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

Volume 1
Sections 1 Through 3

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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 1
Sections 1 Through 3

Date Issued—September 1992

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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

EXECUTIVE SUMMARY (VOLUME 1)

ES.1 OBJECTIVES AND SCOPE

Volume 1 contains Sects. 1, 2, and 3 of the Site Characterization Summary Report (SCSR) for Waste Area Grouping (WAG) 1 at Oak Ridge National Laboratory. Section 1, Introduction, describes the objectives of the SCSR and the regulatory setting in which this investigation was completed. Section 2 describes the field investigation completed at the site. The physical and waste management unit characteristics of the site are described in Sect. 3.

This report is companion to two other reports: the Operable Unit Strategy Document (OUSD) and Preliminary Risk Assessment Report (PRAR). The purpose of the SCSR is to describe the physical characteristics of WAG 1, to present and interpret data collected during the site investigation, describe the nature and extent of contamination, develop a site conceptual model for contaminant fate and transport, and support the OUSD and PRAR.

ES.2 OVERVIEW OF WAG 1 INVESTIGATION

To characterize the nature and extent of contamination, groundwater samples were collected from 109 wells and surface water samples were collected from 15 locations during both low base and high base flow conditions as well as during storm events. Five deep bedrock coreholes were drilled to provide stratigraphic and hydrologic data for bedrock beneath WAG 1. Groundwater samples and hydraulic conductivity and pressure head data were obtained from the new coreholes and several existing coreholes, and a multiport well was installed in a shallow bedrock corehole to characterize elevated levels of radioactivity encountered during drilling. Groundwater elevations were monitored on a monthly basis at 147 locations over a period of 18 months, and continuous water level monitoring was performed at 11 additional locations.

To characterize the nature and extent of contamination attributable to solid waste management units (SWMUs), as well as locations of elevated radiation encountered during a ground surface radiation survey, soil samples were collected from 286 soil borings completed at locations throughout WAG 1. The geotechnical properties of soil samples from 30 locations were also characterized. Ten sediment samples were collected from the channels of White Oak Creek (WOC), First Creek, Fifth Creek, and Northwest Tributary. In addition to the radiation survey, geophysical surveys were completed at two waste burial areas and the site of a former waste pile.

Environmental samples were analyzed for radiological constituents, Target Compound List organic chemicals, Target Analyte List metals, and a variety of other inorganic constituents. Laboratory analytical results for chemicals were validated using criteria established by the Environmental Protection Agency (EPA). Radiological data were validated using procedures established for the project.

ES.3 PHYSICAL CHARACTERISTICS OF THE SITE

WAG 1 is drained by the WOC stream system, which includes WOC, First Creek, Fifth Creek, and Northwest Tributary. The drainage area of the system at the water gap in Haw Ridge near the 7500 bridge, just downstream of WAG 1, is 3.2 mile^2. Between October 1987 and February 1992, stream flow at the 7500 bridge exceeded 7.5 cfs 50% of the time; the flow is derived from outfalls, groundwater discharge, storm flow, and surface runoff. Outfall discharges convey treated wastewater from the sewage treatment plant and the radiological and nonradiological wastewater treatment facilities, and runoff from the coal yard. In addition, there are outfalls associated with the space cooling system, the steam plant, vehicle cleaning operations, and the equipment maintenance facility.

WAG 1 is underlain by a complex network of buried pipelines. In at least the northwest portion of the site, several abandoned sections of storm drains intercept contaminated groundwater and, through infiltration, transfer this contamination directly to First Creek. In other areas, past leaks from the pipeline network have been a source of groundwater and soil contamination. Further investigation is needed to determine the extent to which buried pipelines and associated backfill material act as conduits or preferential pathways for groundwater flow and contaminant transport.

Groundwater at WAG 1 occurs in both overburden material and in bedrock. In most areas, the overburden material can be considered as an isotropic, heterogeneous medium, and groundwater flow directions are largely controlled by the direction of the hydraulic gradient. Local flow conditions can, however, be perturbed by the presence of pipelines and other structures. Groundwater flow in bedrock occurs in fractures and solution features and is thus highly anisotropic. The dominant fracture orientation in the Chickamauga bedrock units results in preferred flow directions along bedding planes and along bedrock strike, which trends along the axis of Bethel Valley.

Strata-bound flow, in which groundwater flow is essentially confined to a single geologic stratum, has been identified in this investigation to be a significant contaminant transport mechanism at WAG 1. 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.

The discharge location for groundwater at WAG 1 is the WOC drainage system. Limited evidence obtained during this investigation at First Creek suggests that some groundwater locally underflows the stream toward the west. However, it is possible that this groundwater is eventually captured by Northwest Tributary, itself a tributary to WOC.

The geochemical characteristics of groundwater suggest that the base of the shallow groundwater circulation system is no deeper than an elevation of approximately 650 ft above mean sea level (approximately 150 to 200 ft beneath ground surface). Groundwater potentiometric head data from coreholes and wells indicate that the effects of direct

groundwater recharge within WAG 1 may be even further limited to the upper 50 ft of the saturated zone.

ES.4 CHARACTERISTICS OF WASTE MANAGEMENT UNITS AND SOURCES OF CONTAMINATION

One hundred sixty-seven SWMUs have been identified at WAG 1; prior to the Phase I investigation, 27 of these were determined by EPA to warrant no further investigation. One hundred twenty-six SWMUs have been investigated as potential sources of contamination, and 14 are structures listed for decontamination and decommissioning under the Department of Energy's Surplus Facilities Management Program. Because these 14 were not previously considered to be sources of environmental contamination, they were not included in the scope of the Phase I investigation.

Seventy-five SWMUs are waste storage tanks; 71 of these have been used for the collection, treatment, and/or storage of low-level liquid waste (LLLW). Approximately 95% of the documented inventory of radionuclides within inactive waste management units is contained in six Gunite underground storage tanks in the South Tank Farm. The North Tank Farm contains inactive underground Gunite and steel tanks. The inventory of alpha-emitting radionuclides among all the tanks is estimated to be 1048 Ci, and the inventory of beta-emitters is estimated to be 22,996 Ci.

The calculations performed in a structural analysis (Fricke 1986) of the Gunite tanks 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 were assumed in the original design specification, 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, 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 the 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. Five inactive impoundments still contain water, one is active, and two have been closed and backfilled. The active impoundment is sewage pond 2544, used as an equalization basin for the sewage treatment plant. Plutonium and other radionuclides detected in the sludges may have entered the pond as a result of inleakage of LLLW or contaminated groundwater into sanitary sewer pipes. The inleakage may have occurred at locations where LLLW lines cross the sanitary sewer lines.

Certain active portions of the LLLW system are now being replaced with double-walled pipe as part of the program for upgrade/replacement of the LLLW collection and

transfer system to meet the secondary containment provisions of the Federal Facility Agreement. Tanks known or suspected to leak have been removed from service.

An estimated 50 miles of underground utility lines are present beneath WAG 1, including LLLW lines, sanitary sewer lines, storm drains, and miscellaneous pipelines. The old LLLW piping system is a significant potential source of contaminants; leaks from the original LLLW system are responsible for 23 SWMUs. Some of the utility lines are in common trenches, creating the potential for crossover from one line to another due to leakage and inflow.

1. INTRODUCTION

This report is a compilation and qualitative interpretation of data obtained during Phase I of the remedial investigation (RI) of Waste Area Grouping (WAG) 1 at Oak Ridge National Laboratory (ORNL). ORNL is a U.S. Department of Energy (DOE) research and development facility located near the city of Oak Ridge, Tennessee. ORNL is one of three principal facilities on DOE's Oak Ridge Reservation (ORR), which was established during the World War II Manhattan Engineer District atomic weapons project in 1942 and 1943. ORNL is currently managed and operated for DOE by Martin Marietta Energy Systems, Inc. (Energy Systems).

WAG 1, an area of approximately 150 acres, contains most of ORNL's original research and development facilities and associated waste management units. The RI was conducted under the ORNL Environmental Restoration (ER) Program.

1.1 PURPOSE

The WAG 1 Remedial Investigation Plan (BNI 1989) indicated that WAG 1 RI data would be collected in phases and an RI Report would be submitted at the end of each phase. However, at a meeting in Oak Ridge on December 4, 1991, the U.S. Environmental Protection Agency (EPA), Region IV, modified the reporting objectives for Phase I of the investigation from the earlier plan. EPA requested that DOE submit three documents—a Site Characterization Summary Report (SCSR), a Preliminary Risk Assessment Report (PRAR), and an Operable Unit Strategy Document (OUSD)—in lieu of an RI Report (Sweeney 1991). Subsequent to this meeting, EPA approved the annotated outline submitted by DOE for each document.

The purpose of this SCSR is to

- present and interpret physical data collected during the field investigation phase of the study, and use these data to refine the understanding of the potential pathways for contaminant migration;
- describe as best as possible the nature and extent of hazardous substances present in groundwater, surface water, soils, and sediments using the results of laboratory analyses of environmental samples collected during the Phase I field investigation;
- present a conceptual model of the fate and transport of hazardous substances within and beyond the boundaries of the WAG;
- furnish data for use in the companion report on a preliminary risk assessment for WAG 1;
- furnish data for use in the companion report on preliminary identification and prioritization of operable units (OUs); and

- provide a technical foundation and source of information for OU-specific RIs and feasibility studies.

Information on the original scope and objectives of the RI is available in two previously published documents: the RI Plan for WAG 1, Revision 1 (BNI 1989), and the RI Plan for WAG 1: Responses to Regulator Comments (BNI 1991).

This report is published in conjunction with two other reports. The first is the WAG 1 PRAR, which evaluates the potential risk to human health and the environment attributable to releases of hazardous substances from WAG 1 as a whole. The second, the OUSD, identifies and prioritizes OUs and presents a preliminary schedule for initiation and completion of remedial actions. These three documents, in combination, support the next phase of OU-specific activities at WAG 1 under the ER Program.

1.2 SITE DESCRIPTION AND BACKGROUND

WAG 1 is located within the ORNL main plant area (Fig. 1.2.1). The facility is approximately 30 miles west of Knoxville and 10 miles southwest of the residential area of the City of Oak Ridge. ORNL, also referred to as X-10, is one of three major operating facilities on the ORR; the other two are the K-25 Site and the Y-12 Plant (a weapons component manufacturing facility).

ORNL is located in Bethel Valley, between Chestnut Ridge to the north and Haw Ridge to the south. Figure 1.2.2 illustrates the extent of WAG 1 and shows the locations of buildings, security fencing, and other major features. WAG 1 is bounded on the north by Bethel Valley Road, on the south by White Oak Creek (WOC), and on the west by First Creek. The eastern boundary follows Fifth Creek on the north but extends east to include Solid Waste Storage Area (SWSA) 2 and Buildings 4501 and 4508. The site is an active research center, and the majority of the approximately 4000 ORNL employees work within the confines of WAG 1.

ORNL was originally designed for atomic weapons materials research and development during World War II. Many changes have occurred in the scope and direction of radioactive materials programs at ORNL over the years, including continuation of nuclear fuel reprocessing research, large-scale production of radioisotopes, and operation of various types of research reactors. Various radioactive and hazardous wastes have been generated by production, operations, and research activities during the operational life of this facility.

One hundred sixty-seven solid waste management units (SWMUs) have been identified and classified in WAG 1 in the 1992 "Annual Update of the Solid Waste Management Units List for the Oak Ridge Reservation (Bates 1992). The SWMUs are individually described in the ORNL "Contaminated Sites Summary Sheets" (CSSS) (ORNL 1990). These SWMUs were identified by ORNL to be potential sources of contamination that might pose a threat to human health or the environment. Table 1.2.1 gives a short description of each SWMU. The presence of the SWMUs is important to the RI to the extent that they may represent either past, current, or potential future sources of contaminant releases to the environment.

However, the objective of the RI process is not limited to these SWMUs. Rather, it is to identify and assess areas of contamination resulting from releases of hazardous substances defined under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA).

Pursuant to a Resource Conservation and Recovery Act (RCRA) permit issued prior to the initiation of the Phase I RI, 27 SWMUs have been classified as requiring no further investigation. Fourteen are listed as for decommissioning and demolition under the DOE surplus facilities program. The surplus facilities are structures that may require further investigation of the extent of internal contamination, but were not considered in the CSSS to be sources of contamination with the potential to be released to the environment. The remaining 126 SWMUs, shown in Fig. 1.2.3, include inactive underground waste storage tanks, waste burial grounds, surface impoundments, low-level liquid waste (LLLW) lines and leak sites, active underground waste storage tanks, and mercury spill sites. A detailed discussion of the characteristics of the SWMUs is presented in Sect. 3.5 of this report.

1.3 APPROACH USED IN IDENTIFYING OPERABLE UNITS

This section provides an overview of the approach used in identifying OUs. WAG 1 OUs are identified in the OUSD, which also describes the relative priorities among the OUs for remedial action and presents a preliminary schedule for remedial actions.

An OU is a discrete remedial action that contributes to the final remediation of a facility or site. This portion of a remedial response manages migration, or it eliminates or mitigates a release, threat of release, or pathway of exposure. Identification of OUs allows remediation of a complex site to be segmented into smaller, more manageable tasks. OUs may address geographical portions of a site, specific site problems, or initial phases of an action. OUs should be capable of early expedition, planning, and implementation.

Site characterization data were used to identify potential contaminant migration and exposure pathways associated with individual or clusters of SWMUs. This analysis indicated that OUs could be identified for three categories of potential exposure conditions.

- Category I: potential for significant on-WAG exposure of current receptors to releases from waste management units,
- Category II: potential for off-WAG exposure of current and future receptors to current releases migrating beyond the WAG boundary, and
- Category III: potential for on-WAG exposure of future receptors to existing contamination present within the WAG.

These categories are described in the following paragraphs.

Approximately 95% of the documented inventory of radionuclides within waste management units in WAG 1 is contained within the underground storage tanks in the South Tank Farm (STF) (see Fig. 1.2.4). Although 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 (Category I). Given the large radiologic inventory and similar construction, these tanks, along with similar but smaller tanks in the North Tank Farm (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 (Category II) 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) unpermitted 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 (Category III) could lead to the 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, such as the "3019 Hotbank," also have temporary covers designed to prevent the migration of transferable contamination. As discussed in Sects. 4 and 5, it appears that the 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 have been identified to address the potential for future exposure to this contamination. These include remediation of contaminated soils, mercury spill areas, and steel underground waste storage tanks.

1.4 REGULATORY AND PROGRAMMATIC SETTING

When ORNL established its ER Program (formerly called the Remedial Action Program), the mission was pursued in accordance with DOE Orders 5820.2, "Radioactive Waste Management," and 5480.14, "Comprehensive Environmental Response, Compensation, and Liability Act Program." DOE Order 5820.2 (superseded by 5820.2A in August 1988) establishes policies, guidelines, and minimum requirements for management of radioactive and mixed wastes and contaminated facilities. DOE Order 5480.14 provides instructions for implementing a CERCLA program to identify and investigate inactive waste disposal sites and to implement remedial actions where needed.

EPA's enforcement role in ORNL ER activities began in September 1986, when EPA issued a RCRA permit for the ORNL Hazardous Material Storage Area, Building 7652, and

invoked RCRA Section 3004(u). In accordance with RCRA Section 3004(u), a RCRA Facility Assessment submitted to EPA in March 1987 identified 20 WAGs. Within WAG 1, ORNL identified an initial set of 99 SWMUs. The list of SWMUs is updated annually; the current total is 167, and 27 of these SWMUs have been judged by EPA to warrant no further investigation.

On November 21, 1989, EPA placed the ORR on the CERCLA National Priorities List (NPL). Because of the number of regulatory programs and regulatory agencies involved, DOE, EPA, and the Tennessee Department of Environment and Conservation (TDEC) have negotiated a three-party Federal Facility Agreement (FFA) for the ORR that satisfies the requirements for an interagency agreement under Sect. 120 of CERCLA, 42 U.S.C. Para. 9620. The general purposes of the FFA include ensuring "that the environmental impacts associated with past and present activities at the site are thoroughly investigated and that appropriate remedial action is taken as necessary to protect the public health and welfare and the environment" and establishing "a procedural framework and schedule for developing, implementing, and monitoring appropriate response actions at the site" (FFA 1992). The FFA specifies a methodology that follows the CERCLA process for addressing contamination of facilities and the environment.

With respect to WAG 1, the FFA specifies the following overall scope of work: "Evaluation of existing information associated with the WAG; identification of additional data necessary to characterize the WAG, to evaluate the risk or potential risk to the public health and environment, and to evaluate potential remedial action alternatives; collection of this data through implementation of an RI; preparation of risk assessments and detailed alternatives assessments; and support for the preparation of decision/NEPA [National Environmental Policy Act] documents" (FFA, Appendix E). The FFA states that the WAG 1 SCSR is to be delivered to EPA and TDEC in the fourth quarter of fiscal year 1992. This document constitutes that submission.

1.5 REPORT ORGANIZATION

This SCSR is organized into an executive summary, seven sections, and a series of technical appendixes. This introduction (Sect. 1) presents the regulatory context and technical objectives and summarizes relevant information concerning site location and physical setting.

Section 2 presents a survey of the methods and procedures employed during Phase I of the site investigation. It also summarizes or references similar information from previous studies conducted by ORNL.

Section 3 provides a synthesis of the physical data collected during the investigation (e.g., information on groundwater level fluctuations and hydraulic characteristics of the subsurface) and presents an interpretive description of the physical characteristics of WAG 1. Information on SWMUs and other potential sources of environmental contamination is also presented, including summary data on recent investigations into the contents and characteristics of a set of underground storage tanks.

Section 4.1 summarizes the precision, accuracy, representativeness, completeness, and comparability (PARCC) of the analytical data reported in the SCSR. Section 4.2 describes the radiological and chemical constituents present in reference location samples. (Reference locations are those that typify groundwater, surface water, sediment, and soil quality in Bethel Valley uninfluenced by WAG 1.) The nature and extent of contamination found in groundwater, soils, surface water, and sediments are described in Sects. 4.3 through 4.6, respectively. Reference sampling results are used as a basis of comparison to identify contamination attributable to releases from sources within WAG 1. The results of previous studies on environmental sampling performed by ORNL and the results of surface radiation walkover surveys using the Ultrasonic Ranging and Data System (USRADS) are included.

Section 5 is a qualitative description of the potential fate and transport of contaminants. The properties of each environmental transport medium, contaminant release mechanisms, and conditions that affect contaminant transport are discussed. This section includes a site conceptual model.

Section 6 presents a summary and conclusions. It also outlines areas where additional information would contribute to a better understanding of the nature and extent of contamination in support of potential remedial action strategies.

Technical appendixes include compilations of all environmental sampling results, organized by environmental medium. Appendix A presents information on soil sampling, and Appendix B presents information regarding groundwater, surface water, and sediment sampling. Appendix C presents a detailed analysis of the PARCC of laboratory analytical results and identifies limitations to the data collected.

Computer tapes containing a digital version of all of the field sampling records and analytical results obtained during the Phase I investigation will be provided to EPA by ORNL in a separate transmittal 30 days after the SCSR is submitted. In addition, ORNL maintains the computer programming codes used to produce various data presentation tables, as described for each table later in this report. These codes will also be made available to EPA.

REFERENCES FOR SECTION 1

Bates, L. D. 1992. "Annual Update of the Solid Waste Management Units List for the Oak Ridge Reservation," Letter ERP-TI/92-053, BNI CCN 014052, Oak Ridge, Tenn.

BNI 1989. *Remedial Investigation Plan for ORNL Waste Area Grouping 1, Revision 1*, ORNL/RAP/Sub-87/99053/4&R1, Oak Ridge, Tenn.

BNI 1991. *Remedial Investigation Plan for Waste Area Grouping 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee: Responses to Regulator Comments*, ES/ER-6&D2, Oak Ridge, Tenn.

FFA 1992. EPA, DOE, and TDEC. *Federal Facility Agreement for the Oak Ridge Reservation*, DOE/OR-1014, Oak Ridge, Tenn.

ORNL 1990. Contaminated Sites Summary Sheets, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Sweeney, J. T. 1991. Minutes, DOE Technical Working Group—WAG 1, BNI CCN 015335, Oak Ridge, Tenn.

Table 1.2.1. Solid waste management units in WAG 1

SWMU No.	Description of unit	Remarks
1.1	Mercury-contaminated soil (3603)	
1.2	Mercury-contaminated soil (3692)	
1.3	Mercury-contaminated soil (4501)	
1.4	Mercury-contaminated soil (4608)	
1.5A	LLLW lines & leak sites - south of Building 3020	
1.5B	LLLW lines & leak sites - east of Building 3020	
1.5C	LLLW lines & leak sites - west of Building 3082	
1.5D	LLLW lines & leak sites - north of Building 3019	
1.5E	LLLW lines & leak sites - southwest corner of Building 3019	
1.5F	LLLW lines & leak sites - between W-5 & WC-19	
1.5G	LLLW lines & leak Sites - underneath Building 3047	
1.5H	LLLW lines & leak sites - gen. isotopes area (3037, 3038, 3034)	
1.5I	LLLW lines & leak sites - Building 3092 area	
1.5J	LLLW lines & leak sites - underneath Building 3026	
1.5K	LLLW lines & leak sites - between WC-1 & W-5	
1.5L	LLLW lines & leak sites - ORR water line (Building 3085)	
1.5M	LLLW lines & leak sites - Building 3028	
1.5N	LLLW lines & leak sites - east of Building 2531	
1.5O	LLLW lines & leak sites - underneath Building 3515	
1.5P	LLLW lines & leak sites - Building 3525 to a sump	
1.5Q	LLLW lines & leak sites - underneath Building 3550	
1.5R	LLLW lines & leak sites - sewer near Building 3500	
1.5S	LLLW lines & leak sites - abandoned line, Central Avenue area	
1.5T	LLLW lines & leak sites - Building 4508, North	
1.5U	LLLW lines & leak sites - Building 3518, West	
1.5V	LLLW lines & leak sites - northwest of SWSA 1	
1.5W	LLLW lines & leak sites - Building 3503, ground contamination	
1.6	Contaminated surfaces & soil from '59 explosion in 3019 cell	
1.7	Contamination at base of 3019 stack	
1.8	Graphite reactor storage canal overflow (3001/3009)	
1.9	Oak Ridge Research Reactor decay tank rupture site (3087)	
1.10	Storage pads (3503/3504)	
1.11	Decommissioned waste holding basin (3512)	
1.12	Waste holding basin (3513)	
1.13	Equalization basin (3524)	
1.14	Process waste pond (3539)	

Table 1.2.1 (continued)

SWMU No.	Description of unit	Remarks
1.15	Process waste pond (3540)	
1.16	Sewage aeration pond (East) - (2543)	
1.17	Sewage aeration pond (West) - (2544)	
1.18	Coal pile settling basin (2545)	No further investigation
1.19	Low Intensity Test Reactor (LITR) Pond (3085W)	
1.20	3517 filter pit (Fission Product Development Lab) - (3517)	
1.21	FPLD LLLW transfer line	
1.22	Isotopes ductwork/3110 filter house	
1.23A	Inactive LLLW collection/storage tank W-1	
1.23B	Inactive LLLW collection/storage tank W-2	
1.24A	Inactive LLLW collection/storage tank W-3	
1.24B	Inactive LLLW collection/storage tank W-4	
1.25A	Inactive LLLW collection/storage tank W-13	
1.25B	Inactive LLLW collection/storage tank W-14	
1.25C	Inactive LLLW collection/storage tank W-15	
1.26A	Inactive LLLW collection/storage tank W-5	
1.26B	Inactive LLLW collection/storage tank W-6	
1.26C	Inactive LLLW collection/storage tank W-7	
1.26D	Inactive LLLW collection/storage tank W-8	
1.26E	Inactive LLLW collection/storage tank W-9	
1.26F	Inactive LLLW collection/storage tank W-10	
1.27	Inactive LLLW collection/storage tank W-11	
1.28	Inactive LLLW collection/storage tank W-1A	
1.29	Inactive LLLW collection/storage tank WC-1	
1.30A	Inactive LLLW collection/storage tank WC-15	
1.30B	Inactive LLLW collection/storage tank WC-17	
1.31A	Inactive LLLW collection/storage tank TH-1	
1.31B	Inactive LLLW collection/storage tank TH-2	
1.31C	Inactive LLLW collection/storage tank TH-3	
1.32	Inactive LLLW collection/storage tank TH-4	
1.33	Active LLLW collection tank 2026A	
1.34	Active LLLW collection tank W-2	
1.35	Active LLLW collection tank W-3	
1.36	Inactive LLLW collection tank WC-4	
1.37A	Inactive LLLW collection tank WC-5	
1.37B	Inactive LLLW collection tank WC-6	
1.37C	Inactive LLLW collection tank WC-8	
1.37D	Active LLLW collection tank WC-9	
1.38	Active LLLW collection tank WC-7	
1.39A	Active LLLW collection tank WC-10	
1.39B	Inactive LLLW collection tank WC-11	
1.39C	Inactive LLLW collection tank WC-12	

Table 1.2.1 (continued)

SWMU No.	Description of unit	Remarks
1.39D	Inactive LLLW collection tank WC-13	
1.39E	Inactive LLLW collection tank WC-14	
1.40	Active LLLW collection tank WC-19	
1.41	Inactive LLLW collection tank WC-12	
1.42A	Inactive LLLW collection tank WC-16	
1.42B	Inactive LLLW collection tank WC-17	
1.42C	Inactive LLLW collection tank WC-18	
1.43A	LLW waste collection tank (W-21)	No further investigation
1.43B	LLW waste collection/storage tank (W-22)	No further investigation
1.44	LLW waste collection tank (W-23)	No further investigation
1.45A	LLW waste concentrate storage tank (C-1)	
1.45B	LLW waste concentrate storage tank (C-2)	
1.46	SWSA 1 (2624)	
1.47	SWSA 2 (4003)	
1.48	Low-level waste evaporator (2631)	No further investigation
1.49	Neutralization facility	No further investigation
1.50	PCB storage area (2018W)	No further investigation
1.51	Process Waste Treatment Plant (3544)	No further investigation
1.52	Sewage Treatment Plant (2521)	No further investigation
1.53	Septic tank for Building 3000 (3078)	No further investigation
1.54	Waste oil storage tanks (2525)	No further investigation
1.55	Septic tank for Building 6506 (5507)	No further investigation
1.57	Site non-rad waste water treatment plant	No further investigation
1.58	Former waste pile area	
1.58A	Inactive LLLW collection tank W-19	
1.58B	Inactive LLLW collection tank W-20	
1.59	Old incinerator site	No further investigation
1.60	Buried lead near north portal	No further investigation
1.61A	Waste accumulation area (1503)	No further investigation
1.61B	Oil storage area (2013)	No further investigation
1.61C	Waste oil storage area (2018)	No further investigation
1.61D	Fluorescent tube container storage area (3025)	No further investigation
1.61E	Waste oil storage area (3038)	No further investigation
1.61F	Oil storage area (3013)	No further investigation
1.61G	Haz waste accumulation area (3500)	No further investigation
1.61H	Waste oil storage area (3500)	No further investigation
1.61I	Waste storage area (4500N)	No further investigation
1.61J	Oil storage area	No further investigation
1.61K	Waste oil storage area (4509)	No further investigation
1.61L	PCB waste container storage area (6000)	No further investigation
1.62	Waste Evaporator Facility (3606)	
1.63	Transfer canal and disolver pit (3605)	

Table 1.2.1 (continued)

SWMU No.	Description of unit	Remarks
1.64A	Active LLLW collection tank S-223	
1.64B	Active LLLW collection tank S-324	
1.64C	Inactive LLLW collection tank S-424	
1.64D	Active LLLW collection tank S-523	
1.65A	Active LLLW collection tank F-201	
1.65B	Active LLLW collection tank F-501	
1.66	Inactive LLLW collection tank W-11	
1.67A	Inactive LLLW collection tank 4501-C	
1.67B	Inactive LLLW collection tank 4501-D	
1.67C	Inactive LLLW collection tank 4501-P	
1.68	Inactive filter house seal tank 3002-A	
1.69A	Active LLLW collection tank N-71	
1.69B	Active LLLW collection tank P-3	
1.69C	Active LLLW collection tank P-4	
1.70	Active LLLW collection tank LA-104	
1.71	Inactive LLLW collection tank H-209	
1.68	Inactive filter house seal tank 3002-A	
1.69A	Active LLLW collection tank N-71	
1.69B	Active LLLW collection tank P-3	
1.69C	Active LLLW collection tank P-4	
1.70	Active LLLW collection tank LA-104	
1.71	Inactive LLLW collection tank H-209	
1.72	Inactive tank 3001 suspect	
1.73	Inactive LLLW collection tank 3001-B	
1.74	Inactive LLLW collection tank 3003-A	
1.75	Inactive LLLW collection tank 3004-B	
1.76	Inactive LLLW collection tank 3013	
1.77	Active LLLW collection tank L-11	
1.78	Inactive LLLW collection tank T-30	
1.79	3001 storage canal	
1.80A	Acid storage tank (3505A)	
1.80B	Caustic storage tank (3505B)	
1A.1A	Graphite Reactor Building 3001	Surplus Facility
1A.1B	Fan house 3003	Surplus Facility
1A.1C	Filter house 3002	Surplus Facility
1A.1D	Stack 3010	Surplus Facility
1A.1E	Underground exhaust ducts 3001-3003	
1A.2A	Low Intensity Test Reactor (LITR) - (3005)	Surplus Facility
1A.2B	Heat exchanger (3077)	Surplus Facility
1A.3	Oak Ridge Research Reactor (3042)	Surplus Facility
1A.4	Cobalt-60 storage garden (3029)	Surplus Facility
1A.5	Fission Product Development Laboratory (3517)	

Table 1.2.1 (continued)

SWMU No.	Description of unit	Remarks
1A.6	Fission Product Pilot Plant (3515)	
1A.7	Metal Recovery Facility (3505)	Surplus Facility
1A.8	Storage garden (3033)	
1A.9	Strontium-90 power generators (3028)	Surplus Facility
1A.11	Ceramic Processing Laboratory (4608)	Surplus Facility
1A.12	High-Level Chemical Development Laboratory (4507)	
1A.13	Remote coating furnace loop (4508)	Surplus Facility
1A.14	Transuranium Research Laboratory 45 (5506)	Surplus Facility
1A.15	Hi-Level Radiochemical Analytical Laboratory (3019B)	
1A.16	Oak Ridge Research Reactor heat exchanger (3087)	Surplus Facility
1A.17	Off-gas filter house (3121)	

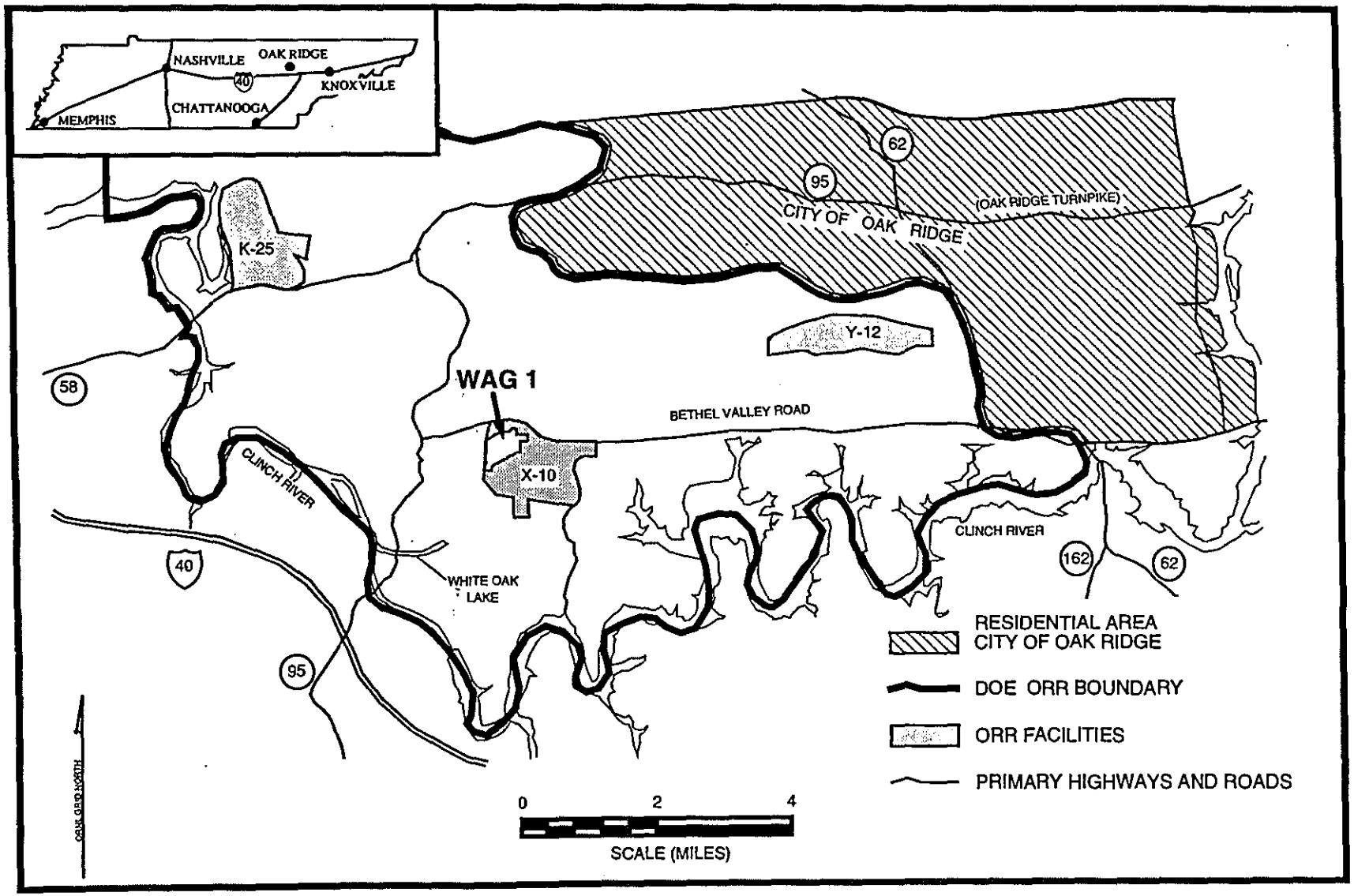
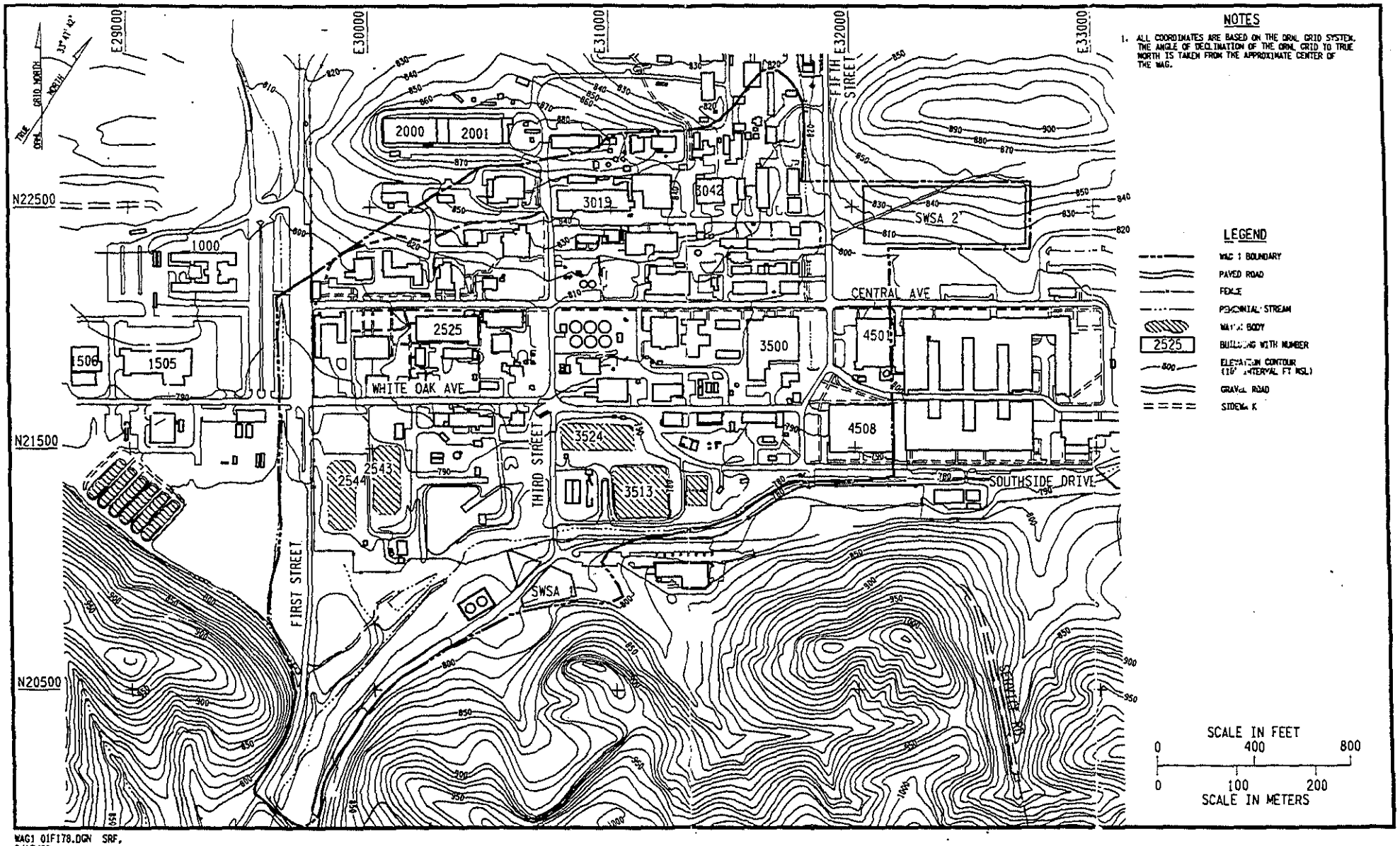


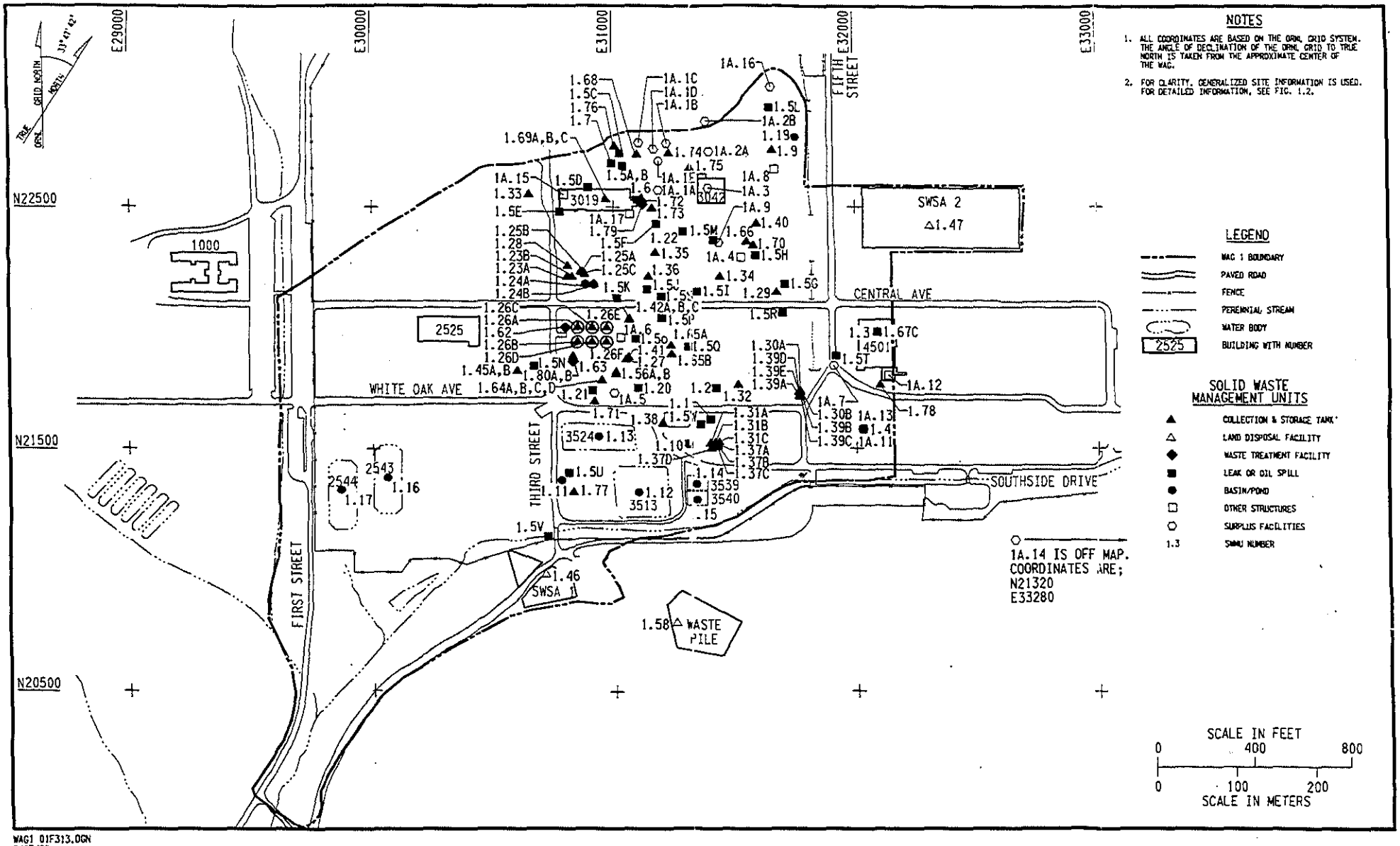
Fig. 1.2.1. DOE Oak Ridge Reservation.

5.33A 6066.30



WAG1 01F178.DGN SRF, 6/15/92

Fig. 1.2.2. Major features at WAG 1.



WAG1 01F313.DGN
9/23/92

Fig. 1.2.3. Solid waste management units.

2. SITE INVESTIGATION ACTIVITIES

As part of meeting the overall goal of environmental restoration at WAG 1 and to supplement existing ORNL data, 13 site investigation activities were conducted from January 1990 to the spring of 1992. These investigations included the following and are discussed in the following order:

- well evaluation/piezometer upgrade,
- well headspace vapor sampling,
- surface radiological surveys,
- surface geophysical surveys,
- reference sampling,
- sump sampling,
- soil borings,
- groundwater/surface water level monitoring,
- groundwater sampling,
- bedrock coreholes,
- surface water and creek channel sediment sampling,
- sewage impoundment sampling, and
- tank monitoring and inspection.

All coordinates referred to in the text of this document are relative to the ORNL grid unless otherwise noted. Plate I (located in the pocket of this report) includes all wells, piezometers, soil borings, and surface water/sediment locations associated with WAG 1; it does not include reference sampling locations geographically removed from the main plant area. Simplified location maps are included with each of the following sections.

2.1 WELL EVALUATION/PIEZOMETER UPGRADE

2.1.1 Scope

Ninety-nine piezometers installed by Energy Systems in 1985 and 1986 were evaluated for their potential to be upgraded and used in this investigation as water quality monitoring wells. Locations of evaluated and upgraded piezometers are shown in Fig. 2.1.1, and the 48 piezometers that were actually upgraded are listed in Table 2.1.1.

The piezometers, originally drilled to allow determination of groundwater flow at WAG 1, were typically drilled with a 6- to 8-in. auger through the overburden and into bedrock to a sufficient depth to reach water. Piezometer completion consisted of a sand-packed polyvinyl chloride (PVC) screen, a 2-ft bentonite seal, and cement/bentonite grout to the surface. The wells were completed with either a flush-mount cover or an above-ground PVC riser casing with a steel protective casing and cover. The flush-mount piezometers were not intended to serve as water quality wells since they allowed rainwater to pond above and around the cap. Sampling the piezometers without an upgrade could provide unreliable data that indicate surface water inflow.

2.1.2 Methodology

The existing 99 piezometers were evaluated to determine which ones were suitable for upgrading. Because the principal criterion for piezometer selection was that the wellhead could be protected, all piezometers in streets or parking lots were eliminated, and only those in grassy or sheltered areas were considered further. Cracked concrete pads were assumed not to affect the integrity of the wells themselves. During the field inspection, some of the piezometers were found to be irreparable. A total of 48 piezometers were upgraded.

The general procedure for upgrading involved removal of the existing cover and installation of a compression coupling (compression end down) on the piezometer casing. The new piezometer casing extension and cap were then installed, followed by installation, splicing, and extension of the protective casing. Upon completion, a lockable protective cap was installed.

The vegetation surrounding the well was excavated, and a concrete slab was installed as a pad. Three guardposts were installed at each upgraded piezometer and embedded in concrete. Posthole diggers and motor-driven augering tools were used to excavate to a depth of 3 ft for the posts, unless rock or construction debris precluded digging past 2 ft. Hand excavation (with posthole diggers) was required at piezometer locations where underground lines or interference from cathodic protection was a concern. Guardposts were not set on existing piping, and concrete was not poured in the hole if it could contact existing piping. Piezometer upgrade procedures are described in more detail in Sect. B2.1.2 of Appendix B. The above-ground portions of the guardposts were painted. Disturbed areas were seeded, and all excavated material was placed in containers and removed.

The piezometers were developed using a combination of surging and pumping. Using a development pump, as much sediment as possible was removed from the bottom of the piezometer. A surge block was then used to surge the piezometer slowly. Water was again pumped from the well, and pH, temperature, and conductivity were measured (these data are found in Appendix B, Attachment B2). Development was complete when three well volumes had been purged, the water quality parameters had stabilized, and the purge water had clarified, or when development had continued for a maximum of 8 h. Piezometers which did not develop after 8 h were added to the sampling network if they yielded sufficient quantities of water to allow purging and sampling. Piezometers with insufficient yields were not used for sampling.

2.2 WELL HEADSPACE VAPOR SAMPLING

2.2.1 Scope

To qualitatively evaluate the presence and migration of volatile organic compounds (VOCs) in groundwater, well headspace vapor analysis was performed on monitoring wells, piezometers, and wellpoints. Sampling results provided initial information concerning areas of potential contamination and were used for design of the soil and groundwater sampling plans.

Headspace vapor samples were collected from 89 piezometers, 46 monitoring wells, and 2 wellpoints between November 21, 1989, and January 16, 1990 (Fig. 2.2.1). The samples were analyzed for 11 VOCs selected on the basis of their concentrations in groundwater or known presence in the inactive tanks and on their vapor pressure and solubility in water.

2.2.2 Methodology

2.2.2.1 Field sampling methodology

Headspaces were sampled with either stainless steel sampling tubes or Teflon tubing if a dedicated pump was installed downhole. Samples were generally collected 2 ft above the air/water interface in the well, or no deeper than 20 ft below the top of the riser. Air temperature was also measured at the sampling depth.

After the thermometer and sampling tube apparatus were lowered into the well, the riser or sampling portal was sealed. After a 5-min equilibration period, headspace samples were collected in 1-L Tedlar bags; duplicate and field blank samples were taken. Control piezometers 606 and 628, selected to monitor variability and evaluate the effects of atmospheric conditions on piezometer headspace vapor quality, were sampled daily from January 9 through 16, 1990. Control piezometers were selected on the basis of whether target compounds were detected during initial sampling and whether they were located in areas that could be sampled frequently without disrupting traffic flow or normal plant operations. Piezometers 606 and 628 were selected because they were the first wells in acceptable locations with detected VOCs.

2.2.2.2 Analytical methodology

A Perkin-Elmer Model 8500 gas chromatograph (GC) was used to analyze the piezometer headspace vapor samples. The GC was initially calibrated by injecting methanol solutions of the target compounds at various levels. Standards and method blanks were run daily, and additional calibrations were performed during the sampling event. Samples were analyzed within the 4-h holding time, and each chromatogram was evaluated with the daily standard and method blank.

2.3 SURFACE RADIOLOGICAL SURVEYS

2.3.1 Purpose

The work was performed to characterize the surface radiation exposure rate, to locate areas of elevated levels of radioactivity for use in radiological risk assessment, and to select areas for biased soil sampling. Additional discussion and maps of the survey results are found in Sect. 4.4.2.

Surface radiological walkover surveys using the Ultrasonic Ranging and Data System (USRADS) were conducted at WAG 1 by Chemrad Tennessee Corporation under subcontract to Bechtel from March 26 through July 10, 1990, and from August 1 through

August 26, 1991. Approximately 85% of the area intended to be surveyed was completed during the 1990 phase of work, and surveys of the remaining areas were completed in 1991. USRADS uses radio frequency communications, ultrasonics, and microcomputers to automatically correlate survey instrument signal input data with the physical location of the data point during the walkover survey. Survey results were digitally recorded on magnetic tape.

2.3.2 Areas Surveyed

The areas surveyed (approximately 170 acres inside and outside the main plant area) include the major portion of the ORNL main plant facilities. The general survey boundaries (Fig. 2.3.1) were Bethel Valley Road on the north, the limits of the main security fence on the east, WOC on the south, and First Creek on the west. In some areas, dense undergrowth limited the survey coverage, and the interiors of buildings were not surveyed.

2.3.3 Survey Methodology

As shown in Fig. 2.3.1, the investigation area was divided into 26 sections identified as summary grids. Except for grids 24, 25, and 26 along WOC, each summary grid was 360,000 ft^2. Each summary grid was further divided into nine 200- by 200-ft grid blocks. Although the surface areas of grids 24, 25, and 26 were not fully surveyed because of difficult terrain, portions along the floodplain were surveyed to quantify the radiation emissions from plant effluents in the WOC basin south of SWSA 1.

Three types of radiological surveillance were conducted: near-surface gamma radiation survey, shielded beta-gamma radiation measurements, and radiation exposure rate measurements. Most data were generated from near-surface gamma radiation surveys and exposure rate measurements.

Daily source checks were performed on the radiation survey instruments using a depleted uranium source. As an additional means of instrument calibration, daily background readings were taken at the RI/FS Field Operations Facility (FOF) before surveying activities began. The FOF is approximately 0.6 mile east of WAG 1.

2.3.3.1 Near-surface gamma radiation survey

A near-surface gamma radiation survey covered approximately 100% of the ground surface within each grid block. The survey was conducted with a 1.5- by 1.5-in. sodium iodide scintillation detector (Eberline SPA-3) positioned within 0.5 ft of the ground surface and slowly moved side to side while the survey technician walked at approximately 1.3 mph. Survey results are expressed in units of counts per minute (cpm).

Areas with radiation levels exceeding a predetermined threshold were marked with a red surveyor's pin flag. (Ten measurements were made in a relatively low-background area within WAG 1; the mean and standard deviation of the measurements were added together and multiplied by three to obtain the threshold.) When a grid survey was complete, a sketch of the area denoting radiation levels was made. Pin flag locations were determined by

measurements using the grid reference points and a 50-ft steel tape. The accuracy of this method of location is estimated to be approximately within ± 1 ft.

2.3.3.2 Shielded beta-gamma radiation measurements

A pancake-type Geiger-Mueller (GM) tube with a tungsten-shielded housing (Eberline HP-210T) was used to obtain surface measurements of total beta-gamma radiation levels at each grid intersect point and at the center of each grid. Measurements were made approximately 0.5 to 1 in. from the local ground surface; survey results are expressed in cpm.

2.3.3.3 Radiation exposure rate measurements

A Victoreen Model 450-P pressurized ionization chamber with an optical interface was used to conduct the gamma exposure rate surveys, which were conducted simultaneously with the near-surface gamma radiation survey. The ionization chamber connects to the USRADS equipment through the optical interface. The chamber is attached to the same boom that carries the near-surface gamma detector but is located about 3 ft above the ground surface. This allows for a constant geometry during the survey. Results are expressed in units of μR/h.

2.3.3.4 Follow-up survey

Areas with anomalously high radiation readings ("hotspots") determined from the March through July 1990 USRADS investigations were evaluated as potential soil sampling sites. The hotspots were resurveyed by the BNI team with conventional hand-held radiation detection meters to assess whether the radiation source was "skyshine" (secondary photon radiation that has been scattered by air, producing measurable radiation levels away from the source) from nearby ORNL operations buildings or surface contamination. Additional detail is provided in Sect. 4.4.2.

The near-surface gamma detection instrument was used to survey an area of approximately 100 ft^2 around each hotspot. In some locations, a cone shield was also used to eliminate skyshine as a cause of the elevated readings. Follow-up survey results were used to sort the potential sampling locations into four categories, with Category I indicating the greatest likelihood of contamination. The categories are as follows:

- Category I—USRADS hotspots where no apparent source of skyshine was observed and elevated radiation readings were encountered during a follow-up survey,

- Category II—USRADS hotspots where an apparent source of skyshine was observed and elevated radiation readings were encountered during a follow-up survey,

- Category III—USRADS hotspots where no apparent source of skyshine was observed and elevated readings were not encountered during a follow-up survey, and

- Category IV—Possible contamination area, located near an USRADS hotspot in an area where no USRADS survey was conducted.

2.3.3.5 USRADS soil sampling

The final phase of this investigation involved soil sampling at 41 locations representing all 4 categories of sampling locations (see Appendix A for sampling locations). Samples were collected in discrete 2-ft intervals using a truck-mounted drill rig, skid rig assembly, or hand auger. Borings were drilled or augered to auger refusal, the water table, an obstruction, or (in the case of hand augering) the practical limit of the method. Samples collected from each 2-ft interval were analyzed for Target Compound List (TCL) VOCs, radiological constituents, metals, base/neutral/acid-extractable (BNAE) constituents, pesticides and polychlorinated biphenyls (PCBs), and cyanide.

Those samples collected with a drill rig or skid rig assembly were collected with a 2-ft stainless steel split spoon sampler. Continuous 2-ft intervals were sampled with clean samplers to auger refusal, and soil lithology and radiation field instrument readings were recorded.

Hand augering was necessary when underground pipelines or utilities were thought to be present. The practical depth for most hand-augered boreholes was 6 to 8 ft. Samples were collected in clean stainless steel buckets from continuous 2-ft intervals. Descriptions of disturbed soil samples were recorded. Trip blanks, equipment rinsate samples, and duplicate samples were taken in accordance with the RI/FS Project Quality Assurance Plan.

2.4 SURFACE GEOPHYSICAL SURVEYS

2.4.1 Scope

Electromagnetic (EM) terrain conductivity and ground magnetometer surveys were performed at SWSA 1, SWSA 2, and the former waste pile area as part of the WAG 1 RI (see Fig. 2.4.1). The ground magnetometer survey detects buried objects containing ferrous metal, and the EM terrain conductivity survey locates low-density areas of disturbed soils possibly containing buried wastes. Both methods were used because each detects different physical properties, which will aid in identifying the nature of the waste. Survey data, methods, and results are reported in Johnson and Wagner (1991); survey results are discussed in more detail in Sect. 3.5 of this report. Raw data are stored in the project environmental data base.

2.4.2 Methodology

2.4.2.1 EM terrain conductivity survey

Chemrad Tennessee Corporation collected the EM data with a Geonics EM-31 ground conductivity meter and an USRADS transmitter that transmitted location coordinates and EM data to a computer for data storage and processing. Although metal buried less than 10 ft

deep is most likely to produce an instrument response, the EM-31 can detect buried metal to depths of up to 20 ft.

The operator carried the EM-31 meter and the USRADS transmitter as he steadily walked north-south and east-west lines across the site; each line was 10 to 25 ft from the previous pass. Data transmitted to the computer at 1-second intervals consisted of x,y coordinates (later converted to ORNL grid coordinates), EM conductivity, and in-phase response.

The raw EM data were processed through several steps leading to their interpretation. Track maps were generated, profile plots of conductivity and in-phase response were prepared using Lotus 1-2-3, and conductivity contour maps were prepared. The profile plots were used to identify anomalies, which were marked on a plan map; anomalies that could not be explained by known features were identified on the interpretation maps found in Johnson and Wagner (1991).

2.4.2.2 Ground magnetometer surveys

Project team geophysicists collected magnetometer data using an EDA OMNI IV magnetometer, a proton precession instrument capable of measuring vertical magnetic gradients. The geophysicists laid out a 40- by 40-ft grid pattern with flags to mark survey lines 10 ft apart and oriented along north-south ORNL grid lines. Readings taken at each station included location coordinates, total magnetic field, vertical magnetic gradient, time, information about equipment operation, and observations about any physical features that might have affected the readings. At the end of each day, data were transferred to a personal computer and rearranged into a grid format with Lotus 1-2-3. Profile plots of the total magnetic field and vertical magnetic gradient and contour maps were prepared. The same procedure used for the EM data was used to interpret the magnetometer data.

2.5 REFERENCE SAMPLING

2.5.1 Scope

A reference sampling program was established for the primary media under investigation—soil, groundwater, creek sediments, and surface water—to determine the presence and distribution of chemical and radiological constituents in an environment that has not been affected by site waste management practices. Concentrations of chemicals and radionuclides in the reference samples were evaluated to assess their representativeness of "reference" concentrations. More details on the evaluation process are presented in Sect. 4.2. WAG 1 concentrations of these constituents in excess of the reference values might then be attributable to known waste management and pilot plant and production facility activities.

WAG 1 reference samples were all collected within Bethel Valley. Locations were chosen at hydraulically upgradient positions or in surface water drainage basins separate from WAG 1 and other known waste disposal sites. Eighteen soil samples, eight groundwater

samples, two sediment samples, and eight surface water samples were collected under this program. Samples generally received a GC screen for VOCs and a radiological screen for gross alpha, gross beta, and tritium content and were further analyzed as described in Appendixes A and B.

2.5.2 Methodology

2.5.2.1 Reference soil sampling

Eighteen reference soil samples were taken from 16 locations in Bethel Valley (Table 2.5.1). Except for BV03 (sampled to 32 ft), all locations were sampled to 6 ft. Most of the sampling locations were along the northern boundary of WAG 1; others were to the east and west of WAG 1 (Fig. 2.5.1). Some locations also served as reference groundwater sampling locations (Sect. 2.5.2.2).

For all reference soil samples, standard 2.5-in. outside diameter (OD), 2-ft-long split spoon samplers were advanced into undisturbed soil. After the split spoons were opened and the samples were scanned, a composite sample of the entire 2-ft interval was taken for VOC analysis. VOC samples were taken over 2-ft intervals to a depth of 6 ft; the 0- to 2-ft sample was submitted for analysis unless field screening indicated that another interval had higher VOC levels. A composite soil sample collected from the first 6 ft or to refusal (if refusal was less than 6 ft) was analyzed for other constituents as described below. Split spoon samples taken below 6 ft were field-screened, and additional VOC samples were taken below 6 ft where indicated by the screening. One duplicate soil sample was collected and analyzed for all parameters. Trip blanks and field rinsate samples were collected as quality control measures.

