01.CH008	21	01.SB096	47	01.SB177	18		
01.CH012	28	01.SB098	39	01.SB180	16		
01.FC31	33	01.SB105	39	01.SB201B	43		
01.SB013	30	01.SB106	50	01.SB208	36		
01.SB019	26	01.SB123	49	01.SB209	46		
01.SB020	35	01.SB131	18	01.SB216	44		
01.SB037	36	01.SB143A	12	01.WOC51	31		
01.SB039	44	01.WOC62	5	01.WOC61	9		
01.SB049	18	01.SB148	4	01.WOC63	1		
01.SB050	28	01.SB166	16	01.WOC82	2		
01.SB076	7	01.SB167	39	01.WOC83	84		
01.WOC92	1						

Note: The summed concentrations represent the sum of the maximum concentrations of all VOCs detected in each depth divided by the number of intervals.

Table 4.4.8. Summary of BNAE compounds detected in WAG 1 soils

BNA CAS No.	Compound	Units	Minimum	Flag	Maximum	Flag	Average	Hits	Count
91-94-1	3,3'-Diclorobenzidine	µg/kg	8	J	8	J	8	1	345
84-66-2	Diethylphthalate	µg/kg	22	J	72	J	39.7	12	347
95-48-7	2-Methylphenol	µg/kg	18	J	18	J	18	1	347
59-50-7	4-Chloro-3-methyl phenol	µg/kg	8	J	57	J	32.5	2	347
106-44-5	4-Methyl Phenol	µg/kg	18	J	18	J	18	1	347
83-32-9	Acenaphthene	µg/kg	35	J	10000		993.29	20	347
208-96-8	Acenaphthylene	µg/kg	25	J	610	J	118.91	11	347
120-12-7	Anthracene	µg/kg	13	J	20000		1222.45	35	347
56-55-3	Benz(a)anthracene	µg/kg	34	J	28000		1372.06	88	346
205-99-2	Benzo(b)fluoranthene	µg/kg	28	J	26000		1439.17	90	345
86-30-6	Benzenamine, N-Nitroso-N	µg/kg	35	J	120	J	63.93	34	347
7005-72-3	Benzene, 1-Chloro-4-Pheno	µg/kg	120	J	120	J	120	1	347
121-14-2	2,4-Dinitrotoluene	µg/kg	120	J	120	J	120	1	347
50-32-8	Benzo(a)pyrene	µg/kg	39	J	21000		1392.29	80	347
191-24-2	Benzo(ghi)Perylene	µg/kg	43	J	140000		1200.61	44	341
207-08-9	Benzo(k)Fluoranthene	µg/kg	33	J	17000		1515.70	58	346
65-85-0	Benzoic Acid	µg/kg	44	J	2400	J	244.48	28	346
100-51-6	Benzyl Alcohol	µg/kg	78	J	130	J	101	3	347
117-81-7	Bis(2-Ethylhexyl) Phthala	µg/kg	22	J	8500		346.52	112	347
85-68-7	Butyl Benzyl Phthalate	µg/kg	24	J	2300		517.76	22	347
108-95-2	Carbolic Acid	µg/kg	41	J	230	J	97.77	15	347
218-01-9	Chrysene	µg/kg	17	J	27000		1379.29	95	347
84-74-2	Di-n-butyl Phthalate	µg/kg	26	J	2400		562.26	62	346
53-70-3	Dibenz(a,h)anthracene	µg/kg	35	J	5100	J	817.19	18	347
132-64-9	Dibenzofuran	µg/kg	29	J	6900	J	750.79	14	347
131-11-3	Dimethyl Phthalate	µg/kg	13	J	13	J	13	1	347
206-44-0	Fluoranthene	µg/kg	22	J	58000		1973.98	116	346
86-73-7	Flourene	µg/kg	27	J	13000		1169.76	19	347
193-39-5	Indeno(1,2,3-cd)Pyrene	µg/kg	38	J	17000		1033.41	50	347
621-64-7	N-Nitrosodi-n-Propylamine	µg/kg	82	J	82	J	82	1	346
91-20-3	Naphthalene	µg/kg	25	J	2600	J	290	16	347
91-57-6	Naphthalene, 2-Methyl	µg/kg	12	J	2500	J	287.36	16	347
87-86-5	Pentachlorophenol	µg/kg	460	J	460	J	460	1	346
85-01-8	Phenanthrene	µg/kg	16	J	74000		2021.82	93	346
51-28-5	Penol, 2,4-Dinitro	µg/kg	42	J	42	J	42	1	347

Table 4.4.8 (continued)

BNA CAS No.	Compound	Units	Minimum	Flag	Maximum	Flag	Average	Hits	Count
117-84-0	Di-n-octylphthalate	µg/kg	21	J	21	J	21	1	347
129-00-0	Pyrene	µg/kg	19	J	45000		1738.7	120	346
106-47-8	4-Chloroaniline	µg/kg	110	J	110	J	110	1	345
100-02-7	4-Nitrophenol	µg/kg	190	J	740	J	465	2	346

Table 4.4.9. Summed BNAEs in boreholes

Location	Total BNAE (μg/kg)	Location	Total BNAE (μg/kg)	Location	Total BNAE (μg/kg)
01.CH006	37	01.SB084	99	01.SB202	232
01.CH008	1859	01.SB087	2542	01.SB203	118
01.CH012	2126	01.SB092	3821	01.SB204	131
01.FC11	260	01.SB093	770	01.SB205	108
01.FC12	800	01.SB094	4709	01.SB211	94
01.FC13	7254	01.SB095	1762	01.SB213	193
01.FC21	1690	01.SB096	319	01.SB214	691
01.FC22	6214	01.SB097	14,978	01.SB216	79
01.FC23	6999	01.SB098	988	01.SB221	78
01.FC31	191	01.SB102	55	01.SB241	1628.5
01.FC32	1738	01.SB106	28	01.SB246	2076
01.FC33	594	01.SB108	2827	01.SB261	1153
01.FC34	450	01.SB109	80	01.SB264	1160
01.FC35	3583	01.SB111	276	01.SB265	1110
01.SB006	43	01.SB112	2381	01.WOC11	2524
01.SB007	52	01.SB114	531	01.WOC12	94,040
01.SB008	124	01.SB121	53	01.WOC13	8830
01.SB009	440	01.SB125	178	01.WOC14	21,581
01.SB011	430	01.SB126	96	01.WOC21	1500
01.SB019	41	01.SB127	43	01.WOC22	21,780
01.SB020	2835	01.SB130	105	01.WOC23	36,460
01.SB021	571	01.SB131	120	01.WOC32	80,350
01.SB030	301	01.SB141	32,875	01.WOC33	1800
01.SB032	1369	01.SB142	440	01.WOC41	6545
01.SB034	1928	01.SB143A	817	01.WOC42	4800
01.SB035	1292	01.SB146	128	01.WOC43	1552
01.SB039	1010	01.SB147	4665	01.WOC51	135,393
01.SB040	47	01.SB150	390	01.WOC52	51,120
01.SB041	2500	01.SB151	124	01.WOC53	2906
01.SB043	68	01.SB152	293	01.WOC61	9700
01.SB044	52	01.SB153	339	01.WOC62	10,950
01.SB047	48	01.SB154	220	01.WOC63	37,710
01.SB048	86	01.SB156	105	01.WOC64	877
01.SB049	223	01.SB166	147	01.WOC71	570
01.SB050	1292	01.SB167	341.5	01.WOC72	359
01.SB051	2141	01.SB168	387,000	01.WOC73	300
01.SB052	4427	01.SB171	123	01.WOC74	718
01.SB054	4070	01.SB173	113	01.WOC81	502
01.SB056	633	01.SB181	1952.5	01.WOC82	4177
01.SB059	2357	01.SB183	823.5	01.WOC83	444
10.SB060	268	01.SB184A	444	01.WOC91	939
01.SB061	79	01.SB185	1184	01.WOC92	2585
01.SB062	1930	01.SB187	86	01.WOC93	590
01.SB063	41	01.SB188	110	01.WOC94	238
01.SB064	2035	01.SB189	45	01.WOC95	330
01.SB067	2216	01.SB190	891	01.WOCG1	3628
01.SB069	53	01.SB191A	427	01.WOCG2	1472

Table 4.4.9 (continued)

Location	Total BNAE (μg/kg)	Location	Total BNAE (μg/kg)	Location	Total BNAE (μg/kg)
01.SB073	557.5	01.SB191B	460	01.WOCG3	2511
01.SB075	796.5	01.SB192	745	01.WOCG4	2597
01.SB076	1176.5	01.SB196	181	01.WOCG5	3942
01.SB077	180	01.SB197	168	01.WOCG6	2822
01.SB082	168	01.SB198	373		
01.SB083	83	01.SB199	2056.5		

NOTE: The concentrations represent the sum of the maximum concentrations of all BNAEs detected in each depth divided by the number of intervals.

Table 4.4.10. Pesticides, PCBs, and cyanide detected in WAG 1 soil

Location	Interval	Compound	Result	Rev qual	Units	Sample type	Sample date	Sample No.
01.CH012	00-02	4,4'-DDT	53		µg/kg	RG		207807
01.SB077	00-01.8	4,4'-DDT	7.6	J	µg/kg	RG	22-Jan-91	145107
01.SB077	00-01.8	Benzene, 1,1'-(dichloroethenlyidine)bis[	51		µg/kg	RG	22-Jan-91	145107
01.SB185	00-02	Chlordane, alpha-	100	J	µg/kg	RG	11-Jul-91	220806
01.SB185	00-02	Chlordane, gamma-	55	J	µg/kg	RG	11-Jul-91	220806
01.SB077	00-01.8	Endrin	2.8	J	µg/kg	RG	22-Jan-91	145107
01.SB063	00-01.8	Heptachlor	12	J	µg/kg	RG	26-Feb-91	153107
PCBs								
01.SB094	00-01	alpha-BHC	22	J	µg/kg	RG	12-Feb-91	149407
01.SB054	00-02	Aroclor 1254	5800		µg/kg	RG	21-Jan-91	143907
01.SB052	00-02	Aroclor 1254	2300		µg/kg	RG	18-Jan-91	143107
01.SB097	00-01.8	Aroclor 1254	1500	J	µg/kg	RG	15-Feb-91	152907
01.SB051	00-02	Aroclor 1254	730		µg/kg	RG	18-Jan-91	143007
01.SB175	02-04	Aroclor 1254	490		µg/kg	RG	17-Jul-91	224706
01.SB176	02-04	Aroclor 1254	400		µg/kg	RG	18-Jul-91	226406
01.SB049	00-02	Aroclor 1254	350	J	µg/kg	RG	28-Dec-90	136513DL
01.CH008	00-02	Aroclor 1254	330		µg/kg	RG		205707
01.SB063	00-01.8	Aroclor 1254	250	J	µg/kg	RG	26-Feb-91	153107
01.SB049	00-02	Aroclor 1254	240	J	µg/kg	DU	28-Dec-90	136517DL
01.SB112	00-00.3	Aroclor 1254	140	J	µg/kg	RG	13-May-91	194107
01.SB035	00-03	Aroclor 1254	120	J	µg/kg	RG	12-Dec-90	134713
01.SB088	00-04	Aroclor 1254	104	J	µg/kg	RG	15-Nov-90	118313
01.SB088	00-04	Aroclor 1254	99	J	µg/kg	DU	15-Nov-90	118413
01.SB048	00-05	Aroclor 1254	33	J	µg/kg	DU	05-Dec-90	119413
01.SB097	00-01.8	Aroclor 1260	1900	J	µg/kg	RG	15-Feb-91	152907
01.SB060	00-02	Aroclor 1260	610	N	µg/kg	RG	19-Feb-91	153007
01.SB114	00-01.3	Aroclor 1260	510		µg/kg	RG	08-May-91	193807
01.SB108	00-01.3	Aroclor 1260	220		µg/kg	RG	09-May-91	193907
01.SB063	00-01.8	Aroclor 1260	150	J	µg/kg	RG	26-Feb-91	153107
01.SB112	00-00.3	Aroclor 1260	130	J	µg/kg	RG	13-May-91	194107
01.SB108	00-01.3	Aroclor 1260	110	J	µg/kg	DU	09-May-91	193911
01.SB061	00-02	Aroclor 1260	88	J	µg/kg	RG	26-Feb-91	151007
Cyanide								
01.SB040	12-18	Cyanide	5100		µg/kg	RG	05-Sep-90	095404
01.SB090	00-05	Cyanide	1100		µg/kg	DU	15-Nov-90	117615
01.SB018	12-16	Cyanide	710		µg/kg	RG	02-Nov-90	111514
01.SB177	00-02	Cyanide	590	J	µg/kg	RG	22-Jul-91	226608
01.SB030	06-12	Cyanide	520		µg/kg	RG	22-Aug-90	091504
01.SB046	00-04	Cyanide	190		µg/kg	RG	29-Oct-90	106412
01.SB037	00-06	Cyanide	160		µg/kg	RG	13-Dec-90	134415
01.SB088	00-04	Cyanide	140		µg/kg	RG	15-Nov-90	118315
01.SB048	00-05	Cyanide	80		µg/kg	RG	05-Dec-90	119114
01.SB073	10-12	Cyanide	80		µg/kg	RG	06-Nov-90	115008
01.SB073	04-06	Cyanide	70		µg/kg	RG	02-Nov-90	114308

Table 4.4.11. Summary of metals detected in WAG 1 soil

CAS No.	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
Metals											
7429-90-5	Aluminum	µg/kg	449000			54200000			14850348	443	444
7440-36-0	Antimony	µg/kg	2400		J	37600		J	10678.7	72	187
7440-38-2	Arsenic	µg/kg	640			27400			7096	425	445
7740-39-3	Barium	µg/kg	8700			1940000		J	103215.4	443	444
7440-41-7	Beryllium	µg/kg	280			212000			2772.6	402	447
7440-42-8	Boron	µg/kg	4800			7000000			1015826.9	54	58
7440-43-9	Cadmium	µg/kg	480			11900		J	3064.5	177	445
7440-70-2	Calcium	µg/kg	281000			331000000		J	3296701.7	443	444
7440-47-3	Chromium	µg/kg	2200			189000			25454.1	442	445
7440-48-4	Cobalt	µg/kg	1200			143000		J	15372.6	438	447
7740-50-8	Copper	µg/kg	1100		J	394000		J	19872.4	407	445
7439-89-6	Iron	µg/kg	2290000			66400000		J	28317826	443	444
7439-92-1	Lead	µg/kg	2600		J	337000			331042.5	438	442
7439-95-4	Magnesium	µg/kg	291000		J	60500000			5551233.3	443	444
7439-96-5	Manganese	µg/kg	42600		J	5800000		J	786422.0	438	440
7439-97-6	Mercury	µg/kg	100			548000			10178	113	376
7439-98-7	Molybdenum	µg/kg	1910			2540			2225	2	58
7440-02-0	Nickel	µg/kg	1800			50300			20271.9	440	445
7440-04-2	Osmium	µg/kg	91600			587000		J	235693	58	58
7440-09-7	Potassium	µg/kg	25100		J	8430000			1438980	433	437
7782-49-2	Selenium	µg/kg	490		J	48500			14054.8	80	332
7440-22-4	Silver	µg/kg	800			32000			6795.7	99	445
7440-23-5	Sodium	µg/kg	23100			2940000			128797.3	332	445
7440-28-0	Thallium	µg/kg	240			98700			14032.2	77	424
7440-31-5	Tin	µg/kg	27100			126000			53658	57	58
7440-62-2	Vanadium	µg/kg	470			64600			24990.9	443	447
7440-66-6	Zinc	µg/kg	6000		J	514000			65826	439	445

Table 4.5.1. Previous surface water studies at WAG 1

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.*
WOC headwaters						
	WOC headwaters	Energy Systems 1987a	^{60}Co	<2.2-<8.1	pCi/L	9
	WOC headwaters		^{137}Cs	<1.6-<8.1	pCi/L	
	WOC headwaters		^{3}H	3,200-70,000	pCi/L	
	WOC headwaters		Pu	<0.011-0.032	pCi/L	
	WOC headwaters		Total Sr	0.27-9.2	pCi/L	
	WOC headwaters		^{228}Th	<0.0054-1.4	pCi/L	
	WOC headwaters		^{230}Th	0.0014-0.54	pCi/L	
	WOC headwaters		^{232}Th	<0.0027-0.54	pCi/L	
	WOC headwaters		Trans Pu	0.027-0.11	pCi/L	
	WOC headwaters		^{234}U	0.0081-0.81	pCi/L	
	WOC headwaters		^{235}U	0.0014-0.14	pCi/L	
	WOC headwaters		^{238}U	0.014-3.2	pCi/L	
	WOC headwaters	Energy Systems 1988	^{241}Am	0.05-0.3	pCi/L	10
	WOC headwaters		^{244}Cm	<0.05-0.12	pCi/L	
	WOC headwaters		^{60}Co	<2.7-8.1	pCi/L	
	WOC headwaters		^{137}Cs	<2.7-15	pCi/L	
	WOC headwaters		Gross alpha	2.2-65	pCi/L	
	WOC headwaters		^{238}Pu	<0.05-0.076	pCi/L	
	WOC headwaters		^{239}Pu	<0.05-2.7	pCi/L	
	WOC headwaters		^{228}Th	<0.05	pCi/L	
	WOC headwaters		^{230}Th	<0.05	pCi/L	
	WOC headwaters		^{232}Th	<0.05	pCi/L	
	WOC headwaters		Total Sr	2-130	pCi/L	
	WOC headwaters		^{3}H	1,500-3,200	pCi/L	
	WOC headwaters		^{234}U	0.19	pCi/L	
	WOC headwaters		^{235}U	<0.05	pCi/L	
	WOC headwaters		^{238}U	0.14	pCi/L	
	WOC headwaters	Energy Systems 1989	^{241}Am	-4.9-0.32	pCi/L	11
	WOC headwaters		^{244}Cm	-4.1-0.38	pCi/L	
	WOC headwaters		^{60}Co	-11-24	pCi/L	
	WOC headwaters		^{137}Cs	-27-16	pCi/L	
	WOC headwaters		Gross alpha	0.0-18	pCi/L	
	WOC headwaters		Gross beta	0.0-38	pCi/L	

Table 4.5.1 (continued)

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.*
	WOC headwaters		^{238}Pu	-0.019-0.086	pCi/L	
	WOC headwaters		^{239}Pu	-0.081-0.21	pCi/L	
	WOC headwaters		Total Sr	-1.9-9.7	pCi/L	
	WOC headwaters		^{3}H	-1,200-970	pCi/L	
	WOC headwaters	Energy Systems 1990	^{241}Am	-0.081-0.38	pCi/L	12
	WOC headwaters		^{244}Cm	0.35	pCi/L	
	WOC headwaters		^{60}Co	-51-49	pCi/L	
	WOC headwaters		^{137}Cs	-24-24	pCi/L	
	WOC headwaters		Gross alpha	-5.4-46	pCi/L	
	WOC headwaters		Gross beta	2.7-46	pCi/L	
	WOC headwaters		^{238}Pu	-0.022-0.059	pCi/L	
	WOC headwaters		^{239}Pu	-0.089-0.027	pCi/L	
	WOC headwaters		Total Sr	-1.6-1.6	pCi/L	
	WOC headwaters		^{3}H	-110-620	pCi/L	
	WOC headwaters	Taylor 1990a	Hg	<0.05	ng/mL	20
	WOC headwaters, 1987	Taylor 1989	Hg	<0.05	ng/mL	19
	WOC headwaters, 1988		Hg	<0.1-0.1	ng/mL	
	WOC headwaters, background area	Taylor 1990b	Aroclor-1254	<1.0-<1.1	µg/L	17
	WOC headwaters, background area		Aroclor-1248	<0.50	µg/L	
	WOC headwaters, background area		Aroclor-1260	<1.0-<1.1	µg/L	
Fifth Creek						
	Fifth Creek	Energy Systems 1987a	^{60}Co	<1.6-<11	pCi/L	9
	Fifth Creek		^{137}Cs	<1.3-<8.1	pCi/L	
	Fifth Creek		Total Sr	25-54	pCi/L	
		Energy Systems 1988	^{60}Co	<2.5–<8.1	pCi/L	10
			^{137}Cs	<2.7–8.1	pCi/L	
			Total Sr	20-46	pCi/L	
	Fifth Creek	Energy Systems 1989	^{60}Co	-8.1-8.1	pCi/L	11
	Fifth Creek		^{137}Cs	-0.81-24	pCi/L	
	Fifth Creek		Total Sr	35-160	pCi/L	
	Fifth Creek	Energy Systems 1990	^{60}Co	-14-51	pCi/L	12
	Fifth Creek		^{137}Cs	-27-14	pCi/L	
	Fifth Creek		Total Sr	1.4-54	pCi/L	
	Fifth Creek		Hg	<0.050-3.7	µg/L	

Table 4.5.1 (continued)

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.*
	Fifth Creek	Taylor 1990a	Hg	<0.05-3.03	ng/mL	20
	Fifth Creek, 1987	Taylor 1990a	Hg	<0.05-4.77	ng/mL	19
	Fifth Creek, 1988		Hg	<0.05-1.87	ng/mL	
	WOC 4500S, below Fifth Creek 4509	Taylor 1990b	Aroclor-1254	<1.0-<1.1	µg/L	17
	Flume station 2 (W16) (1979-1986)	Energy Systems 1987a	^{90}Sr	7.8-20	10^{-9} µCi/mL	9
	Flume station 2 (W16)	Energy Systems 1986	Zinc	0.04-0.1	mg/L	16
	Flume station 2 (W16)		Nitrate nitrogen	0.8-3.0	mg/L	
	Flume station 2 (W16)		Hg	<0.00005-0.0003	mg/L	
	Flume station 2 (W16)		Cr	<0.002-<0.01	mg/L	
Impoundments 3539/3540, 3518, 3544						
	Impoundments 3539/40 (W15) (1979-1986)	Energy Systems 1987a	^{90}Sr	0.2-7.2	10^{-9} µCi/mL	9
	Impoundments 3539/40 discharges (W15)	Energy Systems 1986	Zinc	<0.07-0.29	mg/L	16
	Impoundments 3539/40 discharges (W15)		Nitrate nitrogen	1.0-73	mg/L	
	Impoundments 3539/40 discharges (W15)		Hg	0.013-0.059	mg/L	
	Impoundments 3539/40 discharges (W15)		Cr	<0.005-0.12	mg/L	
	Impoundment 3518	Energy Systems 1988	Gross alpha	1.0-38	pCi/L	10
	Impoundment 3518		Gross beta	4.0-57	pCi/L	
	Impoundment 3544		^{60}Co	<5.4-270	pCi/L	
	Impoundment 3544		^{134}Cs	10-18	pCi/L	
	Impoundment 3544		^{137}Cs	26-2,600	pCi/L	
	Impoundment 3544		^{152}Eu	46-59	pCi/L	
	Impoundment 3544		^{154}Eu	30	pCi/L	
	Impoundment 3544		Gross alpha	59-250	pCi/L	
	Impoundment 3544		Gross beta	270-3,000	pCi/L	
	Impoundment 3544		^{106}Ru	140	pCi/L	
	Impoundment 3544		Total Sr	3.8-140	pCi/L	
	3500 (190) ponds		^{60}Co	<2.7-97	pCi/L	
	3500 (190) ponds		^{137}Cs	5.4-1,700	pCi/L	

Table 4.5.1 (continued)

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.*
	3500 (190) ponds		Gross alpha	2.7-46	pCi/L	
	3500 (190) ponds		Gross beta	4.3-140	pCi/L	
Process Waste Treatment Plant						
	Process Waste Treatment Plant (PWTP) (W-14)	Energy Systems 1987a	^{90}Sr	0.3-33[d]	10^{-9} µCi/mL	
Sewage Treatment Plant						
	Sewage Treatment Plant (STP) (W-13)	Energy Systems 1987a	^{90}Sr	4-36	10^{-9} µCi/mL	
	Mouth of Drainage Area from STP into WOC	Taylor 1990b	Aroclor-1254	~0.3-<1.1	µg/L	17
2000 area	2000 area	Energy Systems 1988	^{60}Co	<2.7-<5.9	pCi/L	10
	2000 area		^{137}Cs	<2.5-<5.4	pCi/L	
	2000 area		Gross beta	4.0-73	pCi/L	
	2000 area		Total Sr	2.0-32	pCi/L	
First Creek	First Creek	Energy Systems 1987a	^{60}Co	<2.7-13	pCi/L	9
	First Creek		^{137}Cs	<2.4-<27	pCi/L	
	First Creek		Total Sr	250-1,000	pCi/L	
	First Creek	Energy Systems 1988	^{60}Co	<2.7-<8.1	pCi/L	10
	First Creek		^{137}Cs	<2.6-<5.4	pCi/L	
	First Creek		Total Sr	300-810	pCi/L	
	First Creek	Energy Systems 1989	^{60}Co	-1.9-27	pCi/L	11
	First Creek		^{137}Cs	-0.54-19	pCi/L	
	First Creek		Total Sr	320-730	pCi/L	
	First Creek	Energy Systems 1990	^{60}Co	-7.6-57	pCi/L	12
	First Creek		^{137}Cs	-22-51	pCi/L	
	First Creek		Total Sr	190-510	pCi/L	
	First Creek		Hg	<0.050-0.39	µg/L	
	First Creek	Taylor 1990a	Hg	<0.05-0.37	ng/mL	20
	First Creek	Taylor 1989	Hg	<0.05	ng/mL	19
	First Creek		Hg	<0.05-0.23	ng/mL	
	Confluence of Northwest Tributary and First Creek	Taylor 1990b	Aroclor-1254	~0.2-<1.3	µg/L	17

Table 4.5.1 (continued)

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.*
1500 Area	1500 Area	Energy Systems 1988	Gross alpha	1.0-32	pCi/L	10
	1500 Area		Gross beta	8.1-130	pCi/L	
Northwest Tributary						
	Northwest Tributary	Energy Systems 1987a	^{60}Co	<1.6-<11	pCi/L	9
	Northwest Tributary		^{137}Cs	<1.4-<11	pCi/L	
	Northwest Tributary		Total Sr	2.7-68	pCi/L	
	Northwest Tributary	Energy Systems 1989	^{60}Co	-8.1-38	pCi/L	11
	Northwest Tributary		^{137}Cs	-5.4-5.4	pCi/L	
	Northwest Tributary		Total Sr	0.70-62	pCi/L	
	Northwest Tributary	Energy Systems 1990	^{60}Co	-35-41	pCi/L	12
	Northwest Tributary		^{137}Cs	-27-24	pCi/L	
	Northwest Tributary		Total Sr	23-78	pCi/L	
	Northwest Tributary		Hg	<0.050	µg/L	
7500 bridge						
	7500 bridge	Energy Systems 1987a	^{60}Co	2.7-760	pCi/L	9
	7500 bridge		^{137}Cs	27-2,200	pCi/L	
	7500 bridge		^{152}Eu	21-1,400	pCi/L	
	7500 bridge		^{154}Eu	16-410	pCi/L	
	7500 bridge		^{155}Eu	22- 110	pCi/L	
	7500 bridge		^{156}Eu	540-1200	pCi/L	
	7500 bridge		Gross alpha	27-1400	pCi/L	
	7500 bridge		Gross beta	220-3500	pCi/L	
	7500 bridge		^{131}I	5.4-14	pCi/L	
	7500 bridge		^{24}Na	13-86	pCi/L	
	7500 bridge		Total Sr	40-840	pCi/L	
	7500 bridge		^{60}Co	4.9-140	pCi/L	
	7500 bridge		^{137}Cs	59-230	pCi/L	
	7500 bridge		^{3}H	<3,200-8200	pCi/L	
	7500 bridge		Total Sr	<68-150	pCi/L	
	7500 bridge		^{90}Sr	72-160	10^{-9} µCi/mL	
	7500 bridge	Energy Systems 1988	^{60Sr}Co	<5.4-12	pCi/L	10
	7500 bridge		^{137}Cs	14-86	pCi/L	
	7500 bridge		Total Sr	49-120	pCi/L	

Table 4.5.1 (continued)

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.*
	7500 bridge		^{3}H	1,500-590,000	pCi/L	
	7500 bridge	Energy Systems 1989	^{60}Co	<1.1-19	pCi/L	11
	7500 bridge		^{137}Cs	49-240	pCi/L	
	7500 bridge		Total Sr	46-120	pCi/L	
	7500 bridge		^{3}H	1,000-120,000	pCi/L	
	7500 bridge	Energy Systems 1990	^{60}Co	-24-54	pCi/L	12
	7500 bridge		^{137}Cs	-5.4-180	pCi/L	
	7500 bridge		Total Sr	49-240	pCi/L	
	7500 bridge		^{3}H	2,400-24,000	pCi/L	
WOC						
	WOC	Energy Systems 1987a	^{60}Co	<2.0-150	pCi/L	9
	WOC		^{137}Cs	62-220	pCi/L	
	WOC		^{3}H	3,500-59,000	pCi/L	
	WOC		Total Sr	92-190	pCi/L	
	WOC	Energy Systems 1986	Zinc	0.03-0.12	mg/L	16
	WOC (W5)		Nitrate nitrogen	3.9-23	mg/L	
	WOC (W5)		Hg	<0.00005-0.0006	mg/L	
	WOC (W5)		Cr	<0.004-<0.01	mg/L	
	WOC	Energy Systems 1990	Hg	<0.050-3.3	µg/L	12
	WOC	Taylor 1990b	Aroclor-1254	~0.50-<1.1	µg/L	17
	WOC (W5)	Energy Systems 1987a	^{90}Sr	65.1-200	10^{-9} µCi/mL	9
White Oak Dam						
	White Oak Dam (W-2)	Energy Systems 1985	Cr	<0.01-0.025	mg/L	3
	White Oak Dam (W-2)		Zn	<0.02-0.036	mg/L	
	White Oak Dam (W-2)		NO_3	0.4-7.2	mg/L	
	White Oak Dam (W-2)		Hg	<0.00005-0.0002	mg/L	
	White Oak Dam (W-1)		Cr	<0.01	mg/L	
	White Oak Dam (W-1)		Zn	<0.02-0.08	mg/L	
	White Oak Dam (W-1)		NO_3 (N)	<0.1-73	mg/L	
	White Oak Dam (W-1)		Hg	<0.00005-0.001	mg/L	
	White Oak Dam (W3)	Energy Systems 1986	^{60}Co	5.0-1,900	10^{-9} µCi/mL	
	White Oak Dam (W3)		^{137}Cs	6.9-650	10^{-9} µCi/mL	
	White Oak Dam (W3)		^{3}H	83-780	10^{-6} µCi/mL	
	White Oak Dam (W3)		^{90}Sr	110-3,500	10^{-9} µCi/mL	

Table 4.5.1 (continued)

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.*
	White Oak Dam (W3)		Transuranics	0.081-2.1	10^{-9} μCi/mL	
	White Oak Dam (W3)		Zn	<0.01-0.07	mg/L	
	White Oak Dam (W3)		NO_3-nitrogen	0.5-16	mg/L	
	White Oak Dam (W3)		Hg	<0.00005-0.0003	mg/L	
Confluence of WOC and Clinch River			Cr	<0.004-<0.015	mg/L	
	Confluence of WOC and Clinch River (W-1)	Energy Systems 1985	^{90}Sr	14-89	10^{-9} μCi/mL	3
	Confluence of WOC and Clinch River (W-1)		^{137}Cs	7.6-270	10^{-9} μCi/mL	
	Confluence of WOC and Clinch River (W-1)		^{60}Co	1.2-38	10^{-9} μCi/mL	
	Confluence of WOC and Clinch River (W-1)		^{3}H	25-360	10^{-6} μCi/mL	
	Confluence WOC at Clinch River (W2)	Energy Systems 1986	^{60}Co	<0.81-170	10^{-9} μCi/mL	16
	Confluence WOC at Clinch River (W2)		^{137}Cs	<1.6-1500	10^{-9} μCi/mL	
	Confluence WOC at Clinch River (W2)		^{3}H	5.4-350	10^{-6} μCi/mL	16
	Confluence WOC at Clinch River (W2)		^{90}Sr	14-350	10^{-9} μCi/mL	

*For map locations, see Fig. 4.5.1.

Table 4.5.2. Summary of analytical results for WAG 1 surface water

Test group	CAS No.	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
ANIONS	16887-00-6	Chloride	µg/L	1000			12,000			4645.2	18	24
	16984-48-8	Fluoride	µg/L	120			1290			523.07692	14	20
	20461-54-5	Iodide	µg/L	1100		J	1600		J	1350	6	13
	1-005	Nitrate/Nitrite	µg/L	80		J	1500			432.30769	13	13
	14265-44-2	Phosphate	µg/L	43		J	490		J	213	11	13
	12143-45-2	Sulfate	mg/L	12.63			12.63		J	12.63	1	1
	12143-45-2	Sulfate	µg/L	8000			54,720			18590.5	22	22
BICARB	0-014	Bicarbonate as $CaCO_3$	µg/L	120,940			168,580			145,027.9	11	11
BNA	86-30-6	Benzenamine, N-Nitroso-N-	µg/L	2		J	3		J	2.5	5	23
	117-81-7	Bis(2-Ethylhexyl) Phthala	µg/L	3		J	35		J	4	2	23
CARB	0-015	Carbonate as CaCO3	µg/L	5260			10,520		J	7890	6	10
CYANIDE	57-12-5	Cyanide	µg/L	1.2			2.4		J	1.8	2	26
METALS-	7429-90-5	Aluminum	µg/L	88.94			2190			611.82	18	21
unfiltered	7440-39-3	Barium	µg/L	23.5		J	48.1			35.46	21	21
	7440-43-9	Cadmium	µg/L	2.5			2.5			2.5	1	21
	7440-70-2	Calcium	µg/L	445.2			51,600			35,714.5	21	21
	7440-47-3	Chromium	µg/L	10.7			13.6			11.85	5	21
	7440-50-8	Copper	µg/L	11.1			96.7			53.9	2	21
	7439-89-6	Iron	µg/L	70.09			2600			588.77	21	21
	7439-92-1	Lead	µg/L	2.1			13.9			5.3	11	18
	7439-95-4	Magnesium	µg/L	113.8			12,500			7723.0381	21	21
	7439-96-5	Manganese	µg/L	14.5			143			36.3	21	21
	7440-02-0	Nickel	µg/L	5.2			6.3			5.7	3	21
	7440-09-7	Potassium	µg/L	599			1710			1201.5	18	18
	7782-49-2	Selenium	µg/L	2.4			2.4			2.4	1	18
	7440-22-4	Silver	µg/L	10.2			12.3			11.0	4	21
	7440-23-5	Sodium	µg/L	40.6			12,300			4074.0	20	21
	7440-62-2	Vanadium	µg/L	3.1			5.1			4	4	21
	7440-66-6	Zinc	µg/L	13.76			57.7			36.84	10	21
METALS -	7429-90-5	Aluminum	µg/L	41.5			201			91.99	9	13
Filtered	7440-38-2	Arsenic	µg/L	2.2			2.2			2.2	1	10
	7440-39-3	Barium	µg/L	16.7			47.7			36.3	13	13
	7440-43-9	Cadmium	µg/L	2.2			2.5			2.4	4	13
	7440-70-2	Calcium	µg/L	25,400			52,200			41,527.7	13	13
	7440-47-3	Chromium	µg/L	10.4			13.3			11.8	4	13
	7440-50-8	Copper	µg/L	8.3			73.4			30.7	3	13
	7439-89-6	Iron	µg/L	11.42			27.4			17.68	6	13

Table 4.5.2 (continued)

Test group	CAS No.	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
	7439-92-1	Lead	µg/L	2.8			3.6			3.3	3	10
	7439-95-4	Magnesium	µg/L	3660			12,600			9614.6	13	13
	7439-96-5	Manganese	µg/L	11.6			39.3			21.7	13	13
	7440-02-0	Nickel	µg/L	6.9			6.9			6.9	1	13
	7440-09-7	Potassium	µg/L	956			1710			1316.8	10	10
	7440-22-4	Silver	µg/L	10.7			12			11.4	3	13
METALS -	7440-23-5	Sodium	µg/L	2410			12,500			5909.2	13	13
Filtered	7440-66-6	Zinc	µg/L	10.91			46.1			27.53	13	13
RAD	12587-46-1	Alpha Particle	pCi/L	1.5	1.3	J	60.4	9.6		9.7	14	21
	12587-47-2	Beta Particle	pCi/L	8.5	2.5		944	95		172.0	21	21
	10045-97-3	Cs-137	pCi/L	17.5	16.2		109	18		46.9	5	20
	13982-63-3	Ra-226	pCi/L	0.18	0.08	J	0.18	0.08	J	0.18	1	9
	15262-20-1	Ra-228	pCi/L	2.06	0.87		152	22		31.42	8	9
	10098-97-2	Sr-90	pCi/L	11.9	01.8		544	55		106.1	8	8
	14133-76-7	Tc-99	pCi/L	1.5	0.9	J	1.5	0.9	J	1.5	1	1
	14274-82-9	Th-228	pCi/L	0.88	0.44	J	3.05	0.99		1.96	2	7
	14269-63-7	Th-230	pCi/L	1.47	0.71		7.25	2.95		3.33	5	7
	7440-29-1	Th-232	pCi/L	10.2	3.5		57.7	46.1		33.95	2	8
	01-00018	Total radioactive strontium	pCi/L	4.88	2.04		475	53	J	82.08	12	12
	10028-17-8	Tritium	pCi/L	490	142		5780	407		1680.9	19	19
	13966-29-5	U-234	pCi/L	1.32	0.4		22.7	2.9		8.65	6	9
	7440-61-1	U-238	pCi/L	0.6	0.39	J	1.65	0.7		1.15	3	9
Rad - Filtered	12587-46-1	Alpha Particle	pCi/L	2.6	1.6		59.2	9.4		13.12	10	11
	12587-47-2	Beta Particle	pCi/L	21.7	2.9		951	144	J	259.2	11	11
	13982-63-3	Ra-226	pCi/L	0.09	0.05	J	0.09	0.05	J	0.09	1	8
	15262-20-1	Ra-228	pCi/L	2.61	1.18		123	18		26.65	7	8
	10098-97-2	Sr-90	pCi/L	11.3	1.7		489	49		105.6	7	7
	14274-82-9	Th-228	pCi/L	1.13	0.49	J	1.13	0.49	J	1.13	1	2
	14269-63-7	Th-230	pCi/L	3.82	1.03		3.82	1.03		3.82	1	2
	01-00018	Total radioactive strontium	pCi/L	35.2	5.29		380	42	J	118.8	5	5
	10028-17-8	Tritium	pCi/L	2560	330	J	2560	330	J	2560	1	1
	13966-29-5	U-234	pCi/L	1.28	0.39		20	2.4		9.08	5	8
	7440-61-1	U-238	pCi/L	0.43	0.34	J	1.11	0.3		0.77	2	8
SULFIDE	18496-25-8	Sulfide	µg/L	50			50			50	1	26
	1-010	Total dissolved solids	µg/L	150,000			250,000			181,472	14	14
	0-008	Total Kjeldahl Nitrogen-T	µg/L	60			730			322.8	18	23
TOC	1-012	Total Organic Carbon	µg/L	2000			4000			3216.2	18	23

Table 4.5.2 (continued)

Test group	CAS No.	Compound	Units	Minimum	Error	Flag	Maximum	Error	Flag	Average	Hits	Count
TOX	01-00017	Organic Iodine	µg/L	130			130			130	1	6
VOC	67-64-1	Acetone	µg/L	12			12			12	1	19
	67-66-3	Chloroform	µg/L	1		J	5			2.8	8	19
	75-71-8	Methane, dichlorofluoro	µg/L	2		J	2		J	2	1	1
	75-27-4	Methane, bromodichloro	µg/L	1		J	1		J	1	2	19
	110-86-1	Pyridine	µg/L	71		J	71		J	71	1	1
	127-18-4	Tetrachloroethylene	µg/L	5			5			5	1	19
	75-69-4	Trichlorofluoromethane	µg/L	3		J	3		J	3	1	1
	123-91-1	p-Dioxane	µg/L	89		J	89		J	89	1	1

Table 4.5.3. Strontium fluxes in creeks

Sampling site	event[a]	Flow (L/s)	Unfiltered concentration (pCi/L)	Flux (pCi/s)
SW-4:	LBNS	26.0	40.1	1,042.6
	HBNS	86.4	23.8	2,056.3
	HBS	399.3	17.1	6,824.0
SW-5:	LBNS	82.1	13.2	1,083.7
	HBNS	135.9	NA[b]	
	HBS	679.7	4.9	3,316.9
SW-7:	LBNS	5.4	544	2,937.6
	HBNS	22.5	142	3,195.0
	HBS	368.2	30.8	11,340.6
SW-8:	LBNS	16.1	86.6	1,394.3
	HBNS	25.5	50	1,275.0
	HBS	679.7	11.3	7,680.6
SW-6:	LBNS	152.9	60.5	9,250.4
	HBNS	269.0	74.6	20,067.4
	HBS	1812.5	47.2	85,550.0

[a]Low base nonstorm (LBNS) concentrations are strontium-90; high base nonstorm (HBNS) and storm (HBS) concentrations are total radioactive strontium.

[b]Not analyzed.

Table 4.6.1. Previous sediment studies at WAG 1

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.*
WOC headwaters						
	WOC headwaters	Spalding and Cerling 1979	Cs-137	9–3409	dpm/g	30
			Co-60	3–554	dpm/g	
			Sr-90 (exchangeable)	ND–107.4	dpm/g	
	WOC upstream of fifth creek	Taylor 1989	Hg	5.39	μg/g	19
	Headwaters of WOC background area		TOC	2.5-4.3	%	
	WOC P-6, 1979	Oakes 1983a	Hg	0.08	ppm	7
	WOC headwaters	Taylor 1990a	Hg	0.02–0.063	μg/g	20
	WOC upstream of fifth creek		Hg	4.65–5.04	μg/g	
	WOC headwaters, background area	Taylor 1990b	Aroclor 1248	0.028-<0.40	μg/g	17
	WOC headwaters, background area	Taylor 1990b	Aroclor 1254	<0.18-<2.6	μg/g	17
	WOC headwaters, background area	Taylor 1990b	Aroclor 1260	<0.36-<5.2	μg/g	17
Fifth Creek						
	Fifth creek below outfall 362	Taylor 1989	Hg	21.10	μg/g	19
	Fifth creek below outfall 362		Hg	67.53	μg/g	
	Fifth creek near outfall 261		Hg	4,874	μg/g	
	Fifth creek below outfall 362	Taylor 1990a	Hg	23.03–112.43	μg/g	20
	Fifth creek outfall 362 box		Hg	5.67–155.81	μg/g	
	Fifth creek near outfall 261		Hg	555.67–7427	μg/g	
WOC						
	WOC near outfall 309	Taylor 1989	Hg	22.20	μg/g	19
	WOC near outfall 309	Taylor 1990a	Hg	2.15–17.70	μg/g	20
	Below fifth creek	Spalding and Cerling 1979	Cs-137	9-3,409	dpm/g	30
			Co-60	3–554	dpm/g	
			Sr-90 (exchangeable)	ND–0.7	dpm/g	

Table 4.6.1 (continued)

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.*
	WOC upstream of equalization basin	Oakes 1983a	Hg	1.6–9.5	μg/g	7
	WOC downstream of equalization basin		Hg	0.4–19	μg/g	
	WOC T-10, 1979		Hg	3.8	ppm	
	6-LT, 1983[a]		Hg	2.9	ppm	
	6-LM, 1983		Hg	2.0	ppm	
	6-LB, 1983		Hg	6.4	ppm	
	6-RT, 1983		Hg	9.5	ppm	
	6-RM, 1983		Hg	1.6	ppm	
	6-RB, 1983		Hg	2.8	ppm	
	7-RT, 1983		Hg	5.1	ppm	
	7-RM, 1983		Hg	18	ppm	
	7-RB, 1983		Hg	19	ppm	
	7-LT, 1983		Hg	8.1	ppm	
	7-LB, 1983		Hg	0.4	ppm	
	WOC[b]	Cerling and Spalding 1981	Co-60 Cs-137 Sr-90	0.0-370 0.0–23,200 0.0–22.4	dpm/g dpm/g dpm/g	30
First Creek						
	First creek upstream of northwest tributary	Oakes 1983a	Hg	0.67	μg/g	7
	First creek upstream of northwest tributary		Hg	1.37–0.06	μg/g	
	First creek	Cerling and Spalding 1981	Co-60 Cs-137 Sr-90	0.0-29.1 0.0–1040 0.0–30	dpm/g dpm/g dpm/g	26
Northwest Tributary						
	Northwest tributary upstream of first creek	Taylor 1989	Hg	0.17	μg/g	19
7500 bridge						

Table 4.6.1 (continued)

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.*
	Confluence of X-10 Sites in WOC	Taylor 1990b	TOC	2.8–5.5	%	17
	WOC T-8, 1979	Oakes 1983a	Hg	0.41	ppm	7
	WOC 8-RT, 1983		Hg	2.5	ppm	
	WOC 8-RM, 1983		Hg	4.5	ppm	
	WOC 8-RB		Hg	1.4	ppm	
	7500 Bridge	Daniels 1989	Cs-137	2300–290,000	Bq/kg	27
			Co-60	11–17,000	Bq/kg	
			Eu-154	190–1,200	Bq/kg	
			Eu-152	78–2,900	Bq/kg	
			Cs-134	72–270	Bq/kg	
			U-234	52–170	Bq/kg	
			Ba-133	510	Bq/kg	
			Am-241	46–160	Bq/kg	
			Cm-244	80–680	Bq/kg	
			Th-232	15–56	Bq/kg	
			Th-230	11–36	Bq/kg	
			Th-228	18–55	Bq/kg	
			Sr-90	37–1100	Bq/kg	
			Pu-239	110–160	Bq/kg	
			Pu-238	4.9–39	Bq/kg	
			U-238	28–75	Bq/kg	
Perimeter						
	Clinch River CRM 20.8	Energy Systems 1985	Co-60	0.49	pCi/g	3
			Cs-137	5.7	pCi/g	
			K-40	12	pCi/g	
			Pu-238	0.0022	pCi/g	
			Pu-239	0.022	pCi/g	
			Sr-90	0.70	pCi/g	
			U-234	0.15	pCi/g	

Table 4.6.1 (continued)

Area	Sample location	Source	Parameter	Concentration	Units	Map Ref. No.[a]
	WOC Station 6 - downgradient of WAG 1 perimeter	Energy Systems 1989	Aroclor 1016	<400–<910	μg/kg	11
			Aroclor 1221	<400–<910	μg/kg	
			Aroclor 1232	<400–<910	μg/kg	
			Aroclor 1242	<400–<910	μg/kg	
			Aroclor 1248	<400–3000	μg/kg	
			Aroclor 1254	200–7800	μg/kg	

[a]For map locations, see Fig. 4.5.1.
[a]R, M, and L indicate right, middle, and left of the stream looking downstream. T, M, and B indicate top, middle, and bottom of a 10-in. core.
[b]WOC samples upstream of its confluences with Northwest Tributary and First Creek.