After sample screening was conducted in the field and at the Close Support Laboratory (CSL), selected soil samples were shipped to the off-site contract analytical laboratory for further analyses. Selected samples were analyzed for Appendix IX VOCs, semivolatile organics, metals, herbicides, organophosphorus pesticides, pesticides/PCBs, dioxins, and furans. Other samples were analyzed for TCL VOCs, semivolatile organics, pesticides, and PCBs; Target Analyte List (TAL) metals; and radiological constituents, cyanide, and sulfide. Results of these analyses are given in Appendix A, Attachment A4.

2.5.2.2 Reference groundwater sampling

The reference groundwater sampling program included sampling from five new and existing monitoring wells at locations in Bethel Valley upgradient of known or suspected contaminant sources (Fig. 2.5.1); completion dates and monitoring zones are shown in Table 2.5.2. To complete the reference groundwater monitoring well network, unconsolidated zone reference wells 4001 and 4002 (formerly designated BV08 and BV09, but renamed by Energy Systems for consistency with the new ORNL-wide well data base) were installed and developed, and soil samples were collected from the boring. The remaining wells were screened in bedrock.

Boreholes in unconsolidated zone wells 4001 and 4002 were advanced by a 6.75-in.-OD hollow stem auger until auger refusal, and the monitoring well screen was installed at the depth where moist or wet cuttings were encountered. Soil samples were taken at 2-ft intervals with split spoon samplers as described in Sect. 4.2.4. The wells were completed with 2-in.-diam, 0.01-in. continuous-slot, stainless steel screen (from 2.5 to 5.0 ft in length) attached to a flush-threaded, 2-in.-diam stainless steel riser pipe. A sand pack was placed from the bottom of the borehole to 1 ft above the screen, the annulus was filled to the surface with bentonite pellets, and the well was completed with a concrete pad, posts, and protective casing with a locking cap. The wells were developed in the same manner as the upgraded piezometers (Sect. 2.1.2).

Air rotary drilling was used to install the bedrock wells, and split spoon samples were collected at 2-ft intervals by pushing the sampler into the soils with the hydraulic driving device on the drilling rig. Wells were completed and developed in the same manner as the unconsolidated wells, except that the annulus from the sand pack top to ground surface was filled with a cement/bentonite grout.

Reference groundwater samples were collected during low base flow conditions (September–October 1990) and high base flow conditions (March–April 1991) (wells 4001 and 4002 were sampled only once, during the spring of 1991). After sample screening was conducted in the field and at the CSL, groundwater samples were shipped to the off-site contract analytical laboratory for further analyses. Selected samples were analyzed for Appendix IX VOCs, semivolatile organics, metals, herbicides, organophosphorus pesticides, pesticides/PCBs, dioxins, and furans. Other samples were analyzed for TCL VOCs, semivolatile organics, and pesticides/PCBs; TAL metals; and radiological constituents. Samples were also analyzed for cyanide, sulfide, anions, carbonate, bicarbonate, total dissolved solids (TDS), total suspended solids (TSS), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), and total organic halogens (TOX). Results are reported in Appendix B, Attachments B20 and B21.

2.5.2.3 Reference creek channel sediment sampling

Reference creek channel sediment sampling was conducted at two locations in conjunction with low base flow, nonstorm sampling in October 1990 (Fig. 2.5.2). Samples were taken at CS009 and CS006 on October 17 and 18, respectively (Table 2.5.3). Stainless steel dippers, spoons, and bowls were used to collect and composite the samples; VOC samples were collected first. After screening of the samples was conducted in the field and at the CSL, selected sediment samples were shipped to the off-site contract analytical laboratory for further analyses. Samples were analyzed for TCL VOCs, semivolatile organics, and pesticides/PCBs; TAL metals; and radiological constituents, cyanide, and sulfide (results are reported in Appendix B, Attachments B22 and B23). Two duplicates and an equipment rinsate sample were also collected.

2.5.2.4 Reference surface water sampling

Between October 1990 and March 1991, reference surface water samples were collected under both low base flow, nonstorm, and high base flow, nonstorm conditions from the three

creeks north of their intersections with Bethel Valley Road. Eight locations were sampled; sampling locations and dates are given in Table 2.5.4, and sampling locations are shown in Fig. 2.5.2. Duplicates, rinsates, and field blanks were also taken.

Samples were taken from downstream to upstream with the sampler facing upstream while collecting water 1 ft below the surface. Samples were transferred directly to sample containers, and VOC sample containers were filled first.

After screening of the samples was conducted in the field and at the CSL, samples were shipped to the off-site contract analytical laboratory for further analyses. Results of analyses are found in Appendix B, Attachments B24 and B25. Selected samples were analyzed for Appendix IX VOCs, semivolatile organics, metals, herbicides, organophosphorus pesticides, pesticides/PCBs, dioxins, and furans. Other samples were analyzed for TCL VOCs, semivolatile organics, and pesticides/PCBs; TAL metals; and radiological constituents. Samples were also analyzed for cyanide, sulfide, anions, carbonate, bicarbonate, TDS, TSS, TOC, TKN, and TOX.

2.6 SUMP SAMPLING

2.6.1 Scope

Twenty-one sumps associated with 10 buildings (including surrounding tanks and pumps) were evaluated and sampled between January 23 and February 6, 1990 (see Appendix B, Fig. B5.1.1). The purpose of the investigation was to establish whether contamination was present and to determine the relationship between contamination in sumps and the surrounding features (i.e., building operations, nearby SWMUs, and clean or contaminated groundwater).

2.6.2 Methodology

Managers of 149 buildings were contacted to determine the presence of sumps that held water; 26 buildings were identified as having sumps with standing water, but only 21 sumps at 10 buildings were eventually sampled (Table 2.6.1). Some sumps could not be sampled because the entrances were sealed, the entrances could not be located, the identified sump was found during a site visit not to be a sump, or other access problems prevented sampling. Locations of the sampled sumps are shown in Fig. 2.6.1.

Most of the sumps were sampled for analysis of VOCs, BNAEs, metals, and radiological parameters including tritium. Sump samples from Buildings 3534, 4501, and 4508 were also analyzed for mercury because spills had occurred in the past. Sampling results are given in Appendix B, Attachment B7.

ORNL personnel were consulted about activities in and around the buildings that may possibly contribute contaminants to the sumps.

2.7 SOIL BORINGS

2.7.1 Scope

Two hundred eighty-six soil borings were drilled or hand augered at WAG 1 as part of the Phase I soil sampling and analysis program. A complete list of the soil borings, depths, and locations is found in Appendix A, and boring locations are depicted in Figs. 2.7.1 through 2.7.4.

Completed between November 1989 and November 1991, this phase was designed to identify areas in which soils are chemically or radiologically contaminated as a result of ORNL activities and to determine the types and concentrations of contaminants. Soil sampling locations were selected to assess documented SWMUs (spill and leak sites, collection and storage tanks, ponds and impoundments, waste treatment facilities, SWSAs, and pipeline trenches), floodplain soils, and hotspots detected during the radiation walkover survey.

Approximately 750 soil samples were screened in the field and at the CSL (GC and radiological screens) and, based on the results, over 400 samples were selected to be sent to a contract laboratory for further analyses, which in most cases did not include a full suite of parameters. Typically, samples found to contain elevated activities of gross beta or gross gamma (based on CSL results) were sent to the contract laboratory for further analyses. Eighty-eight of the more than 400 samples were also analyzed for engineering and physical properties in addition to the chemical and radiological parameters. Data results are included in Appendix A, Attachment A2.

2.7.2 Methodology

Samples were obtained in 2-ft increments by hand augering, by using a 7-in.-OD hollow stem auger with variously sized drilling rigs, or by advancing a 3-in.-OD stainless steel split spoon sampler with a 140-lb hammer. Shelby tubes, also used to collect 2-ft samples, were sealed at both ends and transported to the decontamination facility before material was extruded and samples were composited.

After samples were taken, the auger was advanced to the bottom depth of the previous sample, the drill cuttings were surveyed for chemical and radiological contamination, and a new sample was obtained; the process continued until auger refusal was reached. Boreholes drilled as part of this investigation were plugged and abandoned with either a cement/bentonite grout or bentonite pellets.

In some cases, hand augering to an average depth of 5 to 8 ft was used to avoid shallow buried pipelines and other features, and an auger bucket was used to collect the samples. Environmental, Safety, and Health (ES&H) personnel surveyed the split spoon sample or the auger bucket for chemical or radiological contamination. VOC and GC aliquots were then taken immediately by scraping the length of the spoon or by taking the sample from the first bucket of the 2-ft hand-augered interval.

The remaining sample was described by the on-site geologist and composited in a stainless steel bowl before the other analyte containers were filled. Equipment rinsate blanks, trip blanks, preservation and field blanks, and duplicates were collected in accordance with quality assurance procedures in effect at the time.

2.8 GROUNDWATER AND SURFACE WATER MONITORING

2.8.1 Scope

Physical characteristics (e.g., pH and temperature) of groundwater, surface impoundments, and surface water were measured monthly to provide data for characterization of groundwater movement, quality, and interaction with surface water. Groundwater level, temperature, and specific conductivity were measured in wells, well points, and piezometers (both stick-up and flush-mount); surface water levels were taken; and flows in Fifth Creek were measured. Data are given in Appendix B.

2.8.2 Methodology

2.8.2.1 Periodic monitoring

Beginning June 1990, water levels were measured at approximately 147 locations in the vicinity of WAG 1 (Fig. 2.8.1), primarily within the WAG 1 boundary. A complete list of sampling points is given in Appendix B, Sect. B2.2. Beginning in December 1990 and concluding in January 1992, water levels were measured monthly to determine trends in seasonal fluctuation.

Water levels, temperature, and specific conductivity were measured in 56 wells, 2 wellpoints, and 89 piezometers with a YSI Model 3000 T-L-C water quality meter. When an installed dedicated pump precluded use of the YSI T-L-C meter, only a standard water level sounder with a 0.5-in.-diam probe was used to obtain water level. Probes were decontaminated with an Alquinox™ solution and rinsed thoroughly with deionized water between measurements.

Flow rate, velocity, and water depth were measured monthly at Fifth Creek. While the civil survey crew measured the water depth, the velocity was measured by the six-tenths depth method with a Swoffer Instruments Model 2100 Series current velocity meter. The flow rate was calculated as velocity times the cross-sectional area of the flow normal to the direction of flow.

The water level measurement program was designed to take monthly measurements (as nearly as possible within a 30-day interval) over a maximum of 3 days per sampling event. Water level measurements were delayed if a storm (defined by 0.5 in. or more of precipitation in any 24-h period) occurred within 4 days of the scheduled sampling date. This delay allowed the groundwater and surface water to stabilize, and the schedule was shifted to 30 days from the latest measurements.

2.8.2.2 Continuous water level monitoring

A program of continuous water level monitoring in wells and streams was conducted from April 22 to December 31, 1991. Data loggers and pressure transducers were installed and data were collected to help characterize groundwater level fluctuations, surface water/groundwater relationships, barometric fluctuations, and overall relationships with rainfall patterns.

The continuous water level monitoring system monitored 17 wells (including deep/shallow well pairs where possible); First, Fifth, and White Oak creeks; and barometric pressure (Fig. 2.8.2). The power supply to the transducers was monitored and adjusted when necessary. When data gaps occurred because of equipment or power irregularities, corrections (e.g., replaced battery) were made to prevent recurrence. Comparisons were made of the continuous measurements and the monthly measurements, and discrepancies were corrected according to the monthly measurements. Transducer measurements were converted to elevations, and hydrographs were prepared. Procedures and results for continuous water level monitoring are described in greater detail in Sect. B2.3 of Appendix B.

2.9 GROUNDWATER SAMPLING

2.9.1 Scope

Extensive groundwater sampling was included in the program investigations. Eighty-four wells (including the WAG 1 perimeter wells and upgraded and developed piezometers) were sampled during base flow (both high and low) and high base storm sampling events. Nine temporary piezometers were installed and sampled to assist determination of whether selected pipe trenches were temporary migration pathways for contaminants. During fall 1991, existing piezometers were sampled to assess the possibility of releases to groundwater from an additional 33 SWMUs. After strontium-90 was detected during drilling in CH008, 3 wells and 11 piezometers nearby were sampled as part of a follow-up investigation. Selected coreholes were sampled during corehole packer testing events. Table 2.9.1 lists the wells and piezometers sampled, and Figs. 2.9.1 through 2.9.3 show the sampling locations. Appendix B, Attachment B13 contains the results of the data analyses. Duplicates, field-filling blanks, trip blanks, equipment rinsates, preservation blanks, and field trip blanks were taken in all cases except when grab samples only were specified. Specific dates for each sampling event from September 1990 through March 1992 and the types of analyses performed are given in Table 2.9.2.

2.9.2 Methodology

2.9.2.1 Base flow and storm sampling

Decisions to initiate base flow (both low base and high base) and storm flow sampling were based on the frequency and duration of rainfall and the time of year. High and low base flow sampling was initiated only if at least 4 days had elapsed without 0.5 in. or more of precipitation during a 24-h period. Conversely, storm sampling was conducted only when

precipitation exceeded 2 in. within 24 h; samples were collected after the storm peak but within 3 days to take advantage of the elevated water levels. Eighteen piezometers and wells were sampled during storm events, 82 were sampled during the high base event, and 77 were sampled during the low base event.

Sampling procedures were the same for wells and piezometers. After the well or piezometer was uncapped, it was screened for organic vapors and radiation, and the depth to water was measured. All wells and piezometers were purged before sampling with a WaTerra pump. The dedicated Teflon tubing in the piezometers was fitted with a stainless steel foot valve at the bottom, repositioned in the borehole, and fitted with an extension. The foot valve was kept a minimum of 2 ft above the bottom when the piezometers were purged to prevent intake of any sediment in the bottom of the piezometer.

Purging was accomplished by cycles of pumping one well volume while measuring the designated water quality parameters (temperature, pH, and conductivity) and then pumping another well volume. When the parameters had stabilized (remained essentially the same) for two consecutive well volumes, purging was complete. If no stabilization occurred, the well was purged for five well volumes or until the well was dry.

The wells or piezometers were sampled within 24 h after purging. VOC samples were taken from wells purged to dryness as soon as enough water had recovered to fill the VOC vials. Wells that recharged slowly were sampled the next day, provided that sampling was completed within 24 h. If it was not possible to complete sampling within that time frame, the well was purged again.

Sampling was accomplished by placing the pump or foot valve either 2 ft above the bottom of the well or piezometer or centered within the depth of the screened interval, whichever was shallower. Sample containers were slowly filled and field-filtered as appropriate using an in-line 0.45-micron filter. Both filtered and unfiltered samples were collected. Temperature, pH, and conductivity were typically measured (always from unfiltered samples) after every fifth container and again after all containers were filled.

2.9.2.2 Pipeline trench monitoring

Temporary piezometers were installed in pipeline trenches (typically a soil-filled trench containing LLLW or process waste lines) to determine whether the trenches were acting as migration pathways for contaminants. All but one of the piezometers were consistently dry during nonstorm events, but most of the trench piezometers did contain water after storms. These piezometers are scheduled to be removed in 1992. More details are provided in Sect. B8 of Appendix B.

Typical installation (with a 4-in.-OD hand auger bucket) consisted of a 1-in.-diam PVC riser to depths ranging from 4.3 to 16 ft, with a 2-ft screen, and extending 1 ft above ground surface. The screen was backfilled with 2.5 ft of sand followed by 1 ft of bentonite. A 6-in. cap of sand was placed above the bentonite, followed by a bentonite/cement grout seal to ground surface. The piezometer was capped, and the riser was covered with a 3-ft length

of 3-in.-diam capped PVC pipe extending 1.5 ft above ground surface. Locations and piezometer numbers are given in Table 2.9.3 and Fig. 2.9.2.

After installation, samples from the piezometers were sent to the CSL for VOC analysis with a GC screen and gross alpha, gross beta and tritium analyses. All samples (except the initial sample taken at SB208) were collected with the WaTerra system. Because wells were not purged before sampling, samples were moderately turbid; filtered and unfiltered samples were therefore analyzed to characterize the radioactivity in the sediment fraction. Table 2.9.2 summarizes the types of analyses performed.

2.9.2.3 CH008 follow-up sampling

After elevated levels of strontium-90 were detected during drilling of CH008, an additional surface water and groundwater investigation was conducted from October through December 1991 to determine the extent and sources of contamination.

The program included groundwater samples from three existing wells and ten existing piezometers (both stick-up and flush-mount), surface water samples (during low base flow conditions) at 50-ft intervals along First Creek, sediment samples at seeps and other selected locations, and water samples from four stormwater pipe outfalls. Filtered and unfiltered water samples were collected and analyzed at the CSL by radiological and VOC screening, and gamma spectrometry was performed on selected samples. Table 2.9.1 lists the wells included in this sampling effort, and locations of the wells and piezometers are shown in Fig. 2.9.3. Additional details on this investigation are provided in Sect. B6.1.2 of Appendix B.

2.9.2.4 Additional SWMU sampling

In September 1991, investigations were conducted at 33 additional SWMUs in WAG 1, including waste storage tanks; inactive tanks; storage sites; high-level chemical development and radiochemical analytical laboratories; and underground exhaust ducts. The work was conducted in October and November 1991 and involved ORNL personnel interviews, document and data review, existing piezometer sampling, and drilling and sampling of eight new soil borings. Eight existing piezometers were sampled for TCL VOCs, TAL metals, and radiological parameters to determine the presence of possible contaminants. Grab water samples were taken from six piezometers (both stick-up and flush-mount) and three soil borings for CSL radiological screens only. Locations of wells and piezometers are shown in Fig. 2.9.3.

2.10 BEDROCK COREHOLES

2.10.1 Scope

Two north-south transects with a series of bedrock coreholes were installed near or within WAG 1 to characterize the geology and hydrogeology of the Chickamauga Group. Seven coreholes were originally intended to be drilled, but an adjacent existing corehole was substituted for CH010 on Transect 3 because it provided the opportunity to obtain the

necessary data except those data from coring, and it offered the opportunity to save time and money. Therefore only six coreholes were drilled. Corehole locations are shown in Fig. 2.10.1, and Table 2.10.1 is a summary of corehole installation.

The program was designed not to exceed a maximum corehole depth of 500 ft, and field decisions were made to stop coring if there was a noticeable decrease in fracture density before the 500-ft depth was reached. Soil samples were taken during augering to top of rock, and continuous coring was extended to total depth. A suite of geophysical logs was run on each corehole, and packer testing was performed on selected intervals in each corehole.

2.10.2 Methodology

2.10.2.1 Coring

A Mobile B-61 core rig was first mobilized at each location to auger through the overburden and to take continuous split spoon samples in 2-ft intervals to top of bedrock. After a surface casing was set and grouted to top of rock, a Longyear 44 core rig was mobilized.

Inner casing of sufficient diameter to allow for casing advancing equipment was set, and cores were obtained with triple-tube, size HQ wire line core barrels. Drilling specifications called for at least 90% core recovery, and all triple-tube core barrels were equipped with at least two inner sleeves. Corehole deviation from vertical was limited to no more than 3° per 100 ft, as measured approximately every 100 ft by a Pajari inclination device. Coring of the borehole continued until a field decision was made to stop.

Before coring began at each location, a sample of the water to be used for drilling fluid was taken and sent to the CSL for VOC and radiological analyses to establish drilling fluid background values. Soil core descriptions and lithologic descriptions of the cores were made, and core was stored in marked boxes at the FOF.

2.10.2.2 Geophysical logging

Borehole geophysical logging was performed on five water-filled boreholes drilled in association with the WAG 1 RI (CH006, CH07A, CH009, CH11A, and CH012) and one corehole (FT10) drilled for a previous investigation. CH008 was not logged because of the high levels of contamination encountered, which resulted in the cessation of drilling at a depth of 53.9 ft. ORNL performed all logging, including borehole televiewer and deviation surveys, in accordance with ORNL logging procedures in effect at the time. Comprehensive suites of logs were run on each corehole as shown in Table 2.10.2; the exceptions are also noted in this table.

Coreholes were logged in the approximate order of completion, and FT10 was logged last. Several runs were required to complete the full logging suite shown in Table 2.10.2. Logging tools were generally run in the following order: temperature/differential temperature (downhole), natural gamma ray, spontaneous potential, caliper, resistivity, sonic,

neutron, gamma-gamma density, long/short normal resistivity, borehole televiewer (BHTV), and deviation survey. To avoid mixing effects from lowering and raising the tools in the hole, the temperature and differential logs were always run first as the tool was lowered into the borehole, and other logs were run uphole as the tool was removed.

All logs (except BHTV) were digitally recorded in increments of 0.1 ft. The borehole geophysical logs were produced as hard copies, and log data were provided in digital (ASCII) form. BHTV photos were obtained for each 5-ft interval, composited as a single log, and reproduced with depth notations accompanying the compiled photos.

2.10.2.3 Packer testing

Thirty-eight intervals in eight coreholes at WAG 1 were tested with straddle packers to obtain both quantitative and qualitative data on the geohydraulic properties of the Chickamauga Group. Testing intervals in CH001, CH003, CH006, CH07A, CH009, FT10, CH11A, and CH012 were chosen on the basis of information obtained from geophysical logs and fractures-per-foot logs.

Straddle packers were used to isolate a discrete interval of the borehole so that hydraulic head relationships within the aquifer could be identified and a hydraulic conductivity test could be conducted. The packer assembly consisted of a pressure transducer (attached to a perforated pipe between the straddle packers), a data logger, and a double-piston pump. The packers were inflated with nitrogen, and the pressure head in the interval was allowed to stabilize. After a 100-min period or a head change of <0.02 ft water over a 10-min interval, a pressure head reading was taken. The pressure head plus the elevation head reading equal the piezometric head at that testing interval. Hydraulic conductivity tests were performed by pumping a known volume of water at a constant flow rate and using the data logger to record pressure head displacement. When sufficient volumes of formation fluid could be extracted from the interval being tested and after the pressure tests were completed for an interval, groundwater samples were taken and analyzed for geochemical parameters, radionuclides, and hazardous constituents. Packer testing and related results are discussed in Sect. B4 of Appendix B.

2.11 SURFACE WATER AND CREEK CHANNEL SEDIMENT SAMPLING

2.11.1 Scope

Field activities consisted of low and high base flow surface water sampling (including storm and nonstorm events), sediment sampling, and flow measurements. Surface water and sediment sampling locations are shown in Fig. 2.11.1. Manual grab sampling of base flow surface water was conducted at sampling locations along WOC, First Creek, Fifth Creek, and Northwest Tributary. The interaction between groundwater and surface water flow regimes is discussed in Sect. 3, and the nature and extent of contamination are further discussed in Sect. 4.

Four types of surface water sampling were conducted (Table 2.11.1). For both the low and high base flow conditions, storm and nonstorm events were sampled. (Low base flow exists when surface water and groundwater levels reach their yearly minimums; high base flow conditions exists when levels are at their yearly maximums.)

High water table conditions normally occur from January through March at the site, and low water table conditions exist from August through November. All high base flow sampling was conducted during high water table conditions, and low base flow was sampled during October and November. Procedures and results from the surface water and creek channel sediment sampling efforts are discussed in Sect. B7 of Appendix B.

2.11.2 Methodology

2.11.2.1 High and low base flow surface water sampling

Sampling during both high and low base flow conditions was conducted for both storm and nonstorm conditions. (Low base flow, nonstorm conditions exist when no rainfall has fallen during the 7 days before sampling; high base flow, nonstorm conditions exist when no rainfall has fallen for 3 days before sampling.) Storm event sampling required that a minimum of 0.5 in. of rain must have fallen before sampling was initiated. Ideally, samples were collected 30 to 60 min after the storm peak, but this was not always possible when only one crew was sampling.

Sampling was conducted from downstream to upstream locations to prevent potential sample contamination from previous upstream sampling. Taking care not to disturb bottom sediment when filling sample containers, the sample technician faced upstream while collecting water up to 1 ft below the surface with a stainless steel dipper. The water sample was then transferred directly to the sample containers. VOC vials were filled first, and the other containers were filled to the shoulder of the container and analyzed for the full TCL and radiological parameters. Filtered and unfiltered samples were taken for radiological and metals analyses only at SW-6, and water quality measurements (pH, temperature, and specific conductance) were taken at each station.

The 12 stations used for collection of both surface water and sediment as shown in Fig. 2.11.1 were sampled in the following sequence: (1) CS012, Northwest Tributary; (2) CS011, First Creek; (3) CS010, First Creek; (4) CS009, First Creek; (5) CS006, Fifth Creek; (6) CS005, WOC; (7) CS004, WOC; (8) CS003, WOC; (9) CS008, Fifth Creek; (10) CS007, Fifth Creek; (11) CS001, WOC (Appendix IX sample set required rather than TCL); and (12) CS002, WOC.

The eight stations used only for collection of surface water samples were sampled in the following sequence: (1) SW-6: WOC—filtered and unfiltered samples for metals and radiological parameters (a duplicate sample was taken); (2) SW-8: Northwest Tributary; (3) SW-7: First Creek—field blank; (4) SW-1: First Creek—flow measurements and stream dimensions; (5) SW-5: WOC—duplicate sample; (6) SW-4: Fifth Creek—flow measurements, stream dimensions, and rinsate sample; (7) SW-2: Fifth Creek—flow measurements and stream dimensions; and (8) SW-3: WOC—flow measurements and stream dimensions.

During the high base flow, nonstorm event, several point source discharges into WOC were sampled. The coal pile settling basin outfall (ID number X02) and the water treatment plant National Pollutant Discharge Elimination System (NPDES) outfall (ID number X12, shown in Fig. 2.11.1) were both screened for radiological and VOC constituents at the CSL.

2.11.2.2 Creek channel sediment sampling

Creek channel sediments were sampled once as part of the low base flow, nonstorm sampling event in October 1990. Sediment samples were collected to a depth below creek bottom of 6 in. from CS001 through CS012 after the surface water samples were taken. Samples were collected in the same sequence as the surface water samples (downstream to upstream), and were analyzed for TCL and radiological parameters (except CS001, which was analyzed for Appendix IX rather than TCL constituents).

At each sampling station, sediments were collected across a transect perpendicular to stream flow. The VOC samples were placed in sample containers first with a stainless steel dipper. Sufficient sediment sample was then collected and composited (with either the dipper or a stainless steel spoon) in a stainless steel bowl before the remaining sample containers were filled.

2.11.2.3 Stream flow measurement

Flow measurements were made at each surface water station, either from the continuous flow monitoring devices (i.e., USGS monitoring stations) or by using a Swoffer Model 2100 flow meter. Channel depth and width were measured at sites without flumes or weirs, and velocity readings were taken at up to three points across the stream for flow rate measurements. Flow rate for each of the cross-sectional areas was calculated by multiplying the average velocity by the rectangular area (depth × width) of the sector. Total flow of the creek was the sum of the flows calculated for each sector. Stream flow measurements are discussed in Sect. B7.1.1 of Appendix B.

As part of this sampling effort, flows from the water treatment plant outfall and the coal pile settling basin outfall were noted by observing the discharge (e.g., half-full, full) from the outfall pipes.

2.12 SEWAGE IMPOUNDMENT SAMPLING

2.12.1 Scope

Sewage aeration ponds 2543 and 2544 were designed only for domestic sewage from ORNL, but radioactively contaminated water may have infiltrated the sanitary sewer system and been subsequently conveyed to the ponds. The investigation was designed to characterize the sludge and sediment in the ponds by analyzing samples for radiological and TCL parameters.

2.12.2 Methodology

Three sampling locations were selected at each pond; in addition, a seventh sample (IS007) was composited from random locations in pond 2543 (Table 2.12.1 and Fig. 2.12.1). Each pond was divided into 20 equivalent areas, and the centers of three areas were randomly selected for sampling. Sampling sites were reached by a boat manned by a rower, a sampling technician, and an industrial hygienist/health physicist.

The sampling protocol was modified as needed, depending on field conditions. A sampling device was fashioned from a 1-L stainless steel bucket clamped (with stainless steel clamps) to a 15-ft extension of 1-in.-diam hand auger rod, so that the bucket opening was at right angles to the rod. The sampling device was carefully lowered to the bottom of the pond (approximately 12 ft deep) to avoid puncturing the pond liner. As the rower steadied the boat, the sampling technician dragged the sampling device across the pond bottom, raised the rod hand-over-hand, and decanted the water in the top of the bucket. The sludge/sediment was poured into a 5-gal stainless steel bucket.

When sufficient sample was obtained, the sampling team rowed to shore, where another team filled the sample bottles from the 5-gal bucket. A VOC sample was taken before the sample was thoroughly mixed. Samples were analyzed for radiological and VOC screens, radiological parameters, TCL VOCs, TAL metals, TCL BNAE/PCBs, and TCL cyanide.

Clean, decontaminated buckets were used for each sampling station, and the used buckets were wrapped and sent to the decontamination facility. Auger rods were decontaminated in the field using Alconox and deionized water. Equipment rinsate blanks, trip and field blanks, preservation blanks, and duplicates were collected in accordance with the quality assurance project plan.

2.13 TANK MONITORING AND INSPECTION

Inactive LLLW tanks in WAG 1 were investigated under two tasks: (1) liquid level trend analysis to evaluate tanks tightness; and (2) video inspection of Gunite tanks to identify deterioration. Thirty underground storage tanks in WAG 1 were considered in this program. Table 2.13.1 lists the tanks and the tasks that were performed for each, and Fig. 2.13.1 shows the locations of tank-specific soil sampling stations.

2.13.1 Methodology

2.13.1.1 Level trend analysis

Most of the tanks listed in Table 2.13.1 have existing level gauges, either floats or conductivity probes. Conductivity probe level gauges were installed on four tanks that had no existing level gauge. Level data were collected daily over periods ranging from one to six months and statistically analyzed to determine liquid level trends. Mean liquid level change rates were then calculated based on the level trends. An evaluation of change in tank level was made based on this analysis. The level measurement methodology was within the

RCRA standard for automatic tank gauging described in 40 CFR 280.43(d), which sets a 0.2-gal/h sensitivity standard.

2.13.1.2 Video inspection

Most of the Gunite tanks in WAG 1 were inspected using remotely operated video cameras; the inspections were intended to determine the general extent of deterioration of these 50-year-old tanks. The camera and lights were deployed through access ports in the top of the tanks. The camera was then panned and tilted to observe and record the inner surface of the tank shell. In tanks with large manways for access, a color camera with 6:1 zoom and variable aperture was used. In tanks with limited access, a small color camera (less than 2-in.-diam) with fixed focal length and aperture was used. The inspections were recorded for detailed study. Video inspections were not performed on tanks reported to have no significant inleakage. Video inspection could not be performed on selected tanks due to access problems (e.g., TH-4 was full).

2.13.1.3 Tank-specific and geotechnical soil sampling

Soil borings were drilled and samples were collected in the summer of 1990 in support of a structural integrity assessment (SIA) of inactive LLLW storage tanks at WAG 1. Soil borings were drilled around each tank or group of tanks to determine the properties of the surrounding soil mass.

Soil borings were drilled to refusal with either a drill rig or a tripod apparatus and sampled continuously with 2-ft split spoon samplers to total depth. Up to two samples were collected—only one if bedrock was reached before the predetermined lower depth—at specified depths from each boring and analyzed for soil index and chemical properties. Soil index properties include unit weight, grain size distribution, specific gravity, Atterberg limits, and moisture content; chemical properties include sulfides, sulfates, chlorides, and nitrates. Samples were also taken for field testing of soil pH and resistivity, at approximately the same depths as the soil index and chemical properties sample points. These samples were analyzed at the CSL within 24 h of collection. The geotechnical data are presented in Attachment A3 of Appendix A.

REFERENCES FOR SECTION 2

Bechtel National, Inc. *Quality Assurance Plan for the Oak Ridge National Laboratory Remedial Investigation/Feasibility Study*, ORNL/RAP/Sub-87/99053/13.

Johnson, B. and T. Wagner 1991. *WAG 1 Electromagnetic Terrain Conductivity and Ground Magnetometer Survey*, Technical Memorandum 01-03, Bechtel National, Inc., Oak Ridge, Tenn.

Table 2.1.1. Upgraded piezometers at WAG 1

Number	Northing	Easting
0533	22006.6	28818.8
0536[a]	21889.3	29485.6
0538	22629.8	29736.3
0539	22380.1	29809.1
0540	21955.5	29644.6
0541	21828.8	29816.2
0543	21334.7	29713.6
0545	23004.1	29742.2
0546	22757.4	30034.0
0547	22620.1	30025.3
0548	22071.7	29940.7
0549	23020.1	30301.5
0550	22378.3	30196.2
0553	21583.8	30244.2
0554[a]	21318.7	30180.5
0558	22799.6	30699.4
0560[a]	22447.2	30700.3
0561[a]	22189.8	30659.7
0563[a]	21899.7	30615.8
0564	21835.9	30459.4
0566	21754.2	30625.5
0571	20919.4	30515.7
0572	23037.9	30872.7
0578	21878.2	30852.6
0579[a]	21639.3	30920.1
0583	22298.8	30955.4
0587	22875.1	31289.9
0589	22473.2	31331.5
0597[b]	22287.9	31445.3
0598	22174.7	31359.0
0599	22009.3	31418.2
0601	21496.9	31503.9
0602	22852.4	31476.0
0604	22039.6	31520.3
0610	21409.3	31645.8

Table 2.1.1 (continued)

Number	Northing	Easting
0611	22789.5	31790.3
0612	22588.8	31707.3
0614	22465.0	31803.1
0615	22334.8	31864.7
0616[b]	22222.4	31784.1
0618	21739.5	31855.7
0620	22870.0	31917.0
0621	22459.9	31924.7
0622	22239.9	31960.3
0623	21944.9	31949.4
0626	21686.9	32116.7
0628	22219.0	30957.8
0634	22599.1	32722.0

[a]Hand excavated.
[b]Possibility of encountering contaminated soil during excavation.

NOTE: Upgraded piezometers list was derived from logbooks. Coordinates were taken from civil survey data base.

Table 2.5.1. Reference soil sampling

Boring No.[a]	Northing	Easting	Depth sampled (ft)	Sampling date
BV01	22495.16	23912.64	0–6	11/03/89
BV02 (1250)	22026.15	23139.95	0–6	11/10/89
BV03 (1251)	19941.94	36619.16	0–6 16–22 26–32	11/10/89– 11/13/89
BV04 (1252)	22522.13	43261.22	0–6	11/09/89
BV08 (4001)	23058.82	29503.01	0–6	03/19/91
BV09 (4002)	22235.82	36321.03	0–6	03/19/91
FCBG1	23244.68	29430.78	0–6	11/10/89
FCBG2	23242.24	29439.42	0–6	2/5/90
FCBG3	23240.61	29447.58	0–6	2/5/90
5CBG1	23473.65	31915.11	0–6	11/9/89
5CBG2	23470.08	31920	0–6	11/9/89
5CBG3	23463.37	31928.16	0–6	1/30/90
5CBG4	23458.49	31932.88	0–6	1/30/90
WCBG1	23874.34	37836.36	0–6	11/8/89
WCBG3	23879.72	37813.72	0–6	11/8/89
WCBG4	23880.86	37808.53	0–6	11/7/89

[a]Numbers in parentheses represent Energy Systems renumbering.

NOTE: Location, depth sampled, and sampling dates were derived from logbooks. Sampling dates and depths may also be extracted from bar code system/data base file. Coordinates were taken from civil survey data base.

Table 2.5.2. Reference groundwater sampling

Well No.[a]	Northing	Easting	Installation date[b]	Screened interval[c]	Zone monitored[d]
4001 (BV08)	23058.82	29503.01	03/19/91	1.9–6.9	U
4002 (BV09)	22235.82	36321.03	03/19/91	3.3–5.8	U
1250 (BV02)	22026.15	23139.95	11/07/89–05/08/90	7–22	B
1251 (BV03)	19941.94	36619.16	11/07/89–05/08/90	41–56	B
1252 (BV04)	22522.13	43261.22	11/07/89–05/08/90	14–29	B

[a]Numbers in parentheses represent Energy Systems renumbering.
[b]Installation date begins with date drilled to development.
[c]In ft below ground surface.
[d]U = unconsolidated zone; B = bedrock zone.

NOTE: Information was extracted from logbooks and well construction logs in data base. Coordinates are from civil survey data base.

Table 2.5.3. Reference creek channel sediment sampling

Sampling location	Northing	Easting	Sampling date	Sampling conditions
CS006	23280.74	29440.81	10/18/90	Low base flow, nonstorm
CS009	23430.16	31889.02	10/17/90	Low base flow, nonstorm

NOTE: Extracted from logbooks and civil survey data base.

Table 2.5.4. Reference surface water sampling

Sampling location	Northing	Easting	Sampling date	Sampling conditions
CS006	23430.16	31889.02	10/18/90	Low base flow, nonstorm[a]
CS009	23280.74	29440.81	10/18/90	Low base flow, nonstorm
SW-1	23281	29440	3/12/91	High base flow, nonstorm[b]
SW-2	23305	31889	3/12/91	High base flow, nonstorm
SW-3	22273	36363	3/12/91	High base flow, nonstorm
FCBG[c]	23281	29440	5/22/90	Transitional[d]
5CBG[c]	23305	31889	5/22/90	Transitional[d]
WCBG[c]	22273	36363	5/22/90	Transitional[d]

[a]Low base flow, nonstorm conditions exist when surface water and groundwater levels reach their yearly minimums, and when no rainfall has fallen during the 7 days before sampling.

[b]High base flow, nonstorm conditions exist when surface and groundwater levels are at their yearly maximums, and when no rainfall has fallen for 3 days before sampling.

[c]At the time these surface water samples were taken, these stations had the FCBG, 5CBG, and WCBG designations. These station names were later changed to SW-1, SW-2, and SW-3 respectively, to conform to a surface water station designation.

[d]Transitional conditions that exist between high and low base flow.

NOTE: Extracted from logbooks and civil survey data base.

Table 2.6.1. Building sump sampling

Building No.	Sump ID	Northing[a]	Easting[a]	Date sampled
2531	25312	211762	30570	1/31/90
2533	25331	21851.5	30678	1/31/90
3033	30331	22216	31675	1/30/90
3042	30421	22593	31410	1/26/90
3085	30851	22782	31637	1/23/90
	30852	22818	31656	1/25/90
	30853	22846	31685	2/02/90
	30854	22865	31680	1/26/90
	30855	22838	31675	2/06/90
	30856	22764	31670	2/02/90
	30857	22740	31680	1/24/90
	30858	22735	31638	1/30/90
	30859	22818	31657	1/25/90
3106	31061	22387	31790	1/26/90
3500	35001	21854	31695	1/29/90
3534	35341	21357	31531	2/01/90
4501	45011	21906	32148	1/30/90
	45012	22004	32069	1/29/90
	45013	22947	32075	1/29/90
	45015	22040	32046	1/30/90
4508	45082	21658	31921	2/01/90

[a]All coordinates were estimated from ORNL Atlas drawings.

NOTE: Building numbers, sump numbers, and sampling date taken from logbook. Sampling dates may also be extracted from bar code data base. Coordinates were estimated from ORNL main Atlas as noted.

Table 2.9.1. Summary of groundwater sampling program

Well or soil boring No.	Sampling event: Low base flow[a]	High base flow[b]	High base stormflow[c]	Additional SWMUS	CH008 plume	Temp. piez.
533	X	X		X	X	
535					X	
536	X	X			X	
538	X	X				
539	X	X			X	
540	X	X			X	
541	X	X				
543	X	X				
545	X	X	X			
546		X				
548		X			X	
549	X	X	X			
550		X		X	X	
551					X	
553	X	X	X			
554	X	X	X			
558		X				
561					X	
563		X				
564	X	X				
566	X	X	X			
571	X	X				
572	X	X				
577				X	X	
579	X	X	X			
581				X		
582				X		
584					X	
587	X	X				
588				X		
589	X	X				
590				X		
593				X		
596				X		
597	X	X	X			
598	X	X	X			
599	X	X				
601	X	X				
602	X	X	X			
603				X		
604	X	X				
607				X		
608				X		
610	X	X				

Table 2.9.1 (continued)

Well or soil boring No.	Sampling event					
	Low base flow[a]	High base flow[b]	High base stormflow[c]	Additional SWMUS	CH008 plume	Temp. piez.
611	X	X				
613				X		
614		X				
618	X	X				
620	X	X				
621	X	X				
622	X	X				
623	X	X	X			
634	X	X				
806[d]	X	X				
807[d]	X	X				
808[d]	X	X				
809[d]	X	X				
810[d]	X	X			X[e]	
811[d]	X	X			X[e]	
812[d]	X	X			X[e]	
813[d]	X	X				
814[d]	X	X	X			
815[d]	X	X				
816[d]	X	X				
818[d]	X	X				
819[d]	X	X				
820[d]	X	X	X			
821[d]	X	X				
822[d]	X	X				
823[d]	X	X				
824[d]	X	X	X			
825[d]	X	X				
826[d]	X	X	X			
827[d]	X	X	X			
828[d]	X	X	X			
829[d]	X	X				
830[d]	X	X				
873	X	X	X			
874	X	X				
875	X	X				
876	X	X				
877	X	X				
878	X	X				
879	X	X				
880	X	X				
881	X	X				
882	X	X				
883[e]	X					

Table 2.9.1 (continued)

Well or soil boring No.	Sampling event					
	Low base flow[a]	High base flow[b]	High base stormflow[c]	Additional SWMUS	CH008 plume	Temp. piez.
884	X	X				
885	X	X				
886	X	X				
946[d]	X	X	X			
947[d]	X	X[e]				
1100	X	X				
1101	X	X				
1102	X	X				
1103	X	X				
1104	X	X				
SB131[e]						X
SB132[e]						X
SB133[e]				X		
SB187[e]						X
SB189[e]						X
SB195[f]						
SB197[f]						
SB208[e]						X
SB221[e]						X
SB224[e]						X
SB247[e]				X		
SB260[e]				X		

[a]Low base flow exists when surface water and groundwater levels reach their yearly minimums.
[b]High base flow exists when surface water and groundwater levels reach their yearly maximums.
[c]High base stormflow exists when there is high base flow and when precipitation exceeds 2 in. within 24 h, and samples were collected after the storm peak but within 3 days.
[d]Sample sent to ORNL for analysis.
[e]CSL analyses only.
[f]Dry; unable to sample.

Table 2.9.2. Summary of WAG 1 groundwater analyses

Type of sampling	Sampling dates	Analysis			
		Rad	CSL[a]	TCL	Appendix IX
Low base flow	09/90–10/90	X	X	X	X
High base flow	03/91–05/91	X	X	X	
High base storm	02/91	X	X	X	
Pipeline trenches	11/91–12/91	X	X		
	02/92–03/92	X	X		
Additional SWMUs	10/91–11/91		X		
CH008	10/91–12/91		X		

[a]Close Support Laboratory (gross alpha, gross beta/gamma, and VOCs).

NOTE: The sampling dates along with each of the piezometers were pulled from the groundwater data base table. This output was used to determine what analyses were performed on the groundwater samples.

Table 2.9.3. Piezometers in WAG 1 pipeline trenches

Borehole No.	Area	Total depth[a]	Approximate depth to high water table[a]
SB131	South of Bldg. 3019	15.9	24
SB132	Southwest corner of Bldg. 3019	16.0	24
SB187	Northwest corner of Bldg. 3525	6.0	6
SB189	West side of pond 3524	4.3	6
SB195	Southeast corner of Bldg.3505	8.0	10
SB197	North side of Bldg. 3506	8.75	10
SB208	Northeast of pond 3539	10.9	7.5
SB221	North side of North Tank Farm	8.7	16
SB224	Southwest side of North Tank Farm	6.6	12

[a]Depths in ft below ground surface.

NOTE: The borehole number and area were taken from a WAG 1 map that contained the soil borings. Total depth was taken from a logbook. The approximate depth to high groundwater was estimated by looking at a high water table map for groundwater elevation and estimating ground elevation at the temporary piezometer using nearby piezometer and well surveyed ground elevations.

Table 2.10.1. Summary of corehole installation

Corehole[a]	Coring begun/ completed	Casing left in hole (diam/length)[b]	Top of rock (ft)	Total[c] depth (ft)	Core recovery (ft)
CH006	03/27/91 – 05/13/91	6/70.4	9.0	404.0	370.1
CH07A	02/13/91 – 06/03/91	8/29	28.0	184.6	153.3
CH008	06/05/91 – 06/19/91	8/12.5	11.5	53.5	39.7
CH009	01/08/91 – 02/07/91	4/17.0	12.0	404.7	378.6
CH11A	02/20/91 – 03/12/91	4/15.3	6.8	282.5	273.7
CH012	07/10/91 – 08/07/91	6/15	6.8	490.4	476.4

[a]Energy Systems designation for coreholes:
CH006 = 4003
CH07A = 4004
CH008 = 4005
CH009 = 4006
CH11A = 4008
CH012 = 4009
[b]Diameter is given in inches; length is given in feet.
[c]Depth in ft below ground surface.

NOTE: In addition to field logbooks, the gINT geologic logs have the depth to overburden and rock and total depth. Corehole construction log was used for coring date and casing left in hole.

Table 2.10.2. WAG 1 borehole geophysical logging program summary

Log type	Corehole[a,b]					
	CH006	CH07A	CH009	CH11A	CH012	FT10
Natural gamma ray	X	X	X	X	X	X
Caliper	X	X	X	X	X	X
Temperature	X	X	X	X	X	X
Differential temperature	X	X	X	X	X	X
Self potential (SP)	X	X	X	X	X	X
Borehole televiewer (BHTV)	X	X	X	X	X	X
Variable density acoustic log (VDL)	X	X	X	X	X	X
Short/long normal resistivity	X	X	X	X	X	X
Single point resistance (SPR)	X	X	X	X	X	X
Deviation survey	X	X	X	X	N/A	N/A
4-Pi density	X	X	X	X	X	N/A
Neutron (cps)	X	X	X	X	X	X
Sonic	X	X	X	X	X	X
Borehole flowmeter	N/F	N/A	X	N/F	X	N/A

[a]N/A = Logging not performed.
[b]N/F = Logging was planned but was not performed because of overhead interference such as power lines or downhole interference such as installed packers.

NOTE: Data were manually extracted from logbooks.

Table 2.11.1. Summary of surface water and sediment sampling program

		Surface water, low base flow		Surface water, high base flow	
Location	Sediment sample	Storm event	Nonstorm event	Storm event	Nonstorm event
CS001	X	X			
CS002	X	X			
CS003	X		X		
CS004	X		X		
CS005	X		X		
CS006[a]	X	X			
CS007	X	X			
CS008	X	X			
CS009[a]	X		X		
CS010	X		X		
CS011	X		X		
CS012	X		X		
SW-1[b]					X
SW-2[b]					X
SW-3[b]					X
SW-4			X	X	X
SW-5			X	X	X
SW-6			X	X	X
SW-7			X	X	X
SW-8			X	X	X

[a]Also served as reference samples taken October 17 and 18, 1990.

[b]These station numbers were identified as FCBG, 5CBG, and WCBG when they were sampled as reference stations on May 22, 1990 (these samples are not reflected on this table). They were later changed (FCBG=SW-1, 5CBG=SW-2, and WCBG=SW-3).

NOTE: Data were manually extracted from logbooks.

Table 2.12.1. Sewage impoundment sampling locations

Impoundment	Station No.	Northing	Easting
2544	IS001	21363.00	29800.00
	IS002	21363.00	29800.00
	IS003	21424.00	29888.00
2543	IS004	21482.00	30073.00
	IS005	21374.00	30073.00
	IS006	21428.00	30097.00
	IS007		

Note: Station No. IS007 was a composite sample taken from several random locations in pond 2543.

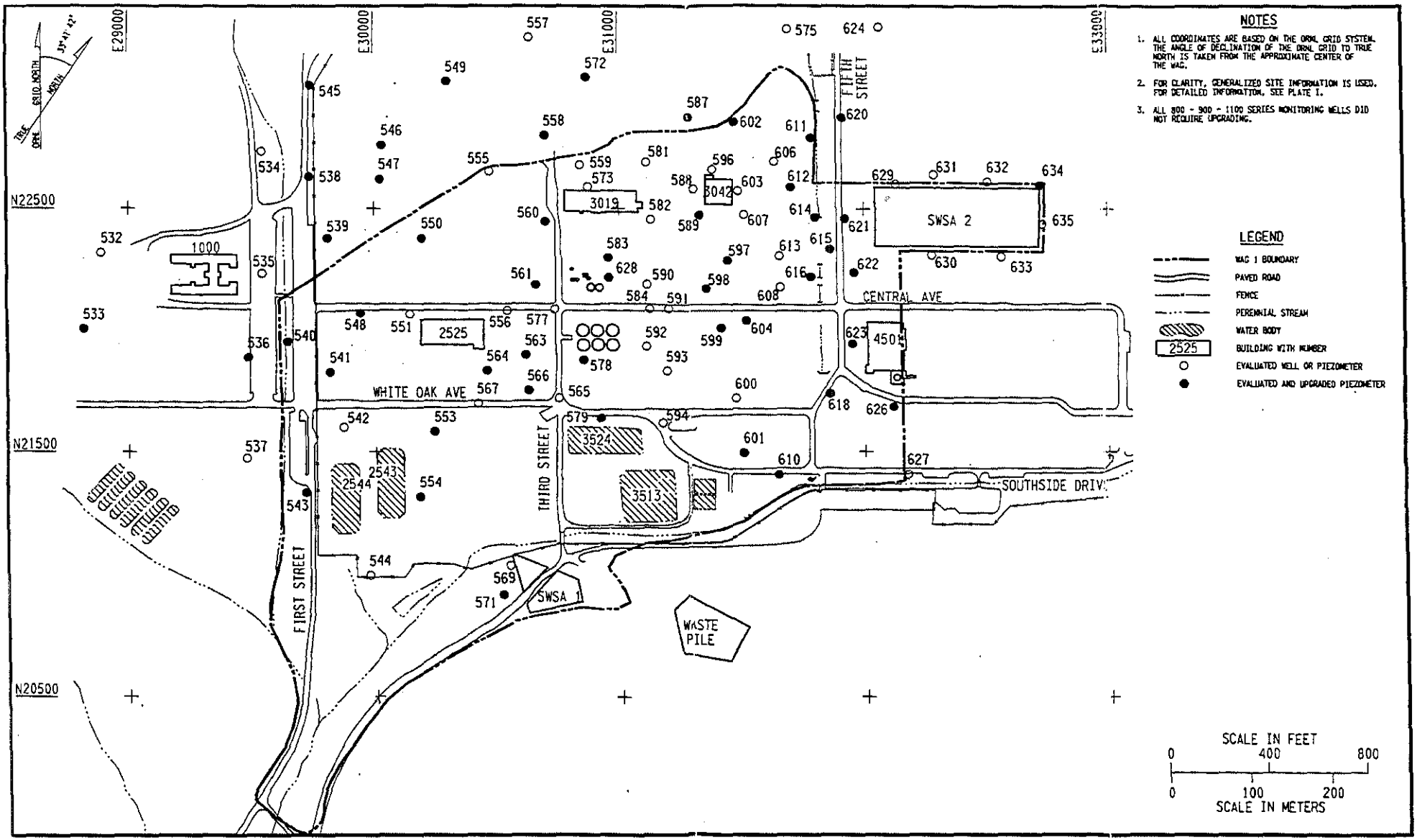
NOTE: Coordinates were taken from civil survey data base.

Table 2.13.1. Inactive LLLW tanks in WAG 1

Tank No.	Level trend analysis	Video inspection	Tank soil borings
T-30	N	N	N
TH-1	N	N	Y
TH-2	N	N	Y
TH-3	N	N	Y
TH-4	Y(I)	N	Y
W-1	Y(I)	Y	Y
W-1A	N	Y	Y
W-2	Y(I)	Y	Y
W-3	Y	N	Y
W-4	Y	Y	Y
W-5	Y	Y	Y
W-6	Y	Y	Y
W-7	Y	Y	Y
W-8	Y	Y	Y
W-9	Y	Y	Y
W-10	Y	Y	Y
W-11	Y	Y	Y
W-13	N	N	Y
W-14	N	N	Y
W-15	N	N	Y
W-19	N	N	Y
W-20	N	N	Y
WC-1	N	N	Y
WC-15	Y(I)	N	Y
WC-17	Y	N	Y
3001-B	P	P	N
3003-A	P	P	Y
3004-B	P	P	N
3013	P	P	Y
H-209	P	P	Y

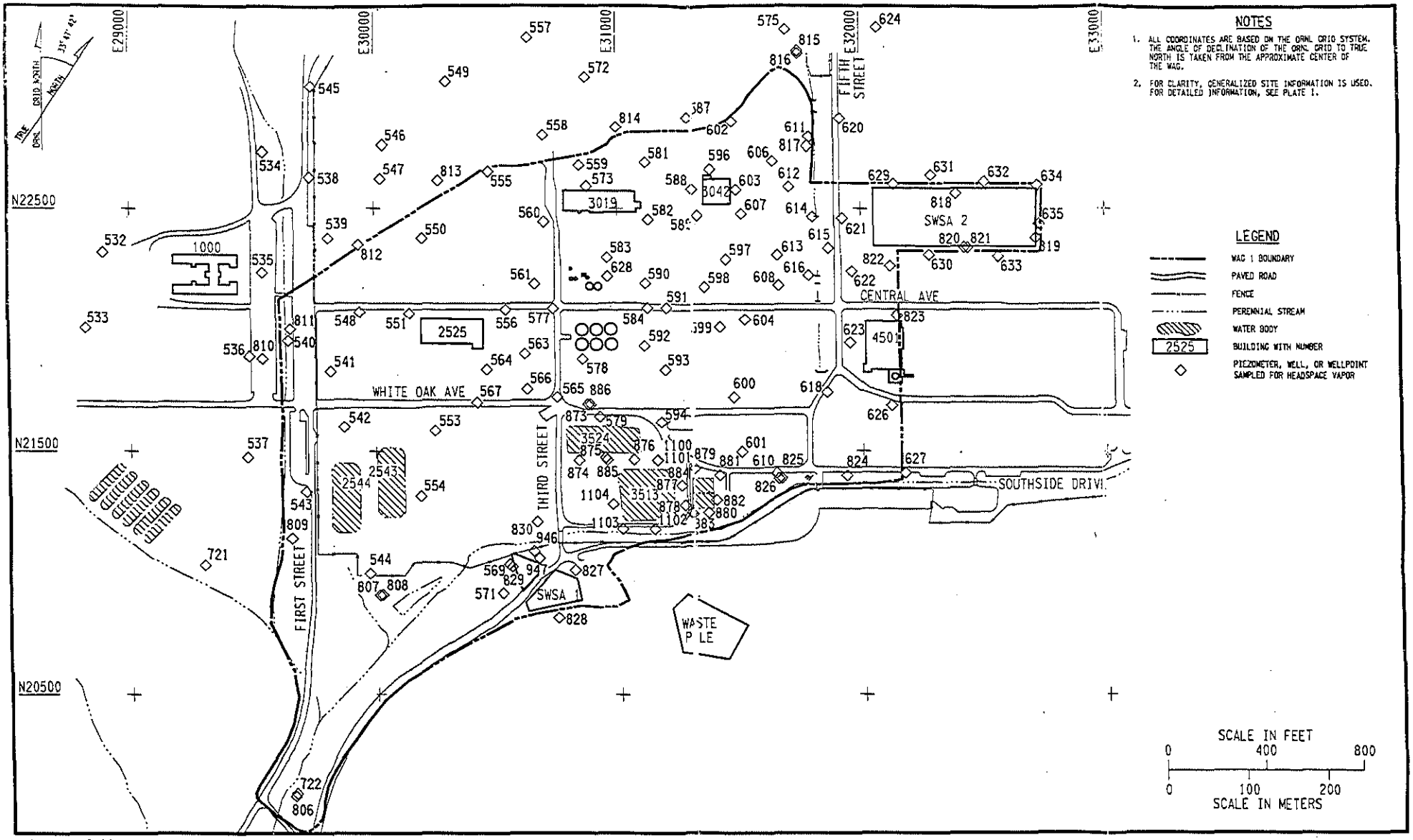
Y = yes.
N = no.
P = planned.
(I) = newly installed level monitor.

NOTE: Data were taken from ORNL Video Inspection Data Manual for Inactive LLLW Tanks and ORNL Leak Detection Data Manual for Inactive LLLW Tanks.



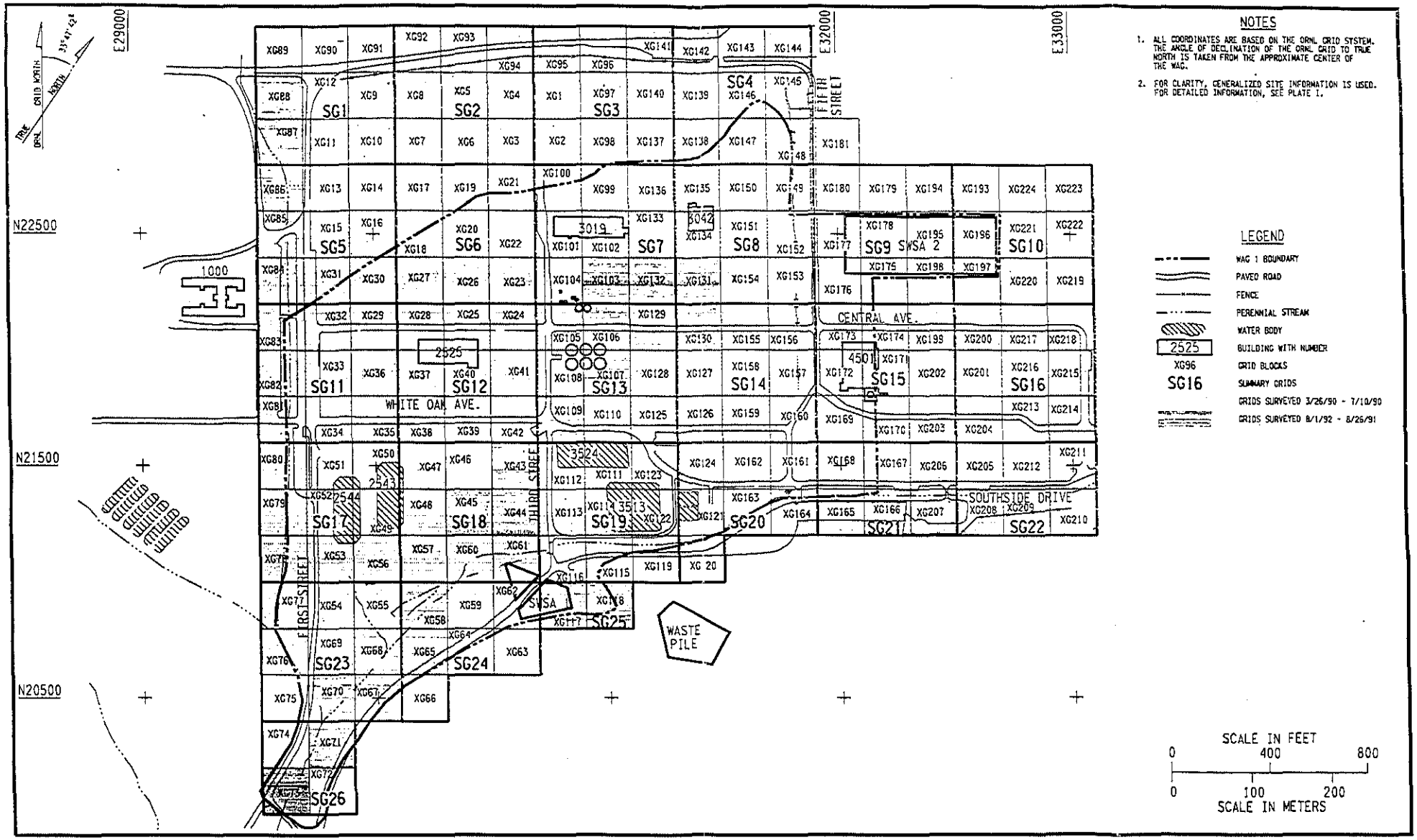
WAG 1 01F126.DGN SRF, 8/27/92

Fig. 2.1.1. Locations of evaluated and upgraded piezometers.



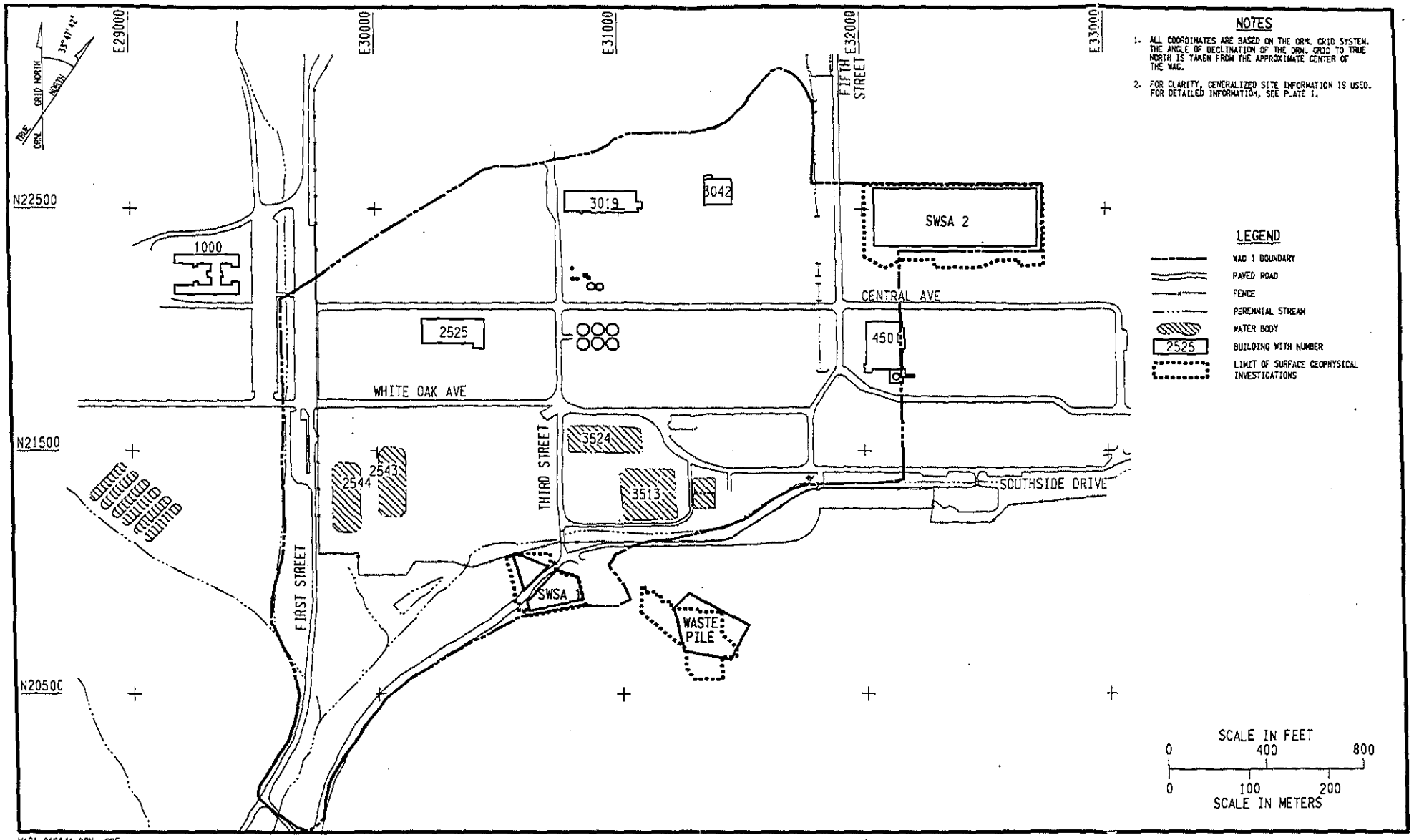
WAG1 01F142.DGN
6/10/92

Fig. 2.2.1. Locations of well headspace vapor sampling stations.



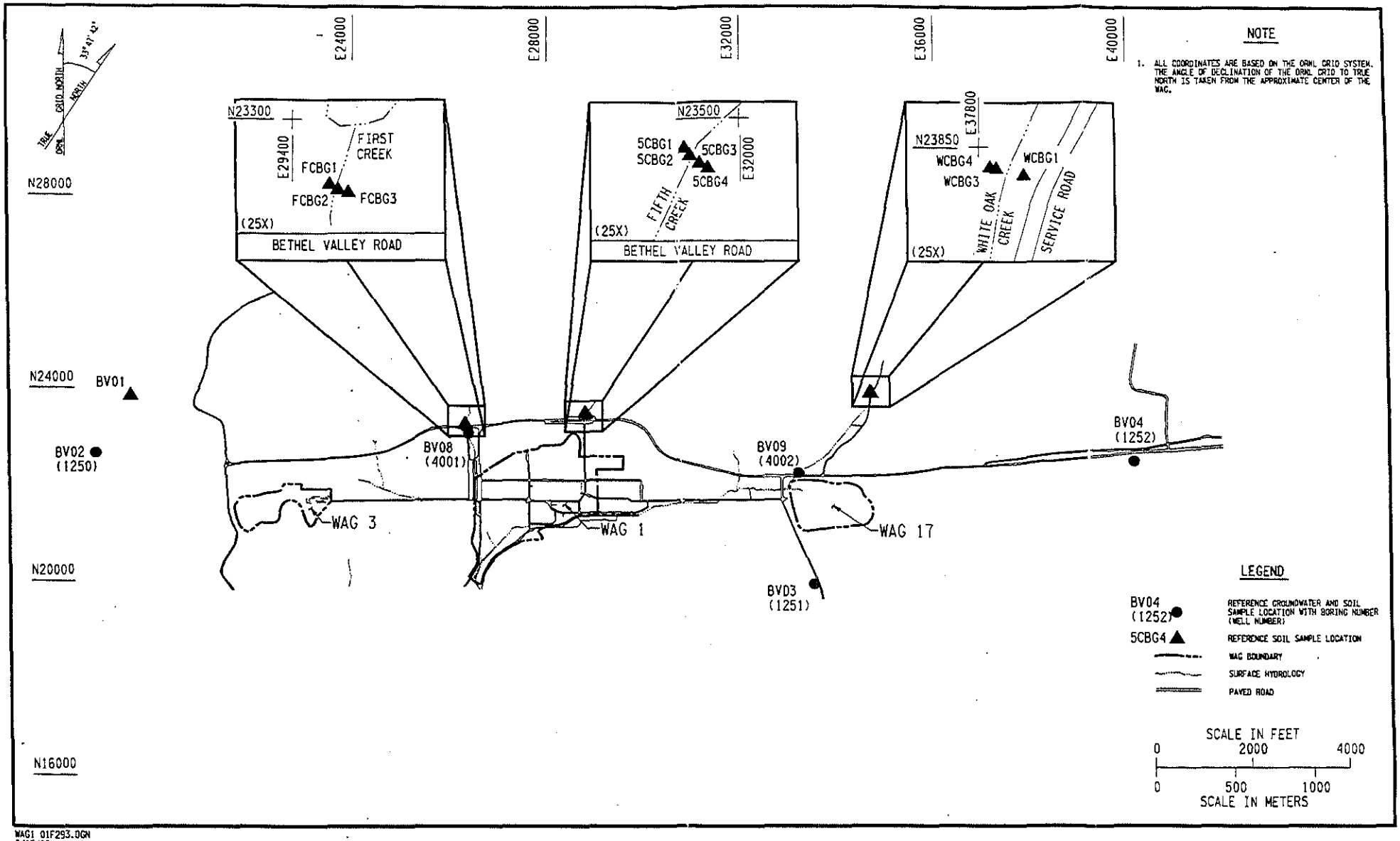
WAG1 01F143.DGN
6/10/92

Fig. 2.3.1. Boundaries of USRADS radiation walkover survey.



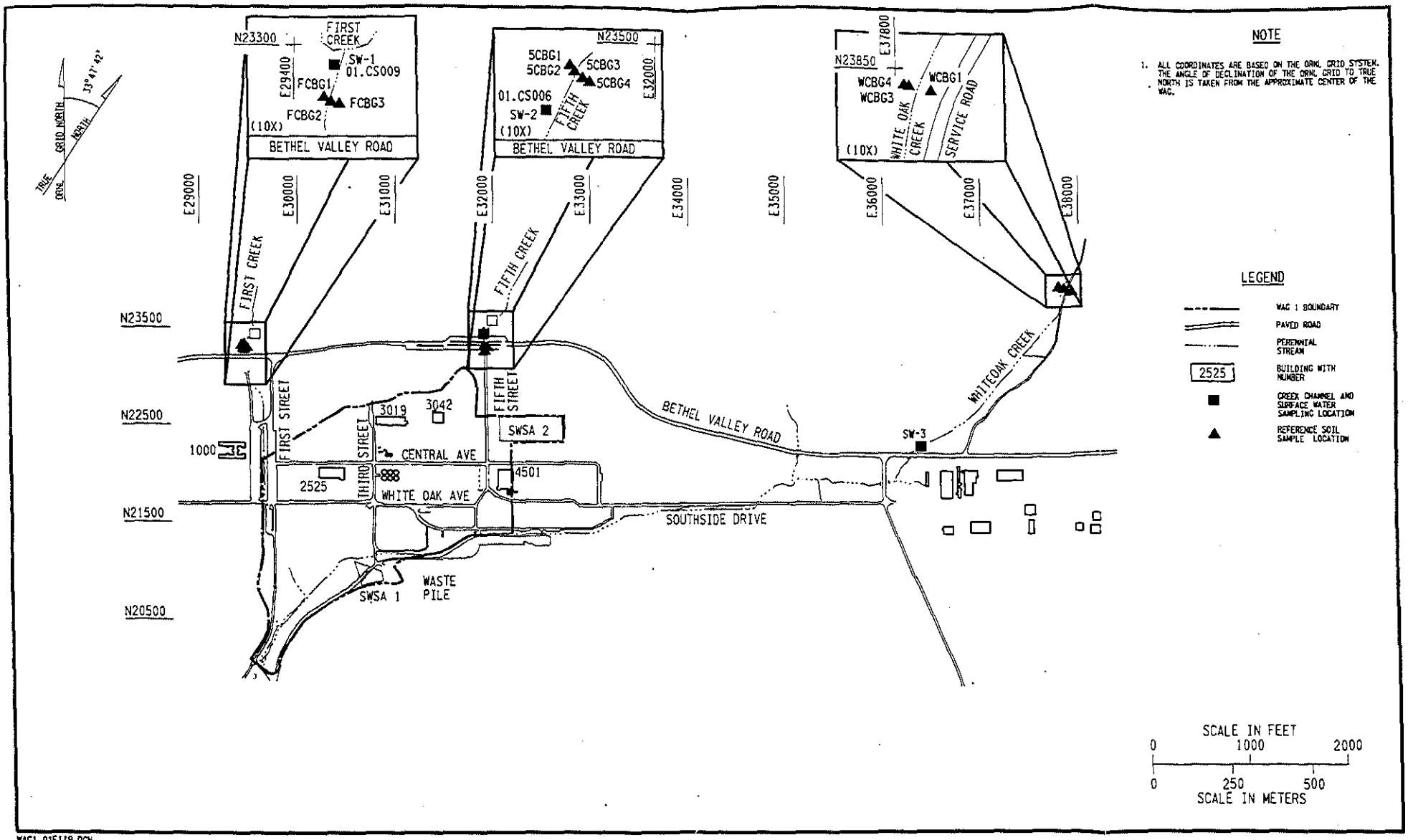
WAG1 01F141.DGN SRF, 6/10/92

Fig. 2.4.1. Locations and extent of EM terrain conductivity and ground magnetometer survey.



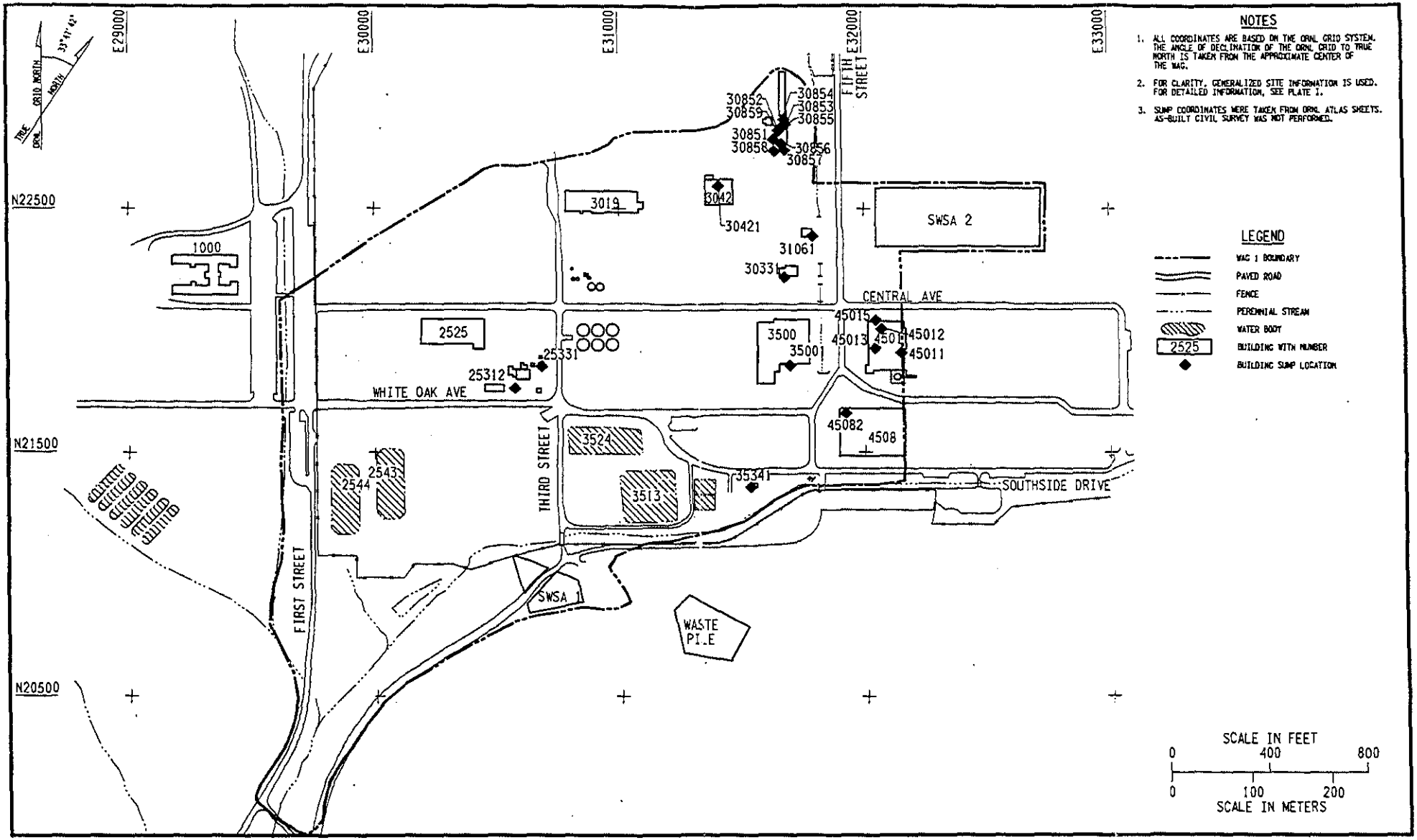
WAG1 01F293.DGN
9/15/92

Fig. 2.5.1. Reference soil and groundwater sampling locations.



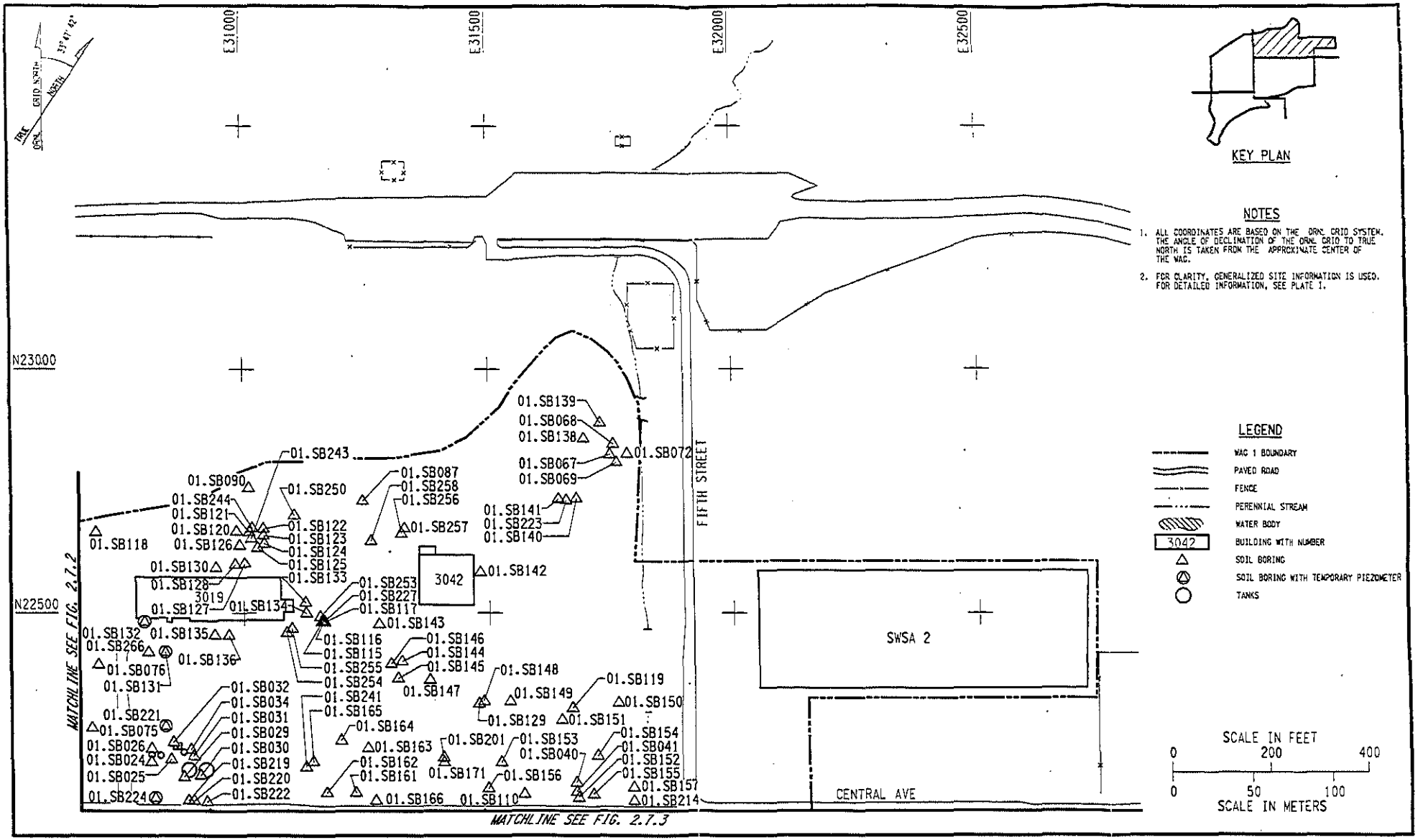
WAG1 01F119.DGN
9/15/92

Fig. 2.5.2. Reference surface water and sediment sampling locations.



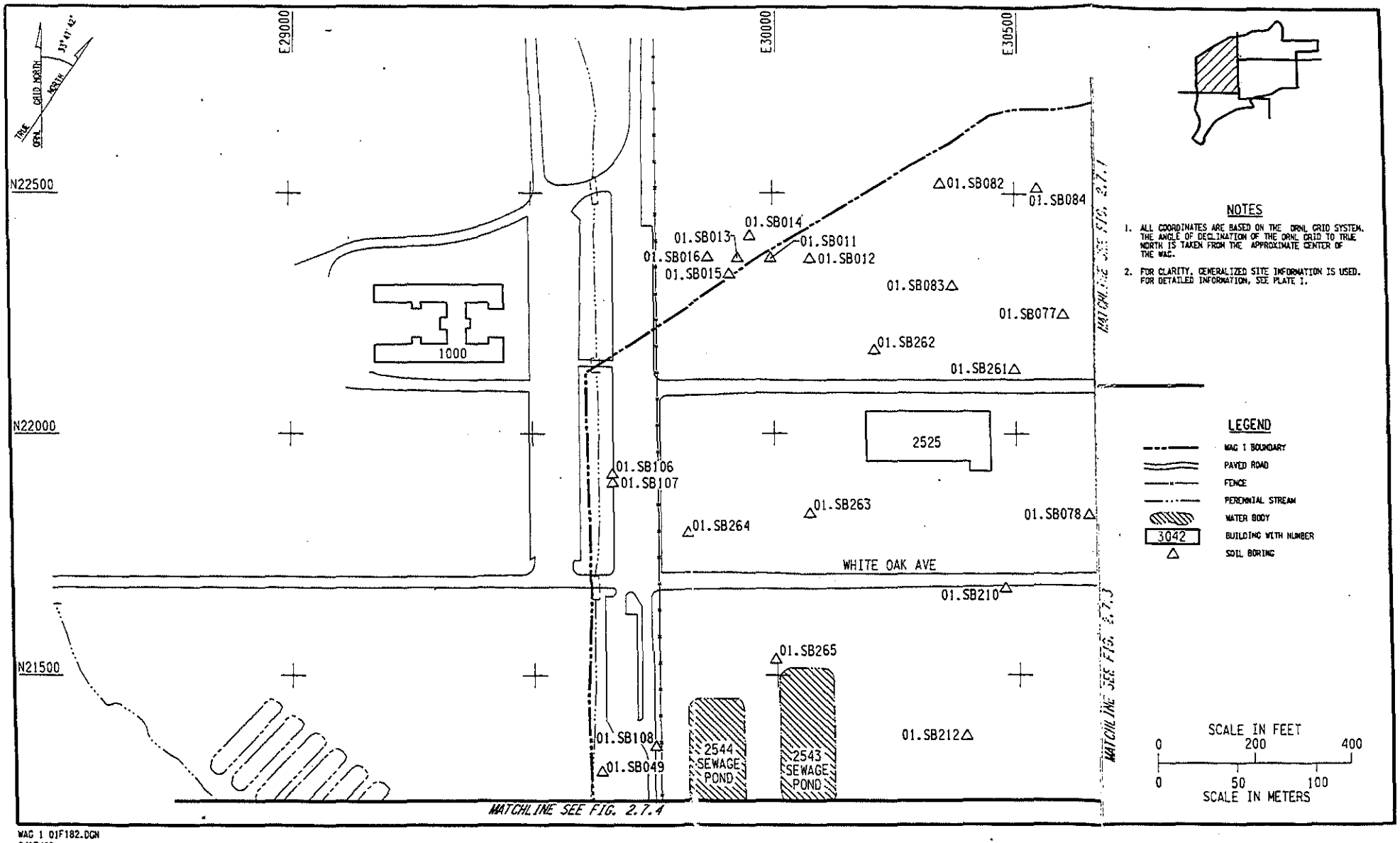
WAG1 01F140.DGN SRF, 6/12/92

Fig. 2.6.1. Locations of sampled building sumps.



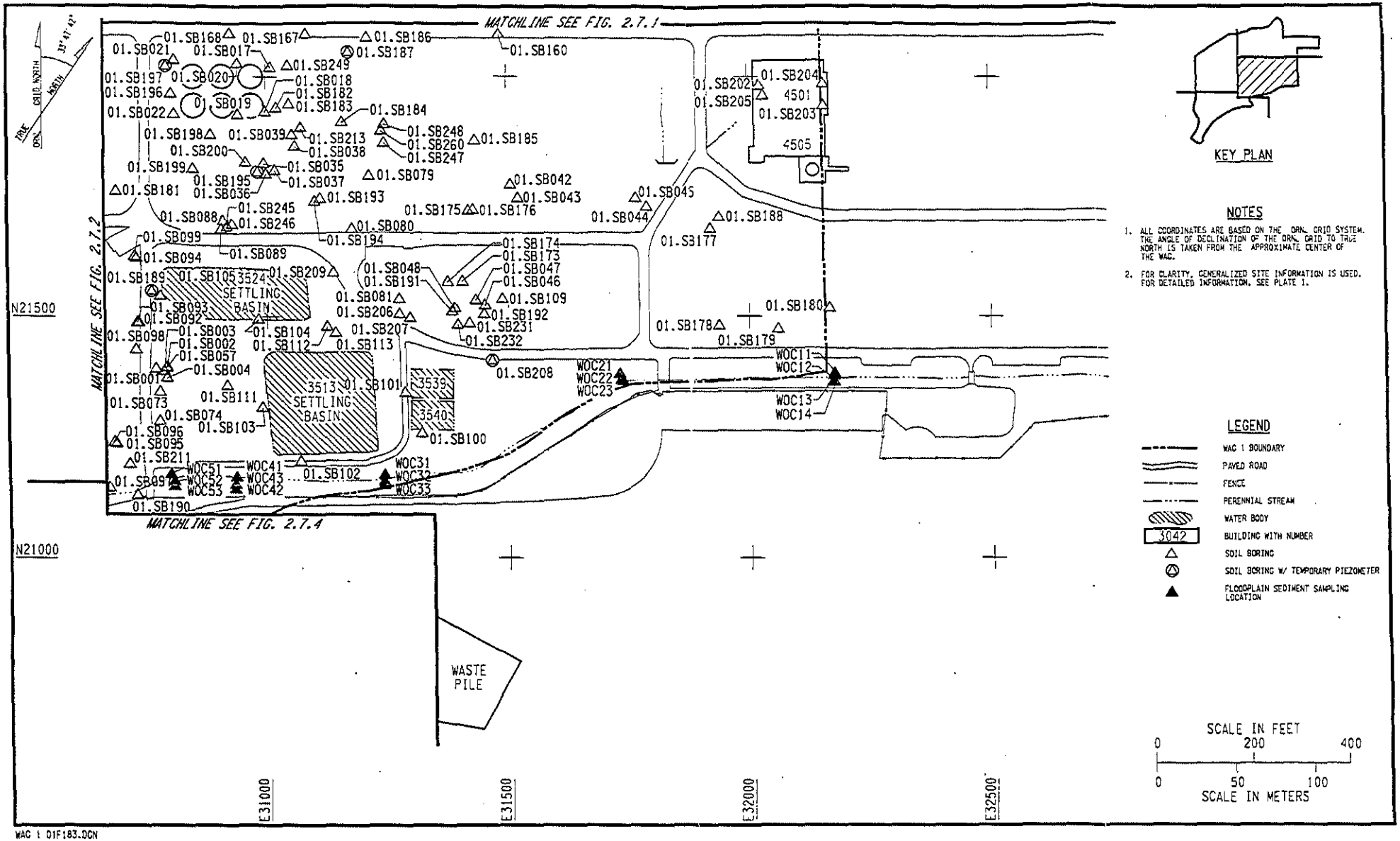
WAG1 01F181.DGN
6/12/92

Fig. 2.7.1. Phase I soil boring locations (northeast quadrant).



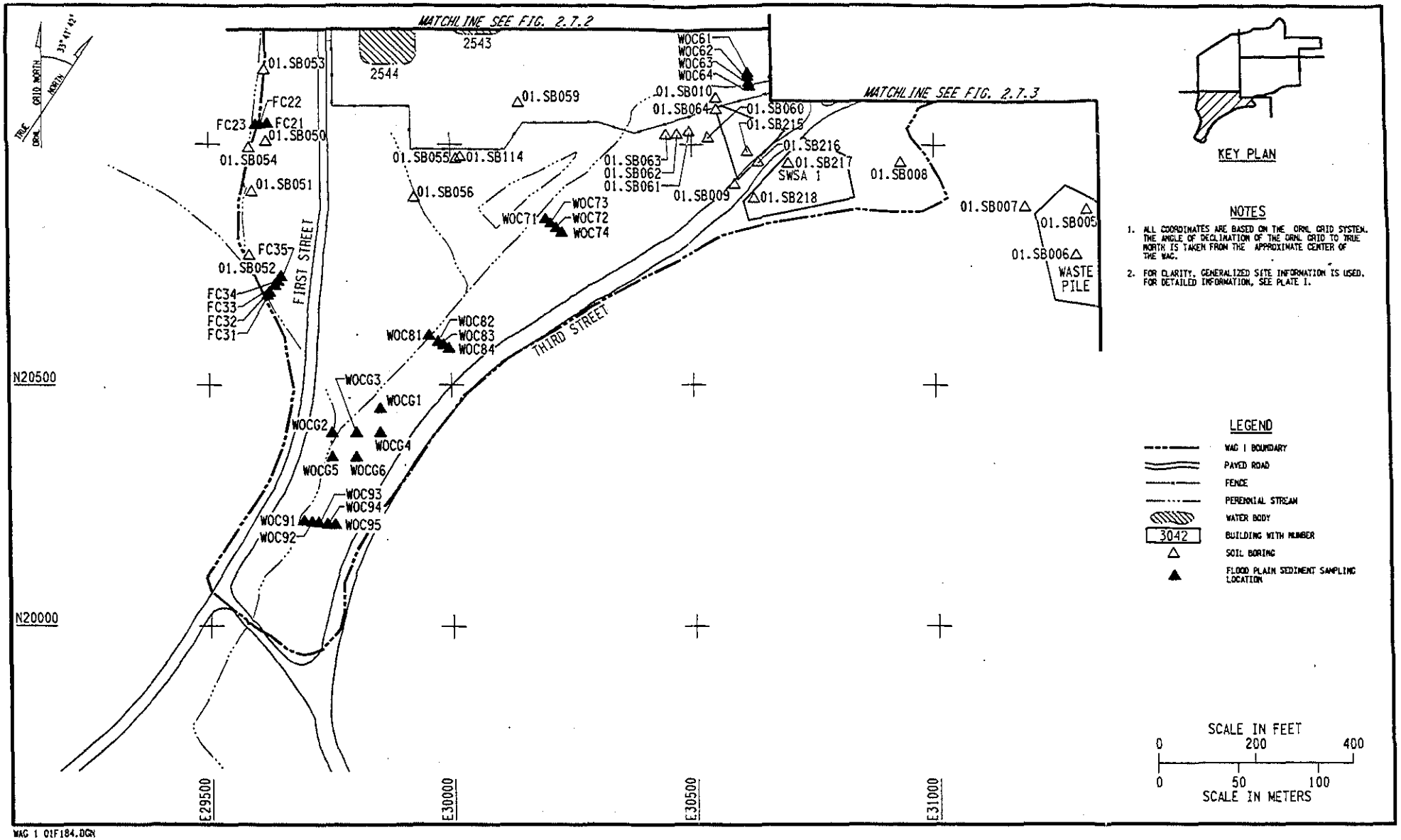
WAG 1 01F182.DGN
6/13/92

Fig. 2.7.2. Phase I soil boring locations (northwest quadrant).



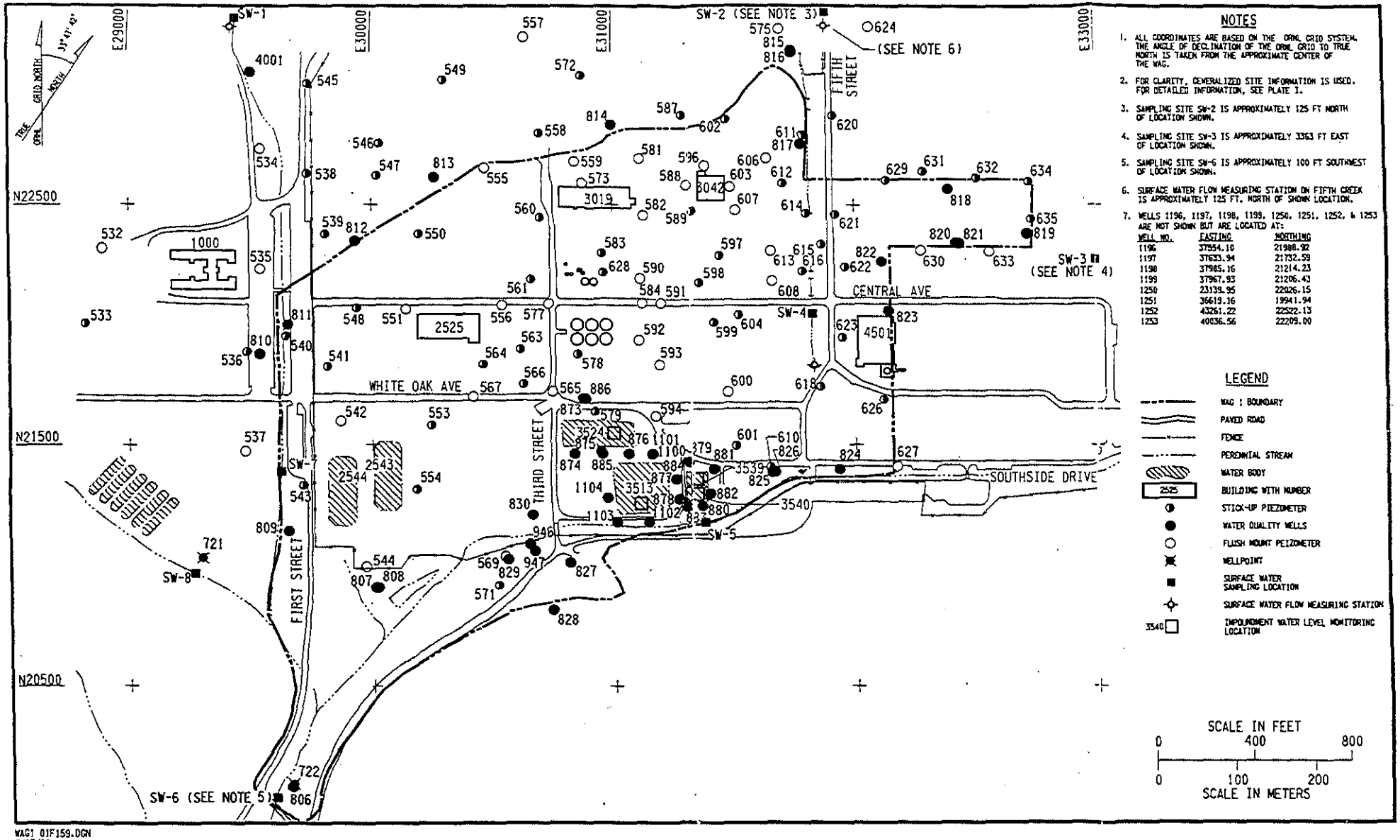
WAG 1 01F183.DGN
6/12/92

Fig. 2.7.3. Phase I soil boring locations (southeast quadrant).



WAG 1 01F184.DGN
6/12/92

Fig. 2.7.4. Phase I soil boring locations (southwest quadrant).



WAG1 01F159.DGN
6/15/92

Fig. 2.8.1. Locations of periodic water level monitoring stations.

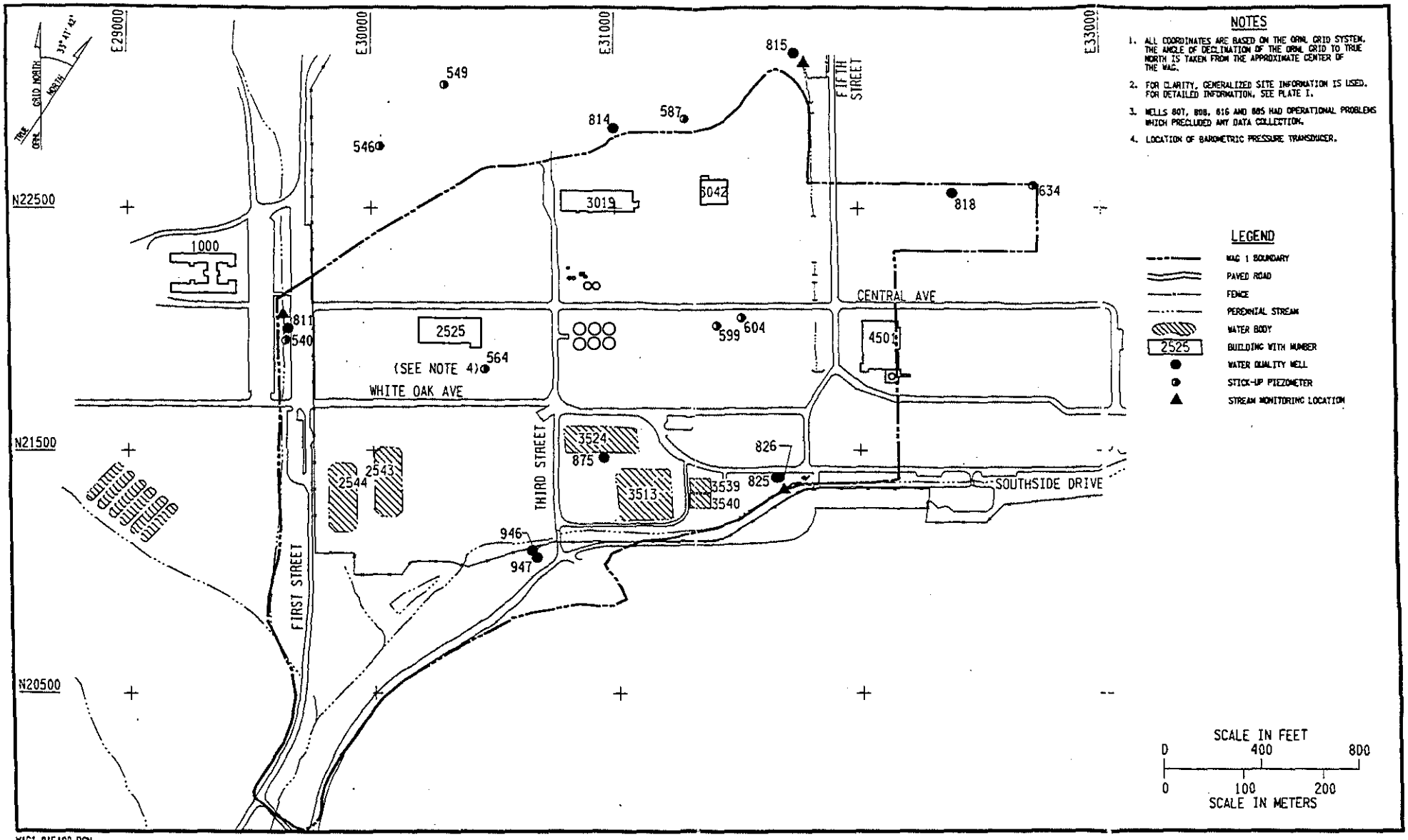
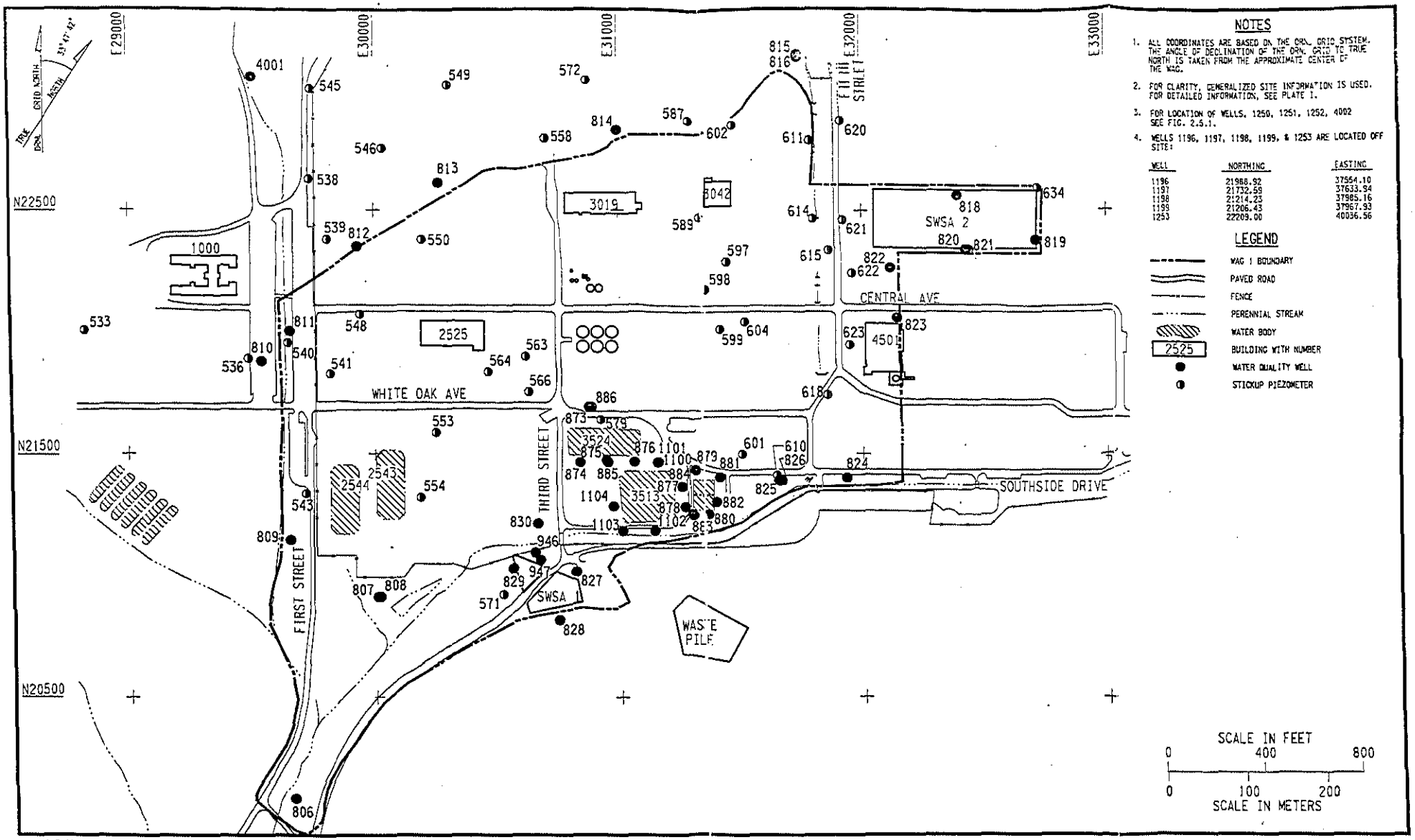
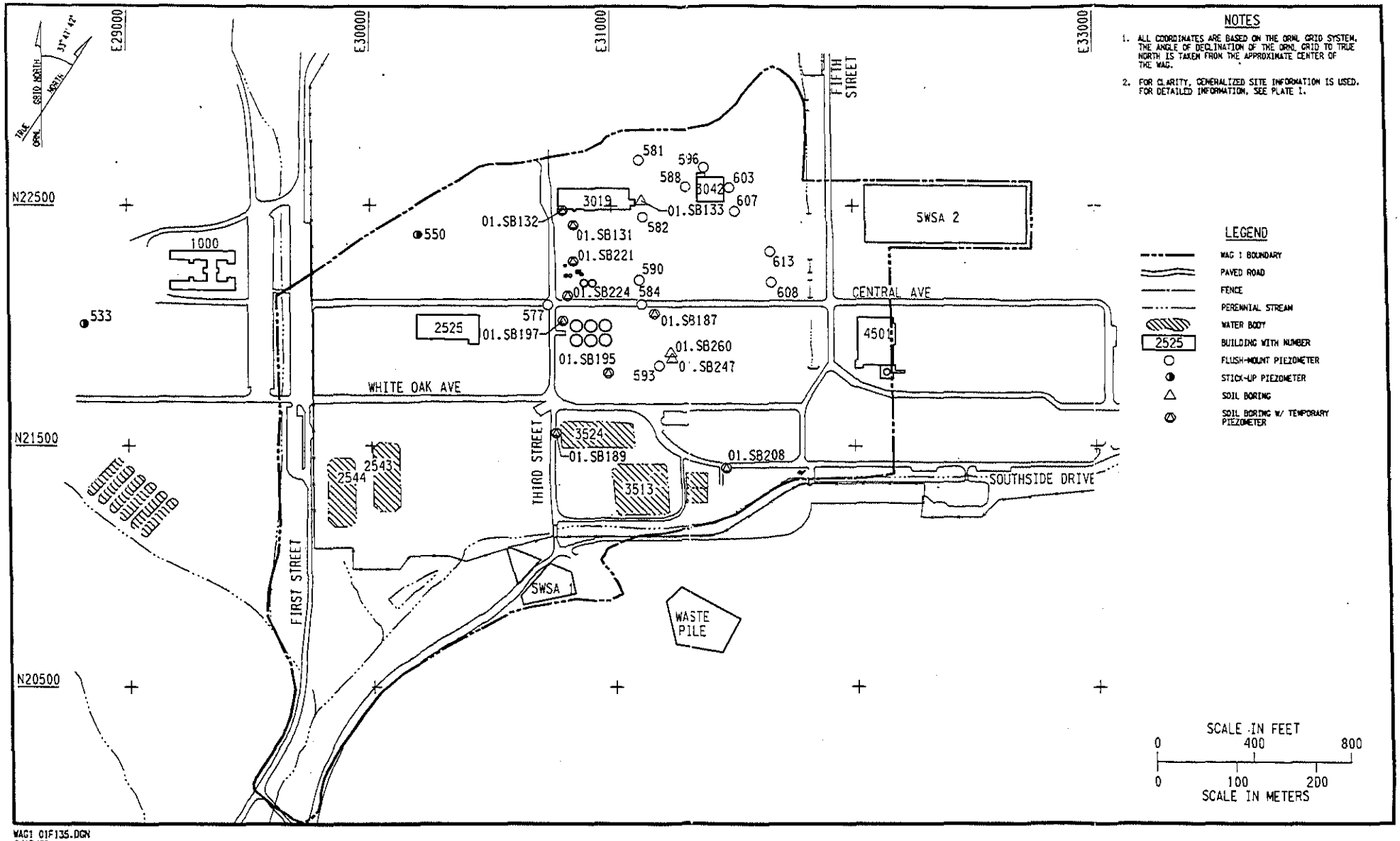


Fig. 2.8.2. Locations of continuous water level monitoring stations.



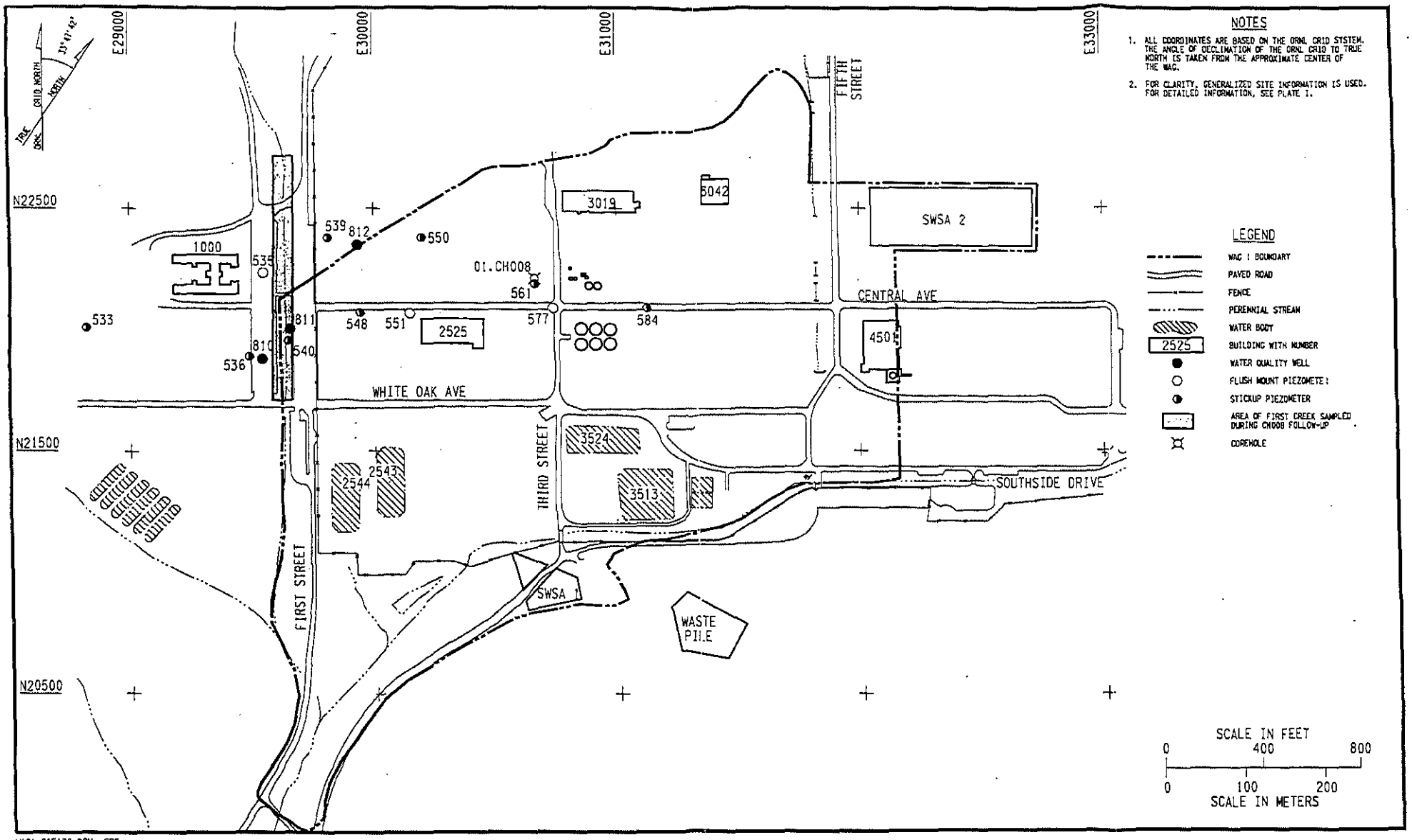
WAG1 01F137.DGN SRF, 6/12/92

Fig. 2.9.1. Locations of base flow and high base storm groundwater sampling stations.



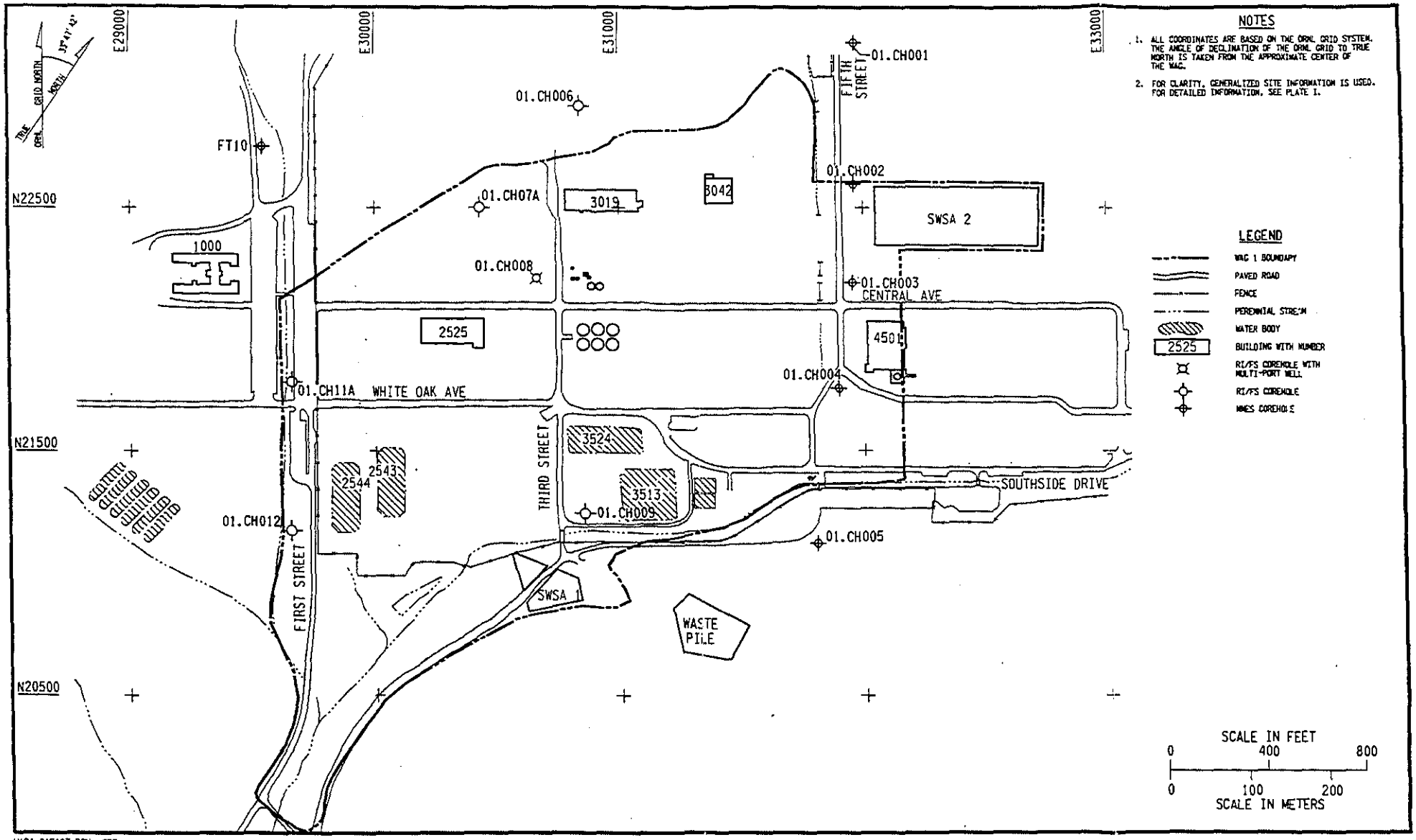
WAG1 01F135.DGN
9/17/92

Fig. 2.9.2. Locations of temporary piezometers and additional SWMU groundwater sampling stations.



WAG1 01F136.DGN SRF, 6/10/92

Fig. 2.9.3. Locations of CH008 follow-up groundwater sampling stations.



WAG1 01F127.DGN SRF, 6/15/92

Fig. 2.10.1. Corehole locations.