Table 4.6.2 (continued)

Test group	CAS No.	Compound	Units	Min.	Error Flag	Max.	Error Flag	Average	Hits	Count
	7440-22-4	Silver	µg/kg	4500		19700		11388.889	9	10
	7440-23-5	Sodium	µg/kg	49900		113000	J	72750	10	10
	7440-28-0	Thallium	µg/kg	890		890		890	1	10
	7440-31-5	Tin	µg/kg	11400	J	11400	J	11400	1	1
	7440-62-2	Vanadium	µg/kg	18400		35500		25450	10	10
	7440-66-6	Zinc	µg/kg	101000	J	458000	J	274600	10	10
PEST/PCB	12672-29-6	Aroclor 1248	µg/kg	620	J	620	J	620	1	9
	11097-69-1	Aroclor 1254	µg/kg	410	J	12000	J	2814.2857	7	10
	11096-82-5	Aroclor 1260	µg/kg	570	J	3900	J	1784	5	10
RAD	12587-46-1	Alpha Particle	pCi/g	13.3	8.1	135	33	67.757143	7	8
	14596-10-2	Am-241	pCi/g	0.15	0.07	5.1	.83	2.325	4	4
	12587-47-2	Beta Particle	pCi/g	13.5	4.6	1910	380	719.5125	8	8
RAD	13966-05-7	Ca-45	pCi/g	5.2	0.6	5.82	.69	5.51	2	2
	0-190	Cm-234/244	pCi/g	10.7	2.4	15.1	3.4	12.9	2	2
	15510-73-3	Cm-242	pCi/g	10.5	2.4	12.5	2.9	11.5	2	2
	10198-40-0	Co-60	pCi/g	0.11	0.02	12.6	1.2	5.6175	4	4
	13967-70-9	Cs-134	pCi/g	0.61	0.15	.61	.15	0.61	1	1
	10045-97-3	Cs-137	pCi/g	1.45	0.19	2480	250	925.41	8	8
	14683-23-9	Eu-152	pCi/g	2.57	0.33	4.81	.45	3.69	2	2
	15585-10-1	Eu-154	pCi/g	2.04	0.25	2.16	.28	2.1	2	2
	14681-59-5	Fe-55	pCi/g	26	9.3	26	9.3	26	1	2
	15046-84-1	I-129	pCi/g	0.2	0.11 J	.24	.12 J	0.22	2	2
	13966-32-0	Na-22	pCi/g	0.14	0.08	.82	.18	0.59	3	3
	13982-63-3	Ra-226	pCi/g	0.47	0.1	.66	.14	0.565	2	8
	15262-20-1	Ra-228	pCi/g	0.68	0.22	1.41	.48	0.86	6	8
	10098-97-2	Sr-90	pCi/g	1.2	0.33	67	6.9	21.8275	8	8
	14274-82-9	Th-228	pCi/g	0.74	0.17	1.29	.23	1.1314286	7	8
	14269-63-7	Th-230	pCi/g	0.61	0.15	.91	.18	0.81166667	6	8
	7440-29-1	Th-232	pCi/g	0.67	0.19	1.1	.21	0.89	7	8
	13966-29-5	U-234	pCi/g	0.97	0.19	4.47	.61	2.45875	8	8
	7440-61-1	U-238	pCi/g	0.78	0.19	3.52	.5	1.8066667	6	8

Table 4.6.2. Summary sediment analyses

Test group	CAS No.	Compound	Units	Min.	Error Flag	Max.	Error Flag	Average	Hits	Count
BNAE	83-32-9	Acenaphthene	µg/kg	490	J	490	J	490	1	9
	120-12-7	Anthracene	µg/kg	130	J	980	J	647.5	4	9
	56-55-3	Benz(a)anthracene	µg/kg	630		4300	J	1892	5	9
	205-99-2	Benz(e)Acephenanthrylene	µg/kg	1500	J	12000		4140	5	9
	50-32-8	Benzo(a)pyrene	µg/kg	560	J	3400	J	1613.3333	3	9
	191-24-2	Benzo(ghi)Perylene	µg/kg	400	J	400	J	400	1	9
	207-08-9	Benzo(k)Fluoranthene	µg/kg	2400	J	2400	J	2400	1	7
	117-81-7	Bis(2-Ethylhexyl)Phthala	µg/kg	200	J	1300		810	3	9
	218-01-9	Chrysene	µg/kg	1000		6500		2900	5	9
	84-74-2	Di-n-butylPhthalate	µg/kg	630	J	630	J	630	1	9
	206-44-0	Fluoranthene	µg/kg	1400		9800		4440	5	9
	85-01-8	Phenanthrene	µg/kg	710		5000	J	3022	5	9
	117-84-0	Phthalic Acid, Dioctyl Es	µg/kg	83	J	83	J	83	1	9
	129-00-0	Pyrene	µg/kg	1200	J	8000	J	3780	5	9
DIOX/FURA	55684-94-1	HxCDF	ng/g	0.95	J	0.95	J	0.95	1	1
METALS	7429-90-5	Aluminum	µg/kg	3420000		9730000		6663000	10	10
	7440-36-0	Antimony	µg/kg	12500	J	12500	J	12500	1	6
	7440-38-2	Arsenic	µg/kg	3200	J	6800		4762.5	10	10
	7440-39-3	Barium	µg/kg	60300		251000		112610	10	10
	7440-41-7	Beryllium	µg/kg	730		1900		1140	9	10
	7440-43-9	Cadmium	µg/kg	2300		4300		2950	10	10
	7440-70-2	Calcium	µg/kg	2390000		77300000		31959000	10	10
	7440-47-3	Chromium	µg/kg	31500		145000		69380	10	10
	7440-48-4	Cobalt	µg/kg	9000		23700		12755.556	10	10
	7440-50-8	Copper	µg/kg	12900		107000	J	44700	10	10
	7439-89-6	Iron	µg/kg	15600000		35800000		24490000	10	10
	7439-92-1	Lead	µg/kg	28400		103000		56190	10	10
	7439-95-4	Magnesium	µg/kg	1240000		16500000		5227000	10	10
	7439-96-5	Manganese	µg/kg	262000	J	1000000	J	696666.67	10	10
	7439-97-6	Mercury	µg/kg	270	J	7900	J	3674	6	10
	7440-02-0	Nickel	µg/kg	12000		22700		16620	10	10
	7440-04-2	Osmium	µg/kg	16900	J	16900	J	16900	1	1
	7440-09-7	Potassium	µg/kg	247000		669000		508400	10	10

Table 4.6.2 (continued)

Test group	CAS No.	Compound	Units	Min.	Error Flag	Max.	Error Flag	Average	Hits	Count
SULFIDE	18496-25-8	Sulfide	µg/kg	4070	J	169170		57000	5	6
VOC	67-64-1	Acetone	µg/kg	17		30		23.5	2	9
	75-15-0	Carbon Disulfide	µg/kg	2	J	2	J	2	1	9
	108-90-7	Chlorobenzene	µg/kg	1	J	1	J	1	1	9
	74-87-3	Methyl Chloride	µg/kg	7	J	7	J	7	1	9
	75-09-2	Methylene Chloride	µg/kg	4	J	4	J	4	3	9
	108-10-1	Methylisobutylketone[a]	µg/kg	2	J	2	J	2	1	9
	127-18-4	Tetrachloroethylene	µg/kg	18		18		18	1	9
	108-88-3	Toluene	µg/kg	5	J	8	J	6.5	2	9

[a]Also known as 4-methyl-2-pentanone.

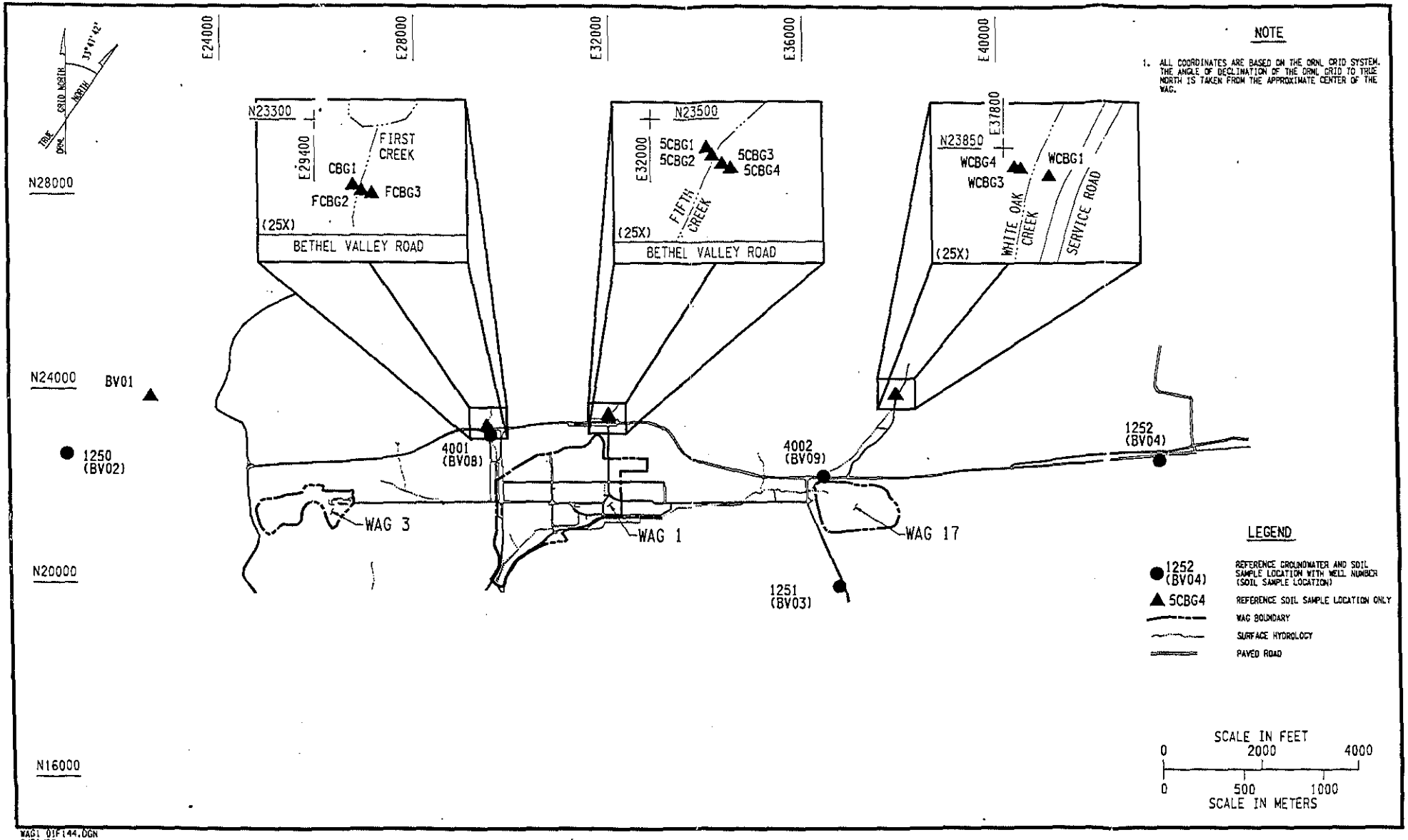
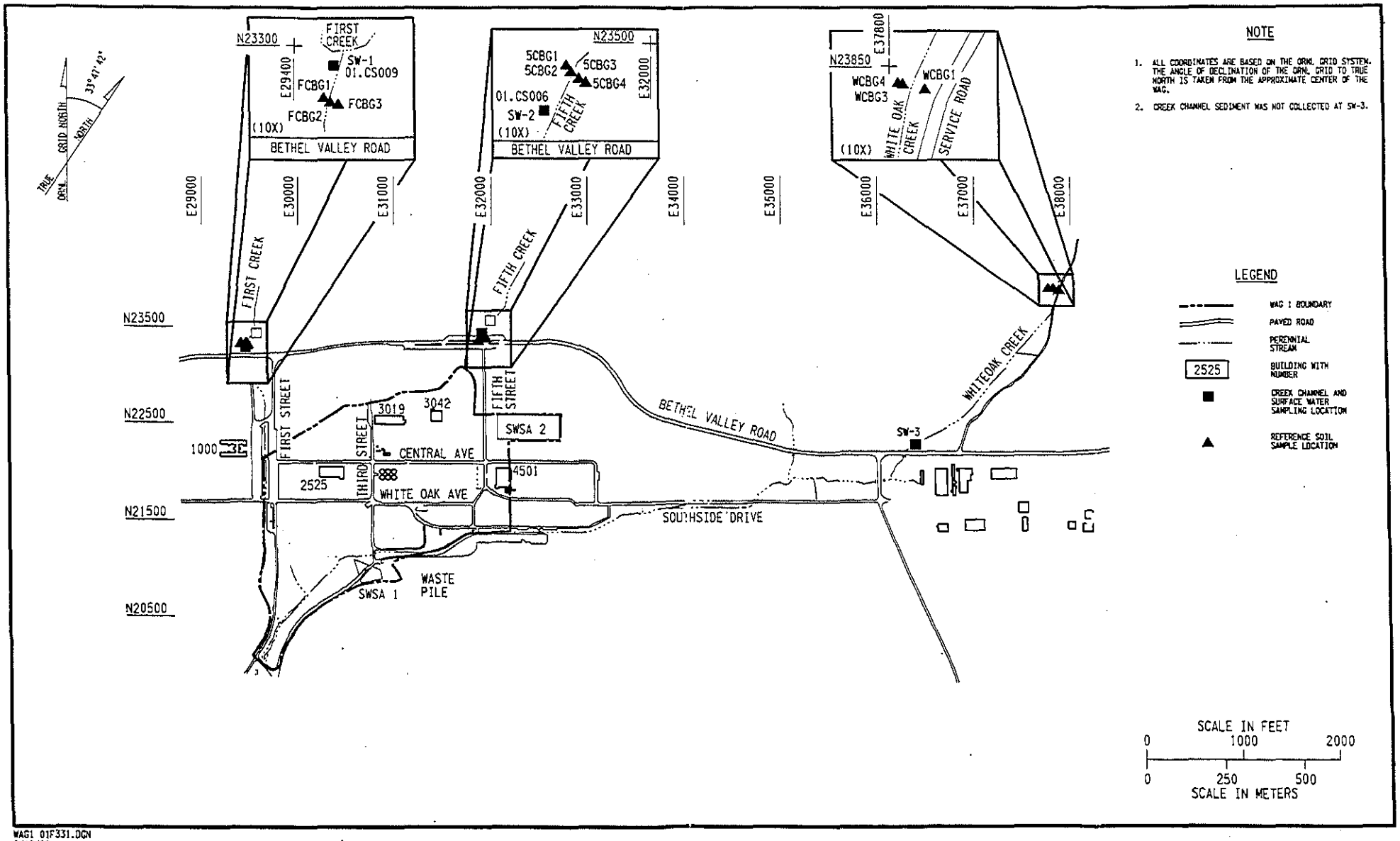
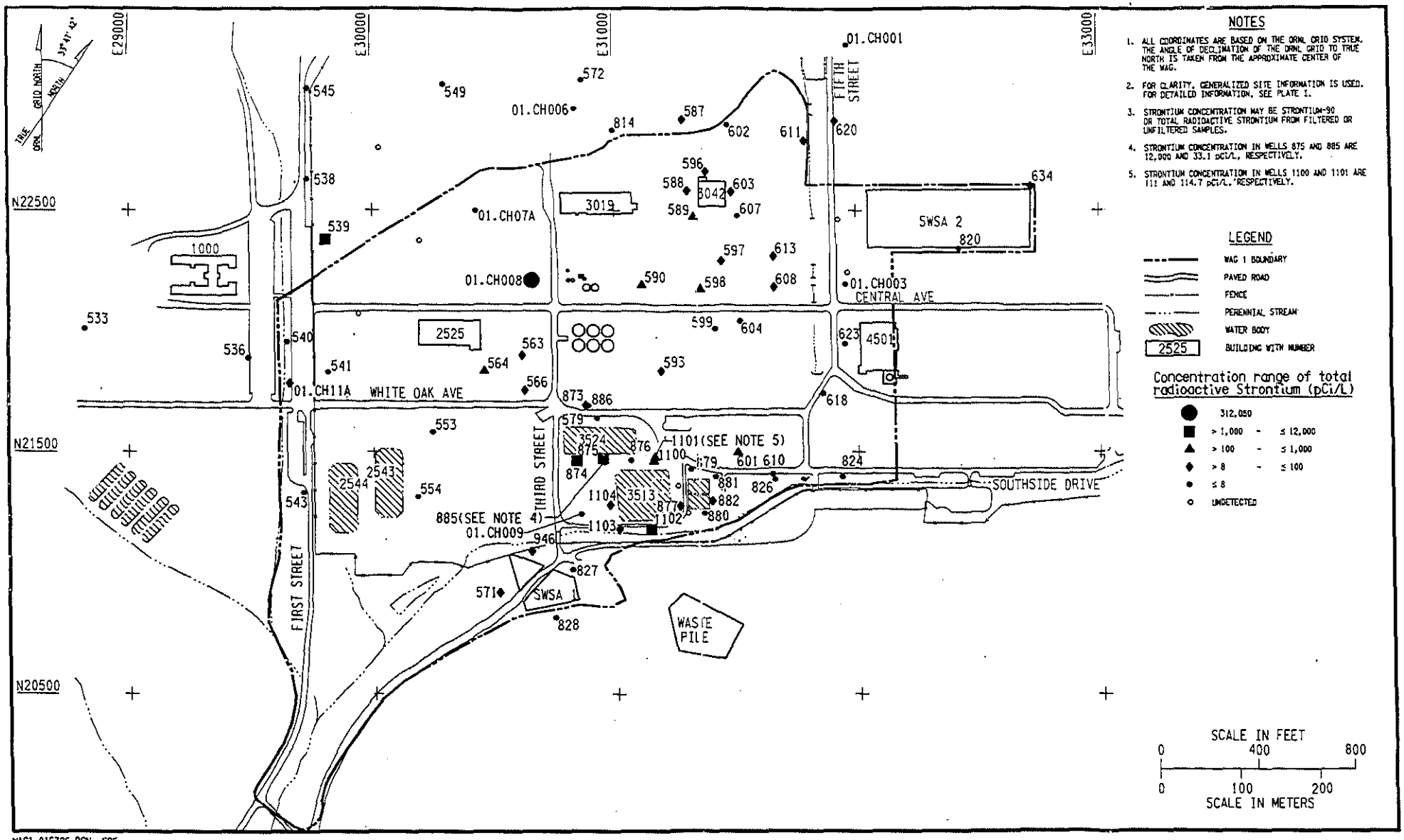


Fig. 4.2.1. Locations of soil and groundwater reference samples.



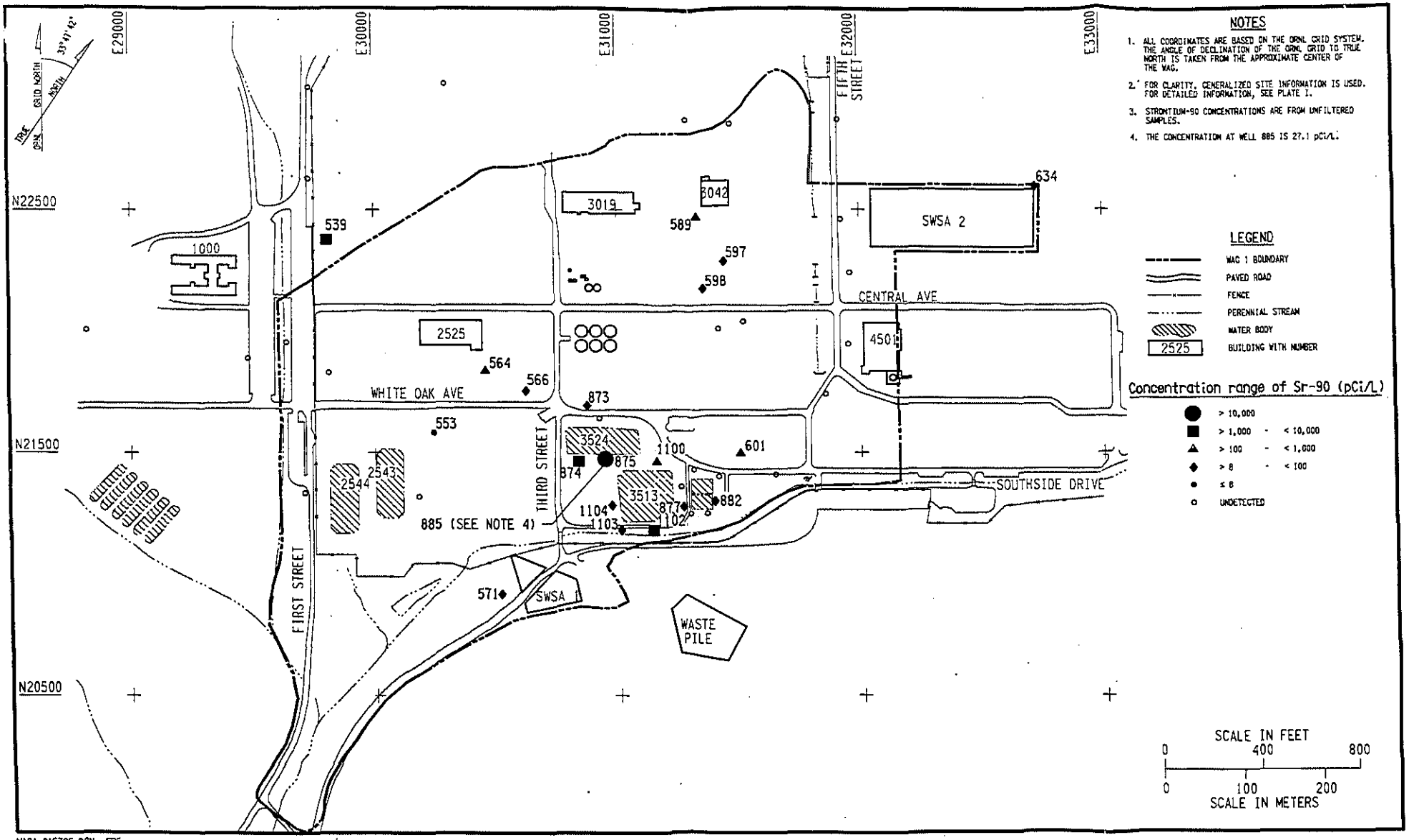
WAG1 01F331.DGN
6/19/92

Fig. 4.2.2. Locations of surface water and creek channel sediment reference samples.



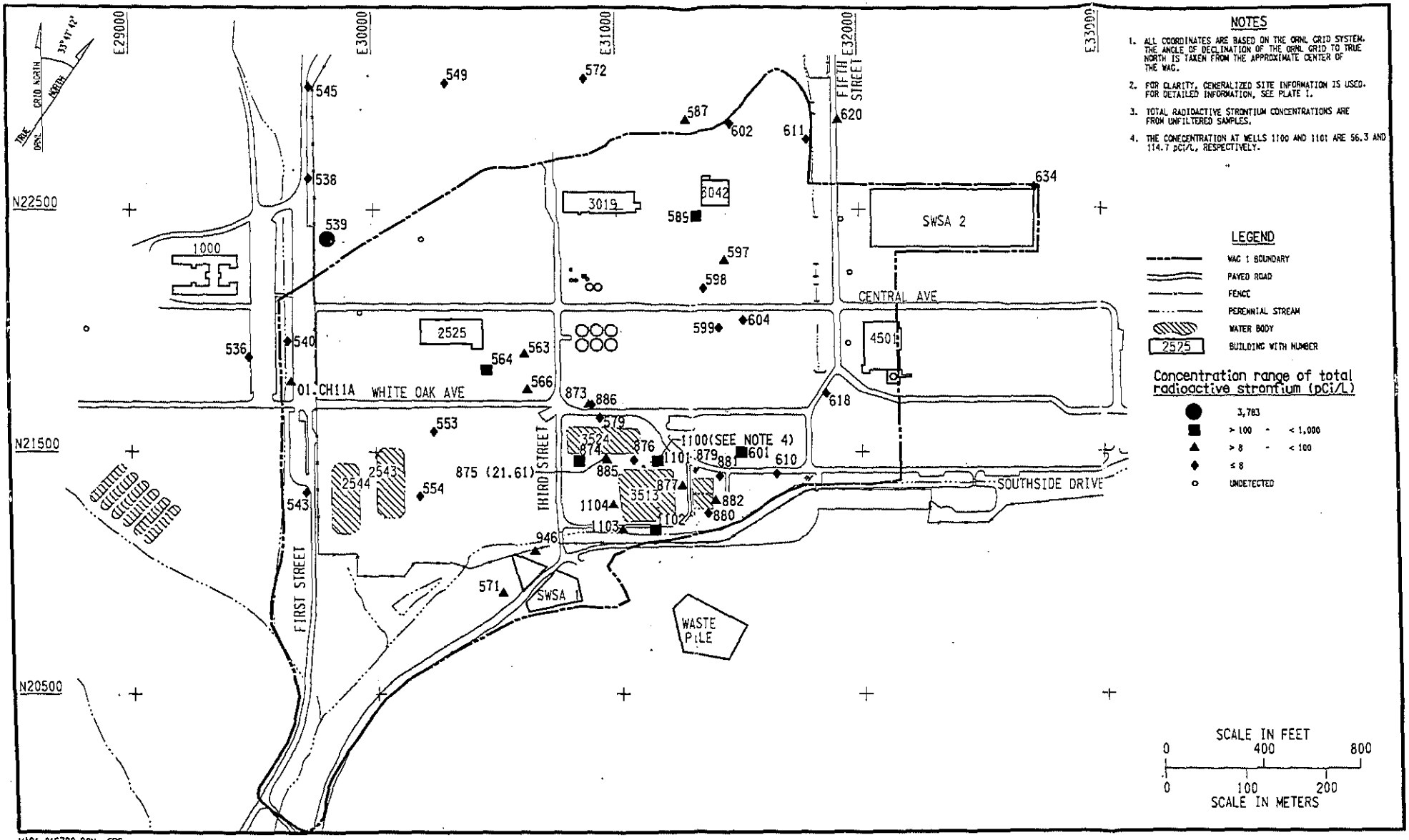
WAG1 01F326.DGN SRF, 9/17/92

Fig. 4.3.1. Strontium: maximum concentrations in all wells, piezometers, and coreholes sampled.



WAG1 01F325.DGN SRF, 9/11/92

Fig. 4.3.2. Strontium-90: maximum consentration in wells and piezometers sampled during low base flow conditions.



WAG1 01F328.DGN SRF, 9/11/92

Fig. 4.3.3. Total radioactive strontium: maximum concentrations in wells and piezometers sampled during high base flow conditions.

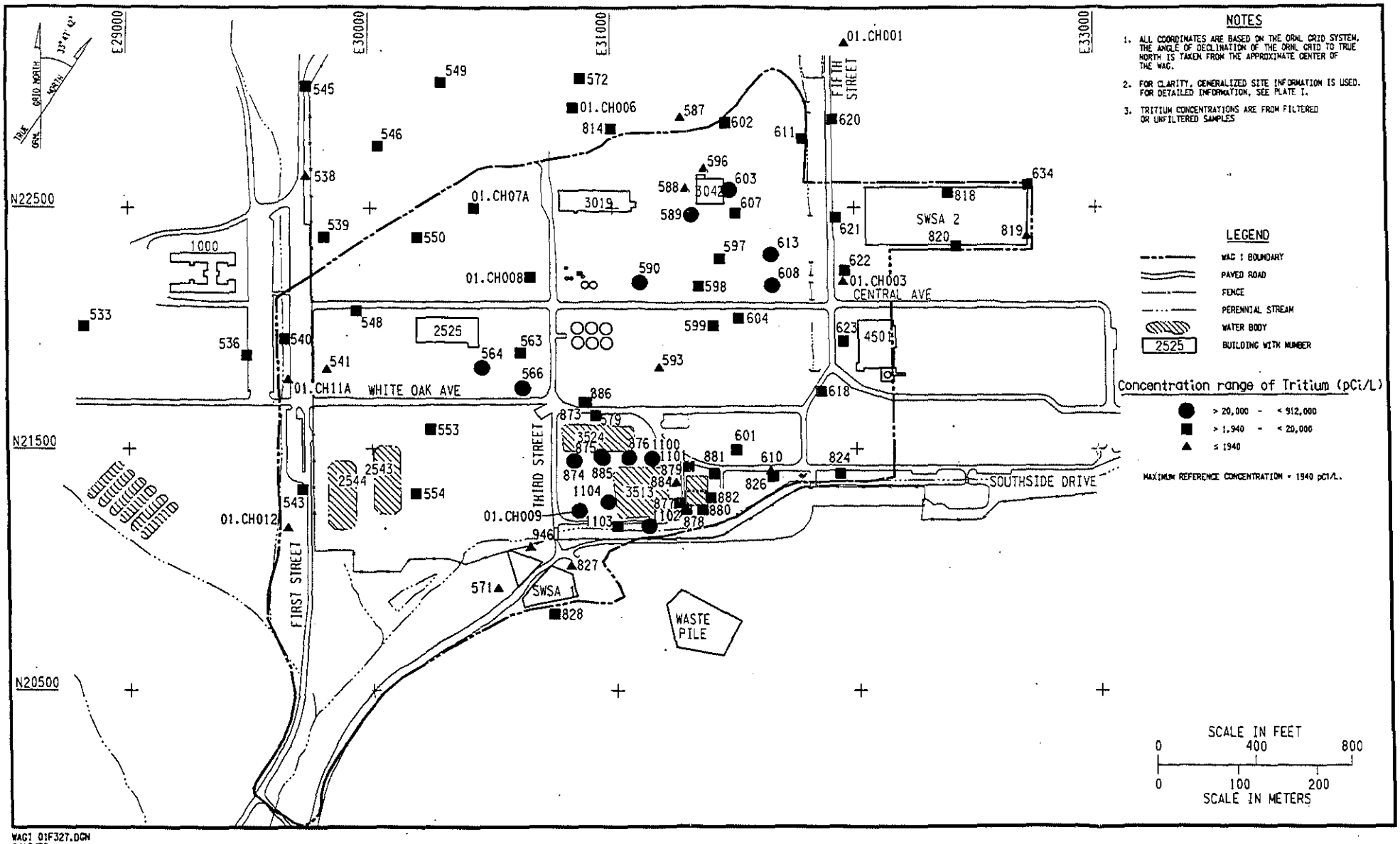
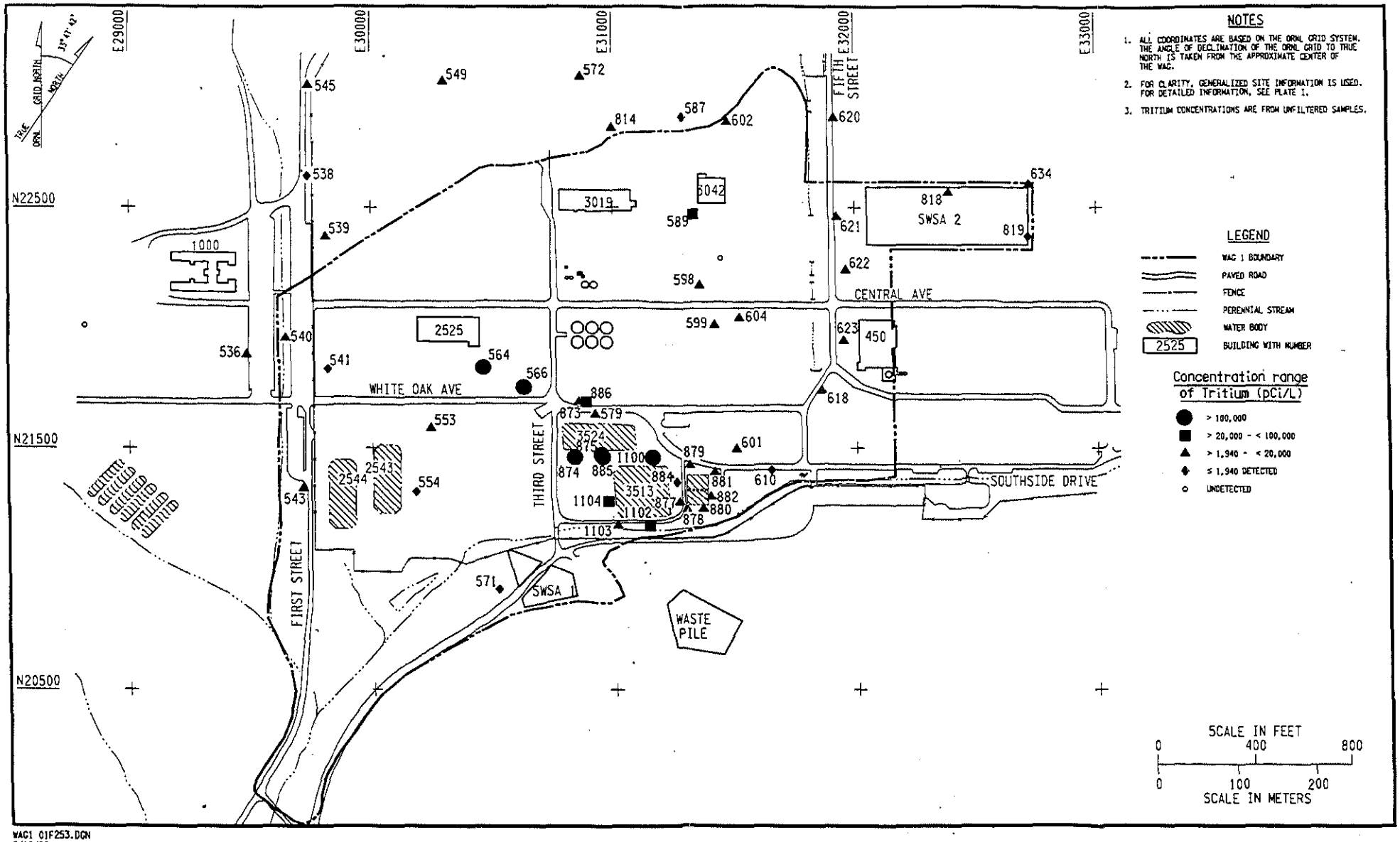
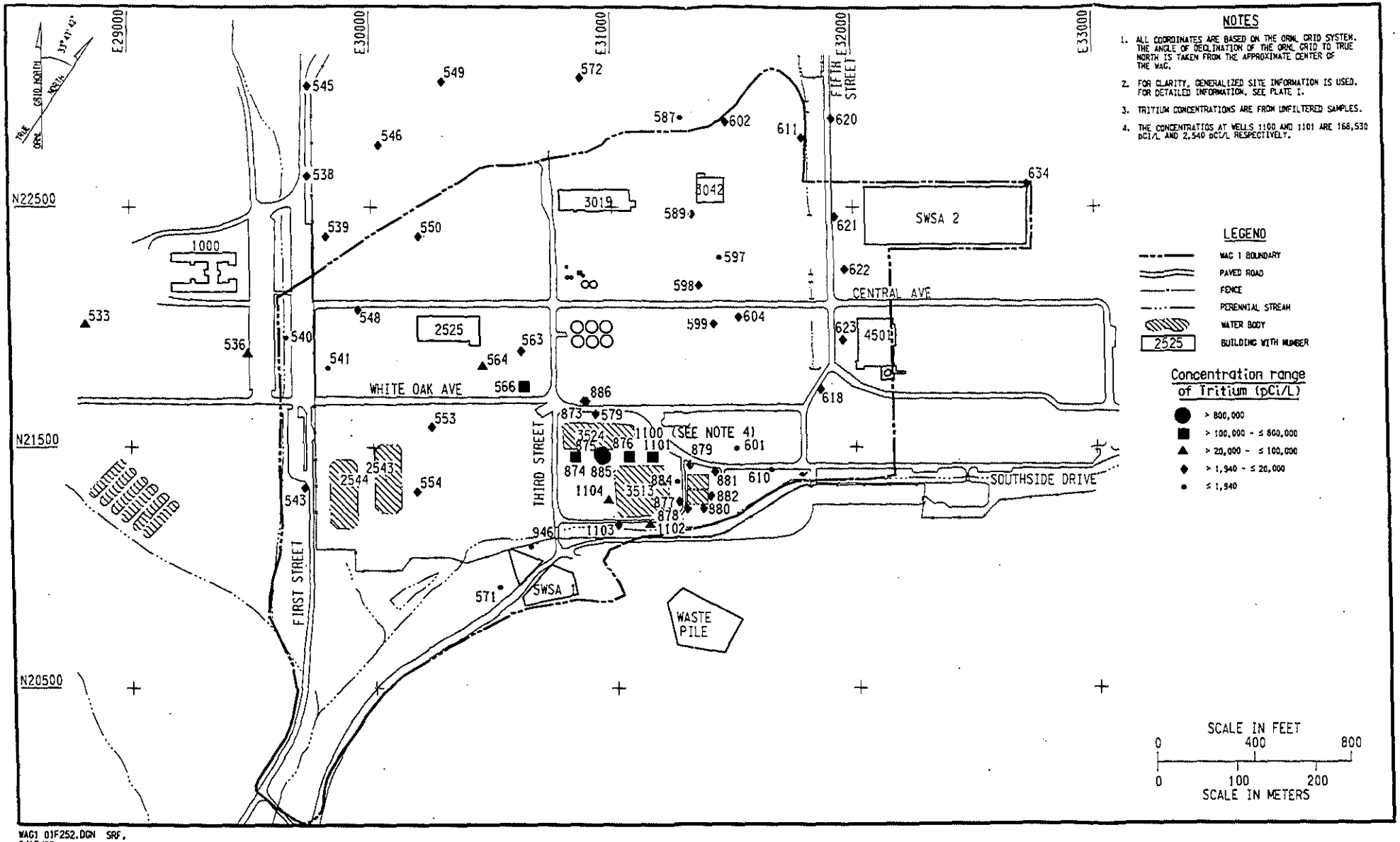


Fig. 4.3.4 Tritium: maximum concentrations in all wells, piezometers and coreholes sampled.



WAG1 01F253.DGN
9/10/92

Fig. 4.3.5. Tritium: maximum concentrations in wells and piezometers sampled during low base flow conditions.



WAG1 01F252.DGN SRF, 9/17/92

Fig. 4.3.6. Tritium: maximum concentration in wells and piezometers sampled during high base flow conditions.

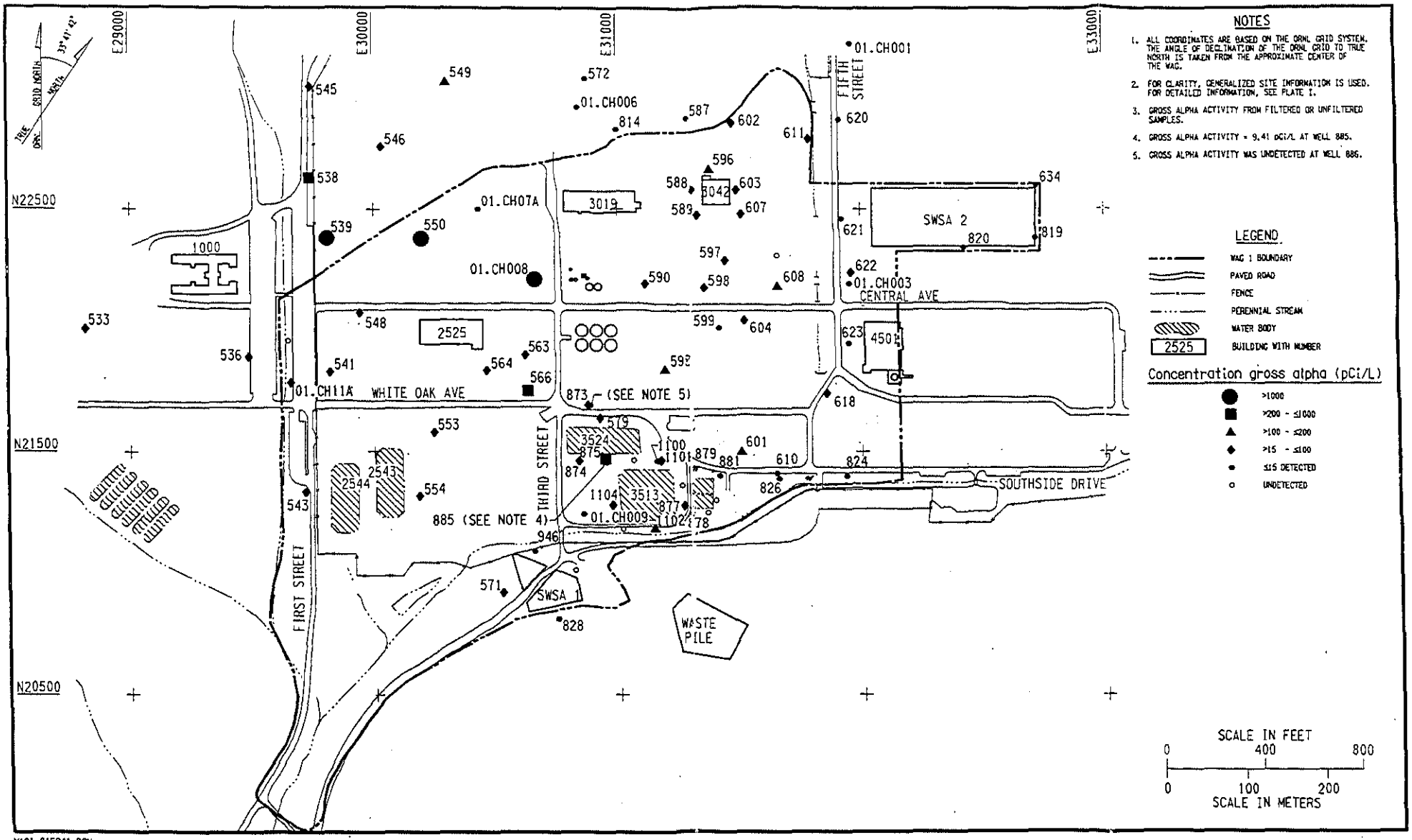
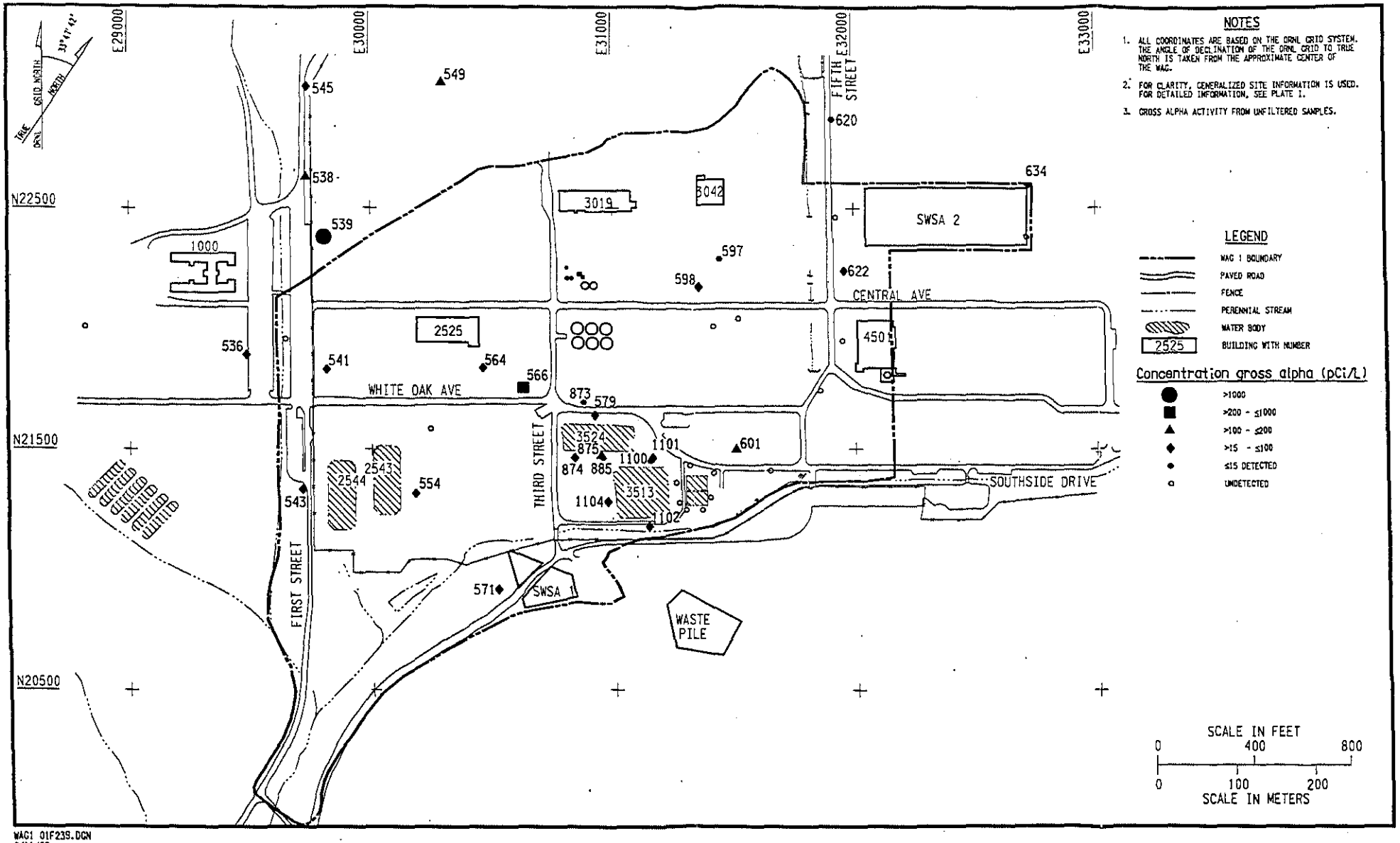
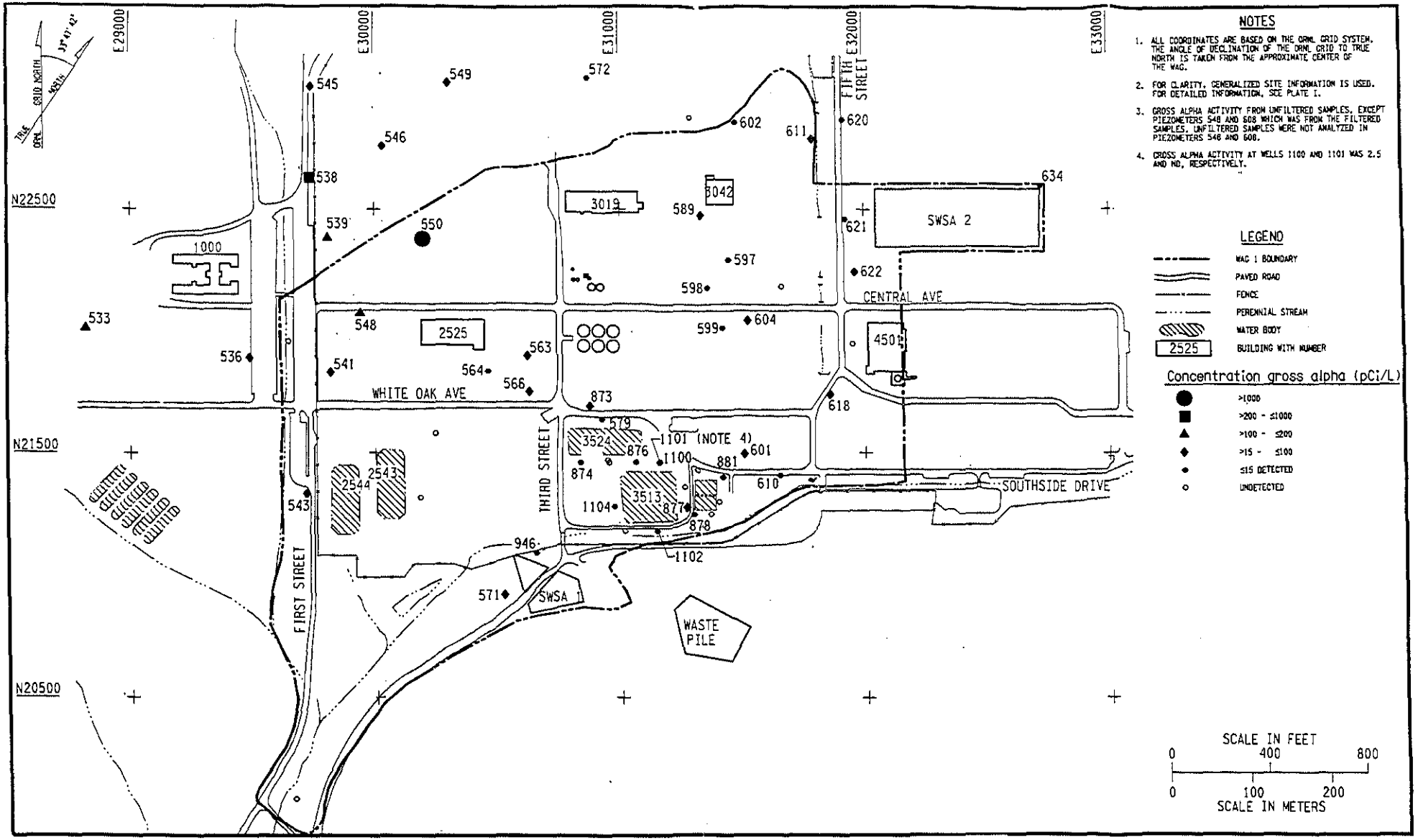


Fig. 4.3.7. Gross alpha: maximum activity in all wells, piezometers and coreholes sampled.



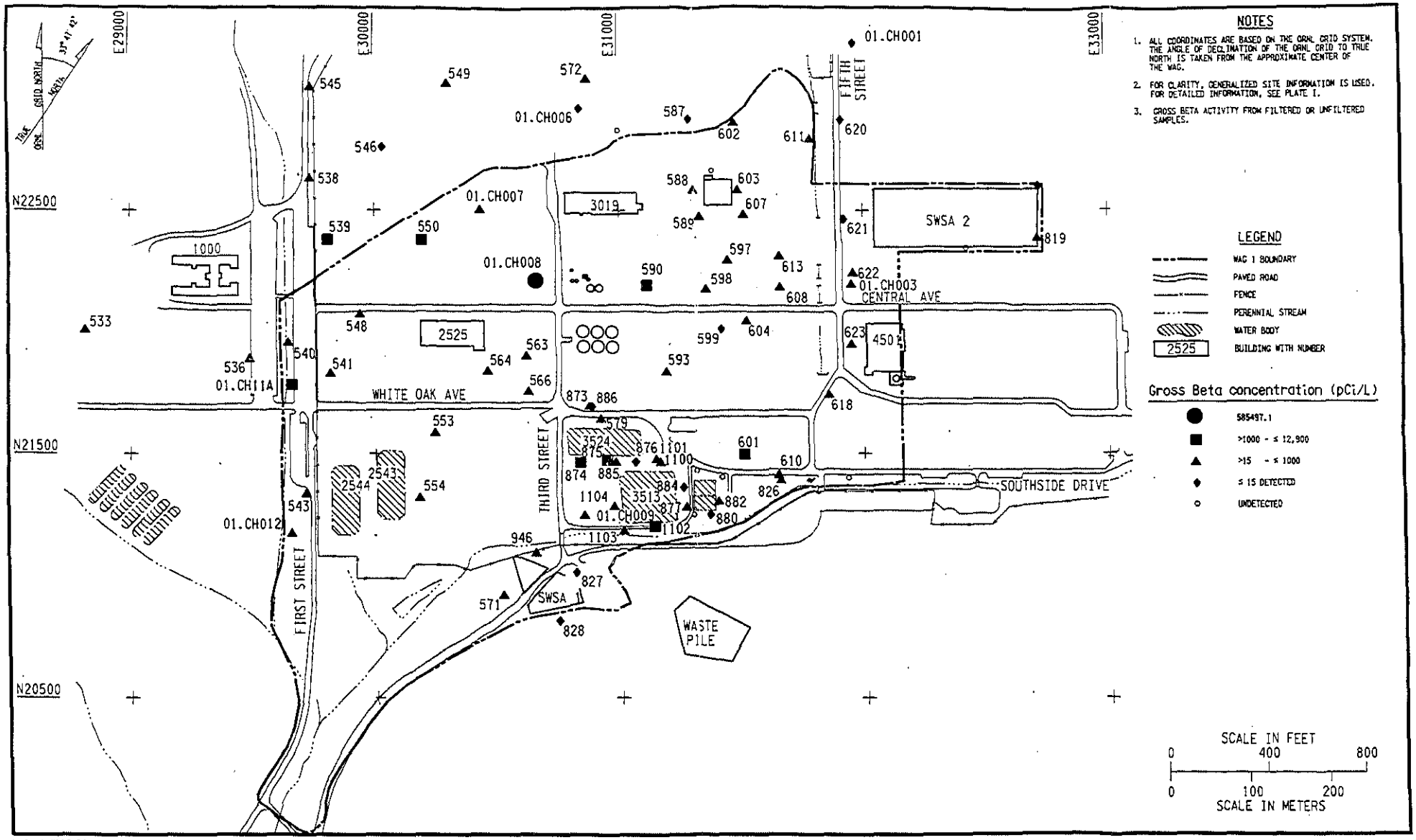
WAG1 01F239.DGN
9/11/92

Fig. 4.3.8. Gross alpha: maximum activity in all wells and piezometers sampled during low base flow conditions.