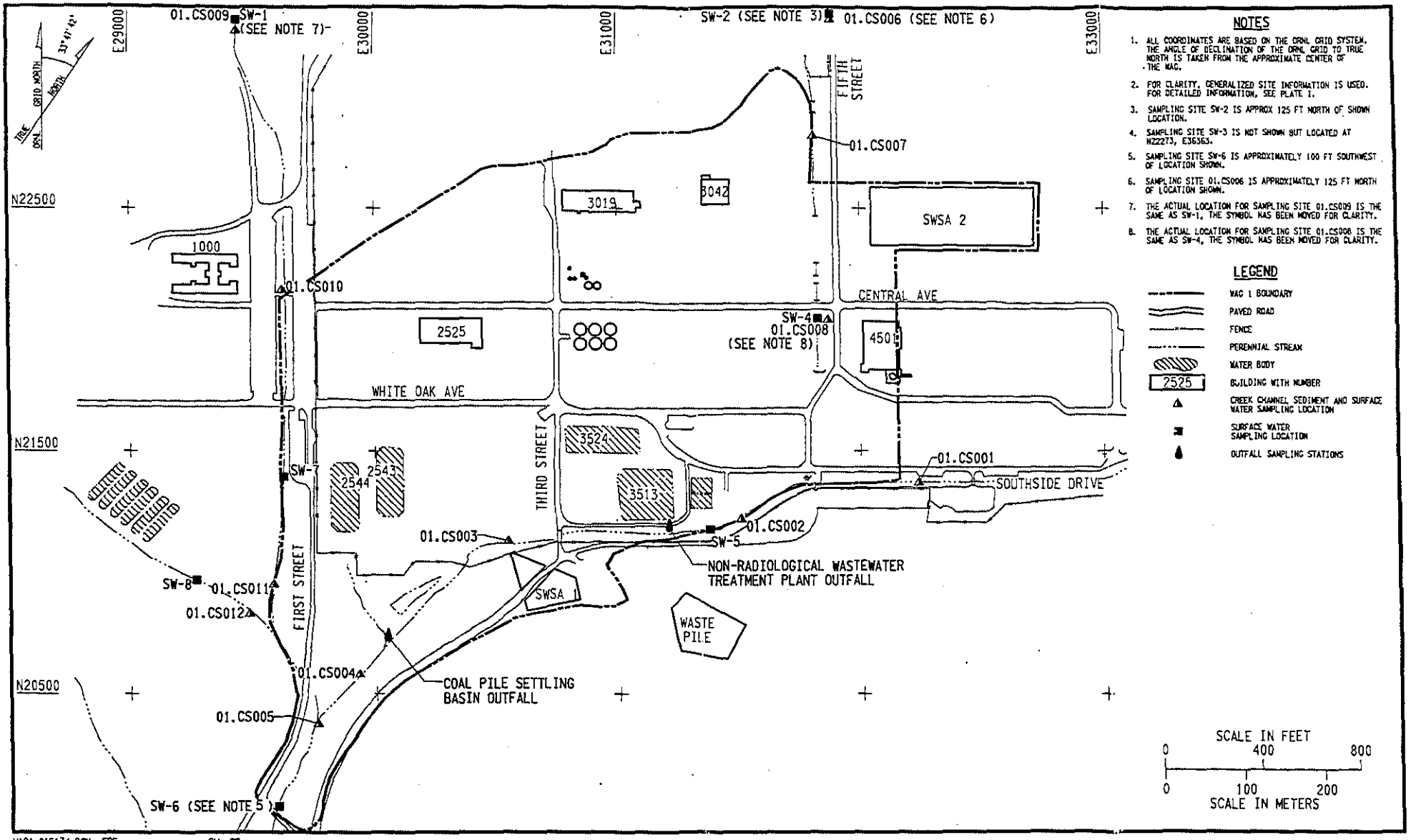
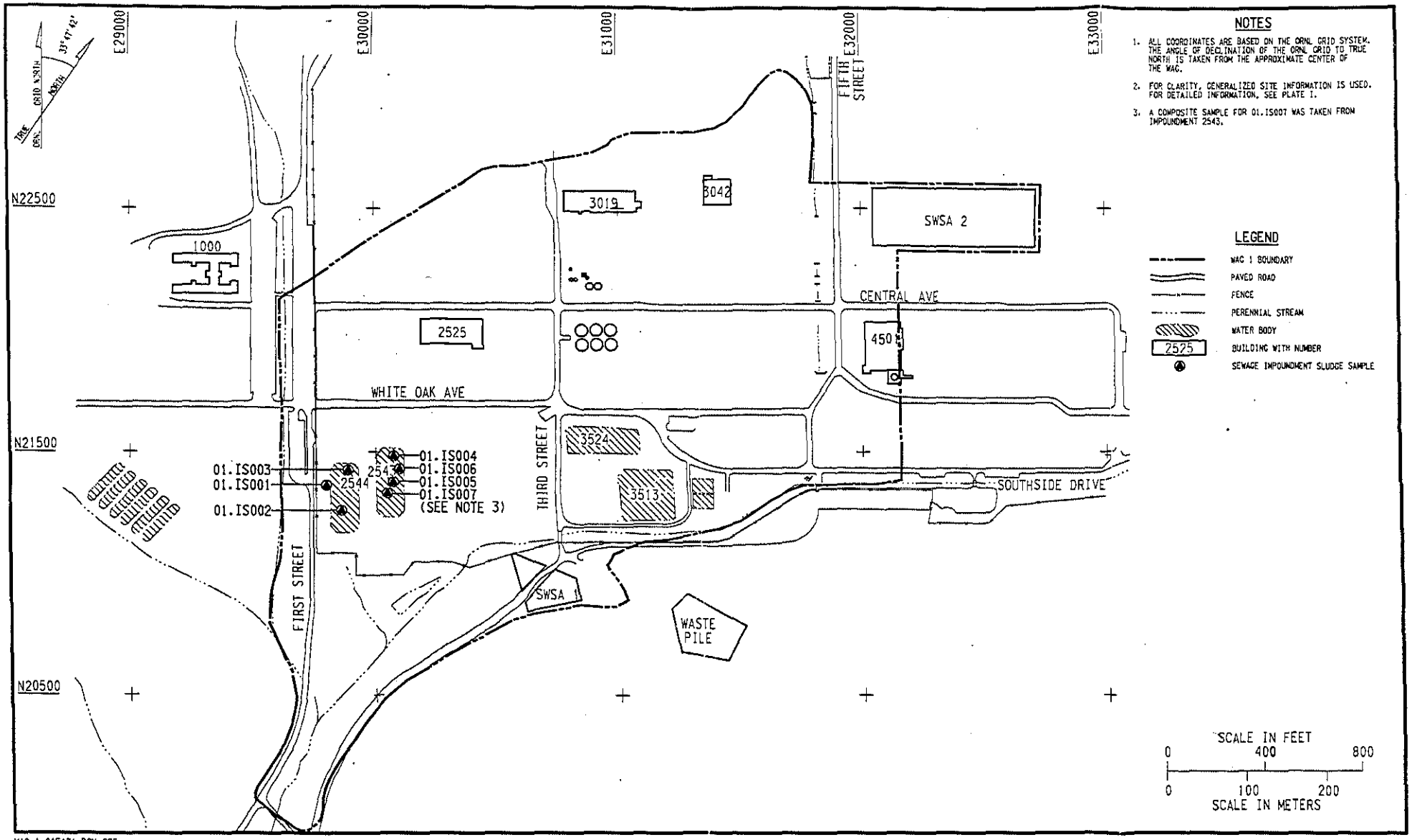
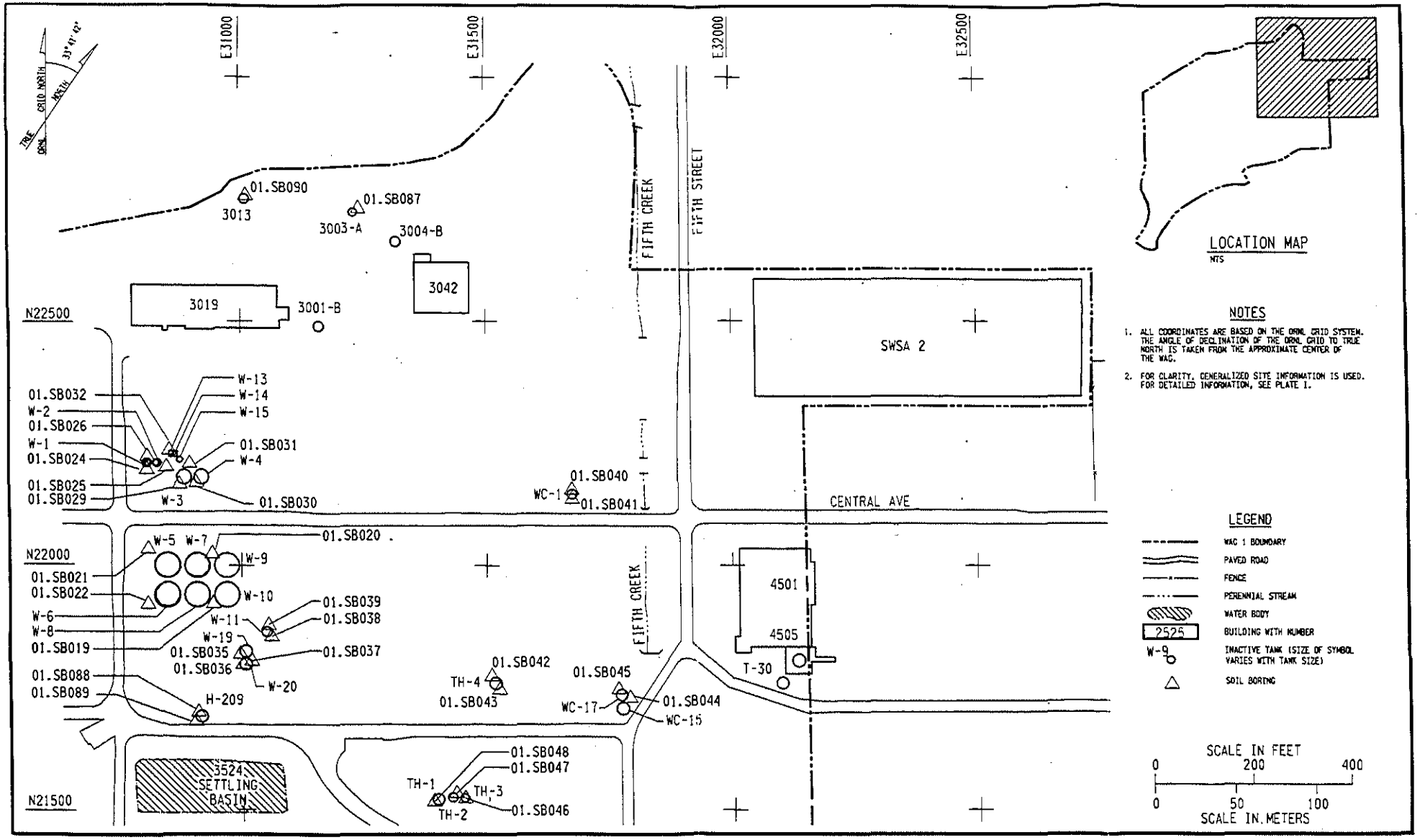


Fig. 2.11.1. Locations of surface water and creek channel sediment and outfall sampling stations.



WAG 1 01F131.DGN SRF,
6/11/92

Fig. 2.12.1. Locations of sewage impoundment sampling stations.



WAG1 01F151.DGN
9/15/92

Fig. 2.13.1. Tank-specific soil sampling locations.

This section of the document contains oversized drawings that the DOEIC cannot reproduce.

If you would like to view the drawings, please schedule an appointment at the DOEIC by telephone at 241-4780, Monday through Friday, from 8:00 a.m. to 5:00 p.m.

3. PHYSICAL CHARACTERISTICS OF WAG 1

This section describes the physical setting at WAG 1. Information presented here is derived primarily from data gathered as part of the RI. In addition, there exists a significant body of previously completed work describing specific aspects of the geology, hydrogeology, hydrology, and waste unit characteristics of WAG 1. Where appropriate, information from these studies has been incorporated into this section. The reader is also referred to the literature for additional details regarding specific aspects of the site.

Section 3.1 describes the general site characteristics and climate, and Sect. 3.2 discusses site geology. Section 3.3 describes the site hydrogeology, discusses the occurrence of groundwater and groundwater flow characteristics, and summarizes the groundwater system and conceptual model. Section 3.4 describes the characteristics of the surface water system at WAG 1, and Sect. 3.5 discusses the characteristics of potential sources of contaminants (waste units).

3.1 SITE TOPOGRAPHY AND CLIMATE

WAG 1 is located in Bethel Valley between Chestnut Ridge to the northwest and Haw Ridge to the southeast. The WAG is approximately 150 acres in size, and includes the main laboratory area at ORNL and consequently has been highly developed. Buildings include offices, research laboratories, reactors, process buildings, and support buildings such as change houses, cafeteria, emergency and security building, steam plant, and waste treatment facilities. Roads, parking lots, and sidewalks provide access to these buildings (see Plate I). Based on estimates made from available site maps, an estimated 40% of the facility is overlain by impervious cover (buildings, roads, parking lots, or sidewalks).

WAG 1 occupies a small portion of the 6.53-mile^2 WOC drainage basin, which is tributary to the Clinch River. Stockdale (1951) describes Bethel Valley as a 7.5-mile-long portion of an elongated northeast-southwest trending trough with a valley floor averaging 1000 ft wide. Chestnut Ridge reaches above 1200 ft in elevation, and Haw Ridge reaches above 1040 ft. The topographic high at the northern boundary of the WAG is just over 900 ft (see Plate I). The southern WAG boundary occurs at a water gap where WOC passes through Haw Ridge at an elevation of 770 ft.

Slopes on Chestnut Ridge in the WAG 1 area average around 14%; those on Haw Ridge range from 20 to 80%. The topographic high inside WAG 1 has slopes on the order of 18 to 25%, and the valley floor slopes southward at 4%.

The natural drainage system includes three perennial streams: First Creek, Fifth Creek, and WOC. WOC has its headwaters to the northeast on Chestnut Ridge and flows southwest along the southeastern boundary of WAG 1 through the water gap in Haw Ridge. WOC ultimately terminates at White Oak Lake prior to discharging into the Clinch River. Its average gradient is just under 10%, but it is less than 1% inside the WAG 1 boundaries. First Creek originates from a spring on Chestnut Ridge and flows southeast to its confluence with the Northwest Tributary; Fifth Creek also originates on Chestnut Ridge and flows

southeast to join with WOC. Both First Creek and Fifth Creek have 4-5% gradients at their headwaters and 1-2% gradients through the WAG area. The natural drainage of the main plant area is augmented by a system of storm drains in roads and parking lots that discharge to the streams.

The climate of the region surrounding the ORR is characterized as humid subtropical (Stockdale 1951). One of the wettest locations in the United States for a facility practicing radioactive waste disposal, the Oak Ridge area receives 51 to 55 in. of precipitation annually (Bedinger 1989, Boegly et al. 1987, McMaster and Waller 1965, Moore 1988, Stockdale 1951). There is seldom a period greater than 5 days without precipitation (Boegly 1984). The wettest months (December through March) are typified by long, low-intensity rainstorms (Moneymaker 1986). Snowfall is not a significant contributor to total precipitation. Early summer thunderstorms result in a second wet period, but the higher intensity of these storms results in a higher percentage of runoff and less infiltration. High runoff and increased potential for evapotranspiration also render the summer storms less effective in providing recharge to groundwater. The driest period of the year normally is September through October; typically, slow-moving high-pressure cells suppress rain and provide clear, dry weather. December was the wettest month in 1990 and 1991, and September and October were the driest months (Table 3.1.1). Precipitation in 1990 was 64.31 in. and in 1991 was 55.62 in. as recorded at the First Creek rain gauge (see Table 3.1.1).

Effective recharge for the ORNL area (including areas outside Bethel Valley) is estimated at 1.25 in./year or 2.4% of annual precipitation (Moore 1989). Recharge at WAG 6 has been estimated at 7 to 9% of annual precipitation (BNI 1991). Recharge at WAG 1 may be lower than either of these estimates because of the high percentage (approximately 40%) of impervious cover and the presence of man-made drainage controls.

The mean annual temperature for the Oak Ridge area is 58°F (Webster and Bradley 1988, McMaster and Waller 1965). The coldest month is usually January, with temperatures averaging approximately 38°F but occasionally dipping as low as 0°F. However, differences in temperature between December through February are minor. Although there is little difference in temperature between June and August, July is the hottest month; mean daily temperatures average 77°F and occasionally peak at over 100°F. Average daily temperatures fluctuate 53.6°F over the course of the year (Davis et al. 1984). August was the hottest month in 1990 with a mean daily temperature of 77.8°F, and July was the hottest month in 1991 (79.2°F). The average frost-free period of about 196 days extends from April 11 to October 24 (Stockdale 1951).

Evapotranspiration has not been measured for the WAG 1 area, but estimates range from 30 in. (Rothschild et al. 1984, Moore 1989) to 41-43 in. (Webster 1976).

Winds in the Oak Ridge area are controlled in large part by the valley and ridge topography. Prevailing winds are either up-valley (northeasterly) or down-valley (southwesterly). Davis et al. (1984) note that daytime winds generally blow up-valley and nighttime winds usually blow down-valley. Speeds are generally less than 7 mph.

3.2 SITE GEOLOGY

The geology of the site has a controlling influence on the occurrence and movement of groundwater. Consequently, site geology plays a major role in contaminant transport and affects the selection and design of remedial action alternatives.

3.2.1 Regional Setting

WAG 1 is situated in the Valley and Ridge Province, which is part of the Appalachian fold and thrust belt. Mountain-building processes associated with the Permian–Pennsylvanian Alleghenian orogeny (approximately 250 million years ago) have produced a succession of northeast-trending thrust faults that duplicate the Paleozoic rock sequences, transposing older rocks above younger rocks in a shingled effect. Subsequent differential erosion resulted in a series of alternating valleys and ridges that parallel the surface traces of the thrust faults. Rocks resistant to weathering (typically sandstones and dolomite or chert units) form the ridges, whereas rocks that are more readily weathered (such as shales and shaley carbonates) underlie the valley floors. Because of the complex mountain-building processes that affected the area, local geology is influenced by structural features at all scales, including regional and local thrust faults, normal and tear faults, local folding, and widespread fracture development.

3.2.2 WAG 1 Geology

Geologic data for WAG 1 were obtained from previous investigations and from coreholes and soil borings (described in Sect. 2). Detailed descriptions of WAG 1 geology are contained in Appendix B, Sect. B3.2. The stratigraphic sequence at WAG 1 includes a relatively thin veneer of overburden overlying bedrock. The overburden has variable composition, including saprolite, alluvial deposits, and colluvial deposits. Colluvium is preweathered soil material transported downslope by gravity and water. Alluvium is transported and deposited by running water in floodplains and low stream terraces (e.g., along the WOC floodplain). Saprolite is weathered bedrock formed in place that retains some relict structural features of the bedrock.

The overburden is underlain by the Chickamauga Group of early to middle Ordovician age. The main influence on the local sequence of the Chickamauga Group is the Copper Creek fault zone, which outcrops on the lower-to-middle northwestern slope of Haw Ridge. This thrust fault separates the younger Chickamauga Group from the older overlying siltstone strata of the middle Cambrian Rome Formation. It is one of several such westward-vergent thrust faults responsible for the repeat sequences of Paleozoic formations throughout the area.

Figure 3.2.1 is the legend for the geologic cross sections developed for transects across WAG 1 and shown in Figs. 3.2.2 through 3.2.12. The sections were developed using data from available coreholes, soil borings, monitoring wells, and historical reports. The geologic contacts on the cross sections are based on those observed in corehole logs and on Stockdale's (1951) geologic map of the site. The geologic contacts are generalized in that their dips are only partially adjusted to accommodate changes in the directions of the transect relative to geologic strike. The thickness of the overburden material and the configuration

of the bedrock surface were interpreted from borehole data. The cross sections also show groundwater geochemistry zones and available hydrologic data (hydraulic conductivities and groundwater elevations) for wells and coreholes. The aquifer materials are described in more detail in the following sections.

3.2.3 Description of Overburden

The overburden material was investigated at 286 soil borings drilled during this investigation. Detailed data and soil descriptions for the borings are contained in Appendix A. The overburden on the Chickamauga limestone at WAG 1 is typically less than 30 ft thick, although the thickness exceeds 60 ft in at least one location. Figure 3.2.13 is a generalized overburden isopach map based on boring information. The map is generalized in that local areas of bedrock outcropping (areas where the overburden is absent) may not be represented on the map unless a boring was drilled at the outcrop. The two areas of thickest overburden are the northwestern portion of the WAG and along Central Avenue south of Building 3525. Overburden thicknesses on the remainder of the WAG range from 6 to 12 ft.

The overburden materials may contain three components: soil material (residual soil, alluvium, and colluvium), fill material (recompacted natural soil, imported material, and waste), and saprolite (weathered bedrock containing relict structures).

3.2.3.1 Soil material

Two hundred eighty-six soil borings were drilled in WAG 1 (see Plate I). Descriptions of soil from these borings indicate that the natural soils are fine-grained, with the predominant soil classification being a low-plasticity silty clay. McMaster and Waller (1965) present a soil series map of the WOC Basin indicating that 11 soil series units are present within the boundary of WAG 1. Lietzke et al. (1986) identified two primary soil groups derived from weathering of the Chickamauga limestone parent rock—the Collegedale and Gladeville groups. Table 3.2.1 presents a correlation between bedrock lithology and soil types and between soil series units used by McMaster and Waller (1965) and the Soil Conservation Service (Moneymaker 1986) soil survey of Anderson County.

Table 3.2.2 summarizes the physical properties of the soil series at WAG 1. A majority of the soils are fine-grained, containing greater than 50% fines. The soils are typically classified as low- to high-plasticity clays and silts. Residual soils with a shallow depth to limestone bedrock (Bland, Carbo, and Gladeville series) and alluvial soils have slightly acidic to slightly basic pH values ranging from 5.1 to 8.4. Deeper residual soils over shale or dolomite bedrock (Fullerton, Armuchee, and Collegedale series) and colluvial soils have acidic pH values ranging from 4.5 to 5.5.

The clay mineralogy of the soils developed on the Chickamauga Group is reported by McMaster and Waller (1965) to include kaolinite and illite, with the possibility of significant amounts of montmorillonite associated with weathering of specific units in the Chickamauga. Carroll (1961) presents a single mineralogic analysis of the clay fraction of soil taken from an excavation at an unspecified location at the X-10 complex. This analysis indicates that

the clay fraction is composed primarily of kaolinite with some mica (illite) and a small portion of quartz. The moderate to high shrink/swell potential reported for the Carbo soil series suggests the presence of swelling clays, such as montmorillonite, in this soil unit. Lietzke et al. (1986) report that bentonite is also present in Chickamauga soils.

Selected samples from the soil borings drilled at WAG 1 were submitted for laboratory analysis of cation exchange capacity (CEC) and distribution coefficients for radionuclides of concern at WAG 1. The results of CEC tests presented in Table 3.2.3 indicate a narrow range of CECs associated with the soils overlying the various Chickamauga units (10 to 16 meq/100 g of soil). A single higher CEC of 42.43 meq/100 g of soil was measured in a sample from soil boring 01.SB165 taken at a depth of 6 to 8.1 ft. A possible explanation for this higher value is the presence of a montmorillonite-rich zone in the soil. Montmorillonite has a CEC approximately 30 times that of kaolinite (Lambe and Whitman 1969). Distribution coefficients, measured for selected WAG 1 soils as well as other published K_d values, are presented in Sect. 5.

3.2.3.2 Fill material

The X-10 complex is underlain by a myriad of underground utilities and backfilled foundation excavations. Additionally, SWSAs 1 and 2 are within WAG 1. The types of fill material encountered in the shallow soil borings include recompacted natural clay soils, clean sands, crushed limestone gravel, and concrete and asphalt. A complete definition of fill distribution within WAG 1 is not practical because of the complex configuration of underground excavations at the facility and the incomplete record of excavation activities. The approach taken to define fill distribution focused on major corridors where multiple buried utility lines are present. These corridors represent areas where there has been a significant disturbance of the natural soils. Figures 3.2.14 through 3.2.16 present the locations of three types of major utility corridors [storm drains, process (nonradiological) sewer lines, and hot (radiological) waste lines]. These utilities are distributed throughout the WAG; the highest density is between Third and Fifth streets.

Investigations at WAG 1, including Stockdale (1951) and Ashwood et al. (1986), have identified the fill around buried utilities as preferential flow pathways for seepage. These higher-permeability zones may be created by granular backfill materials or by inadequate compaction of native clay backfill. The physical and chemical properties of the fill material are difficult to quantify because fill materials range from clean gravels to native clay soils. Soil boring 01.SB181 was drilled through clay backfill over a drain line. A sample of the clay fill material was submitted for laboratory CEC analysis; results (Table 3.2.3) show that the material falls within the range of CECs for the natural soils and suggest that the backfill retains the sorptive properties of the native clay soil from which it was derived.

3.2.3.3 Saprolite

Saprolite was encountered in 11 of the shallow soil borings drilled at WAG 1, most commonly above Unit H of the Chickamauga limestone, but also above Units G, E, and D (near the contact with Unit C). Saprolite is weathered bedrock that maintains some of the structural features (bedding, folding, etc.) of the parent material. The saprolite represents a transition zone between soil and bedrock materials and thus its properties are bounded by the properties of the soil and bedrock. Saprolite development on the Chickamauga Group is primarily associated with calcareous shale, clayey and silty limestone, and siltstone units within the formation (Lietzke et al. 1986). (In areas where "clean" limestone is present, the shallow soil borings indicate that there is an abrupt change from soil to bedrock, without development of saprolite.) Because of the irregular and discontinuous pattern of saprolite development, insufficient data are available for preparation of a saprolite distribution map.

3.2.3.4 Hydrologic characteristics of overburden materials

Direct measurements of total porosity for the overburden materials at WAG 1 are not available. Moore (1988) reported a total porosity of 30 to 50% for clayey materials in the stormflow zone (i.e., shallow interval where unsaturated flow occurs).

Given the high clay content of the overburden, the effective porosity (porosity through which water is capable of moving) is probably much lower than the total porosity; site-specific data, however, have not been collected. Moore (1989) reported effective porosities in the stormflow zone of 0.002; within the vadose zone, estimates of 0.0025 to 0.006 were reported, with an average of approximately 0.0042. These values are for undisturbed soils and may not be representative of WAG 1. Solomon et al. (1989) estimated the effective porosity of the overburden near the surface impoundments to be 1.8%. The low values reported for effective porosity indicate relatively little useful storage capacity and would result in rapid seepage velocities through saturated overburden materials.

Saturated hydraulic conductivity (K) has been measured for only three piezometers and well points completed above the overburden/bedrock interface: piezometer 588 (near Building 3001), well point 721 (near WOC just outside the southwestern boundary of WAG 1), and well point 722 (adjacent to WOC in the southwestern corner of WAG 1). The hydraulic conductivity values were measured using slug tests and are similar for wells 588 and 722 (1.97×10^{-4} cm/s and 1.27×10^{-4} cm/s, respectively) but much lower for well 721 (2.6×10^{-6} cm/s). These values reflect the diverse nature of the overburden material.

Much more hydraulic conductivity data are available for wells screened across the overburden/bedrock interface; however, these data probably represent a composite hydraulic conductivity for both overburden and rock and therefore have little value for determination of the hydraulic characteristics of the overburden. Moore (1989) measured the saturated hydraulic conductivity for vadose zone soils at ORNL (based on infiltrometer tests). Moore's values have a geometric mean of 3.6×10^{-5} cm/s, with a range from the mean minus one to the mean plus one standard deviation of 1.74×10^{-7} to 1×10^{-4} cm/s.

The relatively low hydraulic conductivity in the overburden is consistent with boring log data and observations regarding the composition and distribution of fill and native soils within the overburden. Most of the overburden is composed of clay, in the form of either native clay-rich soils (residuum, alluvium, or colluvium) or clay-rich fill materials brought in during construction and related activities or reworked from on-site excavations. Lietzke et al. (1986) reported that the residual clay soils from the Chickamauga contain bentonite, a clay mineral capable of significantly increasing the shrink-swell potential of soil and creating a material with much lower permeability.

Well construction methods and materials appear to have some effect on hydraulic conductivity values. Figure 3.2.17 reveals that hydraulic conductivity values for piezometers (500–600 series) screened at the soil/rock interface have greater range than the wells (800 series) screened at the interface. Because wells and piezometers are both distributed over large areas of ORNL, this difference in range of values is likely a result of differences in the screen materials and sand pack quality. Piezometers at WAG 1 tend to yield muddy water, often including fine- to medium-grained sand.

Hydraulic conductivity data were also obtained from two temporary piezometers constructed near buried pipelines (locations 01.SB208 and 01.SB224). These data indicate a range of 1 to 4 $\times$ 10^{-4} cm/s, comparable to values obtained elsewhere within the overburden. These values are similar to hydraulic conductivities measured at overburden wells and do not suggest that the trench fill materials are highly permeable conduits for subsurface flow. Although the piezometers are near buried pipelines, they may be too far from the pipes to have intercepted the backfill materials. In addition, the number of piezometers tested (two) is probably insufficient to allow conclusions to be drawn.

3.2.4 Description of Bedrock

Most of WAG 1 is underlain by the Ordovician age Chickamauga Group (Fig. 3.2.18) except the extreme southwestern portion of WAG 1, which is underlain by the Cambrian age Rome Formation. This unit unconformably overlies the younger Chickamauga Group as a result of thrust faulting along the Copper Creek thrust fault. Table 3.2.4 summarizes the characteristics of each unit of the Chickamauga bedrock and the Rome Formation. The descriptions are based on data presented by Stockdale (1951) and Lee and Ketelle (1988) and on information collected from the six new coreholes installed as part of the current investigation (see Appendix B, Sect. B3).

The Chickamauga Group consists of interbedded limestones and siltstones totaling approximately 1730 ft in thickness in the Bethel Valley section. Stockdale (1951) studied rock cores from 51 wells drilled at ORNL and divided the Chickamauga into eight mappable units designated A (oldest) through H (youngest). In a subsequent investigation based on five coreholes, Lee and Ketelle (1988) confirmed Stockdale's designations and further divided the Chickamauga into informal lithologic units.

Bedrock in Bethel Valley strikes east-west and dips towards the south. Dips range from 25 to 40°, and the average dip is approximately 35° (Fig. 3.2.19). As a result of this structural configuration, the units intersect the overburden (subcrop) beneath Bethel Valley

as a series of east-west-trending belts (see Fig. 3.2.18). Except for Unit A, all the units of the Chickamauga intersect the overburden/bedrock interface beneath WAG 1; the intersection of Unit A and the overburden lies north of the WAG boundary. The only significant surface outcrops are along the streams that drain WAG 1.

The eight Chickamauga units range in thickness from less than 35 ft (Unit F) to greater than 350 ft (Unit E). Based on cores from coreholes drilled as part of this investigation and on the descriptions of Stockdale (1951) and Lee and Ketelle (1988), the lithologies range from massively bedded limestone (Unit E) to shaley siltstone (Unit F). The limestone units contain varying amounts of siltstone interbeds, are typically gray in color, fine- to medium-grained, dense, medium hard to hard, and unweathered. Fossil zones are common, and styolites are also present. Bittner and Dreier (1990) observe that styolite content increases with depth. The limestones often contain chert nodules or beds; the relatively high chert content in Unit D is responsible for the line of low hills along the northern boundary of WAG 1 (Stockdale 1951). The siltsone units are described as calcareous to shaley, gray to maroon, soft, thinly to massively bedded, with occasional fossil zones and chert nodules.

The Rome Formation, comprised of interbedded sandstone and shale, underlies Haw Ridge to the south of WAG 1 (Stockdale 1951). The Rome Formation underlies only a very small portion of WAG 1 at the water gap where WOC flows through the gap in Haw Ridge.

3.2.4.1 Configuration of bedrock surface

Figure 3.2.20 is a contour map showing the elevation of the bedrock surface at WAG 1. The map was prepared using available data from coreholes, wells and piezometers, and 46 soil borings that penetrated the full thickness of the overburden. Some areas of the WAG exhibit considerable relief in the bedrock surface, probably as a result of solution features in the limestone bedrock. As a result, the actual configuration of the bedrock surface may vary locally from that shown on the map although the map is a reasonable approximation.

The bedrock surface closely resembles surface topography. A bedrock high exists north of WAG 1 beneath the line of hills extending along Bethel Valley. The bedrock slopes towards the WOC water gap at Haw Ridge; slopes are generally steepest near the high area north of the WAG and less steep in the southern half of the WAG. There are two prominent depressions in the bedrock surface within the WAG boundary. One is adjacent to the Oak Ridge Research Reactor, where piezometer 588 was drilled to a depth of 60 ft without encountering bedrock; this depression may be a solution feature in Chickamauga Unit D. The second depression occurs at STF, where historical photos taken during construction indicate an area of excavation into bedrock.

3.2.4.2 Physical and chemical properties of bedrock

Primary porosity is almost absent from the limestone units (Stockdale 1951; Moore and Young 1992). As a result, groundwater moves through bedrock primarily along secondary porosity features, including fractures and solution channels. Key factors affecting the migration of groundwater and contaminants through bedrock include porosity, open fracture

or solution feature density, hydraulic conductivity, CEC, and distribution coefficients (K_d) of contaminants. Inferences of bedrock properties can be made from general observations of bedrock cores collected from coreholes; otherwise, it is necessary to rely on data collected from other portions of the ORR.

CEC, K_d, bulk density, and pH. To provide an indication of the range of values encountered at the ORR, Table 3.2.5 summarizes the physical and chemical properties of bedrock in Melton Valley. The data are for the Maryville Limestone, the Nolichucky Shale, and the Chickamauga Limestone (CEC only). Values for the Chickamauga rocks are for samples collected by de Laguna et al. (1968) from depths greater that 2000 ft, and may not be representative of shallower Chickamauga rocks at WAG 1. Values for the Nolichucky Shale and the Maryville Limestone are shown for comparison and to provide an indication of the range of values likely to exist at WAG 1. For the samples analyzed, CEC values for the Chickamauga rocks range from 71.7 to 181.5 meq/kg; these values are comparable to values for the Nolichucky Shale and Maryville Limestone samples (154 and 149 meq/kg, respectively).

Solution features. The limestone strata of the Chickamauga are susceptible to dissolution in groundwater, and several solution features have been observed. Stockdale (1951) observed solution features ranging in size from 1 in. to 1 ft in diameter. A solution feature at least 7 ft deep was observed in Unit D at a pipeline leak site north of Building 3019; subsequent dye tracer tests indicated that this solution feature is hydraulically connected to the sump in the basement of Building 3042 (Huff 1985). Review of drillers' logs from coreholes, monitoring wells, and piezometers revealed evidence of solution features at 13 locations (Table 3.2.6). Nine of the observed solution features occur in Unit D; the apparent susceptibility of this unit to dissolution is the likely result of a combination of its relatively massive limestone composition and its outcrop position in a groundwater recharge zone (see Sect. 3.3.2.2).

Porosity and effective porosity. Values for porosity and effective porosity have not been measured for the Chickamauga bedrock within Bethel Valley. De Laguna et al. (1968) measured porosity values in the samples of unfractured Chickamauga rock collected from depths greater than 2000 ft in a corehole in Melton Valley and reported values ranging between 0.39 and 1.5%. Moore (1989) estimated effective porosity at the ORR to be in the range of 0.001 to 0.1%. Values for porosity and effective porosity are likely to be considerably higher in intervals of highly fractured rock.

The storativity of the bedrock aquifer materials at WAG 1 is controlled by porosity and degree of confinement. Storativity values are not available for WAG 1 because of the lack of pump tests, but water level fluctuations in wells in response to precipitation suggest that storativity is variable. Values for bedrock in Melton Valley range from 0.1 to 1.0% with a mean of 0.5% (BNI 1991).

Hydraulic conductivity. Hydraulic conductivity (K) for the bedrock aquifer materials at WAG 1 has been estimated using slug test methods (Moore, Huff, and Ketelle 1987) and packer test methods [Lozier and Pearson (1987); Appendix B]. Hydraulic conductivity values for wells, piezometers, and coreholes at WAG 1 are listed in Appendix B [Attachments B1

(wells and piezometers) and Table B4.2.1 (coreholes)]. K values range from 1×10^{-9} to 0.01 cm/s, with a geometric mean of 8.8×10^{-6} cm/s. These values vary considerably across the site (Fig. 3.2.21). Even though variability in K values does not seem to correlate closely with any one geological unit, some of the highest K values are found in Unit D due to its susceptibility to dissolution. For example, six test intervals were observed to have hydraulic conductivity values greater than 10^{-3} cm/s; three of the six locations (piezometer 538 and two test intervals in corehole CH07A) were in Unit D (Table 3.2.6). Similarly, 19 locations were found to have hydraulic conductivity values greater than 10^{-4} cm/s; of these, 4 each are in Units B, D, and H. Thus, Units B and H may also contain preferred groundwater flow pathways. It is important to note here that the locations for which hydraulic conductivity values are available are not distributed evenly across WAG 1 and that most data are for depths less than 100 ft. Based on existing data, it is impossible to definitively identify all preferred flow pathways. Indeed, only one location in Unit E (well 812) was found to have hydraulic conductivity values greater than 10^{-4} cm/s, yet this unit has been identified as an important preferential groundwater migration pathway, as discussed in Sect. 3.3.4.3.

Although the most transmissive intervals found at WAG 1 appear to be contained within relatively few units, there does not appear to be a consistent relationship between geologic unit and K values. A box plot of hydraulic conductivity of bedrock at WAG 1 (Fig. 3.2.22) illustrates that although the different rock units have different mean values, the overlap in the ranges and standard deviations indicates that the units are not readily differentiated on the basis of hydraulic conductivity. This suggests that even in units where the highest K values have been found, a wide range of K values is likely to exist. For example, while it is true that the highest K values are found in Unit D, there is also a high probability that intervals with low K values will be encountered in the same unit. This relationship suggests a distribution where highly transmissive zones are relatively widely spaced and are separated by relatively nontransmissive intervals. In a separate study, Moore, Huff, and Ketelle (1987) also concluded that lithology has no statistically significant effect on K values in the Chickamauga rock units.

An overall decrease in hydraulic conductivities with depth (illustrated in Fig. 3.2.23) is probably attributable to a decrease in the frequency of open fractures with depth. However, the data exhibit considerable scatter on the graph, and high or low K values are possible at almost any depth. The relationship between hydraulic conductivity and depth is more clearly illustrated in Fig. 3.2.24, which was developed by dividing the hydraulic conductivity data into depth ranges so that each range encompasses 100 ft of depth. Within each range, the data were further divided into categories according to the value for K. Each category (other than the lowermost category) corresponds to one order of magnitude. To simplify the analysis, all values below 10^{-7} cm/s were grouped into one category. Finally, the percentage of values within each category was computed for each depth range.

Figure 3.2.24 shows that within the uppermost depth range (0 to 100 ft), less than 10% of the K values are less than 10^{-7} cm/s. The percentage of observations in this category increases steadily with depth. In the 300- to 400-ft range, more than 45% of the observations are less than 10^{-7} cm/s; in the 400- to 500-ft range, this percentage increases to 67%. The category that includes values from 10^{-6} to 10^{-7} cm/s shows a similar trend.

The opposite trend is apparent in categories that include values greater than 10^{-5} cm/s. More than 40% of the values in the 0- to 100-ft range are in the 10^{-5} to 10^{-4} cm/s category. This percentage decreases with depth, with the exception of a minor increase between the 200- to 300-ft and 300- to 400-ft ranges. There are no values in this category in the deepest depth range. The categories that include values 10^{-3} to 10^{-4} cm/s and values greater than 10^{-3} cm/s show a similar decrease with increasing depth.

This analysis illustrates that, although there is considerable variability in the K values across all depths, most zones of high conductivity occur at relatively shallow depths. For example, ignoring sampling biases due to differences in the number of samples with each depth range, it is estimated that in the 0- to 100-ft depth range there is a greater than 50% chance of encountering a K value greater than 10^{-5} cm/s. This percentage decreases to less than 20% at depths greater than 300 ft; intervals where hydraulic conductivities exceed 10^{-5} cm/s are found in CH003, CH009, and FT010. From these observations it follows that the majority of groundwater flow occurs at relatively shallow depths (especially in the upper 100 ft) in zones dominated by high K values. The analysis also indicates that some localized zones of high K values occur at depths greater than 300 ft; these relatively rare zones probably support most of the active groundwater flow in the deeper intervals.

Anisotropy. Anisotropy, a ratio of hydraulic conductivities along different axes, is another scale-dependent property of fractured aquifers. Local-scale anisotropy is likely to be high relative to a large-scale area due to the smaller number of fracture intersections in a smaller area. Anisotropy near individual fracture zones may range up to several orders of magnitude because of preferred flow along fractures. Over larger areas, the anisotropy decreases as the number of intersecting fractures increases.

3.2.5 Description of Fractures and Faults

The bedrock at WAG 1 exhibits structural features including fractures and faults that are the result of a long and complex stress history in the region. The structural deformations are related to changes in the regional tectonic framework, including early Paleozoic basin subsidence, late Paleozoic folding and thrusting, Mesozoic rifting, and Cenozoic erosional unloading. Fractures and faults are common in most limestones and massive siltstones in the Valley and Ridge Province, as observed and described in detail by Bittner and Dreier (1990). Coring associated with the current investigation has allowed further study of these features. Figure 3.2.25 is a generalized block diagram illustrating the features described below.

Compressional structures include high-angle reverse faults, bedding plane slip surfaces (fractures), and stylolites. The high-angle reverse faults are relatively rare, probably represent little displacement, and often exhibit small-scale drag folds. Examples of this type of fracture occur at a depth of 96.8 ft in Unit B at CH006. Bittner and Dreier (1990) also document this type of fault. High-angle reverse faults can be found in conjugate sets with subhorizontal faults. Faults in shallow bedrock show iron staining, which may indicate groundwater flow pathways.

Bedding plane fractures, occurring to a lesser degree in siltstones, are most prevalent in the shaley partings of the argillaceous limestones. The surfaces exhibit varying degrees

of slickenside development and are often mineralized. Small pyrite crystals were observed on some of the fracture surfaces, and light-to-heavy calcite mineralization is common. These features tend to be slightly open or tight; many have been completely filled with calcite. Solution has opened a few, mostly shallow, surfaces.

Extensional features include dip-normal, oblique, and low-angle fractures (Fig. 3.2.25). These include fractures that are parallel to bedding and either parallel, perpendicular, or at oblique angles to strike (e.g., dip-normal fractures on Fig. 3.2.25). These tend to be discontinuous and are often filled or coated with calcite. Shallow fractures often show iron staining and deeper ones sometimes exhibit pyrite dusting. These joints cross-cut other structural features and intersect other extensional joints, causing zones of disintegration or broken zones. These zones have been observed from 0.5 to 2.5 ft thick in coreholes.

Figure 3.2.26 shows the relationship between fracture density and depth for coreholes CH006 through CH012. The figure illustrates that the greatest density of fractures occurs at depths above 100 ft; densities as high as eight fractures per foot were observed in some cores recovered from depths above 100 ft. The difference in fracture densities for cores recovered from depths above 100 ft and those recovered from depths between 100 and 200 ft is quite pronounced. The fracture density continues to decline at depths greater than 100 ft, but the decline is much less pronounced. Below 200 ft, only one core with more than five fractures per foot was recovered. Similarly, only two rock intervals with more than three fractures per foot were encountered at depths greater than 300 ft.

There is also an apparent decrease in the number of extensional fractures with depth. Based on an analysis of the corehole logs, between 20 and 60% of fractures in rock cores collected from depths above 200 ft were extensional. Extensional fractures in rock cores collected below 200 ft uniformly comprised less than 20% of the total fractures.

Rock type has an apparent influence on fracture density and type. The highest occurrence of bedding plane fractures is in the shaley partings of the argillaceous limestones; the extensional joints occur predominantly in the cleaner limestones and massive siltstones. The limestones typically have more numerous calcite veins than the siltstones. Additional descriptions of rock types encountered at WAG 1 and the fracture types associated with each are provided in Appendix B, Sect. B3.2.3.

3.2.5.1 Copper Creek fault

According to Stockdale (1951), the Copper Creek fault is a thrust fault located on Haw Ridge, where rocks of the Rome Formation were thrust upon rocks of the Chickamauga Group (see Fig. 3.2.18 for surface trace of fault). The fault intersects the surface on the northwest side of the ridge and strikes 56° northeast (true coordinates). Stockdale estimated the dip to be as great as 45° south. The fault extends through WAG 1 at the water gap in Haw Ridge. Stockdale advanced a corehole through the fault zone and described it as "tightly cemented," "quite impermeable," and a likely barrier to horizontal flow across strike.

3.3 SITE HYDROGEOLOGY

3.3.1 Groundwater Monitoring System Used for WAG 1 Investigation

A total of 148 monitoring wells and piezometers were used for the current groundwater investigation. Of this number, 89 are piezometers (locations 532 through 635), 2 are well points (locations 721 and 722), 56 are monitoring wells (locations 806 through 4002), and one is a multiple-port well (CH008). The groundwater sampling and monitoring locations are shown on Plate I. Construction data for the wells and piezometers are given in Appendix B, Attachment B1.

3.3.1.1 Installation of monitoring networks

Table 3.3.1 summarizes the well installation history at WAG 1. Prior to the current investigation, three general types of wells had been installed in and around WAG 1 (piezometers, perimeter wells, and RCRA compliance wells). Piezometers were situated within and surrounding the main plant area to allow preliminary hydrologic mapping of the area and to furnish sampling point locations for an initial chemical and radiological scoping survey. Ninety-nine 2-in. PVC piezometers were installed in and around WAG 1, SWSA 1, and SWSA 2 during 1985 and early 1987.

Selected piezometers were sampled by Energy Systems in 1986 as part of a preliminary scoping survey of chemical and radioactive components in the shallow groundwater system (Moore, Huff, and Ketelle 1987). The groundwater characterization plan and piezometer installation specifications are delineated in Ketelle et al. (1986) and Hyde (1986), respectively. Piezometer boring logs and construction data are presented in Mortimore (1987a). Moore, Huff, and Ketelle (1987) present the results of the groundwater characterization, including a depth to water summary, results of slug tests, preliminary water quality surveys, and a geostatistical analysis of data. Ten of the piezometers were not used for the WAG 1 RI because they were outside the study area or could not be located. The remaining 89 piezometers were used to produce hydrologic maps defining the groundwater flow system, to investigate the range of annual water table fluctuations, and to characterize shallow geologic conditions at WAG 1.

The perimeter wells were installed during 1987 (two wells were added in 1989) in accordance with regulatory compliance requirements. These 25 RCRA compliance monitoring wells were installed surrounding the perimeter of WAG 1 to characterize and assess the potential for off-site migration of hazardous wastes (Hyde 1987; Mortimore 1987b). Two additional wells (946 and 947) were added in 1989. Most of the wells are 2- and 4-in. stainless steel and are screened either across the bedrock/overburden interface or in bedrock. Some bedrock wells are finished open hole. Ten wells were paired to form five shallow/deep well pairs.

Additional RCRA compliance monitoring wells were installed around the 3513, 3524, 3539, and 3540 impoundments. The eleven shallow and three deeper bedrock stainless steel wells are installed around the perimeter of impoundments 3524, 3539, and 3540 (MCI 1986).

Based on slug test results, hydraulic conductivities in the shallow wells range from 1.3×10^{-4} to 7.0×10^{-6} cm/s; the range for the bedrock wells is 1.0×10^{-4} to 4.4×10^{-6} cm/s. Five RCRA compliance 2-in.-diam stainless steel monitoring wells surround impoundment 3513 (Stansfield and Francis 1986b). One overburden/interface well pair is upgradient, two interface wells are along the southern edge of the impoundment, and one interface well is along the western margin. These wells were sampled quarterly by Energy Systems; analytical data are maintained in the Environmental Restoration Program data base at ORNL.

The multiple-port sampling system was installed in corehole CH008 to allow monitoring and sampling of discrete intervals in the bedrock. The well was installed in response to high contaminant concentrations observed during corehole installation. The system includes seven sampling ports at depths from 15.9 to 53.5 ft BGS. Details of the well construction are provided in Appendix B.

The 148 wells and piezometers used for the WAG 1 investigation have been designated as overburden, rock, or interface. These designations were made by comparing the screened interval and the elevation of the top of the sandpack with the reported depth to bedrock. Wells and piezometers designated as overburden type are screened entirely in the overburden material and do not intersect bedrock. In rock wells and piezometers, the top of the screen and the top of the sandpack are below the bedrock surface. If either the screen or the sandpack intersects the bedrock/overburden interface, the location is designated as an interface well or piezometer. Of the 148 wells and piezometers, 8 are designated as overburden type, 64 as rock type, and 76 as interface type. The distribution of different types is shown in Fig. 3.3.1.

To eliminate the need for installing new monitoring wells inside WAG 1, 47 of the piezometers were used for groundwater sampling purposes. Prior to sampling, the selected piezometers were upgraded to reduce the potential for contamination entering the piezometer from surface runoff and to enhance the integrity of the wellhead (see Sect. 2.1). The procedures for selecting and upgrading the piezometers are described in Appendix B.

Five of the monitoring wells are designated as reference locations to provide data on background water quality. These locations are identified on Fig. 2.5.1.

3.3.2 Groundwater Occurrence

Two contour maps of groundwater elevations were prepared—one showing the water table surface during a period of seasonal high water levels (high base conditions) and one showing the water table surface during a period of low water levels (low base conditions). Water level data for all the wells and piezometers are listed in Appendix B, Attachment B3. The map showing high base conditions (Fig. 3.3.2) was prepared using data from the monitoring event that occurred between April 2 and April 4, 1991, when groundwater at most locations was at or near its highest level. Water levels at several wells were slightly higher during March 1991. However, fewer wells were monitored in March than in April (99 vs. 136), and the April data were selected because they provide a more complete indication of groundwater elevations across the WAG. The low base map (Fig. 3.3.3) was

generated using data from the monitoring event of September 30, 1991, when groundwater elevations in most areas were near their lowest point.

The maps were generated using data representative of the shallow groundwater system that occurs in the overburden and in shallow bedrock. Only wells and piezometers screened within the upper 20 ft of the water table were used for the maps. This shallow system generally occurs under unconfined conditions, although locally semiconfined conditions may occur, particularly where the water table is below the top of bedrock.

Two locations were not used for the map because they yielded anomalous groundwater elevation data. Piezometer 558, which is screened from depths of 30 to 45 ft BGS, was not used because it only contains water in the bottom of the casing, as indicated by a lack of water level fluctuations. It is also possible that piezometer 558 penetrates a shallow perched zone and is not representative of the regional water table. Well 883, adjacent to impoundment 3540, is completed as an open hole well from depths of 39.5 to 51 ft BGS. Water levels in this well are consistently 30 to 40 ft lower than those in nearby wells. Such low heads are not found anywhere else in or near WAG 1, indicating that the well is yielding anomalous data.

Figures 3.3.2 and 3.3.3 depict potential groundwater flow directions and gradients; however, much of the groundwater movement at WAG 1 occurs in secondary porosity features in the bedrock and is strongly influenced by structural and stratigraphic controls. Structural and stratigraphic control of groundwater flow directions is well documented elsewhere on the ORR and to some extent has been observed in tracer tests at WAG 1 (e.g., Stueber et al. 1981). Actual groundwater flow directions probably vary significantly from those predicted from available potentiometric data alone. However, the maps provide some indication of general flow directions and illustrate seasonal and spatial variations in groundwater occurrence.

The two maps show similar trends with few, if any, major differences. The water table surface mimics site topography; highs occur north of the WAG and the surface slopes southward towards WOC. Many undulations occur in the water table surface at WAG 1 as a result of local influences. One such feature is a depression in the water table surface near Building 3042. This depression is probably the result of sumps operating in the building and extracting an estimated 8 gpm of groundwater that enters the building through pipeline trenches and as leakage through the walls. The connection between sumps and groundwater was demonstrated by Huff (1985) and Melroy (1986). A cavity in bedrock in Unit D was discovered by Energy Systems in 1985 when investigating a line leak north of Building 3019 and approximately 400 ft along strike with Building 3042. Dye tracers were injected into the cavity during two separate tests (a "wet weather test" and a "dry weather test") to evaluate flow pathways (Huff 1985; Melroy 1986). In both tests, dye was detected in the 3042 sumps, suggesting a groundwater connection between the cavity north of Buildings 3019 and 3042. Finally, the presence of a bedrock depression (greater than 60 ft deep) at piezometer 588 may also be influencing groundwater elevations in the vicinity (see Sect. 3.2.4).

During both the April and September 1991 monitoring events, a small groundwater divide was present directly west of Third Street. The divide indicates that flow lines originating from the north diverge towards the southeast and southwest.

Surface impoundments 3524, 3539, and 3540 appear to exert a localized impact on groundwater levels. Mounding in association with the 3500 series impoundments has appeared, in some shape or form, on most water table maps for WAG 1 as far back as Stockdale (1951). Figure 3.3.4 shows hydrographs for the impoundments and for wells and piezometers located in their immediate vicinity. The hydrographs for three of the four impoundments (the exception is impoundment 3513) have approximately the same shape as the wells and piezometers. Water levels increased from January through March 1991 and began to decrease when the next measurement was taken in June 1991. This pattern is seen in the wells and in impoundments 3524, 3539, and 3540, suggesting communication between the impoundments and groundwater.

During the September 1991 monitoring round, the water elevations in the ponds were higher than those in surrounding monitoring wells (measurements are not available for the impoundments for the April 1991 monitoring round). The greatest effect is seen near impoundments 3539 and 3540, which cause a small mound in the water table surface. Impoundment 3524 appears to cause smaller, less pronounced mounds in the water table surface.

Mounding in the vicinity of the impoundments is evidence of leakage and suggests that the impoundments are actively recharging the water table. Potential mechanisms responsible for this leakage include seepage through the soil materials lining the bottom or sides of the basins or leakage along preferential flow paths (e.g., pipeline trenches) beneath or adjacent to the impoundments. Ashwood et al. (1986) conducted a study of leakage from the equalization basin and found flow pathways associated with abandoned stormwater and sanitary sewer lines underlying a portion of the basin. The extent to which similar mechanisms exist for the other impoundments is not known.

A localized mound in the vicinity of piezometer 563 was also observed in both April and September 1991. The water level associated with this mound did not change significantly between April and September; in contrast, water levels in the mounds associated with the 3539 and 3540 impoundments varied by 1 to 3 ft during the same period. The lack of fluctuation at piezometer 563 is believed to be caused by man-made controls (in this case possibly a leaking pipeline), as described in Moore, Huff, and Ketelle (1987).

3.3.2.1 Groundwater fluctuations

Water level fluctuations were investigated using the monthly water level data and continuous monitoring data collected as part of the RI field effort. Continuous data were collected from 20 locations, including 17 wells and piezometers and 3 stream locations, between April 22 and December 31, 1992 (see Fig. 2.8.1). All the monitoring data are listed in Appendix B, Attachment B3; continuous monitoring hydrographs are provided on Figs. B2.3.3 through B2.3.22.

Figures 3.3.5 through 3.3.11 show water level fluctuations along with records of precipitation for plots of continuous monitoring data for selected locations. For some locations, the monthly data are shown to illustrate long-term fluctuations; continuous monitoring data are shown to illustrate short-term fluctuations. Typical long-term fluctuations are shown in the hydrograph for piezometer 572 (Fig. 3.3.5). Groundwater increased in elevation from June 1990 through April 1991, followed by a decline until July, when water levels rose in response to short-duration summer storms. After July, water levels again fell until December 1991. The December round was preceded by a 2-day rainfall event of approximately 1.5 in., which strongly affected the groundwater levels.

Streams exhibited maximum water levels during the 1991 summer storms. Their minimum levels occurred in September and October 1991, when baseflow was lowest. Streams monitored during the study were characterized by ranges of just over 1 ft at Fifth Creek to over 4 ft at WOC. Table 3.3.2 presents statistics on the continuous monitoring locations.

Single storm events did not cause a lasting effect on groundwater levels, as illustrated in the hydrographs for the continuous monitoring stations at piezometer 540 (Fig. 3.3.6) (adjacent to First Creek) and piezometer 549 (Fig. 3.3.7) (near the crest of the hill north of WAG 1). Piezometer 540 showed almost instantaneous response to rainfall, but well 549 lagged about 6 h behind the streams. Most wells showed response 3 to 4 h after response appeared in streams. Peak water levels lagged from 1 h to 2 days or more behind peak levels in the streams, with over half the wells lagging less than 6 h. In most wells, much of the rise dissipated a day or two after the peak, but the full decline sometimes took several weeks.

Significant changes in the groundwater baseflow occurred during storm clusters, when water levels could not decline fully after one storm before the next storm started. This is illustrated by the continuous monitoring data for well 826 (Fig. 3.3.8). Small storm clusters occurred in June and July, and larger ones occurred in November and December. The overall result was a slow baseline recession starting in April, briefly interrupted by late spring and early summer storms, and reaching a low around October–November before rising again in the late November.

Twice-daily fluctuations of less than 0.2 ft were seen in some wells, most notably deeper wells like 811 (see Fig. 3.3.6) and 825 (Fig. 3.3.9). These are likely earth tidal effects caused by lunar gravitational forces. This type of fluctuation is not seen in strictly water table aquifers, indicating that some of the deeper areas in the aquifer in WAG 1 are at least partially confined.

Variations in the distribution and magnitude of water level fluctuations may reflect variations in site geology and drainage characteristics. Examples of differences in geology can be seen in hydrographs of monthly data for piezometer 572 (see Fig. 3.3.5) and well 814 (Fig. 3.3.10). Both locations are screened in bedrock in an apparent recharge area north of WAG 1. Piezometer 572 is completed in Unit B, and well 814 is completed in Unit C. The hydrograph for piezometer 572 shows that groundwater elevations at that location are strongly influenced by seasonal effects. The groundwater elevation fluctuated 13.38 ft

between April and October 1991. The magnitude of these fluctuations suggests that groundwater elevations in the vicinity of piezometer 572 are highly sensitive to recharge events and indicates that the storage capacity of the aquifer is relatively low. In addition, the effects of recharge events are maintained for relatively long time periods, as illustrated by the strong seasonal trends observed in the water elevations. This indicates that the aquifer is unable to discharge the water from one recharge event before the next recharge event begins and suggests a relatively low aquifer transmissivity in this area.

A different pattern is seen in the hydrograph for well 814. Although this well is also located in the major recharge zone north of the WAG, groundwater fluctuations are less than 1 ft except for the measurement taken in December 1991. The relatively large increase observed in December (approximately 13 ft) suggests that the area does receive significant amounts of recharge. However, the absence of strong seasonal fluctuations indicates that the effects of recharge are relatively short-lived and suggests that the transmissivity of the aquifer is relatively high at well 814 compared to that at piezometer 572. The hydraulic conductivity of the aquifer has not been estimated at piezometer 572; however, hydraulic conductivity at well 814 is relatively high (3×10^{-3} cm/s), suggesting that the aquifer in this area is able to transmit large amounts of water relatively quickly.

A high degree of correlation was seen between the following well pairs: 540 and 811 near First Creek (see Fig. 3.3.6); 825 (see Fig. 3.3.9) and 826 near WOC (see Fig. 3.3.8), and 946 and 947 near WOC southwest of impoundments (Fig. 3.3.11); their records are nearly identical except for slight differences in the magnitude of the fluctuations. Well pair 540/811 showed an upward gradient throughout the period of study, varying from about 0.08 to 0.09 ft/ft. The gradients were lower during precipitation events. All three well pairs consist of a shallow well and a deep well. The differences in elevations of the monitored zones for the shallow and deep wells range from approximately 40 ft (well pairs 540/811 and 826/825) to approximately 49 ft (well pair 946/947). The similarities in groundwater fluctuations within well pairs indicates that groundwater at these depths responds similarly to recharge events. The response in the shallow wells is the result of direct infiltration into the overburden material. Head fluctuations in the bedrock system, however, reflect pressure changes where the water-transmitting fractures intersect the overburden. As most of the fractures in the Chickamauga units are bedding plane fractures, the heads respond to pressure changes that occur in the updip (northerly) direction where the strata intersect the overburden material.

The variability of groundwater fluctuations in wells and piezometers across WAG 1 is also illustrated in Fig. 3.3.12, which shows the maximum water level fluctuation in each well and piezometer. The complex pattern of groundwater fluctuation observed at WAG 1 reflects variations in site geology, recharge rates, and influences from pipeline networks and building sumps. Fluctuations within the WAG 1 boundary were generally less than 6 ft, and most were less than 3 ft. These results reflect generally low recharge rates within the WAG due to the high density of paved areas, buildings, and surface drainage controls. Isolated areas within the WAG that exhibit greater fluctuations [for example, piezometers 567, 566 (southwest of STF), and 556 (along Central Avenue west of STF)] may indicate local recharge areas or contributions from pipeline trenches or drains.

The maximum amount of fluctuation ranged from 0.46 ft (piezometer 626) to 13.38 ft (piezometer 572). The average fluctuation was approximately 3.5 ft at wells for which data for at least 1 year are available. The recharge area north of the WAG near Buildings 2001 and 2002 showed the largest fluctuations. One exception in this area is the groundwater in piezometer 558, which showed only 0.41 ft of fluctuation over 14 monitoring rounds. Alternative explanations for these results are that the piezometer is intercepting a local perched groundwater zone, that man-made controls (for example, sump or pipeline trench) are impacting water levels, or that the zone is unsaturated and surface water is seeping into the piezometer and collecting in the bottom of the casing. Extremely low recharge rates (almost no recharge in 6 h of observation following pumping) were noted during attempts to develop this piezometer, also suggesting that this piezometer may not penetrate the saturated zone. Whatever the instance, the data from this location are not likely representative of true groundwater conditions in that area.

Moore, Huff, and Ketelle (1987) used probability plots (i.e., the plotting of sorted data values on cumulative probability paper) to analyze data from the groundwater level monitoring program. This analysis found that the seasonal water level change for wells in WAG 1 had a geometric mean fluctuation of 1.3 ft, compared with a geometric mean fluctuation for wells outside of WAG 1 of 3.1 to 3.9 ft. The discrepancy was attributed to the influence of man-made controls in the subsurface of WAG 1, including backfilled pipeline trenches (reportedly having a higher permeability than undisturbed soil).

Buried pipelines, if they leak, would control water level fluctuations by acting as drains, in effect preventing the rise of a water table above the level of the pipe; water so collected by these pipelines would presumably move laterally for discharge into WOC or its tributaries. This scenario occurs in the northwest portion of the WAG, where storm drains are intercepting contaminated groundwater and discharging directly to First Creek (see Sect. 3.3.3.3). Finally, the large impervious areas in WAG 1 due to pavement, buildings, etc. also serve to minimize infiltration and reduce the potential for large groundwater fluctuations.