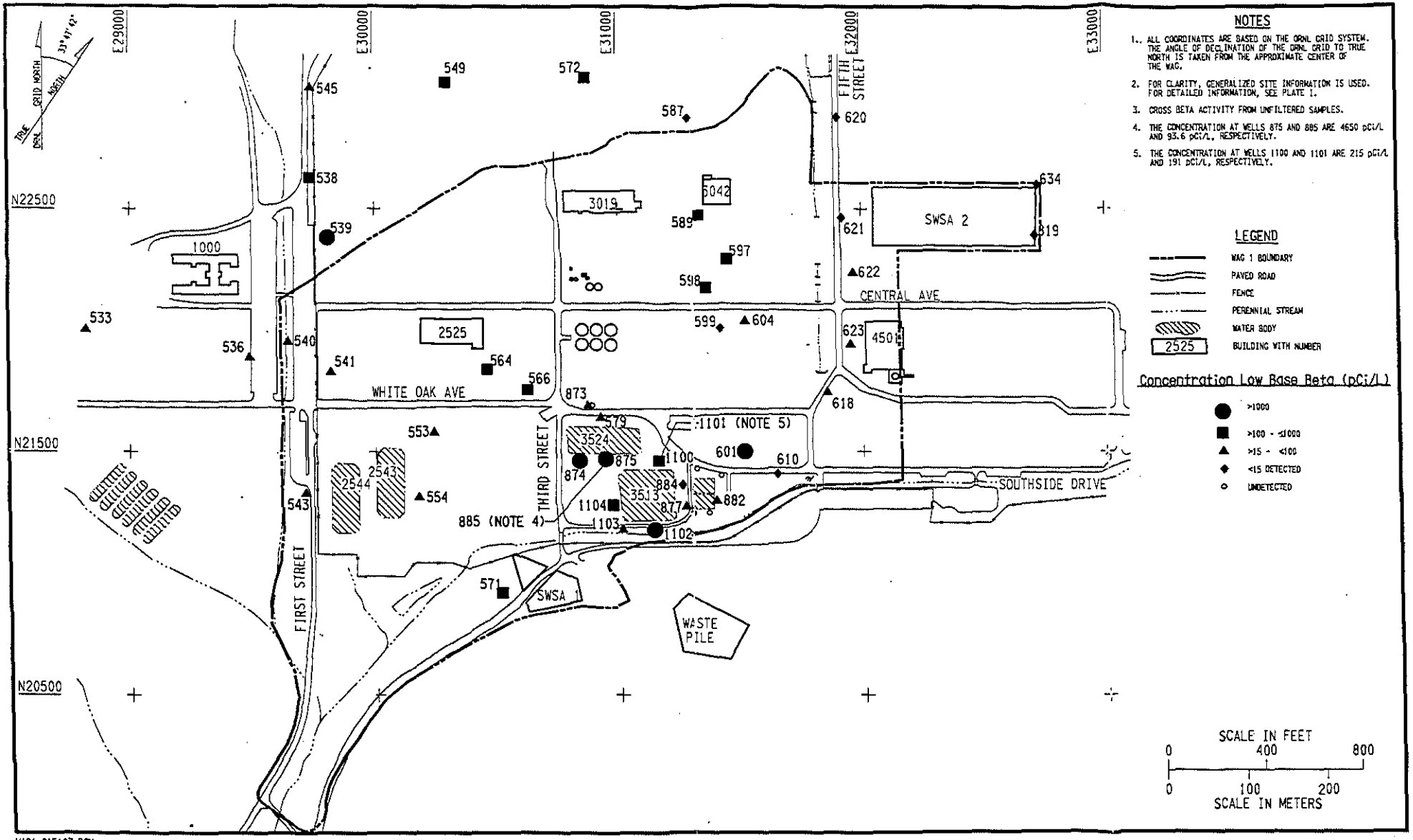
WAG1 01F240.DGN SRF, 9/17/92

Fig. 4.3.9. Gross alpha: maximum activity in wells and piezometers sampled during high base flow conditions.



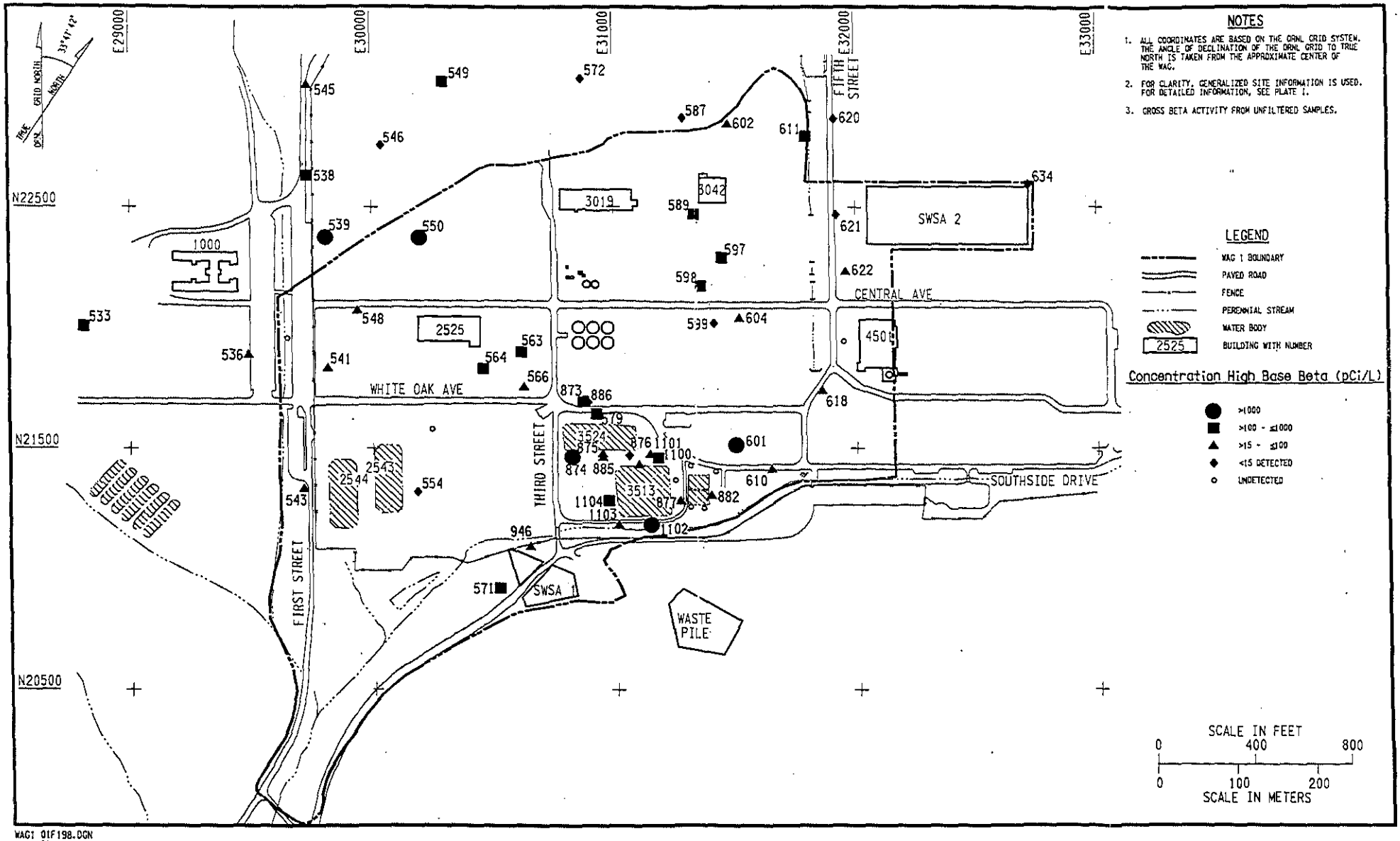
WAG1 01F339.DGN
9/17/92

Fig. 4.3.10. Gross beta: maximum activity in all wells piezometers and coreholes sampled.



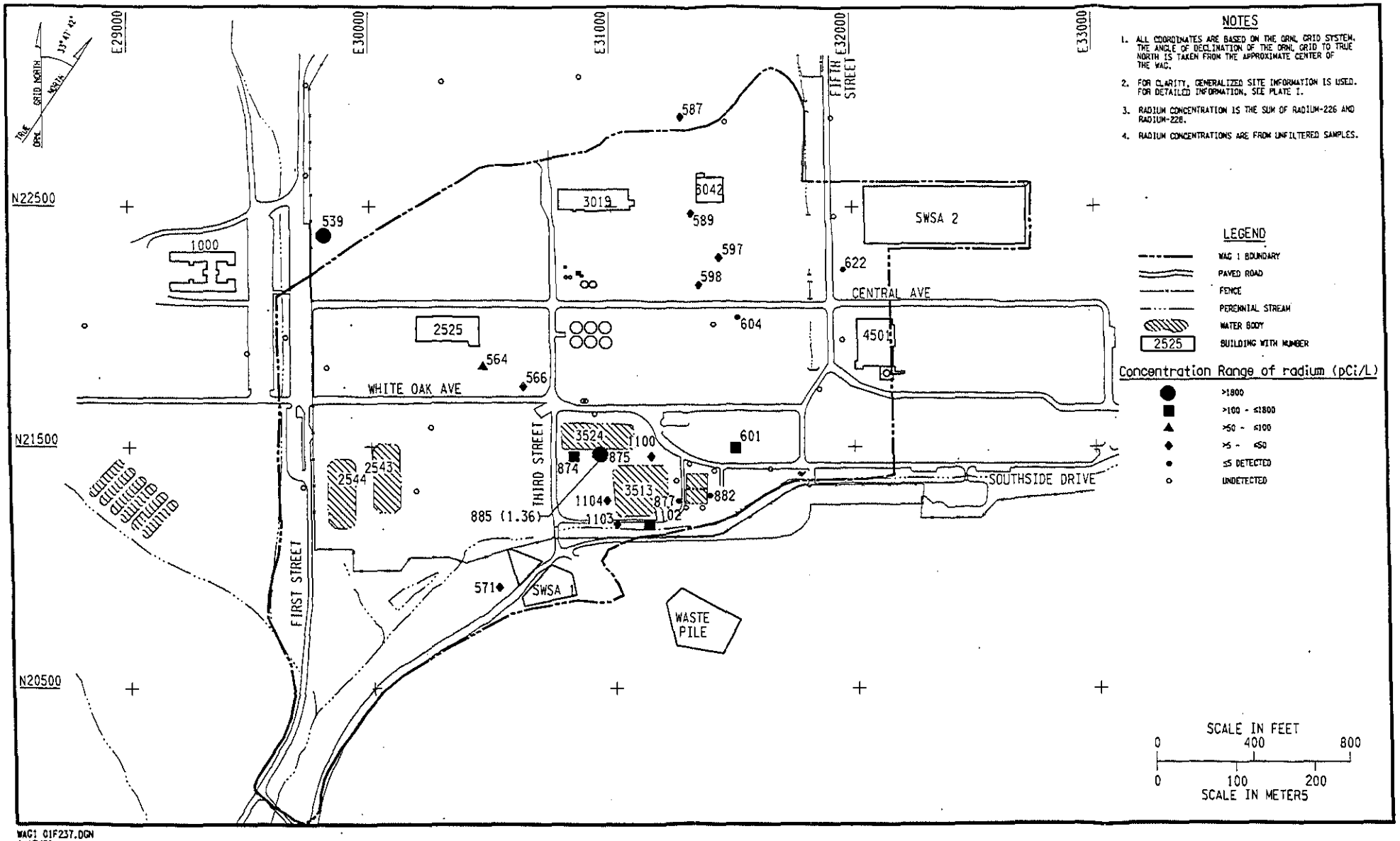
WAG1 01F197.DGN
9/24/92

Fig. 4.3.11. Gross Beta: maximum activity in wells and piezometers sampled during low base flow conditions.



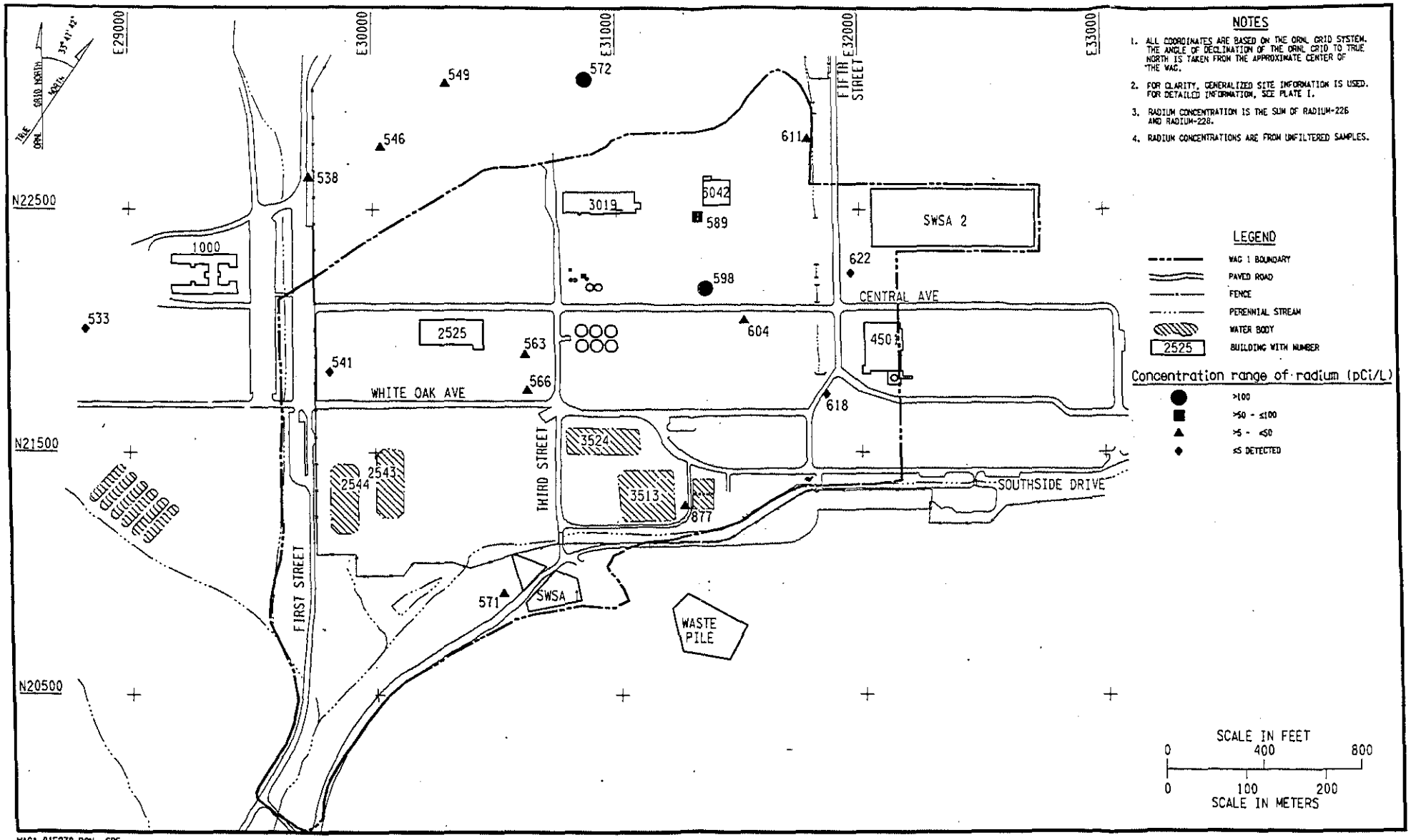
WAG1 01F198.DGN
9/24/92

Fig. 4.3.12. Gross Beta: maximum activity in wells and piezometers sampled during high base flow conditions.



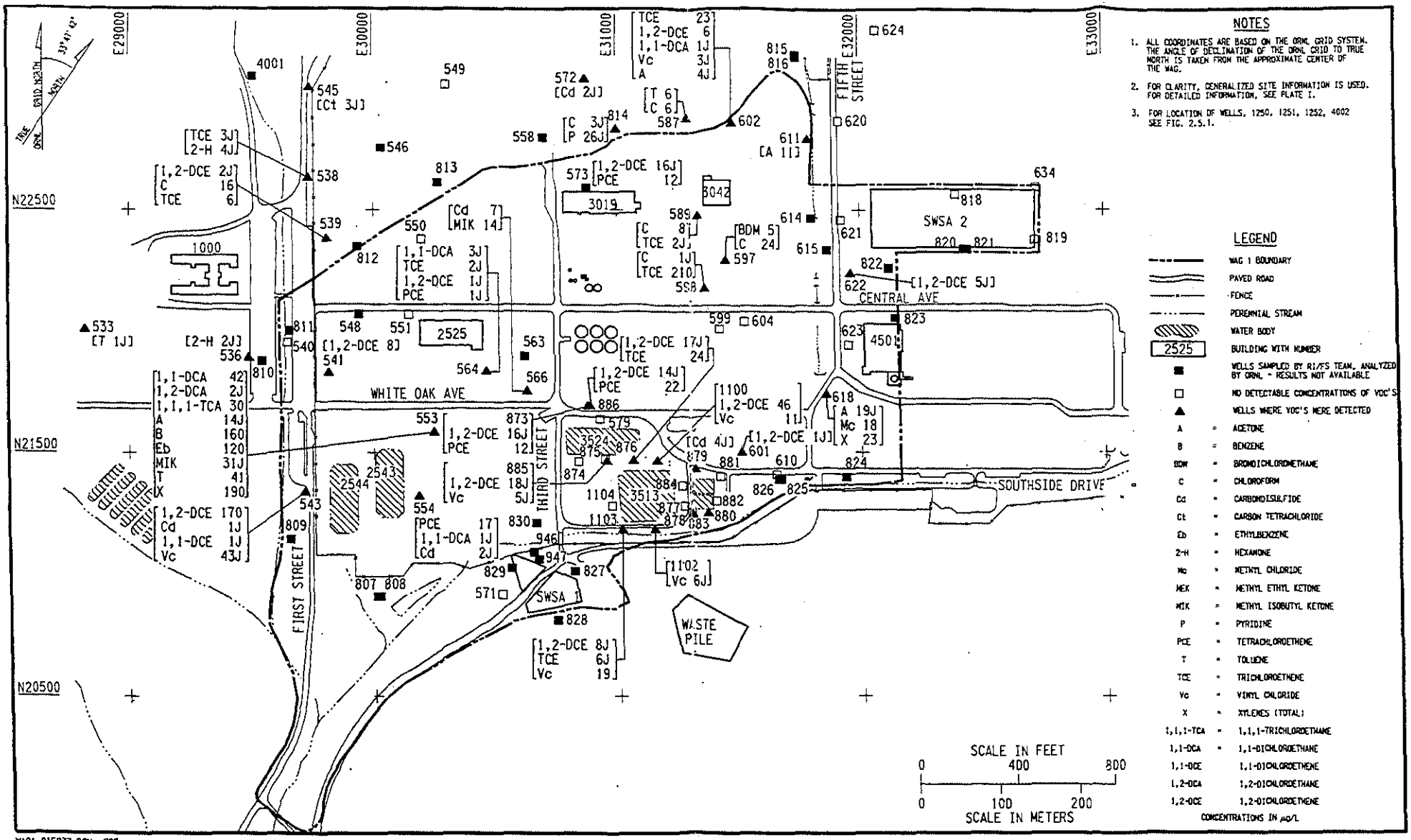
WAC1 01F237.DGN
9/17/92

Fig. 4.3.13 Radium: maximum concentration in wells a piezometers sampled during low base flow conditions.



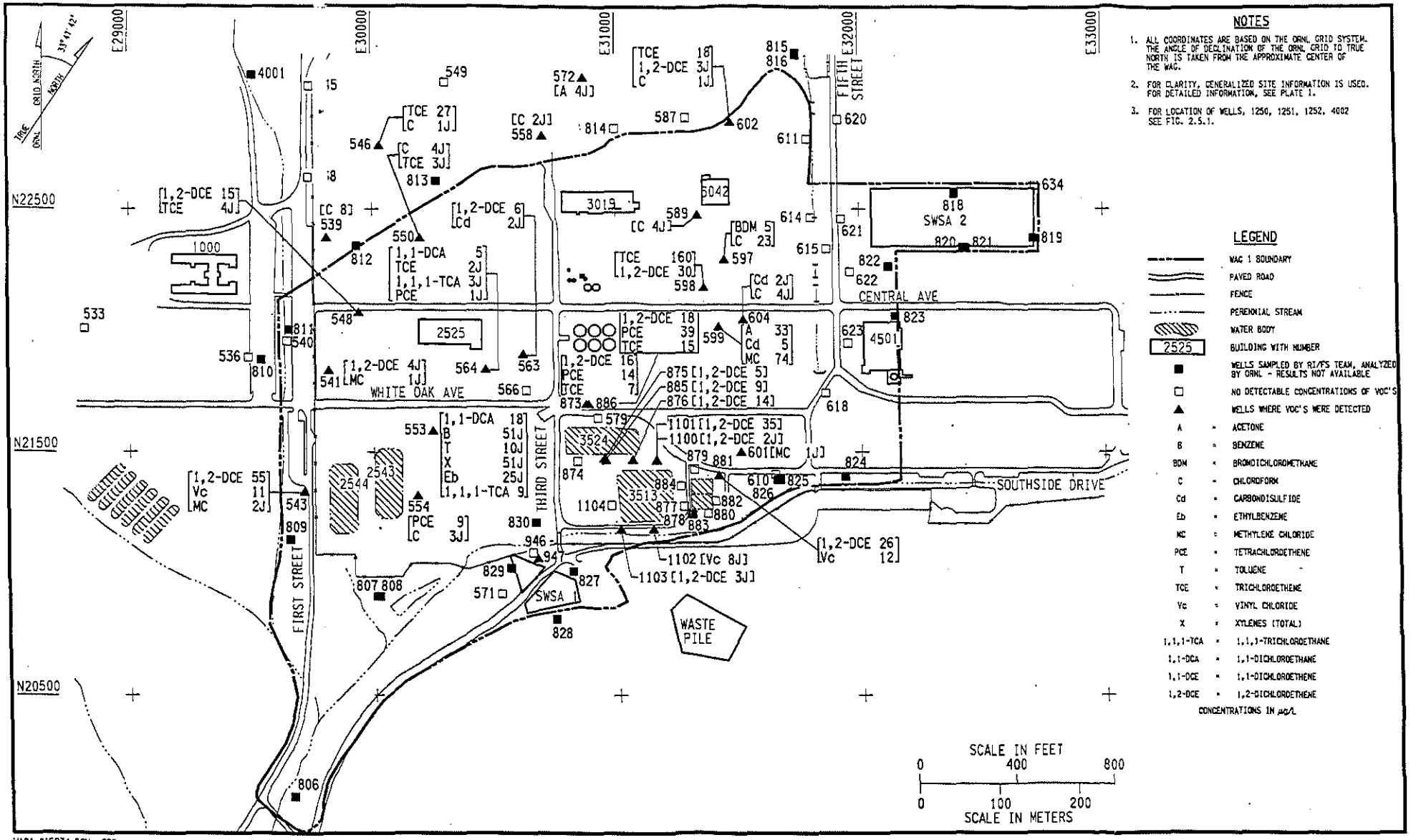
WAG1 01F238.DGN SRF, 9/17/92

Fig. 4.3.14. Radium: maximum concentration in wells a piezometers sampled during high base flow conditions.



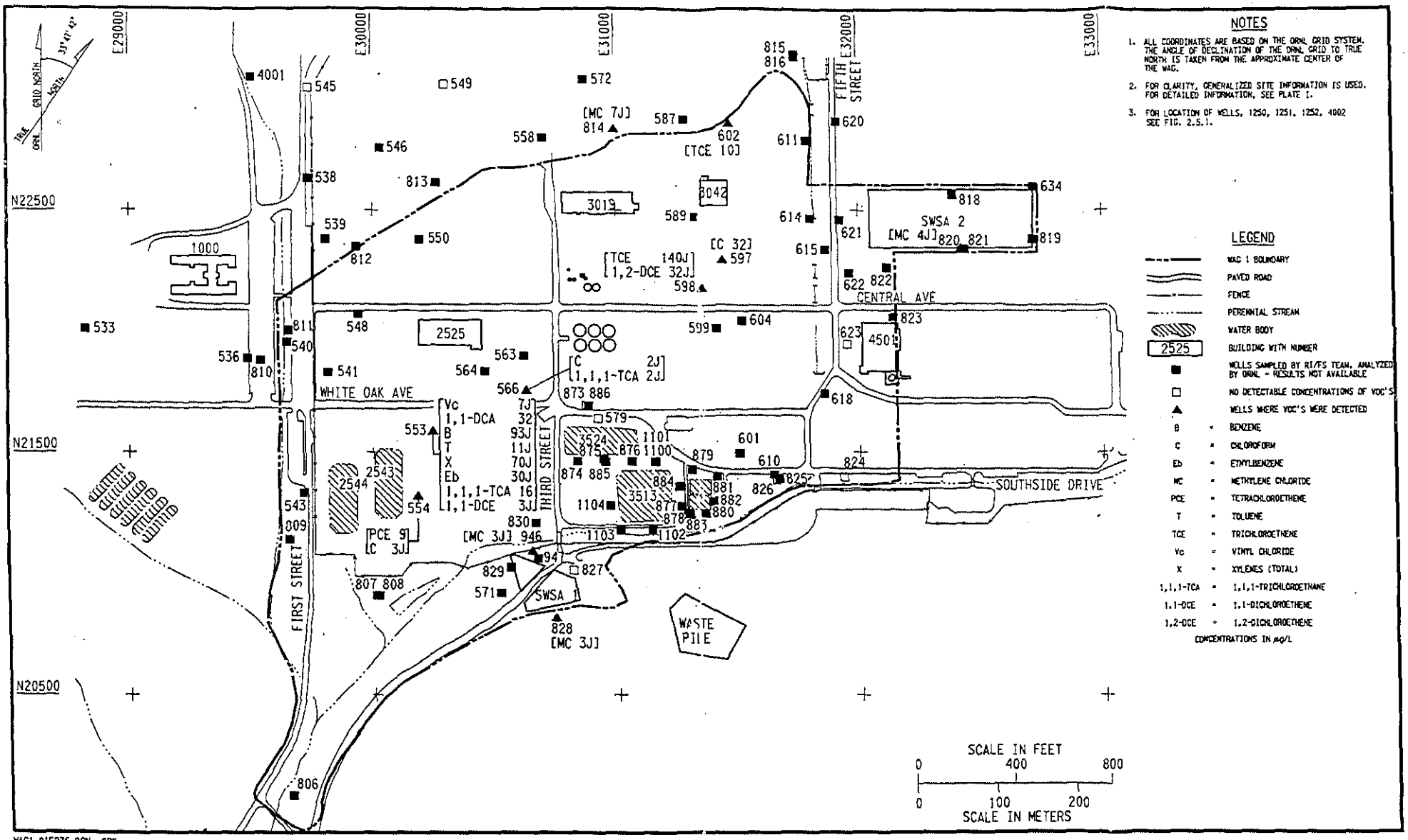
WAG1 01F233.DGN SRF, 9/22/92

Fig. 4.3.15. Volatile organic compounds detected in groundwater during low base flow conditions.



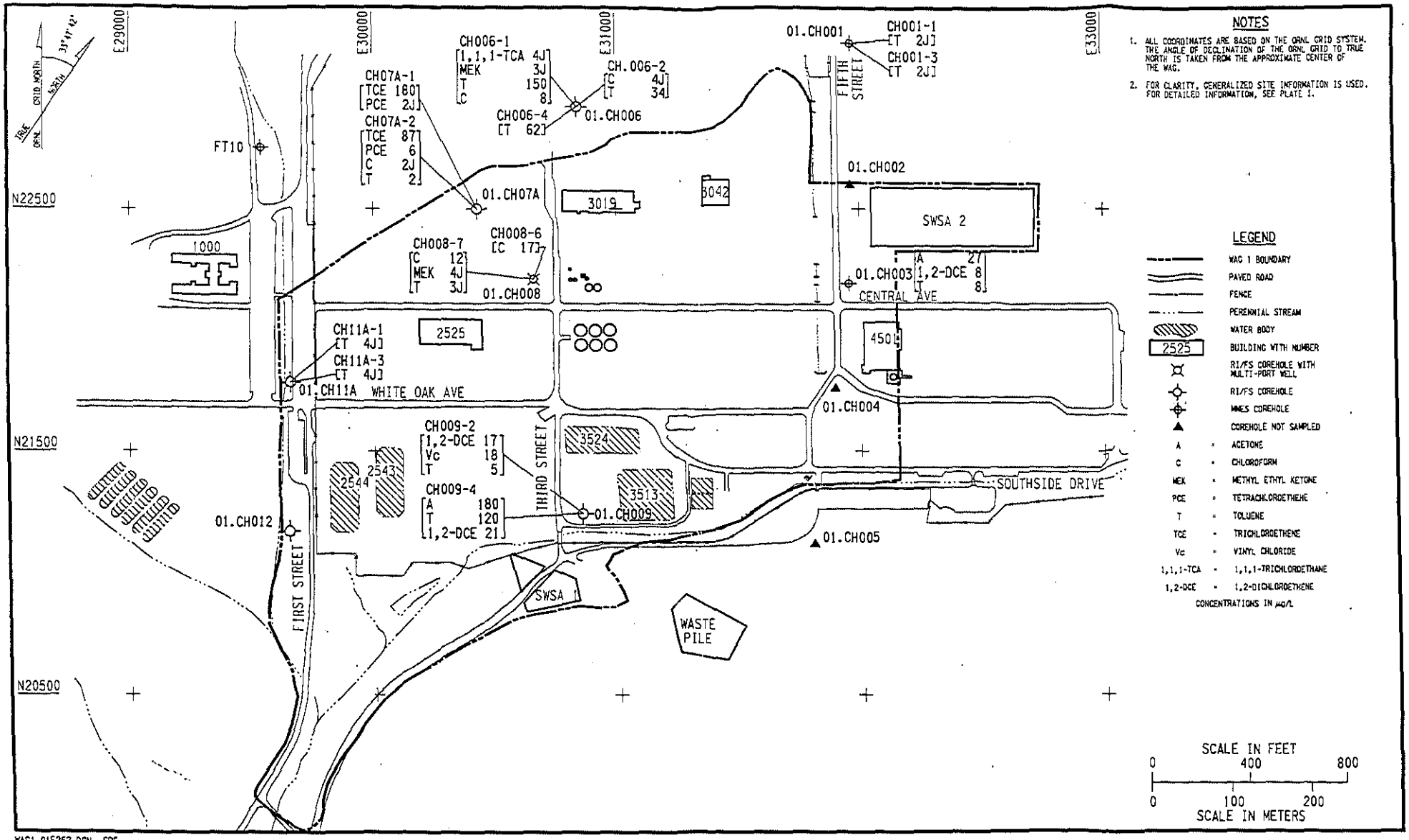
WAG1 01F234.DGN SRF, 6/22/92

Fig. 4.3.16. Volatile organic compounds detected in groundwater during high base flow conditions.



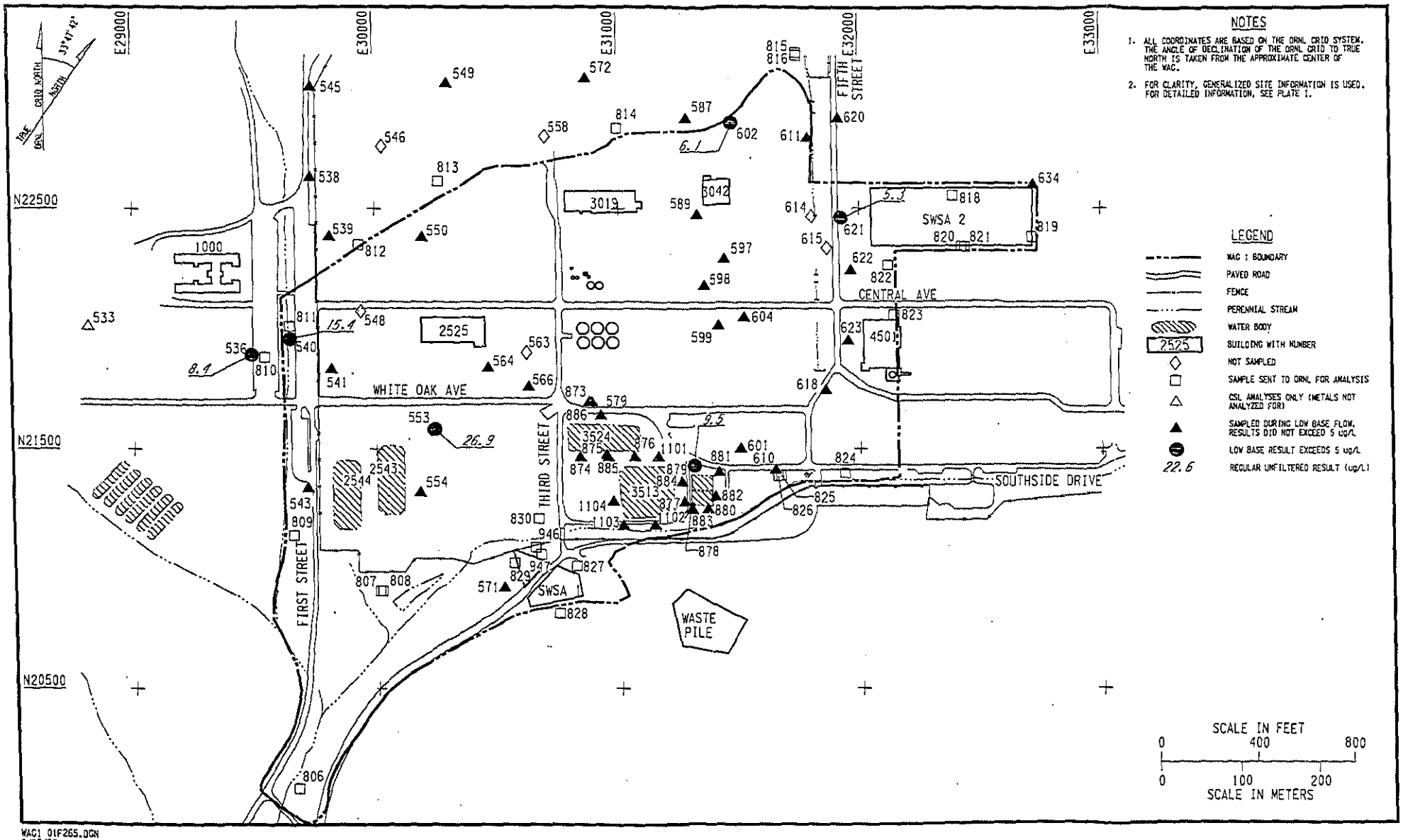
WAG1 01F235.DGN SRF, 9/22/92

Fig. 4.3.17. Volatile organic compounds detected in groundwater during a storm event, high base flow conditions.



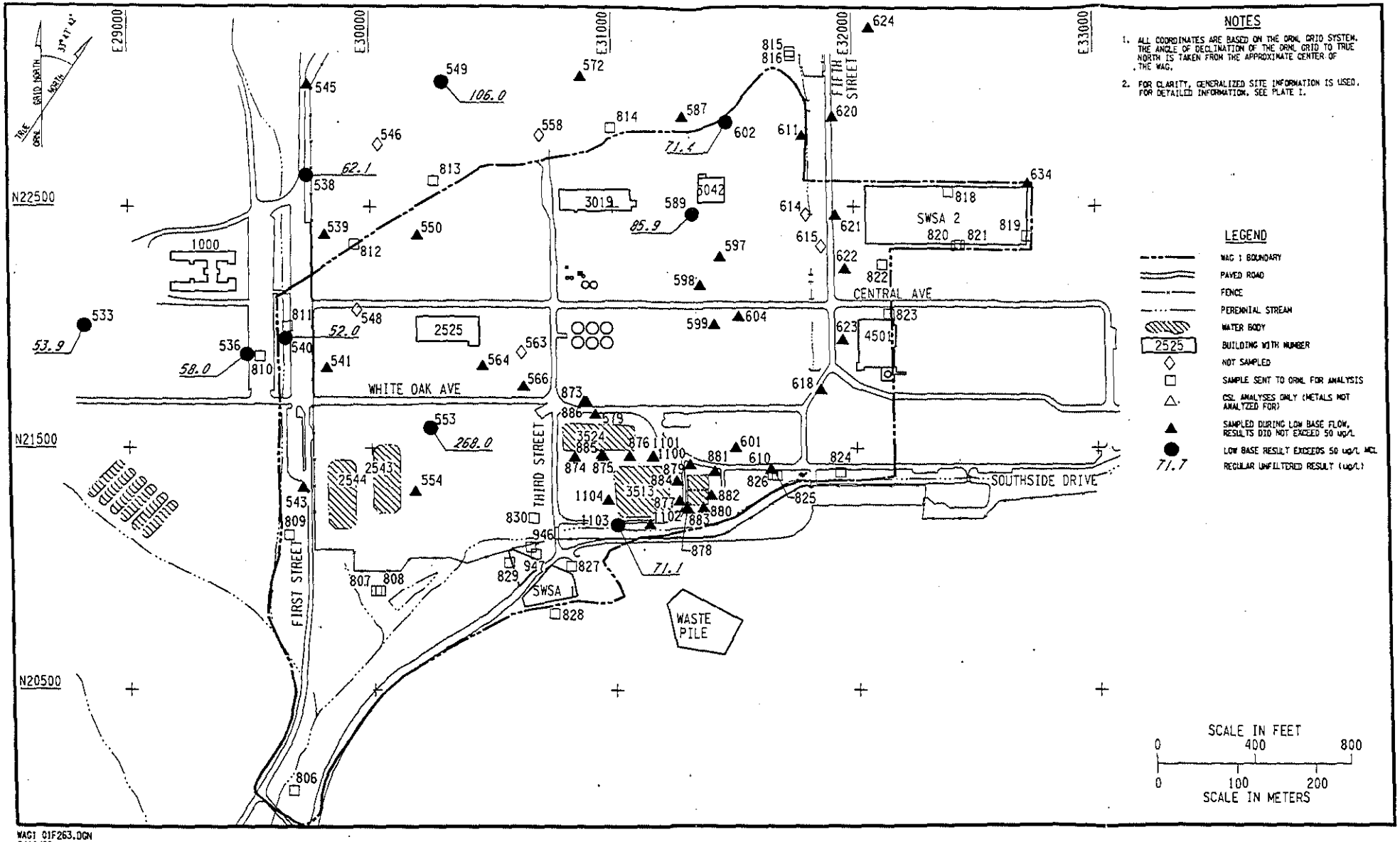
WAG1 01F262.DGN SRF, 6/19/92

Fig. 4.3.18. Volatile organic compounds detected in groundwater from corehole locations.



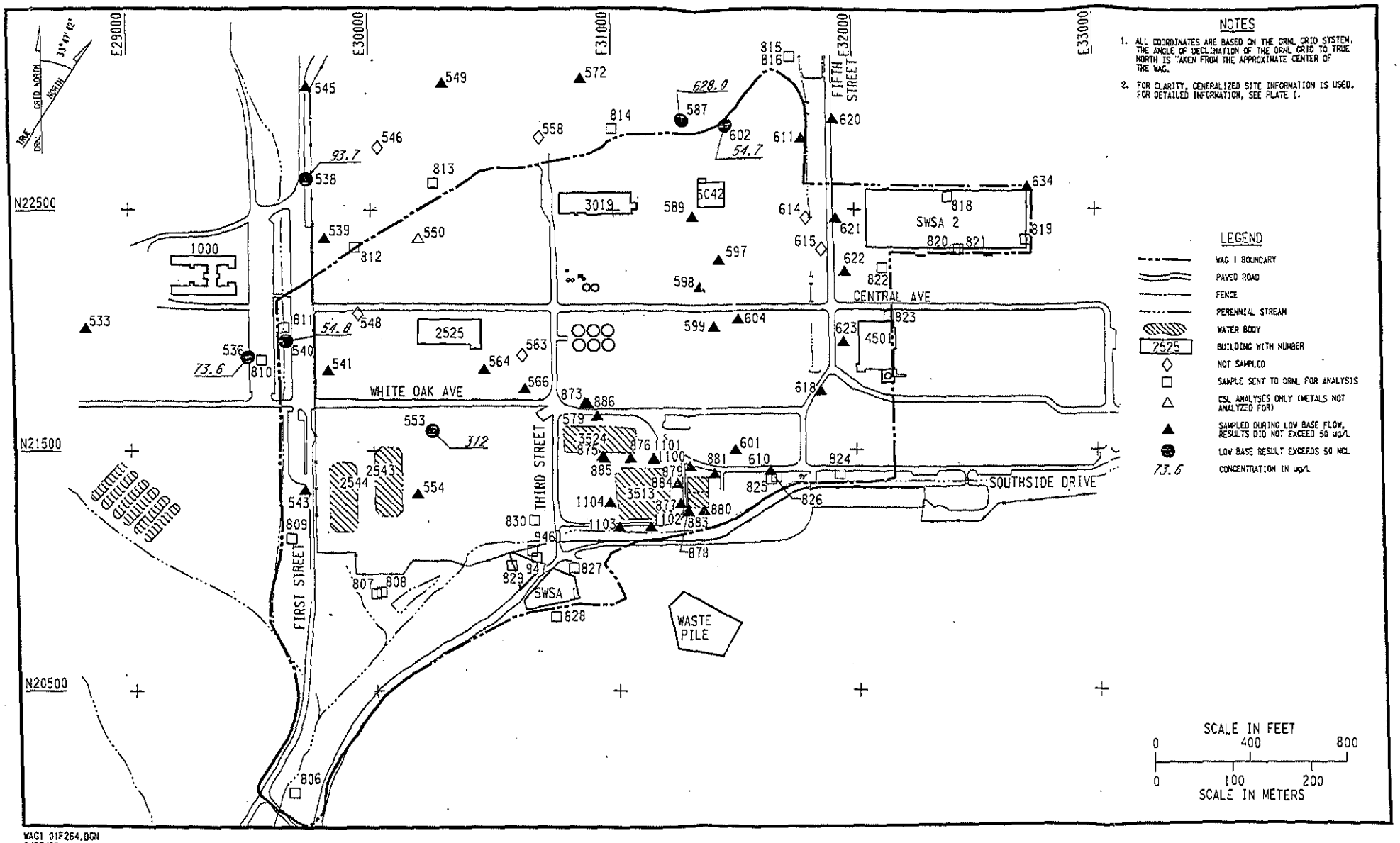
WAC1 01F265.DGN
9/25/92

Fig. 4.3.19. Cadmium detected in unfiltered groundwater samples exceeding 5 ug/L during low base flow conditions.



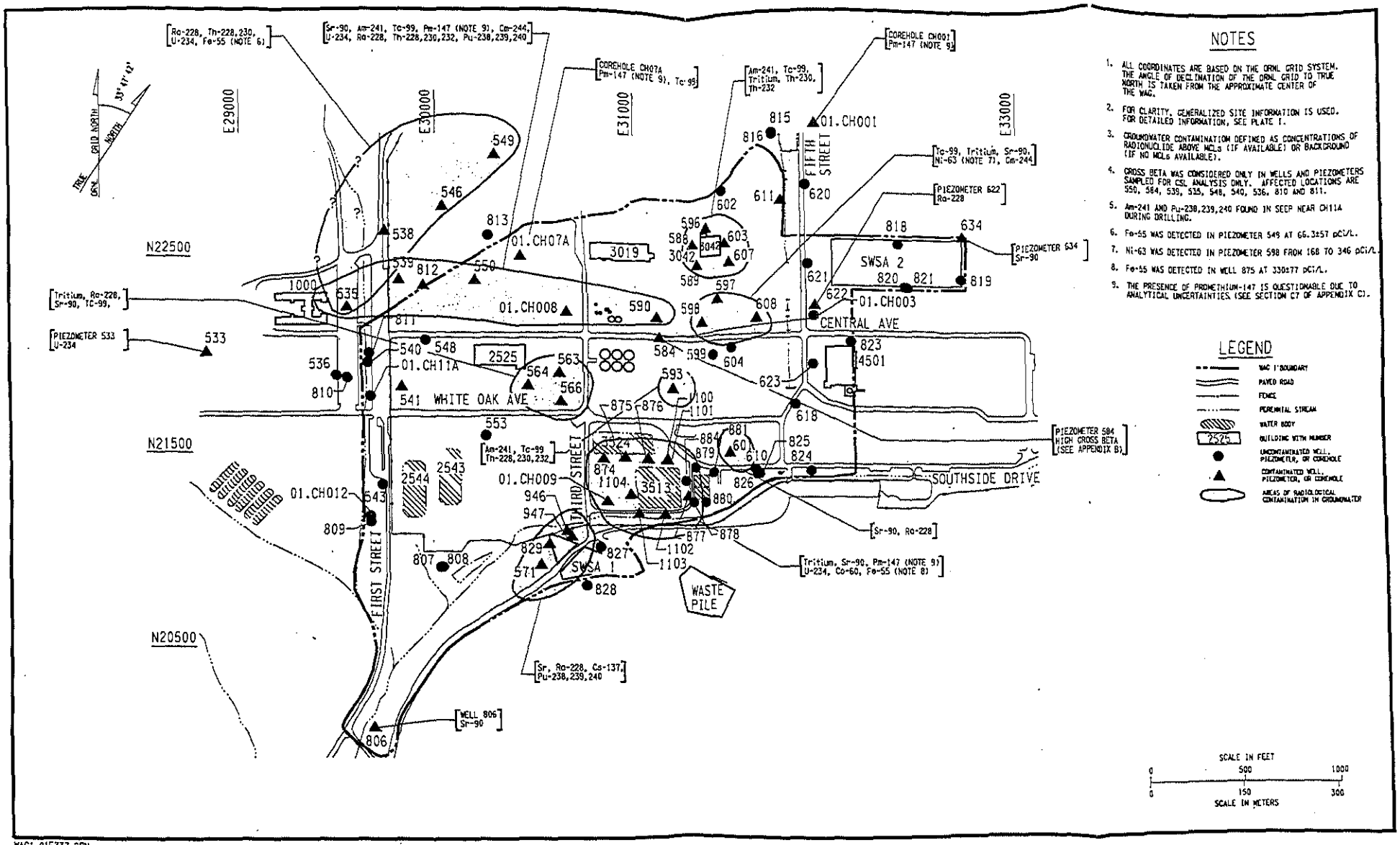
WAG1 01F263.DGN
9/16/92

Fig. 4.3.20. Chromium detected in unfiltered groundwater samples exceeding 50 ug/L during low base flow conditions.



WAG1 01F264.DGN
9/25/92

Fig. 4.3.21. Lead detected in unfiltered groundwater samples exceeding 50 ug/L during low base flow conditions.



WAG1 01F337.DGN
9/25/92

Fig. 4.3.22. Overview of radiological contamination in groundwater.

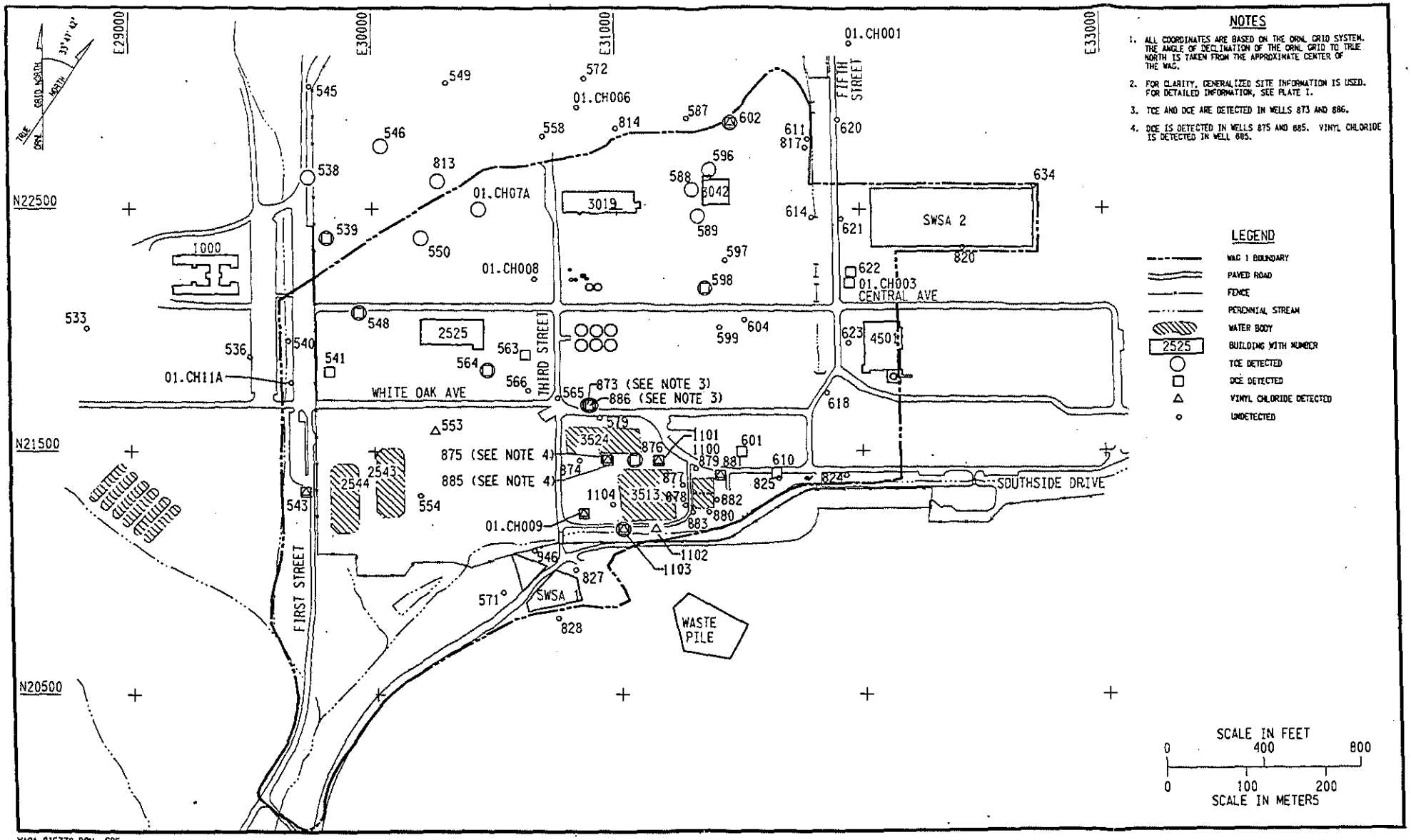
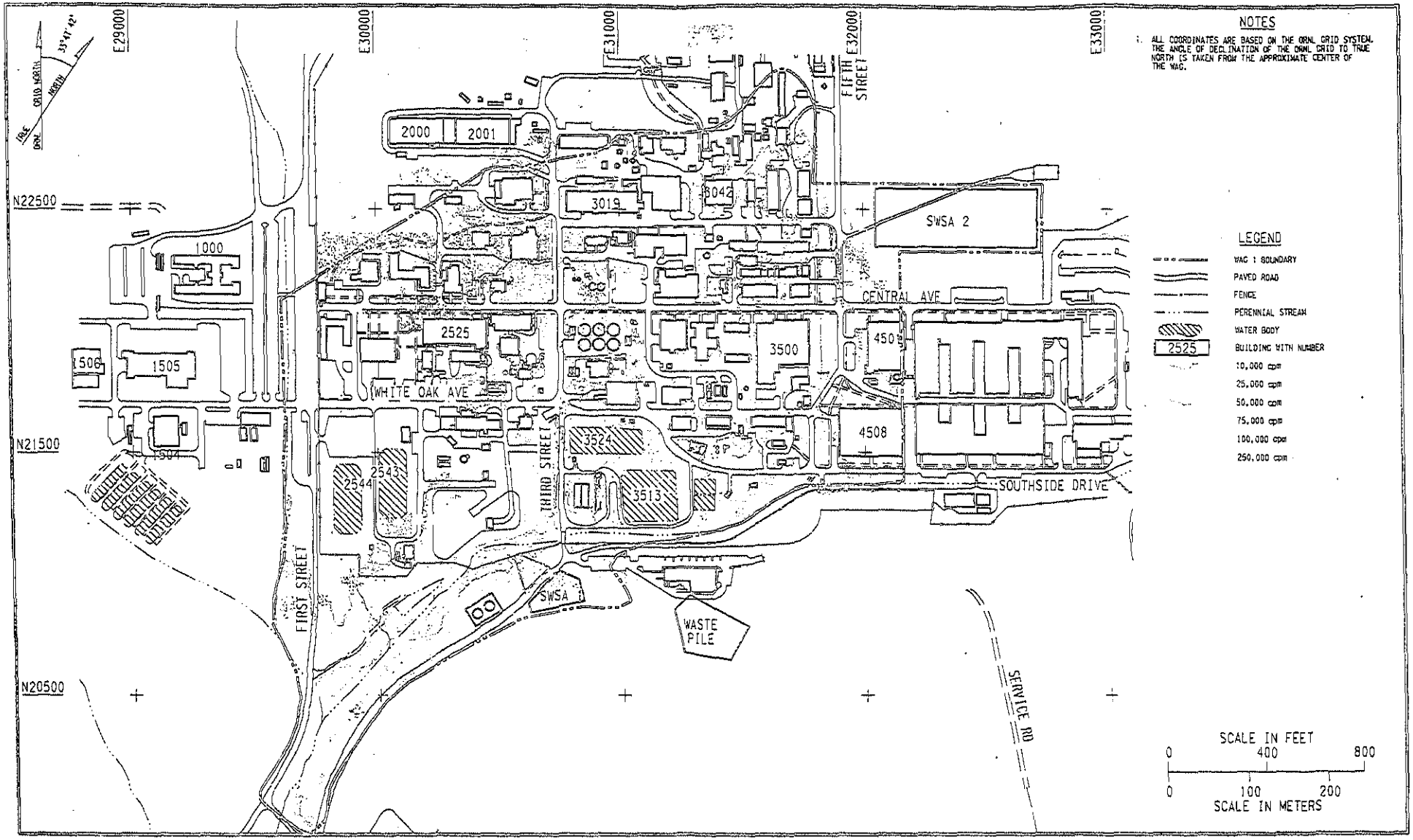


Fig. 4.3.23. Distribution of TCE and degradation produc in groundwater.



WAG1 01F341.DGN SRF, 6/13/92

Fig. 4.4.1. USRADS survey cpm contours.

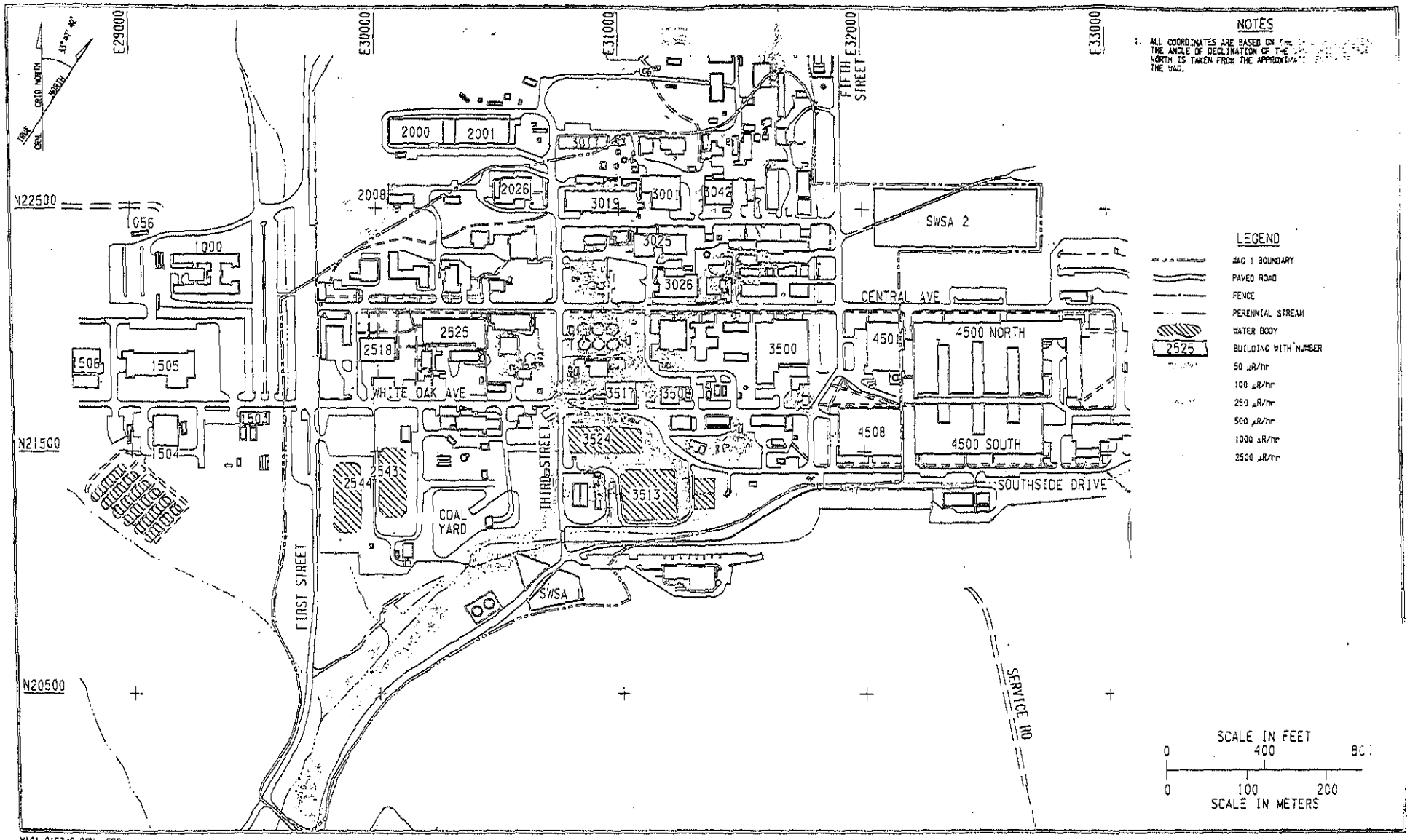
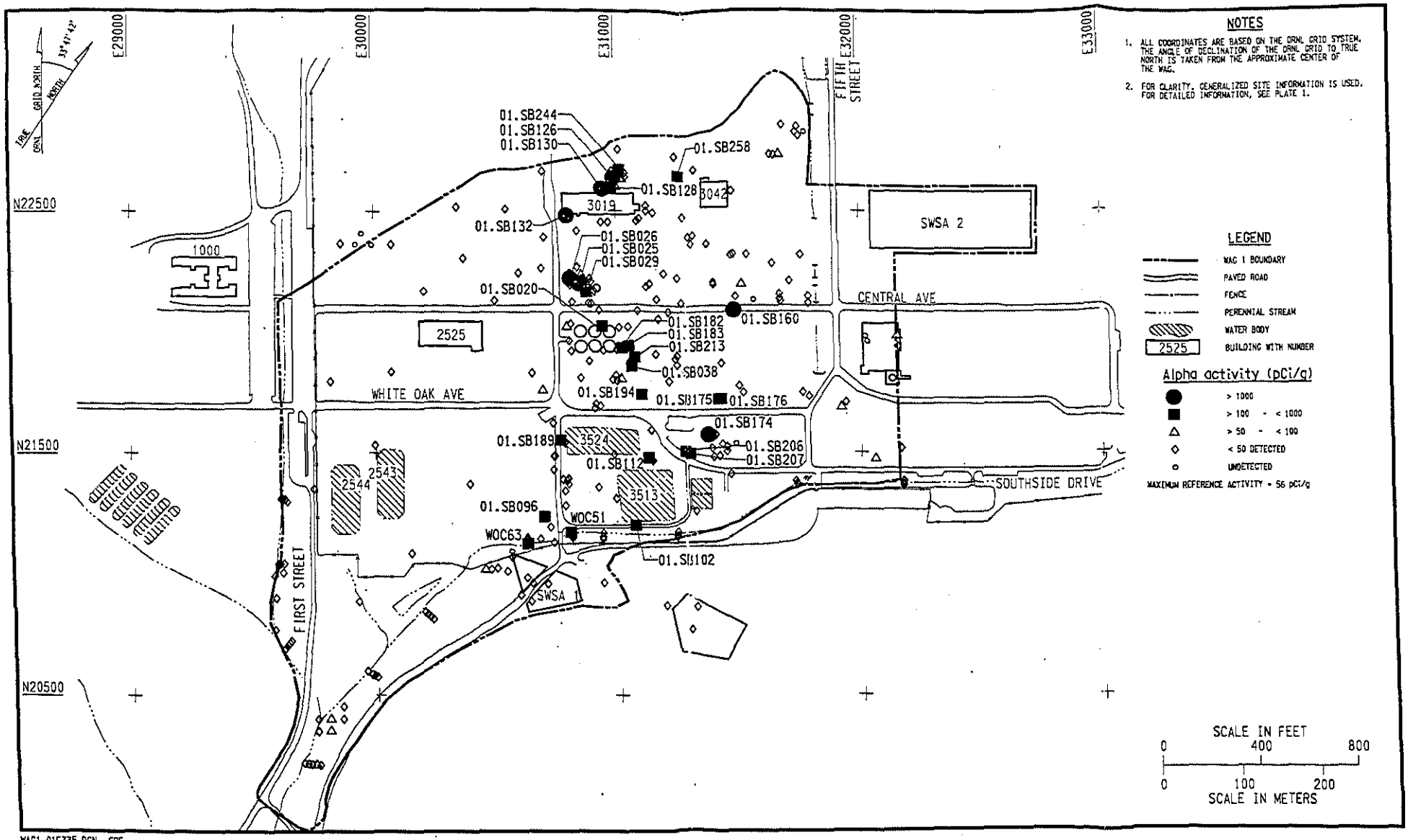


Fig. 4.4.2. USRADS survey µR/h contours.



WAC1 01F335.DGN SRF, 9/21/92

Fig. 4.4.3. Maximum gross alpha activity in soil borings.

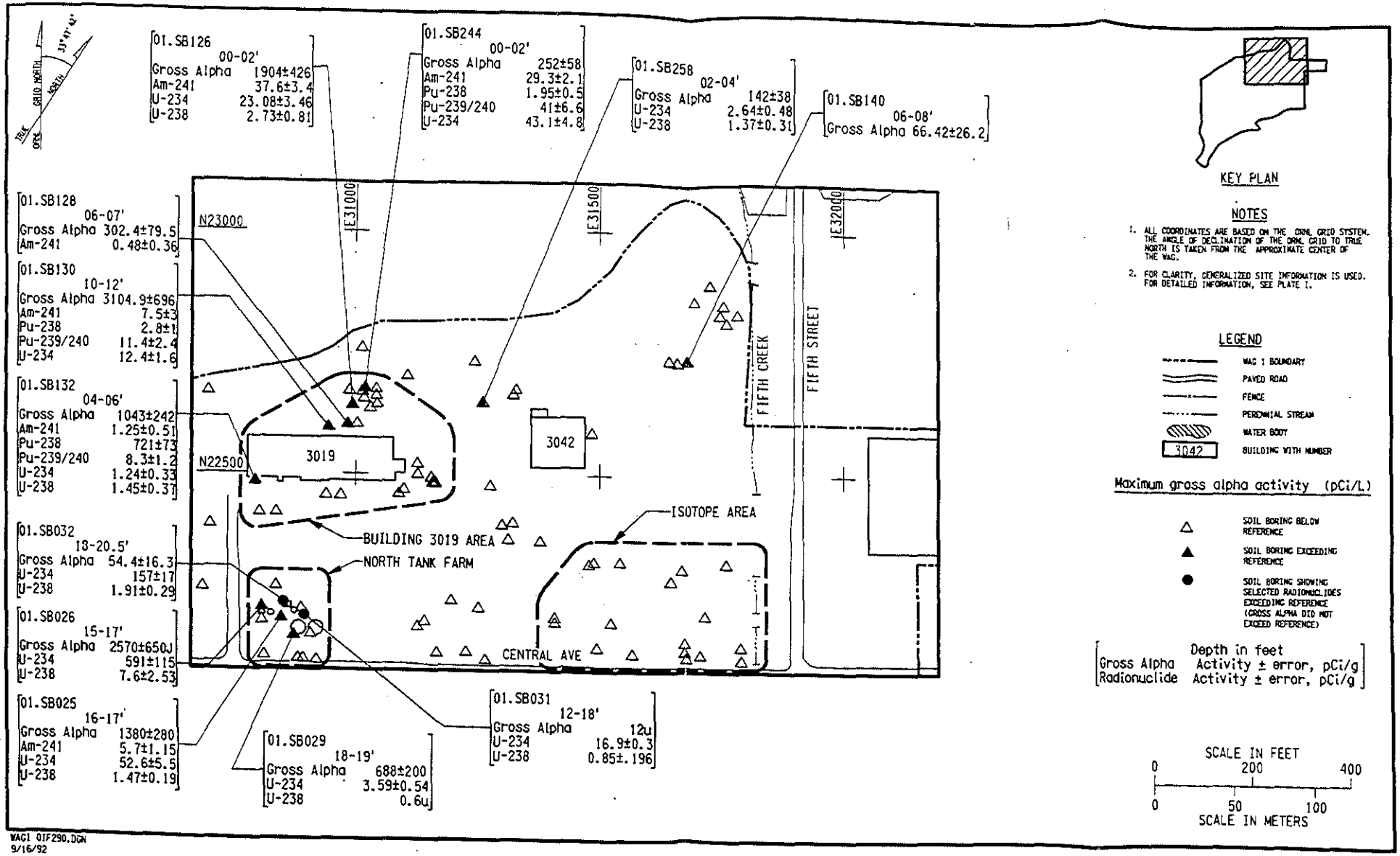


Fig. 4.4.4. Alpha-1. Selected alpha-emitting radionuclides and maximum gross alpha exceeding reference in soil borings.

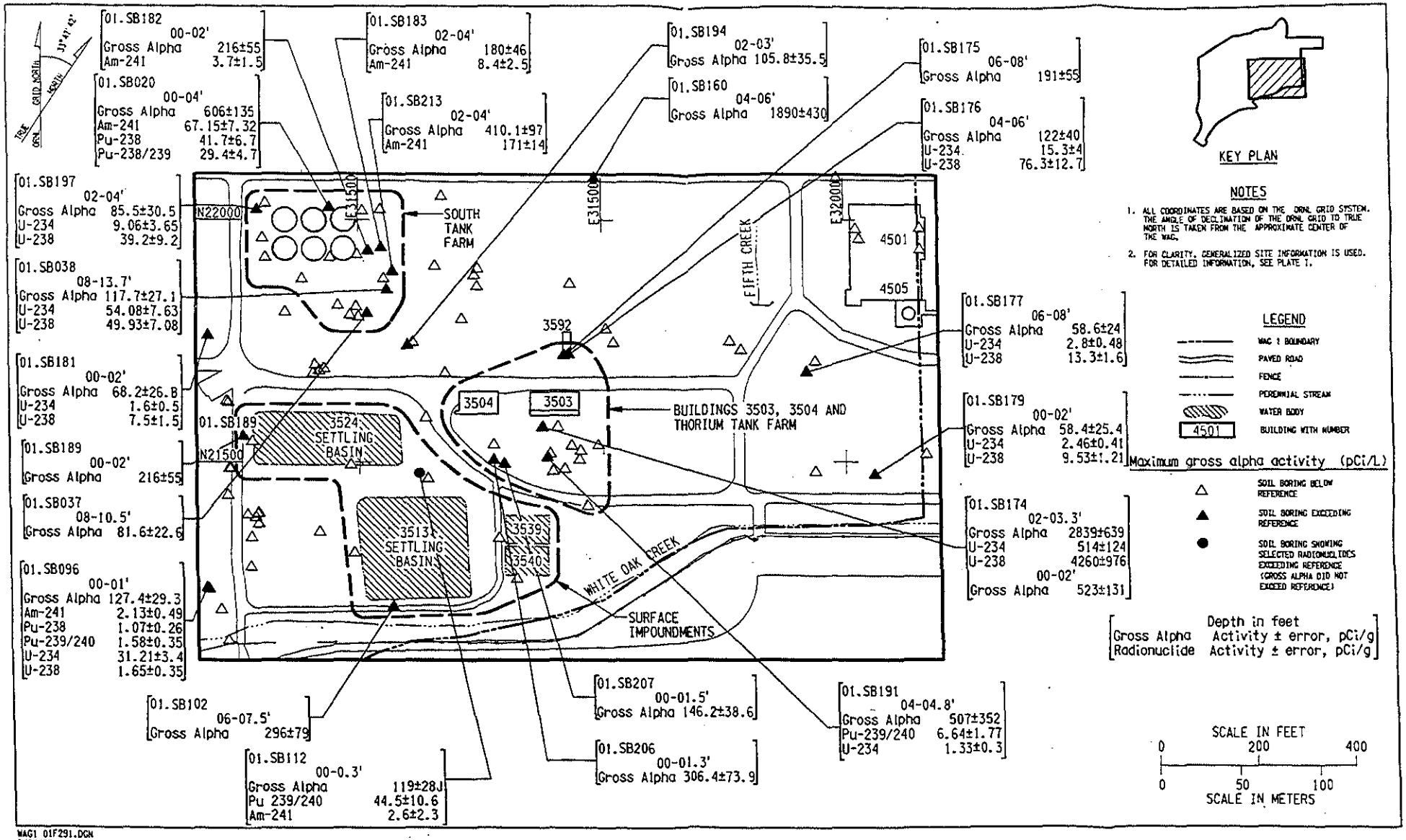
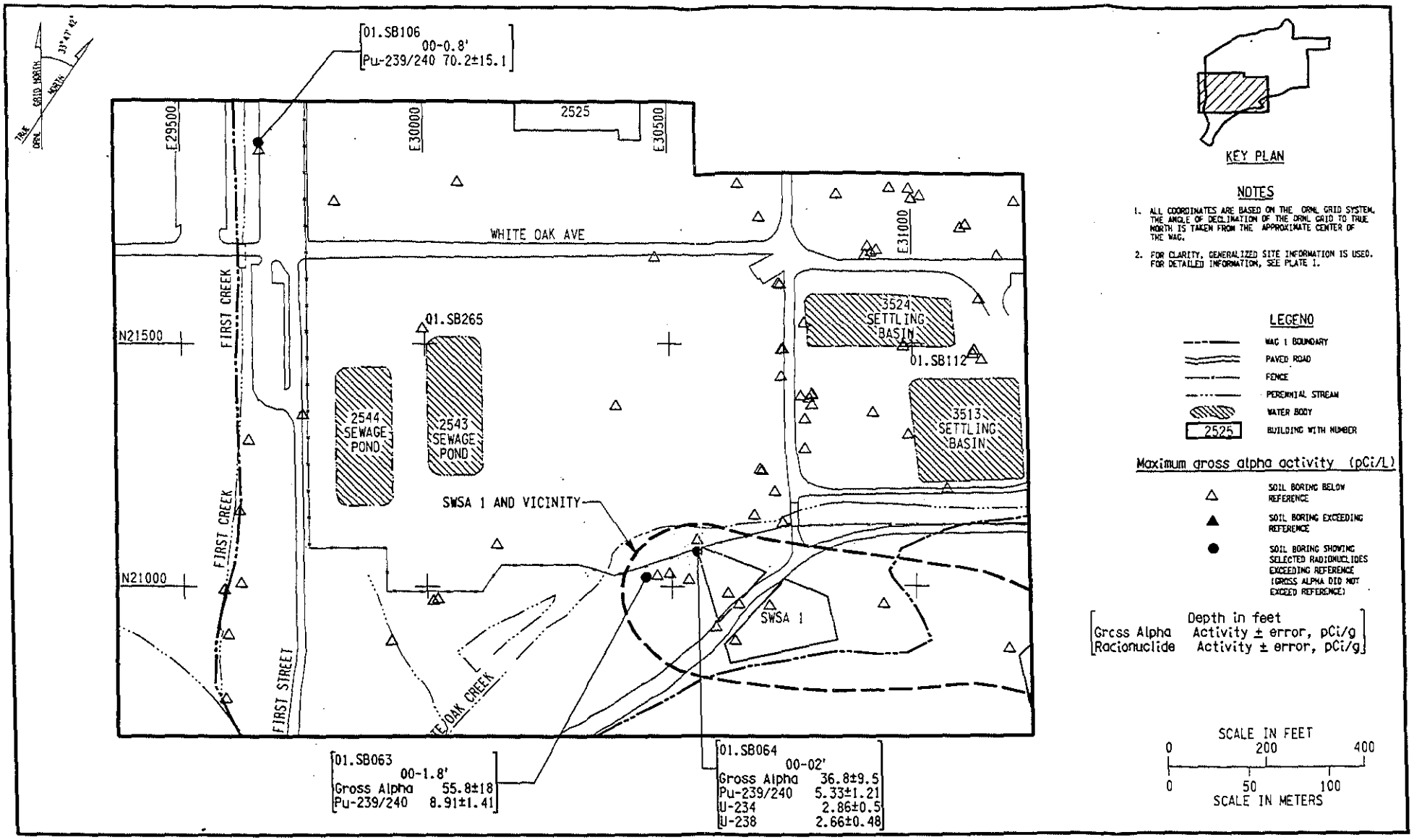
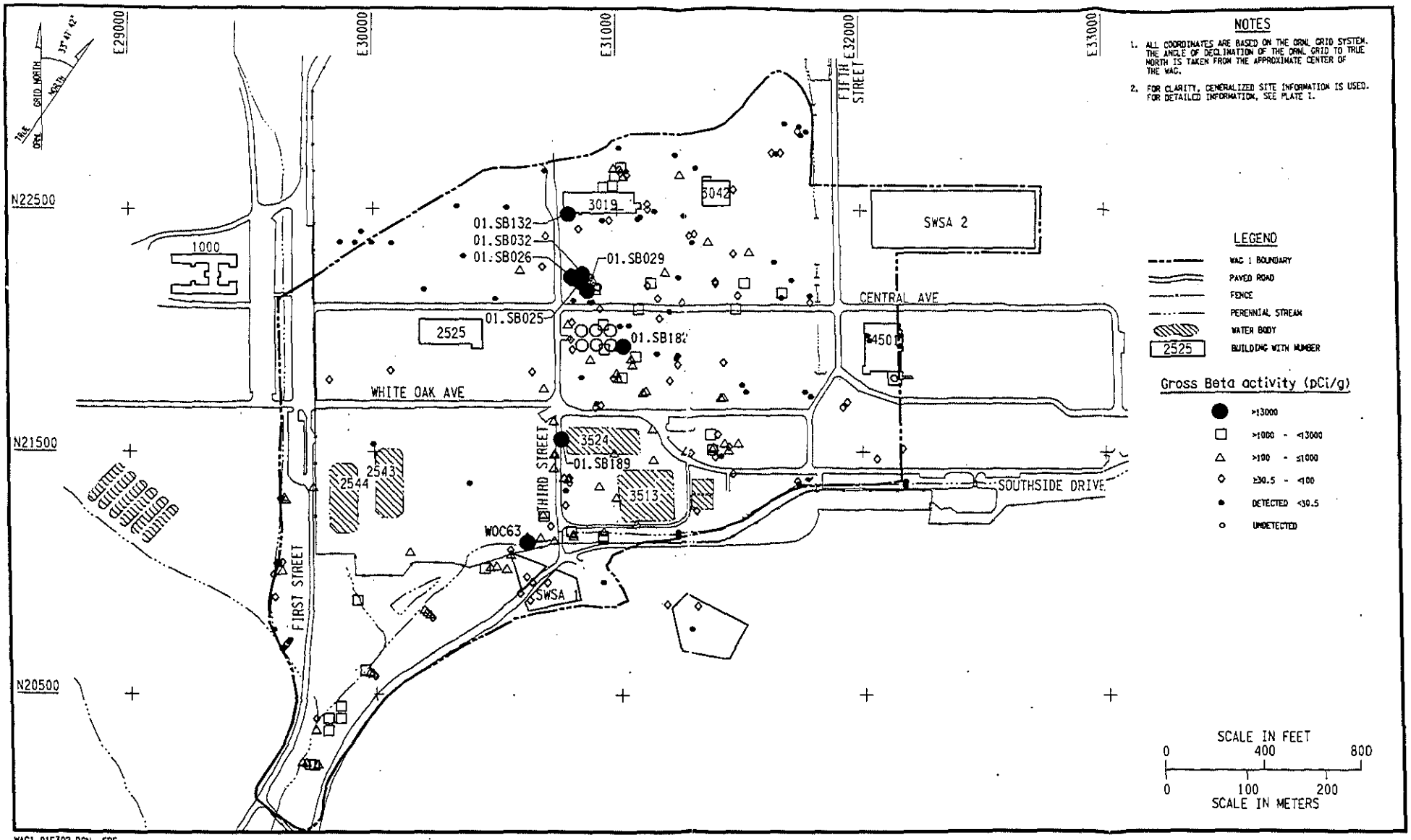


Fig. 4.4.5. Alpha-2. Selected alpha emitting radionuclides and maximum gross alpha activity exceeding reference in soil borings.



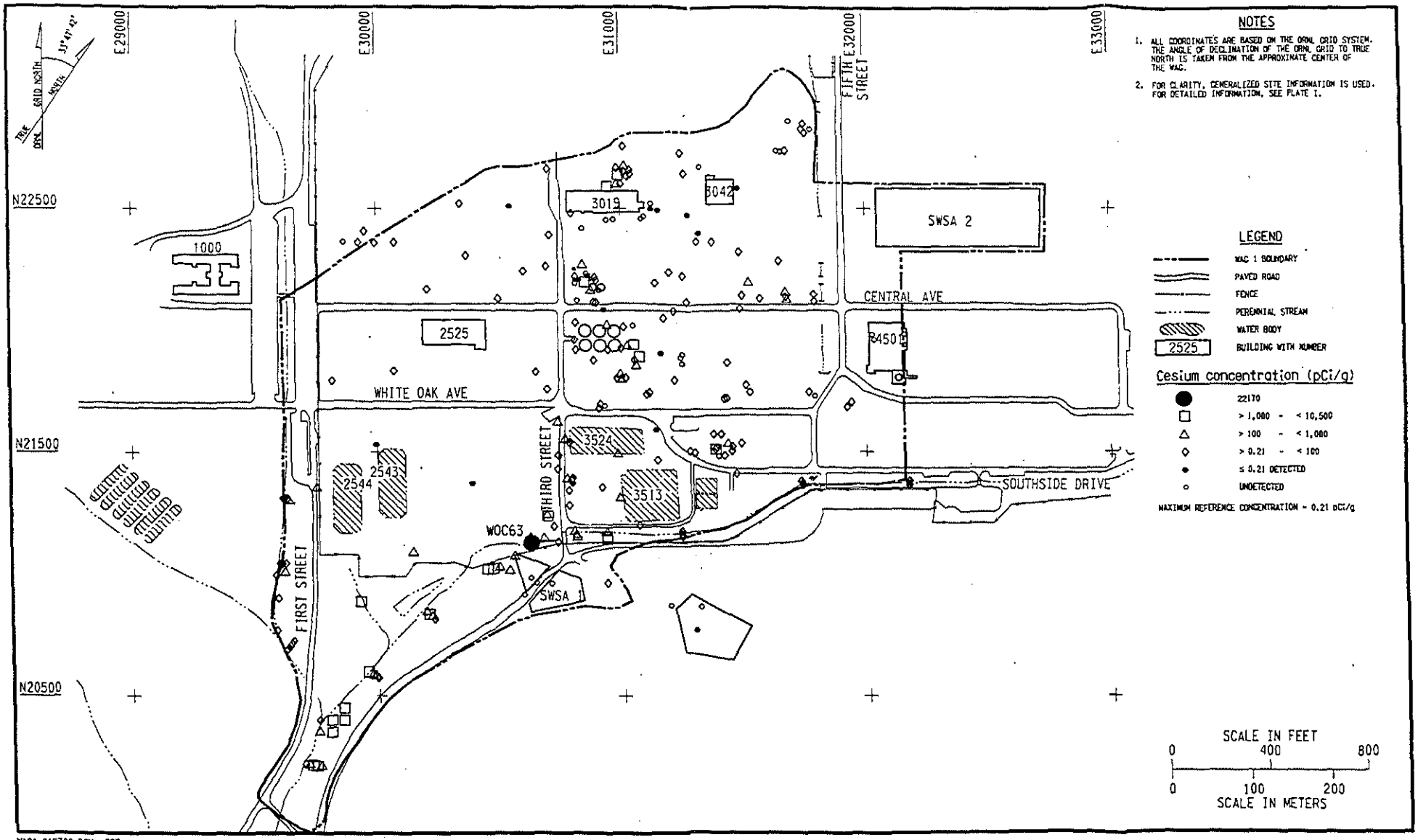
WAG1 01F292.DGN
9/16/92

Fig. 4.4.6. Alpha-3. Selected alpha-emitting radionuclides and maximum gross alpha activity exceeding reference in soil borings.



WAG1 01F302.DGN SRF, 9/16/92

Fig. 4.4.7. Maximum gross beta activity in soil borings.



WAG1 01F300.DGN SRF,
9/22/92

Fig. 4.4.8. Maximum cesium-137 concentrations in soil borings.

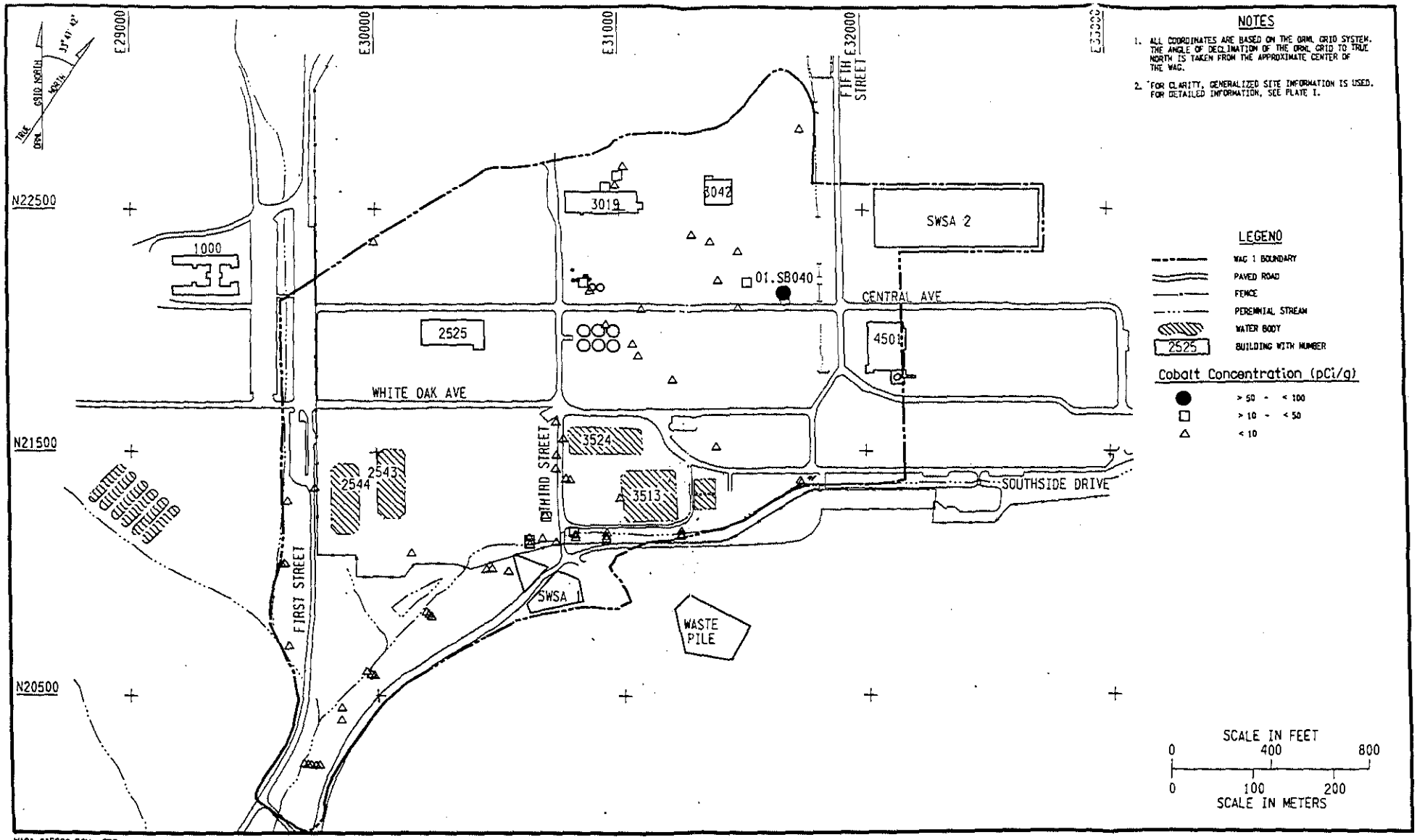


Fig. 4.4.9. Maximum cobalt-60 concentrations in soil borings.

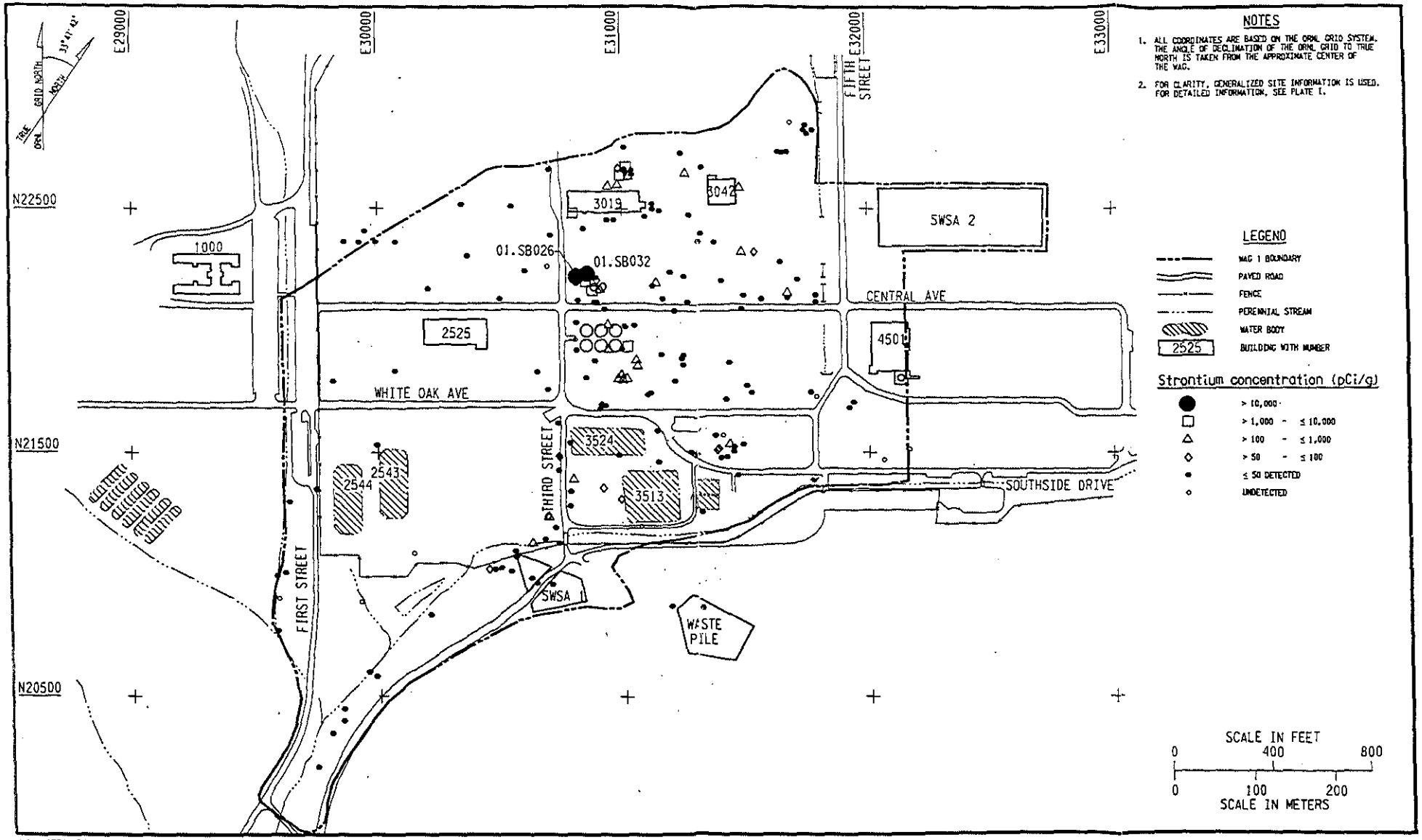
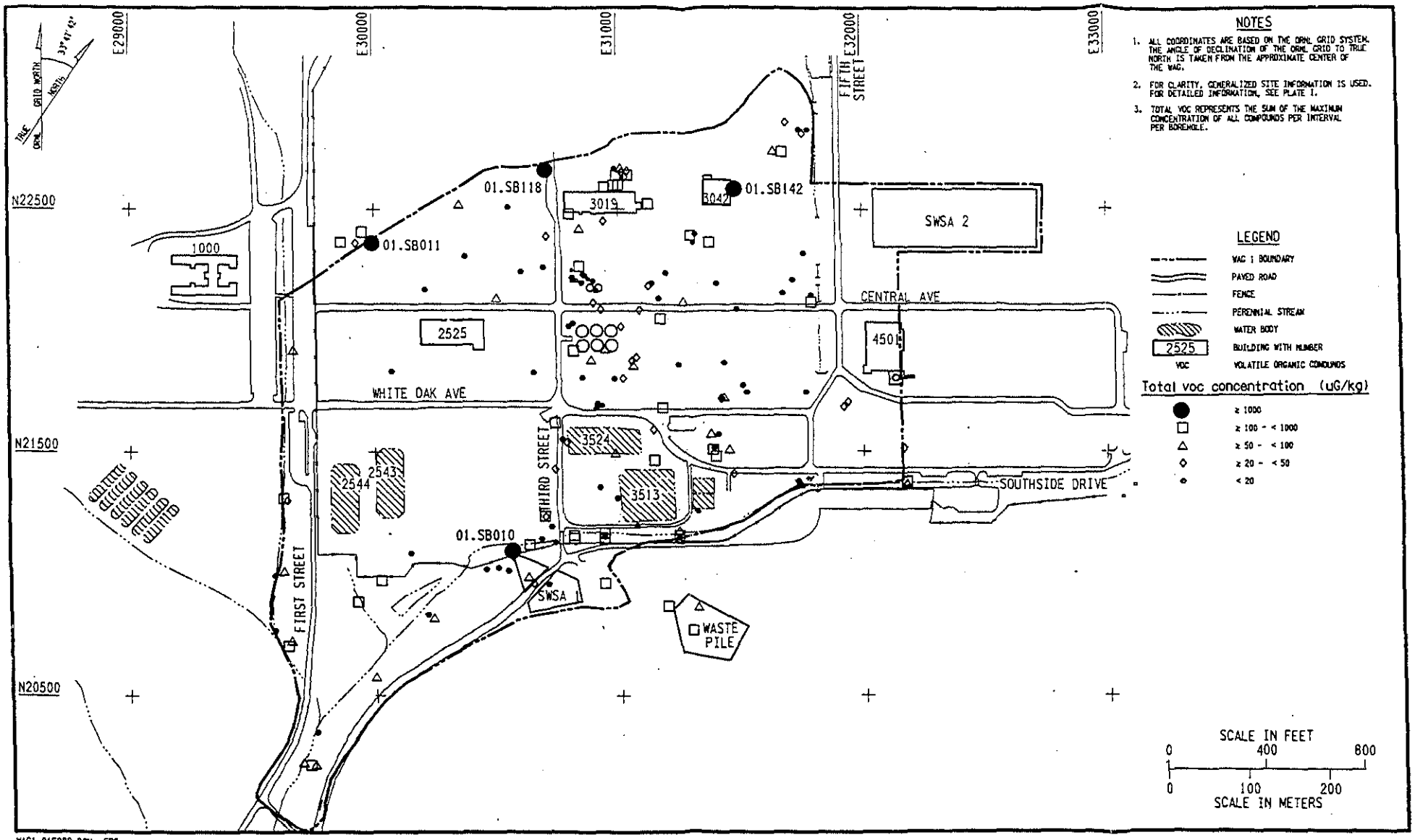
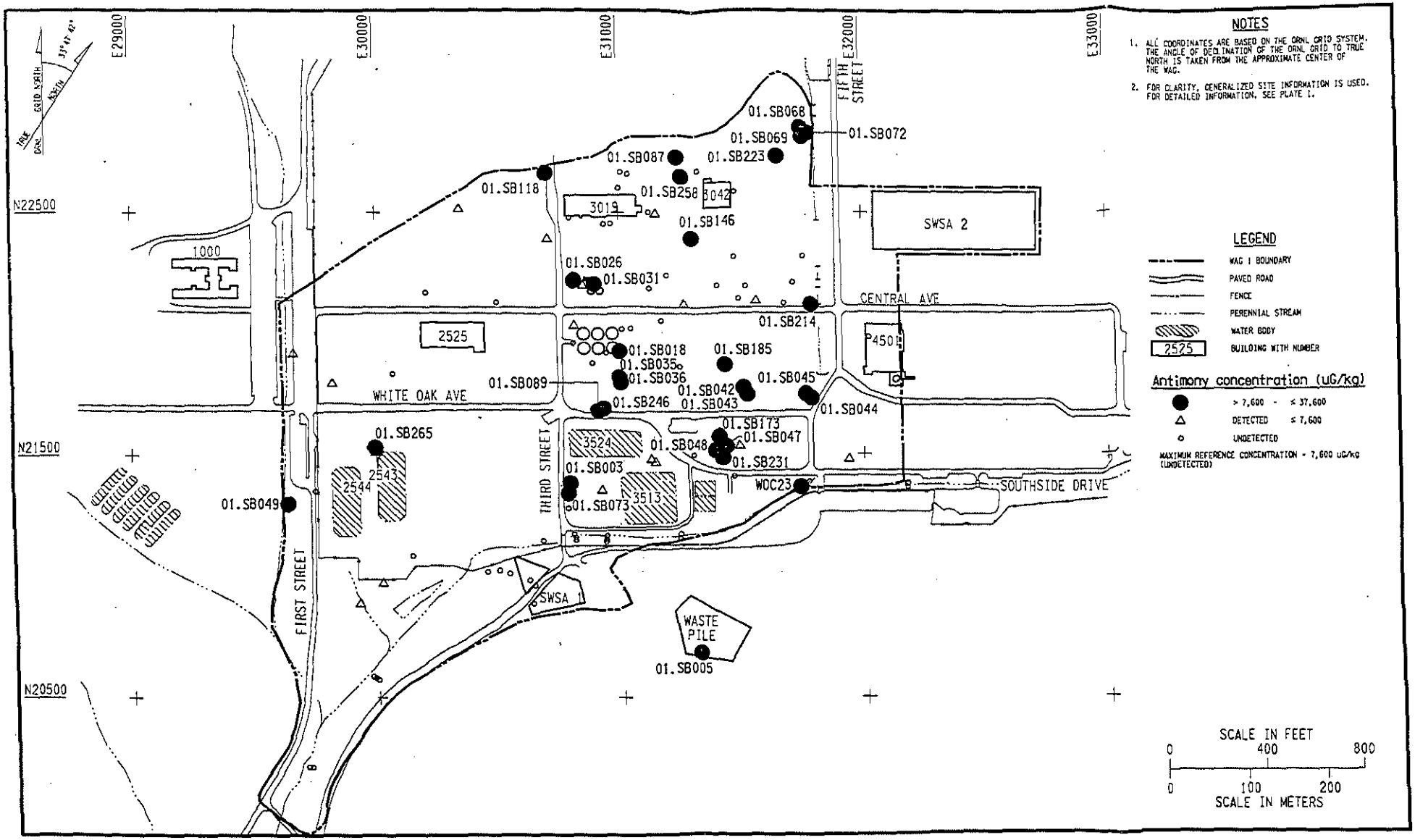


Fig. 4.4.10. Maximum strontium concentrations in soil borings.



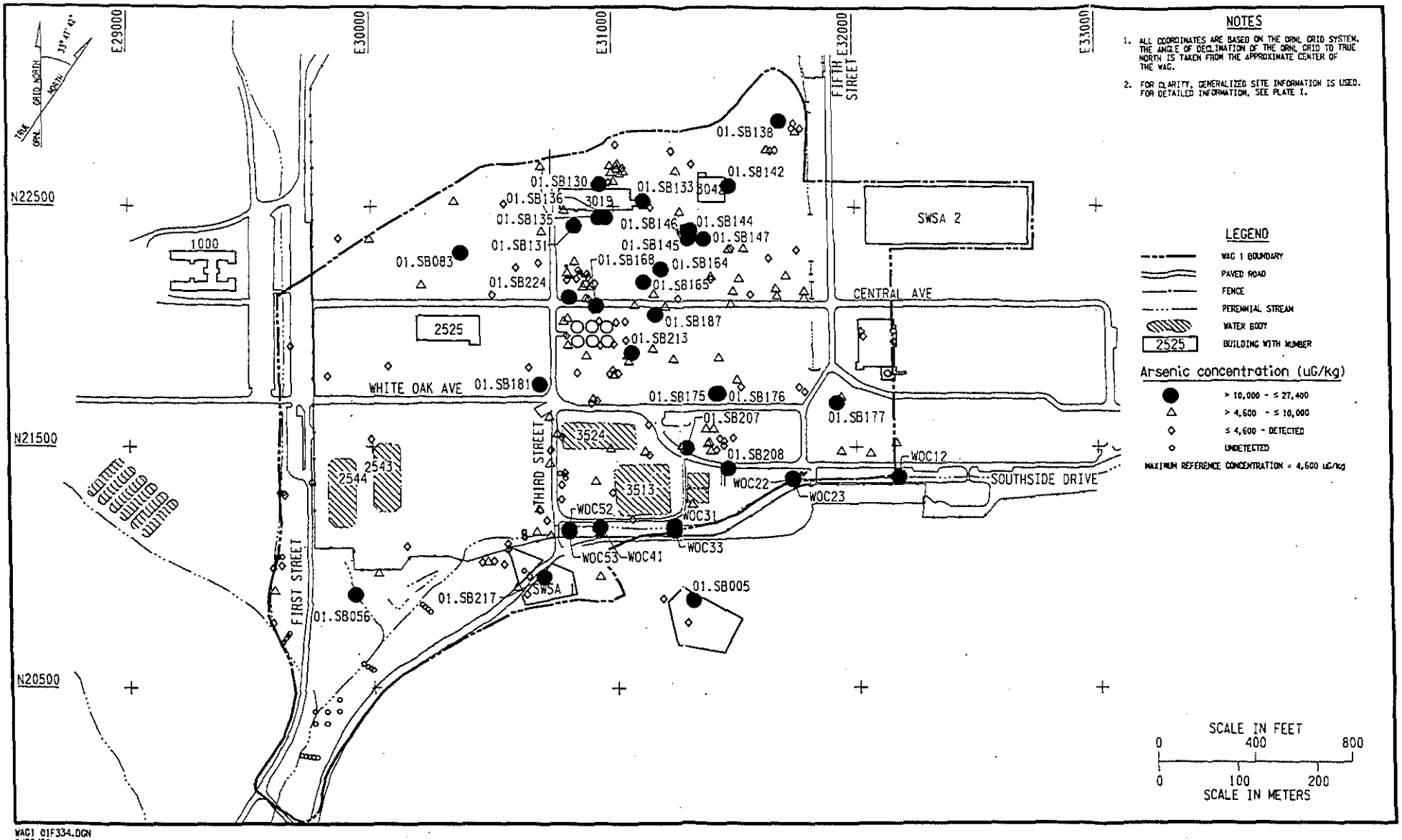
WAG1 01F289.DGN SRF, 6/14/92

Fig. 4.4.11. Total VOCs in soil borings.