3.3.2.2 Groundwater recharge and discharge areas

In general, groundwater recharge areas correspond to higher ground, and discharge areas are along the WOC drainage system. The area directly to the north of WAG 1 near Building 2000 is a major recharge area, as indicated by the groundwater mound (see Figs. 3.3.2 and 3.3.3) and by the high fluctuations in water levels discussed previously. It is also likely that the topographic high north of SWSA 2 provides recharge to the WAG, as indicated by the direction of groundwater flow from that area. Groundwater recharge is also received from areas east of the WAG between WOC and SWSA 2. Based on limited head data from areas south of the WAG, Haw Ridge is contributing recharge to WOC and the southern portion of the WAG.

Groundwater contours suggest that groundwater exits WAG 1 through the WOC water gap that passes through Haw Ridge. Locally, flow directions vary widely due to influences from local recharge and discharge areas. For example, flow lines originating at the major recharge area north of the WAG radiate in directions ranging from east to west. In addition, some seepage of groundwater probably occurs locally into First Creek and Fifth Creek.

However, the flow lines eventually converge at the WOC water gap at the southwestern boundary of WAG 1.

Vertical gradient data. The distribution of discharge and recharge areas is further indicated by vertical gradients observed in well pairs at WAG 1. Table 3.3.3 and Fig. 3.3.13 contain the gradient data for ten well pairs located within the WAG. Except for one well pair, vertical gradients were calculated for the April and September 1991 monitoring events. The exception is well pair 5, for which sufficient groundwater elevation data were only available for the January 30, 1991, monitoring round. For each well pair, the vertical gradient was computed between the midpoint of the monitoring zone for the deep well and the midpoint of the monitoring zone for the shallow well. The midpoint was computed as the center of the interval between the bottom of the well screen and the top of the sand pack.

It is important to note that vertical gradients reflect the potential for vertical flow; upward or downward flow will not occur unless the aquifer material is sufficiently transmissive.

Geologic structure may also impact the distribution of vertical gradient; the heads at any one point in the bedrock are impacted by the head at the location where the fracture intersects the overburden material. At WAG 1, the most common fractures are parallel to bedding planes. The heads along a bedding plane fracture are governed in part by the heads that are present where the bedding plane intersects the overburden material (subcrop location) in the updip (or northerly at WAG 1) direction. Because the water table surface at WAG 1 generally slopes towards the south, the heads present in the overburden material at the subcrop location are generally higher than the heads present in the overburden material at the well itself. Thus, it would be expected that upward potentials would often exist between bedrock fracture systems and the overlying saturated overburden. Upward potential in this situation does not necessarily indicate that groundwater discharge is occurring.

The computed vertical gradients range from 0.42 ft/ft in the upward direction (suggesting discharge) to 1.21 ft/ft in the downward direction. Downward vertical gradients were observed at well pairs 4 (820/821), 7 (878/883), and 8 (1100/1101). Well pair 4 is near SWSA 2 in a groundwater recharge area. The downward gradient observed in well pair 8 (wells 1100 and 1101) may reflect influences from impoundment 3513. Leakage from the impoundment may cause higher heads in the shallow zone and may induce a localized downward gradient. Well pair 7 (south of impoundment 3540) showed the strongest gradient (1.21 ft/ft in the downward direction). This gradient reflects the extremely low heads [739.13 ft above mean sea level (MSL) for April 1991 and 742.80 ft mean sea level for September 1991] measured in well 883. As mentioned earlier, this head is considered anomalous and does not appear to represent groundwater conditions in the area.

Upward vertical gradients (suggesting discharge) were computed for well pairs 1 (540/811), 2 (610/825), 3 (815/816), 5 (825/826), 6 (875/885), and 10 (807/808). All of these well pairs are situated near streams, and the upward vertical gradients indicate that these locations are groundwater discharge areas.

The vertical gradients exhibited some seasonal fluctuations; the most pronounced was observed at well pair 3 (815/816), where the upward vertical gradient ranged from 0.02 ft/ft (April 1991) to 0.13 ft/ft (September 1991). This variation was induced by an increase in groundwater elevation in the deep well and a corresponding decrease in water level in the shallow well between April and September. At well pair 1 (piezometer 540 and well 811), the upward vertical gradient varied between 0.12 ft/ft (April 1991) and 0.08 ft/ft (September 1991). Most of this variation can be accounted for by a 0.73-ft decrease in groundwater elevations in well 811 between April and September.

Gradient reversals were observed only in one well pair adjacent to the equalization basin (873/886); an upward gradient present in April was replaced by a downward gradient in September. Other well pairs exhibited a constant gradient between April and September, suggesting that the seasonal fluctuations in the water table for adjacent wells screened at different depths are similar. This consistency in the vertical gradient direction also indicates that the rate and magnitude of potential discharge or recharge at a given location do not fluctuate significantly on a seasonal basis.

The vertical gradients identified areas of recharge on the basis of potential for downward flow from the overburden into bedrock. The vertical gradients did not delineate the extent to which recharge from precipitation or other sources (e.g., leakage from pipelines) also occurs. Moore (1989) reported that the land surface on the ORR is very permeable and nearly all precipitation (132 cm/year) infiltrates; however, very little of this water actually recharges the water table (3.2 cm/year) due to evapotranspiration losses, lateral discharge through the vadose zone, or other phenomena. These findings were based largely on data from forested and relatively undeveloped portions of the ORR and therefore have only limited relevance to WAG 1, given the presence there of buildings, roads, controlled surface drainage, and other man-made features.

Groundwater discharge process. Previous investigations of the hydrogeology at ORNL identified a number of discharge processes, including springs, wet-weather seeps, and discharge into WOC and its tributaries (Stockdale 1951). Within WAG 1, additional discharge occurs in association with pipeline trenches, building sumps, and other man-made features in the subsurface. Given the stratigraphic and structural controls on groundwater flow in the bedrock, a discharge area identified on the basis of an upward gradient between the bedrock and overburden may not be an actual discharge area unless the two zones are hydraulically connected. The extent to which these zones are hydraulically connected can be inferred from water level data but is most accurately determined using aquifer tests. Aquifer tests have not been completed at WAG 1.

Direct measurements of groundwater discharge on WAG 1 are not available. An analysis by Moore and Young (1992), using hydrographs, reported a maximum rate of groundwater discharge to streams of 4.7 L/s per kilometer of stream profile in areas underlain by aquitards (including the Chickamauga). Groundwater discharge into buried pipelines and pipeline trenches has not been measured but is potentially a significant contributor to streamflow. Boegly et al. (1987) report that it has been estimated that as much as 50% of the water traveling through process wastewater treatment lines (and ultimately

discharging into surface water) every month is attributable to surface water and groundwater input.

Sump 30421 in Building 3042 is known to be pumping groundwater (Huff 1985). Other sumps below the groundwater table include 30331 in Building 3033, sumps in Building 4501, and sumps in Building 3106. However, there is no direct evidence that these sumps are interacting with groundwater.

3.3.2.3 Lateral hydraulic gradients and flow velocities

The hydraulic gradients and computed flow velocities for the flowlines shown on the groundwater contour maps are listed in Table 3.3.4. Hydraulic gradients in the shallow flow system vary widely across the WAG, ranging from 0.011 to 0.15 ft/ft. The steepest gradients occur in the northern portion of the WAG as a result of the strong influence exerted by the groundwater mound in this area. Gradients in this vicinity averaged 0.078 ft/ft during September 1991. Gradients decrease in the southerly direction; gradients in the southern portion of the WAG averaged 0.038 ft/ft during September 1991.

Gradients in the northern portion of the WAG are generally steeper in the spring because of large increases in groundwater elevations in the recharge areas relative to the rest of the WAG. The average gradient in the northern portion of the WAG was 0.078 ft/ft in April versus 0.065 ft/ft in September. For the southern portion of the WAG, the average gradient in April (0.038 ft/ft) was virtually the same as the gradient in September (0.035 ft/ft).

These gradients are consistent with data presented in Moore, Huff, and Ketelle (1987) based on a low water table flow net for WAG 1 using October 1986 data. The flow net indicated horizontal hydraulic gradients in the range of 0.3 to 0.4 on the hillsides; for the valley floors, a median cross-valley (N-S) gradient of 0.016 and a median along-valley (E-W) gradient of 0.0070 were reported.

Flow velocities were computed using a modification of the Darcy equation:

$$v = \frac{\text{Hydraulic conductivity} \times \text{gradient}}{\text{Effective porosity}}$$

The Darcy equation assumes that flow is laminar and occurs through a porous medium (i.e., flow through conduits is not adequately described by the Darcy equation). Because of the fractured nature of the bedrock and the presence of solution features, these assumptions are undoubtedly violated to some degree in some areas of the WAG. In addition, the aquifer materials at WAG 1 are heterogeneous, and all the parameters used for the velocity calculations are variable across the site. Thus, the accuracy of the computations is limited by the ability to characterize this variability. However, the computations are useful for estimating approximate potential flow velocities and for evaluating the range of potential velocities at the site.

The hydraulic conductivity for nearby wells was used for each flow line. Hydraulic conductivity values specific to the media under consideration were used. For groundwater flow velocities in bedrock, bedrock wells were used if they were available; if not, interface wells were used. If no bedrock or interface wells were available, values from nearby flow line were used. For the northern portion of the WAG, no hydraulic conductivity values were available for bedrock at flow line 2A, 3A, 7A, 8A, 12, or 10B due to a lack of slug tests data for these areas (see Figs. 3.3.2 and 3.3.3). For these vectors, the average hydraulic conductivity values for vectors 1A and 10A were used to compute flow velocities. Similarly, for flow in overburden, wells screened in overburden or interface wells were used if they were available; otherwise, values from nearby flow lines were substituted.

The most difficult parameter to estimate at WAG 1 was effective porosity. As discussed in Sect. 3.3.2, this parameter has not been measured for WAG 1 soil and rock materials. Estimates for the soil range from 0.2 to 3%. For purposes of computing flow velocities, the value of 1.8%, as estimated by Solomon et al. (1989), was used for both the overburden and bedrock materials. Actual values vary across the site depending upon the type of fill material and the characteristics of fracture zones in bedrock.

The computed flow velocities are listed in Table 3.3.4. Because of the uncertainty in the effective porosity values at WAG 1, the computed flow velocities should be considered order-of-magnitude estimates. The velocities range from a low of 0.004 to 45 ft/day. The highest velocities are in the northern section of the WAG in the groundwater recharge zone. For example, velocities in this area averaged 24.0 ft/day in rock during high base conditions (April) versus 6 ft/day in rock during high base conditions (September) in the southern portion of the WAG. The spatial differences are partially the result of the higher gradients observed in the northern portion of WAG 1. The differences in velocities are also the result of higher hydraulic conductivities in the northern section associated with dissolution features in Unit D.

There are notable differences in groundwater flow velocities between the overburden and bedrock material in the northern portion of the WAG. As mentioned, flow velocities in bedrock for the northern flow lines averaged 24.0 ft/day in April. Velocities for overburden were 4.17 ft/day during the same time period. The differences reflect the higher hydraulic conductivity values for bedrock in that area. There is less variation in hydraulic conductivity values and flow velocities in the southern portion of the WAG. Average velocities in bedrock in the southern portion during April were 6 ft/day versus 2 ft/day for overburden.

Seasonal variations in flow velocities are the result of increased recharge in the northern portion of the WAG that causes mounding of groundwater in that area. Velocities are highest during high base conditions (for example, 24.0 ft/day during April versus 19.4 ft/day during September for flow in bedrock along northern flow lines). The differences are most pronounced in the northern section near the recharge area. Velocities in bedrock in the northern area decrease 19% from April to September versus a decrease of 4% in the southern portion of WAG 1.

3.3.2.4 Groundwater geochemistry

Geochemical analyses of groundwater samples collected at WAG 1 (Fig. 3.3.14) indicate that groundwater is stratified. The geochemistry was evaluated using data from all 14 corehole packer test intervals from which samples were collected and from 15 groundwater monitoring wells selected to provide consistent geographic coverage throughout the WAG 1 area. Twenty-nine samples taken from intervals ranging in depth from 9.5 to 325 ft BGS were included in the analysis. Filtered samples were used to minimize the effects of variations in well construction, and field pH values measured at the end of sampling were used for the interpretation. Table 3.3.5 summarizes the data used for the analysis.

Figure 3.3.15 is a plot of sample pH versus sampling depth; the data show considerable scatter, but there is a general increase of pH with depth. The pH of shallow samples (above 100 ft BGS) typically was between 6.5 and 7.6; below 100 ft BGS the pH was greater than 7.5 in all samples.

The specific conductance of the water samples also correlates with sampling depth (Fig. 3.3.16). Above a depth of 100 ft, specific conductance ranged from approximately 300 to 1000 μmhos/cm; at depths greater than 100 ft, the range was from 500 to 3770 μmhos/cm. The higher values with depth indicate that total dissolved solids (likely the result of increased chloride concentration) increase with depth in the groundwater.

Trilinear analysis. Figure 3.3.17 is a trilinear plot of the sample data. With one exception, the data plot into three groups: a calcium-bicarbonate to calcium-magnesium-bicarbonate type, a sodium-bicarbonate type, and a sodium-chloride type. The exception is the sample from piezometer 548, which plotted as a sodium-bicarbonate type. Piezometer 548 is an upgraded piezometer that is 15 ft deep and screened across the overburden/bedrock interface. Because this water chemistry has not been identified at any other locations included in the evaluation, it is likely that the sodium bicarbonate water chemistry at this location represents relic contamination from surface runoff or other sources.

Figure 3.3.17 shows that the groups are distributed according to the elevation of the sampling interval. Calcium-bicarbonate to calcium-magnesium-bicarbonate waters occur in the shallowest sampling intervals, ranging from approximately 725 to 850 ft in elevation (depth of 0 to 135 ft BGS). These samples had an average total dissolved solid (TDS) concentration of 406 mg/L. The intermediate interval, ranging from 625 to 725 ft in elevation (approximately 100 to 175 ft BGS), is characterized by sodium-bicarbonate type water, and samples from this interval have TDS that averaged 1160 mg/L and ranged from 480 to 1845 mg/L. Three samples are sodium-chloride type (average TDS of 1740 mg/L); two of these were collected at elevations below 550 ft (350 ft BGS).

The third sample with sodium-chloride type water was collected from an elevation of approximately 650 ft in corehole CH009. Although the packer interval was purged prior to sampling, the water chemistry at this location may be a relic of groundwater circulation in the open borehole. Figure 3.3.18 shows vertical flow data collected in CH009 using a conductivity-based borehole flowmeter (Moore and Young 1992). The data indicate that groundwater enters the borehole at a depth of 320 ft (elevation 465 ft) BGS. The water

flows up the corehole at a rate of up to 0.16 gpm. At 135 ft of depth (elevation of 650 ft), the rate decreases to 0.007 gpm, indicating that water is flowing out of the borehole at that depth. The depth of groundwater inflow (320 ft BGS; elevation of 435 ft) and outflow (135 ft BGS; 650 ft elevation) occur within packer intervals from which groundwater samples were collected. Both samples were characterized as sodium-chloride type. The fact that water flows from the deep interval to the shallow interval suggests that the chemistry of the water in the shallow interval may be affected by this borehole circulation and that the shallow interval was not sufficiently purged before sampling to remove the circulated water.

Additional evidence to support this interpretation was found in the chemistry of the shallow sample from CH009, which suggests that mixing occurs between the shallow and deep zones in CH009. The shallow sample contains 10% calcium and 10% magnesium (in terms of equivalents per million). The sample has the lowest specific conductance (1589 μmhos/cm) and the highest alkalinity (337 mg/L) of the three sodium-chloride type samples. The shallow sample contains 1.2 mg/L bromide, compared with 3.5 mg/L bromide found in the deep sample; these measurements suggest mixing between a calcium-magnesium-bicarbonate water (shallow) and a sodium-chloride water (deep). Given the observed vertical flow, it is likely that the mixing occurred as a result of borehole circulation; therefore, the analytical results from the shallow sample may not be a good indicator of the chemistry of groundwater in that zone.

It is possible that borehole circulation has also impacted groundwater chemistry at other boreholes. Moore and Young (1992) found measurable flow in coreholes CH002, CH003, CH009, and CH012. The highest flow rate (0.52 gpm in the upward direction) was measured in CH003, but all the coreholes had at least one interval with flow greater than 0.1 gpm. These results suggest that chemical results from packer test data must be interpreted carefully and that borehole circulation effects must be considered. Chemical data from coreholes other than CH009 do not exhibit any obvious impacts from borehole circulation and appear to provide a reasonable representation of aquifer conditions.

The presence of three water types is typical of the ORR and suggests stratification of the groundwater (for example, see BNI 1991). The chemistry of the calcium-bicarbonate water in the shallowest zone is common worldwide, especially in limestone and dolomite aquifers. All of the shallow samples have relatively low specific conductance (310 to 1100 μmhos/cm). With four exceptions, the pH of the calcium-bicarbonate water ranges from 6.5 to 7.5, which is typical for waters of this type. The exceptions are samples from 124 to 136.3 ft BGS in CH006 (pH 8.54), 84.4 to 96.7 ft BGS in CH006 (pH of 9.19), well 820 (pH of 7.57), and piezometer 597 (pH of 7.96).

Sodium begins to increase at relatively shallow depths even in the calcium-bicarbonate zone (e.g., CH001 from 51 to 63 ft BGS and CH006 from 124 to 136 ft BGS). The sodium-bicarbonate chemistry observed in the intermediate depths is typical of ion exchange wherein calcium, from groundwater recharge, replaces sodium on clays within the aquifer material. This change is also typical of sodium-chloride water mixing with calcium-bicarbonate water and causing the precipitation of calcium-bicarbonate to form calcite. The presence of numerous calcite veins and infillings in the corehole logs suggests that precipitation is an important process at WAG 1.

The sodium-chloride water found at depth is similar to oilfield brines found elsewhere in the eastern United States (Macfarlane and Hathaway 1987; Bloch and Key 1981; Gott and Hill 1953). Oil-stained vugs (small cavities in the rock) were noted in several rock cores collected at WAG 1. In addition, the two deepest samples (318 to 330 ft in CH009 and 318 to 331 ft in CH006) contain relatively high concentrations of bromide and fluoride, both of which are typical of deep oil field brines.

The distribution of tritium in groundwater provides further indication of stratification. Tritium is common in shallow groundwater and surface water as a result of long-term operations at ORNL. However, it is present only in very low concentrations in samples from deep packer test intervals (Fig. 3.3.19). If extensive mixing were occurring between the shallow and deep groundwater, the tritium concentrations in the deeper zone would be similar to concentrations in the shallow zone.

Based on the limited data available for the deeper two chemical zones, the interfaces between zones are more clearly defined by sample elevation than by sample depth. This is illustrated in Fig. 3.3.20, which is a plot of the occurrence of the water types with depth. The plot shows considerable overlap among the chemical zones, while the data in Fig. 3.3.21 show a good correlation with elevation. These relationships suggest that the boundaries between the zones are relatively flat across WAG 1, although some variation is likely as a result of local groundwater recharge.

In summary, the geochemistry of the groundwater at WAG 1 suggests that there is stratification with elevation. The upper zone is characterized by calcium-bicarbonate water and occurs above an elevation of 700 to 725 ft; in this zone, complete mixing of groundwater is possible. Below the upper zone is a transitional (sodium-bicarbonate) zone that extends from the bottom of the calcium-bicarbonate zone to a lower elevation of between 550 and 625 ft. Below the transitional zone is a deep zone consisting of sodium-chloride water; there is apparently little mixing between the upper calcium-bicarbonate water and the lower sodium-chloride water.

Exact elevations of the three geochemical boundaries cannot be discerned from the available data. For example, ignoring the previously discounted data for the upper zone in corehole CH009, the transition between the sodium bicarbonate water and the sodium-chloride water is between 550 and 625 ft in elevation. Similarly, the top of the sodium-bicarbonate zone is between 700 and 725 ft in elevation. Thus, the thickness of the sodium-bicarbonate zone is between 75 and 175 ft. As mentioned earlier, it is also likely that the boundaries vary somewhat across WAG 1 as a function of local groundwater recharge.

3.3.3 Groundwater Flow in Overburden

Groundwater beneath WAG 1 is present in both the overburden and bedrock horizons; the water table generally occurs within 3 to 5 ft of the overburden/bedrock interface, at a depth ranging from less than 2 to more than 40 ft BGS. The shallow depths to water are associated with lower elevations and increasing proximity to WOC. At higher elevations, including the low hill in the northwest portion of the site, the water table occurs below the

overburden/bedrock interface. Within the main plant area, additional areas where the water table occurs in the bedrock have been identified. The number and size of these areas vary seasonally and are believed to be caused by man-made controls (e.g., pipeline trenches, sumps). Examples of features that appear to reduce groundwater levels below the top of bedrock include the Building 3042 sump, the NTF sump, and, possibly, pipelines in the isotopes area. The impacts of artificial groundwater discharge in these areas are evidenced by depressions in the piezometric surface (see Sect. 3.3.3.2).

Previous investigations at ORNL have described a number of discrete hydrologic intervals within the overburden and upper bedrock, including a stormflow zone, a vadose zone, and a shallow aquifer (Moore 1989). Hydraulic characteristics described for each of these zones have been used to develop a conceptual hydrologic framework with the goal of understanding hydrogeologic processes governing contaminant migration. The extensive reworking of overburden materials and the presence of an extensive pipeline network and deep building foundations in the WAG 1 area have resulted in a complex hydrogeologic environment not readily evaluated using the conceptual framework developed for other portions of the ORNL facility.

The overburden exhibits a high degree of heterogeneity, and areally extensive stratification of soil or fill layers was not observed. Thus the hydraulic properties of the overburden materials vary widely between locations as well as vertically at any given location. These variations can explain the occurrence and discontinuous nature of the perched water tables that have been encountered in numerous areas across the site, but they greatly complicate generalizations regarding the nature or hydraulic properties of either saturated or unsaturated materials in the subsurface.

Because of the extensive development and construction activities in WAG 1, the water table in the overburden is generally encountered in fill material. Saturated soils and saprolite have also been observed, but in a much smaller number of borings and wells. As described in Sect. 3.2.3, the fill includes both fines (clay and silty clay) and coarse-grained (sands and gravel) material; the native soils are predominantly clays with varying amounts of gravel-sized chert, and the saprolite is typically weathered shale.

Groundwater in the overburden occurs primarily in the intergranular pore space within the soil and fill materials; for the purposes of analyses regarding groundwater flow and contaminant transport, the overburden is characterized as a porous medium. Within the saprolite, intergranular porosity is also present due to weathering processes and dissolution of minerals, but in most locations the bulk of the groundwater is associated with relict bedrock features such as bedding planes and fractures (Lietzke et al. 1986). However, groundwater flow and transport within the saprolite can be approximated using concepts developed for a porous medium.

3.3.3.1 Perched water table

Perched water tables have been encountered at WAG 1, generally at depths ranging from 2 to 10 ft BGS. These zones are believed to result from localized variations in permeability within the vadose zone (for example, backfilled material along buried pipeline alignments)

and are apparently transient in most areas. A stormflow zone as described by Moore (1989) was not observed in WAG 1, probably because of the lack of vegetation, predominance of fill material, and presence of man-made drainage controls and conduits in the subsurface.

Perched saturation was observed in a variety of settings—in pipeline trench backfill materials (e.g., soil boring SB132 adjacent to Building 3019), in backfill materials adjacent to buried tanks (e.g., soil borings SB020 and SB025), above obstructions or otherwise impenetrable layers (as demonstrated by refusal of hand auger), and in areas where there was no evidence of underground structures (e.g., soil boring SB146 near Building 3025). Soil boring and water level data from nearby monitoring wells indicate that perched water tables not associated with pipeline trenches are usually transient in nature. However, water level data from the temporary piezometers installed in trench backfill materials indicate that the perched water tables in these areas are often perennial.

3.3.3.2 Saturated thicknesses

Figures 3.3.22 and 3.3.23 are maps of saturated overburden thickness based on measurements made in April and September 1991. On the basis of April 1991 water level measurements, saturated overburden thicknesses are generally less than 5 ft north of Central Avenue and between 0 and 10 ft elsewhere. Exceptions to this occur in areas where the water table is within the bedrock as well as at scattered locations in the vicinity of WOC and the surface impoundments in the southern portion of the site, where saturated thicknesses may range up to 11.5 ft.

One of the most obvious features of the saturated thickness maps is the presence of relatively prominent areas in the central portion of WAG 1 where the water table falls below the overburden/bedrock interface. The occurrence of the water table in the bedrock was expected to the north due to the higher elevations associated with the hill in the northern portion of the WAG.

In April, three areas were present: one between NTF and STF, a second immediately northwest of the 3524 impoundment (soil boring data in these areas do not indicate a bedrock high), and a third at Isotopes Circle. In September, which coincided with the seasonal low for most of the water level data, there was an additional dry area near the sewage ponds. The tank farm and settling basin areas were more extensive in September and in both cases exhibited an east-west orientation roughly parallel to the strike of the underlying Chickamauga limestone units. The dry area at Isotopes Circle had become inundated by September.

3.3.3.3 Man-made zones and structures

The role of pipeline trenches in influencing the occurrence and movement of groundwater has been cited in a number of earlier investigations [e.g., Ashwood et al. (1986 and 1988), Huff (1985), Stansfield and Francis (1986a), Geraghty and Miller (1986)].

Figure 3.3.24 shows the pipelines that were below the water table in April 1991. The map is intended to illustrate areas where leaks in the pipeline system may have an immediate

impact on groundwater quality and where the pipelines and associated backfill material may be affecting groundwater flow. The figure was generated by overlaying a map showing the process waste, hot waste, and storm drain pipelines (see Figs. 3.2.15 through 3.2.17) onto a contour map showing water table elevations (see Fig. 3.3.2). Areas where the pipelines were below the water table, as indicated by pipeline invert elevations, were digitized.

Figure 3.3.24 shows several areas of inundated pipelines. A large portion of a storm drain network in the northwest portion of the WAG was inundated during April 1991. This network intercepts an area where groundwater is contaminated with strontium-90 (see Sect. 4.3). Samples collected from the outfalls of the storm drain showed elevated activities of gross beta, suggesting that contaminated groundwater is seeping into the network. Although the system has been lined, there are apparently unlined portions where seepage may be occurring. Ketelle and Lee (1992) have sampled the network at various locations and have identified areas north of Building 2013 where contaminated groundwater is apparently seeping into the drains.

Pipelines near the impoundments were also inundated in April 1991. A dye tracer test completed by Ashwood et al. (1986) in which dye was injected into the ponds demonstrated that water in the impoundments is hydraulically connected to the storm drains. These storm drain pipes are below the water table; because they are not pressurized, groundwater and associated contaminants may enter the pipes and be transported within the storm drain network. Pipelines were also below the April 1991 water table in the Isotopes Circle area. Several pipeline leaks have been identified in this area (Geraghty and Miller 1986); the proximity of pipelines to groundwater suggests that pipeline leaks are likely to impact groundwater quality in the vicinity and that the pipeline system may provide pathways for contaminant migration.

Other pipeline segments scattered throughout the WAG were also inundated during April 1991—areas near NTF and STF and Building 3042 and areas south of Isotopes Circle. It is likely that additional pipelines become temporarily inundated following significant rainfall events.

Berry and Yook (1987) completed an evaluation of wastewater pipe system integrity using smoke testing and televiewing. The pipelines studied, constructed of vitrified clay, were found to have poor connections at intersections, offset joints, and crushed segments of pipe. Damaged pipelines are subject to inflow of groundwater if they are below the water table or if the surrounding trench becomes saturated.

Evidence that the pipelines are capable of transmitting liquids was presented in Grimsby (1986), which was a study of low-level waste line leak sites. The report described a number of sites where contamination of soils or discharge of contamination into WOC had occurred through crossover between hot waste lines and sanitary sewer lines (i.e., leakage out of one and into another). Crossover was also observed between process waste lines and storm sewer lines.

Where pipeline trenches are above the water table, infiltration or other water that enters the trench [e.g., from pipeline leaks in the trench, from pipelines in nearby trenches, or from

flow in intersecting trenches (Ashwood et al. 1986)] may cause a portion of the trench to form a perched zone with lateral flow (i.e., along the trench) and/or seepage into surrounding material; if seepage is significant enough, a groundwater mound may result.

Ashwood et al. (1986) reported that subsurface pipe trenches were backfilled after placement of the pipe with material excavated from the trench and/or with crushed stone; in both cases, the resulting material is believed to have a higher permeability than the native materials surrounding the trench. Geraghty and Miller (1986) described man-made zones of high permeability in the vicinity of Building 3028, including foundation backfill, sub-base gravel under floor slabs, and pipeline trench fill, all of which would have a higher hydraulic conductivity than surrounding materials.

Some BNI borings completed within pipeline trenches encountered gravel or mixtures of gravel, sand, silt, and clay immediately above the buried pipe (e.g., SB126, SB219, and SB241). Several additional borings, including SB140 and SB246, were completed adjacent to buried pipelines such that the pipe was visible on the side of the hole. In these borings, the layer of coarse-grained fill (pipe bedding) extended up to 2 ft below the pipeline. Borings that did not encounter coarse materials typically found silty clay above the pipeline (e.g., SB078 and SB181).

BNI installed nine temporary piezometers along buried pipeline alignments to investigate the existence of perched water tables in the pipeline trenches and obtain an estimate of the quantity and quality of water flowing within these horizons (see Sect. 2.9.2.2). Saturated conditions were encountered during drilling in four of the piezometer borings. Of the other five, one piezometer (01.SB131) was not observed to contain any water during the period of measurement (December 1991–March 1992); two of the piezometers (01.SB195 and 01.SB197) became dry during the period of measurement; and two piezometers that were dry following installation were later found to contain water.

3.3.4 Groundwater Flow in Bedrock

Groundwater flow in the overburden material is generally controlled by the direction and magnitude of the hydraulic gradient (with the exception of influences from pipelines and other features discussed previously), and groundwater flow in bedrock is controlled both by gradient and by the orientation of secondary porosity features (e.g., bedding planes, fractures, etc.). The secondary porosity features are predominantly strike-parallel, resulting in a strong strike-parallel flow component at WAG 1. Bedding plane fractures provide flow pathways in the directions parallel to bedrock dip and strike. Fractures that are perpendicular to bedding and parallel to strike provide flow pathways in the direction of strike. Flow may diverge from these preferred directions where fractures intersect or where other fractures or solution features cross bedding planes. The result is a pattern of groundwater flow and contaminant transport that is controlled by the orientation of the secondary porosity features, rather than the direction of the maximum hydraulic gradient.

A generalized conceptual model of groundwater flow in bedrock is depicted in Fig. 3.3.25. Most of the groundwater in bedrock at WAG 1 originates in areas north and east of the WAG or as downward vertical leakage from overburden material within the

WAG boundary. Locally, the surface impoundments also contribute recharge to the bedrock aquifer. Once within the bedrock, groundwater flows primarily along solution features and fracture zones. The orientation of these features results in flow directions that are in the direction of geologic strike or along bedrock dip.

Groundwater in the Chickamauga bedrock occurs under confined or semiconfined conditions at depth and under confined, semiconfined, or unconfined conditions near the bedrock/overburden interface. In some areas, confined or semiconfined conditions occur immediately below the rock/overburden interface. Confined conditions occur as a result of bedrock confinement of fracture intervals or, locally, as a result of clayey overburden overlying fractured bedrock. Confined conditions are evidenced by the occasional presence of artesian conditions in some wells, piezometers, and coreholes (e.g., 534, 539, 822, CH003, and FT10). These locations are directly downgradient of major recharge zones north and northeast of WAG 1 that probably induce the artesian pressures. Earth tidal influences observed in bedrock well 811 also support the interpretation of confined conditions in bedrock, as these influences would only be observed in aquifers with the low storativities typical of confined aquifers. A review of soil boring logs for areas where nearby wells indicate that the piezometric surface is above the bedrock/overburden interface suggests that semiconfined or confined conditions also occur locally near the bedrock/overburden interface. At some locations, saturated soils were not encountered in soil borings even though the borings penetrated below the elevation of the piezometric surface identified in nearby wells. These conditions were not found at all borings and appear to be local in nature. Finally, packer test data and borehole flowmeter measurements indicate confined conditions in bedrock. The presence of irregular head profiles and discrete, active flow zones (Moore et al. 1992) supports the presence of confined flow intervals in bedrock.

3.3.4.1 Piezometric surface for bedrock system

Figure 3.3.26 is a contour map showing the piezometric surface heads measured from deep corehole test intervals (intervals greater than 100 ft BGS). Sufficient data are not available to develop maps for discrete deep flow regimes (e.g., the sodium-chloride regime) or for specific depth intervals; therefore, the map was developed using average head for packer test intervals greater than 100 ft deep. The resulting map provides a general indication of the piezometric surface for deep bedrock.

Because flow directions are affected by the orientation of secondary porosity features, the piezometric contours indicate only the potential directions of flow, and not necessarily the actual flow directions. The general potential gradient in bedrock is toward the south and southwest. These potential gradient directions, which generally agree with gradient directions shown earlier for shallow groundwater, suggest that the recharge areas are north of the WAG and that groundwater discharges along the WOC drainage system.

The groundwater flow system is further illustrated in the cross sections shown in Figs. 3.3.27 through 3.3.29. Lines of equal potential and flow lines have been drawn on the sections to show the direction of groundwater movement. In section C-C′, which shows a north-south section of the site, the potential gradient is in the upward direction at all areas except at the recharge area located north of WAG 1. Even in the recharge area (near CH006

on the cross section), a downward potential gradient exists only within approximately 50 ft of the piezometric surface. This suggests that local groundwater recharge impacts only the upper part of the aquifer at this location. The other cross sections (A-A′ and I-I′) also show upward vertical gradients in almost all locations. The gradients in all the cross sections suggest that the WOC drainage system is the major groundwater discharge location at WAG 1.

The distribution of piezometric heads within the bedrock illustrates the heterogeneity of the bedrock flow system. Figure 3.3.30 shows head potential graphs representing the vertical potential in bedrock at WAG 1. The data represent the heads measured during packer testing of the coreholes (see Appendix B for details of packer tests). Piezometric heads (i.e., measured head) are plotted along the X-axis, and elevation heads (i.e., elevation at which head was measured) are plotted along the Y-axis. If no potential vertical gradient existed in a corehole, the data would plot as a vertical line. A negative slope (slope upward toward the left) indicates an upward potential gradient, and a positive slope indicates a downward potential gradient.

The net potential gradient direction in all coreholes is upward, which is consistent with the observation that WAG 1 is predominantly a groundwater discharge area. Piezometric heads in bedrock are affected by heads in higher areas along Chestnut Ridge and in Bethel Valley north and east of WAG 1. However, within some coreholes, downward potential gradients exist over relatively short intervals (e.g., CH07A, CH008, and CH11A). Strata in which downward potential gradients are observed are generally associated with zones of higher hydraulic conductivity. For example, a downward potential gradient was observed in CH07A between the upper three test intervals and the lower three test intervals (see Fig. 3.3.30). The shift in the direction of potential gradient is associated with an increase in hydraulic conductivities from approximately 10^{-5} and 10^{-6} cm/s in the upper intervals to 10^{-2} and 10^{-3} cm/s in the lower intervals. Fluctuations in potential gradient directions may also reflect the extent and configuration of various fracture systems in the bedrock. In areas where several fractures occur, the heads in the fractures may differ as a function of the extent of each fracture and the characteristics of flow zones to which it connects. This sometimes results in heads that vary considerably in fractures that occur over a relatively small vertical interval (for example, see head values for CH008 in Fig. 3.3.30).

Solution features offer obvious groundwater and contaminant transport pathways. Solution features in Chickamauga rocks typically follow bedding planes and, thus, form elongated cavities. As discussed in Sect. 3.2.4.1, solution features have been observed at 13 locations at WAG 1; most of the features (9 of 13) occur within Unit D. As would be expected, hydraulic conductivities in these zones are considerably higher than conductivities in zones that do not contain solution features. Solution features were not found at depths greater than 133 ft in any corehole, indicating that conduit flow is limited to relatively shallow bedrock.

3.3.4.2 Distribution of groundwater flow zones in bedrock

The occurrence of groundwater flow zones at WAG 1 has been investigated in this and other investigations using packer test data, geophysical means, flowmeter measurements, dye

tracer tests, and direct observations of fractures in rock cores. Previous investigations have identified fractures and solution features in bedrock and recognized their importance as transmitting groundwater flow pathways [e.g., Stockdale (1951), Baughn (1987), Bittner and Dreier (1990), and Lozier and Pearson (1987)].

As discussed in Sect. 3.2.4.2, results from packer tests completed as part of the current investigation and from slug tests completed on wells and piezometers confirm that there is considerable variability in the hydraulic conductivity values. A slight overall decrease in hydraulic conductivity values with depth suggests that there are fewer water-transmitting fractures in the deeper bedrock. The decrease is not uniform across the site or even within a single corehole, implying that either high or low hydraulic conductivities may be found at any depth tested, depending on the fracture characteristics of the bedrock at that location. Zones that are relatively transmissive do exist in deeper bedrock, although they are fewer in number than in the shallow bedrock. Conversely, test intervals in shallow bedrock sometimes yielded low conductivities, indicating relatively unweathered rock and poorly developed fracture systems.

The distribution of groundwater-transmitting fractures was investigated at CH006, CH07A, CH009, CH11A, FT10, and CH012 using corehole geophysics, and at CH009 and CH012 using downhole flowmeter measurements. Figure 3.3.31 presents the results of the analysis. In most of the coreholes, the highest density of water-transmitting fractures occurs within the upper 200 ft of corehole; fractures in this interval often occur less than 10 ft apart. In most coreholes that extend deeper than 200 ft, water-bearing/transmitting fractures become more widely spaced (typically greater than 25 ft) with depth (e.g., CH006, FT10, CH11A, and CH009). In all of these coreholes, the spacing of water-transmitting zones decreases sharply below a depth of 200 ft. These results indicate that groundwater flow occurs mostly within discrete zones within the upper 200 ft of bedrock. An exception is CH012, where the spacing of water-transmitting fractures is approximately the same (between 10 and 25 ft) throughout the interval.

3.3.4.3 Strata-bound flow

The prevalence of strike-parallel and dip-parallel fracture sets results in preferential flow in these directions. The result is that groundwater flow and contaminant transport in bedrock are largely confined to geologic strata that offer the least resistant pathway (i.e., flow may become "strata-bound"). In strata dominated by strike-parallel, dip-normal fractures, flow may occur predominantly in the strike direction along the fractures (Fig. 3.3.32 illustrates this concept).

Strata-bound flow has been identified elsewhere on the ORR. At WAG 3, strontium-90 was found to be migrating in bedrock in the direction of geologic strike (Stueber et al. 1981). Lee and Ketelle (1987) identified strata-bound flow in the Knox Group bedrock along Chestnut Ridge. Other places where strata-bound flow has been found to influence groundwater and contaminant flow directions include the S-3 ponds at Y-12 (Geraghty and Miller 1990) and WAG 7 in Melton Valley (Olsen et al. 1983).

It is unlikely that flow is strictly confined to a stratum over long distances. As discussed in Sect. 3.2.5, bedrock is characterized by at least three distinct types of fractures, and the intersections of these fractures and solution cavities provide pathways for groundwater flow across strata. The result is "leakage" in directions away from the primary flow pathways. Thus, groundwater and contaminants may follow irregular, stair-step flow pathways that eventually cross several geologic strata.

An example of strata-bound flow at WAG 1 is offered by data from CH008. Contaminants in the corehole are associated with a high density of dip-normal and dip-parallel fractures. Gross beta activities in samples of groundwater from the fractured interval have been as high as 585,000 pCi/L (see Sect. 4.3). Other wells and piezometers in the area have also been sampled; other than piezometer 584, which has contamination associated with a pipeline leak along Central Avenue, the only locations found to contain high gross beta activities are well 812 and piezometers 539 and 550, all of which are screened stratigraphically below the contaminated interval in CH008 and below a siltstone bed that is apparently a confining layer. All other locations sampled in the vicinity are screened stratigraphically above the contaminated interval and did not yield samples with significant levels of contamination (Fig. 3.3.33). Sampling of surface water from First Creek also revealed a contaminated seep along strike from CH008.

These results indicate that the contamination at CH008 is migrating along strike and is apparently confined to the stratigraphic interval that corresponds to the zone being monitoring in the corehole. The heads in CH008 are higher than the elevation of First Creek; thus a mechanism exists to cause groundwater to flow in that direction. The strike-parallel and dip-parallel fracture sets observed in the interval apparently provide the flow pathway. It is also possible that contamination is migrating downdip along dip-parallel fractures. No monitoring locations exist in the interval in the downdip direction to confirm this.

Strata-bound flow may also occur in some geologic units as a result of solution features. For example, solution features have been identified in Unit D in CH07A, wells 813 and 818, piezometer 634, and (possibly) piezometer 588. As discussed earlier, a solution feature was also identified when a pipeline leak north of Building 3019 was being repaired. Dye tracer tests confirmed a hydraulic connection between the cavity and the Building 3042 sump located along strike from the location where the cavity was discovered at the original leak site. As a result of solution features, hydraulic conductivities measured for Unit D are among the highest values observed at WAG 1 (see Sect. 3.2.4.2). The prevalence of solution features indicates that strata-bound flow is likely within Unit D.

Strata-bound groundwater flow along bedding plane fractures can occur in any direction parallel to geologic strike, along dip, or at oblique angles to strike and dip. The predominant flow directions in strata-bound bedding plane fracture intervals at WAG 1 cannot be defined in detail from the available data. However, the available data suggest that the depths are relatively shallow, probably less than 100 ft, and that flow along strike is relatively common. As described in Sect. 3.3.4.1, downward head potentials are observed only within the upper 50 ft of saturated aquifer, suggesting that downdip flow does not occur at greater depths. In addition, contaminant data collected from discrete vertical intervals in corehole CH008 indicate that concentrations of contaminants begin to decrease at the deepest (46.2 ft BGS)

sampling depth, suggesting that the bottom of the corehole may be near the lower limit of contamination. Ketelle and Lee (1992) point out that a downward head potential exists between all corehole CH008 sampling intervals and First Creek and thus demonstrated the potential for groundwater flow in the direction of strike. In some areas, the lower limit of downdip migration may be limited by the availability of water transmitting fractures. As discussed in Sect. 3.2.5, the number of fractures generally decreases with depth. Finally, the geochemical stratification described in Sect. 3.3.2.4 suggests that the lower limit of active groundwater circulation is between 550 and 625 ft in elevation. All these factors suggest that flow in the downdip direction occurs only at relatively shallow depths.

The presence of strata-bound flow implies that contaminants may migrate along strata and bypass local groundwater discharge points (e.g., the gross beta plume extending from CH008 to First Creek). Although a contaminant seep was identified in First Creek, it is possible that some contamination may be bypassing the creek and migrating farther westward; evidence of westward contaminant migration is found at piezometer 535, located west of First Creek. The piezometer is screened stratigraphically above the elevation of well 812 and piezometer 539 (see Fig. 3.3.33). The gross beta concentration in unfiltered groundwater samples from the piezometer was 320 pCi/L, indicating moderate levels of contamination. Radiological contamination was also noted in the accumulated sediments during piezometer development. As there are no known sources of contamination upgradient of piezometer 535, these observations indicate that contamination may have migrated past First Creek under strata-bound conditions.

3.3.5 Summary

Groundwater at WAG 1 occurs in bedrock and in overburden. In the northern portion, the water table occurs within bedrock below the overburden; in the central and southern portion, the water table occurs within overburden.

The water table surface at WAG 1 mimics topography. The highest areas occur to the the north, and the surface slopes southward towards WOC.

The bedrock aquifer can be divided into two regimes which are identified largely on the basis of water chemistry. The upper portion occurs above an elevation of 725 ft MSL, and is characterized by calcium-bicarbonate groundwater chemistry. The lower regime lies below an elevation of 650 ft and contains sodium-chloride water. The interval between 650 and 725 ft MSL is characterized by sodium-bicarbonate water and represents a mixing zone between the upper and lower regimes. Most of the active flow occurs within the upper regime.

Most of the groundwater flow occurs at relatively shallow depths. Head data from coreholes in the recharge areas north of WAG 1 indicate that downward flow is limited to approximately the upper 50 ft of bedrock. Observed vertical gradients in most coreholes and at most well pairs are upward, suggesting groundwater discharge. Thus, groundwater flow lines originating within WAG 1 are relatively short, with groundwater discharge areas occurring in close proximity (usually within 2000 ft) to groundwater recharge areas.

That groundwater flow occurs predominantly within the shallow system is further supported by the distribution of hydraulic conductivities measured for the bedrock aquifer in WAG 1. Hydraulic conductivities of the bedrock are highly variable but appear to be correlated with depth. Bedrock intervals with high hydraulic conductivities are more likely to be encountered at shallow depths, but low hydraulic conductivities may be encountered at any depth. More than 50% of test intervals within the upper 100 ft of bedrock had hydraulic conductivities greater than 10^{-5} cm/s, while more than 75% of the intervals below 100 ft had hydraulic conductivities less than 10^{-5} cm/s. The occurrence of highly transmissive zones is related to the characteristics and extent of fractures; there is no apparent correlation between fracture density and hydraulic conductivity. High conductivities occur in zones where fractures are interconnected or where solution features exist.

Groundwater flow in bedrock occurs in fractures and solution features. The two dominant fracture types are strike-parallel, dip-normal fractures and bedding plane fractures. As a result, groundwater flow is anisotropic, with preferred flow directions along bedding planes and along bedrock strike.

Where present, solution features provide obvious pathways for groundwater flow. Most of the observed solution features occur in Unit D in the northern portion of the WAG, probably as a result of local groundwater recharge in that area.

The overburden material can be considered as an isotropic, heterogeneous medium. Groundwater flow directions in overburden are largely controlled by the direction of the hydraulic gradient.

The good correlation in water level fluctuations between shallow and deep wells indicate that there is a hydraulic connection within the upper 50 ft of saturated aquifer. This correlation also suggests that there is some communication between the saturated overburden and the upper part of the bedrock aquifer.

The principal groundwater discharge locations are WOC, First Creek, and Fifth Creek. The direction and magnitude of vertical potential gradients in groundwater near the creeks is upward, indicating groundwater discharge. It is likely that some groundwater also passes under First Creek and discharges further west into Northwest Tributary.

Groundwater in overburden occurs under unconfined conditions. Groundwater in the bedrock occurs under semiconfined to confined conditions, and the degree of confinement increases with depth.

Average lateral gradients range from 0.15 ft/ft in the northern portion of the WAG to 0.011 ft/ft in the southern portion. Estimated potential flow velocities range from 0.004 to 45 ft/day. Flowrates in bedrock may vary considerably over short distances because of the presence of solution features or highly fractured intervals.

The principal influence on groundwater levels at WAG 1 is precipitation recharge. Monitoring data suggest that groundwater elevations change in response to precipitation events, and that seasonal variations reflect precipitation density. The responses are most

pronounced (up to 14 ft) in the recharge zone north of WAG 1. Within the WAG boundary, pavement, buildings, and drainage controls reduce the amount of recharge to groundwater and result in smaller fluctuations in water levels.

Local influences on groundwater levels and flow directions include the Building 3042 sump, pipeline trenches, and impoundments. NTF and STF do not exert an obvious influence on the piezometric surface.

WAG 1 is predominantly a groundwater discharge area. Local recharge occurs only in the northern most portion of the WAG and locally at the impoundments and leaking pipelines and tanks. Precipitation recharge within the WAG is limited by the presence of pavement and drainage controls.

The pipeline network below WAG 1 exerts local influences on the groundwater system and on the distribution of contamination in groundwater. Storm drains in at least one area (northwestern portion of WAG 1) are intercepting contaminated groundwater. It is likely that inleakage into leaking pipelines are impacting the site hydrogeology in other portions of the WAG as well. In addition, several authors suggest that the backfill material surrounding pipelines has a strong influence on site hydrogeology. However, limited data collected as part of this investigation do not suggest that the pipeline backfill material is significantly more permeable than the surrounding overburden.

Strata-bound flow has been identified at WAG 1. Groundwater flow along geologic strata results in groundwater and contaminant flow directions at oblique angles to the direction of greatest hydraulic gradient. Strata-bound flow may allow contaminants to locally bypass groundwater discharge points along the WOC drainage system if the confining strata sufficiently limit the amount of vertical groundwater leakage.

3.4 SURFACE WATER HYDROLOGY

This section describes the surface water hydrology of WAG 1, including characteristics of the drainage areas and streamflows, plant effluent discharges, storm hydrographs, sediments, and the natural quality of surface waters.

3.4.1 Drainage Area Characteristics

WAG 1 lies within the Bethel Valley portion of the WOC drainage basin (Fig. 3.4.1). WOC borders the southern boundary of WAG 1 and flows to the southwest through a water gap in Haw Ridge and into Melton Valley. From this point WOC flows through Melton Valley, joins Melton Branch, and ultimately discharges into White Oak Lake.

All site drainage from WAG 1 and its vicinity is into the WOC and its tributaries (Fifth Creek, First Creek, and Northwest Tributary). The drainage area of WOC at the 7500 bridge, just southwest of WAG 1, is 3.2 mile^2. Fifth Creek joins WOC near the southeast corner of WAG 1. Just below the confluence with Fifth Creek, at U.S. Geological Survey (USGS) gauging station GS5, the drainage area of the WOC is 2.1 mile^2. From this point

on, the WOC channel runs west and southwest for about 1/2 mile within a marshy floodplain before reaching the 7500 bridge. First Creek, after joining Northwest Tributary, enters WOC about 650 ft upstream of the 7500 bridge. The drainage area of First Creek at USGS station GS1 is 0.33 mile^2, and the drainage area of Northwest Tributary at station GS4 is 0.67 mile^2.

The topography of WAG 1 and its vicinity is gently to moderately sloping, and except for the main plant area and roads, the basin is well wooded. Approximately 75 acres of the main plant area is covered with impervious surfaces including roads, parking lots, and buildings.

The lengths of Fifth Creek, First Creek, and Northwest Tributary are approximately 1.0, 0.6, and 1.25 miles, respectively. The channel gradients are steep (i.e., 4 to 5%) at their headwaters but are less than 2% at the valley floor. The channels of the tributaries are narrow and shallow; the WOC channel at the 7500 bridge is about 15 ft wide, and the average depth of water in the channel is about 18 in. In the main plant area, the channels of First and Fifth creeks pass through many culverts under roads and sidewalks. Approximately 500 ft of the Fifth Creek channel just before its confluence with WOC is an underground concrete pipe-arch 72 in. wide and 44 in. high.

3.4.2 Streamflow Characteristics

3.4.2.1 Flow gauging stations

The flows of WOC and its tributaries within the vicinity of WAG 1 are being monitored at the six flow gauging sites shown in Fig. 3.4.1 and described in Table 3.4.1. For brevity, the common names of the stations are used instead of the official USGS names. The station numbers include both the USGS number and the common designation at ORNL. The WOC headwaters (WOCHW) station is operated by the ORNL Environmental Sciences Division; the other five stations are operated by USGS.

WOCHW, north of the Bethel Valley Road in upstream WOC, serves as the environmental monitoring and surveillance background station for WOC. Upper WOC station GS6 is downstream of WOCHW, east of the east gate of the main plant area. WOC Parshall flume station GS5 is downstream of the Fifth Creek confluence and upstream of the Sewage Treatment Plant outfall, approximately 3700 ft downstream of GS6. Station GS3 (7500 bridge) is the farthest downstream on WOC; stage data are transmitted from GS3 via satellite telemetry to the USGS data base in Nashville, Tennessee. The First Creek station is on First Creek, upstream of its confluence with Northwest Tributary. Northwest Tributary station GS4 is on Northwest Tributary upstream of its confluence with First Creek.

Rating curves (stage/discharge relationships) are available for each gauging station. The accuracy of high flow measurements at these stations has been questioned because there has been no field rating of these stage/discharge relationships (Borders et al.1991). Further, routine inspection of the gauging sites indicates that ratings of the gauging stations are subject to degradation as a result of sediment and debris buildup in the approach and tailwater sections of the channels at the hydraulic controls and because of vegetation growth in the

channels. Corrective measures are being planned to improve the quality of data being collected. The station ratings for high flows will be field verified by USGS beginning in 1992 (Borders et al.1991).

The Northwest Tributary station will be instrumented for high flow measurements because the present triangular weir at the site is submerged during high flows. Also, replacement of the existing weirs with weirs of new design or flumes is being considered; flumes would avoid the problem of sediment accumulation in the approach channels.

3.4.2.2 General nature of flows

The flows of WOC and its tributaries within WAG 1 include surface runoff from pervious areas, runoff from impervious areas (mainly from the main plant area), interflow (stormflow), baseflow (groundwater discharge), and imported water brought to the plant from the DOE water supply treatment plant. WOC and its tributaries are also fed by springs along the southwest slopes of Chestnut Ridge and in the valleys. These springs are believed to have large recharge areas extending beyond the surface water drainage divide on Chestnut Ridge.

The amount of impervious area runoff at the main plant area has not been determined; however, the impervious surface area amounts to approximately 3.8% of the drainage area of WOC at the 7500 bridge. Therefore, impervious area runoff significantly increases flows in the tributaries and WOC during wet weather.

Baseflow contributes at a steady rate to the flow of WOC and its tributaries. As discussed in Sect. 3.3, vertical hydraulic gradients observed in wells near the streams show upward gradients, indicating occurrence of groundwater discharge. Some of the storm drain network at the main plant is under the water table for a portion of the year. The network of submerged drains then discharges groundwater to the creeks, thus sustaining streamflow during dry weather at a level higher than it would be under natural conditions. An example of this is the network that discharges to outfalls 341 and 342 at First Creek, which transports groundwater from the northwest portion of WAG 1 to First Creek (Sect. 3.3).

Water (potable and process) is brought to WAG 1 from the DOE water treatment plant at an approximate rate of 4.0 million gal/day (6.19 cfs). It is estimated that about 38% of this imported water is lost as evaporation and the remaining 62% (3.84 cfs) is discharged to WOC and its tributaries at various outlets (Borders et al. 1991).

3.4.2.3 Flow analysis

The mean daily flows of the five USGS stations were obtained for the period of record shown in Table 3.4.1 and directly input to the direct-access data base of the ANNIE computer program for analysis. ANNIE is an interactive computer program designed by USGS to manage spatial, parametric, and time-series data for hydrologic models such as HSPF (Lumb et al. 1990). Analyses performed using ANNIE include flow-duration, N-day low and high flow, and mean monthly and annual flow.

Mean daily flow hydrographs. Daily flow hydrographs for calendar year 1991 at five stations are presented in Figs. 3.4.2 through 3.4.6 to illustrate the flow characteristics of WOC and its tributary streams. As seen in these figures, streams had water year-round owing to steady groundwater contribution and plant effluent discharges. However, WOC was dry at the upstream WOC station GS6 for most days in July through November (Fig. 3.4.6). At other times, baseflow was a relatively small portion of the flow.

Dry weather flow measurements performed by ORNL during April 1992 at upstream stations upper WOC and WOCHW, showed that the flow of the downstream station was only 20% of that at the upstream station, indicating loss of flow due to infiltration from the streambed despite the increase in the drainage area (Borders 1992). This confirms the previous observations that the reach of WOC within the vicinity of this gauging station, up to about 900 ft upstream of Bethel Valley Road, is a losing reach. The baseflow increases in the downstream reaches, consistent with the observation that WOC is a discharge location for groundwater in WAG 1 (see Sect. 3.3).

Flow duration relationships. Using daily flow data (October 1, 1987, through March 9, 1992), at the five gauging stations, the flow duration curves of the daily flows were constructed and plotted in Fig. 3.4.7. As shown in the figure, 99% of the time the mean daily flow exceeded 0.11 cfs at GS1, 4.4 cfs at GS3, 0.26 cfs at GS4, 2.1 cfs at GS5, and 0.02 cfs at GS6. The relative importance of effluent and groundwater discharges in augmenting the flow of the streams can be seen from the flow duration curves. The flow duration curves of stations GS3 (7500 bridge) and GS5 (WOC flume) are flatter, indicating that the effluent discharges and groundwater contributions sustain the dry weather flow at higher levels all year around. On the other hand, the flow duration curve of station GS6 (upper WOC) is relatively steep, indicating that the mean daily flows are highly variable; at GS6, the groundwater contribution to the stream is small, and there are no effluent discharges in upper WOC.

N-day low mean and high mean flows. Annual low and high flows for various durations (1-, 2-, 3-, 7-, 10-, 30-, 60-, 90-, 183-, 365-day) are computed from the daily flows for the 1988–1991 period at each of the five stations; the low mean flows are shown in Table 3.4.2, and the high mean flows in Table 3.4.3.

Mean monthly and annual flows. The mean monthly and mean annual flow of these stations, and the mean monthly and mean annual rainfall at the Oak Ridge rainfall station for 1988–1991 are shown in Table 3.4.4. Mean monthly flows, expressed as inches over the respective drainage areas, are plotted together with the monthly rainfall in Fig. 3.4.8 for comparison. Flow at GS1, GS3, and GS5 exceeds the corresponding rainfall during some months, indicating that effluent discharges constitute a major portion of the flow.

The long-term mean annual runoff of the streams in the ORNL area was estimated to be about 42% of the average annual rainfall (22 in. runoff, 52 in. rainfall, and 30 in. evaporation in an average year) (Moore 1989). Assuming that the mean annual rainfall for 1988–1991 at the Oak Ridge gauge (58.6 in.) is representative of the WAG 1 area, the corresponding mean annual runoff at WAG 1 is estimated to be 25 in.

The mean annual runoff computed for the upper WOC and Northwest Tributary basins for 1988–1991 are 17.0 and 26.3 in., respectively. Obviously, annual runoff at upper WOC is quite low compared with the ORNL average value of 25 in., which is indicative of loss of water in the vicinity of the gauge. On the other hand, annual runoff for Northwest Tributary is quite reasonable as compared with the ORNL value.

The mean annual runoff computed for WOC at the 7500 bridge (GS3) for 1988–1991 was 47.3 in. Effluent discharges make up a large portion of this runoff, and runoff from impervious areas is significant. Breakdown of the mean annual runoff into components such as pervious area runoff, impervious area runoff, and effluent discharge is a complex task. However, an approximation can be made based on a set of assumptions. Assuming that effluent discharge (imported water contribution to WOC) is 3.9 cfs/year (Borders et al. 1991), which is equal to 16 in. of runoff per year over the WOC basin at the 7500 bridge, the balance of the annual runoff at the 7500 bridge (31.3 in.), accounts for the sum of pervious and impervious area runoff. Annual runoff from the impervious areas (about 7.8% of the drainage area producing runoff at the rainfall rate of 58.6 in.) is estimated to be 2.2 in. Thus, the remaining 29.1 in. can be considered an estimate of the pervious area (natural) runoff (mean value for 1988–1991). However, this estimate is 4.3 in. more than the estimate of 24.8 in., which is based on long-term regional mean annual runoff. Various factors contribute to this apparent discrepancy:

- The total effluent discharges are larger than the assumed value.
- Annual average rainfall at WAG 1 is higher than the estimated regional average, and average annual evaporation is higher than the estimated regional average.
- Groundwater discharges are higher than assumed.
- Springs at the headwaters of WOC have large recharge areas extending beyond the surface drainage divide, thereby making the effective size of the drainage area larger than the size of the WOC basin at 7500 bridge.