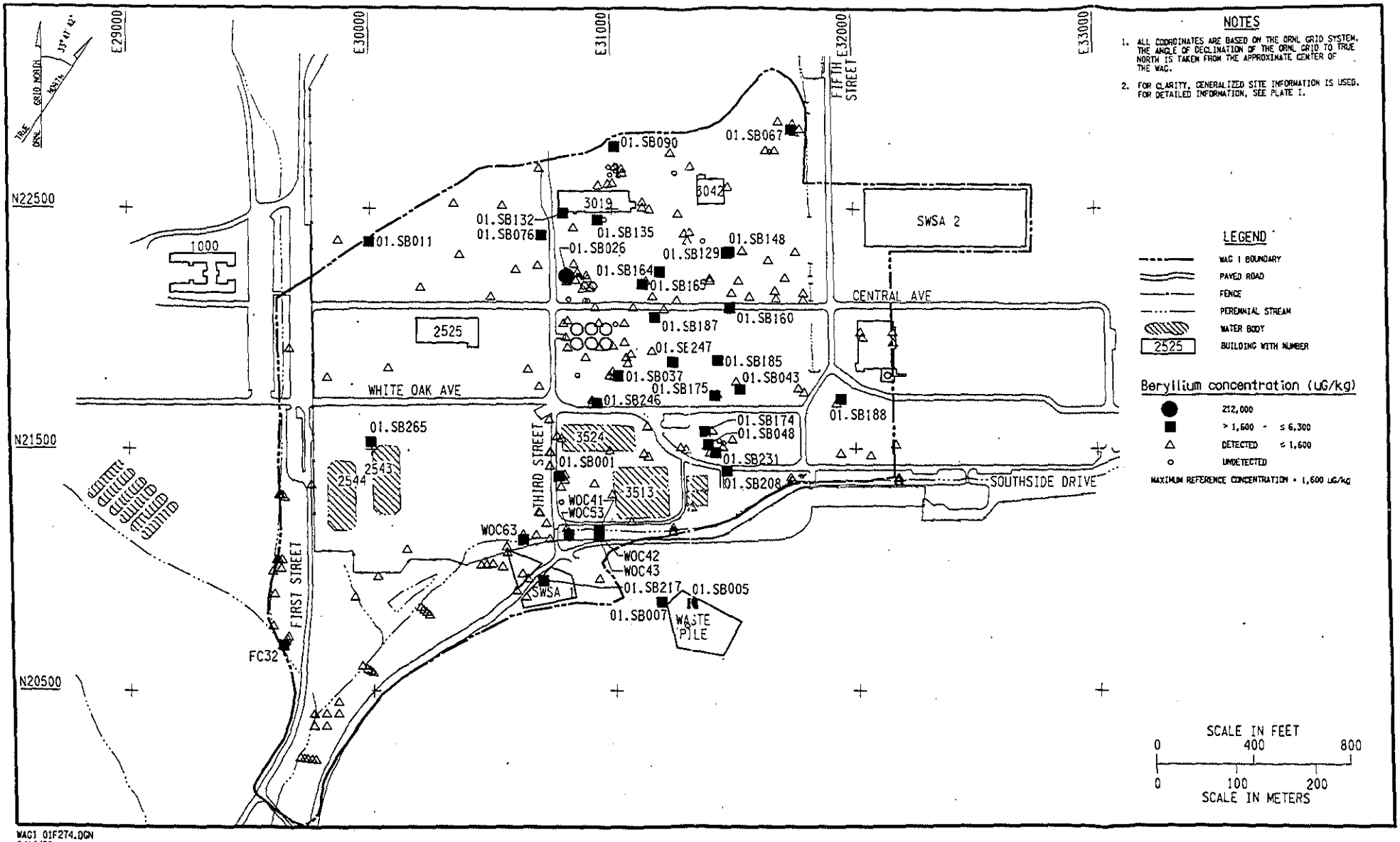
WAG1 01F273.DGN
6/13/92

Fig. 4.4.12. Maximum antimony concentrations in soil borings.



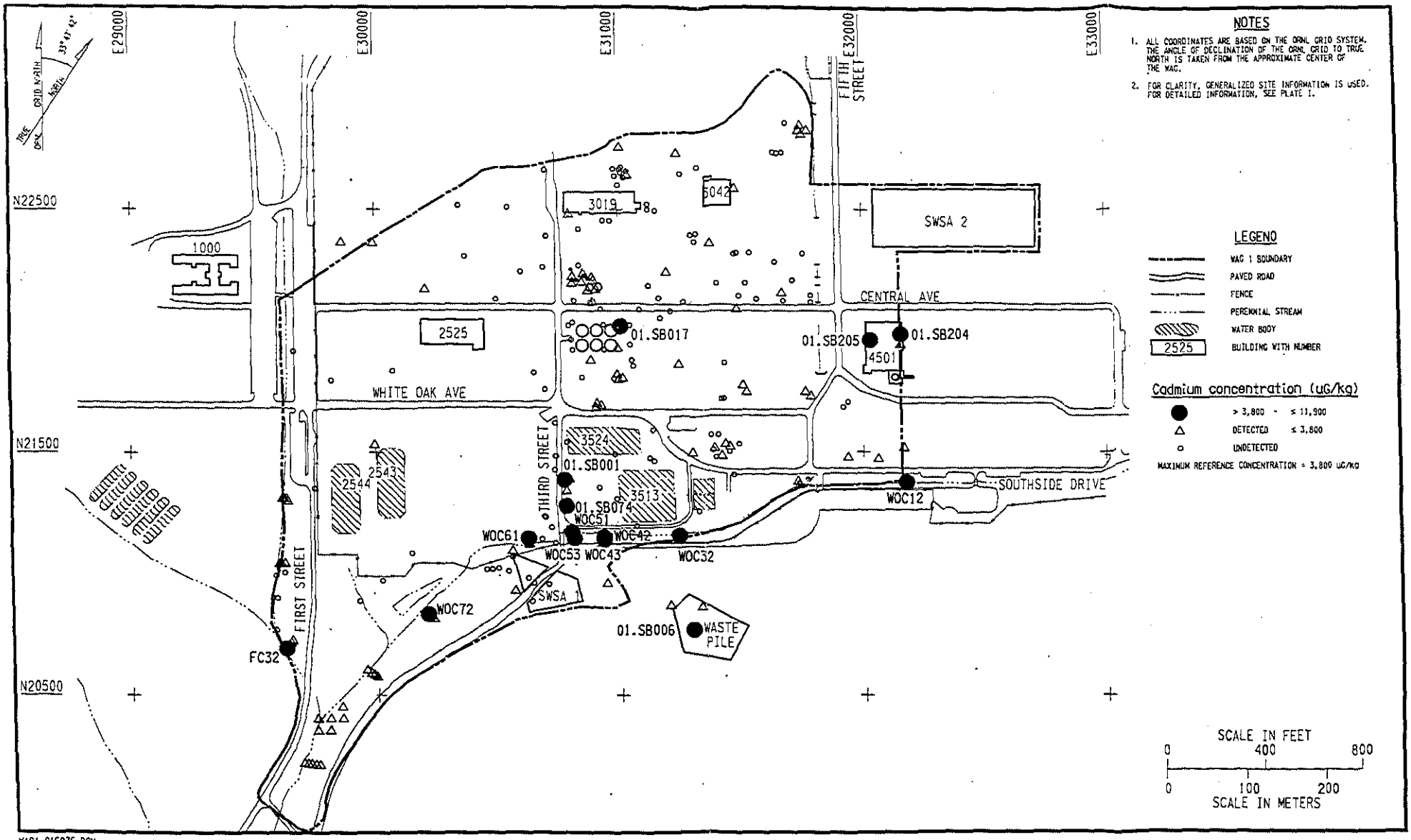
WAG1 01F334.DGN
9/22/92

Fig. 4.4.13. Maximum arsenic concentrations in soil borings.



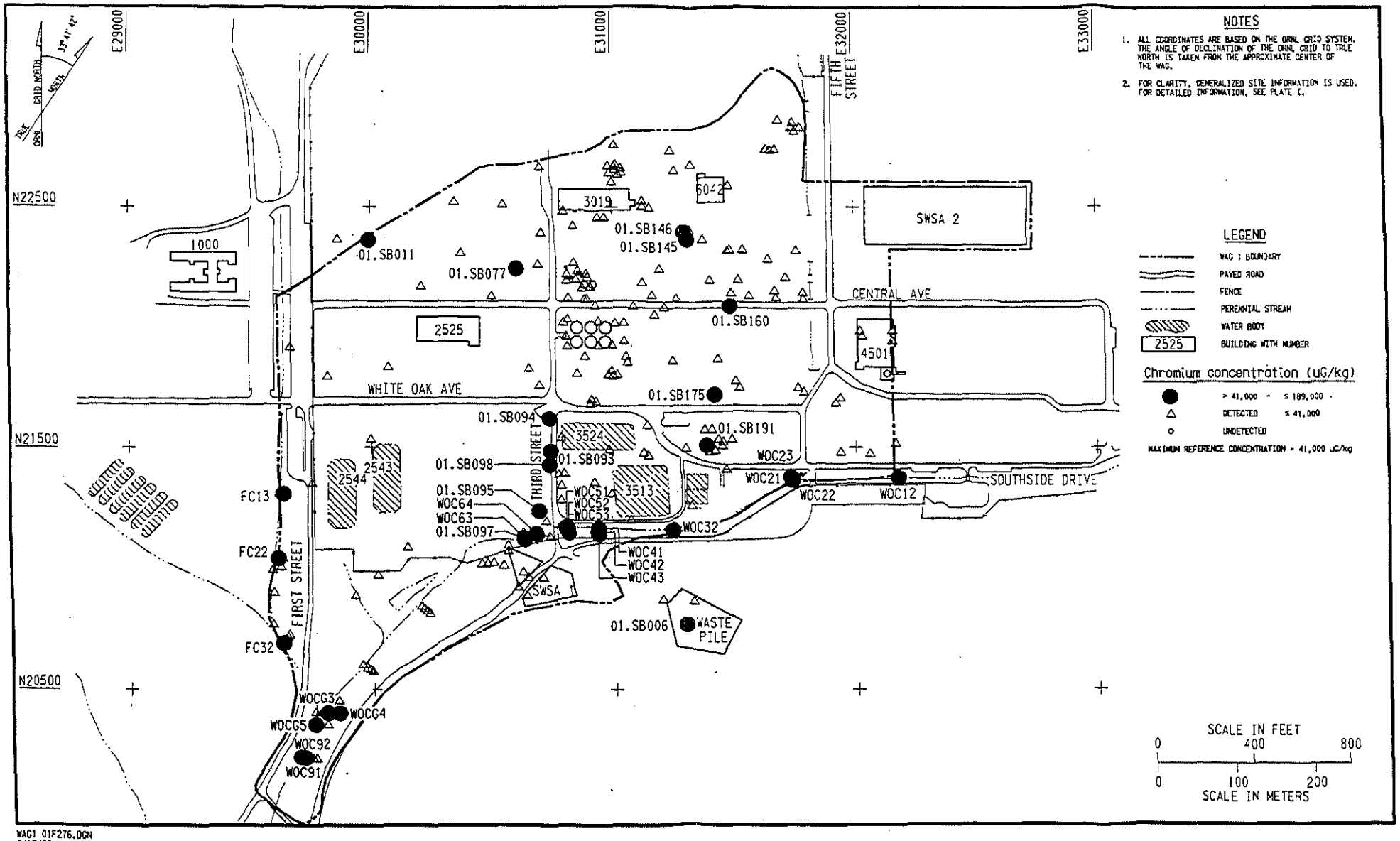
WAG1 01F274.DGN
9/14/92

Fig. 4.4.14. Maximum beryllium concentrations in soil borings.



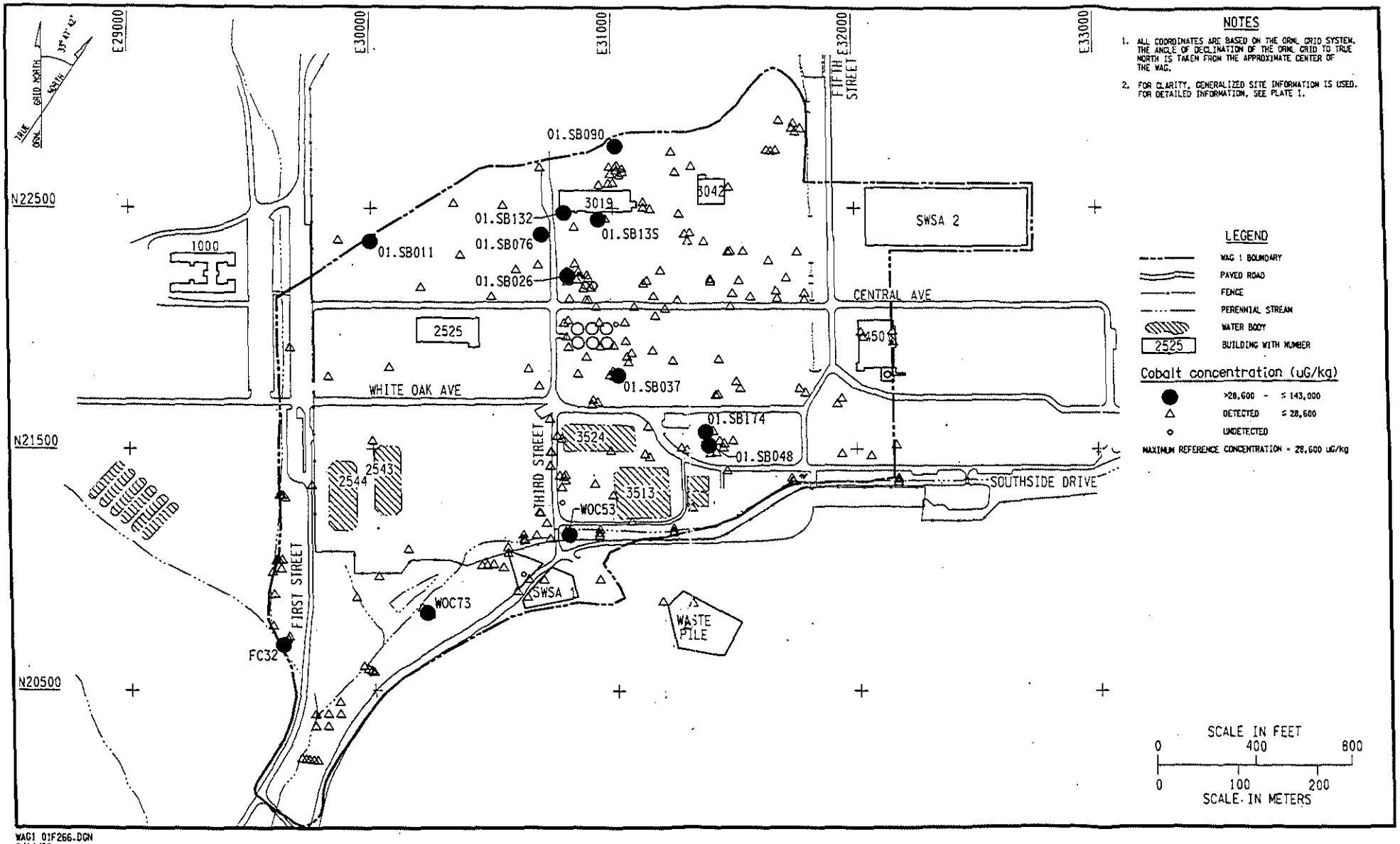
WAG1 01F275.DGN
6/13/92

Fig. 4.4.15. Maximum cadmium concentrations in soil borings.



WAG1 01F276.DGN
9/15/92

Fig. 4.4.16. Maximum chromium concentrations in soil borings.



WAG1 01F266.DGN
9/14/92

Fig. 4.4.17. Maximum cobalt concentrations in soil borings.

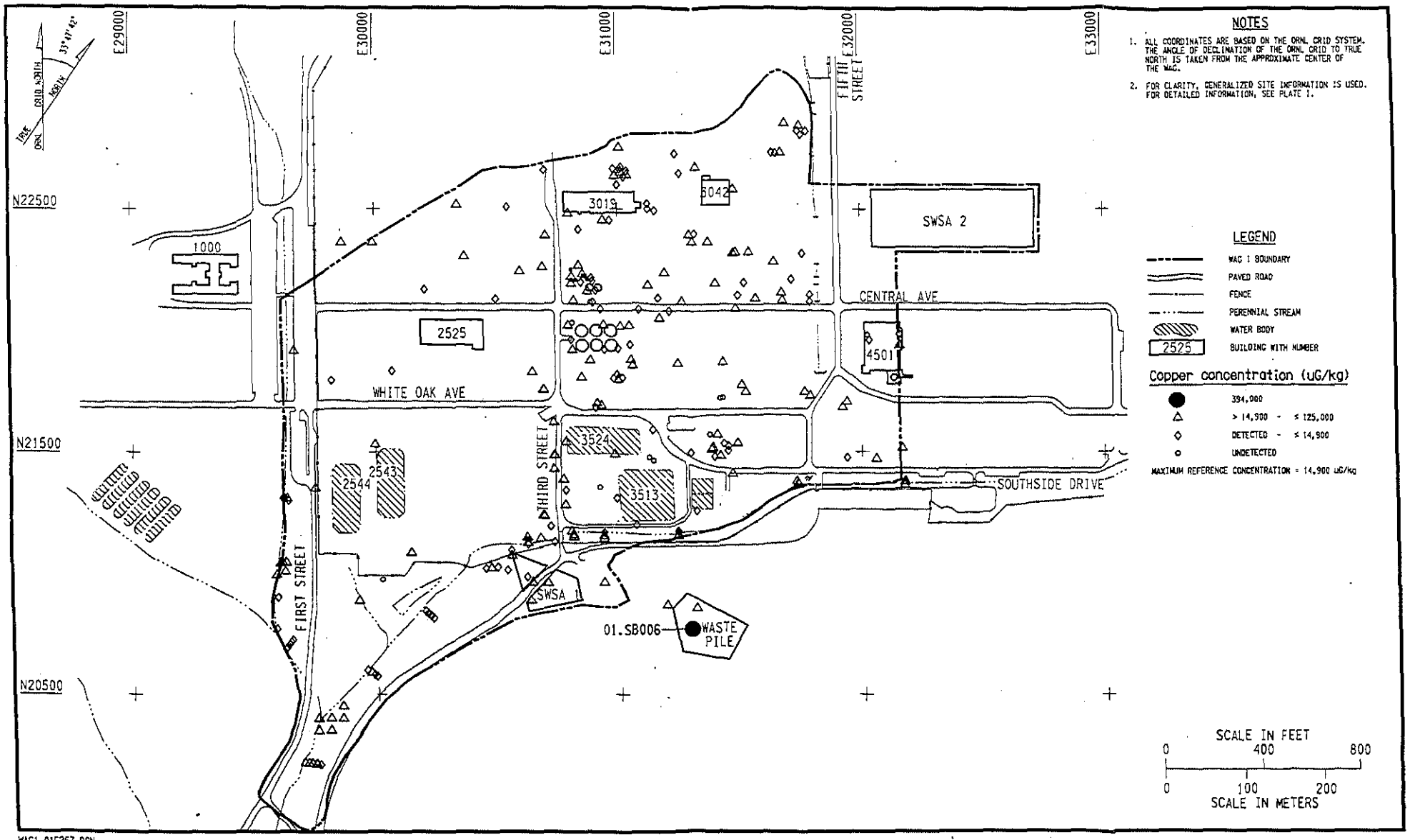
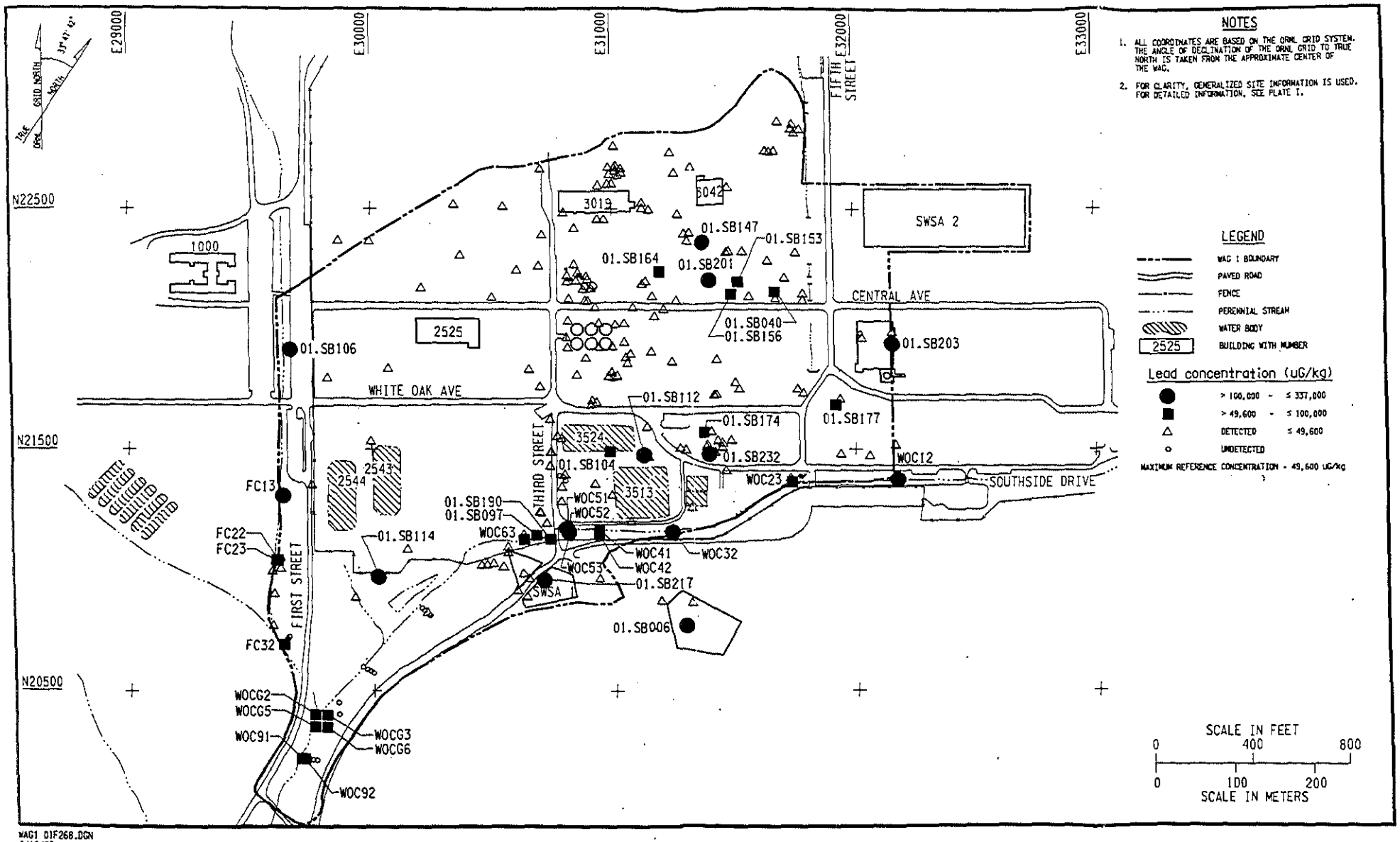


Fig. 4.4.18. Maximum copper concentrations in soil borings.



WAG1 01F268.DGN
9/16/92

Fig. 4.4.19. Maximum lead concentrations in soil borings.

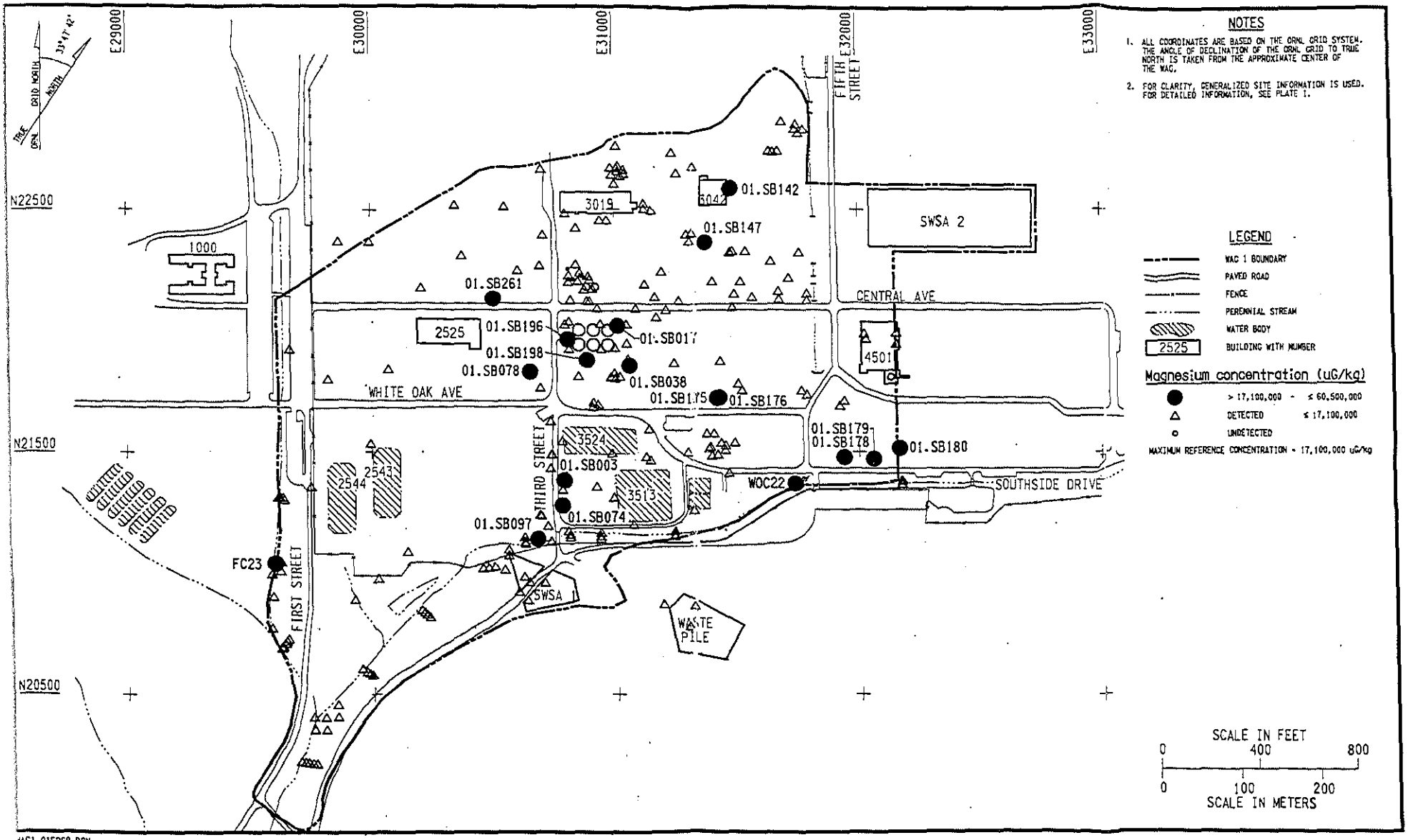
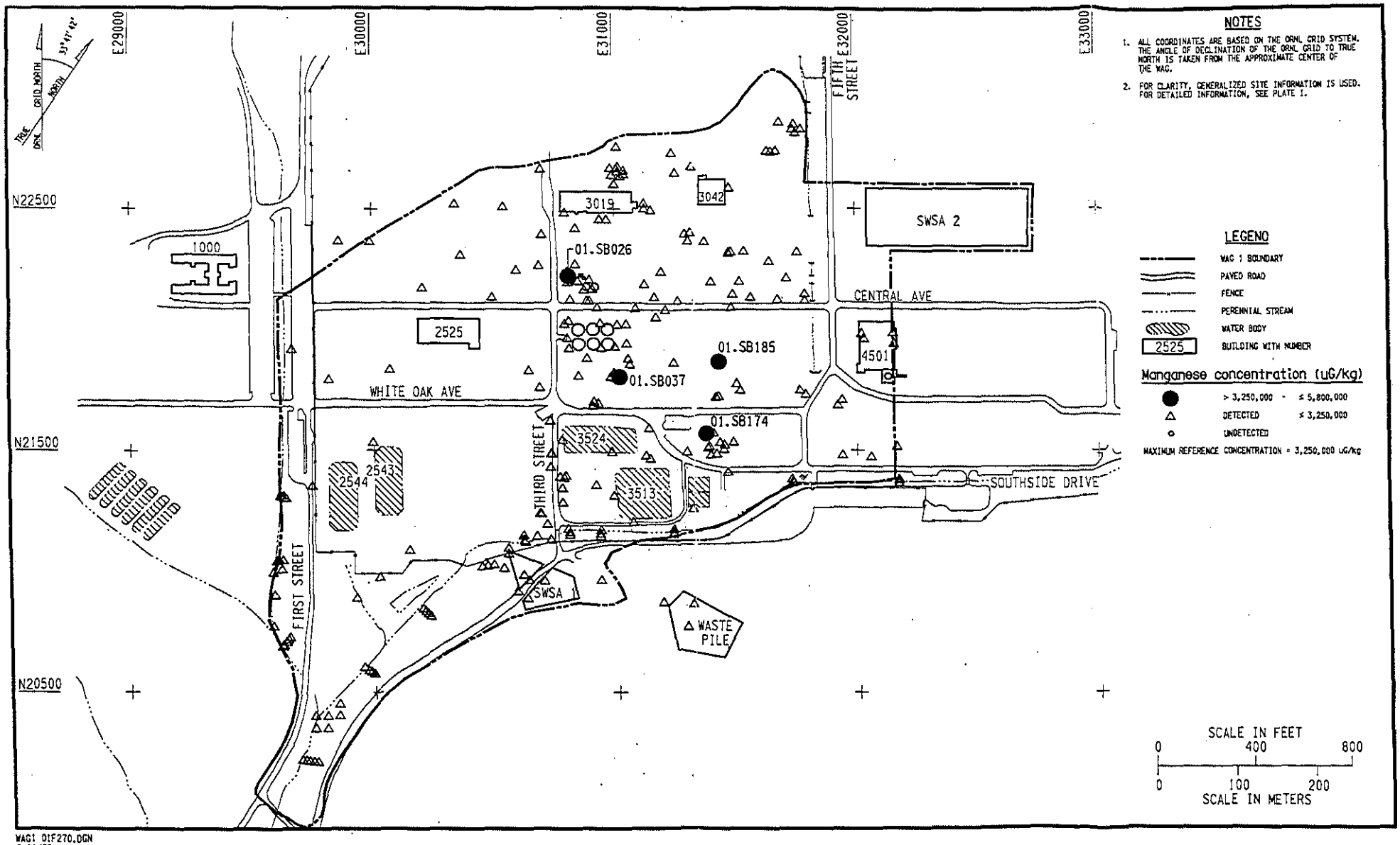
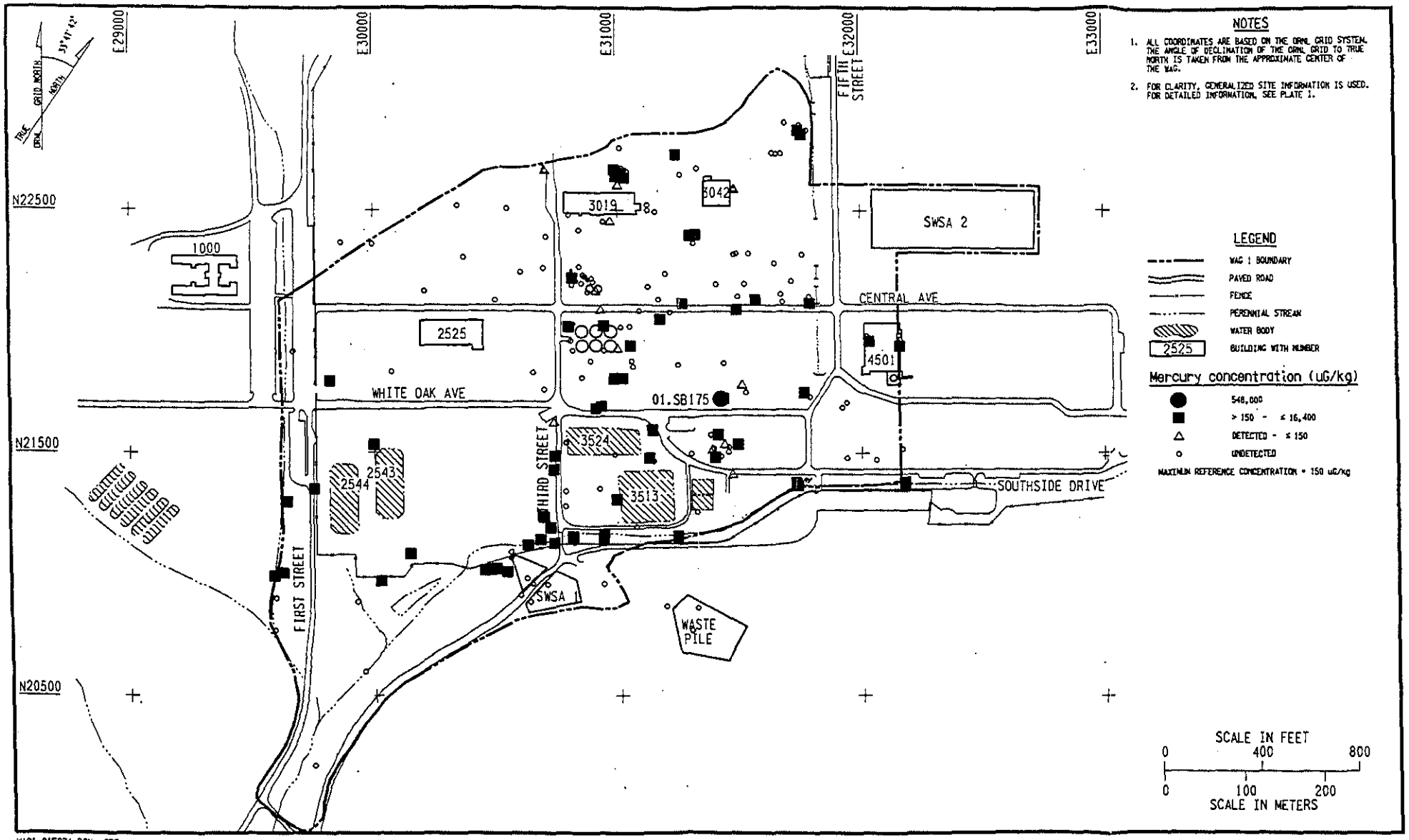


Fig. 4.4.20. Maximum magnesium concentrations in soil borings.



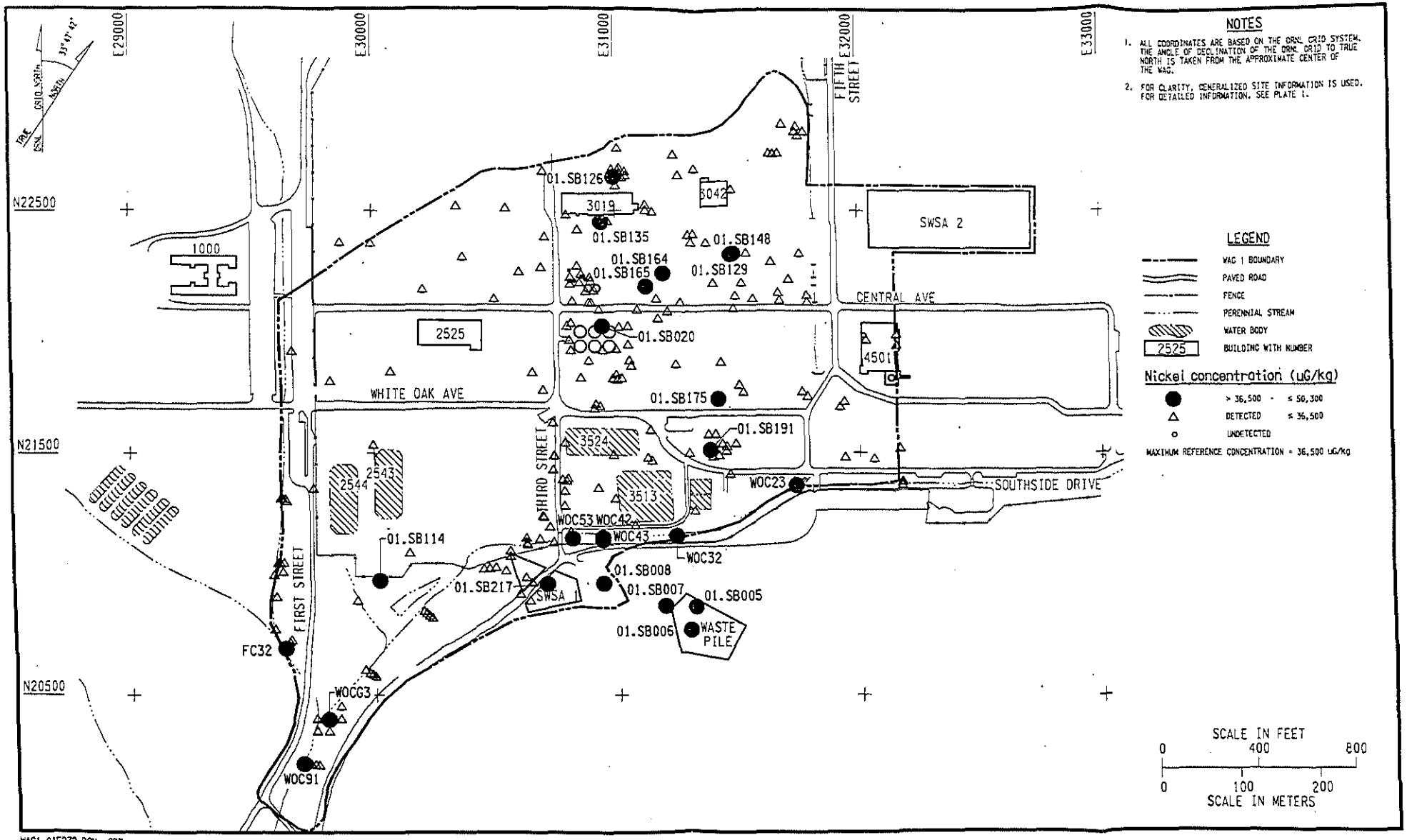
WAG1 01F270.DGN
6/21/92

Fig. 4.4.21. Maximum manganese concentrations in soil borings.



WAG1 01F271.DGN SRF, 6/14/92

Fig. 4.4.22. Maximum mercury concentrations in soil borings.



WAG1 01F272.DGN SRF, 6/13/92

Fig. 4.4.23. Maximum nickel concentrations in soil borings.

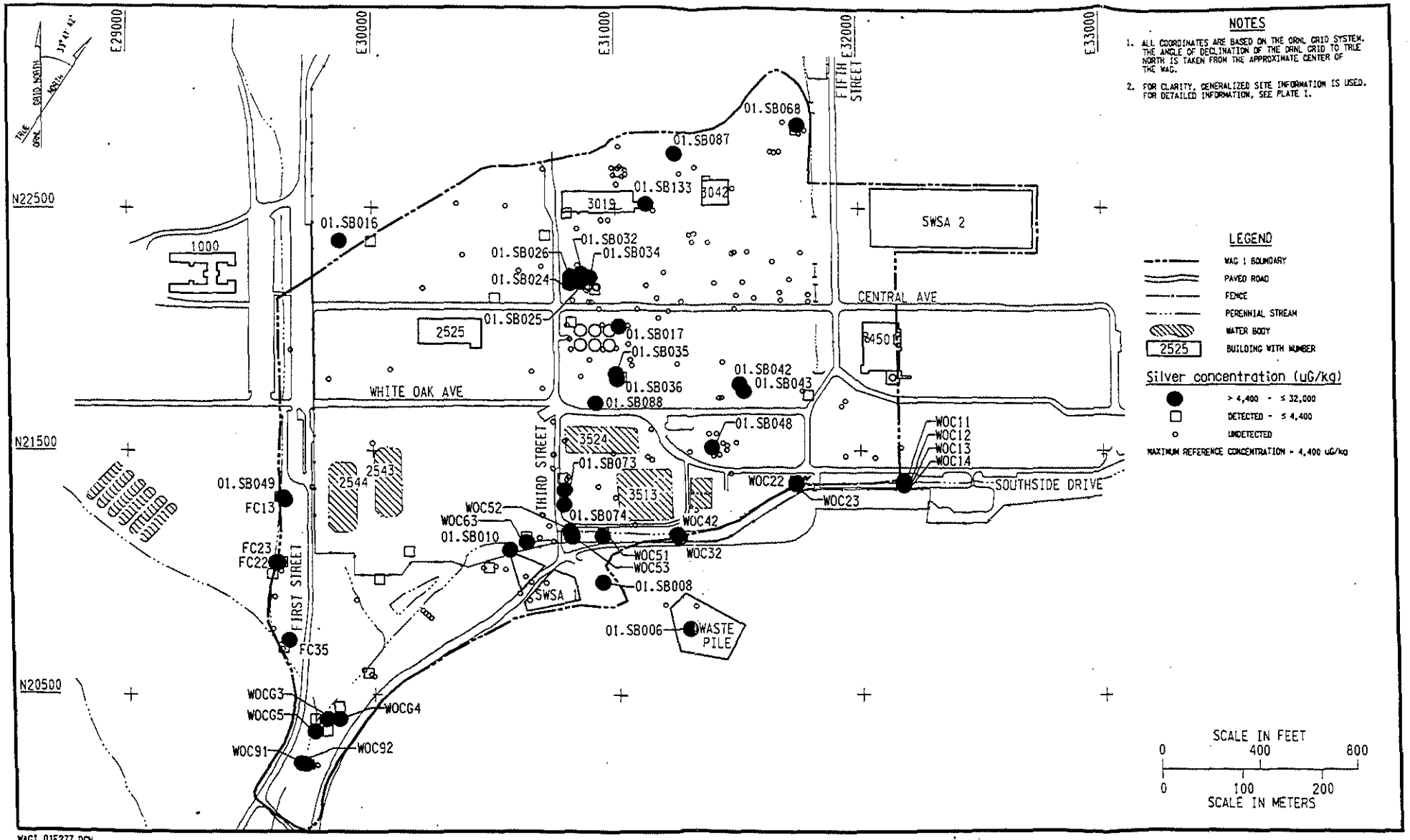
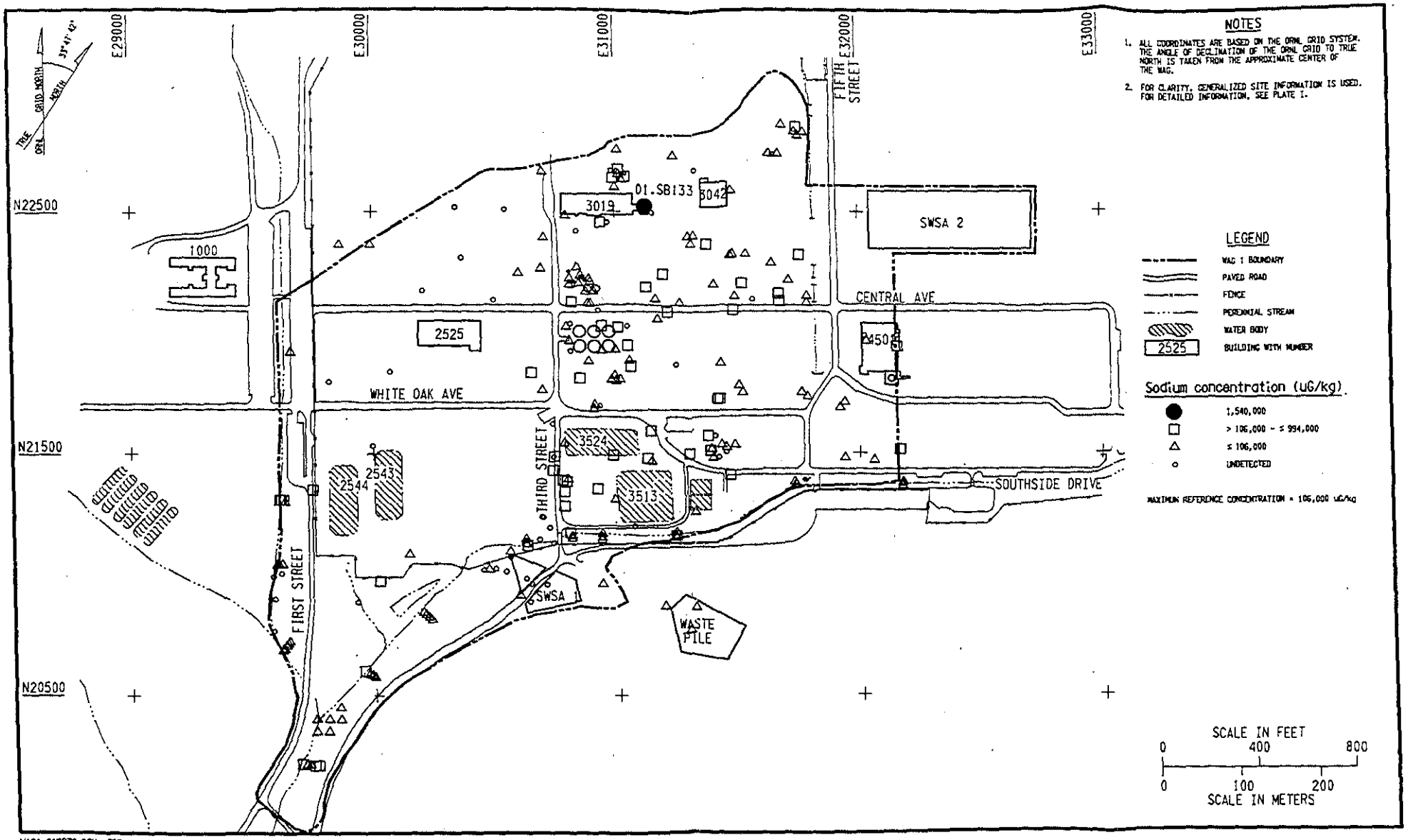
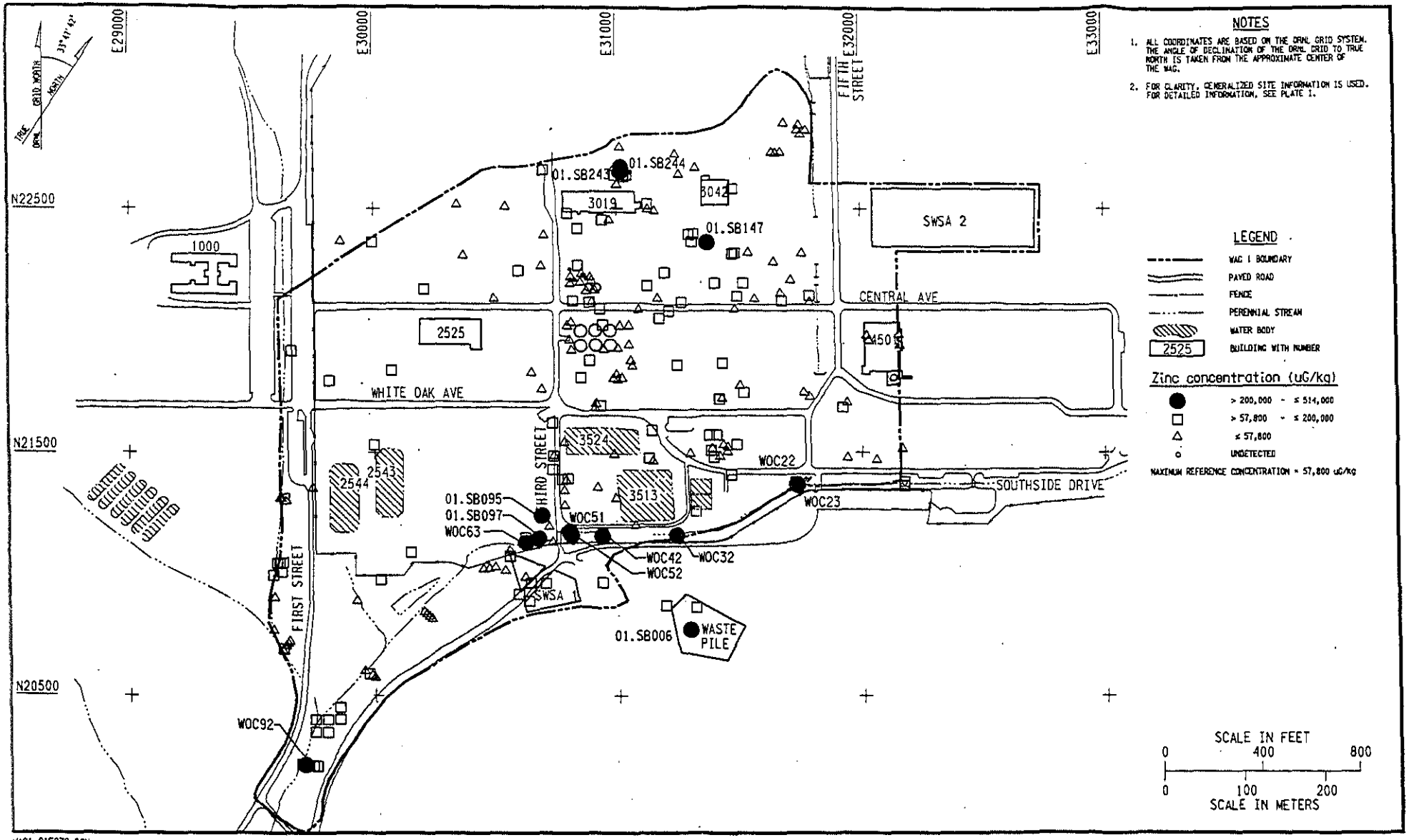


Fig. 4.4.24. Maximum silver concentrations in soil borings.



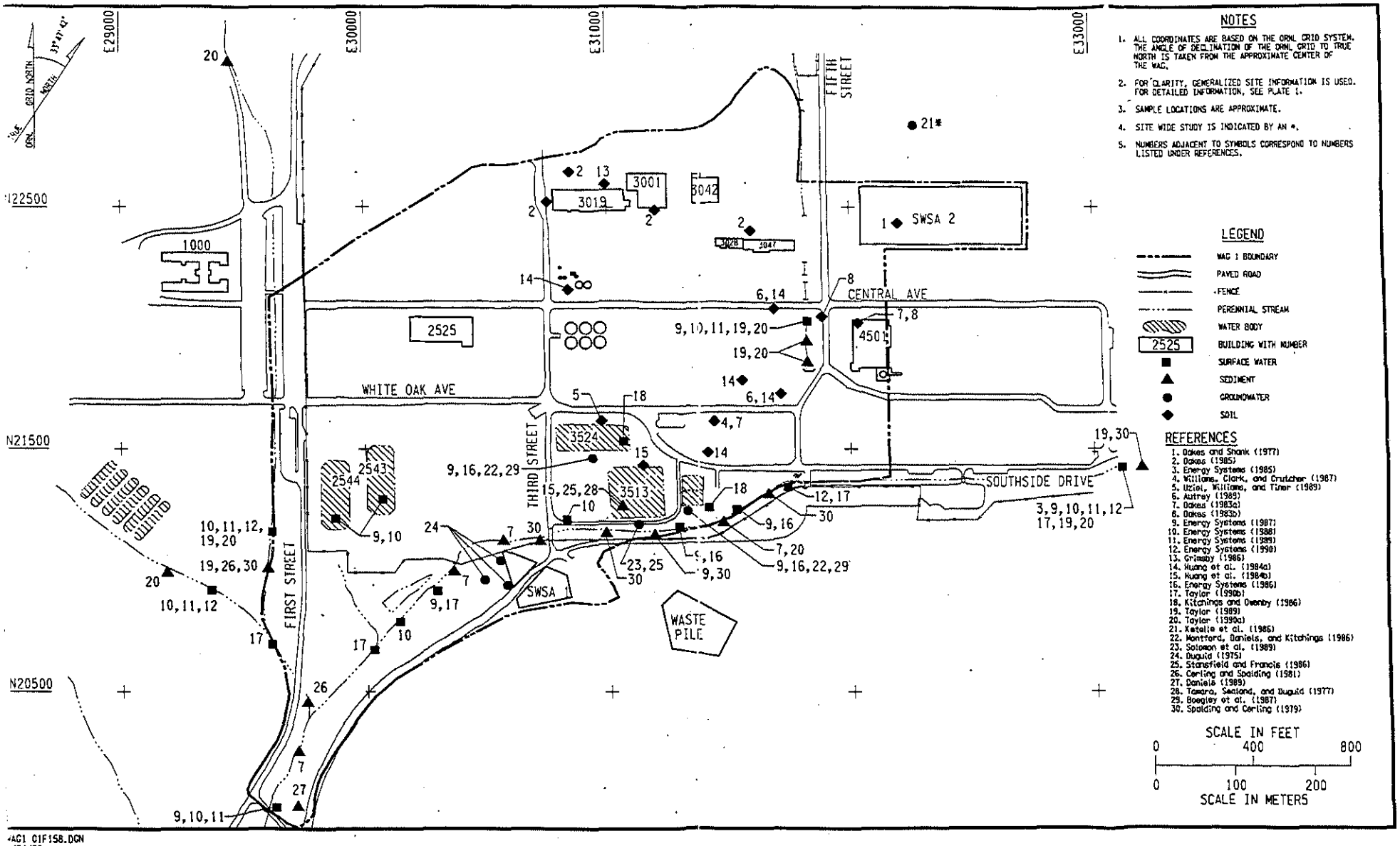
WAG1 01F278.DGN SRF, 6/14/92

Fig. 4.4.25. Maximum sodium concentrations in soil borings.



WAG1 01F279.DGN
5/14/92

Fig. 4.4.26. Maximum zinc concentrations in soil borings.



4AG1 01F158.DGN
/24/92

Fig. 4.5.1. Locations of previous studies and available data of groundwater, soil surface water and sediments.

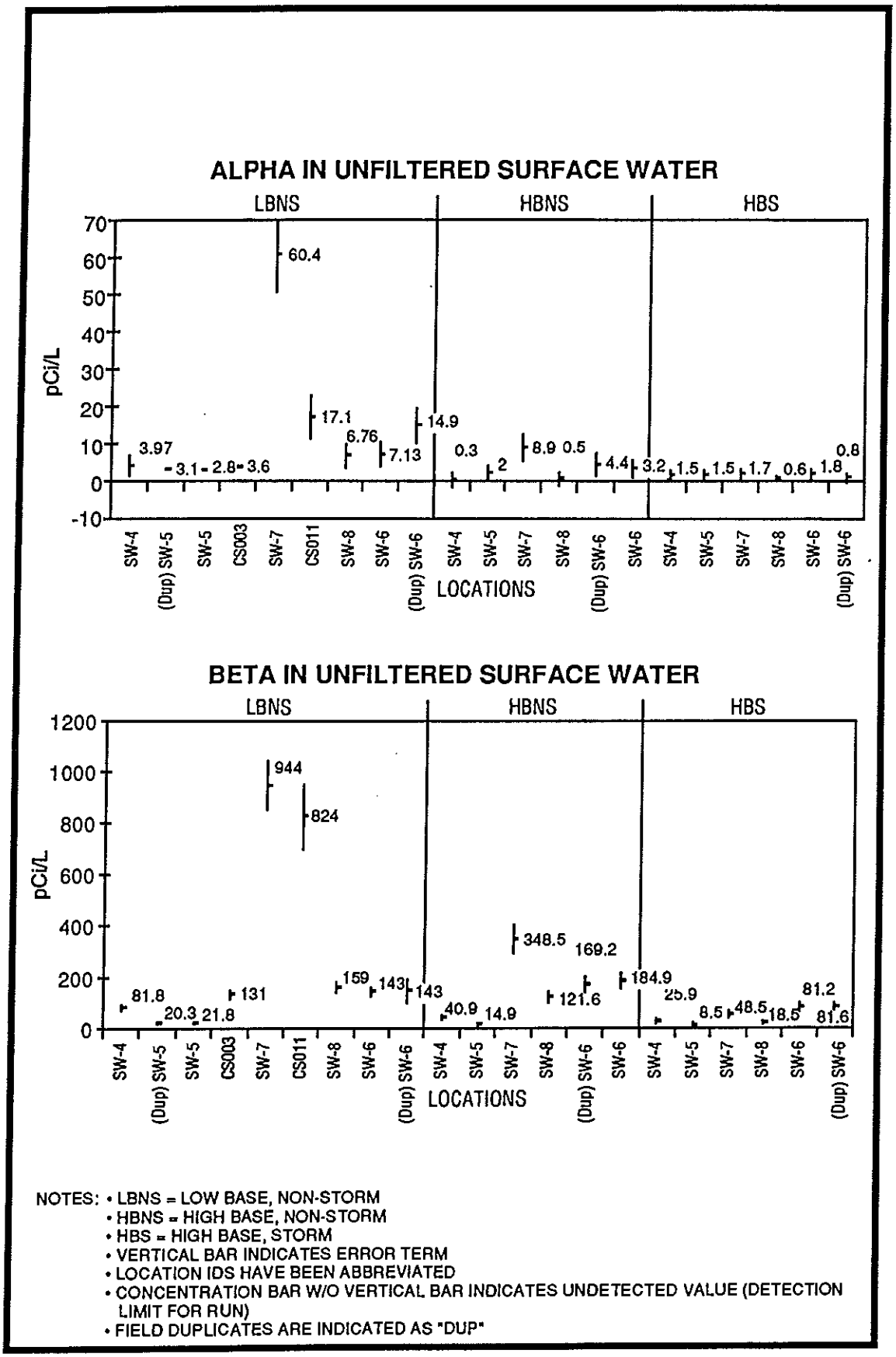


Fig. 4.5.2. Gross alpha and gross beta in unfiltered surface water.

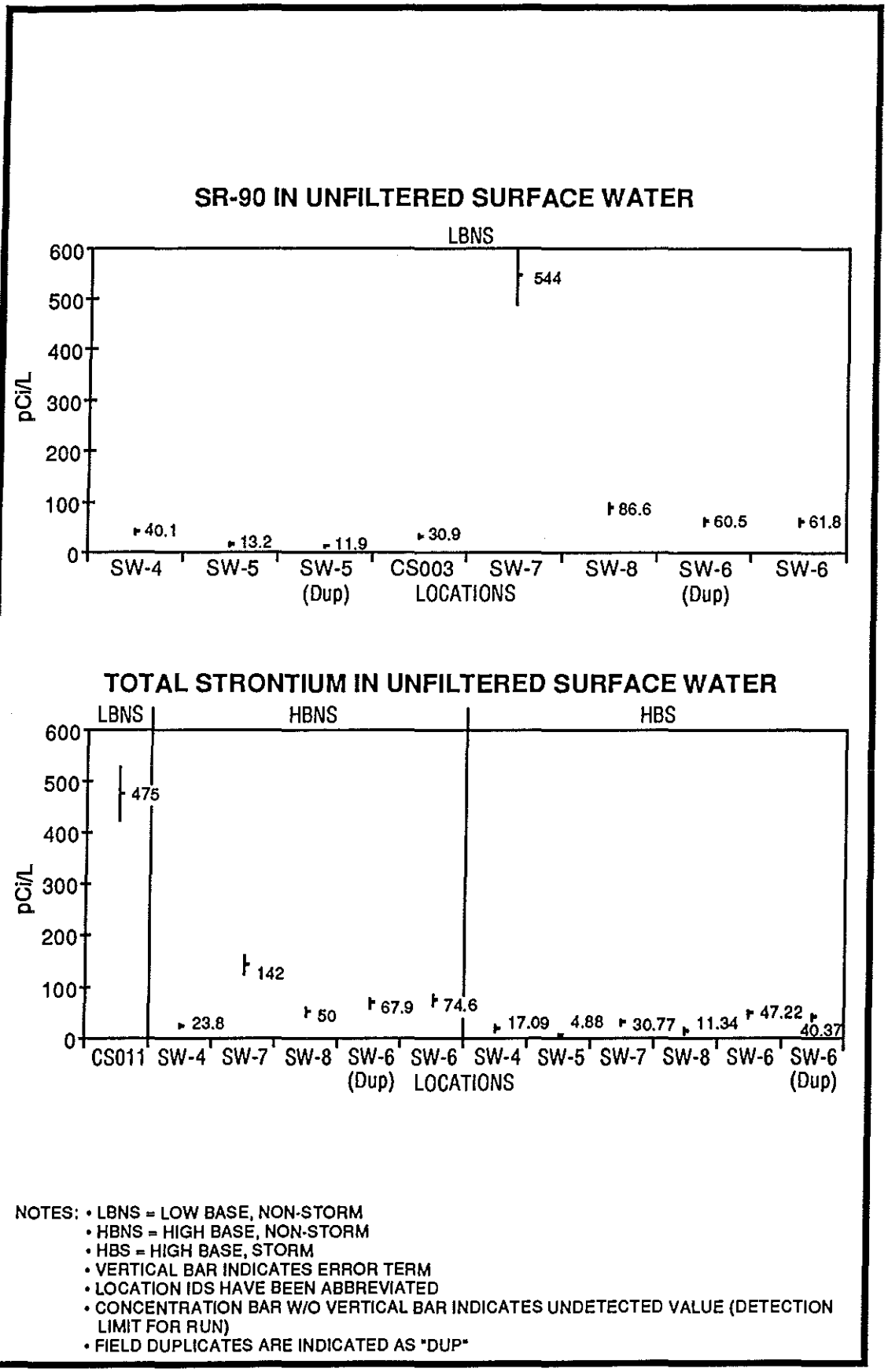
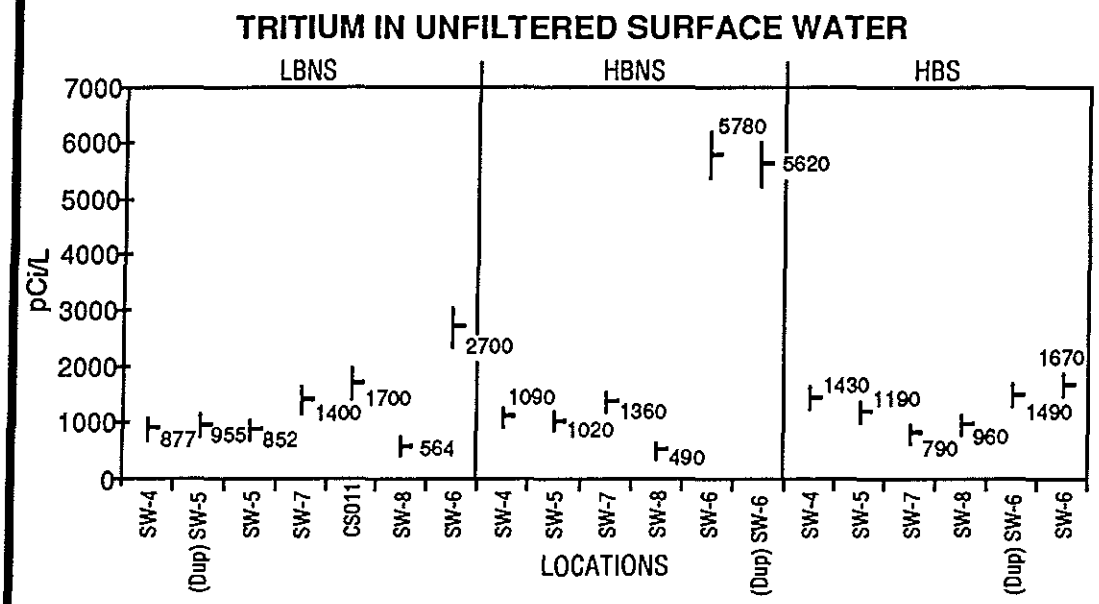
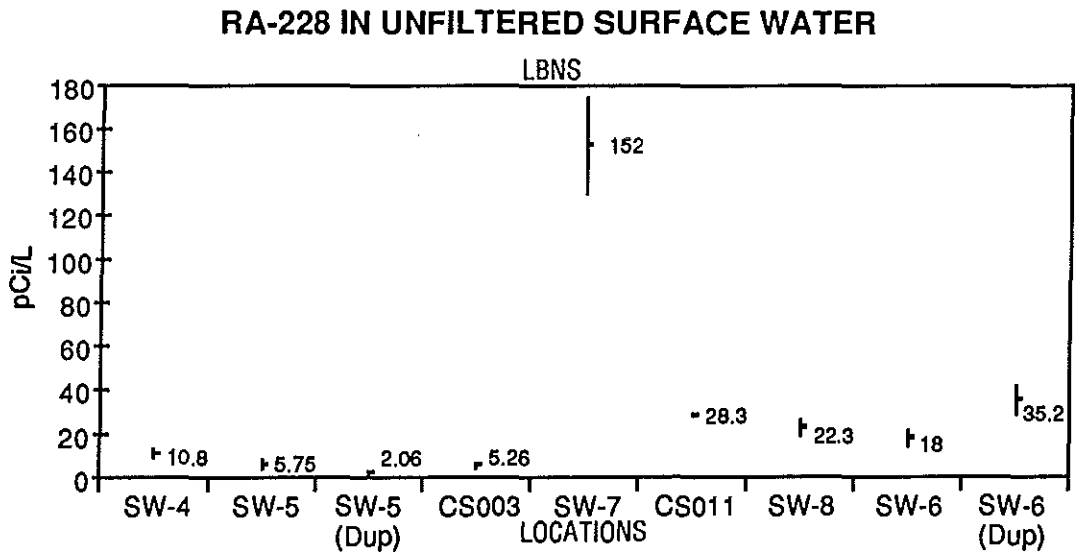


Fig. 4.5.3. Strontium-90 and total radioactive strontium in unfiltered surface water.

5.33A 6066.18B





NOTES:
- LBNS = LOW BASE, NON-STORM
- HBNS = HIGH BASE, NON-STORM
- HBS = HIGH BASE, STORM
- VERTICAL BAR INDICATES ERROR TERM
- LOCATION IDS HAVE BEEN ABBREVIATED
- CONCENTRATION BAR W/O VERTICAL BAR INDICATES UNDETECTED VALUE (DETECTION LIMIT FOR RUN)
- FIELD DUPLICATES ARE INDICATED AS "DUP"

Fig. 4.5.4. Tritium and radium-228 in unfiltered surface water.

5.33A 6066.17

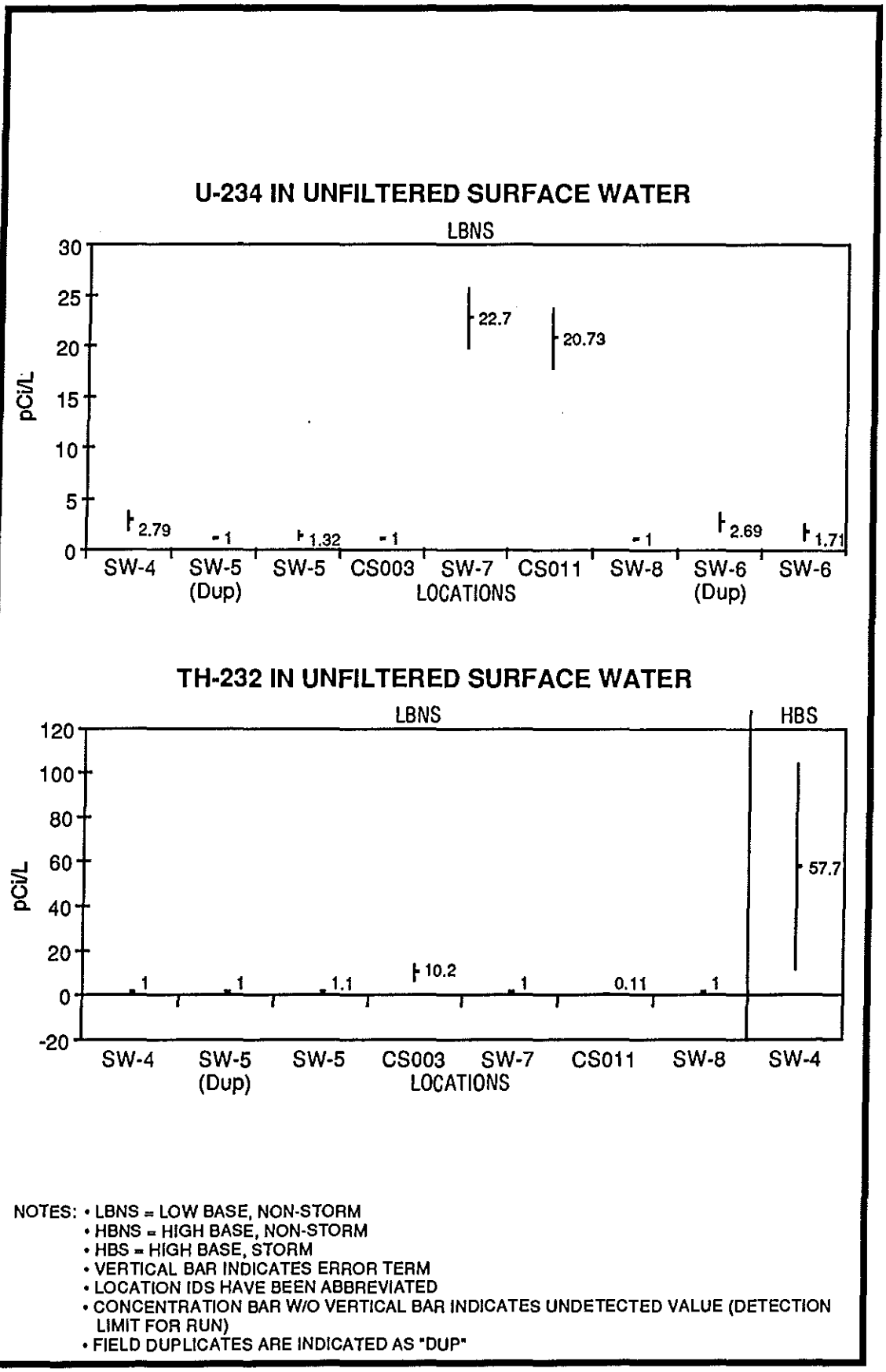
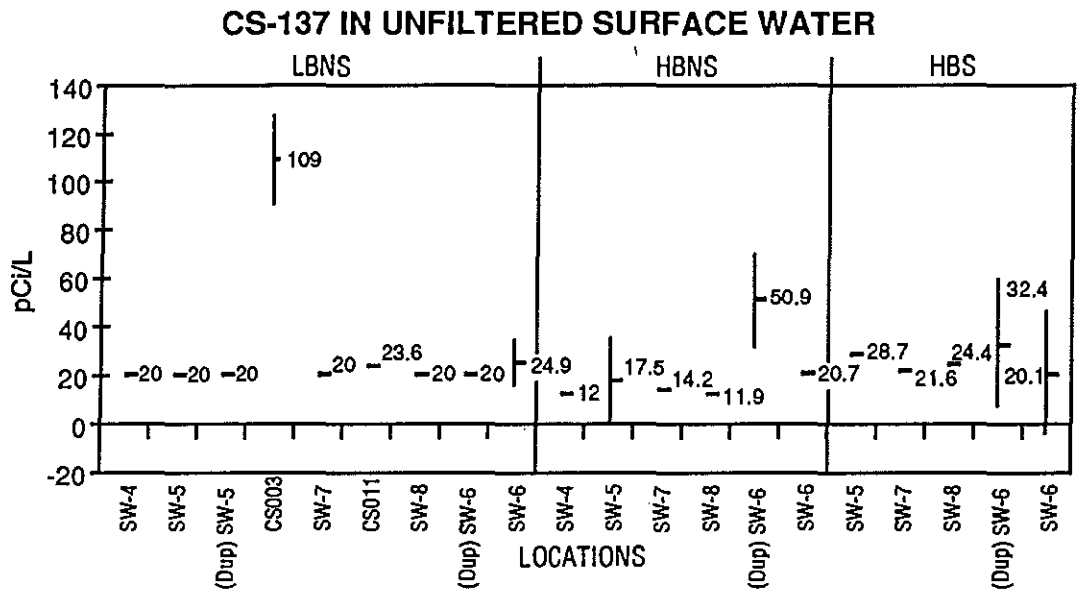


Fig. 4.5.5. Uranium-234 and thorium-232 in unfiltered surface water.

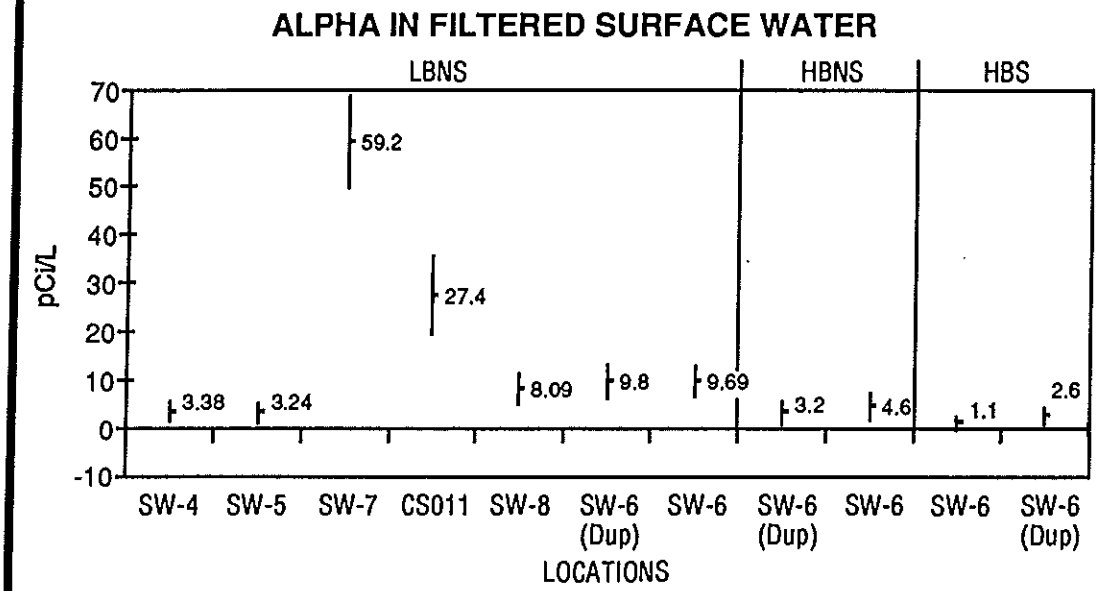
5.33A 6066.18

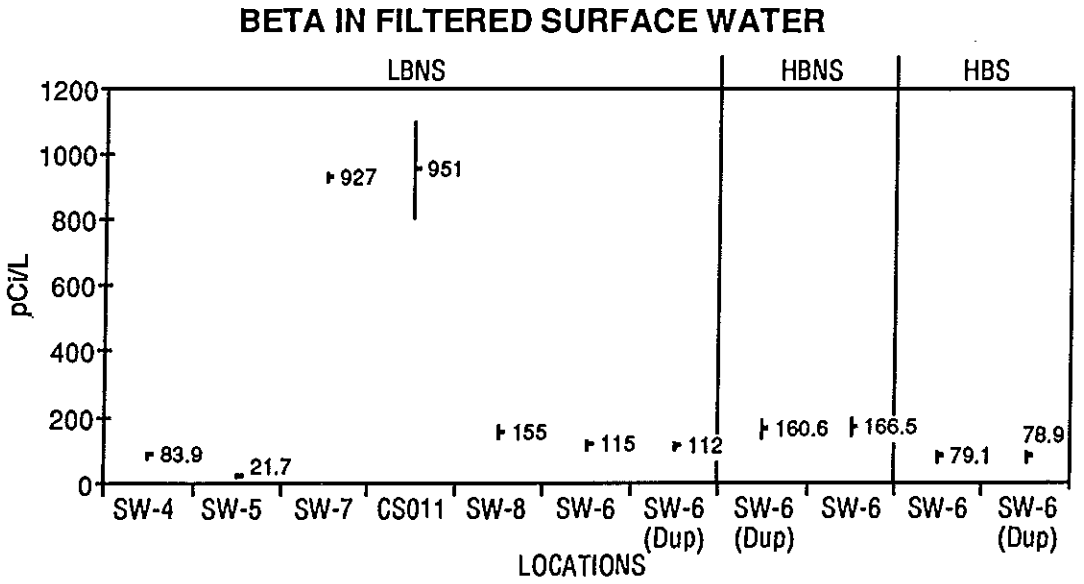


NOTES:
- LBNS = LOW BASE, NON-STORM
- HBNS = HIGH BASE, NON-STORM
- HBS = HIGH BASE, STORM
- VERTICAL BAR INDICATES ERROR TERM
- LOCATION IDS HAVE BEEN ABBREVIATED
- CONCENTRATION BAR W/O VERTICAL BAR INDICATES UNDETECTED VALUE (DETECTION LIMIT FOR RUN)
- FIELD DUPLICATES ARE INDICATED AS "DUP"

Fig. 4.5.6. Cesium-137 in unfiltered surface water.

5.33A 6066.18A





NOTES:
- LBNS = LOW BASE, NON-STORM
- HBNS = HIGH BASE, NON-STORM
- HBS = HIGH BASE, STORM
- VERTICAL BAR INDICATES ERROR TERM
- LOCATION IDS HAVE BEEN ABBREVIATED
- CONCENTRATION BAR W/O VERTICAL BAR INDICATES UNDETECTED VALUE (DETECTION LIMIT FOR RUN)
- FIELD DUPLICATES ARE INDICATED AS "DUP"

5.33C 6086.13

Fig. 4.5.7. Gross alpha and gross beta in filtered surface water.

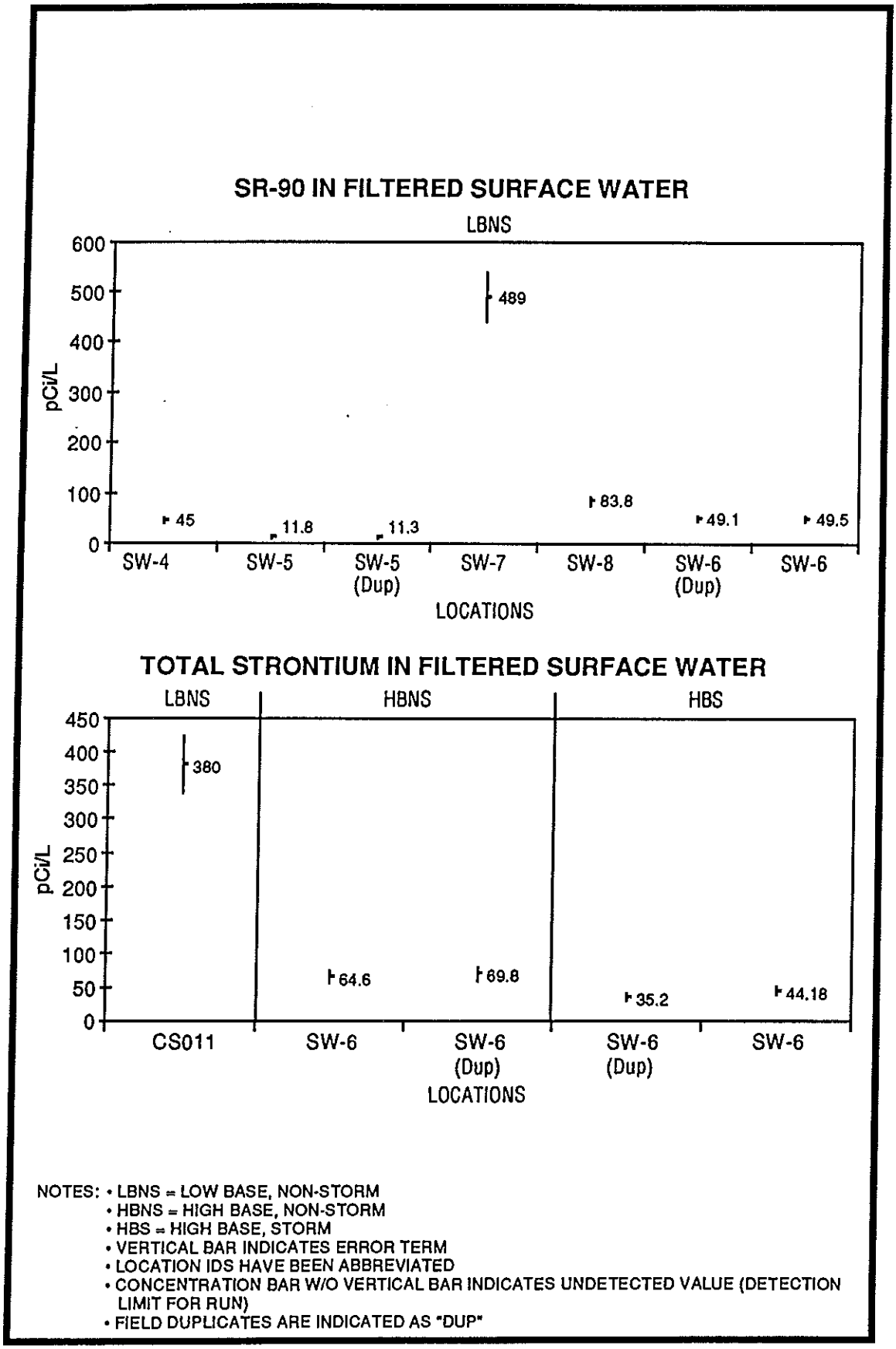
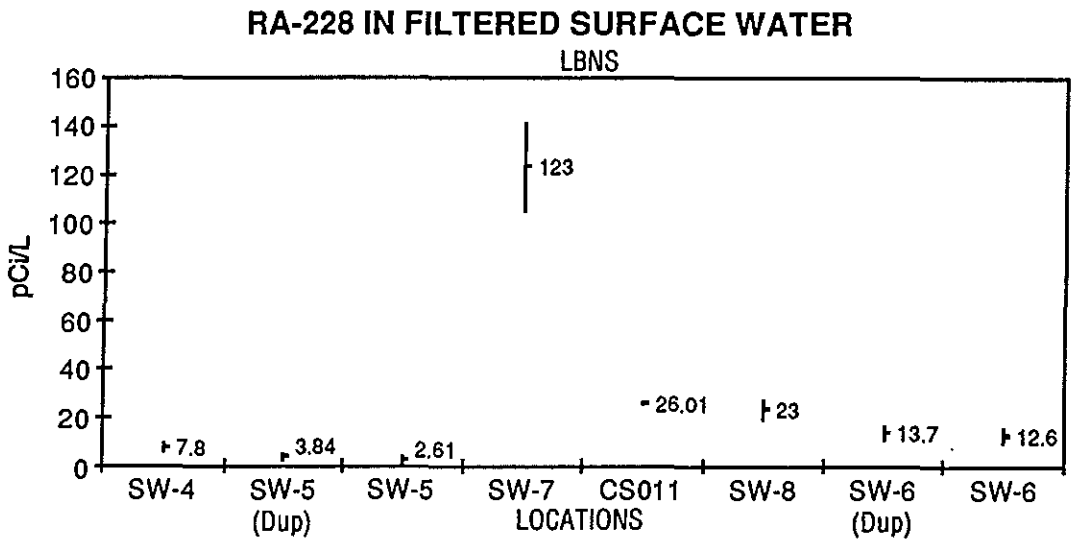


Fig. 4.5.8. Strontium-90 and total radioactive strontium in filtered surface water.

5.33C 6066.14



NOTES:
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- HBNS = HIGH BASE, NON-STORM
- HBS = HIGH BASE, STORM
- VERTICAL BAR INDICATES ERROR TERM
- LOCATION IDS HAVE BEEN ABBREVIATED
- CONCENTRATION BAR W/O VERTICAL BAR INDICATES UNDETECTED VALUE (DETECTION LIMIT FOR RUN)
- FIELD DUPLICATES ARE INDICATED AS "DUP"

5.33a 6066.15

Fig. 4.5.9. Radium-228 in filtered surface water.

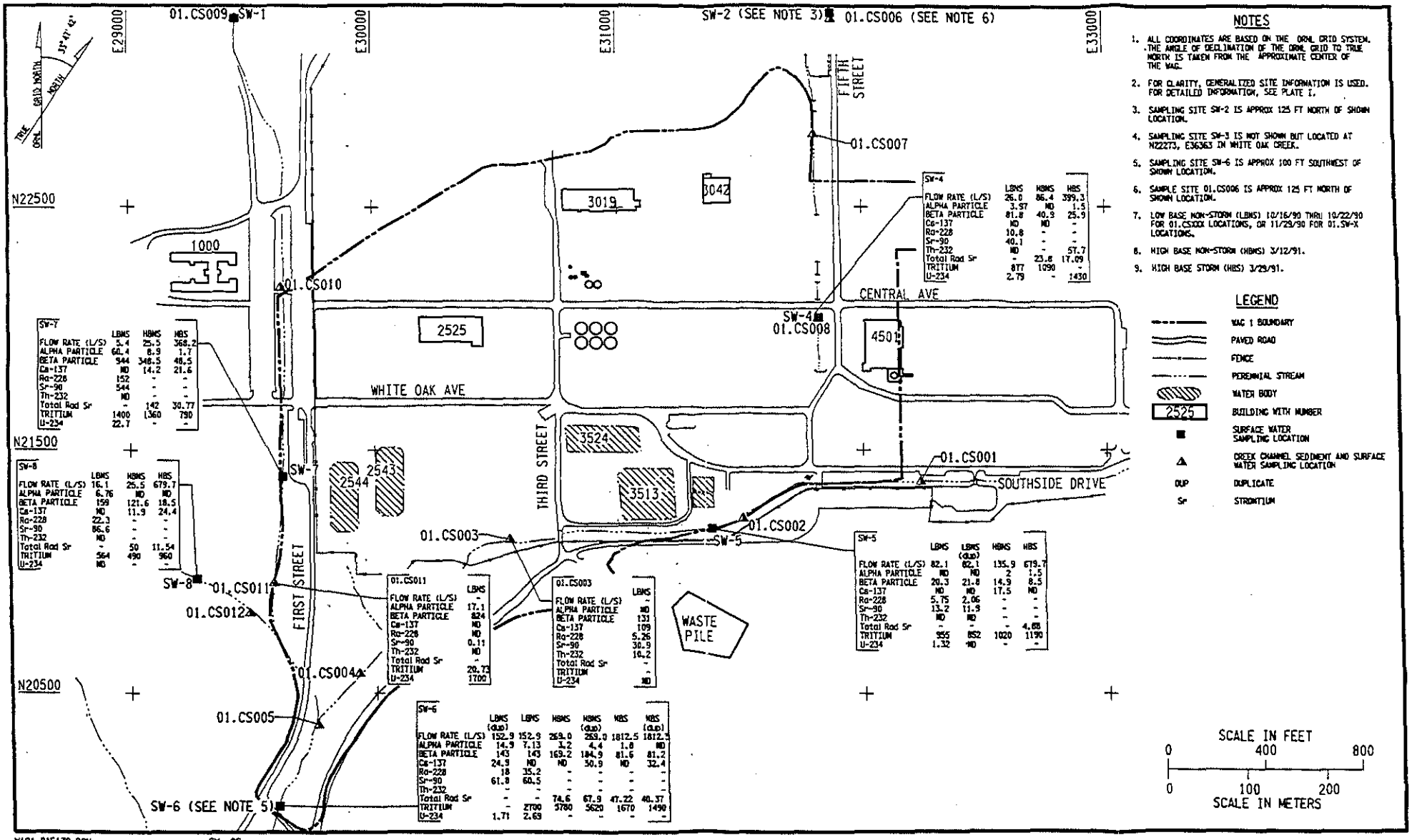


Fig. 4.5.10. Flow rates and radiological results (pCi/L) in surface water.

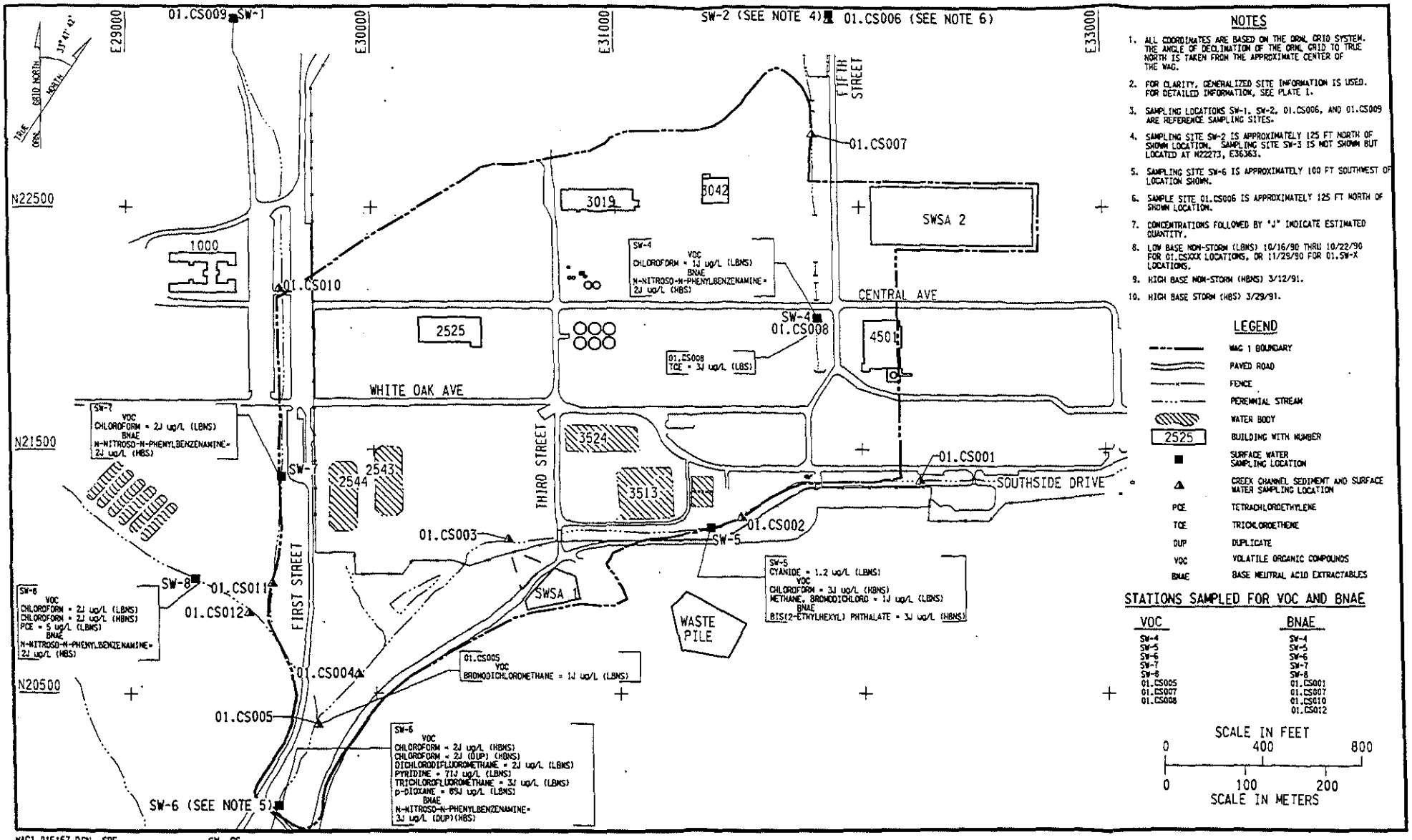
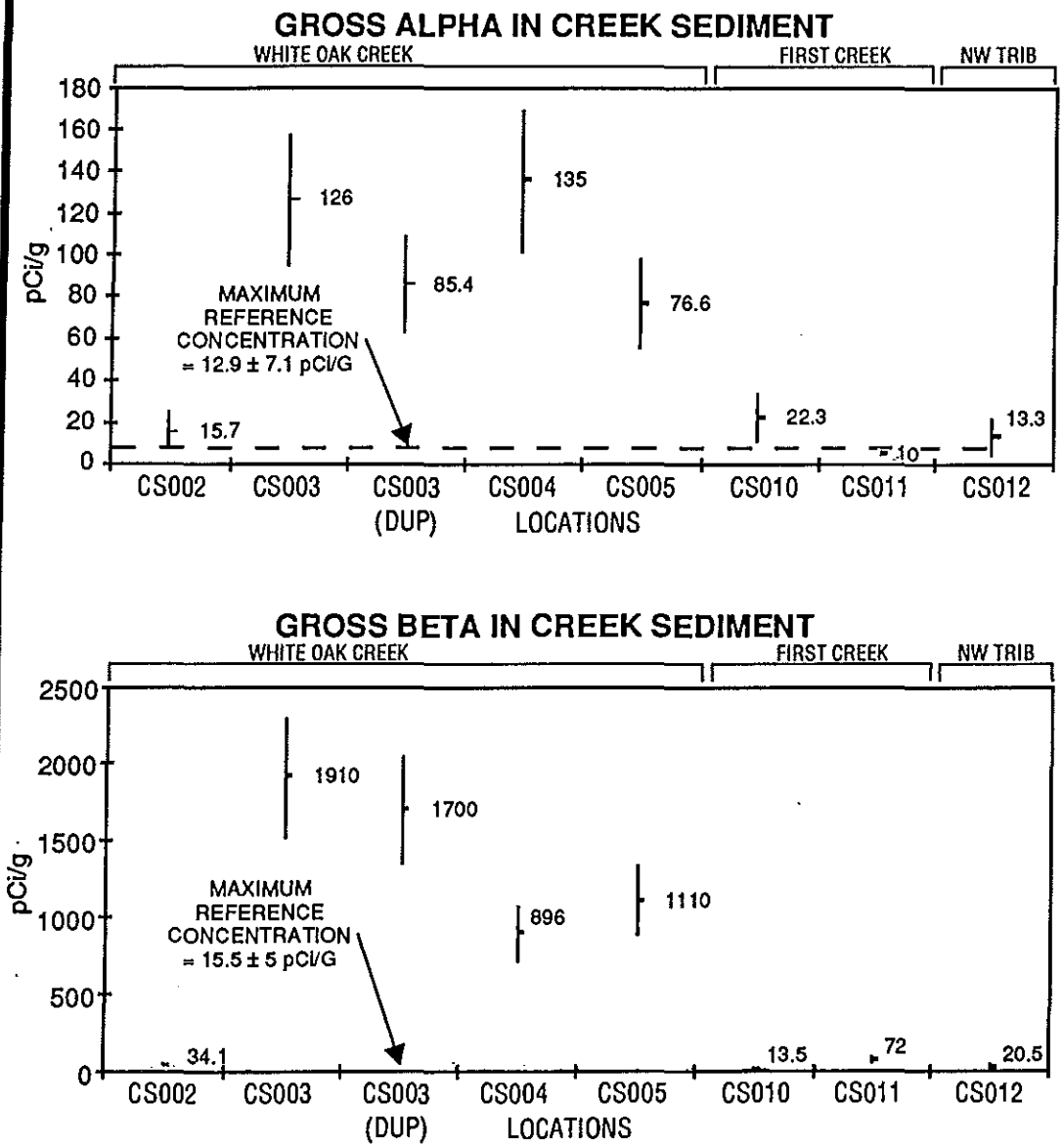


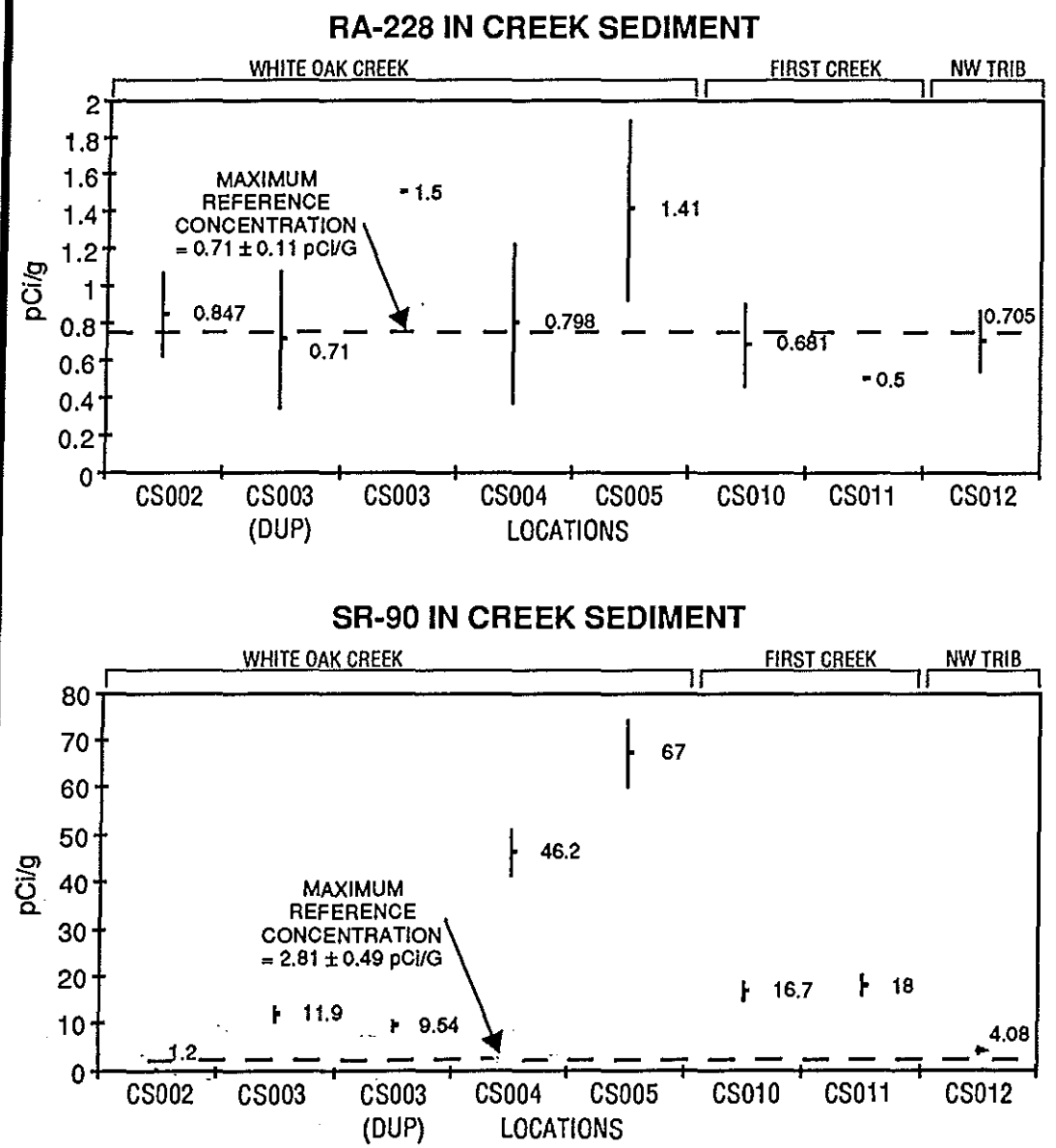
Fig. 4.5.11. VOCs, BNAEs, and cyanide detected in surface water.