3.4.3 Storm Hydrographs

Streamflow is continuously recorded at 15-min intervals at the gauging stations (except at the First Creek station, where it is recorded at 5-min intervals). Figures 3.4.9 through 3.4.12 are storm hydrographs for the November 28–30, 1990, storm at First Creek, Northwest Tributary, the WOC Parshall flume, and the 7500 bridge. Hydrographs for the other storms sampled in October 1990 and March 1991 are presented in Appendix B.

The storm hydrographs show sharp peaks and quick response to rainfall, signifying that surface runoff and impervious area runoff dominate the peaks. Separation of the hydrographs into components such as surface runoff and baseflow could not be done because the effluent discharge rates during the storm periods were unknown.

3.4.4 Point-Source NPDES Discharges

ORNL discharges plant effluents into WOC, First Creek, and Fifth Creek in accordance with the ORNL NPDES permit (TN0002941). ORNL is currently operating with a permit that expired on March 31, 1991; because the application for a new permit was filed more

than 180 days prior to the expiration of the existing permit, ORNL is allowed to operate under the terms of the old permit (Borders et al. 1991). Various outfalls (at least 176 in the original permit) have been consolidated over the years. At present, the outfalls within the WAG 1 vicinity consist of

- Sewage Treatment Plant (X01),
- Coal Yard Runoff Facility (X02),
- Nonradiological Wastewater Treatment Facility (NRWTF) (X12),
- Category I outfalls,
- Category II outfalls,
- Space cooling system, and
- Miscellaneous outfalls
  - steam plant (SP2519)
  - vehicle cleaning (VC7002)
  - equipment maintenance facility (EF7002).

Outfalls X01, X02, and X12, shown in Fig. 3.4.1, discharge treated effluent at average rates of 0.34, 0.048, and 0.62 cfs, respectively. The total discharge from these three plants is 1.008 cfs (Borders 1991). NRWTF went into service in March 1990. The facility replaced the following eight outfalls: 1500 area (X03), 2000 area (X04), 190 ponds (X06), Process Waste Treatment Plant (X07), TRU ponds (X08), HFIR ponds (X09), ORR Resin Regeneration Facility (X10), and the Acid Neutralization Facility (X11).

The Category I and II outfalls are summarized in Table 3.4.5. Forty storm drains identified as Category I outfalls in the NPDES permit discharge noncontaminated stormwater runoff into WOC, First Creek, and Fifth Creek. Seventy outfalls discharging potentially contaminated stormwater from roof drains, parking lots, storage areas, and spill areas are classified as Category II. Various sources contribute once-through cooling water, cooling water blowdown, and condensate to the Category II outfalls. Thirty-two outlets designated as Category III in the past are now reclassified in the new permit as either Category I or II; 8 of them have been plugged and abandoned. At the end of the discharge pipe of the Category I and II outfalls, waters are tested quarterly for pH, oil and grease, total suspended solids, and gross beta.

The space cooling system includes the cooling towers and the once-through, noncontact cooling systems. Discharge from this system to WOC is about 1.65 MGD (2.55 cfs), which consists of 0.24 MGD (0.39 cfs) cooling tower blowdown and 1.4 MGD (2.17 cfs) once-through, noncontact cooling water (Borders et al. 1991).

The miscellaneous outlets are specific to special categories identified by EPA and include vehicle and equipment cleaning facilities, vehicle and equipment maintenance facilities, and the steam plant.

The NPDES permit specifies chemicals to be monitored, sampling frequency, and discharge limitations specific to each outlet. Energy Systems publishes quarterly and annual reports on the results of environmental surveillance and effluent monitoring on the ORR, including ORNL.

Table 3.4.6 summarized effluent parameters and associated discharge limitations as specified in the NPDES permit. The frequency of analysis for pH is also indicated in the table for each discharge point. The frequency of sampling and analysis of various chemicals varies from daily to monthly; Category I outfalls are sampled annually, and Category II outfalls are sampled quarterly.

In addition to sampling of chemical and field water quality parameters at the effluent discharge points as indicated in Table 3.4.6, the NPDES program has five other components:

- Monitoring of ambient water locations to assess the impact of the facilities on the receiving waters at or near the facility boundaries. These ambient water samples are analyzed for parameters identified in the NPDES effluent monitoring plan.

- The radiological monitoring plan includes sampling of effluent discharge points as well as the ambient water sampling locations.

- Toxicity control and monitoring programs (TCMPs) expose freshwater animals to water samples collected from the monitoring locations to assess the toxic impact of effluent and ambient waters.

- Biological monitoring and abatement programs (BMAPs) demonstrate that the effluent limitation established by the NPDES permit are effective in protecting the classified uses of the receiving waters.

- The PCB monitoring plan addresses the presence of PCBs in effluent discharge and ambient waters. Sediment data are also collected as part of this program.

The radiological sampling locations near WAG 1 and the associated sampling frequency, sampling type, sample type, parameters, and analysis frequency are summarized in Table 3.4.7.

3.4.5 Flood Hydrology

ORNL has determined the characteristics of the 100-year flood, the 500-year flood, and the probable maximum flood (PMF) for the WOC watershed. The PMF is the flood associated with the probable maximum precipitation, which is the theoretically greatest amount of precipitation for a given duration that is physically possible over a given size storm area at a particular geographic location at a certain time of the year (NOAA 1982). The inundated areas within WAG 1 under the 100-year flood, the 500-year flood, and PMF are shown in Fig. 3.4.13 .

3.4.6 Sediment

Sediment production in the watersheds of WAG 1 and sediment transport in WOC and its tributaries are not quantified. Neither bed load nor suspended load data are available for the streams. A comprehensive stream survey was performed from October 1978 through February 1979 in the streambed gravels of the WOC watershed to map the areal distribution

of cobalt-60, cesium-137, and strontium-90 (Cerling and Spalding 1981). Gravels of Northwest Tributary and upper WOC were found to be predominantly composed of chert and limestone fragments.

As part of the WAG 2 investigations, ORNL has initiated an extensive storm sampling program in WOC and its tributaries. At the writing of this report, partial sampling results have been available for four storms that occurred in December 1991 and in February–April 1992. Samples were analyzed for suspended sediment (SS), total gamma, and cesium-137. SS was also analyzed for particle size distribution. At the WOC weir, about 4000 ft downstream of the 7500 bridge station, particle size analysis of SS shows 10% fine sand, 59% coarse silt, 27% fine silt, and 4% clay (Fontaine 1992). Further downstream in WOC, the percentage of fines in suspended sediment increases.

Sediments within the creeks near WAG 1 are easily scoured, suspended, and transported during storm events. During storms, streams are turbid due to suspended sediment load; however, water is typically clear to slightly turbid during dry weather. At the 7500 bridge station, the SS concentration was 42 mg/L during February 25, 1992, when the streamflow was above normal baseflow level, following a low-intensity rainfall of about 12-h duration; it was 33 mg/L at station GS5, further upstream. At the 7500 bridge on March 18, 1992, following a small steady rain, flow in WOC was slightly higher than the normal baseflow level and the SS concentration was 10 mg/L. During the same day, the SS concentration in Northwest Tributary near the USGS gauging site was 12 mg/L (Fontaine 1992).

SS concentrations in WOC increase during wet weather relative to baseflow conditions; however, concentrations then decrease with higher flow rates during storms due to dilution. At the WOC weir during the storm on April 12, 1992, peak flow was 200 cfs in WOC and the peak SS concentration was 2200 mg/L. During the storm of December 1–2, 1991, (a long-duration winter storm), peak flow was 440 cfs and the peak SS concentration was 300 mg/L (Fontaine 1992).

3.4.7 Water Quality

The quality of natural surface waters is a function of the geochemistry of the surrounding soils and groundwater discharges, unless they are impacted by effluent discharges. In WAG 1 streams, waters are of the calcium-bicarbonate type, are moderately hard to very hard, and have low sodium, potassium, and chloride content (McMaster 1967).

During October 1990 and March 1991, surface water grab samples were collected from the WOC and its tributaries during both low base and high base flow conditions, as well as during storms that occurred during low and high base conditions. The available field parameters and selected water quality parameters from the sampling events are shown in Table 3.4.8 for First Creek, Fifth Creek, Northwest Tributary, and WOC. Sampling stations SW-4 through SW-8 in Table 3.4.8 correspond to the USGS gauging stations on First Creek, Fifth Creek, Northwest Tributary, and WOC. There are no apparent differences in the quality of the surface waters among tributaries, as indicated by the limited data shown in Table 3.4.8. The water temperatures ranged between 11.4 and 14.1°C during the high base flow events (March 1991), and between 11.1 and 16.6°C for the low base flow events

(October–November 1990). The pH of the surface waters ranged from 6.89 to 8.08, indicating neutral waters. In general, conductivity, and chloride, nitrate/nitrite, and sulfate concentrations appear to be inversely correlated with the flow rate—the higher the flow rate, the lower the concentration through dilution.

3.5 PHYSICAL CHARACTERISTICS OF POTENTIAL CONTAMINANT SOURCES

This section describes the SWMUs within WAG 1 that have been identified as potential sources of contamination. These SWMUs are listed in the 1992 "Annual Update of the Solid Waste Management Units List for the Oak Ridge Reservation" (Bates 1992), which lists 167 SWMUs within the boundaries of WAG 1. The SWMUs are individually described in the Contaminated Sites Summary Sheets (CSSSs) (ORNL 1990), which provide general information including the name, location, dimensions and capacities, functions, dates of operation, waste characteristics, release data, regulatory authority, and characterization status. Table 1.2.1 lists, briefly describes, and indicates the status of each SWMU within WAG 1.

The locations of 140 of these SWMUs are shown in Fig. 3.5.1—126 that have been investigated as potential sources of contamination and 14 SWMUs that are listed for decommissioning and demolition under the DOE surplus facilities program. These 14 SWMUs are structures that may require further investigation to determine the extent of the contamination within them but were not considered in the CSSS to be sources of contamination that could be released to the environment beyond the interior of the structures. Hence, they were not considered to require analysis under the CERCLA RI/FS program. The remaining 27 SWMUs (Fig. 3.5.2) were not included in the investigation as they were classified as needing no further investigation (Bates 1992).

Figure 3.5.3 shows the three waste burial sites, six existing and two abandoned (backfilled) surface impoundments, and the tank farms, which contain the primary inventories of hazardous substances at WAG 1. Based on their contents and physical characteristics, these SWMUs represent the greatest potential sources for hazardous and radioactive contaminant release.

Below-ground SWMUs investigated as potential sources of contamination include two radioactive material storage gardens (subsurface stainless steel storage containers for nonliquid retrievable materials), contaminated underground piping and utility trenches, various pits and canals that are repositories of contained materials, and sites where contaminants have been spilled directly onto the ground. Spill sites are not discussed in this section; results of soil sampling performed at these sites are presented in Sect. 4.4.

Above-ground SWMUs investigated as potential sources of contamination include buildings and structures (e.g., concrete storage pads, exhaust ducts, filter houses, and stacks) that were used as laboratory process facilities and became contaminated either by virtue of their function or by an accidental release of contaminants. Some of these facilities are a combination of above-ground and subsurface structures that may have contaminated surfaces or may contain accumulations of residual contamination in the form of sludge or liquid.

3.5.1 Waste Collection and Storage Tanks

Seventy-three waste storage tanks within WAG 1 are listed as SWMUs; 69 were installed for the collection, treatment, and/or storage of LLLW. The remaining four are two small above-ground steel tanks for temporary waste oil accumulation and storage (SWMU 1.54), an above-ground stainless steel tank used for nitric acid (SWMU 1.80A), and an above-ground stainless steel tank used for sodium hydroxide (SWMU 1.80B). Of the 73 tanks, 23 are active [receiving programmatic wastes from continuing operations at ORNL (Fig. 3.5.4)], 2 are in active use for waste oil collection, and 48 are inactive [physically or administratively isolated from LLLW program sources but still may be collecting nonprogrammatic wastes (Robinson et al. 1991) such as inleakage from vault seals, wastes from floor drains and sumps, and condensate collected in the gaseous ventilation systems (Fig. 3.5.5)].

Of the 48 inactive tanks, 32 are in the ER Program and 16 are operated by Waste Management or the generating divisions (including the acid tank and the caustic soda tank) (Robinson et al. 1991). The 14 inactive tanks will be transferred to the ER Program after meeting specific criteria related to content removal and residual contamination. Inactive tank systems were removed from service either because they were no longer being used and did not meet the RCRA criteria for secondary containment and release detection systems, or because they are known or are suspected to leak (Robinson et al. 1991).

The active LLLW tanks described herein are those that are near one or more inactive tanks that were investigated because of their physical characteristics and/or the characteristics of their contents. All 23 of the active tanks in the LLLW system within WAG 1 are constructed of stainless steel, and the 2 above-ground waste oil tanks (SWMU 1.54) are carbon steel. Details of the programs for upgrade and replacement of the active LLLW tanks are discussed in Robinson et al. (1991). Soil samples were taken near the active tanks to investigate the possibility of contaminant releases; results are presented in Sect. 4.4.

The early nuclear research and development facilities at ORNL include an extensive underground storage tank system to collect and store LLLW from various process and laboratory buildings. A network of gravity drain pipes and valve boxes was laid in trenches to transport LLLW to the central group of six large underground Gunite tanks in STF (Binford and Orfi 1979). The waste was generally highly acidic as a result of the processes from which it was derived. The liquid in the tanks was treated with sodium hydroxide to raise the pH and thereby precipitate the radionuclides and reduce the potential for acid corrosion of the concrete tanks (Mynatt and Webster 1963). The resulting sludges were stored in the tanks.

Waste collection tanks and associated buried piping systems were added to the system during the early 1950s (Binford and Orfi 1979). Most of these tanks were stainless steel, and some were covered with or encased in concrete to provide shielding. Many of the tanks were buried directly in the earth, while others were placed in below-ground or under-floor concrete vaults. Wastes were routinely stored for a short time and sampled before a decision was made regarding their disposition (i.e., removal and storage in the STF Gunite tanks or release to the process waste system for treatment before disposal).

Table 3.5.1 provides general information on the status (active/inactive), FFA category, construction materials, size, and source of waste materials in the tanks that are SWMUs within WAG 1. Detailed information on the operational history and physical description of the tanks can be found in Huang et al. (1984), Taylor (1986b), Horton (1984), Peretz et al. (1986), Binford and Orfi (1979), MCI (1985), Coobs and Myrick (1983), and West (1991).

3.5.1.1 Tanks that are potential sources of contamination

The waste storage tanks investigated are (1) inactive tanks that are known to contain hazardous materials based on results from past sampling, have a history of past leaks (in or out) or releases, and/or have an operational history that implies the possibility that they may contain radioactive or chemical wastes, and (2) active tanks that receive LLLW waste.

The waste storage tanks at WAG 1 are constructed of either Gunite (a construction process in which a mixture of sand, Portland cement, and water is applied in layers by spraying onto formed steel reinforcement bars and/or welded wire mesh) or stainless steel except for tank S-424 (constructed of glass-lined carbon steel).

Typical cross sections for buried LLLW tanks are shown in Figs. 3.5.6, 3.5.7, and 3.5.8. Underground tanks generally depend on earth cover for shielding, but some are encased or partially covered with concrete. Other tanks are shielded by being placed in concrete vaults above or below ground.

3.5.1.2 Tank farms that are potential sources of contamination

In the following subsections, the tanks are described in their physical groupings because remediation of an individual tank may have an influence upon, or may be influenced by, adjacent tanks. Only those tanks known or suspected to contain significant quantities of waste and/or are of Gunite construction are described in detail. When such tanks are part of a tank farm, all tanks in that tank farm are described. Where available, tank content inventory data are listed to provide an indication of which tanks are most susceptible to significant releases of contaminants. These data are generally not available for active tanks because the contents of these tanks change frequently.

North Tank Farm. NTF occupies an area of approximately 100 by 200 ft in the northeastern corner of the intersection of Central Avenue and Third Street (Figs. 3.5.3 and 3.5.9) and contains eight buried inactive tanks (four Gunite and four stainless steel).

Samples of liquid, soft sludge, and hard sludge collected from some NTF tanks were classified by ORNL staff (Autrey et al. 1990) as RCRA hazardous or mixed waste because of high levels of chromium, mercury, lead, nickel, and cadmium in the liquids and high levels of cadmium, chromium, lead, and/or mercury in the sludges. Other metals found in the samples were uranium, silver, barium, and selenium. ORNL classified liquids in W-14 and W-15 as corrosive RCRA hazardous liquid wastes with pH between 0.2 and 0.6.

Tanks W-1 (SWMU 1.23A) and W-2 (SWMU 1.23B). Tanks W-1 and W-2 are 4800-gal Gunite tanks (Fig. 3.5.6) built in 1943 and used together to collect LLLW from Building

3019. Liquid that contained fissionable materials and radioactive metal wastes drained from the building into W-1, and the overflow was piped into W-2. Both tanks were removed from service in 1960 because of reported leakage (Taylor 1986b).

The tanks have a 12-ft inside diameter on a flat base, and the 8-ft vertical sidewalls are 5 in. thick. The concrete pads under the tanks have a larger diameter than the tanks and a curb and gutter system draining to a dry well. The top domes are 3 in. thick and buried beneath approximately 6 ft of compacted soil. The backfill material around each tank was a 3-ft layer of 2-in. crushed stone surrounding the tank from the base to the top. Tank W-1 is known to collect leakage during rainstorms, but the specific source of the leakage has not been determined. The water had to be pumped out of W-1 to provide camera access when an internal video inspection (BNI 1992) was performed in 1992, but W-2 was inspected without requiring pumping.

The major contaminants remaining in these two tanks are cesium and unidentified beta emitters (Thomson 1991). Tanks W-1 and W-2 have estimated gross beta activities of 1.1×10^{-1} and 4.9×10^{-2} Ci, respectively. Detailed analyses of the chemical and radiological contents of these tanks are presented in Autrey et al. (1990) based on sampling performed in 1988. These analyses indicated that W-1 and W-2 do not contain RCRA-hazardous constituents.

Tank W-1A (SWMU 1.28). Tank W-1A is a 4000-gal horizontal stainless steel tank (Fig. 3.5.7) installed in 1951 to collect LLLW from Buildings 2026, 3019, and 3019-B. The tank, removed from service in 1986 because of a suspected leak in the line leading from Buildings 2026 and 3019, now receives stormwater inleakage (ORNL 1990). Its contents are routinely pumped to the LLLW system. Analysis of samples taken in 1988 indicated that the liquid should be classified as having RCRA waste characteristics, but no sludge was found (ORNL 1990). The major radioactive contaminants remaining are uranium, plutonium, strontium, cesium, americium, cobalt, and curium. Gross alpha activity is estimated at 2.8×10^{-3} Ci, and gross beta activity is estimated at 3.3×10^{-3} Ci (Thomson 1991). Detailed analyses of the chemical and radiological contents of this tank are presented in Autrey et al. (1990) based on sampling performed in 1988. Because of storm water inleakage, the concentrations have likely changed since that sampling event.

Tanks W-3 (SWMU 1.24A) and W-4 (SWMU 1.24B). Tanks W-3 and W-4 are 42,500-gal Gunite tanks (Fig. 3.5.6) built in 1943 to receive LLLW from Building 3019. The tanks have a 25-ft inside diameter on a flat base, and the vertical sidewalls are 12 ft high and 5 in. thick. The top domes are 3.6 in. thick and buried beneath approximately 6 ft of compacted soil (Horton 1984). Both tanks were removed from service in the 1960s because of surface water and groundwater infiltration (ORNL 1990). The concrete pads under the tanks have a larger diameter than the tanks and a curb and gutter system draining to a dry well. Crushed stone was used as backfill material surrounding the tanks from the base to the top, out to a distance of about 3 ft from the tank sidewalls.

Tank W-3 collected plutonium waste and tank W-4 collected uranium waste. Wastes were neutralized to prevent corrosion of the concrete and to precipitate the radionuclides and heavy metals (Horton 1984).

The major contaminants remaining in these two tanks are strontium, cesium, uranium, plutonium, and cobalt. The total gross beta activity in W-3 is estimated to be approximately 5.2×10^2 Ci, mostly from strontium-90 and cesium-137 (Thomson 1991), and the total gross alpha activity is approximately 2.9 Ci, mostly from plutonium-239/240 and uranium iosotopes. The total gross beta activity in W-4 is estimated to be approximately 1.9×10^2 Ci, mostly from strontium-90 and cesium-137 (Thomson 1991), and the total gross alpha activity is approximately 4.0 Ci, mostly from uranium-233 and -238. A sample from W-3 exhibited a methyl ethyl ketone concentration of 5 mg/L, and a sample from W-4 exhibited a trichloroethylene concentration of 14 μg/L. Detailed analyses of the chemical and radiological contents of these tanks are presented in Autrey et al. (1990) based on sampling performed in 1988.

Tanks W-13 (SWMU 1.25A), W-14 (SWMU 1.25B), and W-15 (SMWU 1.25C). Tanks W-13 and W-14 are 2000-gal horizontal stainless steel tanks (Fig. 3.5.7), and W-15 is a 2000-gal vertical stainless steel tank (Fig. 3.5.8); all were installed in 1950 to collect LLLW from drains in Building 3019 and chemical waste from fission product recovery. All three were placed on concrete pads and totally encased in concrete (18 to 24 in. thick above the tanks). The concrete casement is buried beneath approximately 5 ft of compacted soil. Tank W-13 served the Chemistry Division's Hot Laboratory, and W-14 and W-15 served the Radioisotope Department of the Operations Division. The tanks were taken out of service in 1958 because they were no longer needed. No releases have been reported.

The total gross beta activity in tank W-13 is estimated to be approximately 6.5×10^1 Ci, mostly from strontium-90 and cesium-137 (Thomson 1991), and the total gross alpha activity is approximately 3.6×10^{-2} Ci, mostly from plutonium-238. The total gross beta activity in W-14 is estimated to be approximately 2.6×10^1 Ci, mostly from strontium-90 and cesium-137 (Thomson 1991), and the total gross alpha activity is approximately 2.2×10^{-1} Ci, mostly from thorium iosotopes. The total gross beta activity in tank W-15 is estimated to be approximately 2.4×10^2 Ci, mostly from strontium-90 and cesium-137 (Thomson 1991), and the total gross alpha activity is approximately 1.8×10^{-1} Ci, mostly from thorium isotopes.

The detection limits for hazardous chemical wastes are far above RCRA-hazardous waste characteristic allowable concentrations because of the high dilution factors required to enable handling of radioactive tank liquids for analytical work. The resulting analyses exceeded the RCRA hazardous waste criteria for cadmium, mercury, uranium, chromium, lead, acetone, trichloroethene, toluene, methylene chloride, bis(2-ethylhexyl)phthalate, di-n-butylphthalate, naphthalene, and di-n-octylphthalate. Tanks W-14 and W-15 contain hazardous waste based on corrosivity (pH < 2), and all three tanks are categorized as containing RCRA-hazardous wastes (Autrey et al. 1990).

South Tank Farm. STF occupies an area of approximately 130×200 ft containing six large buried Gunite storage tanks (W-5 through W-10) in the southeastern corner of the intersection of Central Avenue and Third Street (Figs. 3.5.3 and 3.5.10); it also includes a contiguous area to the east of approximately 80×230 ft containing another smaller buried Gunite tank (W-11) and six buried stainless steel tanks (W-12, W-16, W-17, W-18, W-19, and W-20). Only W-16 is active.

Tanks W-5, W-6, W-7, W-8, W-9, and W-10 (SWMUs 1.26A through 1.26F). These are large (170,000-gal) Gunite tanks (Fig. 3.5.6) arranged in two rows of three tanks each in the western portion of STF, with a center-to-center distance of 60 ft between adjacent tanks. The tanks were constructed in 1943 by excavating a large shallow basin, pouring individual concrete pads directly on bedrock, erecting the tanks and backfilling the entire area. The inside diameter of the tanks is 50 ft, and the 12-ft vertical sidewalls are 7.5 in. thick. The bottom Gunite liner is 3 in. thick on top of the concrete pad, and the domes are 10 in. thick at the center, increasing in thickness at the tank wall and rising an additional 6.25 ft in the center.

The backfill material around each tank was a 3-ft layer of 2-in. crushed stone surrounding the tank from the base to the top (about 12 ft). The concrete pads under the tanks have a larger diameter than the tanks and a curb and gutter system that drains via a 6-in. terra cotta drain tile system to six individual dry wells, all of which connect to a common drain for pumping to the equalization basin. In the event of a leak, the liquid was intended to flow down through the crushed stone, collect in the saucer, and be captured in the dry wells, where routine monitoring would detect the leak. In the early 1960s, this system was draining an average of 26,500 gal per day from the dry wells (Mynatt and Webster 1963), believed to be a result of the local water table being higher than the elevation of the bottom of the tanks.

The six main Gunite tanks were originally built for permanent storage of radioactive liquid waste produced by the plutonium pilot plant and were intended to be operated in pairs. They were to receive waste from the building drains uphill to the north and to overflow from one tank to the next toward the south. W-5 initially received radioactive liquid chemical waste and overflowed into W-6, W-7 initially received liquid uranium waste and overflowed into W-8, and W-9 initially received liquid uranium waste and overflowed into W-10 (Mynatt and Webster 1963). As the laboratory grew, the storage tanks became inadequate to handle the volume of liquid waste that was being generated. The wastes were precipitated in the tanks by raising the pH with sodium hydroxide, and the supernatant was decanted to waste holding basin 3513 and subsequently discharged to WOC. This practice changed in 1949 when a new process was begun to concentrate the effluent from these tanks using a pot-type evaporator. The concentrate from the evaporator was returned to one of the storage tanks, and the condensate was discharged to WOC. From 1954 to 1965, the waste was diverted to three 1,000,000-gal open pits in WAG 7, where it was concentrated by solar evaporation and ion exchange on the Conasauga Shale (Binford and Orfi 1979).

The use of each tank changed according to the growing needs of the laboratory over the years. As much as 130 tons of uranium was reclaimed from W-7, W-8, W-9, and W-10 (Mynatt and Webster 1963) between 1952 and 1957, making more room for waste in the tanks. By the early 1960s, W-7, W-9, and W-10 were not being used, but they contained a solution of water, NaOH, and radioactive sludges. Tank W-7 had 30,000 gal of radioactive chemical waste sludge, W-9 had 12,000 gal of metal sludge, and W-10 had 10,000 gal of metal sludge.

In 1963, W-5, W-6, and W-8 were averaging 336,000 gal per month throughput of radioactive chemical waste. At that time, the tanks were used mainly as holdup tanks,

storing the radioactive liquids while short-lived radioisotopes were allowed to decay and precipitation and sedimentation took place to remove a large portion of the radioactive materials before the liquid was discharged to the pits in WAG 7 for evaporation. Tank W-5, designated to receive organic solvents discharged as waste, was maintained with a blanket of nitrogen gas in the headspace to prevent development of an explosive atmosphere.

The effects of using W-5 and W-6 for hazardous liquids with pH ranging from 7.0 to 7.5 (Mynatt and Webster 1963) were revealed by an internal inspection of these tanks in 1992 using remote video cameras. Considerably more deterioration of the inner concrete walls was observed in W-5 and W-6 than in other STF Gunite tanks. Practice in the 1960s had evolved to maintaining a pH of 10 or more in the liquid discharged to the tanks to reduce acid corrosion. A detailed report of this inspection is included in the Video Inspection Data Manual (BNI 1992).

A structural analysis of W-5 through W-10 was performed in 1986 to assess their structural adequacy when subjected to seismic loads. 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 were 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 frictions, deformation at the dome ring, and excessive bending in that part of the tank. Given the absence of as-built drawings 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 the variables used for the analysis, the actual structural behavior of these tanks is difficult to predict.

A vigorous sludge removal campaign was conducted in the mid-1980s to reduce the total hazardous waste inventory in these tanks. A sluicing technique that utilized a high-pressure, remotely operated water lance with a bentonite slurry was used to break up the sludge into particles small enough to be suspended in the slurry so that it could be pumped to the New Hydrofracture Facility (WAG 10) in Melton Valley for deep-well disposal. Slurries from the other five tanks were pumped to W-10, which was used as a main staging tank, and the final slurry was pumped from W-10 to the Melton Valley waste storage tanks for disposal.

The major contaminants remaining in these six tanks are strontium-90, cesium-137, thorium, uranium-233, plutonium-238 and -239/240, and curium-244. The total gross beta activity is estimated to be approximately 22,800 Ci from strontium-90 and cesium-137 (Thomson 1991), and the total gross alpha activity is approximately 156 Ci, mostly from plutonium and curium. The total estimated activity from other isotopes is less than 40 Ci. This represents about 95% of all documented activity in the inactive tanks inventory. Almost half of this 95% is in W-10, which holds most of the residual sludge from the sluicing operations. The estimated total sludge volume is 26,900 gal, and the liquid volume, which has increased because of rainwater inleakage through openings and pipes in the tops of the

tanks, is estimated to be a minimum of 206,100 gal (ORNL 1990). All six tanks are classified as containing RCRA-hazardous wastes. Detailed information concerning the characteristics of the tank contents is available in Autrey et al. (1990).

Tank W-11 (SWMU 1.27). W-11 is an underground 1500-gal tank of Gunite construction very similar to that described for the six large tanks in the main storage area (Fig. 3.5.6). The tank is 80 ft east of W-10 and 100 ft north of the eastern end of Building 3517 in the southeast corner of STF (Fig. 3.5.10). It was built on a flat concrete pad, with vertical 5.5-ft sidewalls and an inside diameter of 8 ft. The Gunite bottom and the domed top are 3 in. thick. This tank was constructed in 1943 and received LLLW from laboratories in Building 3550. It was removed from service and the contents were pumped out in 1948 because of leaks (Huang et al. 1984a), but it remained connected to W-12 via a 3-in. stainless steel overflow pipe. Tank W-12 (Horton 1984) was removed from service in 1991. Sampling in 1988 (Autrey et al. 1990) indicated a volume of 897 gal of aqueous solution and 62 gal of sludge in W-11.

Tank W-11 samples included both liquid (L) and hard sludge (H). The sludge is classified as RCRA-hazardous waste because of high levels of chromium, lead, and mercury. Other metals found in the waste samples were uranium (L), arsenic (H), barium (H), cadmium (H), and nickel (H). The pH of the liquid was between 7.7 and 8.

Radionuclides identified in the tank liquid were strontium-90, tritium, and carbon-14. VOCs (chlorobenzene and trichloroethene) detected in the liquid samples were below reporting limits. Semivolatile organic compounds reported for the sludge included bis(2-ethylhexyl)phthalate, di-n-butylphthalate, and the polyaromatic hydrocarbons benzo(a)anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, chrysene, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene.

Tank W-12 (SWMU 1.41). W-12 is a 700-gal vertical stainless steel tank mounted on a concrete slab and buried under compacted soil (Fig. 3.5.8), located southwest of Building 3525, and approximately 9 ft northeast of W-11 (Fig. 3.5.10). The tank collected LLLW streams from Building 3525 and the hot cell sump pit drain in Building 3517 until it was removed from service in 1991 because of inleakage. No releases have been reported. The remaining contents of the tank are unknown, but the major nuclides of concern while the tank was in operation under the RCRA permit were strontium-90, cesium-137, cobalt-60, and TRU. Because of the sample dilutions required to allow handling of radioactive liquid samples, the detection limits are considerably above those required for RCRA-hazardous waste determinations. Only limited chemical analyses have been performed to date (ORNL 1990).

Tanks W-16 (SWMU 1.42A), W-17 (SWMU 1.42B), and W-18 (SWMU 1.42C). These tanks are clustered together in the northeast corner of STF (Fig. 3.5.10). W-16 is an active storage tank that collects LLLW from hot cells in Building 3026 and is emptied by pumping or jetting to the LLLW system. Until tanks W-17 and W-18 were removed from service in 1991, they collected waste from hot cells in Building 3026 and liquids from the 3500 area cell ventilation duct; these three 1000-gal vertical stainless steel tanks are 5.5 ft in diameter and 7.3 ft tall (Fig. 3.5.8). They are 70 ft northeast of W-9, mounted on a concrete slab,

and buried under approximately 9.3 ft of compacted soil. The major nuclides of concern are strontium-90, cesium-137, cobalt-60, and TRU (although the exact contents of W-17 and W-18 are unknown). Because of the sample dilutions required to allow handling of radioactive liquid samples, the detection limits are considerably above those required for RCRA-hazardous waste determinations. Only limited chemical analyses have been performed to date (ORNL 1990). No releases have been reported.

Tanks W-19 (SWMU 1.56A) and W-20 (SWMU 1.56B). Tanks W-19 and W-20 are similar 2250-gal vertical stainless steel tanks mounted on a common concrete slab and buried under approximately 4 ft of compacted soil (Fig. 3.5.8). The tanks, built in 1955, are about 110 ft south of W-10, about 60 ft southwest of W-11, and 50 ft north of Building 3505 (Fig. 3.5.10). They collected LLLW from Building 3505 until they were removed from service in the early 1960s (ORNL 1990). When sampled in 1989, the tanks were found to be empty but internally contaminated; the major nuclides of concern are strontium-90, cesium-137, plutonium, cerium, and promethium-147. There have been no reported leaks or releases from these tanks.

Thorium tank farm (Building 3503 area). This tank farm is about 65 ft south of Building 3505 and approximately 40 ft north of Southside Drive (Fig. 3.5.11). It consists of seven tanks served by a complex network of piping and valves housed in a below-ground concrete pump pit and by another concrete-lined valve pit serving the three thorium tanks separately. TH-1, TH-2, and TH-3 were used to collect waste from the thorium pilot plant. Tanks WC-5, WC-6, and WC-8 were removed from service in 1991 because they were no longer needed. The sole active tank in this tank farm is WC-9.

Tank TH-1 (SWMU 1.31A). TH-1 is a vertical stainless steel 2500-gal tank, 7.5 ft in diameter and 10 ft tall, mounted on a concrete slab and buried under approximately 5 ft of compacted soil (Fig. 3.5.8). The tank was salvaged from the burial ground and placed in service in 1948 (Horton 1984). It is in the northwestern corner of the tank farm, approximately 20 ft north of WC-9, 25 ft west of TH-2, and south of Building 3503. The tank, which collected waste from the thorium pilot project in Building 3503, was taken out of service in 1970 and emptied. No releases have been reported, but contamination from both cesium-137 and strontium-90 has been found in nearby surface soils and groundwater (Taylor 1986b).

The 1988 sampling event (Autrey et al. 1990) indicated a volume of approximately 278 gal of liquid waste with a pH of 1.8. The major nuclides of concern are cesium, cobalt, strontium, and traces of TRU, and the contents are classified as having RCRA waste characteristics. Gross beta activity is approximately 1.1 Ci, mostly from strontium-90 and cesium-137, and gross alpha activity is approximately 1.2×10^{-2} Ci, from thorium isotopes and uranium-233.

Tank TH-2 (SWMU 1.31B): TH-2 is a vertical stainless steel 2400-gal tank, 7 ft in diameter and 10 ft tall, mounted on a concrete slab and buried under approximately 5 ft of compacted soil (Fig. 3.5.8). The tank, which had been previously used, was placed in service in 1952 (Horton 1984). It is in the north-central edge of the tank farm, approximately 4 ft north of WC-5, 25 ft east of TH-1, 5 ft west of TH-3, and south of

Building 3503. The tank, which collected waste from the thorium pilot project in Building 3503, was taken out of service in 1970 and emptied. No releases have been reported from this tank (ORNL 1990), but contamination from both cesium-137 and strontium-90 has been found in nearby surface soils and groundwater (ORNL 1990).

When TH-2 was sampled in 1990 (Autrey et al. 1992), it was found to contain 72 gal of liquid contaminated mainly with strontium-90, cesium-137, cobalt-60, tritium, carbon 14, and uranium isotopes. Gross beta activity is approximately 7.0×10^{-2} Ci, and gross alpha activity is approximately 6.5×10^{-4} Ci, from uranium. Organic compounds discovered in the sampling effort were below RCRA limits, and only mercury exceeded the RCRA limit for metals.

Tank TH-3 (SWMU 1.31C). TH-3 is a vertical stainless steel 3300-gal tank, 9.2 ft in diameter and 10 ft tall, mounted on a concrete slab and buried under approximately 5 ft of compacted soil (Fig. 3.5.8). The tank was salvaged and placed in service in 1952 (Horton 1984). Located in the northeast corner of the tank farm, approximately 5 ft east of TH-2 and south of Building 3503, the tank collected waste from Building 3503. The tank was removed from service in 1970 and emptied. No releases have been reported, but cesium and strontium contamination has been found in nearby surface soils and groundwater (ORNL 1990).

When the tank was sampled in 1988 (Autrey et al. 1990), it was found to contain 140 gal of liquid contaminated with strontium, cesium, tritium, carbon-14, uranium, and thorium; the pH of the liquid was 1.8. Chlorobenzene was detected at 2 μg/L, and mercury was detected at 11 μg/L. Gross beta activity is approximately 4.7×10^{-1}, mostly from strontium and cesium, and gross alpha activity is approximately 2.2×10^{-3}, mostly from uranium.

Tanks WC-5 (SWMU 1.37B), WC-6 (SWMU 1.37C), and WC-8 (SWMU 1.37D). These three vertical stainless steel tanks, south of Building 3503 in the center of the thorium tank farm, are mounted in a row on a common concrete slab and buried under approximately 8 ft of compacted soil. WC-5 and WC-8 are 1000-gal tanks, 5.5 ft in diameter and 7.3 ft tall. The center tank, WC-6, has a capacity of 500 gal, a diameter of 4.5 ft, and a height of 5.7 ft (Fig. 3.5.11). Placed in service in 1952 (ORNL 1990), the tanks collected waste from Buildings 3503, 3508, 3541, and 3592; they were removed from service in 1991. No releases have been reported. The remaining contents of the tanks are unknown, but the major nuclides of concern while the tanks were operating were strontium-90, cesium-137, cobalt-60, and TRU. Because of the sample dilutions required to allow handling of radioactive liquid samples, the detection limits are considerably above those required for RCRA-hazardous waste determinations. Only limited chemical analyses have been performed (ORNL 1990).

Tank WC-9 (SWMU 1.37E). WC-9 is a 10.75-ft, vertical stainless steel 2140-gal tank, 7 ft in diameter. It is mounted on a concrete slab and buried under approximately 6.5 ft of compacted soil (Fig. 3.5.8), south of Building 3503 in the southwest corner of the tank farm, approximately 20 ft south of tank TH-1 and 25 ft west of tank WC-8 (Fig. 3.5.11). Placed in service in 1952 (ORNL 1990), the tank receives waste from Building 3503. The waste is pumped or jetted to the LLLW system at preset times or when the tank is filled to its normal operating volume of 1550 gal.

Area 4500 tank farm. This tank farm is approximately 30 ft southeast of Building 3587 in a central area of the main ORNL complex, adjacent to several active facilities and near pedestrian and vehicle thoroughfares (Fig 3.5.12). Fifth Creek lies approximately 20 ft to the east, flowing from north to south. The tank farm, put in service in 1951, consists of seven buried stainless steel tanks served by a complex network of piping and valves in two below-ground concrete pump pits and by an off-gas filter system. The tanks are on a common concrete collection pad that drains to an operable dry well and collection system and are covered with approximately 10 ft of gravel and soil (Burwinkle 1987). Tanks WC-11, WC-12, WC-13, and WC-14 were removed from service in 1991, and WC-15 and WC-17 were removed from service in the 1960s. This group of tanks was used to collect mixed waste from the laboratories in Building 4500 (Burwinkle 1987) and Buildings 4501, 4505, 4507, 4508, and 4556 (ORNL 1990). WC-10 is the only active tank in this tank farm.

The current contents of WC-10, WC-11, WC-12, WC-13, and WC-14 are unknown, but based on recent service, the major nuclides of concern are strontium-90, cesium-137, cobalt-60, and TRU. Because of the sample dilutions required to allow handling of radioactive liquid samples, the detection limits are considerably above those required for RCRA-hazardous waste determinations. Only limited chemical analyses have been performed to date (ORNL 1990). No releases have been reported.

Tank WC-10 (SWMU 1.39A). WC-10 is a 2300-gal horizontal tank (Fig. 3.5.7), 6.3 ft in diameter and 10.3 ft long (ORNL 1990). The tank's long axis is from north to south, parallel to, and immediately to the west of the row of five vertical tanks. This tank collects mixed wastes from Buildings 3029, 3030, 3031, 3032, 3033, 3039, 3047, and 3092.

Tank WC-11 (SWMU 1.39B). WC-11 is a 4600-gal horizontal tank (Fig. 3.5.7), 7.7 ft in diameter and 13.7 ft long (ORNL 1990). The tank's long axis is from north to south, parallel to, and immediately to the west of the five vertical tanks. This tank was in service from 1951 to 1991 and collected waste from Buildings 4500N (Wing 1), 4505, 4507, and 4556.

Tank WC-12 (SWMU 1.39C). WC-12 is fifth from the north in a row of five identical vertical 1000-gal tanks (Fig. 3.5.8). It has an outside diameter of 5.5 ft and a height of 6.8 ft and stands on short stainless steel legs anchored to the concrete pad. The tank was in service from 1951 to 1991 and received wastes from Buildings 4505 and 4507.

Tank WC-13 (SWMU 1.39D). WC-13 is third from the north in the row of vertical tanks. It has an outside diameter of 5.5 ft and a height of 6.8 ft and stands on short stainless steel legs anchored to the concrete pad. The tank was in service from 1951 to 1991 and received wastes from Buildings 4500S, 4500N, 4501, and 4508.

Tank WC-14 (SWMU 1.39E). WC-14 is fourth from the north in the row of vertical tanks. It also has an outside diameter of 5.5 ft and a height of 6.8 ft and stands on short stainless steel legs anchored to the concrete pad. The tank was in service from 1951 to 1991 and collected wastes from Building 4501.

Tank WC-15 (SWMU 1.30A). WC-15 is second from the north in the row of vertical tanks. The tank also has an outside diameter of 5.5 ft and a height of 6.8 ft and stands on short stainless steel legs anchored to the concrete pad. The tank collected waste from Building 4500 from 1951 through 1960, when it was emptied and removed from service. When it was sampled in 1990 (Autrey et al. 1992), WC-15 was found to be completely full with approximately 1000 gal of aqueous waste and a thin surface layer of oil. Only trace levels of metals and radionuclides were measured in the oil and water. There were no TCL constituents detected or tentatively identified compounds for the semivolatile organics analysis in the aqueous phase; only traces of dichloroethene (14 to 14 μg/L) and ethyl ether (15 to 17 μg/L) were detected. The oil layer showed only one TCL constituent, di-n-butylphthalate at 1900 μg/L. Low levels of chlorinated aromatics were detected, for which identification is continuing. The tank is known to have leaked in at the seams.

Tank WC-17 (SWMU 1.30B). WC-17 is first from the north in the row of vertical tanks. This tank also has an outside diameter of 5.5 ft and a height of 6.8 ft and stands on short stainless steel legs anchored to the concrete pad. The tank collected waste from Building 4500 from 1951 through 1960, when it was emptied and removed from service because of leaks (Horton 1984).

A statistical analysis was performed in 1991 of the liquid level readings in the tank using data collected with the existing pneumatic level gauge. The analysis indicated a very slight upward trend in the liquid level; over a period of 180 days (September 1990 to March 1991), the level increased by an amount equal to an average of 0.002 gal per day. A liquid volume of 370 gal of dilute aqueous waste and oil was measured in 1988 (Autrey et al. 1990). Chemical analysis of the liquid and sludge samples indicated the presence of metals (mercury, cadmium, chromium, and lead) and VOCs (trichloroethylene and methylene chloride) that categorize the contents as mixed wastes. The radiological content was relatively minor (thorium isotopes at 6.1×10^{-7} Ci and cesium-137 at 4.9×10^{-5} Ci), which is consistent with the tank having been emptied when it was removed from service.

3.5.1.3 Tank TH-4

TH-4 is the only waste storage tank with a significant liquid content that is not part of a tank farm. It is a 14,000-gal Gunite tank, 20 ft in diameter, and 9 ft from the floor to the center of its domed roof. The 6.5-ft vertical sidewalls are 6 in. thick, and the roof is 4 in. thick; the 3-in. Gunite floor is over a concrete slab that extends beyond the perimeter of the tank to form a 12-in.-wide perimeter gutter (Fig. 3.5.6). The tank is buried under approximately 6 ft of compacted soil and is surrounded by crushed stone or gravel backfill to permit any leaks to run down and be collected in the gutter. The gutter drains to an adjacent drywell, which is 2 ft^2 inside and extends 15 ft from the bottom up to the ground surface. The tank is about 50 ft west of the southwestern corner of Building 3500 and approximately 300 ft away from the nearest waste storage tank.

TH-4, built in 1943 to collect radioactive waste from the thorium and uranium pilot plant in Building 3550, was taken out of service in 1970. The 1988 sampling results showed the tank to be filled with liquid to a level above its design capacity, with approximately 6315 gal of sludge in the bottom (Autrey et al. 1990).

Gross beta activity is approximately 10.8 Ci, mostly from strontium-90 and cesium-137, and gross alpha activity is approximately 2.8 Ci, mostly from uranium and thorium. RCRA-hazardous constituents include chromium (290 μg/g), mercury (4.9 μg/g), lead (99 μg/g), and the VOCs trichloroethylene (5 μg/L), methylene chloride (210 μg/L), methyl ethyl ketone (2000 μg/L), chlorobenzene (8 μg/L), carbon tetrachloride (11 μg/L), and toluene (79 μg/L). Other VOCs include acetone, methanol, and methyl isobutyl ketone; semivolatiles include phthalates and polycyclic aromatic hydrocarbons.

3.5.2 Surface Impoundments

Surface impoundments were used for (1) sewage treatment as part of the sanitary waste treatment system; (2) settling and/or emergency storage of LLLW waste as part of the LLLW system; and (3) surge, equalization, and settling basins as part of the Process Waste Treatment Plant (PWTP) system. The eight surface impoundments within WAG 1 designated as SWMUs include five inactive impoundments that still contain water and one active impoundment. The two inactive impoundments without water [waste holding basin 3512 and the Low Intensity Test Reactor (LITR) pond] have been abandoned and backfilled.

The active impoundment is sewage pond 2544 (Fig. 3.5.3), used as an equalization basin for the sewage treatment plant. The five inactive impoundments containing water are sewage treatment pond 2543, waste holding basin 3513 (built for LLLW), equalization basin 3524 (originally built as two LLLW ponds and later converted to one large process waste water pond), and process waste ponds 3539 and 3540. The two impoundments that have been abandoned and backfilled are waste holding basin 3512 and the LITR pond. More detailed information can be obtained from Taylor (1986a), Francis and Stansfield (1986), Stansfield and Francis (1986a,b), Kitchings and Owenby (1986), and Braunstein et al. (1984).

3.5.2.1 Inactive surface impoundments

Waste holding basin 3513 (SWMU 1.12). Constructed in 1944 by scooping out a depression in the native clay and constructing earthen berms around the perimeter, this basin measures 220 by 220 ft at the top of the berm and has an operating depth of 6.5 ft (Figs. 3.5.3 and 3.5.13). In some places the bottom of the basin is within 1 ft of the limestone bedrock. The unlined basin, which has a 1,880,000-gal capacity, received the supernatant outflow from the STF LLLW tanks via five pipes along the northern side of the basin. Later, water treated in the original process waste treatment plant by using fly ash and soda lime to precipitate radionuclides was discharged to the 3513 settling basin before being discharged into WOC. The basin was removed from service in 1976 but still contains water and contaminated bottom sediments (Stansfield and Francis 1986a). If the level in the pond exceeds 778 ft MSL, outflow from the effluent lines goes to a sump that is pumped to basin 3524 (Stansfield and Francis 1986a).

Water and sludge samples were taken from the basin in 1984 and 1985 (Stansfield and Francis 1986a) as part of a program to determine whether the water and bottom sludges, already known to contain radioactive wastes, would be classified as RCRA- hazardous waste.

For water analysis, the detection limits imposed by the ICP method exceeded National Interim Primary Drinking Water Standards (NIPDWS) levels for some metals; chromium, lead, and selenium exceeded the NIPDWS (0.05 mg/L), and arsenic, barium, cadmium, fluoride, mercury, nitrate, herbicides, and pesticides were below the maximum allowable NIPDWS. PCBs were detected 0.006 mg/L. The radioactivity in the water is from cesium-137 at 7.8 pCi/mL and strontium-90 at 11 pCi/mL with an estimated inventory in 1985 of 0.05 Ci of cesium-137 and 0.03 Ci of strontium-90. Gross beta activity (25 pCi/mL) is predominantly from strontium-90 decay, and gross alpha activity is less than 0.65 pCi/mL (Stansfield and Francis 1986b).

The sludge samples contained less than allowed by the RCRA hazardous material criteria (metals, herbicides, and pesticides) except for mercury and, possibly, selenium, for which the detection limits by ICP were 1 to 2 mg/L higher than the RCRA criteria. The total mercury inventory for the basin sludge is estimated by Huang to be 25 kg (Stansfield and Francis 1986b). Radiological sampling indicated the presence of cobalt-60, cesium-137, strontium-90, europium-154, plutonium-238, plutonium-239, americium-241, and curium-244 in sediments. The inventory of radionuclides in bottom sediments was estimated by Stansfield and Francis (1986a) to be 200 Ci of cesium-137, 30 Ci of strontium-90, and 5 Ci from the others listed.

Equalization basin 3524 (SWMU 1.13). This basin was originally built in 1945 as two adjacent, unlined 290,000-gal ponds for emergency storage of LLLW (Figs. 3.5.3 and 3.5.13). In 1957 the earthen dike between the two ponds was removed to create a larger basin for use as a flow equalization basin for the original PWTP. The basin was further enlarged to 95 × 250 ft with a maximum depth of 6.5 ft (1-million-gal capacity) in 1961 and was finally removed from service in 1989, although it is still available for emergency overflows. The basin presently contains water and contaminated bottom sediments.

Characterization studies for basin 3524 were performed starting with sludge sampling in 1984 and 1986. Analysis of the sediment samples in 1984 indicated the inventory of cesium-137 at 102 Ci, strontium-90 at 29 Ci, total gross alpha at 11 Ci, americium-241 at 4.6 Ci, and cobalt-60 and europium-154 combined at 6.8 Ci (Braunstein et al. 1984). Analysis of sediment samples for VOCs in 1986 indicated benzene, chloroform, and methylene chloride, with average concentrations of 6.8, 3.6, and 6.4 μg/L, respectively (Kitchings and Owenby 1986).

Samples were collected in January and February 1986 from the influent water entering the ponds and from the water directly above the sludge in the bottom of the ponds to measure for EP toxicity constituents and other VOCs (Kitchings and Owenby 1986). The EP toxicity constituents were below RCRA-hazardous waste characteristic thresholds in all samples. The highest VOCs present in the influent water samples were trichloroethylene at 2.2 μg/L, chloroform at 7.9 μg/L, methylene chloride at 23 μg/L, and 1,2-dichloroethane at 2.8 μg/L. In the samples of water directly overlying the sludge, the VOCs and their highest concentrations detected were methylene chloride at 288 μg/L, chloroform at 119 μg/L, and benzene at 6 μg/L.

Process waste ponds 3539 (SWMU 1.14) and 3540 (SWMU 1.15). These ponds were constructed in 1964 with 6-in. compacted clay liners as a dual surge basin system designed to alternately receive and discharge process waste streams from the Building 4500 complex. The ponds were removed from service in 1990 (ORNL 1990). Each pond measures about 65 × 92 ft at the top of the berm, is 7.9 ft deep at the deepest point, and is designed to hold 150,000 gal (Figs. 3.5.3 and 3.5.13). The discharge from the ponds can be directed either to WOC or to basin 3524 for treatment in the PWTP. Water levels vary seasonally, and the ponds contain mixed waste sludges. The elevation of the bottom of the ponds is approximately 779 ft above MSL, compared with the normal water level of 778 ft in basin 3513, which lies about 80 ft due west (see Figs. 3.5.3 and 3.5.13).

Samples were collected in January and February 1986 from the influent water entering the ponds and from the water directly above the sludge in the bottom of the ponds (Kitchings and Owenby 1986) to measure for EP toxicity constituents and other VOCs. The EP toxicity constituents were below RCRA-hazardous waste characteristic thresholds in all samples. The highest VOCs in the influent water were dichlorobromomethane, trichloroethylene, chloroform, methylene chloride, and 1,2-dichloroethane, at 5.2, 4.2, 130.8, 8.4, and 2.80 μg/L, respectively. In the samples of water directly overlying the sludge, the VOCs detected were methylene chloride and chloroform at 8 and 2.4 μg/L, respectively.

Sludge samples were collected from the ponds in January and February 1986 and analyzed for RCRA metals, pesticides, herbicides, and VOCs. None of the samples exceeded EP toxicity limits for RCRA metals. Pesticide/herbicide extracts were also below EP toxicity limits. Methylene chloride and 1,2-transdichloroethylene were present in average concentrations of 7.6 and 2.1 μg/L, respectively (Kitchings and Owenby 1986). Total radioactivity in the ponds is estimated to be less than 10 Ci (Myrick et al. undated). Groundwater monitoring revealed significantly higher concentrations of chlorides, iron, manganese, lead, and gross beta in groundwater from wells downgradient of the waste ponds than in groundwater from upgradient wells (ORNL 1990).

Sewage aeration pond 2543 (SWMU 1.16). This pond was operated in series with pond 2544 as an aeration lagoon for treating sanitary sewage (Fig. 3.5.3). The pond has a capacity of about 1 million gal. The aeration ponds were constructed in 1974 with plastic liners (ORNL 1990) and aeration systems and were used until the new STP was completed. Pond 2543 has been removed from service (ORNL 1990), but is available for emergency use. Some radioactivity can be detected in the sludge, assumed to be due to leakage of contaminated groundwater and of LLLW from leaking pipelines into the domestic sewer lines (Grimsby 1986). The inventory of radionuclides in the sludge is estimated to be less than 10 Ci (ORNL 1990).

Analysis of samples of the sludges (85 to 95% water) in the bottom of this pond collected in August 1991 indicated tritium at 2940 pCi/L, americium-241 at 247 pCi/L, cobalt-60 at 1279 pCi/L, cesium-137 at 31,120 pCi/L, europium-152 at 966 pCi/L, europium-154 at 279 pCi/L, and europium-155 at 182 pCi/L. Chemical analysis of the sludge showed barium at 540 mg/kg, cadmium at 23 mg/kg, chromium at 188 mg/kg, lead at 315 mg/kg, mercury at .0146 mg/kg, nickel at 95.6 mg/kg, and silver at 833 mg/kg. Section 4 of this report describes these samples and reports the analytical results.

Decommissioned waste holding basin 3512 (SWMU 1.11). This basin (Fig. 3.5.3) was constructed in the 1940s with an earthen dike perimeter; it measured approximately 40 × 40 ft and had a holding capacity of approximately 30,000 gal (ORNL 1990). The pond was used as a retention pond from 1944 to 1950 as part of the LLLW system, receiving process waste from the LLLW storage tanks. After it was removed from service in 1957, the soil was excavated in conjunction with construction of the PWTP and the hole was backfilled with gravel.

Remaining radioactive contamination has been estimated at less than 10 Ci. In addition to radionuclides from the LLLW tanks, the pond is known to have received as much as 250 gal of isobutyl methyl ketone during the late 1940s (ORNL 1990). The site is presently the parking lot for Building 3544. Soil sampling was performed in this area in 1991; results are described in Sect. 4.

LITR pond 3075 (SWMU 1.19). Two 18,000-gal retention ponds measuring 8 by 40 ft and ranging in depth from 6 to 8 ft were built in 1951 to retain primary coolant water from LITR (Fig. 3.5.3). The water contained low levels of radioactive contaminants. After treatment in these ponds, water was released to the Fifth Creek branch of WOC (ORNL 1990). The ponds, removed from service in 1964, were later filled with soil and clay. Soil and sludge samples were collected from each former pond location in 1985 to a depth of 7 to 8 ft (Taylor 1986a). The inventory of radioactive materials at this site was estimated to be 20 mCi of cesium-137, 1 mCi of strontium-90, and 100 μCi of plutonium-239. Levels of curium, lead, and selenium were higher than RCRA criteria for hazardous wastes. Mercury concentrations ranged from 0.04 to 0.39 mg/kg in five core samples. The contaminant inventory may be incomplete because the soil borings did not extend deeper than the bottom of the ponds.

3.5.2.2 Active surface impoundment

Sewage aeration pond 2544 (SWMU 1.17). This pond was operated in series with pond 2543 as an aeration lagoon for treating sanitary sewage (Fig. 3.5.3); it has a capacity of about 1 million gal. The aeration ponds were constructed in 1974 with plastic liners and aeration systems and were used until the STP was completed; 2544 is still in operation as an equalization basin and is available for holdup and temporary treatment of sewage if STP is out of service. Effluent from this pond currently goes to STP; before construction of STP, effluent was chlorinated and discharged to WOC.

Analysis of samples of the sludges (85 to 95% water) collected from the bottom of this pond in August 1991 showed the presence of the following radionuclides (reported at their highest detection levels): tritium at 1800 pCi/L, americium-241 at 109 pCi/L, cobalt-60 at 1186 pCi/L, cesium-137 at 21,050 pCi/L, europium-152 at 1311 pCi/L, europium-154 at 707 pCi/L, europium-155 at 269 pCi/L, plutonium-238 at 185 pCi/L, and plutonium-239/240 at 292 pCi/L. The level of plutonium detected in three sludge samples from this pond is higher than levels detected in soil and groundwater samples taken elsewhere at WAG 1 and may have entered the sanitary sewer system where sewer lines cross leaking LLLW lines. These high concentrations are also likely the result of accumulation of plutonium by adsorption onto the fine-grained sludge sediment.

Chemical analysis of the sludge revealed barium at 693 mg/kg, cadmium at 26.4 mg/kg, chromium at 272 mg/kg, lead at 262 mg/kg, mercury at 21.9 mg/kg, and nickel at 65.0 mg/kg. Section 4 describes these samples and reports the analytical results.

3.5.3 Burial Grounds

During early operations at ORNL (1943 to 1946), radioactive solid wastes were buried at two sites within the WAG 1 boundary, SWSA 1 and SWSA 2. Another site (called the former waste pile area) was used as a borrow pit and for disposal of noncontaminated construction debris. The latter is included with WAG 1 although it lies just beyond the south WAG 1 boundary, east of SWSA 1 (Fig. 3.5.3).