NOTE: • SEDIMENTS WERE SAMPLED BETWEEN OCT. 16 AND 22, 1990. SURFACE WATER SAMPLED CONCURRENTLY DURING THE LOW BASE FLOW NON-STORM EVENT
• LOCATION ID ABBREVIATED
• THE BAR ABOVE AND BELOW THE CONCENTRATION VALUE REPRESENTS THE ERROR TERM

Fig. 4.6.1. Gross alpha and gross beta in sediment.

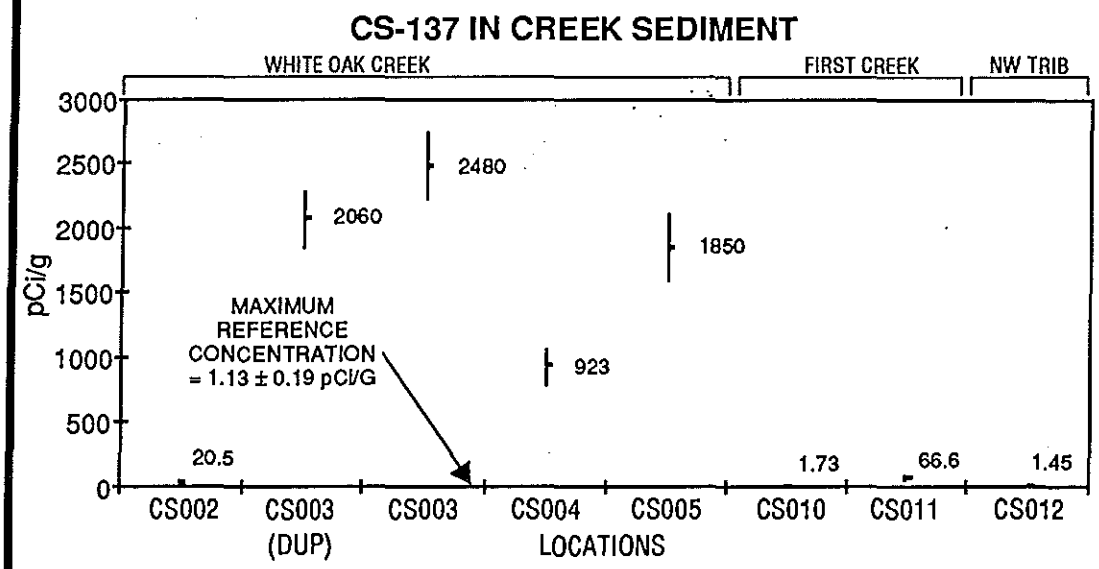
5.33A 6066.28



NOTE:
- SEDIMENTS WERE SAMPLED BETWEEN OCT. 16 AND 22, 1990. SURFACE WATER SAMPLED CONCURRENTLY DURING THE LOW BASE FLOW NON-STORM EVENT
- LOCATION ID ABBREVIATED
- THE BAR ABOVE AND BELOW THE CONCENTRATION VALUE REPRESENTS THE ERROR TERM

Fig. 4.6.2. Radium-228 and strontium-90 in sediment.

5.33A 6066.29



NOTE: • SEDIMENTS WERE SAMPLED BETWEEN OCT. 16 AND 22, 1990. SURFACE WATER SAMPLED CONCURRENTLY DURING THE LOW BASE FLOW NON-STORM EVENT
• LOCATION ID ABBREVIATED
• THE BAR ABOVE AND BELOW THE CONCENTRATION VALUE REPRESENTS THE ERROR TERM

Fig. 4.6.3. Cesium-137 in sediment.

5.33A 6066.29A

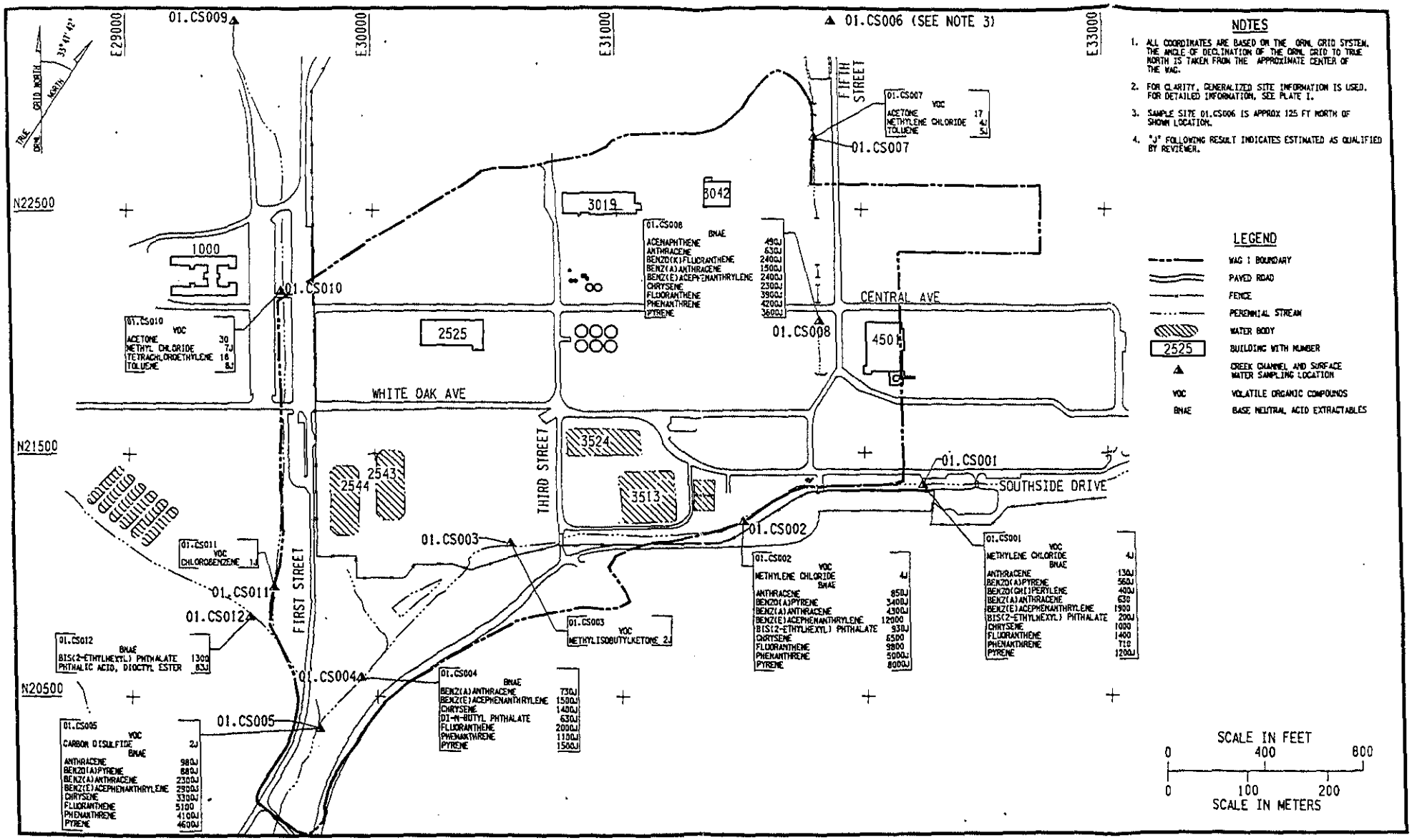
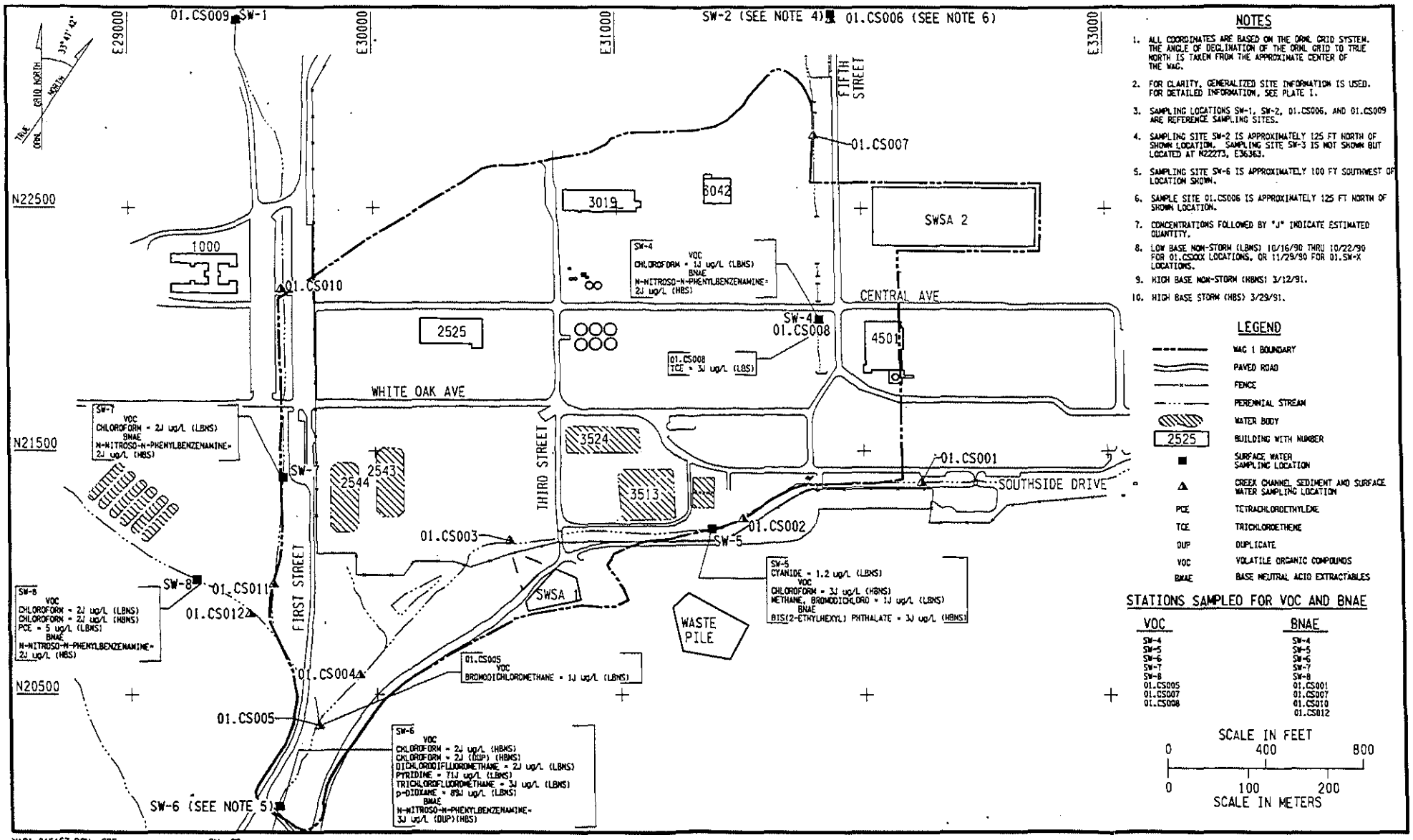


Fig. 4.6.4. VOC and BNAE results (µg/kg) from creek sediment samples.



WAG1 01F157.DGN SRF, SW, CS,
9/15/92

Fig. 4.5.11. VOCs, BNAEs, and cyanide detected in surface water.

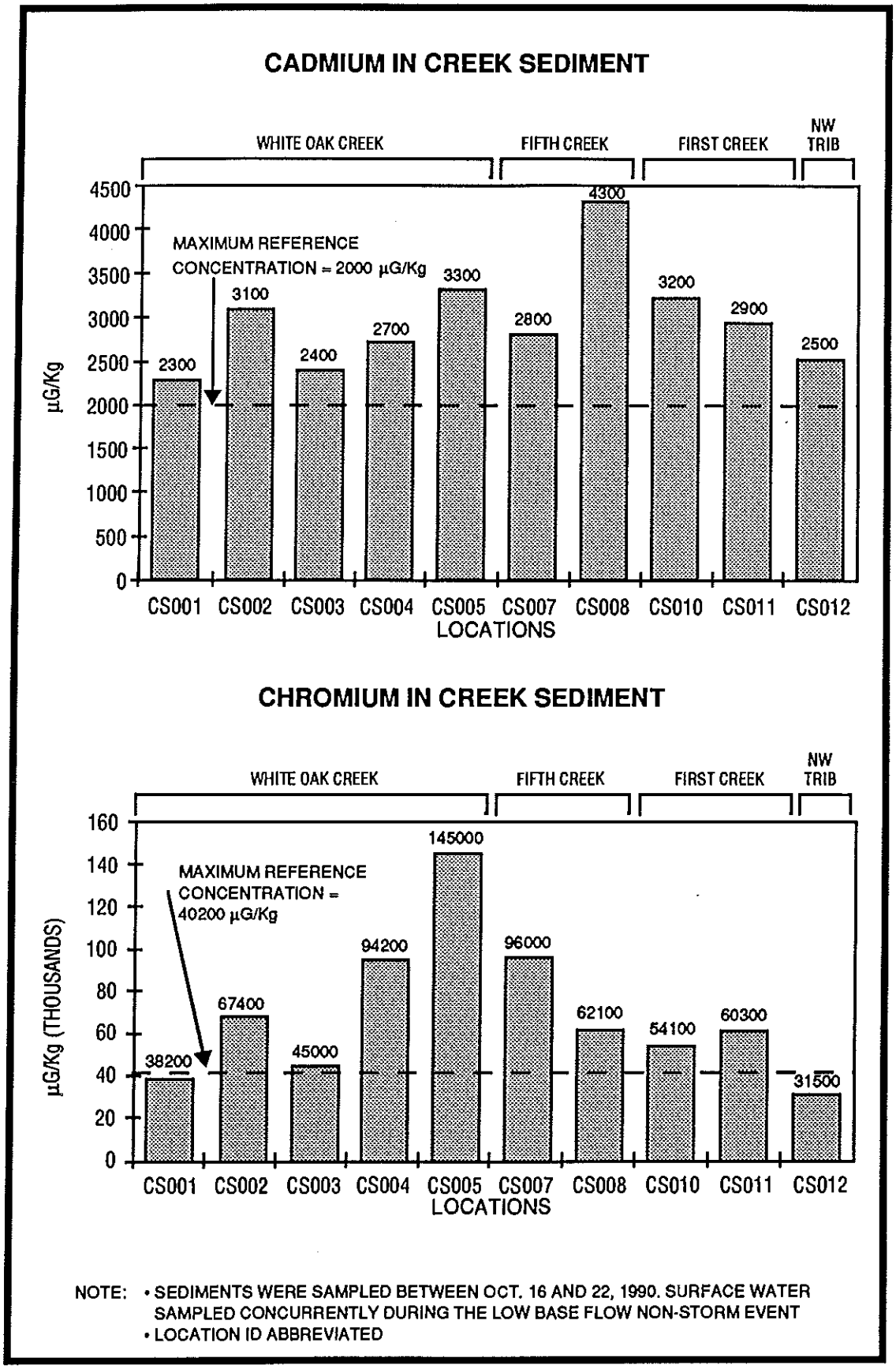


Fig. 4.6.5. Cadmium and chromium in creek channel sediment.

5.33A 6066.27

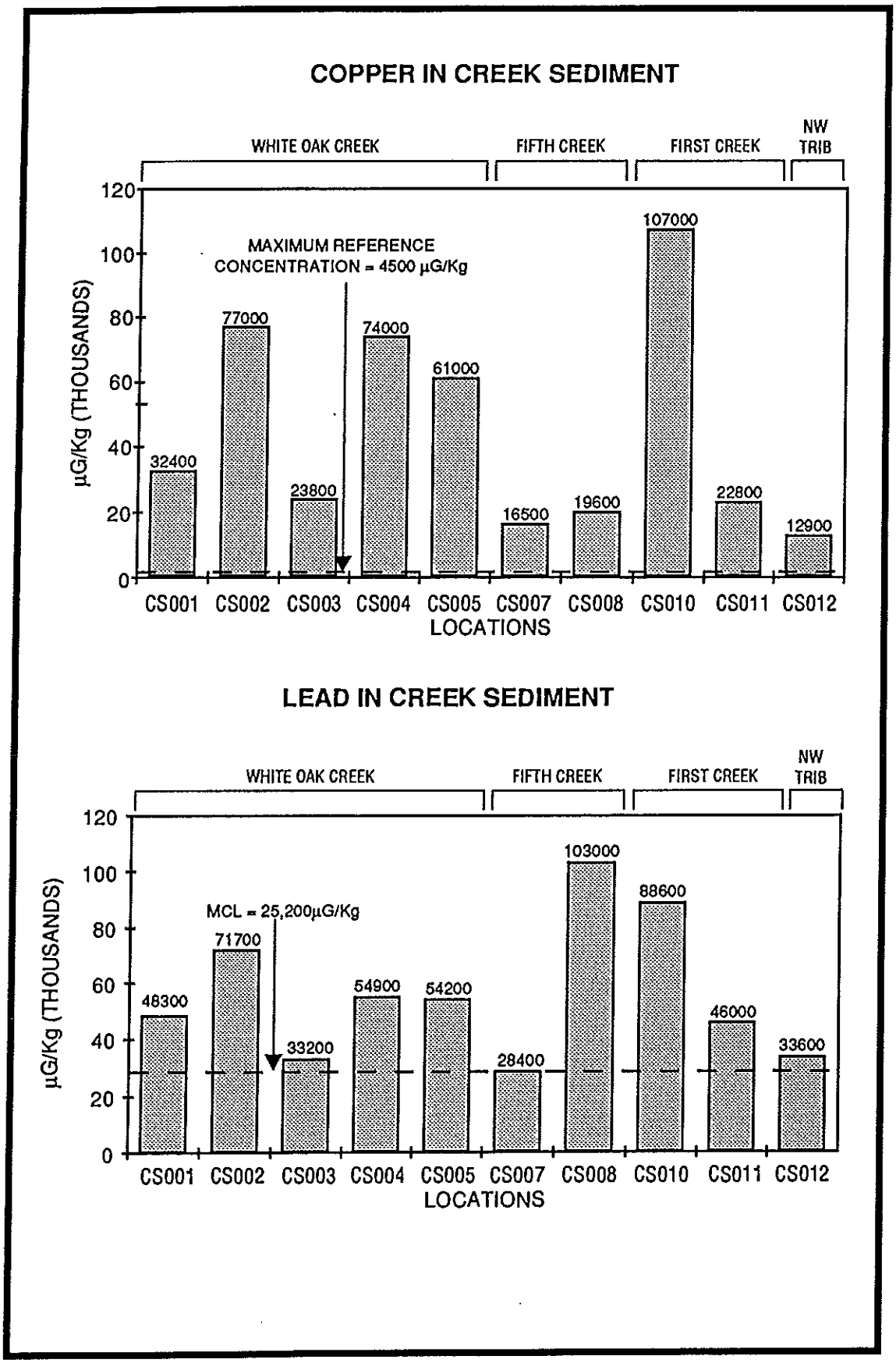
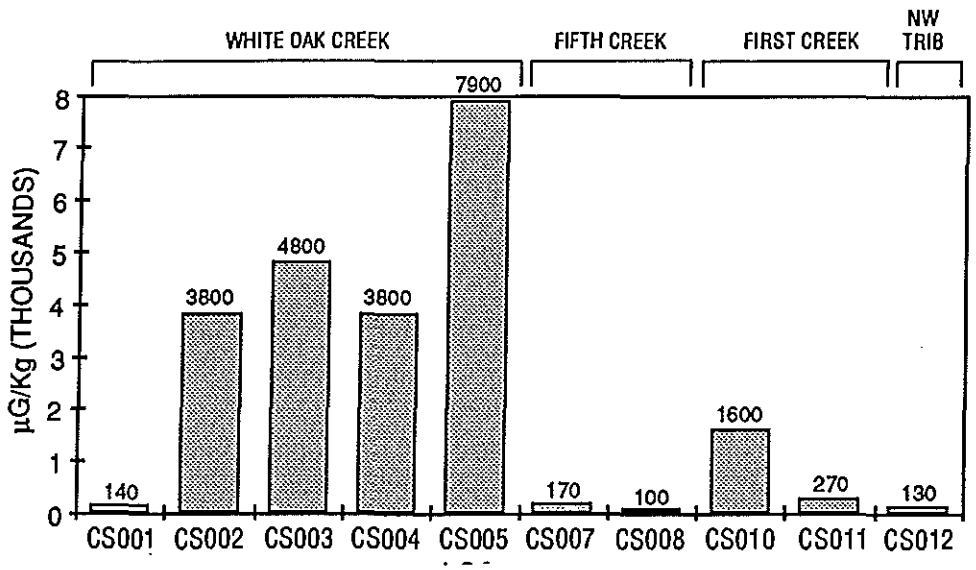
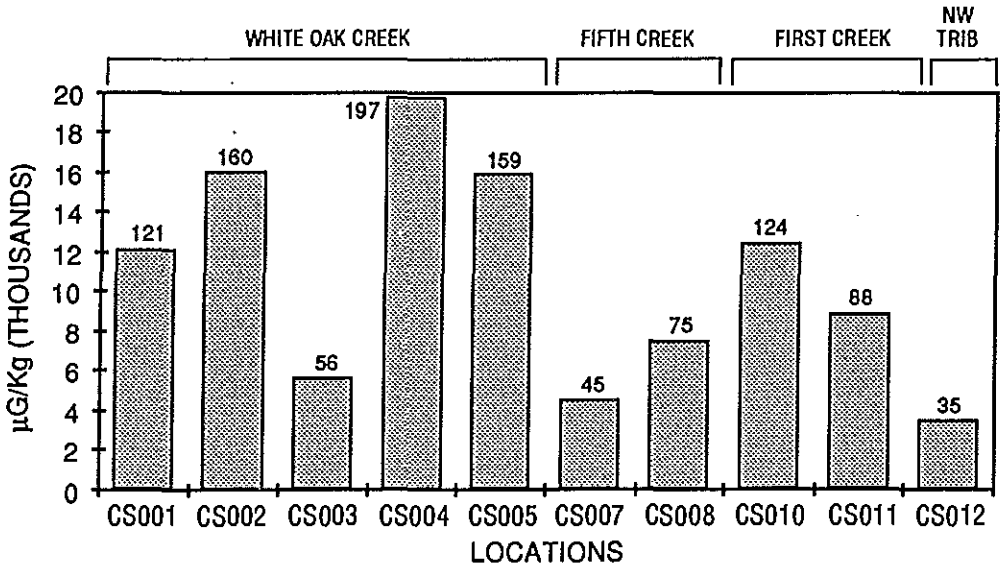


Fig. 4.6.6. Copper and lead in creek channel sediment.



NOTE: MERCURY NOT DETECTED IN REFERENCE SAMPLES (MAX. ESTIMATED DETECTED = 120 µG/Kg).



NOTE:
- SILVER NOT DETECTED IN REFERENCE SAMPLES (MAX. UNDETECTED = 2900 µG/Kg)
- SEDIMENTS WERE SAMPLED BETWEEN OCT. 16 AND 22, 1990. SURFACE WATER SAMPLED CONCURRENTLY DURING THE LOW BASE FLOW NON-STORM EVENT
- LOCATION ID ABBREVIATED

Fig. 4.6.7. Mercury and silver in creek channel sediment.

5.33A 6066.25

5. CONTAMINANT FATE AND TRANSPORT

This section describes the analysis of fate and transport of contaminants in WAG 1; the analysis, essentially qualitative, is not directed at determining exposure point contaminant concentrations. Calculations in this section are not calibrated to specific sources or receptors. The purpose of this section is to provide general information on the fate and transport process at WAG 1, which will form the basis for more detailed, operable unit-specific evaluations to be completed during future investigations. Fate and transport are addressed for all environmental media except air, which was not assessed as part of this investigation. Fate and transport of contaminants via the food chain is also not addressed.

Fate and transport of a contaminant in an environmental medium are governed by the physical, chemical, and biological characteristics of the contaminant and the environmental medium with which it interacts. In addition, transport is governed by environmental factors including meteorology, hydrology, and geology.

Analysis of the fate and transport of contaminants requires consideration of transformation, transport, and speciation processes. This section considers these processes generally, using both literature-based and site-specific data. For example, the effect of speciation processes on the mobility of metals and radionuclides is addressed through distribution coefficients having values based on the physical and chemical characteristics of the contaminated media. Similarly, biochemical transformation processes, which are especially important for organics, are complex and site-specific; any description of biotransformation processes is generalized for the WAG 1 site. Transformation of radionuclides through radioactive decay is generally well understood. Phase I of the RI did not include numerical modeling of groundwater flow and contaminant transport in WAG 1.

Section 5.1 describes the relevant physical, chemical, and biological characteristics of the contaminants and the environmental media. Section 5.2 uses information on the physical characteristics of WAG 1 (given in Sect. 3) to develop a site conceptual model for the analysis of fate and transport. Section 5.3 integrates information on the physical characteristics of WAG 1 with the information on the nature and extent of contamination described in Sect. 4 to perform the fate and transport analysis within the conceptual framework developed in Sect. 5.2.

5.1 CHARACTERISTICS OF CONTAMINANTS AND ENVIRONMENTAL MEDIA

5.1.1 Contaminants

WAG 1 is a mixed-waste site with both radiological and chemical contaminants present in the various media; however, radiological contamination is dominant.

5.1.1.1 Radiological contaminants

Radiological contaminants of potential concern for WAG 1 are listed with their half-lives in Table 5.1.1. The list includes fission and activation products and daughter products of the plutonium-241, uranium-238, and thorium-232 series.

The properties of radionuclides most relevant to their fate and transport are their half-lives and their mobility in water. Half-lives are radionuclide-specific and can be obtained from literature. The mobility of radionuclides is influenced by such site-specific factors as the particular chemical form of the radionuclide, the geochemistry of the waters in which the radionuclide is transported, and the mineralogic composition and texture of the solid medium with which the transporting water comes in contact. These factors are incorporated into the distribution coefficient (K_d), which is a bulk measure of the mobility of the solute. A high distribution coefficient indicates low mobility, and a low distribution coefficient indicates high mobility. The two most important parameters that influence the distribution coefficient are the soil/rock type and the pH of the transporting water.

Table 5.1.2 lists distribution coefficients of radionuclides. Values for cesium, cobalt, radium, strontium, and technetium in soils are based on laboratory measurements for soil samples from three WAG 1 soil borings. Section A.5 of Appendix A describes the locations and the methodologies used to derive the estimates. Typical values not specific to WAG 1 are also listed for various soil and rock types. The large variation in K_d values illustrates the sensitivity of the values to local site characteristics, including pH and soil type. For example, the values for cesium in soil at WAG 1 range from 330 to 1429. These variations introduce a high degree of uncertainty to estimates of subsurface contaminant transport velocities in addition to uncertainties associated with the complex hydrogeology of the site.

5.1.1.2 Metals

Metals of potential concern found in WAG 1 are listed in Table 5.1.3, as are typical distribution coefficients. Mobility and sorption of metals in groundwater depend on the aqueous and solid matrix chemistry in a very complex manner. Heavy metals such as mercury are generally strongly retained by the soil material, so leaching is often negligible. As mentioned earlier, mobility and sorption characteristics of metals are expressed here in terms of distribution coefficients.

5.1.1.3 Organic contaminants

Table 5.1.4 lists organic contaminants of potential concern found in WAG 1 and five chemical properties of each that are important for fate and transport: water solubility, vapor pressure, Henry's law constant, organic carbon partition coefficient (K_{oc}), and persistence in various media. The first eight organics listed, all BNAEs, are distinguished by their low water solubility and high K_{oc}; they tend to remain fixed in soils. The last 11 organics in the table are all volatiles distinguished by their high solubility in water and relatively low K_{oc}; these have been detected in some groundwater and surface water samples (see Sect. 4).

Organics biodegrade to varying degrees both in soil and water in the presence of certain microbial populations. Abiotic transformations caused by hydrolysis and photolysis can also be important, and transformed products are often more mobile and toxic than their parent materials. A notable example of an organic found in groundwater of WAG 1 that biodegrades to more toxic products is trichloroethylene (TCE); the microbial degradation chain of TCE is depicted in Fig. 5.1.1.

5.1.2 Environmental Media

A typical pathway of a contaminant from its source to an exposure point involves one or more of the following media: vadose zone (soil/saprolite), groundwater, surface water, and sediments. Characteristics of these media are detailed in Sect. 3. Characteristics relevant to contaminant fate and transport are summarized in this section.

5.1.2.1 Vadose zone

South of Central Avenue, the vadose zone is generally within the regolith, but north of Central Avenue, it includes weathered and fresh rock. The thickness of the vadose zone decreases from topographic highs to topographic lows at groundwater discharge areas. The vadose zone thickness in WAG 1 ranges from 0 to approximately 60 ft. At any vertical section it varies with water table fluctuations, which are more than 13 ft in the northern (recharge) portion of the WAG.

The physical properties of the vadose zone that influence the movement of water are saturated hydraulic conductivity; total and effective porosities; moisture content; and characteristic curves relating hydraulic conductivity and moisture content to the pressure head. Transport of particle-reactive contaminants is influenced by pH, cation exchange capacity, and total organic content of the vadose zone medium. While most of these parameters were not measured specifically for WAG 1 during this phase of the RI, approximate values can be assigned on the basis of the soil type and properties and the results of previous investigations conducted in and around ORNL.

The total porosity of the vadose zone is probably in the range of 0.3–0.7, typical of clay-rich soils (Freeze and Cherry 1979). The effective porosity, however, may be considerably less, on the order of 10^{-2} to 10^{-3} (Moore 1989; Solomon et al. 1989). Saturated hydraulic conductivity is probably on the order of 10^{-2} to 10^{-3} m/day (Moore 1989).

WAG 1 soils are generally strongly leached, often acidic, and low in organic content. TOC is probably on the order of 0.01–0.1%, and the CEC is between 10 and 50 meq/100 g of soil (see Sect. 3.2). The pH is in the 4.5–8.2 range (Boegly et al. 1987). The higher pH is associated with Gladeville clay series, one of the two principal clay series found in the ORNL complex. Collegedale, the other principal clay series, has pH ranging from 4.5 to 5.5.

Significant portions of the vadose zone have been excavated and backfilled occasionally in connection with construction activities. Materials used in the backfill and their degree of compaction generally differ from the native soil and can alter the flow characteristics of the

disturbed zone. Hydrologic properties of the vadose zone reported by Moore (1989) are applicable to the entire ORR, including undisturbed areas. Values within WAG 1 may vary from these estimates. However, in preliminary tests in the pipeline trench backfills, hydraulic conductivity was not found to be significantly different from the native soil (see Sect. 3.3).

5.1.2.2 Groundwater

Groundwater flow in WAG 1 occurs in two distinct hydrogeologic regions. The upper region is in the regolith, where flow directions are controlled by hydraulic gradients; this is also the region where man-made influences are the most pronounced. The lower region is in the fractured bedrock, where flow directions are chiefly controlled by the geologic structure of the rock. Much of this flow tends to be along fractures (see Sect. 3.3.4).

Geochemically, an upper flow region that includes both regolith and fractured bedrock is characterized by waters rich in calcium bicarbonate. This is underlain by a transition zone characterized by waters rich in sodium bicarbonate. A deeper third region is characterized by waters rich in sodium chloride without circulation. The combined thickness of the upper two regions, where there is groundwater circulation, is approximately 150 ft. Limited head data from coreholes in recharge areas suggest that local groundwater recharge affects only the upper 50 ft of the saturated aquifer (see Sect. 3.3).

The groundwater flow regime in WAG 1 is controlled by the presence of three discharge boundaries—First Creek to the west, Fifth Creek to the east, and WOC to the south—as well as a recharge area to the north. It is believed that most of the flowing groundwater ends up in one of the three creeks. It is possible that some groundwater may remain strata-bound and flow under the creek beds. However, based on evidence available to date, it is assumed that all groundwater discharges into the WOC drainage system.

Groundwater flow is governed by the saturated hydraulic conductivity, direction and magnitude of the hydraulic gradient, orientation of fracture zone or solution features, and effective porosity. Mobility of particle-reactive contaminants in groundwater is influenced by aqueous and solid-matrix chemistry. As discussed in Sects. 5.1.1.1 and 5.1.1.2, sorption and mobility characteristics of metals and radionuclides are expressed in terms of distribution coefficients. Transport is also influenced by the bulk density of the solid matrix and total and effective porosities (or primary and secondary porosities for fractured rocks).

Saturated hydraulic conductivity. Measurements of hydraulic conductivity in the various mappable units of the shallow bedrock revealed considerable variation, though an overall trend of decreasing conductivities with depth could be discerned (see Sect. 3). On average, there is little difference between the hydraulic conductivity of the overburden material and that of the bedrock aquifer. The mean hydraulic conductivity for overburden and bedrock is about 4×10^{-4} cm/s.

Hydraulic gradients. Horizontal hydraulic gradients in the overburden shallow bedrock as estimated from water table contour maps range from about 0.01 to 0.1. Vertical hydraulic gradients, based on head measurements in the coreholes, are generally steeper and upward;

gradients are downward in the recharge areas. The steepest vertical hydraulic gradient (approximately 0.15 upward) was observed in CH001.

Total and effective porosities. No measurements of total and effective porosities have been made for the WAG 1 aquifer. In fractured rock, storativity is commonly assumed to be equal to effective porosity (Moore 1988). Moore (1988) estimates a mean effective porosity of 0.0025 for the shallow aquifer in the ORNL area. Solomon et al. (1989), however, have used a value of 1.8% for effective porosity. The total porosity would be much higher, probably between 0.3 and 0.5.

5.1.2.3 Surface water and sediments

The physical properties of surface water relevant to fate and transport are flow discharge and velocities, lateral and vertical extent of flow, and the amount of suspended sediment present. Lateral and vertical extent of flow are important factors for large streams where mixing of contaminants can be confined to a portion of the total flow cross section. WAG 1 streams are small, however, and total mixing of contaminants in the entire flow cross section can be reasonably assumed.

Flows in First Creek are generally less than 1 cfs at gauging station SW-7 and only about 0.1 cfs when the groundwater is low (see Sect. 3.4). At station SW-4 in Fifth Creek, calculated base flows ranged from about 0.5 to 3.0 cfs during the RI. At WOC station SW-6, base flows during the RI ranged from about 6 to 9.5 cfs. An approximately 5-year record (from April 17, 1985, to December 8, 1990) of flows at SW-6 shows the median flow to be about 7 cfs. A significant fraction, especially during low flows, of WOC flows is imported water from the DOE water treatment plant, supplied at an average rate of approximately 6.2 cfs to satisfy ORNL's potable and process water needs. About 62% of this water is discharged to the WOC surface water system.

Flow velocities, measured only in Fifth Creek, were generally less than 1 fps. On the basis of stream size, flow velocities in First Creek are expected to be lower than in Fifth Creek and somewhat higher in WOC.

Concentrations of suspended sediment were not measured. As comparisons of cesium-137 (a highly particle-reactive contaminant) concentrations in filtered surface water samples with unfiltered sample concentrations demonstrate, suspended sediment can play a significant role in transport of particle-reactive contaminants.

Beyond analyzing for contaminant concentrations, detailed physical and chemical characterization of streambed sediments was not performed. The primary physical characteristics are texture and organic matter content, including humic material. These physical properties influence the affinity of sediments for all classes of contaminants. Visual observations suggest that bed sediments have a significant proportion of coarse-textured particles with low humic content.

The chemical properties of sediments that affect their mobility and bioavailability include pH, oxidation-reduction, particle mineralogy, and the amount of potentially reactive iron and

manganese present. Cerling and Spalding (1981) measured the iron and manganese concentrations in bed sediments of WOC and tributaries. The concentrations of both metals ranged from a few hundred to a few thousand micrograms per gram.

The mineralogy of sediments of the WOC drainage system in WAG 1 is influenced by the presence of limestone, chert, and sandstone in the parent bedrock. Cerling and Spalding (1981) measured the K_d of cobalt, strontium, and cesium in these sediments; values ranged from about 200 to 700 cm^3/g for cobalt, from about 13 to 20 cm^3/g for strontium, and from about 2000 to 6000 cm^3/g for cesium.

5.2 SITE CONCEPTUAL MODEL

The process of contamination of an environmental medium, in its most rudimentary form, involves a source of contamination and a release mechanism whereby contamination is transferred from the source to the environmental medium. Once in the environmental medium, the contaminant can reside in it, be transported with it, or be transferred to another medium. For WAG 1, the principal potential source→release mechanism→contaminated media chains are presented in Table 5.2.1.

5.2.1 Sources

Although each SWMU within WAG 1 is a potential source for the spread of contamination in the various media, it is impractical to address them separately. Section 3.5 describes individual waste management units within WAG 1. SWMUs can be grouped together on the basis of their proximity and similarity of contaminant inventory; Table 5.2.1 uses such groupings of sources.

The principal sources of WAG 1 contamination, both radiological and chemical, are the inactive tanks and associated pipes and radiological impoundments and the contaminated soils around them. The contaminant inventories of the tanks and impoundments are described in Sect. 3.5.

Approximately 95% of the total documented radioactivity of the inactive waste management units in WAG 1 is contained in the six large Gunite tanks in STF. The radiological impoundments are believed to be a major source of tritium contamination of groundwater as evidenced by very high concentrations (ranging from a few hundred thousand to over 800,000 pCi/L) in the groundwater downgradient of them (see Sect. 4.3). The inventory of tritium in these impoundments is not known. Impoundments are also sources of strontium-90 contamination of groundwater.

An NPDES-permitted outfall associated with the Process Waste Treatment Plant (X07) has been a known source of cobalt-60 and cesium-137 discharges into WOC. However, since April 1, 1990, when the new Nonradiological Wastewater Treatment Facility began operating, this outfall and some others have been eliminated (Energy Systems 1991). Some contaminants (e.g., pyridine and p-dioxane) may have discharged to the WOC surface water

system through outfalls. These contaminants are distinguished by their presence in surface water only and have not been identified in groundwater samples (see Sects. 4.3 and 4.5).

5.2.2 Release Mechanisms

Leaks from underground tanks and associated piping and seepage from impoundments are the primary release mechanisms responsible for contamination of the surrounding soil and groundwater. Infiltrating precipitation transfers soil contamination deeper, finally contaminating groundwater. Contaminated groundwater transfers contaminants to the solid aquifer matrix through direct contact, and, for fractured bedrock, also through slow diffusion into the rock matrix pores. Surface water is contaminated through discharge of contaminated groundwater. Because of the extensive network of pipeline trenches in WAG 1, some below the groundwater table, contaminated groundwater has leaked into the outfall systems. In the past, some outfall discharges, most notably X07, were significant contributors to surface water contamination. Release of contaminants by surface runoff is not believed to be significant. Sediments are contaminated through direct contact with contaminated surface water.

Some release mechanisms (e.g., those involving direct contact) are reversible, depending on the relative concentrations of contaminants in the media involved. For example, contaminated sediments can contaminate surface water through desorption. Such reverse releases are usually important after some level of cleanup of one of the media has been achieved.

Because of the deteriorating condition of some of the tanks (see Sect. 3.5), a potential for release of contaminants exists following structural failure (e.g., collapse of a tank roof). Contaminants could be released to the environment through suspension and transport of soil particles in air, through volatilization and transport of volatiles in air, and through direct radiation from radioactively contaminated sludges.

5.2.3 Transport Media

Water is the principal transport medium for contaminants in WAG 1. All contaminants are soluble in water to varying degrees, and most are predominantly transported in dissolved phase. For particle-reactive contaminants such as cesium-137, transport associated with colloids and suspended sediment can also be important.

The subsurface/surface water system is described in detail in Sects. 3.3 and 3.4 and is summarized in Sect. 5.1.2.2. A few additional observations that have particular relevance to transport of contaminants are presented here.

Subsurface flow in the vadose zone takes place under approximately a unit hydraulic gradient. Using a hydraulic conductivity on the order of 0.3 ft/day (approximately equal to the WAG 1 average saturated hydraulic conductivity of 10^{-4} cm/s) and an effective porosity on the order of 10^{-2}, the average linear flow velocity in the vadose zone is estimated to be on the order of 30 ft/day. This is a high velocity resulting from flow being confined to relatively few macropores of very small overall porosities. The total porosity, however, is

quite large, more than an order of magnitude higher than the macropore porosities. Thus, a large, relatively immobile buffer zone exists for the contaminants from which they can flow in and out through slow diffusion.

Most of the groundwater flow takes place in the shallow bedrock in discrete intervals containing fractures. Strike-preferential flow resulting from flows in fractures aligned with bedding planes can be referred to in terms of anisotropy. There is unmistakable evidence of this anisotropy in WAG 1 aquifers, as evidenced by the observed directions of contaminant plumes in relation to the hydraulic gradients (see Sect. 4.3).

Average linear groundwater velocities in different regions of WAG 1 were calculated for the overburden and shallow bedrock on the basis of local hydraulic gradients and hydraulic conductivities. An effective porosity of 1.8% was assumed in both the overburden and shallow bedrock (Solomon 1989); the results are presented in Sect. 3.3. The velocities ranged from 0.0042 to about 45 ft/day. The mean groundwater flow velocity in the portion of the WAG south of Central Avenue, where most of the contaminant transport takes place, is estimated to be between 1.3 and 1.5 ft/day. Computed velocities in this region range from less than 0.01 ft/day to greater than 12 ft/day.

An analog of what exists in the vadose zone exists in the saturated zone, where flow takes place predominantly in discrete rock fractures of very low overall porosities, and a large, relatively immobile volume exists in the fine pores of the rock matrix. This sets the stage for the well-known phenomenon of matrix diffusion of contaminants. Contaminant transport takes place largely by advection in discrete fractures. At the same time, contaminants are transferred from fractures to the rock matrix by slow diffusion. Matrix diffusion retards and attenuates contaminant migration. Contaminants in the matrix are potential sources.

Another phenomenon that may be important for transport of particle-reactive contaminants is transport by colloids. Contaminants attached to colloids are much more mobile than would be expected based on their distribution-coefficient-dependent retardation factors. Colloidal transport may be important in both the macropores of the vadose zone and the fractures of the saturated zone. The degree to which such transport is important depends on the colloid attachment following collisions with surfaces of macropores or fractures, or on the so-called sticking efficiency of the surfaces (LLNL 1992). This, in turn, depends on the electrostatic and van der Waals forces between the particles and the surface. When the ionic strength of the solution is weak, sticking efficiencies approach zero. Even when sticking efficiencies are low, "colloids should not be transported more than a few tens of meters unless other processes are at work to release them" (LLNL 1992). In large fractures such as those found in the northern section of WAG 1, enough turbulence may exist to release colloids from surfaces.

The active zone of groundwater flow is confined to approximately the upper 150 ft or less of the water table aquifer. Sufficient vertical gradients near the three discharge boundaries exist, suggesting that most contaminants in the active flow zone may discharge to streams. However, some contaminants may flow under the stream as strata-bound flow (see Sect. 3.3). When contaminants flow toward First or Fifth Creek, the flow appears to

be strata-bound and is confined to certain geologic layers. However, flows toward WOC are interstrata.

Groundwater discharging into the WOC surface water system flows off site as part of creek base flows. Surface water is the final transport medium for contaminants that are carried off site either in dissolved phase or bound to suspended particles.

5.3 FATE AND TRANSPORT

The medium most immediately and most commonly affected by a contaminant release from its source is soil. The nature and extent of soil contamination is described in Sect. 4. The leachability of contaminants from soil is a good indicator of their mobility and transferability to other media. Soil samples were selected from areas suspected of high metal and radiological contamination and subjected to leachability (modified TCLP) analysis using deionized water. The analytical results of this leachability test are presented in Appendix A, Sect. A.5. Based on results of this analysis, all metals and radiological contaminants, with the obvious exception of tritium, are found to be strongly held in soils (Table 5.3.1). Radioactive strontium was the only other radionuclide consistently detected in the extracts above quantitation limits (cesium-137 was detected in two extracts). These observations are consistent with the generally widespread occurrence of tritium and strontium in groundwater samples (see Sect. 4).

The relative immobility of metals and radionuclides in soils explains why, although their concentrations in soils may be high, they remain relatively low in groundwater and surface water. All BNAEs listed in Table 5.1.4 are also strongly held in soils, as indicated by their high K_{oc} values; few BNAEs have been detected in surface water. Volatile organics, on the other hand, leach readily from soil to groundwater and, because their distribution coefficients are generally low, are transported in groundwater relatively rapidly. When discharged into surface water, their concentrations decrease rapidly because of loss from volatilization.

5.3.1 Groundwater

Subsurface transport of particle-reactive contaminants occurs at a velocity that depends both on the average linear groundwater velocity and contaminant-specific distribution coefficient. The velocity of contaminant transport is given by

$$V_c = \frac{V_g}{\left(1 + \frac{\rho_b K_d}{\theta}\right)} = \frac{V_g}{R}$$

where V_c = velocity of contaminant transport, LT^{-1}
V_g = average linear groundwater velocity, LT^{-1}
ρ_b = bulk density of the solid matrix, ML^{-3}
K_d = distribution coefficient, L^3M^{-1}
θ = moisture content, dimensionless, and
R = retardation factor, dimensionless.

This equation assumes Darcian (porous-media) flow; actual flow velocities of WAG 1 are likely to be greater in localized areas because of the presence of solution channels and highly developed fracture systems. The contaminant-specific retardation factor, R, must be estimated to ascertain the rate of contaminant migration. As an example, the retardation factor is estimated for TCE, an organic observed to be present in WAG 1 groundwater. The distribution coefficient of an organic can be expressed as $K_d = f_{oc} K_{oc}$, where f_{oc} = mass fraction of organic carbon content and K_{oc} has been previously defined. Assuming an f_{oc} of 0.0005, and K_{oc} of 126 cm^3/g (see Table 5.1.4), a value of 0.063 cm^3/g for K_d is determined. Assuming $\rho_b = 1.8$ cm^3/g and $\Theta = 0.4$, a retardation factor of 1.28 is calculated. This value is close to 1, indicating that TCE and other volatiles with comparable K_{oc} levels move relatively unretarded in groundwater in a low organic carbon environment such as that expected at WAG 1.

Similar calculations for metals and radionuclides would show that most metals and radionuclides are significantly retarded because of their particle-reactive nature. Tables 5.3.2 and 5.3.3 list the ranges of transport velocities of the radionuclides of concern in the northern and southern portions of WAG 1, respectively. This information is based on average linear groundwater velocities presented in Sect. 3 and distribution coefficients presented in Table 5.1.2. Because of wide variations in distribution coefficients, considerable uncertainty surrounds these velocities. This is in addition to a high level of uncertainty about groundwater velocities and about chemical complexation and other factors that affect migration velocities. A further complicating factor is the matrix diffusion phenomenon, which results in apparent retardation of contaminant movement during the active phase of contamination when it acts as a buffer for contaminants. The spread of contaminants is also significantly influenced by dispersion in the heterogeneous porous media. As a result of these uncertainties, all transport velocities should be considered rough approximations.

5.3.1.1 Radiological

Radiological contaminants found in groundwater migrate at velocities that depend on the groundwater velocity and the contaminant-specific retardation factor. While migrating, they undergo radioactive decay at a radionuclide-specific decay rate and form daughter products that may be more or less mobile than the parent.

Because of the complex hydrogeology of the WAG 1 site, contaminant migration velocities can only be approximated. Since tritium moves unretarded in groundwater ($K_{d=0}$), its transport is discussed first.

The principal sources of tritium contamination of WAG 1 groundwater are the radiological impoundments. A typical groundwater velocity of 0.2 ft/day can be assumed for the impoundment area (see Table 3.34), and the distances from the impoundments to WOC, the discharge boundary, are approximately 100 to 300 ft. The groundwater residence time of tritium originating from the impoundments would, therefore, range from 1 to 4 years. Because the half-life of tritium is 12.3 years (see Table 5.1.1), no significant decay of tritium for this case is expected. Consequently, the large differences in tritium concentrations in surface and groundwater around the impoundment areas (see Sects. 4.3 and 4.5) can be attributed to dilution alone.

Impoundments are also sources of strontium-90 and thorium-232. The latter is virtually immobile, having a very high K_d (see Table 5.1.2). However, a daughter, radium-228, is relatively mobile and is detected in significant concentrations in wells downgradient of the impoundments. Using the estimated groundwater transport velocities for radium of 5.7×10^{-3} ft/day to 0.15 ft/day, it would take between 2 and 48 years for radium-228 to travel 100 ft from the 3513 and 3540 impoundments to WOC. Time estimates to travel 300 ft from the 3524 impoundment to WOC range from 6 to 144 years. If local groundwater velocities (0.2 ft/day) are used instead of area-wide averages, the transport travel times for radium range from 12 to 330 years to migrate 100 ft and 36 to 995 years to migrate 300 ft. Thus, radium-228 may have migrated from the southernmost impoundments to WOC, but it is much less likely that radium-228 traveling in groundwater from the northernmost impoundments could have reached WOC. Also, radium-228 would undergo significant decay before reaching WOC. [The half-life of radium-228 is only 5.76 years (see Table 5.1.1)]. Strontium-90, which has a migration velocity about three times that of radium-228 (see Table 5.3.2), would take between 34 and 50 years to travel from the farthest impoundment (3524) to WOC and would also undergo some decay. [The half-life of strontium-90 is 28.8 years (see Table 5.1.1).] Concentrations of strontium-90 and radium-228 in surface waters would reflect the effects of both radioactive decay in groundwater and dilution in groundwater and surface water.