Geophysical surveys (Johnson and Wagner 1991) were performed in these areas in 1990 using electromagnetic (EM) terrain conductivity and ground magnetometer survey techniques to collect information regarding buried waste that might be present at all three locations. These surveys are discussed in Sect. 2.4, and the extent of the areas surveyed is shown in Fig. 2.4.1.

3.5.3.1 SWSA 1

SWSA 1 is a triangular area of approximately 1 acre 25 ft south of WOC (Fig. 3.5.1). In 1944, contaminated solid wastes were buried in SWSA 1 in trenches using earthen cover. The area is fenced and covered with grass. The geophysical surveys indicated five discrete areas of possible buried solid wastes in SWSA 1, all of which were located by the magnetometer survey and three of which were located by both the magnetometer and EM surveys (Fig. 3.5.14). Overhead power lines and the metal fence surrounding the area interfered with data collection and may have masked additional areas of buried waste (Johnson and Wagner 1991). The feature on Fig. 3.5.14 shown as "interpreted underground utility" (a straight line shown diagonally from southwest to southeast in the northwest portion of the WAG) is believed to be an abandoned section of LLLW pipeline that may have leaked in the late 1950s (Trabalka 1992).

3.5.3.2 SWSA 2

SWSA 2 is a rectangular area of approximately 3.6 acres near the eastern entrance of ORNL, adjacent to the main parking area (Fig. 3.5.3). The area was used from 1944 to 1946 to dispose of contaminated solid waste with gamma and beta activity, liquid waste contaminated with plutonium in stainless steel drums, and alpha-contaminated material from off site. The waste and contaminated soil reportedly were removed and reburied in SWSA 3 some time after 1946, although there have been unsubstantiated reports that some waste (mainly storage tanks and vehicles) remain buried at the site (Bates 1983). The site was backfilled with clean soil and is covered with grass and unfenced (but it is within the greater fenced and secured portion of the main plant area). The geophysical surveys indicated 17 discrete anomalies, 9 of which correspond to locations marking a previous soil boring program (Fig. 3.5.15). Magnetometer data indicated ferrous metal at 15 of the locations, and EM data identified the other 2 locations, neither of which correlated to the soil boring program.

3.5.3.3 Former waste pile area

The former waste pile area is an irregularly shaped area of approximately 1.58 acres located south of the nonradiological wastewater treatment facility (Fig. 3.5.3). Interviews with ORNL staff indicate that the site was used as both a soil borrow area and a disposal area for construction debris (Nix 1989). Excavation for installation of a pipeline uncovered metal and glass containers, transite (asbestos), and miscellaneous metal piping and scrap.

The geophysical (EM and magnetometer) surveys indicated four discrete anomalies (Fig. 3.5.16). One location was influenced by a large steel culvert pipe on the surface within the boundaries of the area; additional ferrous material may be buried east of the culvert pipe. Three buried pipelines were indicated in the northern corner of the area, two trending northwest to southeast, with another crossing the entire waste disposal area from southwest to northeast. One of the suspected pipelines in the northern corner correlates with the location of a double-walled, 2-in. stainless steel pipeline that connects tank W-33 near Building 2531 with the Melton Valley tanks (Binford and Orfi 1979). The other pipelines do not appear on the ORNL Atlas drawings (sheet 28).

3.5.4 Below-Ground SWMUs at WAG 1

3.5.4.1 Piping and utility trenches

When the underground storage tank system was installed at ORNL in 1943 to collect and store LLLW from various process and laboratory buildings, a network of gravity drain pipes and valve boxes was laid in trenches to transport intermediate-level liquid waste (ILW) to a central group of large underground Gunite tanks in STF (Binford and Orfi 1979). NTF was also started in 1943 with four buried Gunite waste collection tanks; it was expanded in 1950 to collect wastes from additional processes in Building 3019. Pipelines were laid in trenches from the building to valve pits, to the NTF tanks, and from the tanks to retention ponds and the large STF Gunite tanks. Additional buried piping was installed for the process waste treatment system to handle liquid wastes generated during normal operations that were not known to be contaminated but required treatment and monitoring before discharge to WOC.

Individual waste collection tanks and associated buried piping systems were added to the LLLW system during the early 1950s for individual buildings and processes at ORNL that were generating radioactive and chemical wastes (Binford and Orfi 1979). Piping systems were added to provide interconnections from most of the newly added tanks to various valve pits for connection to pipes running to the large STF tanks, the ultimate destination for most of the radioactive and chemical waste generated at ORNL. Lines were run to many of the tanks to provide steam for jetting liquids from one tank to another. Vent lines were also run to many tanks to carry the radioactive off-gas wastes to filtration and condensation systems.

The LLLW piping system was modified to meet the operational needs of ORNL activities. The supernatant liquid from the STF tanks was piped to waste holding basin 3513 from 1944 until 1949, when the system was changed to divert the liquids to the pot-type evaporator. The evaporator received the liquid from STF until 1954, when the piping was again changed to transport the effluent from the STF tanks to open pits in WAG 7. That

system was superseded in 1965 when a new evaporator system was built to reduce liquid waste by separating the water from the solid contaminants.

Documentation for many of the older underground piping systems is incomplete. The burial of these piping systems and subsequent burial of other utilities such as water, sewer, steam, gas, and electricity resulted in a complex network of trenches that crisscross the entire main plant area and intersect one another at an undocumented number of locations. The ORNL Atlas process waste maps show that these underground lines are particularly dense around the heart of WAG 1, at Isotopes Circle, the tank farms, and the Graphite and Oak Ridge Research reactors. The Atlas index lists 24 types of underground lines, conduits, ducts, and sewers constructed of 18 different materials.

The 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 primarily of single-walled stainless steel pipe; leaks from these pipes are responsible for 23 SWMUs identified in WAG 1. Known pipeline leaks data back as far as the 1950s. Twenty of the 23 leak sites are located in the 3000 and 3500 blocks of the ORNL complex (see Plate I). Most of the leaks are located close to facilities (buildings or tanks); contamination has been reported under buildings 3026, 3047, 3515, and 3550 (Grimsby 1986). The leaks are commonly near transfer line and tank junctions, and contamination ranges in depth from the ground surface to 20 feet below the ground surface. Contamination has also been documented in the sanitary sewer system as a result of inleakage from leaks in the LLLW lines (Grimsby 1986).

Contaminants from LLLW leaks include fission products (e.g., strontium-90 and cesium-137), activation products (e.g., cobalt-60 and cadmium-115), and transuranics (e.g., americium-241 and plutonium-239). In some cases, contaminated soil was removed when the leak was repaired, although in other cases the soil was not removed. Grimsby (1986) describes individual leak sites in detail.

Certain active singly-contained portions of the LLLW system are now being replaced with double-walled pipe as part of the program for upgrade/replacement of the collection and transfer system to meet the secondary containment provisions of the FFA (Robinson et al. 1991).

An estimate of the total length of known underground lines in WAG 1, based on the Atlas, yields approximately 50 miles of buried lines. Some of these lines are in common trenches, and some lines were not counted because they are not on the Atlas drawings.

Types of lines identified in the Atlas include potable water, process water, distilled water, sanitary sewer, process sewer, cooling water, hot waste, demineralized water, steam, chemical, condensate, air, telephone, electrical conduit, exhaust duct, electrical cable, natural gas, off gas, fuel, hydrogen/helium, oxygen, nitrogen, vacuum, and storm sewer. Construction materials include vitrified pipe, chemical ware, cast iron, galvanized iron, Hastelloy, wrought iron, copper, reinforced concrete, corrugated metal, aluminum, sheet iron, steel, wrought steel, Duriron, stainless steel, concrete-coated steel, concrete-encased conduit, concrete, and PVC. The LLLW system consists primarily of stainless steel pipe,

while the process waste and sewer lines are typically vitrified clay pipe. Most of the process waste and some of the sewer lines have been lined using the Insituform process. Over the long history of ORNL, many construction materials and methods have been used, making generalizations of system characteristics difficult.

Chen et al. (1988) modeled the effects of trenches on shallow groundwater flow and concluded that a factor of 10 difference in hydraulic conductivity between trench fill materials and native soils would cause groundwater flow to preferentially follow the trenches. This could lead to accelerated contaminant transport and could result in inaccurate interpretations of data from piezometers and monitoring wells that miss these preferential flow paths. In 1985, a dye-tracing investigation provided some evidence for this theory (Huff 1985). Dye injected at a line break north of Building 3019 moved east, toward a nearby sump and along strike, and south. The movement south is believed to follow sewer trenches under Building 3019. A limited assessment of contaminant migration along trench backfill soils performed as part of the Phase I investigation is discussed in Sect. 3.3. No significant differences in hydraulic conduction were found between the trench backfill material and the surrounding overburden. The relationship between buried pipelines and groundwater is shown graphically in Fig. 3.3.24.

In summary, the underground LLLW piping has been major source of potential contamination in WAG 1. The trenches in which these and other pipes are located are likely to provide preferential pathways for groundwater flow and contaminant transport. With approximately 50 miles of trenches in WAG 1, distortion of shallow groundwater flow could be significant.

3.5.4.2 Radioactive material storage gardens

Cobalt-60 storage garden 3029 (SWMU 1.A4). This subsurface radioisotope storage facility is located in Building 3029. Constructed in the late 1950s (ORNL 1990), it is still operable, though it is not being used in active programs. The current inventory of the facility is about 3500 Ci of metallic form cobalt-60 (Whitehead 1992). No waste is produced by this facility, and no releases have been reported. This facility is housed in a concrete vault that is 8.5 ft deep and about 4.5 ft by 4.5 ft inside. The cobalt-60 storage cans are located in the bottom of 92 vertical stainless steel tubes that extend about 1 ft above the floor. The tubes are arranged around a central irradiation chamber 1 ft square by 6.8 ft deep. Shielding is provided by 22 in. of lead bricks plus 22 in. of barite concrete around the chamber and lead plugs at the tops of the cobalt-60 tubes.

Storage garden 3033 (SWMU 1.8A). This site of a former subsurface radioactive material storage facility is outside on the north side of Building 3033. The facility originally consisted of seven stainless steel cylinders about 1 ft in diameter and 5 ft deep, set in concrete, with about 3 in. extending above ground level. It was constructed in 1956, removed from service in 1976; and decommissioned in 1990 when the contents of the stainless steel cylinders were emptied and the cylinders were removed from the ground (ORNL 1990). The cylinders were leak-tested and found to be tight before they were removed, and no contamination was detected outside them. The site was backfilled and covered with a concrete slab to match the surrounding pavement.

3.5.4.3 Below-ground pits and canals

3517 filter pit (SWMU 1.20). This concrete pit east of Building 3517 houses air filters from the Building 3517. The filter system was put in operation in 1958; fiber filters were replaced in 1960 with washable stainless steel filters. The washable filters were in turn replaced in the 1970s with HEPA filters (Taylor 1986b). A general facility upgrade was completed in 1986 (ORNL 1990) and the filter pit is presently in use. This filter pit was contaminated by backwash water from the former stainless steel filter system. Recent excavation at the site removed large quantities (ORNL 1990) of contaminated soil; maximum radiation levels of 30 R/h were recorded by one monitoring meter. An undetermined amount of contaminated soil remains in place. Levels of radiation in the filters currently measure approximately 200 R/h; the primary radionuclides present are cesium-137 and strontium-90.

Transfer canal and dissolver pit 3505 (SWMU 1.63). These below-ground concrete structures are on the west side of Building 3505. The dissolver pit is under the building and is about 10 ft by 6.5 ft by 10 ft deep. The transfer canal extends beyond the west side of the building and is about 50 ft long, 6.5 ft wide, and 14 ft deep. These structures were used to handle fuel elements from 1952 to 1960, when they were removed from service because they lacked secondary containment. The process involved dissolving fuel element metal cladding for uranium recovery, and water was used for shielding. The structures still contain water, and no releases have been reported. Slight contamination of the canal walls and water with strontium-90, cesium-137, cobalt-60, and uranium and plutonium isotopes is possible. The facility is currently monitored under the surplus facility program.

3001 storage canal (SWMU 1.79). This below-ground concrete structure connects the Graphite Reactor in Building 3001 with the Radiochemical Processing Pilot Plant in Building 3019. The 7-ft-wide, 11.5-ft-deep, and 101-ft-long canal is covered with a concrete lid and soil and has a capacity of 62,000 gal (ORNL 1990). Used for underwater transfer of spent fuel from the reactor to Building 3001, the canal was in operation from 1943 to 1963 when the reactor was shut down. The canal was then used for storage of radioisotopes until 1990, when a leak was discovered and removal of the stored material was initiated (ORNL 1990). The leak was stopped, and remediation of the contaminants in the canal was begun in 1992 in accordance with an approved closure plan.

3.5.5 Above-Ground Structures or Process Facilities

3.5.5.1 Contamination at base of 3019 stack (SWMU 1.7)

This site now referred to as the "3019 Hot Bank" is an area south of Building 3020 and west of Building 3091. Although no longer designated as a structure specifically, the site is included here because of reports that it is a continual source of surface water contamination (ORNL 1990). The area was contaminated in the 1950s and 1960s by a combination of emissions from 3019 stack and LLLW line leaks in the area. A water sample taken in 1987 from the storm sewer catch basin southwest of the chimney-vent station contained 200 pCi/L of strontium-90 and a gross beta activity of 260 pCi/g and sediment samples contained 51 pCi/g of strontium-90 and a gross beta activity of 190 pCi/g (ORNL 1990).

3.5.5.2 Storage pad 3503-3504 (SWMU 1.10A)

These storage pads are located together southwest of Building 3503. The concrete pad covers an area of about 29 ft by 39 ft. Two parts of the pad are roofed over where drums and surplus miscellaneous equipment are stored on metal trays. The equipment and materials are contaminated with radionuclides. Built in the late 1950s, the site is still in use. A 4-in.-thick concrete slab was poured over the pad in the 1970s to cover radionuclide contamination, which is believed to be uranium-238 and plutonium-239 (ORNL 1990). When biased soil samples were taken at the site in 1986, the dominant detectable radionuclide was cesium-137; no RCRA-hazardous substances were detected (ORNL 1990).

The storage pad is just north of WOC, and migration of contamination to the creek by rainwater runoff is possible.

3.5.5.3 Isotopes ductwork/3110 filter house (SWMU 1.22)

This site, on Hillside Avenue between Third and Fifth Streets, consists of the 3110 filter house and underground ductwork connecting to several buildings. The ductwork was put in operation in the 1960s, and the filter house is in continuous operation. Without internal investigation, the inside surfaces of the ductwork are assumed to be contaminated with various radionuclides. A floor drain in the filter house collects water and discharges it to the LLLW system (ORNL 1990). Specific characterization and release data are not available.

3.5.5.4 Waste evaporator facility 3506 (SWMU 1.62)

This facility in Building 3506 consists of a concrete cell with underground piping, a valve pit, and an attached wood-framed operating area. The facility was in service from 1949 to 1954 to use evaporation as a method for concentration and volume reduction of LLLW prior to final disposal. Until roof leaks were repaired in 1990 (ORNL 1990), water from the leaks was pumped to process drains. Inside the structure, contaminated pipe chases and surplus support equipment exhibit dose rates up to 10 mrad/h, with transferable surface contamination of several thousand dpm/100 cm^2 (ORNL 1990). Primary radionuclides are strontium-90, cesium-137, ruthenium-106, and cobalt-60; plutonium, uranium, and other transuranic isotopes are also present.

3.5.5.5 Underground exhaust ducts 3001–3003 (SWMU 1.A1E)

This underground duct system north of Building 3001 was constructed in 1943 to convey air from the Graphite Reactor (3001) to the filter house (3002), the fan house (3003), and then to the stack (3010). It is currently in operation. The inside surfaces of the duct have not been characterized, but they are probably contaminated with fission products (ORNL 1990). No releases from the ducts have been reported.

3.5.5.6 Fission product pilot plant 3515 (SWMU 1.A6)

This structure is located on the east side of STF in Building 3515. This facility has also been called the ruthenium-106 tank arrangement, which consisted of a concrete pad and tanks surrounded by stacks of concrete blocks. The present facility consists of an unlined concrete-shielded cell, approximately 19.7 ft by 9.9 ft by 7.9 ft high, with an adjacent shielded operating area (ORNL 1990). The facility, which was constructed in 1948 and removed from service in 1958, was used to separate curie quantities of various radionuclides from LLLW (ORNL 1990). Specific waste characterization data are not available, but the current radionuclide inventory is believed to be in the range of 10 to 100 Ci (ORNL 1990). A release from the facility was recorded in 1988, but no estimate of radionuclides released is available. The facility was roofed over and the ground to the east was covered with Hypalon and gravel and placarded as a contamination area (ORNL 1990).

3.5.5.7 High-level chemical development laboratory 4507 (SWMU 1.A12)

This facility in Building 4507 is an above-ground structure containing a ground level with four hot cells, a second level for chemical make-up equipment, and a penthouse area above the hot cells with glove boxes, a gantry crane, and a shielded manipulator. Constructed in 1957, the building was removed from service in 1980 and mothballed. The inventory of radionuclides inside this structure is estimated to be less than 1000 Ci, but specific characterization data are not available. No releases have been reported.

3.5.5.8 High-level radiochemical analytical laboratory 3019B (SWMU 1.A15)

This building, located at the intersection of Third Street and Hillside Avenue, is 36 ft by 64 ft and contains seven hot cells and a storage cell. Constructed in 1955 to perform chemical analyses on highly radioactive materials, the facility was removed from service in 1980. Specific characterization data for the contents of the building are not available, but residual contamination from strontium-90, cesium-137, and transuranic materials is probable (ORNL 1990). No releases have been reported.

3.5.5.9 Off-gas filter house 3121 (SWMU 1.A17)

Built in 1966, this structure southeast of Building 3019 contains air filters that were used to filter exhaust air from hot cells in the building. The structure was removed from service in 1986, and no releases have been reported. Specific characterization data for the inside of the structure are not available, but filtered air and gases probably contained volatile fission products from hot cell fuel reprocessing operations (ORNL 1990).

REFERENCES FOR SECTION 3

Ashwood, T. L. et al. 1986. "An Experimental Approach to Determine Subsurface Leakage from a Surface Impoundment Using a Radioactive Tracer," *Proceedings of the Focus Conference on Southeastern Groundwater Issues, October 6-8, 1986, Tampa, Florida,* National Water Well Association, Dublin, Ohio.

Ashwood, T. L. 1988. *Flow in Pipeline Trenches in the Main Plant Area (WAG 1): A Status Report on FY 1988 Activities,* ORNL/RAP/LTR-88/54, ORNL, Oak Ridge, Tenn.

Autrey, J. W. et al., 1990. *Sampling and Analysis of the Inactive Waste Storage Tanks Contents at ORNL,* ORNL/ER-13, Oak Ridge National Laboratory, Oak Ridge Tenn.

Autrey, J. W. et al. 1992. *Sampling and Analysis of the Inactive Waste Tanks TH-2, WC-1, and WC-15,* ORNL/ER-19, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Bates, L. D. 1983. *Radioactive Solid Waste Storage and Disposal at Oak Ridge National Laboratory; Description and Safety Analysis,* ORNL/TM-8201, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Bates, L.D. 1992. "Annual Update of the Solid Waste Management Units List for the Oak Ridge Reservation," Letter ERP-TI/92-053, Martin Marietta Energy Systems, Oak Ridge, Tenn.

Baughn, D. C. 1987. *Preliminary Geohydrologic Site Characterization and Proposed Water Quality Well Locations for WAG 4, WAG 5, WAG 3 and SWSA 1,* ORNL/RAP/Sub-86/72139/1, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Bedinger, M. S. 1989. *Geohydrologic Aspects for Siting and Design of Low-Level Radioactive-Waste Disposal,* U. S. Geological Survey Circular 1034.

Berry, J. B. and H. R. Yook 1987. *Environmental Restoration and Facilities Upgrade, Water Pollution Control Strategy,* ORNL/TM-10343, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Binford, F. T. and S. D. Orfi 1979. *The Intermediate-Level Liquid Waste System at the Oak Ridge National Laboratory—Description and Safety Analysis,* ORNL/TM-6959, Oak Ridge National Laboratory, Oak Ridge Tenn.

Bittner, E. and R. B. Dreier 1990. "Core Fracture Analysis Applied to Groundwater Flow Systems: Chickamauga Group, Oak Ridge, Tennessee," in *Case Studies and Applied Geology in the Southeastern U.S.*; Georgia Dept. of Natural Resources, Environmental Protection Division, Georgia Geol. Survey Bul. 122; Denny Bearce and Michael Neilson, editors.

Bloch, S. and R. M. Key 1981. *Modes of Formation of Anomalously High Radioactivity in Oil Field Brines,* American Association of Petroleum Geologists, Geologic Notes.

BNI 1991. *RCRA Facility Investigation Report for Waste Area Grouping 6 at Oak Ridge National Laboratory, Oak Ridge, Tennessee,* ES/ER-22/V1&D1, ORNL/ER/Sub-87/99053/5/V1, Oak Ridge, Tenn.

BNI 1992. *Video Inspection Data Manual for Inactive LLLW Storage Tanks at Oak Ridge National Laboratory,* ORNL/ER/Sub/87-99053/45, Bechtel National, Inc., Oak Ridge, Tenn.

Boegly, W. J., Jr. 1984. *Site Characterization Data for Solid Waste Storage Area 6,* ORNL/TM-9442, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Boegly, W. J. et al. 1987. *Environmental Data Package for the Main Plant Area (WAG 1),* ORNL/RAP-13, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Borders, D. M. et al. 1991. *Annual Hydrologic Summary for the White Oak Creek Watershed Water Year 1990 (October 1989–September 1990),* ORNL/ER-55, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Borders, D. M. 1992. D. M. Borders (Oak Ridge National Laboratory), personal communication with Vefa Yucel (Bechtel National, Inc.), Oak Ridge, Tenn.

Braunstein, H. M. et al. 1984. *An Investigation of the Concentration, Distribution, and Inventory of Radionuclides in the Sediment of Process Waste System Basin 3524,* ORNL/TM-8682, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Burwinkle, T.W. 1987. *The ORNL Surplue Facilities Management Program Maintenance and Surveillance Plan, FY 1988–1997,* ORNL/RAP-16, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Carroll, D. 1961. *Soils and Rocks of the Oak Ridge Area, Tennessee,* U. S. Geological Survey, TEI-785 (Trace Element Investigations).

Cerling, T. E. and B. P. Spalding 1981. *Areal Distribution of Co-60, Cs-137, and Sr-90 in Streambed Gravels of White Oak Creek Watershed, Oak Ridge, Tennessee,* ORNL/TM-7318, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Chen, G. L. et al. 1988. *Simulation of Groundwater Flow in a Pipeline Trench Network Using a 3-Dimensional Finite Element Model of Water Flow Through Saturated-Unsaturated Media,* ORNL/RAP/LTR-88/45, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Coobs, J. H. and T. E. Myrick 1983. *The ORNL Surplus Facilities Management Program Maintenance and Surveillance Plan for Fiscal Year 1984,* ORNL/CF-83/56, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Davis, E. C. et al. 1984. *Site Characterization Techniques Used at a Low-Level Waste Shallow Land Burial Field Demonstration Facility,* ORNL/TM-9146, Oak Ridge National Laboratory, Oak Ridge, Tenn.

de Laguna, W. et al. 1968. *Engineering Development of Hydraulic Fracturing as a Method for Permanent Disposal of Radioactive Wastes,* ORNL-4259, Oak Ridge National Laboratory, Oak Ridge, Tenn.

EPA 1984. *RCRA 1984 Hazardous and Solid Waste Amendments (HSWA) Permit, Building 7652-Oak Ridge National Laboratory, EPA ID Number-TNI 890090003, Permit Number HSWA TN 001, Department of Energy, Oak Ridge, Tennessee.*

Fontaine, T. A. 1992. T. A. Fontaine (ORNL), personal communication with Vefa Yucel (Bechtel National, Inc.), BNI CCN 016568, Oak Ridge, Tenn.

Francis, C. W. and R. G. Stansfield 1986. *Groundwater Monitoring at Three Oak Ridge National Laboratory Inactive Waste Impoundments,* ORNL/TM-10193, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Fricke, K. E. 1986. *Seismic Analysis of the Underground Gunite Tanks at the ORNL South Tank Farm,* X-OE-313, Oak Ridge Gaseous Diffusion Plant, Oak Ridge, Tenn.

Geraghty and Miller, Inc. 1986. *Monitoring Plan for Characterization of the Building 3019 Leak Site,* ORNL/Sub/85-97368/1, Oak Ridge, Tenn.

Geraghty and Miller, Inc. 1990. *Monitoring Plan for Characterization of the Building 3028 Leak Site,* ORNL/Sub/85-97368/2, Oak Ridge, Tenn.

Gott, G. B. and J. W. Hill 1953. *Radioactivity in Some Oil Fields of Southeastern Kansas,* U. S. Geological Survey Bulletin 988-E, pp. 69-122.

Grimsby, H. J. 1986. *Identification of Low-Level Waste Line Leak Sites at Oak Ridge National Laboratory,* ORNL/RAP/LTR-86/8, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Horton, J. R. 1984. *Preliminary Decommissioning Study Reports, Volume 3: Low-Level Liquid Waste (LLLW) Collection and Storage Tanks,* X-0E-231, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Huang, S. F. et al. 1984. *Preliminary Radiological Characterization of Fifteen Waste Tanks at Oak Ridge National Laboratory,* ORNL/CF-84/203, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Huff, D. D. 1985. *Dry-weather Dye Tracing Investigation—Groundwater Flow Pathways from Line Break,* RAP-85-6, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Hyde, L. D. 1986. *1986 Piezometer Well Installation at ORNL,* ORNL/RAP/LTR-86/97, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Hyde, L. D. 1987. *Water Quality Monitoring Well Installation at ORNL,* ORNL/RAP/LTR-87/10, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Johnson, D. and T. Wagner 1991. *WAG 1 Electromagnetic Terrain Conductivity and Ground Magnetometer Survey,* Technical Memorandum 01-03, Bechtel National, Inc., Oak Ridge, Tenn.

Ketelle, R. H. et al. 1986. *1986 Groundwater System Characterization*, ORNL/RAP/86-75, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Ketelle, R. H. and R. R. Lee 1992. *Migration of a Groundwater Contaminant Plume by Strata-bound Flow in WAG 1 at Oak Ridge National Laboratory, Oak Ridge, Tennessee,* ORNL/ER-126, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Kitchings, J. T. and R. K. Owenby 1986. *Applicability of RCRA Part B Permitting Requirments to ORNL's Surface Impoundments 3524, 3539, 3540, 7905, 7906, 7907, and 7908*, ORNL/RAP/LTR-86/43, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Lambe, T. W. and R. V. Whitman 1969. *Soil Mechanics,* John Wiley and Sons, Inc., New York.

Lee, R. R. and R. H. Ketelle 1987. *Stratigraphic Influence on Deep Groundwater Flow in the Knox Group Copper Ridge Dolomite on the West Chestnut Ridge Site*, ORNL/TM-10479, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Lee, R. R. and R. H. Ketelle 1988. *Subsurface Geology of the Chickamauga Group at Oak Ridge National Laboratory,* ORNL/TM-10749, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Lietzke, D. A., S. Y. Lee, and T. Tamura 1986. *Resource Management Plan for the Oak Ridge Reservation, Volume 20: Soil Conservation Plan for the Oak Ridge Reservation,* ORNL/ESH-1/V20, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Lozier, W. B. and R. Pearson 1987. *Installation of Packers and Hydraulic Testing of Coreholes CH-1 through CH-5, ORNL Plant Area, Volumes 1 and 2,* ORNL/Sub/86-32136/3/V1&2, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Lumb, A. M. et al. 1990. *Users Manual for ANNIE, A Computer Program for Interactive Hydrologic Analyses and Data Management*, U.S. Geological Survey, Water-Resources Investigations Report 89–4080, Reston, Virginia.

MacFarlane, P. A. and L. R. Hathaway 1987. *The Hydrogeology of Ground Waters from the Lower Paleozoic Aquifers in the Tri-State Region of Kansas, Missouri, and Oklahoma,* Kansas Geological Survey, Ground-Water Series 9, p. 37.

MCI Consulting Engineers, Inc. and H&R Technical Associates, Inc. 1985. *Liquid Low-Level Waste System Active Storage Tanks: Closure Plan*, prepared for Oak Ridge National Laboratory, Oak Ridge, Tenn.

MCI Consulting Engineers, Inc. 1986. *RCRA Monitoring Well Installation Report—Surface Impoundments 3524, 3539, 3540, 7905, 7906, 7907, 7908,* Oak Ridge, Tenn.

McMaster, W. M. 1967. "Hydrologic Data for the Oak Ridge Area, Tennessee," U. S. Geological Survey Water-Supply Paper 1839-N, Nashville, Tenn.

McMaster, W. M. and H. D. Waller 1965. *Geology and Soils of White Oak Creek Basin, Tennessee,* ORNL/TM-1108, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Melroy, L. 1986. *3019/3074 Wet Weather Dye Tracer Study,* RAP 86-42, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Moneymaker 1981. *Soil Survey of Anderson County, Tennessee,* U. S. Department of Agriculture, Soil Conservation Service.

Moore, G. K., D. D. Huff, and R. H. Ketelle 1987. *FY 1987 Piezometer Well Data Summary,* ORNL/RAP/LTR-87/80, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Moore, G. K. 1988. *Concepts of Groundwater Occurrence and Flow Near Oak Ridge National Laboratory, Tennessee,* ORNL/TM-10969, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Moore, G. K. 1989. *Groundwater Parameters and Flow Systems Near Oak Ridge National Laboratory,* TM-11368, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Moore, G. K. and S. C. Young 1992. *Identification of Groundwater-Producing Fractures by Using an Electromagnetic Borehole Flowmeter in Monitoring Wells on the Oak Ridge Reservation, Oak Ridge, Tennessee,* ORNL/ER-91, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Mortimore, J. A. 1987a. *Groundwater Quality Monitoring Well Installation in WAG 1, Oak Ridge National Laboratory, Oak Ridge, Tennessee,* ORNL/RAP-47, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Mortimore, J. A. 1987b. *Piezometer Installation in WAG 1: The Main Plant Area, SWSA 1, and SWSA 2,* ORNL/RAP/LTR-87/53, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Mynatt, F. R. and C. C. Webster 1963. *An Analysis of the South Tank Farm and the Potential Hazards Associated with Continued Use of the Tanks as Part of the Intermediate-Level Liquid Waste Disposal System*, ORNL/TM-604, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Myrick, T. E. (undated). *The ORNL Surplus Facilities Management Program Long Range Plan*, ORNL/TM-8957, Oak Ridge National Laboratory, Oak Ridge, Tenn.

NOAA 1982. *Application of Probable Precipitation Estimates, United States East of the 105th Meridian,* Hydrometeorological Report No. 52.

Nix, C. E. 1989. C. E. Nix (ORNL), personal communication with J. T. Kitchings (ORNL), Oak Ridge, Tenn. (June).

Olsen, C. R. et al. 1983. *Chemical, Geological, and Hydrological Factors Governing Radionuclide Migration from a Formerly Used Seepage Trench: A Field Study,* ORNL/TM-8839, Oak Ridge National Laboratory, Oak Ridge, Tenn.

ORNL 1990. *Contaminated Sites Summary Sheets*, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Peretz, F. J. et al. 1986. *Characterization of Low-Level Liquid Wastes at the Oak Ridge National Laboratory,* ORNL/TM-10218, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Robinson, S. M. et al. 1991. *Federal Facility Agreement Contingency, Upgrade, and Replacement Plans for the ORNL Active Low-Level Radioactive Waste Tank System,* ORNL/TM-11795, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Rothschild, E. R. et al. 1984. *Geohydrologic Characterization of Proposed SWSA 7,* ORNL/TM-9314, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Solomon, D. K. et al. 1989. *Groundwater Monitoring in 1988 at Three Oak Ridge National Laboratory Inactive Waste Impoundments*, ORNL/TM-11022, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Stansfield, R. G., and C. W. Francis 1986a. *Characterization Plan for the Waste Holding Basin (3513 Impoundment),* ORNL/TM-9969, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Stansfield, R. G. and C. W. Francis 1986b. *Characteristics of the 3513 Impoundment,* ORNL/TM-9936, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Stockdale, P. B. 1951. *Geological Conditions at the ORNL (X-10) Area Relevant to the Disposal of Radioactive Waste,* ORO-58, Oak Ridge, Tenn.

Stueber, A. M. et al. 1981. *An Investigation of Radioactive Release from Solid Waste Disposal Area 3, Oak Ridge National Laboratory,* ORNL/TM-7323, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Taylor, F. G. 1986a. *Inventory of ORNL Remedial Action Sites: Process Ponds,* RAP/86-14/R1, Oak Ridge National Laboratory, Oak Ridge, Tenn.

Taylor, F. G. 1986b. *Inventory of ORNL Remedial Action Sites: Radwaste Facilities*, ORNL/RAP-86-22/R1, Oak Ridge National Laboratory, Oak Ridge Tenn.

Thomson, S. L. 1991. *Radionuclide Inventory in the WAG 1 Inactive Tanks*, ORNL RI/FS Technical Bulletin 01-TB-018, Bechtel National, Inc., Oak Ridge, Tenn.

Trabalka, J. R. 1992. Memorandum (August 28) to Linda Kaiser (ORNL)," Inactive Low-Level Liquid Waste Pipeline in Solid Waste Storage Area 1," BNI CCN 016469, Oak Ridge, Tenn.

Webster, D. A. 1976. *A Review of Hydrologic and Geologic Conditions Related to the Radioactive Solid-Waste Burial Grounds at Oak Ridge National Laboratory, Tennessee*, U. S. Geological Survey Open File Report 76-727, Knoxville, Tenn.

Webster, D. A. and M. W. Bradley 1988. *Hydrology of the Melton Valley Radioactive-Waste Burial Grounds at Oak Ridge National Laboratory, Oak Ridge, Tennessee*, U.S. Geological Survey Open-File Report 87-686, Knoxville, Tenn.

West, J. S. 1991. "LLLW Tank System Information," Letter to L. H. Stinton et al. (January 31), Oak Ridge National Laboratory, Oak Ridge, Tenn.

Whitehead, L. 1992. Memorandum (August 31) to A. Day (Bechtel), "Comments on Site Characterization Summary Report," BNI CCN 016392, Oak Ridge, Tenn.

Table 3.1.1. Climate data for 1990–1991

	1990[a]			1991[b]		
	Mean daily maximum temperature (°F)	Mean daily minimum temperature (°F)	Total monthly precipitation (in.)	Mean daily maximum temperature (°F)	Mean daily minimum temperature (°F)	Total monthly precipitation (in.)
January	52.9	32.6	5.54	48.2	32.3	2.54
February	59.4	35.9	7.51	54.3	30.8	8.08
March	65.0	42.3	4.72	64.1	38.8	7.32
April	70.2	42.2	2.50	75.4	50.2	2.99
May	76.5	52.7	7.83	83.2	61.1	4.06
June	87.0	62.9	1.68	83.2	66.5	5.12
July	88.2	66.3	8.11	89.0	69.2	3.12
August	88.4	66.8	6.51	87.4	66.2	3.35
September	78.1	60.2	1.41	82.6	60.2	1.87
October	72.7	45.5	4.25	75.5	45.9	1.59
November	65.1	35.6	2.39	56.6	34.4	4.38
December	52.7	33.3	11.86	52.1	32.1	11.19

Sources: Temperature: Atmospheric Turbulence and Diffusion Laboratory, National Oceanic and Atmospheric Administration, Oak Ridge, Tenn. Rainfall: Environmental Sciences Division, Energy Systems First Creek rain gauge.

[a]1990 average annual temperature was 60.4°F; total annual precipitation was 64.31 in.
[b]1991 average annual temperature was 60.2°F; total annual precipitation was 55.62 in.

Table 3.2.1. Soil series at WAG 1

Chickamauga Group unit		Soil series	Soil Conservation Service series	Map unit
B	Upland soils			
		Bland	Same	BaE
		Colbert	Carbo/Gladeville	CeC/GdC
C	Upland soils			
		Fullerton	Same	FuE
		Clarksville	Fullerton	FuE
	Colluvial soils			
		Minvale	Same	MaC
D	Upland soils			
E		Talbott	Collegedale/Gladeville	CoD/GdC
F		Colbert	Carbo/Gladeville	CeC/GdC
G	Alluvial-colluvial soils			
		Linside	Newark	Ne
		Minvale	Same	MaC
H	Upland soils			
		Litz	Collegedale	CoC
		Armuchee	Same	AmD
	Colluvial soils			
		Muse	Shouns	ShD

Notes:
(1) Modified from McMaster and Waller (1965).
(2) Soil Conservation Service soil series from Moneymaker (1981).
(3) Map unit refers to Soil Conservation Service map unit.

Table 3.2.2. Physical properties of soil

Soil series	Depth	Unified soil classification	Liquid limit (%)	Plasticity index	Shrink/swell potential	Soil reaction pH	Percent fines (passing No. 200)	Permeability (in./h)
Residuum								
Bland	Surface	CL,CH	50-60	25-35	Moderate	5.1-7.3	60-95	0.6-2.0
	Subsoil	MH,CH,GC,GM	65-75	35-45	Moderate	5.1-7.3	20-90	0.2-0.6
Carbo	Surface	CH,CL	45-60	20-35	Moderate	6.1-7.3	75-85	0.2-0.6
	Subsoil	CH	65-75	35-45	High	6.6-7.8	70-90	0.06-0.2
Gladeville	Surface	GC,CL,CH	38-55	20-34	Moderate	6.6-8.4	20-55	0.6-2.0
	Subsoil	Bedrock	NA	NA	NA	NA	NA	NA
Fullerton	Surface	ML,CL-ML,CL,GM	16-30	3-10	Low	4.5-5.5	30-70	0.6-2.0
	Subsoil	CL,GC,SC,MH,ML	29-78	11-42	Low-Moderate	4.5-5.5	30-75	0.6-2.0
Armuchee	Surface	CL,ML,CL-ML	25-39	5-15	Low	4.5-5.5	70-85	0.6-2.0
	Subsoil	MH,ML,CL,CH,GC	32-70	12-35	Moderate	4.5-5.5	15-70	0.2-0.6
Collegedale	Surface	ML,CL-ML,CL	24-39	5-16	Low	4.5-5.5	70-90	0.6-2.0
	Subsoil	MH,CH,CL	41-80	18-46	Moderate	4.5-5.5	75-95	0.6-0.06
Colluvium								
Minvale	Surface	ML,CL,CL-ML	<30	NP-10	Low	4.5-5.5	55-75	2.0-6.0
	Subsoil	CL,CL-ML,GC,GM-GC	20-30	5-15	Low	4.5-5.5	36-65	0.6-2.0
Shouns	Surface	ML,CL,CL-ML	15-30	3-12	Low	5.1-6.0	55-90	0.6-2.0
	Subsoil	CL	25-45	8-20	Low	5.1-6.0	50-90	0.6-2.0
Alluvium								
Newark	Surface	ML,CL,CL-ML	<30	NP-10	Low	5.6-7.8	55-95	0.6-2.0
	Subsoil	ML,CL,CL-ML	22-42	4-20	Low	5.6-7.8	55-95	0.6-2.0

Notes:
(1) Data from Soil Survey of Anderson County (Moneymaker 1981).
(2) Map unit refers to Soil Conservation Service map unit.
(3) Percent fines is the percent passing the Number 200 sieve.
(4) NP = Nonplastic.
(5) NA = Not applicable.

Table 3.2.3. Cation exchange capacity results for WAG 1 soil samples

Boring No.	Underlying Chickamauga unit	Sample depth (ft)	Unified soil classification of material	Cation exchange capacity (meq/100 g soil)
01.SB130	D	10-12	CL	12.38
01.SB135	D	24-25.8	CL	13.95
01.SB165	E	4-6	CL	16.39
01.SB165	E	6-8.1	CL	42.43
01.SB184B	E	6-8	CL	15.96
01.SB181[a]	E/F	6-7.2	OL-CL	12.11
01.SB208[b]	G	6-8	CL	13.59
01.SB208[b]	G	8-10	CL	15.99
01.SB208[b]	G	10-10.9	GM	10.37
01.SB103	G	8-9.9	CL	14.51

[a]Boring 01.SB181 drilled through backfill over drain line.
[b]Boring 01.SB208 may be in backfill material.

Table 3.2.4. Description of Chickamauga Group bedrock units

Unit				
Stockdate (1951)	Lemiszki (1992)	Range in thickness (ft)	Lithologic description	Degree of fracture
Rome Formation		>1000	Evenly bedded, fine-grained sandstone, siltstone and shale; displays banding of shades of maroon, red, greenish-blue, olive-green, yellow, brown, and gray; forms narrow and steep sided ridges.	Unknown
A	Edison and Five Oaks	240-347	Thick interbedded sections of maroon and olive-gray calcareous silstone and light gray laminar limestone; fossiliferous; chert nodules and beds.	Low
B	Hogskin and Fleanor	215-284	Massively bedded, calcareous, maroon siltstone with light gray, fine- to medium-grained limestone beds; dark olive-gray calcareous silstone in extreme upper and lower portions of unit.	High
C	Rockdell	95-105[a]	Medium- to massive-bedded, fine- to medium-grained, stylolitic limestone with thin beds of dark olive-gray siltstone; cherty, micritic, burrowed.	Moderate
D	Rockdell	160-168	Thinly to massively bedded, micritic- to medium-grained, nodular, fossiliferous limestone with stylolites, chert nodules, and beds; thinly bedded, bioturbated olive-gray siltstone in upper portion of unit.	Moderate
E	Benbolt	349-380	Uppermost lithology is massive, fine- to medium-grained calcarenite. Middle lithology is unfossiliferous siltstone with light gray laminar limestone. Lowermost lithology is medium gray, micritic- to medium-grained, fossiliferous, nodular limestone.	Low to Moderate
F	Bowen	21-35	Maroon, thin- to medium-bedded, calcareous and shaly silstone; extensively burrowed.	Low to Moderate
G	Witten	300-319	Uppermost lithology is thin-bedded, dark gray silstone and light gray limestone, slightly fossiliferous, stylolitic, extensively burrowed; middle lithology is light gray, fine- to medium-grained limestone interbedded with olive to brownish gray wavy silstone partings; lowermost lithology is fossiliferous, nodular limestone, evenly burrowed throughout.	High
H	Moccasin	300	Interbedded fine-grained, gray- to buff-colored limestone and calcareous gray- and maroon-colored siltstone; some fossiliferous zones.	Moderate

[a]Unit C at corehole FT10 is 40 ft thick (based on geophysical logs).

Table 3.2.5. Physical and chemical properties of Maryville Limestone and Nolichucky Shale in Melton Valley

		Unit	Maryville Limestone[a]	Nolichucky Shale[b]	Chickamauga Limestone[c]
K_ds	^{241}Am	L/kg	27,600	28,400	
	^{85}Ar	L/kg	63.1	38	
	^{134}Cs	L/kg	27,400	26,200	
	^{58}Co	L/kg	2,720	2,197	
	^{125}I	L/kg	9.4	12.5	
	Ca+Mg	L/kg	56	40.8	
Exchangeable Ca		meq/kg	113	119	
Exchangeable Mg		meq/kg	19.1	22	
Exchangeable Na		meq/kg	0.3	0.4	
Exchangeable acidity		meq/kg	16.0	11.0	
CEC		meq/kg	149	154	11.25
pH		-log[H^+]	7.6	7.7	
Bulk density		g/cm^3	2.63	NA[d]	
Total porosity[e]		%	1.8	NA	0.74

Source: BNI 1991.

[a]Mean of 23 Maryville rock cutting samples (<2 mm) from the 115-ft deep well 10 in SWSA 7 (Davis et al. 1984)

[b]Mean of 3 Nolichucky rock cutting samples from the 25-ft deep well 13 at SWSA 7 (Rothschild et al. 1984b)

[c]Mean of 13 core samples for CEC and 5 core samples for total porosity, collected from depths greater than 2000 ft in the Joy test well in Melton Valley (deLaguna et al. 1968).

[d]NA = Not analyzed.

[e]Mean total porosity calculated, where total porosity = [(1-(bulk density/2.68) × 100].

Table 3.2.6. Solution features identified at and near WAG 1

Location	Unit	Approximate depth (ft)	Description
547	D	31.5–36.0	Mud filled
634	D	27.0–28.0	No description
813	D	26.1–29.0	Clay filled
813	D	30.0–39.0	Open void
818	D	17.0–21.0	No description
818	D	34.0–35.0	No description
819	E	7.0–9.0	Mud filled
828	H	17.0–19.0	Open
588	D	<60	Clay filled
883	G	47.5–49.5	Clay filled (sandy clay)
CH07A	D	<133 (several zones)	Several broken or soft zones
CH006	C	18–27	Rubble zone; no return of circulation water
CH006	C/D	50.8–60.8	Rubble zone; no return of circulation water

Table 3.3.1. Well installation history

Well No.	No. wells	Date installed	Description[a]	Reference
530-635	99 (89 used for RI)	1985-1987	2-in. PVC piezometer (water levels and chemistry)	Mortimore 1987
721-722	2	1987	2-in. SS wellpoints (water levels and chemistry)	Mortimore 1987
806-830	25	1987	2-in. and 4-in. SS well w/ dedicated positive displacement pumps (RCRA perimeter monitoring)	Hyde 1987
873-886	14	1985	2-in. SS (883 is 4-in.) w/ dedicated "well wizards" (RCRA monitoring of 3524, 3539, and 3540 impoundments)	MCI Consulting Eng. 1986
946-947	2	1989	2-in. and 4-in. SS wells with dedicated positive displacement pumps. Perimeter monitoring.	EDGE, date unknown
1100-1104	5	1985	2-in. SS well with dedicated positive displacement pumps. RCRA monitoring of 3513 impoundment.	Stansfield and Francis 1986
1196-1199	4	1989	2-in. and 4-in. SS wells with dedicated positive displacement pumps. WAG 17	Geotek, date unknown
1250-1252	3	1990	2-in. SS piezometer; reference monitor for water level and chemistry	BNI
4001-4002	2	1991	2-in. SS piezometer; reference monitor for water level and chemistry	BNI
CH008(4005)	1	1991	Multiport Westbay sampling system	BNI

[a]SS = stainless steel; PVC = polyvinyl chloride.

NOTE: This table was prepared manually. The source of information is the literature cited in the table. For BNI wells, installation dates were obtained from the well construction logs; these data reside in the RI/FS well construction data tables.

Table 3.3.2. Statistics for continuous monitoring data

	Water elevation (ft MSL)				
Location	Minimum	Maximum	Average	Std. dev.	Maximum fluctuation
634	815.40	816.14	815.66	0.11	0.74
818	811.96	817.40	813.28	1.53	5.44
Fifth Creek	815.31	816.47	815.41	0.09	1.16
815	815.35	818.49	816.60	0.70	3.14
599	792.63	796.98	794.43	0.86	4.35
604	788.94	798.48	796.64	0.70	9.54
825	778.80	780.78	779.21	0.34	1.98
826 (depth)	3.48	6.21	3.86	0.39	2.73
WOC	776.19	780.57	776.68	0.27	4.38
875	778.88	780.87	779.90	0.35	1.99
946	771.33	775.30	772.64	0.68	3.97
947	770.09	772.68	770.73	0.39	2.59
540	777.18	788.03	786.19	0.51	10.85
811	782.30	791.14	789.82	0.40	8.84
First Creek	786.13	787.64	786.42	0.21	1.51
546	803.99	817.28	806.24	1.86	13.29
549	817.10	830.48	821.94	2.90	13.38
587	804.78	810.58	809.73	0.31	5.80
814	809.54	810.60	810.14	0.27	1.06
564	786.85	794.36	789.18	1.41	7.51

Table 3.3.3. WAG 1 vertical gradient data

							April 1991			September 1991		
Pair	Location	Type	Depth (ft)	Top of sand (ft MSL)	Bottom of hole (ft MSL)	Mid Pt. Elevation (ft MSL)	GW elevation (ft MSL)	Diff. (ft)	Grad.[a] (ft/ft)	GW elevation (ft MSL)	Diff. (ft)	Grad.[a] (ft/ft)
1	540	ROCK	18.60	781.33	770.73	776.03	785.34	4.79	0.12	785.99	3.41	0.08
	811	ROCK	66.70	747.07	724.57	735.82	790.13			789.40		
2	610	INT.	14.00	781.21	775.01	778.11	777.95	1.77	0.04	777.62	1.42	0.03
	825	ROCK	60.00	746.34	727.84	737.09	779.72			779.04		
3	815	ROCK	26.00	809.74	798.04	803.89	818.30	0.66	0.02	815.95	4.06	0.13
	816	ROCK	60.00	783.66	763.66	773.66	818.96			820.01		
4	820	ROCK	20.00	804.76	788.46	796.61	803.25	-1.38	-0.03	803.67	-1.45	-0.03
	821	ROCK	80.00	769.11	729.11	749.11	801.87			802.22		
5[b]	826	INT.	11.80	783.94	772.94	778.44	778.22	1.02	0.02	ND		
	825	ROCK	60.00	746.34	727.84	737.09	779.24			ND		
6	875	INT.	13.10	777.64	771.14	774.39	780.66	1.88	0.05	779.26	2.01	0.06
	885	ROCK	51.00	745.51	732.51	739.01	782.54			781.27		
7	878	INT.	17.60	779.40	770.50	774.95	778.85	-39.72	-1.21	776.65	-33.85	-1.03
	883	ROCK	51.00	747.81	736.31	742.06	739.13			742.80		
8	1100	OB.	11.90	778.51	771.61	775.06	778.04	-0.72	-0.07	ND		0.00
	1101	ROCK	25.00	769.79	758.69	764.24	777.32			ND		
9	873	INT.	22.7	785.11	771.41	778.26	783.53	0.02	0.00	781.71	-0.04	-0.004
	886	ROCK	29.5	772.32	764.52	768.42	783.55			781.67		
10	807	INT.	16.3	771.77	758.47	765.12	772.07	15.00	0.42	ND		
	808	ROCK	55	739.53	719.53	729.53	787.07			771.82		

[a]Negative gradients indicate downward potential.
[b]Groundwater elevations for well pair number 5 are from 1/30/91.

Note: Groundwater elevations were derived from a listing of the groundwater elevation data table. The well construction information (depths to top and bottom of well screen) was obtained from Energy Systems well construction data. Well elevation data (top of casing) were obtained from the RI/FS civil survey data table. These values were used to manually compute vertical gradients at each well pair.

R:\WAG1SCS\SECTION3.TAB

Table 3.3.4. Lateral groundwater gradients and computed potential flow velocities

Flow vector[a]	Wells used to estimate hydraulic conductivity: Rock	Wells used to estimate hydraulic conductivity: Overburden	Area	Hydraulic conductivity: Rock	Hydraulic conductivity: Soil	Hydraulic gradient: 4/91	Hydraulic gradient: 9/91	Effective porosity	Potential flow rates (ft/d): Rock 4/91	Rock 9/91	Overburden 4/91	Overburden 9/91
10A	814	588	NORTH	1.00E+01	5.58E-01	0.081	0.050	0.018	4.50E+01	2.78E+01	2.51E+00	1.55E+00
12	814,547,539,538	588	NORTH	5.83E+00	5.58E-01	0.124	0.146	0.018	4.01E+01	4.73E+01	3.85E+00	4.53E+00
13A	814,547,539,538	588	NORTH	5.83E+00	5.58E-01	NV[b]	0.083	0.018	NV	2.69E+01	NV	2.57E+00
13B	814,547,539,538	588	NORTH	5.83E+00	5.58E-01	NV	0.063	0.018	NV	2.04E+01	NV	1.95E+00
1A	813		NORTH	1.65E+00	NR[c]	0.139	0.130	0.018	1.27E+01	1.19E+01	NR	NR
1B	547,539,538	547	NORTH	9.54E+00	2.49E+01	0.010	0.009	0.018	5.30E+00	4.77E+00	1.39E+01	1.25E+01
2A	814,547,539,538		NORTH	5.83E+00	NR	0.105	0.070	0.018	3.40E+01	2.27E+01	NR	NR
3A	814,547,539,538		NORTH	5.83E+00	NR	0.084	0.061	0.018	2.72E+01	1.98E+01	NR	NR
7A	814,547,539,538		NORTH	5.83E+00	NR	0.065	0.037	0.018	2.10E+01	1.20E+01	NR	NR
8A	814,547,539,538		NORTH	5.83E+00	NR	0.074	0.043	0.018	2.40E+01	1.39E+01	NR	NR
10B	814,547,539,538	588	NORTH	5.83E+00	5.58E-01	0.020	0.019	0.018	6.48E+00	6.15E+00	6.20E-01	5.89E-01
14A	818		NORTH	4.00E-03		0.030	0.095	0.018	6.67E-03	2.11E-02		
MIN				4.00E+03	5.58E-01	0.010	0.009		6.67E+03	2.11E-02	0.00E+00	5.89E-01
MAX				1.00E+01	2.49E+01	0.139	0.146		4.50E+01	4.73E+01	1.39E+01	1.25E+01
AVG				5.65E+00	4.62E+00	0.073	0.067		2.16E+01	1.78E+01	4.17E+00	3.95E+00
11	540,810,543,809	810,543,809	SOUTH	3.27E-01	4.14E-01	0.014	0.011	0.018	2.55E-01	2.00E-01	3.22E-01	2.53E-01
2B	551,552,542	874,830	SOUTH	1.46E+00	2.78E-03	0.032	0.027	0.018	2.60E+00	2.19E+00	4.94E-03	4.17E-03
2C	543,805,806,807,808	543,809,806,807	SOUTH	7.21E-01	8.99E-01	0.005	0.006	0.018	2.00E-01	2.40E-01	2.50E-01	3.00E-01
3B	577,556	577,556	SOUTH	7.21E-03	7.21E-03	0.044	0.035	0.018	1.76E-02	1.40E-02	1.76E-02	1.40E-02
3C	824,930	874,830	SOUTH	1.62E-01	1.62E-01	0.025	0.022	0.018	2.25E-01	1.98E-01	2.25E-01	1.98E-01
3D	556,564,567	566	SOUTH	2.15E-02	2.78E-03	0.034	0.033	0.018	4.06E-02	3.94E-02	5.25E-03	5.09E-03
4	563	563,567,566,830	SOUTH	9.05E-01	7.35E-01	0.035	0.035	0.018	1.76E+00	1.76E+00	1.43E+00	1.43E+00
5	827,577,556	563	SOUTH	3.20E+00	3.20E+00	0.068	0.068	0.018	1.21E+01	1.21E+01	1.21E+01	1.21E+01
6	827,570	827	SOUTH	7.64E-01	1.03E+00	0.050	0.018	0.018	2.12E+00	7.64E-01	2.87E+00	1.03E+00
7B	577,556	577,556	SOUTH	7.21E-03	7.21E-03	0.043	0.039	0.018	1.72E-02	1.56E-02	1.72E-02	1.56E-02
8B	604	604	SOUTH	1.74E-02	1.74E-02	0.031	0.027	0.018	2.99E-02	2.61E-02	2.99E-02	2.61E-02
8C	618,610,824,825,826	610,824,826,826	SOUTH	1.47E+00	2.19E+00	0.019	0.027	0.018	1.55E+00	2.21E+00	2.31E+00	3.29E+00
9	829	829	SOUTH	1.92E-01	1.92E-01	0.002	0.001	0.018	2.14E-02	1.07E-02	2.14E-02	1.07E-02
14B	626,618	822, 823, 623	SOUTH	7.0E-02	1.30E+00	0.020	0.050	0.018	7.78E-02	1.94E-01	1.44E+00	3.61E+00
MIN				7.21E-03	2.78E-03	0.002	0.001		1.72E-02	1.07E-02	4.94E-03	4.17E-03
MAX				3.20E+00	3.20E+00	0.068	0.068		1.27E+01	1.21E+01	1.21E+01	1.21E+01
AVG				6.67E-01	7.26E-01	0.030	0.027		1.50E+00	1.27E+00	1.50E+00	1.37E+00

[a]Flow vectors refer to Figs. 3.3.2 and 3.3.3.
[b]NV = no corresponding flow vector for April 1991.
[c]NR = no groundwater flow in overburden at these locations.

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Table 3.3.5. Data used for groundwater geochemical analysis

Location	Packer test interval	Sample No.	Midpoint elevation (ft MSL)	pH	Specific conductance (μmhos/cm)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	K (mg/L)	Alkalinity (mg/L $CaCo_3$)	HCO_3 (mg/L)	CO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Anion/ cation balance error (%)
CH001	1	2582	765.87	7.53	605	55.80	26.10	31.30	3.27	282.00	343.0	0.60	22.0	22.0	-2.63
CH001	2	2583	726.87	7.03	598	74.70	28.30	11.60	3.78	310.00	378.0	0.20	22.0	19.0	-3.90
CH006	1	2255	780.45	9.19	487	54.60	22.10	11.40	3.10	242.00	256.0	19.50	17.0	2.7	-1.53
CH006	2	2256	741.68	8.54	510	37.00	28.40	25.20	5.22	268.00	316.0	5.40	14.0	6.8	-3.83
CH11A	1	2277	750.73	7.23	587	54.30	30.70	24.90	6.17	272.00	331.0	0.30	87.0	21.0	-9.52
CH07A	1	2625	764.16	7.00	568	107.00	11.70	5.74	1.06	230.00	280.0	0.10	78.0	14.0	6.36
CH07A	2	2745	731.62	7.19	558	82.10	16.60	14.70	1.34	236.00	287.0	0.20	64.0	13.0	-2.18
CH001	3	2623	652.87	7.82	490	22.30	14.90	55.20	3.30	234.00	284.0	0.90	0.8	0.0	1.28
CH003	1	2275	698.58	9.14	975	1.39	0.64	216.00	1.17	724.00	488.0	52.80	18.0	39.0	.39
CH11A	3	2542	683.43	9.02	1132	1.30	0.72	270.00	2.70	527.00	582.0	30.00	90.0	33.0	-5.56
CH012	5	2624	629.26	7.90	645	16.50	9.02	119.00	3.46	298.00	361.0	1.40	8.8	29.0	-0.97
CH006	4	2258	547.28	8.95	3770	7.90	5.05	732.00	6.80	302.00	338.0	14.90	510.0	720.0	-5.92
CH009	2	2259	649.55	7.75	1589	30.80	18.20	279.00	3.48	337.00	409.0	1.10	44.0	300.0	-2.73
CH009	4	2260	460.65	8.34	2170	9.81	8.18	409.00	3.35	302.00	361.0	3.90	31.0	490.0	-3.72
538		1816	786.87	6.91	508	88.10	8.07	3.74	1.08	253.00	308.00	0.10	14.00	7.00	-2.69
548		1635	785.60	7.02	2000	178.00	33.60	82.20	2.15	202.00	246.00	0.10	21.00	610.00	-4.15
550		1759	804.63	7.30	548	82.60	12.90	4.22	0.89	223.00	272.00	0.30	42.00	8.00	-1.63
553		1700	782.41	7.15	628	111.00	6.13	8.91	0.37	297.00	362.00	0.0	4.00	28.00	-2.84
597		1726	804.96	7.96	273	35.70	8.32	4.87	1.45	106.00	128.00	0.60	26.00	4.00	-1.05
602		1715	807.06	6.92	801	132.00	7.49	31.40	0.75	265.00	323.00	0.10	34.00	64.00	4.74
621		1859	773.18	6.96	659	79.80	31.20	12.70	2.47	330.00	402.00	0.20	60.00	2.40	-4.97
814		0009	813.24	7.00	310	92.40	5.60	5.37	0.68	235.00	286.0	0.10	20.0	10.0	-0.63
820		1555	795.96	7.57	560	108.00	13.50	3.98	0.78	311.00	378.0	0.70	48.0	2.0	-4.17
824		1562	776.71	6.97	854	132.00	18.40	20.00	1.13	364.00	444.0	0.20	66.0	43.0	-4.62
827		1560	774.93	6.97	327	49.80	9.53	1.81	1.77	160.00	195.0	0.10	18.0	2.0	-3.39
828		1557	775.33	6.98	759	131.00	20.40	5.32	1.19	392.00	478.0	0.20	34.0	2.0	-0.75
873		1558	774.21	7.21	640	102.00	9.25	22.90	0.86	265.00	323.0	0.30	95.0	7.0	-4.26
875		1739	773.84	7.60	643	58.70	32.70	20.80	3.46	323.00	392.0	0.80	13.0	9.0	-2.68
876		1804	773.72	7.22	843	146.00	11.00	16.60	0.31	390.00	475.0	0.40	72.0	3.0	-2.53
878		1748	773.20	6.58	662	116.00	10.80	4.57	1.03	333.00	406.0	0.10	11.0	3.0	-0.50
879		1813	774.66	7.07	NA	170.00	45.00	23.80		379.00	462.0	0.30	370.0	6.0	-7.70
880		1800	774.46	7.31	469	67.90	6.45	6.41	0.63	200.00	244.0	0.20	38.0	5.0	-7.92
881		1758	773.23	6.61	828	133.00	12.10	14.00	0.74	384.00	468.0	0.10	62.0	8.0	-5.33
882		1814	775.00	7.21	591	95.00	14.50	5.81	1.47	257.00	313.0	0.30	82.0	4.0	-5.59
884		1760	772.64	6.60	785	150.00	7.77	5.01	0.38	419.00	511.0	0.10	12.0	7.0	-2.76
885		1819	737.01	7.35	633	66.40	28.80	20.95	2.19	332.00	404.0	0.40	12.0	11.5	-4.04

NOTE: This table was created manually. Chemical data were derived from listings of WAG 1 groundwater chemical data. pH and specific conductance were derived from field logbooks; these data are now stored in RI/FS data base in field data tables. The anion/cation balances were computed using the GEOBASE computer software program.