Potential sources of radiological contaminants associated with NTF and STF and associated piping are approximately in the center of the WAG. The contaminant migration pathway (for any contamination that is not captured by the tank farm sump system) would be predominantly along strike toward First Creek, a distance of approximately 1200 ft. A higher groundwater velocity can be assumed for this area because groundwater flow is predominantly in bedrock at steeper hydraulic gradients. Assuming a groundwater velocity of 5 ft/day for this area (see Table 3.3.4), the groundwater residence time of tritium would be less than a year, too short for any significant decay. Regardless of the location of a tritium source within WAG 1, the groundwater residence time appears to be too short for any significant decay to occur.

Rates of potential migration of strontium-90 from the NTF/STF area may vary from 0.15 to 1 ft/day (see Table 5.3.2). Assuming a rate of migration of 0.5 ft/day, it would take about 7 years for strontium-90 to reach First Creek. No significant decay is expected. Radium-228, however, might take three times longer and would decay to about one-twelfth its source value.

The migration pathway of radiological contaminants potentially originating in the graphite reactor area is decidedly toward Fifth Creek. Because of the relatively short distance to the discharge boundary, no significant decay in groundwater of tritium or strontium-90, the major contaminant, is expected. Americium-241, identified in groundwater samples collected near the Building 3042 area, flows toward Fifth Creek. K_d values were not measured for americium as part of this RI, but the literature values for distribution coefficients range from 1 to 22,000 cm^3/g. Given this high degree of variability, it is

possible that americium could reach Fifth Creek within a few years, but the migration velocity cannot be estimated without site-specific K_d values; therefore, its migration velocity cannot be estimated. However, it is likely that some or most of the contamination is captured by the 3042 building sump, which has been shown to interact with groundwater (see Sect. 3.3).

Plutonium-238 and plutonium-239/40 have been detected in some wells. Plutonium has a high K_d (see Table 5.1.2) and is relatively immobile. However, because of the long half-lives of plutonium-239/240, they would persist in groundwater for a long time.

Technetium-99 has been detected at high concentrations in well 590 near the isotope production facility, Building 3026. It has also been detected in CH008 and several wells at smaller concentrations. The distribution coefficient of technetium is almost zero. For this reason and because it has a long half-life, it is expected to reach First Creek, the expected discharge boundary, undecayed. However, no technetium-99 has been detected in any surface water samples.

The presence in surface water of certain radionuclides (for example, uranium-234 and thorium-232) that have very high distribution coefficients cannot be explained in terms of Darcian groundwater velocities and distribution-coefficient-dependent retardation factors. Their presence may indicate that their mobility is affected by variations in the speciation and solubility of the elements and that these variations are not well represented by the K_d values used for the computations. It is also possible that groundwater in this area is migrating faster than can be explained using porous-media estimation methods, or that contaminants have entered the surface water system through inleakage of groundwater to the storm water system, through colloidal transport, or both.

5.3.1.2 Organics

Well 598 has the highest concentration of any organic compound detected in WAG 1 groundwater. The maximum concentration of the volatile TCE at this well was 210 mg/L (see Sect. 4.3). TCE appears to have completely biotransformed into other products within about 600 ft downgradient from this well; no TCE was detected in wells further downgradient, although its degradation products, vinyl chloride and 1,2-DCE, were detected. (For degradation products of TCE, see Fig. 5.1.1). These transformed products in some wells could have been derived from PCE, which was detected in wells 554, 564, 873, and 886 (see Sect. 4.3).

Except for 3 μg/L of TCE found in one sample from Fifth Creek, none of these organics were detected in surface water, where they are rapidly lost by volatilization.

Well 553 shows significant concentrations of BTEX organics. A diesel fuel storage tank at this location, which has recently been removed, is the likely source of this contamination.

Because the contamination is limited in extent, the release is probably recent. BTEX can readily biodegrade in shallow groundwater in the presence of oxygen.

5.3.1.3 Metals

Metal contamination in groundwater has not been analyzed for fate and transport. In general, metal contamination is found in plumes also associated with radiological contamination. The most prevalent metals detected in groundwater are lead, chromium, and cadmium. Although several SWMUs with mercury spills have been identified, no significant mercury contamination has been detected in groundwater.

5.3.2 Surface Water/Sediment

It is believed that all contaminated groundwater within WAG 1 discharges into the WOC drainage system. Surface water is thus the final off-site transport medium. Contaminants are carried either in dissolved phase or bound to suspended particles; the latter mode, however, is believed to be less important except during large floods, when contaminated floodplain sediments can constitute a significant portion of the total stream contaminant load.

In First and Fifth creeks, maximum radiological concentrations are typically observed during low base flow. During high groundwater and during storm events, the effect of dilution dominates the effect from any fresh releases and results in overall dilution of contaminants. In WOC downstream of the 3513, 3524, 3539, and 3540 impoundments, this trend is not observed. The maximum radiological contamination, primarily tritium, appears to coincide with high groundwater. This difference in the pattern of contamination in WOC might be the result of influences from the surface impoundments. A plausible explanation is that high groundwater flushes out tritium from the impoundments and into pipeline trenches and the shallow groundwater system, and these in turn discharge the tritium into WOC.

In general, radiological contamination in the surface water system is consistent with the groundwater contamination. The maximum VOC contamination observed in surface water, consisting primarily of pyridine and p-dioxane, occurred at sampling location SW-6. This event is believed to be transitory, caused perhaps by episodic discharge from building drains. A sample taken a few months earlier at location 0.1CS005, just upstream of SW-6, showed none of these volatiles. In general, unless there is a continuous source, organic contaminants would be lost from surface waters within a few days to a few months because of volatilization or other degradation processes (see Table 5.1.4 for half-lives in surface water).

The occurrence of metals and highly sorbent radionuclides in the surface water system is primarily associated with sediments. For example, cesium-137 was only detected in unfiltered samples collected as part of the RI. Cesium-137 was also detected in sediment samples from WOC at concentrations as high as 2480 pCi/g. These observations are consistent with the high K_d values (330 to 1429 cm^3/g) measured for cesium in WAG 1 soils and illustrate the strong affinity of cesium-137 to soil particles. Other contaminants with

similar characteristics include thorium, uranium, plutonium, cobalt (to a lesser degree), and mercury.

The nature and extent of sediment contamination (an indicator of the history of contamination) is described in Sect. 4.6. Because improved waste management practices have reduced contamination in point-source discharges, desorption of contaminants from sediments is expected. For example, bed sediment contamination with cesium-137 downstream of the impoundments was caused, in part, by outfall X07 discharges. Following removal of this outfall in April 1990, some desorption of cesium-137 from sediments into surface water is expected. However, sediment transport is the chief migration mechanism for these contaminants in surface water.

Floodplain sediments and soils around known mercury spill sites show elevated concentrations of mercury, commonly as much as tens of thousands of micrograms per kilogram. Vaporization of mercury at these levels could be significant, depending on the acidity and humic content of the soil. Mediation by microbial processes could also be important for mercury vaporization (Nriagu 1979). The extent of the mercury vaporization problem was not investigated during this phase of the RI. Because leaching of mercury is negligible in almost all circumstances, no significant migration of mercury in solution is occurring through the water pathway.

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Table 5.1.1. Half-lives of radiological contaminants of concern at WAG 1

Radionuclide	Half-life (years)
Tritium	12.33
Cobalt-60	5.27
Strontium-90	28.8
Technetium-99	2.13×10^5
Cesium-137	30.17
Promethium-147[a]	2.62
Radium-226	1.6×10^3
Radium-228	5.76
Thorium-232	1.41×10^{10}
Uranium-234	2.45×10^5
Uranium-235	7.038×10^8
Uranium-238	4.468×10^9
Plutonium-238	87.74
Plutonium-239	2.41×10^4
Plutonium-240	6.57×10^3
Plutonium-241	433

Source: Gilbert, T. L. et al. 1989. *A Manual for Implementing Residual Radioactive Material Guidelines*, Argonne National Laboratory, ANL/ES-160.

[a]The presence of ^{147}Pm is probably a false positive resulting from analytical procedures, as described in Appendix C, Sect. C7.

Table 5.1.2. Distribution coefficients (K_d) for radiological contaminants[a]

Radionuclide	WAG 1 K_d (cm^3/g)[b]	Gilbert et al. 1989 Soil/rock type	pH	Range of K_d (cm^3/g)[c]
Cesium[d]	300–1429	Soils		190–1,000
		Shaly siltstone, greater than 4 mm		
				100–310
		Alluvium, 0.5–4 mm		120–3,200
			5	150
			8	905
Cobalt	10.6–64	Soils and clays		1,000
Radium	1.7–52.5	Soils and clays		70
				60
			6	100
Strontium	13.5–18.1	Soils and clays	7	30
				1.4–8
		Shaly siltstone, greater than 4 mm		48–2,400
			7	500
		Alluvium, 0.5–4 mm		
Technetium	0.6–1.0			
Thorium		Soils and clays		60,000
		Silt loam, calcium- saturated clay	6.5	160,000
		Montmorillonite, calcium-saturated clay	6.5	400,000
Uranium		Clay soil, U(vi), 5mM$Ca(NO_3)^2$	6.5	4,400
			6.5	62,000
		Silt loam, U(vi), calcium-saturated		
Plutonium		Soils and clays		2000
Americium[e]		Sandy clay	2.5–3.1	1–280
		Dolomite	6.5–7.8	2,600–22,000

[a]K_d of tritium is zero.

[b]See Sect. A5.1 (Appendix A) for details.

[c]*Source:* Gilbert, T. L. et al. 1989. *A Manual for Implementing Residual Radioactive Material Guidelines*, Argonne National Laboratory, ANL/ES-160.

[d]Only the name of the element is given. Isotopic form does not influence K_d.

[e]Americium values are from Isherwood 1979, quoted by W.G. Sutcliffe et al., *Uncertainties and Sensitivities in the Performance of Geologic Nuclear Waste Isolation Systems*, Vol. 2, Lawrence Livermore Natl. Lab., ONWI-352/UCRL-53142, April 1981, pp. 85–86.

Table 5.1.3. Distribution coefficients in soils and clay of selected metals

Metal	Distribution coefficient[a] K_d (cm^3/g)	Geometric standard deviation
Arsenic	3	1.8
Cadmium	7	2.4
Copper	20	3.0
Lead	100	5.5
Mercury	100	
Silver	100	

Source: Gilbert, T. L. et al. 1989. *A Manual for Implementing Residual Radioactive Material Guidelines*, Argonne National Laboratory, ANL/ES-160.

[a]Geometric means.

Table 5.1.4. Physical, chemical, and fate data for selected organic contaminants

Chemical	Mole weight (g/mole)	Water solubility (mg/L)	Vapor pressure (mm Hg)	Henry's Law constant	K_{oc} (mL/g)	Half-life range (days)	
						Soil	Surface water
Benzo(a) pyrene	252	1.20E-03	5.60E-09	1.55E-06	5.5E+06	420–480	0.4
Benzo(a) anthracene	228	5.70E-03	2.20E-08	1.16E-06	1.38E+06		0.1–5.0
Phenanthrene	178	1.00E+00	6.80E-04	1.59E-04	1.40E+04		0.38–2.00
Benzo(g,h,i)perylene	276	7.00E-04	1.03E-10	5.34E-08	1.60E+06		
Benzo(b)fluoranthene	252	1.40E-02	5.00E-07	1.19E-05	5.50E+05		1.0–2.0
Benzo(k)fluoranthene	252	4.30E-03	5.10E-07	3.94E-05	5.50E+05		
Pyridine	79	1.00E+06	2.00E+01				2.0
p-Dioxane	88	4.31E+05	3.99E+01	1.07E-05	3.5		
Trichloroethylene	131	1.10E+01	5.79E+01	9.10E-03	126		1.0–90.0
Vinyl chloride	63	2.67E+03	2.66E+03	8.19E-02	57		1.0–5.0
1,2 Dichloroethylene (trans)	97	6.30E+3	3.24E+02	6.56E-03	59		1.0–6.0
1,2 Dichloroethylene (cis)	97	3.50E+03	2.08E+02	7.58E-03	49		1.0–6.0
Benzene	78	1.75E+03	9.52E+01	5.59E-03	83		1.0–6.0
Toluene	92	5.35E+02	2.81E+01	6.37E-03	300		0.17
Tetrachloroethane	166	1.50E+02	1.78E+01	2.59E-02	364		1.0-30.0

Source: EPA 1988. *Superfund Public Health Evaluation Manual*, EPA/540/1-86/060.

Table 5.2.1. Principal source-release mechanism–contaminated media chains for WAG 1

Source/operable unit	Release mechanism	Contaminated medium
Tanks, pipes	Leaks	Soils, groundwater
Tanks	Structural failure[a]	Soils, direct radiation
Impoundments	Seepage	Soils, groundwater
Contaminated soils, SWSA/waste pile	Infiltrating precipitation	Soils in deeper vadose zone, groundwater
Contaminated groundwater	Direct contact, diffusion	Aquifer matrix
Contaminated groundwater	Discharge	Surface water
Surface water	Direct contact	Sediments

[a]Postulated, not actual.

Table 5.3.1. Maximum extract concentrations for selected WAG 1 contaminants

Analyte	Maximum water extract concentration	Corresponding soil concentration
Cadmium	6.6 μg/L	9,000 μg/kg
Chromium	68.8 μg/L	14,200 μg/kg
Lead	3.6 μg/L	30,200 μg/kg
Mercury	0.7 μg/L	ND (100U μg/kg)
Cesium-137	247 pCi/L	1,148 pCi/g
Total radioactive strontium	21,730 pCi/L	169 pCi/g[a]

ND = not detected.

[a]Extract value is higher than expected from soil concentration. Sample nonhomogeneity is suspected to be the reason for the unexpectedly high extraction result.

Table 5.3.2. Ranges of radionuclide transport velocities—north WAG 1

Radionuclide	Estimated range of transport velocity[a] (ft/day)	
	Soil	Rock[b]
Cesium	8.8×10^{-4}–4.9×10^{-3}	1.4×10^{-2}–5.3×10^{-2}
Cobalt	8.8×10^{-4}[c]	[d]
Radium	1.2×10^{-2}[c]	[d]
Strontium	3×10^{-2}[c]	5.2×10^{-1}–3.3
Thorium	1.5×10^{-5}[c]	[d]
Uranium	2.0×10^{-4}[c]	[d]

[a]Based on average groundwater velocities (Table 3.3.4) and K_ds for soil and shaly siltstone when available (Table 5.1.2). Low range is based on low average groundwater velocity and high K_d. High range is based on high average groundwater velocity and low K_d. $\rho_b = 1.8$ cm^3/g and $\Theta = 0.4$ are assumed.

[b]For rock, K_d for shaly siltstone is used. Site-specific K_d values for fractured rock may differ considerably from these values.

[c]Range is too narrow. Only mean value is reported.

[d]No K_d values available for rock.

Table 5.3.3. Ranges of radionuclide transport velocities—south WAG 1

Radionuclide	Estimated range of transport velocity[a] (ft/day)	
	Soil	Rock[b]
Cesium	4.7×10^{-4}–2.6×10^{-3}	4.1×10^{-3}–1.3×10^{-2}
Cobalt	4.7×10^{-4}	[c]
Radium	6.5×10^{-3}	[c]
Strontium	1.9×10^{-2}	1.5×10^{-1}–1.0
Thorium	10^{-5}	[c]
Uranium	1.3×10^{-4}	[c]

[a]Based on average groundwater velocities (Table 3.3.4) and K_ds for soil and shaly siltstone when available (Table 5.1.2). Low range is based on low average groundwater velocity and high K_d. High range is based on high average groundwater velocity and low K_d. $\rho_b = 1.8$ cm^3/g and $\Theta = 0.4$ are assumed.

[b]For rock, K_d for shaly siltstone is used. Site-specific K_d values for fractured rock may differ considerably from these values.

[c]No K_d values available for rock.

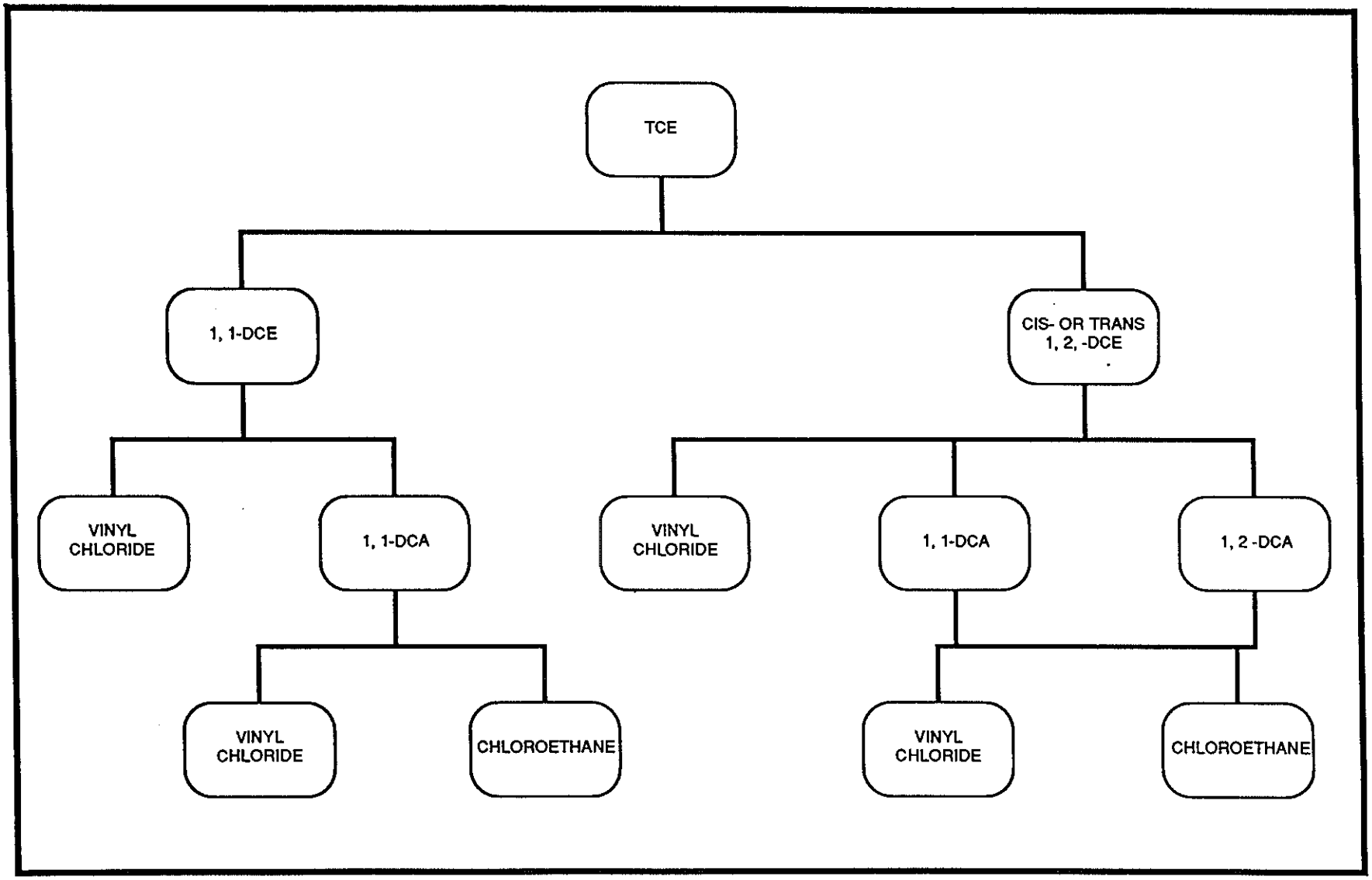


Fig. 5.1.1. Microbial degradation of TCE.

6. SUMMARY AND CONCLUSIONS

This report fulfills an FFA commitment by DOE to document the results of Phase I of the WAG 1 RI, which was conducted in accordance with criteria established in the National Contingency Plan for remedial investigations under CERCLA. Data presented in this report support definition and prioritization of OUs within WAG 1 and development of a preliminary risk assessment. The OU and risk assessment results are presented in separate documents.

6.1 PHYSICAL CHARACTERISTICS OF THE SITE

Groundwater at WAG 1 occurs in bedrock and in overburden soils. In the northern portion of the site, the water table occurs within bedrock below the overburden; in the central and southern portions, the water table occurs within the overburden.

WAG 1 is underlain by a complex network of buried pipes. In the northwest portion, a part of the storm drain network intercepts contaminated groundwater and transfers it directly to First Creek. Previous studies reported that some of the pipeline trench backfill material is more permeable than the surrounding soil and thus provides a preferred pathway for groundwater flow and contaminant transport. Preliminary data collected as part of this investigation did not identify significant differences in the hydraulic conductivity of the trench backfill material and the surrounding overburden material.

Strata-bound flow, in which groundwater flow is essentially confined to a single geologic stratum, was identified as a significant groundwater and contaminant transport mechanism. Because strata-bound flow is controlled by the orientation of bedrock strata and associated fracture patterns, flow directions cannot be predicted by hydraulic gradient data alone. Thus, strata-bound flow has obvious impacts on the development of groundwater monitoring systems and on the selection and design of remedial action alternatives.

Vertical hydraulic gradients in groundwater at WAG 1 are predominantly upward, identifying the site as a groundwater discharge area. Local recharge to shallow groundwater occurs only in the northernmost portion of the WAG and locally at the surface impoundments. Recharge of groundwater through precipitation within the WAG is limited by the presence of pavement and drainage controls. The dlscharge location for groundwater at WAG 1 is the WOC drainage system. There is limited evidence that some groundwater locally underflows First Creek toward the west, and it Is assumed that this groundwater is eventually captured by Northwest Tributary, itself a tributary to WOC.

6.2 CHARACTERISTICS OF WASTE MANAGEMENT UNITS AND SOURCES OF CONTAMINATION

One hundred sixty-seven SWMUs have been identified at WAG 1. Before the Phase I investigation, 27 of these SWMUs had been identified by EPA as warranting no further investigation. Seventy-five of the remaining SWMUs are waste storage tanks; 71 of these have been used for collection, treatment, and/or storage of LLLW. Of the remaining four,

two are small above-ground steel tanks for temporary waste oil accumulation and storage, one is an above-ground stainless steel tank used for nitric acid, and another is an above-ground stainless steel tank used for sodium hydroxide storage. Twenty-five of the tanks are active and 50 are inactive. The inactive tanks were removed from service because of known or suspected in- or outleakage, the absence of secondary containment, or the fact that they were no longer needed. The active tank systems are subject to contaminant and leak detection monitoring under the FFA.

The major contaminants remaining in the six large Gunite tanks are strontium, cesium, thorium, uranium, plutonium, and curium. The activity in these tanks represents about 95% of all of the documented activity in inactive waste management units in WAG 1. Almost half of this 95% is in tank W-10, which holds most of the residual sludge from a previous sluicing operation conducted to remove sludge from the tanks. All six tanks are classified as containing RCRA-hazardous wastes.

The calculations performed in the structural analysis (Fricke 1986) revealed that the reinforcement steel in the part of the tank where the top dome meets the vertical sidewalls does not have sufficient strength to handle the size of the loads that are assumed in the original design specifications, without the support of the prestressed steel hoops in that part of the tank. This apparent weakness may be the result of overly conservative assumptions concerning the remaining strength in the steel used to form the hoops in the dome edge region or in the other reinforcing steel and the concrete in that area. These assumptions would theoretically allow creep and shrinkage in the concrete, losses in strength due to internal friction, deformation at the dome ring, and excessive bending in that part of the tank. Given the absence of as-built drawings, however, it is also possible that design and/or material specifications were exceeded in the construction, resulting in greater strength than specified in the design. Because of uncertainties in estimating variables used for the analysis, the actual structural behavior of these tanks is difficult to predict.

Eight surface impoundments within WAG 1 are designated as SWMUs. Two of them have been used for sewage treatment as part of the sanitary waste treatment system; the others have been used for treatment, settling, and emergency storage of LLLW waste as part of the LLLW system, and for surge or equalization basins as part of the PWTP system. One sewage impoundment contains elevated levels of radionuclides, confirming previous studies indicating that these contaminants probably infiltrated the sanitary sewer pipelines from leaks in other pipelines.

At SWSA 1, five discrete areas of possible buried solid wastes were identified on the basis of geophysical evidence. At SWSA 2, the geophysical surveys indicated 17 discrete anomalies, 9 of which correspond to locations marking a previous soil boring program. Magnetic data indicated the presence of ferrous metal at 15 of the locations, and EM data identified the other 2 locations, neither of which correlated to the soil boring program.

The old LLLW piping system has been a significant potential source of contaminants, and the interconnecting utility trench system has the potential to provide preferred pathways for contaminant transport. The original LLLW system piping consists of single-walled, stainless steel pipe; past leaks from these pipes are responsible for 23 SWMUs identified in

WAG 1. The active portions of the LLLW piping system are being replaced with a new double-walled system designed to prevent leaks.

6.3 NATURE AND EXTENT OF CONTAMINATION

6.3.1 Groundwater

Several general areas of contamination were identified on the basis of results of the groundwater sampling program (see Fig. 4.3.26). Both radiological and chemical contaminants were identified in groundwater. The primary radionuclides found in groundwater at WAG 1 are strontium and tritium. Radionuclides found less frequently include radium-226/228, technetium-99, uranium-234, uranium-238, thorium-228/230/232, plutonium-238 and plutonium-239/240, americium-241, cobalt-60, nickel-63, iron-55, and cesium-137. Promethium-147 was also detected, but results are suspect because of the probable misidentification of this radionuclide.

There is evidence that strontium-90 is migrating from WAG 1 and seeping into First Creek. There is also limited evidence that some of this same plume may be underflowing First Creek and migrating westward. Other locations where groundwater may be impacting surface water quality are near the surface impoundments and near SWSA 1. Additional data are needed in these areas to confirm sources of contamination in surface water (see Sect. 6.5).

The most widespread organic compounds found in groundwater at WAG 1 are TCE and its degradation products 1,2-DCE and vinyl chloride. Benzene, toluene, xylene, and ethylbenze were found associated with a buried petroleum storage tank near the steam plant (Building 2519). This tank has since been removed. The metals silver, cadmium, chromium, lead, and mercury (one sample) were detected at concentrations exceeding MCLs in unfiltered groundwater samples from wells within and outside of WAG 1. Cadmium, chromium, and lead, in excess of their respective MCLs, tend to occur in the same wells. Cadmium, the most widespread metal at elevated concentrations, exceeded the MCL at the largest number of locations throughout WAG 1.

6.3.2 Soils

Both man-made and naturally occurring alpha-emitting radionuclides were detected in soil samples from WAG 1. Naturally occurring alpha-emitters detected include those from the thorium series [thorium-232, thorium-228, radium-224, and bismuth-212 (which emits both alpha and beta particles)], and the uranium series (uranium-238 and -234, thorium-230, and radium-226). Man-made alpha-emitters detected include americium-241, plutonium-238, and plutonium-239/240. Most of the contamination is found in the 3019 area, NTF, STF, isotope area, surface impoundments, Buildings 3503/3504 storage pad, floodplain soils, SWSA 1 and vicinity, and the thorium tank farm. Beta-emitting radionuclides commonly found in soils include cesium-137, strontium-90, and cobalt-60. A variety of other man-made radionuclides exceed reference levels (e.g., technetium-99, europium-152/154/155, nickel-63, calcium-45, and tritium) but were found less often and are not as widespread. Naturally

occurring beta-emitters detected above typical reference values include thorium-232/234 and radium-228.

Contamination in soil included 20 VOCs, 39 BNAEs, 7 pesticides, 2 PCBs, and cyanide. PCBs were detected in samples from the CH008 location, which is the site of a former coal storage area and near an associated former steam plant. Other borings that yielded samples containing PCBs were near Building 3529, south of STF (two borings), the surface impoundment (one boring), near the sewage impoundments, and along WOC and First Creek. Dioxins, furans, and herbicides were not detected.

All metals analyzed were detected in soil samples. The concentrations varied widely, possibly indicating both natural variability in the soils and the presence of contamination. Concentrations of individual metals in the main plant area and the floodplain soils varied by orders of magnitude. Metals that exceeded reference include beryllium, cadmium, chromium, cobalt, and mercury. The two highest concentrations of mercury were from samples near Building 3592 at a known mercury spill site; the third and fifth highest were found in the WOC floodplain soil near the Fifth Creek confluence with WOC.

6.3.3 Surface Water

Both man-made and naturally occurring radionuclides were detected during the Phase I investigation of WOC, First Creek, Fifth Creek, and Northwest Tributary. The most frequently detected were strontium-90 and tritium.

The highest concentrations of strontium were found in First Creek. Flux calculations indicate that during the low base sampling event, approximately half of the strontium in the WOC system above the 7500 bridge could be attributed to First Creek and Northwest Tributary. During the high base sampling event (including a storm episode), the total strontium loadings within First Creek and the rest of the WOC system increased but the relative amount of contamination contributed by First Creek and Northwest Tributary declined to approximately 25% of the total amount. Evidently there was a strontium source that discharged greater quantities to WOC during high base and high base storm flow conditions than during low base conditions. Potential sources may include a number of outfalls, SWSA 1 runoff or leachate, leaking LLLW lines, contaminated groundwater discharge from the main plant area, or seepage from the 3513/3524 surface impoundments.

Results of a screening survey performed in October 1991 indicated that elevated gross beta activity, presumably strontium, enters First Creek via a seep near the contact between Chickamauga Units D and E, and two storm water outfalls (341 and 342) west of Building 2500.

Concentrations of tritium detected in surface water were below the SDWA MCL of 20,000 pCi/L. Previous studies reported significantly higher concentrations at the 7500 bridge (i.e., up to 590,000 pCi/L), approximately 100 ft upstream of SW-6 in WOC. This suggests that there is a potential for high variability in the amount of tritium in WOC.

The highest concentration of cesium-137 was found in samples collected during low base conditions at a location near the surface impoundment and SWSA 1. Cesium-137 was not detected in filtered samples, indicating that it is transported through adsorption to suspended sediments. Potential sources of cesium-137 include seepage from waste management units along WOC (including the surface impoundments and SWSA 1), discharge from outfalls, and erosion/suspension from bottom sediments and floodplain soils.

No metals were detected at concentrations exceeding their respective MCLs. No organophosphorous pesticides, dioxins/furans, or chlorinated herbicides were detected in surface water samples. Of the few VOCs and BNAEs detected, only the VOCs pyridine and p-dioxane may be of concern, although they were detected in only one sample.

6.3.4 Sediment

Both man-made and naturally occurring radionuclides were detected in sediment samples from WAG 1. Radionuclides associated with the natural uranium and thorium decay series were detected at concentrations within reference ranges and are not considered site contaminants. All man-made radionuclides, including the transuranics americium-241, curium-242, and curium-243/244, were detected at concentrations exceeding reference levels, indicating that these are site contaminants. Cesium-137 was the most frequently detected man-made radionuclide in sediments. Sediment from three WOC locations between Third Street and First Creek contained cesium-137 at concentrations 1 to 2 orders of magnitude greater than reference concentrations.

VOC contamination in sediments was minimal. However, PAHs associated with coal combustion and parking lot runoff were detected in samples throughout WOC and in Fifth Creek. The metals cadmium, chromium, copper, lead, and mercury were detected above reference levels.

The concentrations of mercury detected were comparable to those reported in previous studies, although the maximum concentrations found in previous studies at locations associated with outfalls into Fifth Creek were not encountered. This difference is likely due to the selection of sampling locations and should not be viewed as an indication that the high concentrations of mercury detected in previous studies (e.g., 4874 to 7427 $\mu g/g$ near outfall 261 (Taylor 1990a) have dissipated.

6.4 GENERAL OBSERVATIONS ON OPERABLE UNITS

Based on the results of the Phase I investigation and previous studies, three types of releases and potential exposure conditions can be recognized.

Approximately 95% of the documented inventory of radionuclides within inactive waste management units in WAG 1 is contained within the underground storage tanks in STF. While there have been no documented releases from these Gunite tanks, their age and uncertain structural integrity suggest the potential for a release in the future. Given the large radiological inventory and similar construction, these tanks, along with similar but smaller

tanks in NTF and tanks W-11 and TH-4, are grouped as one source control OU designed to prevent future releases that might result in either groundwater contamination or exposure of the on-site work force to airborne contamination.

Continued migration of releases beyond the WAG boundary could potentially introduce contamination to environmental receptors via surface water or could contaminate groundwater within Bethel Valley. Continued discharge of contamination could also increase the scope and costs of future remedial actions. Specific OUs identified to control the discharge of contamination beyond the WAG boundary include the control of (1) discharges to surface waters through the network of storm drains and pipelines, (2) discharge of contaminated groundwater to surface water, and (3) potential erosion of contaminated floodplain soils and sediments along WOC through scour, suspension, and transport of bed sediments.

Existing contamination within the WAG 1 boundary could lead to potential exposure of the on-site work force or future receptors unless control measures are maintained. ORNL has a rigorous environmental health and safety program designed to protect the work force from both occupational and environmental hazards. Administrative controls are in place at contaminated areas to prevent inadvertent worker exposure; some areas also have temporary covers designed to retard the migration of transferable contamination. Based on preliminary analysis, it appears that contamination within the soils is relatively immobile because of the absorption capacity of the clayey soils for radionuclides. However, in the absence of these administrative controls, future occupants would be exposed to this contamination. Specific OUs identified to address the potential for future exposure to this contamination include remediation of contaminated soils (including isotope area, 3000 watershed soils, mercury spill areas, and miscellaneous soils), waste pile, SWSA 2, and underground stainless steel waste storage tanks.

In all, 13 preliminary OUs were defined for WAG 1: 2 for inactive tanks, 1 for surface impoundments, 3 for disposal/debris areas, 6 for contaminated media, and 1 that focuses on the pipeline network as a contaminant transport pathway (Fig. 6.1). The OUs were defined using characterization information provided in the SCSR and definition criteria developed from CERCLA and FFA guidance. The definition criteria address release and transport pathways, remedial action technologies, geographical considerations, initial phases of remedial action, and overall implementation efficiency. Because the criteria are subjective, the OUs are not considered unique groupings; other permutations are possible, and the proposed OUs are defined with elements and boundaries that can be optimized in the future on the basis of new characterization data or alternatives evaluations. A complete description of each OU is presented in the OUSD.

Further analysis of OU-specific characterization data is presented in the WAG 1 Preliminary Risk Assessment Report, which accompanies this SCSR. Characterization data have been used to compute a Hazard Screening Index (HSI) for each OU; the HSI scores enable ranking of each OU by its hazard potential. These scores are used with other information in the WAG 1 Operable Unit Strategy Document to present a preliminary plan for remedial actions. Figure 6.1 shows the locations of source areas and areas of contamination associated with most OUs. Certain OUs (e.g., groundwater) cannot be depicted, as explained on this figure.

6.5 ADDITIONAL INFORMATION NEEDS AND UNCERTAINTIES

There are a number of areas where additional information would contribute to a better understanding of the nature and extent of contamination or the fate and transport of contaminants. Addressing these topics would contribute to developing remedial action plans.

6.5.1 Waste Unit Characterization

6.5.1.1 Surface impoundments

Tritium was detected at high concentrations in wells associated with the 3513/3524 surface impoundments; data on the tritium levels within these impoundments were not available. If the tritium concentrations detected in the monitoring wells are derived from the impoundments, there should be a significant concentration of tritium within the impoundments. Samples from these impoundments should be analyzed for tritium. Because tritium is volatile, an air exposure pathway may be of concern.

6.5.1.2 Short-lived radionuclides

Radionuclides with short half-lives, (e.g., calcium-45 and sodium-22) were detected in soil and sediment samples. These radionuclides are either fission products, activation products, or daughters of known site contaminants. The presence of such isotopes may be an indication of a potential chronic discharge from an ongoing process within WAG 1, or the residual activity of previous releases. The relationship of these radionuclides to potential sources should be considered further.

6.5.1.3 Gunite tanks

Water inleakage into several Gunite tanks in STF has been documented, but the causes have not been conclusively determined. Potential causes are groundwater seepage, rainwater infiltration through loose-fitting plugs in the domes, and unsuspected discharges from other tanks. The causes of infiltration should be determined before these tanks are remediated.

6.5.1.4 NTF and STF

Data collected from NTF and STF suggest soil contamination in those areas. However, groundwater quality data from the vicinity of the tank farms are limited. Monitoring wells should be installed into bedrock within the tank farms and sampled to assess water quality. The wells would also provide data on water level fluctuations needed to assess tank inleakage.

6.5.1.5 Storm drain network

In at least one instance, contaminated groundwater infiltrates an underground stormwater drainage network, which in turn discharges to surface water (i.e., the corehole CH008 plume). Other instances are suspected, such as the association of radiological contaminants

in wells 814 and 587 with process pipelines or storm drains in the hilltop area and the association of radiological contaminants in piezometers 549, 545, 546, and 538 with the storm drain network. These associations should be evaluated in more detail; additional sampling of outfalls, catch basins, and other access points in the storm drain network may be necessary to determine whether the upstream pipeline/drain network is receiving infiltrating contaminated groundwater. Samples from outfalls 341 and 342 should be analyzed for radionuclides to confirm the suspected presence of strontium-90 and radium-228.

6.5.1.6 SWSA 1

The presence of drummed waste buried in SWSA 1 is suspected on the basis of geophysical survey data. To support future remedial action decisions, sampling to identify the presence and nature of these wastes should be considered. Additional sampling of sediments and surface water in WOC would be useful in the characterization of potential releases of contamination from SWSA 1. There is also radiological contamination in groundwater near SWSA 1. If contamination is leaching from SWSA 1, portions of it may become strata-bound and migrate downdip (southward). A deep bedrock well south of SWSA 1 on the slopes of Haw Ridge is needed to evaluate whether this is occurring.

6.5.1.7 SWSA 2

Anomalies detected during the geophysical survey of SWSA 2 suggest the presence of isolated metallic objects. Some anomalies correspond to the sites of former drilling, suggesting that drilling pipe remains in the hole. Other anomalies do not correlate with former investigation locations and could indicate the presence of metallic wastes. A limited invasive sampling effort should be considered because, in other respects, SWSA 2 is a candidate for a "No-Further-Investigation" classification.

6.5.1.8 Tank W-1A

Thorium-232 was found in groundwater in this area. Tank W-1A was removed from service, but pipelines associated with it and other pipelines in the area may have been the source of contamination. Residual contamination in soils surrounding the pipelines may serve as a secondary source of contamination. Additional soil borings in this area may be needed to evaluate the source of contamination.

6.5.1.9 Characteristics of surplus facilities

Buildings 3506 and 3515 (adjacent to STF), surplus facilities included in the DOE Decontamination and Decommissioning Program, are located close to source areas and known areas of groundwater and soil contamination. These structures might be impediments to execution of remedial action plans for these source areas and areas of contamination; their presence after completion of remediation of soyils and groundwater could also pose a threat of recontamination. To fully identify and assess OU-specific remedial action alternatives, the characteristics of these structures and the contamination present within them must be determined.

6.5.2 Groundwater, Surface Water, Soil, and Sediment

Surface water, sediment, and floodplain soil samples indicate that a significant amount of contaminant loading to WOC occurs in the vicinity of the impoundments and SWSA 1. Potential sources of this contamination include seepage from the surface impoundments and SWSA 1, outfalls, leaking waste or drain lines, and groundwater discharge. Additional characterization, including detailed sampling of surface water and sediments, is needed to further delineate the sources of contamination in this area.

A groundwater plume has been identified as extending from the corehole CH008 area to First Creek and possibly as far west as piezometer 535. This plume was identified only on the basis of CSL screening level analyses of groundwater and surface water samples, which did not include determinations of specific isotopes, but rather measured broader parameters (gross alpha and beta). Resampling of the First Creek seep location and piezometer 550 is justified to confirm the nature of contamination in the plume. In addition, flux rates of contaminated water from the plume into First Creek have not been computed. Two to three piezometers should be installed near the First Creek seep location; these piezometers and the seep should be sampled on a regular basis to provide data on the flux of contamination into First Creek. Water level measurements should also be made regularly, possibly using continuous water level recorders.

The depth and western extent of the plume (presumed to be predominantly strontium-90) also have not been determined. Additional multiport monitoring wells and piezometers would assist in defining the depth and extent of the plume. In addition, the source of the plume is not known; additional wells near NTF and in the hilltop area are needed to identify the source.

Contaminated sediments (mostly cesium-137 and mercury) were widely detected in WOC, and the transport mechanisms for these sediments are not well understood. Because these sediments represent potentially significant pathways for off-WAG migration to White Oak Lake, data on transport mechanisms and levels of contamination are needed to support future evaluations of remedial alternatives. Numerical modeling of sediment transport would be useful.

A significant number of surface water and sump samples exceeded holding time guidelines for mercury analysis. Due to the volatility of mercury and its confirmed presence in sediment samples, it is possible that reported concentrations for surface water and sump samples could be biased low or could represent false negative results. Additional sampling of surface water and sump locations to confirm the presence or absence of mercury may be warranted.

Significant radiological contamination was detected in floodplain soils; additional data on the vertical and areal extent of contamination are needed to evaluate the need for remediation. Data on the erodibility of the floodplain soils and other geotechnical parameters are also needed to evaluate the need for and selection of remedial actions. Numerical modeling of surface water processes and the erosion and transport of the floodplain soils would be useful.

Groundwater contamination has been identified within bedrock fractures and solution cavities of Unit D of the Chickamauga Group, but neither the extent of contamination nor all sources are understood. Additional monitoring wells completed in Unit D within WAG 1 would be needed; most of the existing monitoring network is completed in the bedrock/overburden interface zone and may be too shallow to detect primary contamination zones.

Elevated levels of VOCs and tritium were detected in groundwater samples from the 318- and 331-ft depth intervals of corehole CH009, respectively. Because the potentiometric head and flowmeter data indicate that flow is upward in these intervals, the presence of these contaminants is believed to be due to transfer of shallow contamination during packer testing. Similarly, elevated concentrations of tritium were detected in a sample from 129 to 141 ft of depth. This tritium may have entered the test interval during the packer test as a result of leakage around the packers. Additional sampling, preceded by thorough purging of the monitored intervals, would resolve this uncertainty.

Many building sumps at WAG 1 were found to contain contaminated liquids. For most sumps, neither the source nor ultimate disposition of these liquids is known. Future efforts should focus on identifying the sources of the contamination detected in the sumps and on the potential for releases of these contaminants into the environment.

Several open coreholes already drilled in WAG 1 could be fitted with sampling and testing equipment to provide additional data on site hydrology and groundwater contamination. Instrumentation would include installation of sampling systems to allow groundwater sampling and hydraulic testing at selected intervals. Corehole instrumentation could include the following.

- Evaluation of VOC and radiological contamination at corehole CH07A would provide data on the possibility of strata-bound flow in Unit D.

- Coreholes CH11A and CH012 would provide data on possible underflow of contamination below First Creek, on the presence of radiological contamination at corehole CH11A and nearby piezometer 541, and on the hydrologic and geochemical characteristics of Unit F.

- There is evidence of radiological and chemical contamination in corehole CH009. However, packer tests completed on this corehole may not have provided water quality samples representative of the intervals being tested. Installation of a multiport well would allow the presence or absence of contamination to be confirmed.

- Instrumentation of corehole CH003 would provide data on groundwater contamination and hydrogeology near Fifth Creek. There has been little data collected thus far regarding the interaction between groundwater and Fifth Creek.

The conceptual groundwater model of WAG 1 indicates that all groundwater is captured by the WOC system. However, there is evidence of local underflow of First Creek. It is assumed that this underflow is eventually captured by Northwest Tributary, but there is little

evidence to support or contradict this assumption. Additional wells located west of WAG 1 and near Northwest Tributary would be needed to address this issue. These activities should also include the location and sampling of groundwater seeps and detailed calculation of water balances for the WOC drainage system.

High activities of gross beta and gross alpha were found in unfiltered samples from piezometer 584, located at the intersection of Central Avenue and Fourth Street. Samples were analyzed at the CSL only, and no isotopic analyses were completed. Additional sampling, including filtered samples, is needed to confirm and characterize the presence of contamination at this location.

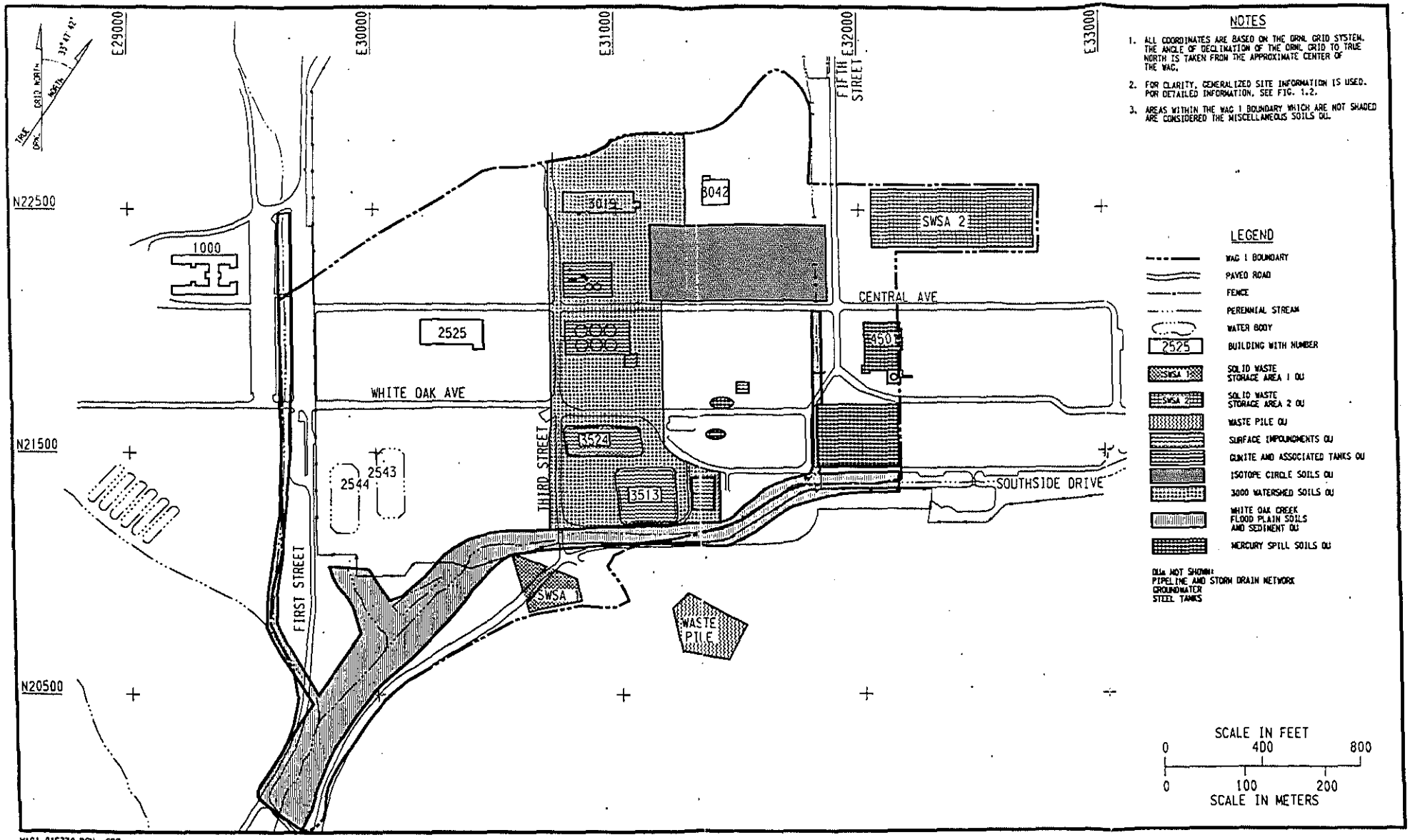
Elevated concentrations of radium were found in piezometers northwest of WAG 1. Tritium was also detected above background concentrations in piezometer 539. The source of this contamination is not known; additional review of information on waste management practices in this area is needed to help determine a source of the groundwater contamination.

Corehole CH07A contained elevated concentrations of VOCs and radionuclides. There are no nearby bedrock wells to evaluate the extent of the contamination or to define possible source areas; additional bedrock wells may be needed in Unit D in this area.

The hydrologic characteristics of the pipeline trenches have not been adequately characterized. Soil borings drilled during the Phase I RI provided limited data, but safety restrictions on the proximity of the borings to the pipelines and on the approved augering methods may have resulted in many borings being too shallow and too far from the pipelines to allow interception with the trenches.

6.5.3 Representativeness of Reference Data

Concentrations of certain metals (e.g., aluminum, iron, potassium) vary widely in samples from WAG 1 but only within a very narrow range in the reference samples. This difference may be due to contrasts in the geochemistry of the stratigraphic units between the reference well and WAG 1 well locations. Similarly, concentrations of naturally occurring radionuclides vary significantly, making it difficult to recognize with certainty where naturally occurring isotopes could be present as contaminants (due to their concentration or enrichment through various operations). Currently, the reference groundwater network for WAG 1 consists of two locations at which two rounds of sampling have been conducted and three locations at which one round has been completed. An expanded reference well network would be needed to support a more definitive interpretation of metals contamination in WAG 1 groundwater.



WAG1 01F330.DGN SRF, 9/23/92

Fig. 6.1. Operable units.

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