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Table 3.4.1. Streamflow gauging stations in the vicinity of WAG 1

Station name	ORNL designation	Station No.	Drainage area ($mile^2$)	Period of record	Data interval	Hydraulic control	Instrumentation
WOC headwaters	WOCHW		0.8	11/1/88–present	15-min	Compound stainless steel critical-flow flume	Stevens Model 7001 float-type gauge, digital punch, stage recorder
Upper WOC	GS6	USGS #03536 320	1.31	4/1/87–present	15-min	Natural bedrock outcrop	Stevens Model 7001 float-type gauge, digital punch, stage recorder
WOC Parshall flume	GS5	USGS #03536 380	2.1	10/1/87–present	15-min	Concrete structure with stainless steel Parshall flume	Digital punch, stage recorder
First Creek	GS1	USGS #03536 450	0.33	2/1/87–present	5-min	Compound stainless steel critical-flow flume	Stevens Model 7001 float-type gauge, digital punch, stage recorder
Northwest Tributary	GS4	USGS #03536 440	0.67	10/1/87–present	15-min	Concrete structure with stainless steel, short-crested triangular weir	Bubbler gauge, digital punch, stage recorder
7500 bridge	GS3	USGS #03536 550	3.28	4/17/85–present	15-min	Compound stainless steel sharp-crested weir	Bubbler gauge, digital punch, stage recorder, data collection platform system rain gauge

Table 3.4.2. Low mean discharge values for consecutive days (cfs)

Year	1-day	2-day	3-day	7-day	10-day	30-day	60-day	90-day	183-day	365-day	Station
1988	0.19	0.2	0.21	0.22	0.22	0.24	0.27	0.32	0.36	0.56	GS1
1989	0.23	0.24	0.25	0.25	0.25	0.31	0.38	0.67	0.88	1.27	
1990	0.13	0.13	0.13	0.15	0.15	0.21	0.25	0.26	0.4	1.08	
1991	0.1	0.1	0.1	0.11	0.11	0.13	0.17	0.17	0.32	1.01	
1988	4.5	4.8	5	5.09	5.11	5.25	5.73	6.44	6.59	7.84	GS3
1989	5.5	5.75	5.8	5.91	5.94	7.12	7.96	10.3	11.2	13.9	
1990	4.5	4.6	4.67	4.77	4.86	5.66	6.09	6.11	7.65	13.3	
1991	4.3	4.35	4.4	4.53	4.68	4.93	5.17	5.39	7.24	11.9	
1988	0.34	0.39	0.41	0.46	0.47	0.5	0.57	0.63	0.65	0.87	GS4
1989	0.47	0.47	0.48	0.49	0.49	0.56	0.62	0.96	1.19	1.74	
1990	0.33	0.33	0.33	0.36	0.37	0.46	0.49	0.51	0.63	1.44	
1991	0.25	0.26	0.27	0.27	0.28	0.31	0.32	0.36	0.47	1.2	
1988	2.3	2.4	2.47	2.49	2.51	2.6	2.71	2.99	3.13	4	GS5
1989	2.6	2.65	2.73	2.89	2.98	3.72	4.15	5.41	6.18	7.91	
1990	2.1	2.15	2.17	2.19	2.25	2.67	2.9	2.93	3.97	6.96	
1991	1.9	1.9	1.93	2.03	2.08	2.19	2.43	2.46	3.71	6.62	
1988	0.01	0.01	0.01	0.02	0.02	0.03	0.05	0.12	0.18	0.49	GS6
1989	0.05	0.06	0.06	0.07	0.07	0.19	0.38	0.95	1.49	2.23	
1990	0.04	0.04	0.04	0.04	0.05	0.1	0.17	0.18	0.59	1.95	
1991	0.04	0.04	0.04	0.04	0.05	0.06	0.11	0.11	0.69	1.99	

Table 3.4.3. High mean discharge values for consecutive days (cfs)

Year	1-day	2-day	3-day	7-day	10-day	30-day	60-day	90-day	183-day	365-day	Station
1988	5.9	5.2	4.1	2.34	1.88	1.13	1.03	0.92	0.68	0.57	GS1
1989	11	9	7.73	5.2	4.49	2.44	2.1	1.93	1.65	1.27	
1990	9.1	8.05	6.6	4.29	4.18	3.15	2.49	2.14	1.53	1.08	
1991	17	16	14	7.99	6.25	3.26	2.54	2.01	1.36	1.01	
1988	58	53.5	40.7	23.3	18.7	12.5	11.4	10.2	8.52	7.92	GS3
1989	93	73.5	62	41.9	36.8	24.5	18.8	17.9	16.6	13.9	
1990	254	186	137	77.7	67.1	29.6	23.2	20.2	15.3	13.3	
1991	140	137	118	68	54.5	29.6	22.9	19.1	14.8	11.9	
1988	9.3	8.6	6.4	3.5	2.69	1.59	1.42	1.21	0.95	0.88	GS4
1989	22	16	12.9	7.86	6.69	3.55	2.87	2.6	2.26	1.74	
1990	16	14	10.8	6.6	6.13	4.45	3.43	2.81	1.94	1.44	
1991	29	28.5	23.3	12.1	9.43	4.29	3.05	2.35	1.48	1.2	
1988	36	32.5	24.8	14	11.1	7.05	6.41	5.52	4.33	4.05	GS5
1989	65	50.5	42	27.3	23.7	13.5	11.4	10.7	9.58	7.91	
1990	58	55	43.3	26.3	25.2	18.1	14.4	12.2	8.83	6.96	
1991	93	91.5	78.7	43.9	34.5	17.6	13.4	10.9	8.38	6.62	
1988	18	17	12.1	5.68	4.03	1.81	1.55	1.13	0.65	0.51	GS6
1989	38	29	23	13.6	11.3	4.82	3.95	3.55	2.89	2.23	
1990	28	24	18.7	11	10.7	7.37	5.57	4.45	2.75	1.95	
1991	59	57.5	48.7	25.1	18.9	8.05	5.56	4.13	2.89	1.99	

Table 3.4.4. Mean monthly and annual flows for 1988–1991

	GS1		GS3		GS4		GS5		GS6		Rainfall
Month	(cfs)	(in.)	(cfs)	(in.)	(cfs)	(in.)	(cfs)	(in.)	(cfs)	(in.)	(in.)
January	1.61	5.63	15.69	5.51	1.99	3.42	8.87	4.92	2.89	2.54	5.16
February	2.00	6.33	19.16	6.08	2.76	4.29	11.62	5.76	4.32	3.43	6.17
March	1.59	5.56	15.49	5.44	1.97	3.39	8.88	4.87	2.76	2.43	5.59
April	0.90	3.03	9.740	3.31	0.94	1.57	5.22	2.77	0.95	0.81	3.15
May	0.88	3.07	10.70	3.76	1.12	1.93	5.62	3.09	1.15	1.01	4.48
June	0.87	2.95	11.98	4.08	1.22	2.03	6.52	3.46	1.88	1.60	2.56
July	0.63	2.220	9.18	3.23	0.90	1.55	4.79	2.63	0.67	0.59	5.08
August	0.37	1.28	7.79	2.74	0.60	1.03	4.03	2.221	0.58	0.51	4.00
September	0.44	1.50	8.11	2.76	0.79	1.32	4.19	2.22	0.75	0.64	4.70
October	0.43	1.50	7.11	2.50	0.68	1.17	3.71	2.03	0.58	0.51	2.57
November	0.69	2.34	9.09	3.09	0.96	1.60	4.95	2.63	0.98	0.83	4.79
December	1.35	4.70	13.58	4.77	1.79	3.08	7.86	4.31	2.43	2.13	7.83
Annual	0.98	40.11	11.142	47.28	1.30	26.37	6.33	40.92	1.64	17.03	58.58

Table 3.4.5. Summary of Category I and II outfalls in WAG 1 vicinity

Category	Location	Subtotal	Total
I	White Oak Creek		16
I	First Creek		8
I	Fifth Creek		16
II	White Oak Creek		42
II	Parking lot runoff	20	
II	Condensate	6	
II	Noncontact cooling water/parking lot runoff	13	
II	Cooling tower blowdown	2	
II	Spill area drain	1	
II	First Creek		10
II	Parking lot runoff	7	
II	Storage area drain	2	
II	Noncontact cooling water/parking lot runoff	1	
II	Fifth Creek		18
II	Spill area and storage area drains	3	
II	Parking lot runoff	7	
II	Noncontact cooling water/parking lot runoff	2	
II	Condensate	4	
II	Cooling tower blowdown	2	

Source: Borders, D. M. et al. 1991. *Annual Hydrologic Data Summary for the White Oak Creek Watershed, Water Year 1990 (October 1989–September 1990),* ORNL/ER-55, Oak Ridge National Laboratory, Oak Ridge, Tenn.

3.4.6. NPDES compliance at ORNL

Discharge point	Effluent parameters	Discharge limitations: Monthly average (kg/d)	Daily max (kg/d)	Monthly average (mg/L)	Daily max (mg/L)	pH Analysis frequency
X01 (Sewage Treatment Plant)	Biochemical oxygen demand (summer)	8.7	13.1	10	15	Weekly
	Biochemical oxygen demand (winter)	17.4	26.2	20	30	
	Total suspended solids	26.2	39.2	30	45	
	Ammonia (N) (summer)	3.5	5.2	4	6	
	Ammonia (N) (winter)	7.8	11.8	9	13.5	
	Oil and grease	8.7	13.1	10	15	
	Dissolved oxygen				6.0[a]	
	pH (standard units)					
	Residual chlorine				0.05	
	Fecal coliform, geometric mean			1000[b]	5000[b]	
X02 (Coal Yard Runoff Treatment Facility)	Temperature, °C				30.5	Weekly
	Total suspended solids				50	
	Oil and grease			15.0	20.0	
	Chromium, total			0.2	0.2	
	Copper, total			1.0	1.0	
	Iron, total			1.0	1.0	
	pH (standard units)					
	Zinc			1.0	1.0	
X12 (Nonradiological Wastewater Treatment Facility)	Temperature, °C				30.5	Continuous
	Total suspended solids	93.9	182	31	60	

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Table 3.4.6 (continued)

Discharge point	Effluent parameters	Discharge limitations: Monthly average (kg/d)	Daily max (kg/d)	Monthly average (mg/L)	Daily max (mg/L)	pH Analysis frequency
	Oil and grease	30.3	45.4	10	15	
	Total toxic organics		6.45		2.13	
	Cyanide, total	1.97	3.64	0.65	1.20	
	Cadmium, total	0.79	2.09	0.26	0.69	
	Chromium, total	5.18	8.39	1.71	2.77	
	Copper, total	6.27	10.24	2.07	3.38	
	Lead, total	1.30	2.09	0.43	0.69	
	Nickel, total	7.21	12.06	2.38	3.98	
	pH (standard units)					
	Silver, total	0.73	1.30	0.24	0.43	
	Zinc, total	4.48	7.91	1.48	2.61	
				10	15	
Category I	Oil and grease					Yearly
	pH (standard units)					
	Temperature, °C				30.5	
	Total suspended solids			30	50	
Category II	Oil and grease			10	15	Quarterly
	pH (standard units)					
	Total suspended solids			30	50	
Steam plant (SP2519)	pH (standard units)					Quarterly
	Temperature, °C			35	38	
Vehicle cleaning (VC7002)	Biochemical oxygen demand			30	45	
	Fecal coliform			200[b]		Monthly
	Oil and grease			10	15	

R:\WAG1SCS\SECTION3.TAB

Table 3.4.6 (continued)

Discharge point	Effluent parameters	Discharge limitations: Monthly average (kg/d)	Daily max (kg/d)	Monthly average (mg/L)	Daily max (mg/L)	pH Analysis frequency
	pH (standard units)					
	Phenols			1.0	2.0	
	Total suspended solids			25	40	
Equipment Maintenance Facility (EF7002)	Oil and grease				15	Quarterly
	pH (standard units)					
	Chlorine				0.2	
	Chromium				1.0	
	Copper			0.5	1.0	
	Temperature, °C			35	38	
	Zinc			0.5	1.0	
	pH (standard units)					

Source: Martin Marietta Energy Systems, Inc., Oak Ridge Environmental Report, Vol. 1—1990, Oak Ridge, Tenn.

[a]Minimum.
[b]Colonies per 100 mL.

Table 3.4.7. Summary of collection and analysis frequencies of surface and effluent water samples

Station	Collection frequency	Sample type	Parameters	Analysis frequency
7500 bridge	Weekly	Flow proportional	Gamma scan, total Sr[a], ^{3}H	Monthly
First Creek, Fifth Creek	Weekly	Grab	Gamma scan, total Sr[a]	Monthly
NRWTF (X12)	Weekly	Flow proportional	^{3}H, gamma scan, gross alpha, gross beta, total Sr[a]	Monthly
Northwest tributary	Weekly	Flow proportional	Gamma scan, total Sr[a]	Monthly
STP (X01)	Weekly	Flow proportional	Gamma scan, total gross beta, total Sr[a]	Monthly
WOC headwaters	Weekly	Flow proportional	Gamma scan, total gross alpha[b], total gross beta[c]	Monthly

Source: Martin Marietta Energy Systems, Inc., Oak Ridge Environmental Report, Vol. 1—1990, Oak Ridge, Tenn.

[a]Total radioactive strontium (^{89}Sr + ^{90}Sr).
[b]If gross alpha > 27 pCi/L, then analyze for ^{248}Am, ^{244}Cm, ^{239}Pu, ^{228}Th, ^{230}Th, ^{233}Th, ^{234}U, ^{235}U, and ^{238}U.
[c]If gross beta > 810 pCi/L, then analyze for total radioactive strontium.

Table 3.4.8. Water quality parameters during RI sampling in surface waters in WAG 1

	First Creek	Fifth Creek	NW tributary	WOC	
	SW-7	SW-4	SW-8	SW-5	SW-6
Low baseflow nonstorm event					
Flow, cfs	0.19	0.92	0.57		
Temp, °C	15.4	14.6	11.1		
pH	7.75	8.08	7.5		
Conductivity, μmhos/cm	344	299	322		
TDS, μg/L	199.5	150	159.5		
Chloride, μg/L	4330		5230		
Sulfate, μg/L	8580				
Bicarbonate as $CACO_3$, μg/L	163470		145590		
Low baseflow storm event					
Flow, cfs				2.9	5.4
Temp, °C		16.6		16	15
pH		7.44		7.95	7.14
Conductivity, μmhos/cm		305		310	368
TDS, μg/L	195	167.5	181.5	180	189.5
Chloride, μg/L	7110	4880	4020	5400	7340
Sulfate, μg/L	20750	13940	18500	24180	54720
Bicarbonate as $CACO_3$, μg/L	149860	136720	152490	131460	120940
High baseflow nonstorm event					
Flow, cfs	0.9	3.05	0.9	4.8	9.5
Temp, °C	12.1	14.1	11.4	13.7	10.9
pH	7.97	7.96	7.95	8.19	7.4
Conductivity, μmhos/cm	227	245	280	259	313
Chloride, μg/L	1000	2000	3000	4000	12000
Nitrate/nitrite, μg/L	620	220	210	230	1500
Sulfate, μg/L	10000	9000	19000	14000	33000
High baseflow storm event					
Flow, cfs	13	14.1	24	24	64
Temp, °C	12.9	13.8	12.3	13	12.8
pH	7.28	7.11	7.08	7.11	6.89
Conductivity, μmhos/cm	130	180	139	141	181
Chloride, μg/L	1000 U	1000 U	1000 U	1000 U	2000
Nitrate/nitrite, μg/L	160 J	140 J	130	150 J	420
Sulfate, μg/L	8000	11000	8000	8000	15000

Table 3.5.1. Waste storage tank SWMUs

Tank identification: Tank No.	Tank identification: SWMU No.	Active (A) Inactive (I)	FFA Appendix "F" Category	Location	Material of construction	Source of waste materials	Size of tank
W-1	1.23A	I	D	North Tank Farm	Gunite	3019 Radiochemical Pilot Plant	4800 gal
W-2	1.23B	I	D	North Tank Farm	Gunite	Overflow from Tank W-1	4800 gal
W-3	1.24A	I	D	North Tank Farm	Gunite	Plutonium Waste from Bldg 3019	42500 gal
W-4	1.24B	I	D	North Tank Farm	Gunite	Uranium Waste from Bldg 3019	42500 gal
W-13	1.25A	I	D	North Tank Farm	Stainless steel	Radioactive Waste from Chem. Div. Hot Lab.	2000 gal
W-14	1.25B	I	D	North Tank Farm	Stainless steel	Radioactive Waste from Operations Division	2000 gal
W-15	1.25C	I	D	North Tank Farm	Stainless steel	Radioactive Waste from Operations Division	2000 gal
W-5	1.26A	I	D	South Tank Farm	Gunite	Mixed Waste from various sources on LLLW system	170000 gal
W-6	1.26B	I	D	South Tank Farm	Gunite	Mixed Waste from various sources on LLLW system	170000 gal
W-7	1.26C	I	D	South Tank Farm	Gunite	Mixed Waste from various sources on LLLW system	170000 gal
W-8	1.26D	I	D	South Tank Farm	Gunite	Mixed Waste from various sources on LLLW system	170000 gal
W-9	1.26E	I	D	South Tank Farm	Gunite	Mixed Waste from various sources on LLLW system	170000 gal
W-10	1.26F	I	D	South Tank Farm	Gunite	Mixed Waste from various sources on LLLW system	170000 gal
W-11	1.27	I	D	South Tank Farm	Gunite	Building 3550 mixed waste	1500 gal
W-1A	1.28	I	D	North Tank Farm	Stainless steel	Buildings 2026, 3019, and 3019B radioactive waste	4000 gal
WC-1	1.29	I	D	Between Buildings 3037 and 3038	Stainless steel	Radioactive waste from Buildings 3028, 3029, 3030, 3031, 3032, 3033, 3038 and 3047, and3039 stack, 3092 scrubber, and 3110 filter.	2000 gal
WC-15	1.30A	I	D	South of Building 3587	Stainless steel	Radioactive waste from Building 4500 research labs.	1000 gal
WC-17	1.30B	I	D	South of Building 3587	Stainless steel	Radioactive waste from Building 4500 research labs.	1000 gal
TH-1	1.31A	I	D	South of Building 3503	Stainless steel	Mixed waste from Thorium Pilot Plant Building 3503	2500 gal
TH-2	1.31B	I	D	South of Building 3503	Stainless steel	Waste from Thorium Pilot Plant Building 3503	2400 gal
TH-3	1.31C	I	D	South of Building 3503	Stainless steel	Mixed waste from Thorium Pilot Plant Building 3503	3300 gal
TH-4	1.32	I	D	West of Building 4500	Gunite	Mixed waste from Building 3550 thorium and uranium development projects	14000 gal
WC-4	1.36	I	D	West of Building 3026	Stainless steel	Radioactive waste from Building 3026	1700 gal
WC-5	1.37A	I	D	South of Building 3503	Stainless steel	Mixed waste from Building 3503	1000 gal
WC-6	1.37B	I	D	South of Building 3503	Stainless steel	Mixed waste from Building 3503	500 gal
WC-8	1.37C	I	D	South of Building 3503	Stainless steel	Mixed waste from Building 3503	1000 gal
WC-11	1.39B	I	D	South of Building 3587	Stainless steel	Mixed waste from Buildings 4500N Wing 1, 4505, 4507, and 4556; disch. to South Tank Farm	4600 gal
WC-12	1.39C	I	D	South of Building 3587	Stainless steel	Mixed waste from Buildings 4505 and 4507; disch. to South Tank Farm	1000 gal
WC-13	1.39D	I	D	South of Building 3587	Stainless steel	Mixed waste from Buildings 4500S, 4500N, 4501, and 4508; disch. to South Tank Farm	1000 gal
WC-14	1.39E	I	D	South of Building 3587	Stainless steel	Mixed waste from Building 4501; disch. to South Tank Farm	1000 gal
W-12	1.41	I	D	South Tank Farm	Stainless steel	Mixed waste from Buildings 3525 and 3517;	700 gal
W-17	1.42B	I	D	South Tank Farm	Stainless steel	Mixed waste from Building 3026	1000 gal

Table 3.5.1 (continued)

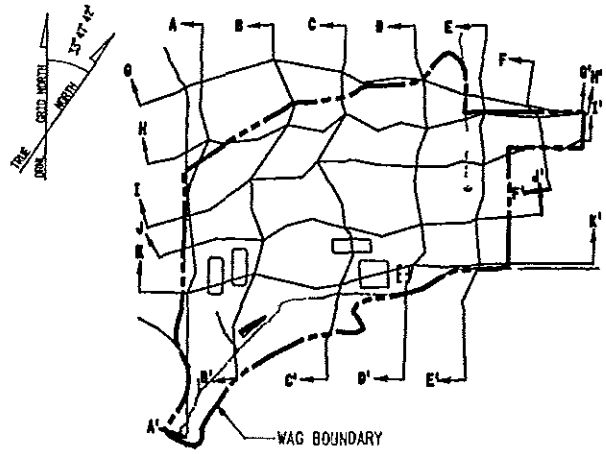
Tank identification		Active (A) Inactive (I)	FFA Appendix "F" Category	Location	Material of construction	Source of waste materials	Size of tank
Tank No.	SWMU No.						
W-18	1.42C	I	D	South Tank Farm	Stainless steel	Mixed waste from Building 3026 and 3500 Area Cell ventilation duct	1000 gal
W-19	1.56A	I	D	South Tank Farm	Stainless steel	Mixed waste from Building 3503 and Fission Product Development Laboratory	2250 gal
W-20	1.56B	I	D	South Tank Farm	Stainless steel	Mixed waste from Building 3503 and Fission Product Development Laboratory	2250 gal
S-424	1.64C	I	D	Northwest corner of Building 3517	Glass-lined steel	Radioactive waste from fission product separations in Building 3517	500 gal
W-1(I)	1.66	I	D	Under Building 3028	Stainless steel	Radioactive waste from hot cell in Building 3028	500 gal
4501-C	1.67A	I	D	Inside Building 4501 basement (Room BG74)	Stainless steel	Radioactive waste from High Level Radiochemical Laboratory (4501)	100 gal
4501-D	1.67B	I	D	Inside Building 4501 basement (Room BG74)	Stainless steel	Radioactive waste from High Level Radiochemical Laboratory (4501)	100 gal
4501-P	1.67C	I	D	Under basement floor in Building 4501	Stainless steel	Plutonium and Thorium waste from projects in Building 4501	140 gal
3002A	1.68	I	D	South of Building 3002	Stainless steel	Drainage from 3002 filter house	1600 gal
H-209	1.71	I	D	Southwest corner of Building 3517	Stainless steel	Contaminated process waste and condensate from floor drains in Building 3517	2500 gal
3001-S	1.72	I	D	South of Building 3001 (suspect tank based on drawings)	Stainless steel	Unknown	2000 gal
3001-B	1.73	I	D	South of Building 3001	Stainless steel	Hot lab drains, for irradiated samplea in Building 3001	375 gal
3003-A	1.74	I	D	South of Building 3003	Concrete	Waste from floor drains in Building 3003, and Graphite Reactor stack	16000 gal
3004-B	1.75	I	D	East of Building 3008	Stainless steel	Hot waste from the Low Intensity Test Reactor	30 gal
3013	1.76	I	D	South of Building 3013	Stainless steel	Floor drains from Building 3013; processing very low contami-nation environmental samples	350 gal
T-30	1.78	I	D	SW corner Building 4507	Stainless steel	Radioactive waste from hot cell operations	824 gal
3505A	1.80A	I	D	East of Building 3505	Stainless steel	Nitric acid for process waste treatment facility	2250 gal
3505B	1.80B	I	D	East of Building 3505	Stainless steel	Sodium hydroxide for process waste treatment facility	2250 gal
2026A	1.33	A	C	East of Building 2026	Stainless steel; in vault under 11.3 ft. of soil	Mixed waste from analytical chemistry lab Building 2026	500 gal
WC-2	1.34	A	C	East of Building 3029	Stainless steel; buried	Waste with I-131 from Buildings 3028, 3038, and 3110	1000 gal
WC-3	1.35	A	C	South of Building 3025	Stainless steel; buried	Mixed waste from Building 3025 and 3110	1000 gal
WC-9	1.37D	A	C	South of Building 3503	Stainless steel; buried 6.5 ft. below ground surface	Mixed waste from Building 3503	2140 gal
WC-7	1.38	A	C	West of Building 3504	Stainless steel; buried 4.7 ft. below ground surface	Mixed waste from Building 3504	1100 gal
WC-10	1.39A	A	C	Isotopes area south of Building 3587	Stainless steel; buried 10.3 feet below ground surface	Mixed waste from Buildings 3029, 3030, 3031, 3032, 3033, 3039, 3047, and 3092; disch. to South Tank Farm	2000 gal

Table 3.... (continued)

Tank identification		Active (A) Inactive (I)	FFA Appendix "F" Category	Location	Material of construction	Source of waste materials	Size of tank
Tank No.	SWMU No.						
WC-3	1.35	A	C	South of Building 3025	Stainless steel; buried	Mixed waste from Building 3025 and 3110	1000 gal
WC-9	1.37D	A	C	South of Building 3503	Stainless steel; buried 6.5 ft. below ground surface	Mixed waste from Building 3503	2140 gal
WC-7	1.38	A	C	West of Building 3504	Stainless steel; buried 4.7 ft. below ground surface	Mixed waste from Building 3504	1100 gal
WC-10	1.39A	A	C	Isotopes area south of Building 3587	Stainless steel; buried 10.3 feet below ground surface	Mixed waste from Buildings 3029, 3030, 3031, 3032, 3033, 3039, 3047, and 3092; disch. to South Tank Farm	2000 gal
WC-19	1.40	A	C	Northeast of Building 3028	Stainless steel; in vault; tank 12.9 ft. below ground surface	Mixed waste from Buildings 3001, 3002, 3003, 3004, 3005, 3008, 3010, 3042, 3109, and 3119	1500 gal
W-16	1.42A	A	C	South Tank Farm	Stainless steel; buried 9.3 feet below ground surface	Mixed waste from Building 3026	1000 gal
S-223	1.64A	A	B	Northwest corner of Building 3517	Stainless steel; in epoxy lined vault with monitored sump; below ground; secondary containment	Radioactive waste from Building 3517; fission products separation	2500 gal
S-324	1.64B	A	B	Northwest corner of Building 3517	Stainless steel; in epoxy lined vault with monitored sump; below ground; secondary containment	Radioactive waste from Building 3517; fission products separation	1000 gal
S-523	1.64D	A	B	Northwest corner of Building 3517	Stainless steel; in epoxy lined vault with monitored sump; below ground; secondary containment	Radioactive waste from Building 3517; fission products separation	1000 gal
F-201	1.65A	A	C	South of Building 3525	Stainless steel; in unlined pit, below ground	Radioactive waste from High Rad Level Examination Lab 3525; condensate from off-gas system	50 gal
F-501	1.65B	A	C	Southeast corner of Building 3525	Stainless steel; in unlined concrete vault below ground	Radioactive waste from High Rad Level Examination Lab 3525	200 gal
N-71	1.69A	A	B	In Cell VII of Building 3019	Stainless steel; in above ground vault; secondary containment	Mixed waste from Building 3019	240 gal
P-3	1.69B	A	B	In Cell VI of Building 3019	Stainless steel; in above ground vault; secondary containment	Mixed waste from Building 3019	200 gal
P-4	1.69C	A	B	In Cell VI of Building 3019	Stainless steel; in above ground vault; secondary containment	Mixed waste from Building 3019	200 gal

Table 3.5.1 (continued)

Tank identification		Active (A) Inactive (I)	FFA Appendix "F" Category	Location	Material of construction	Source of waste materials	Size of tank
Tank No.	SWMU No.						
W-22	1.43B	A	B	North of Building 2531 in tank farm for collection of LLLW for processing in the LLLW evaporator	Stainless steel; in stainless steel lined concrete vault; secondary containment	Mixed waste from LLLW system at South Tank Farm, collection and holding for evap. processing	50000 gal
W-23	1.44	A	B	North of Building 2531 in tank farm for collection of LLLW that was processed in the LLLW evaporator	Stainless steel; in stainless steel lined concrete vault; secondary containment	Stores concentrated waste from LLLW evaporator prior to transfer to tanks W-24 to W-31 in Melton Valley	50000 gal
C-1	1.45A	A	B	North of Building 2531 in tank farm for collection of LLLW that was processed in the LLLW evaporator	Stainless steel; in concrete vault; secondary containment	Stores concentrated waste from LLLW evaporator prior to transfer to tank W-23, for transfer to Melton Valley tanks	50000 gal
C-2	1.45B	A	B	North of Building 2531 in tank farm for collection of LLLW that was processed in the LLLW evaporator	Stainless steel; in concrete vault; secondary containment	Stores concentrated waste from LLLW evaporator prior to transfer to tank W-23, for transfer to Melton Valley tanks	50000 gal
2525	1.54	A	NA	South of Building 2525	Steel; above-ground	Waste oil (two 500 gal. each); hold oil for recycling	1000 gal



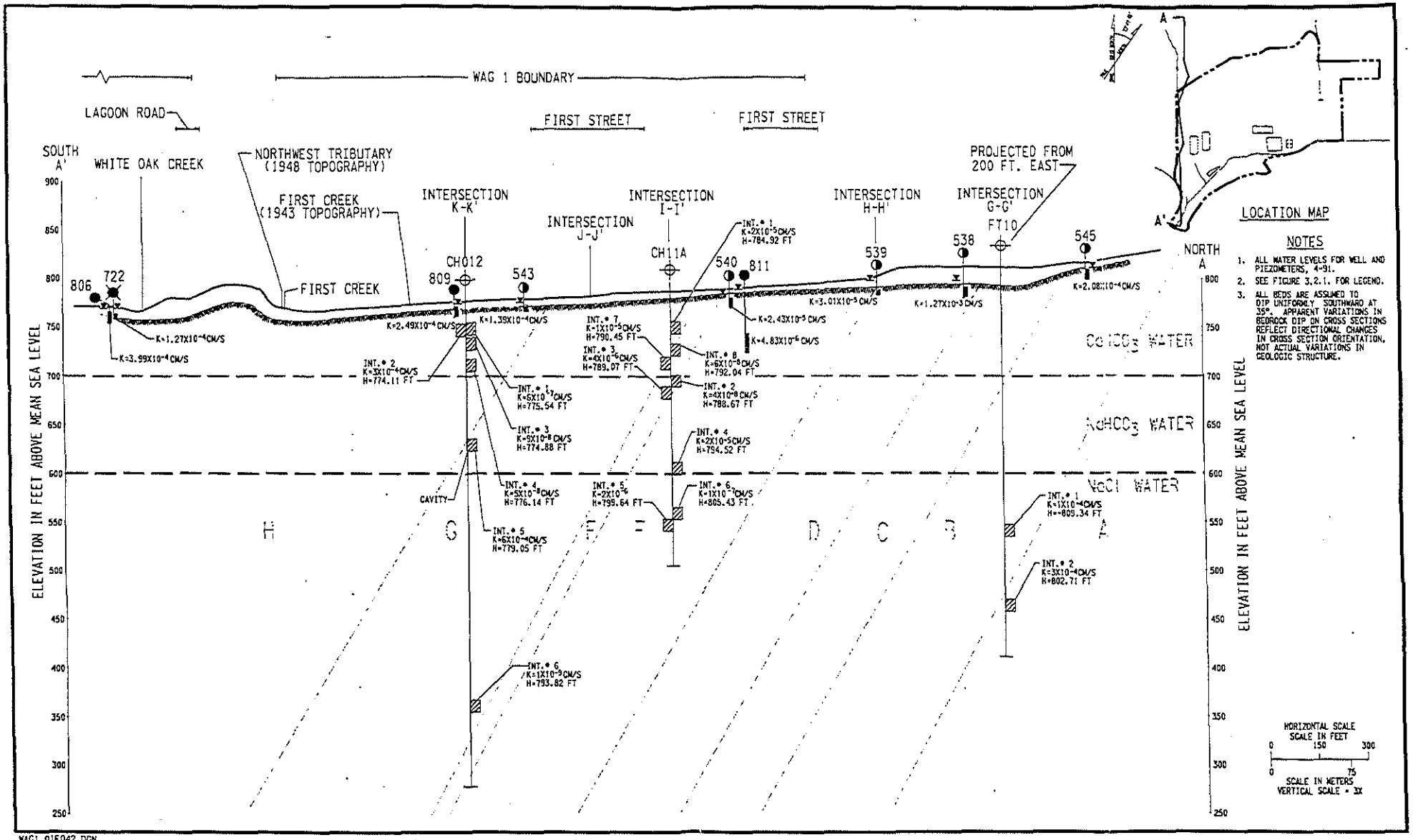
LOCATION MAP

LEGEND

●	WATER QUALITY WELL	▨	1991 BNI TEAM PACKER TEST
○	FLUSH MOUNT PIEZOMETER	▤	1989 GOLDER PACKER TEST
◑	STICKUP PIEZOMETER	▧	WESTBAY
	WELLPOINT	K=2.0E-4	HYDRAULIC CONDUCTIVITY (CM/S), BASED ON SLUG TESTS OR COREHOLE PACKER TESTS.
	COREHOLE		
C / D	CHICKAMAUGA GROUP (UNIT C AND D CONTACT)	"NT"	NOT TESTED
		"NA"	NOT AVAILABLE
▼	WATER TABLE	"H=779.05"	HEAD VALUE IN FT MSL
	SCREENED INTERVAL	"CaHCO3 WATER"	WATER CHEMISTRY TYPE BASED ON GEOCHEMICAL ANALYSIS
	OPEN HOLE		
	TOP OF BEDROCK		
- - - -	GROUNDWATER INTERFACE		

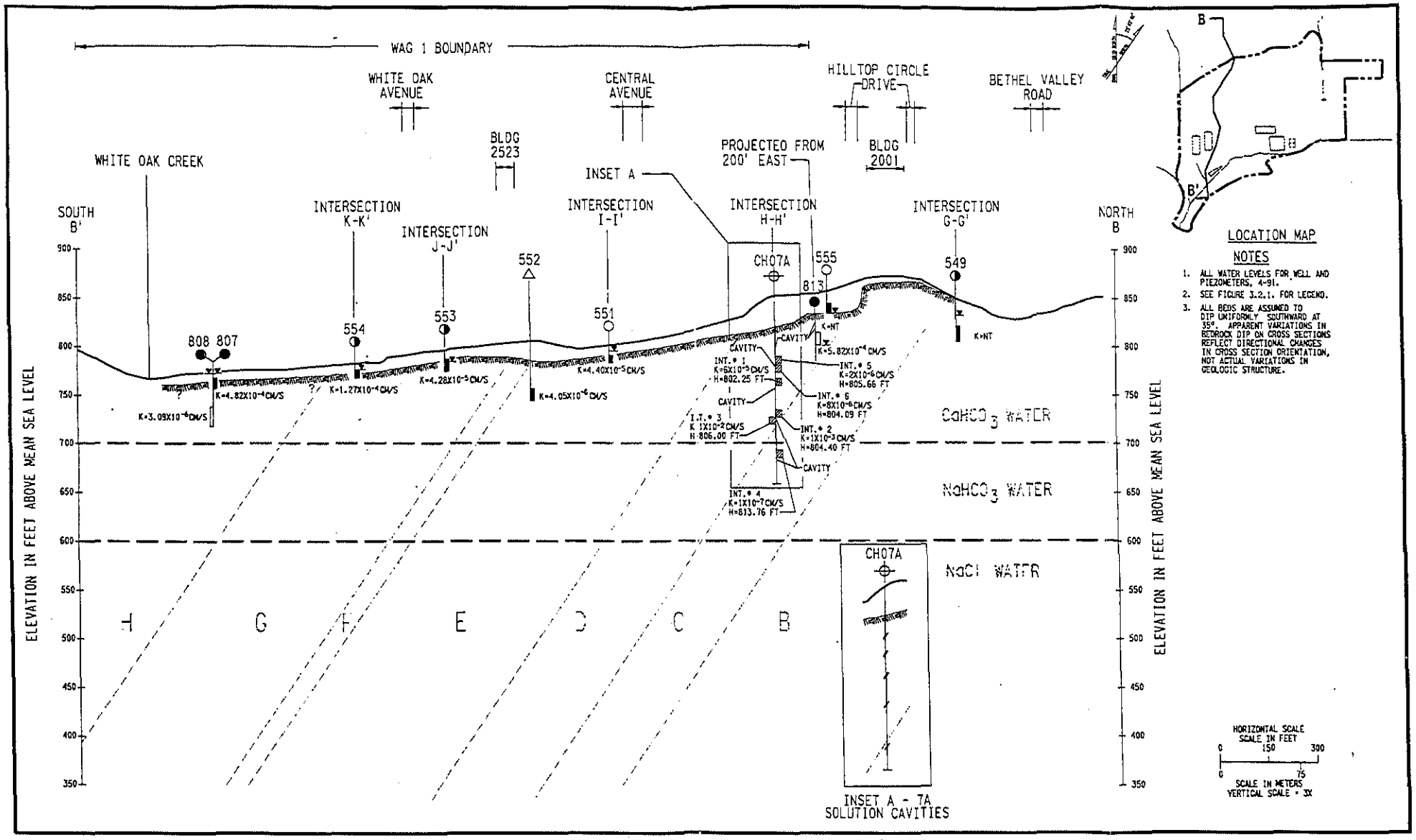
WAG 1 01F245.DGN
6/15/92

Fig. 3.2.1. Legend sheet for cross sections A-K.



WAG1 01F042.DGN
9/23/92

Fig. 3.2.2. Cross section A - A'.



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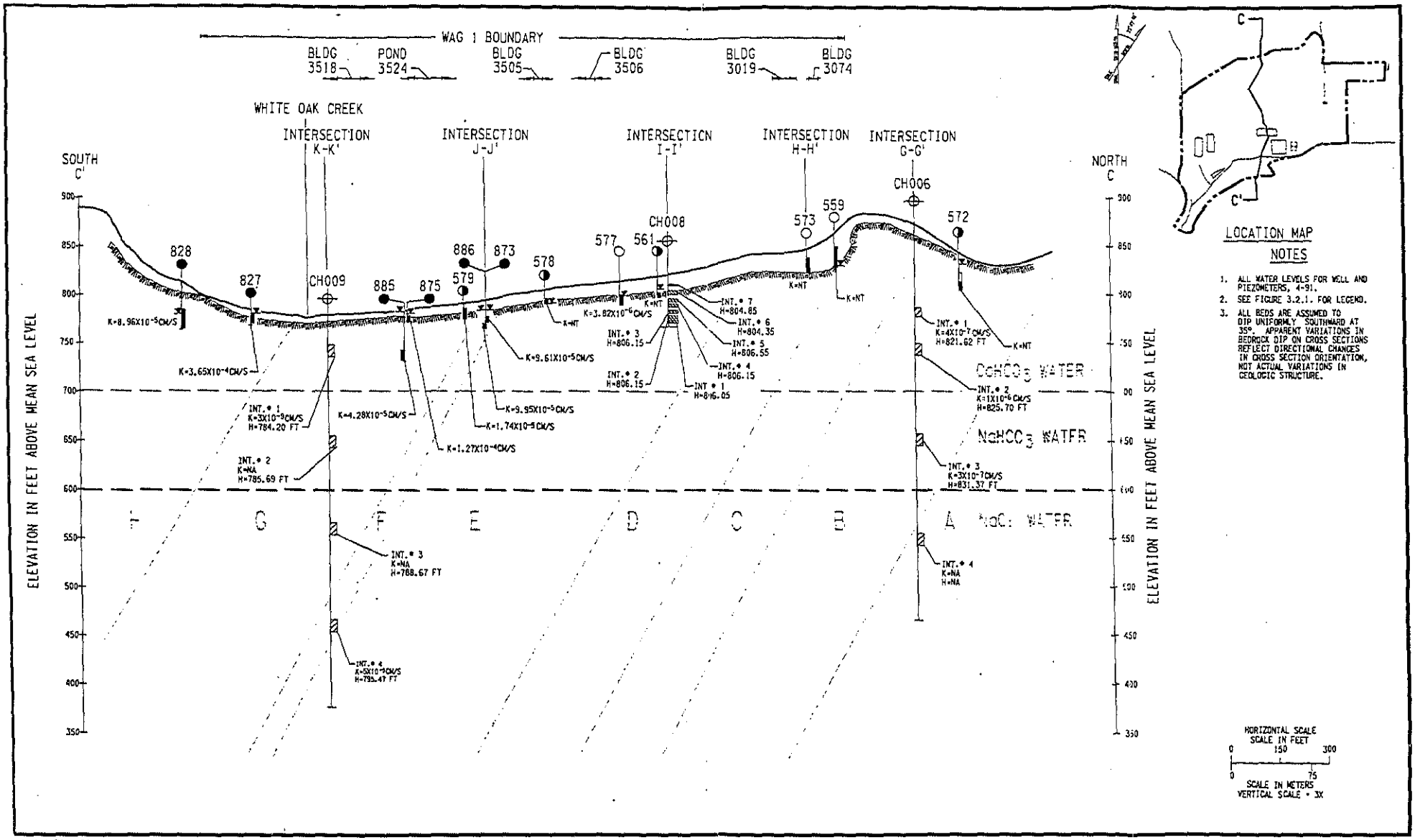
9/23/92

Fig. 3.2.3. Cross section B - B'.



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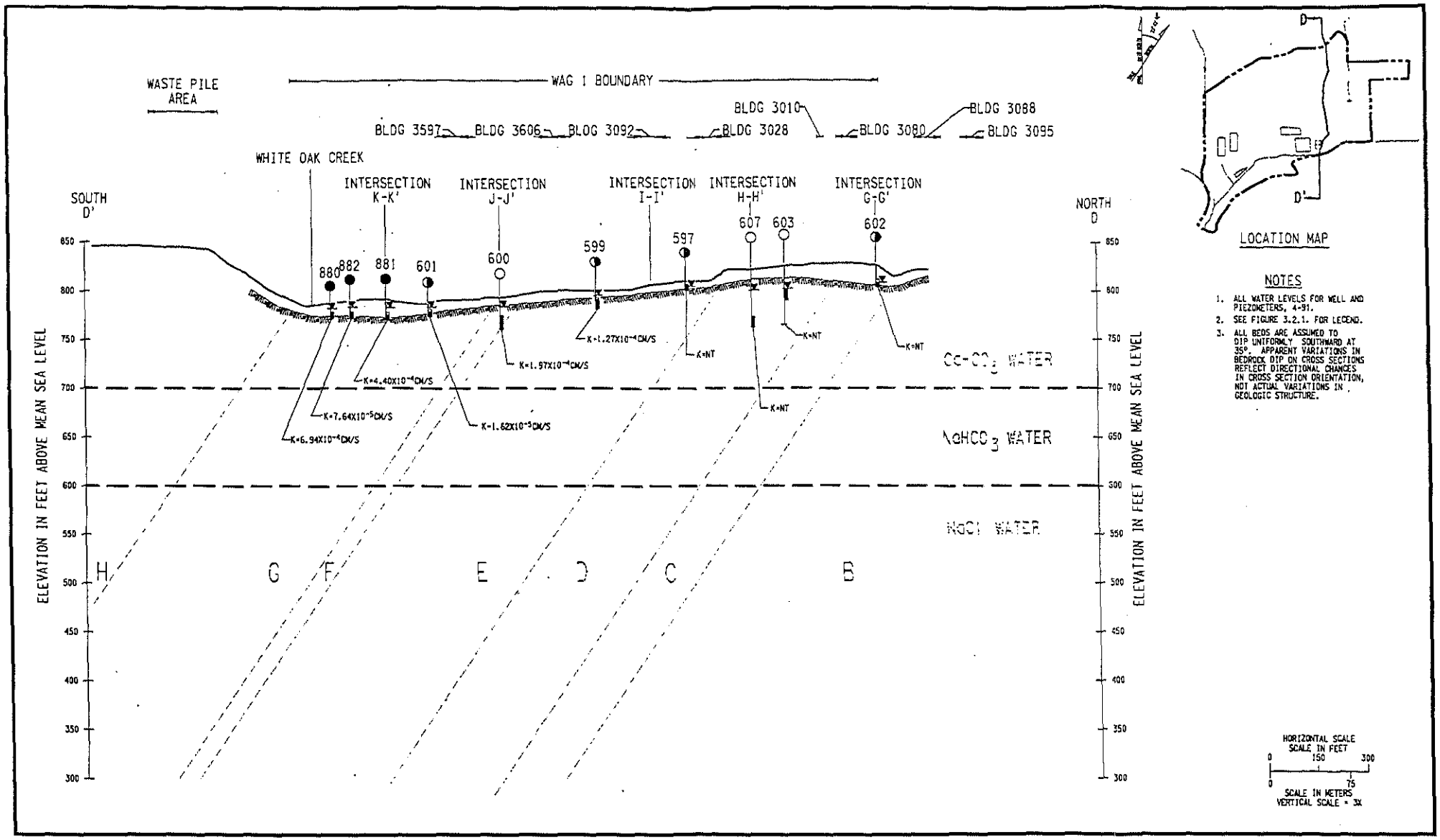
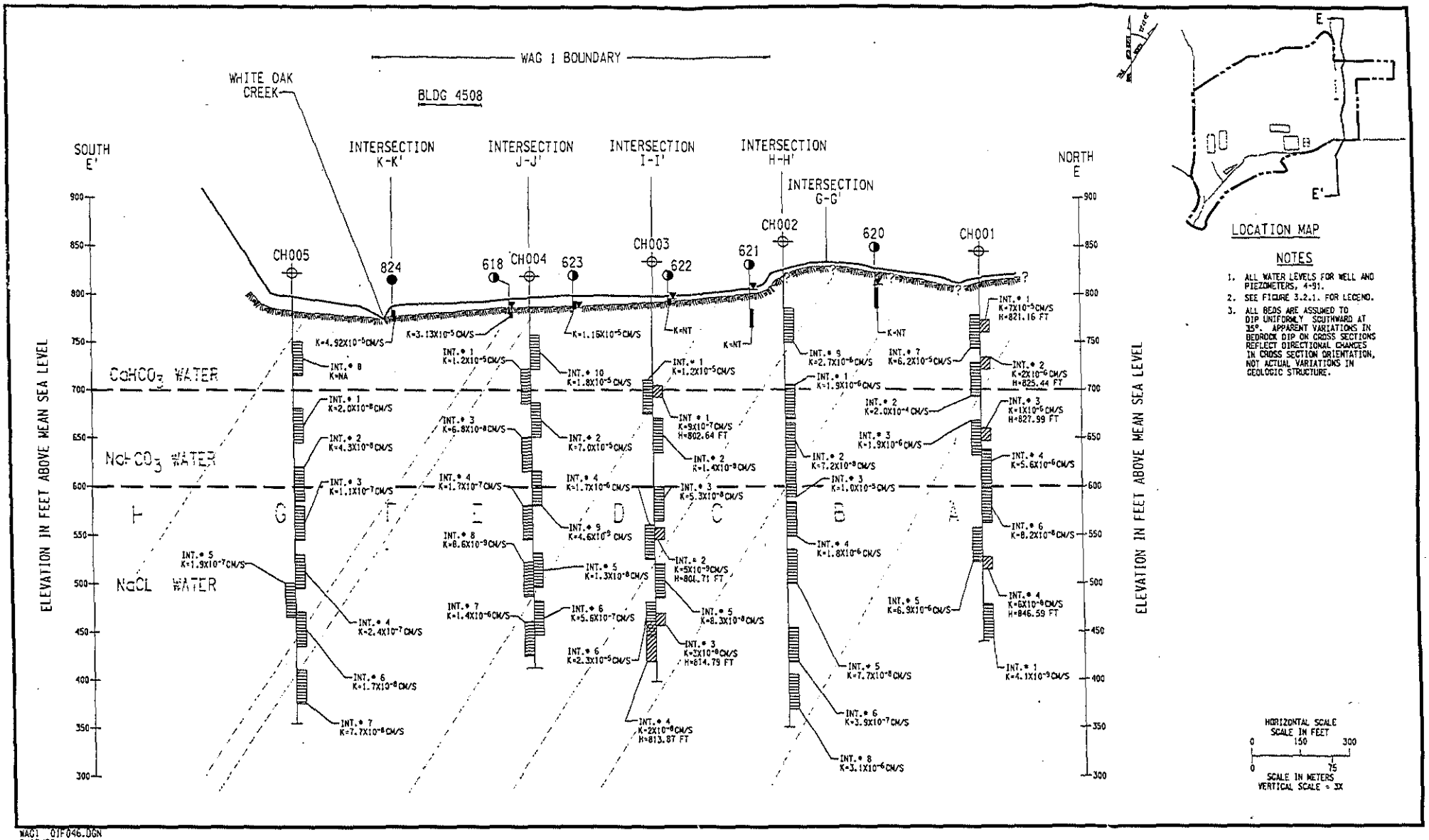
9/23/92

Fig. 3.2.4. Cross section C - C'.



WAG 1 01F045.DGN
9/23/92

Fig. 3.2.5. Cross section D - D'.



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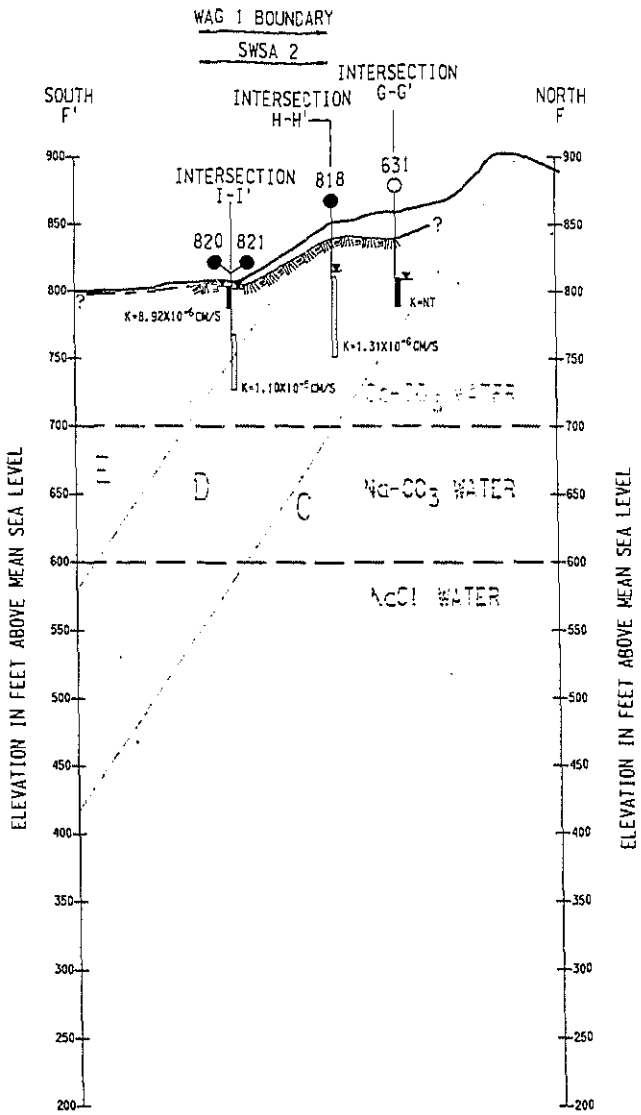
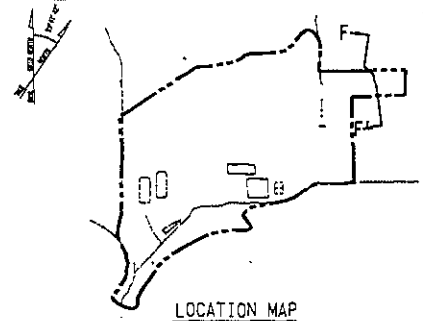
9/23/92

Fig. 3.2.6. Cross section E - E'.





LOCATION MAP

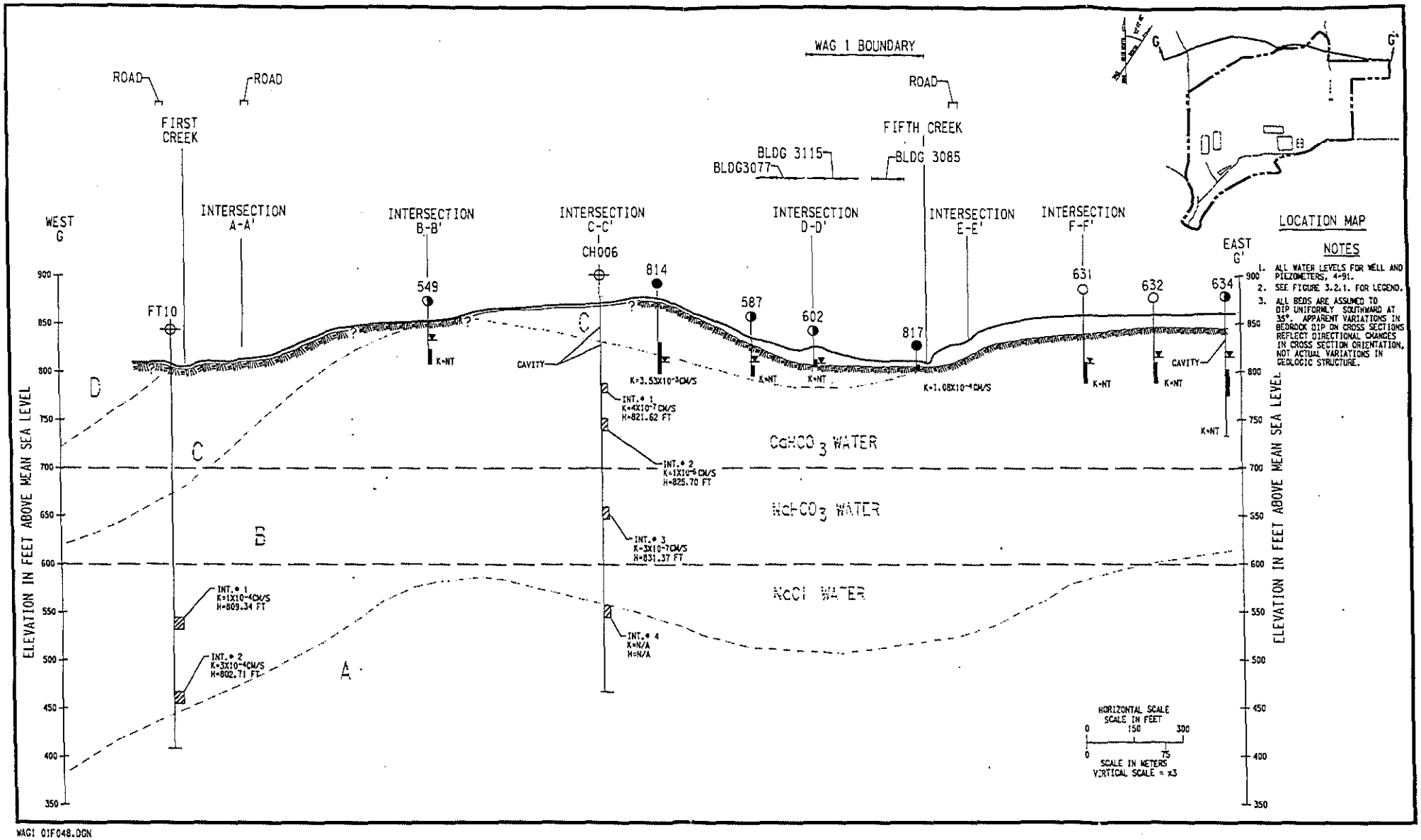
NOTES

1. ALL WATER LEVELS FOR WELL AND PIEZOMETERS, 4-91.
2. SEE FIGURE 3.2.1. FOR LEGEND.
3. ALL BEDS ARE ASSUMED TO DIP UNIFORMLY SOUTHWARD AT 35°. APPARENT VARIATIONS IN BEDROCK DIP ON CROSS SECTIONS REFLECT DIRECTIONAL CHANGES IN CROSS SECTION ORIENTATION, NOT ACTUAL VARIATIONS IN GEOLOGIC STRUCTURE.

HORIZONTAL SCALE
SCALE IN FEET
0 150 300
0 75
SCALE IN METERS
VERTICAL SCALE = 3X

WAG 1 01F047.DGN
9/23/92

Fig. 3.2.7. Cross section F - F'.



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9/23/92

Fig. 3.2.8. Cross section G - G'.

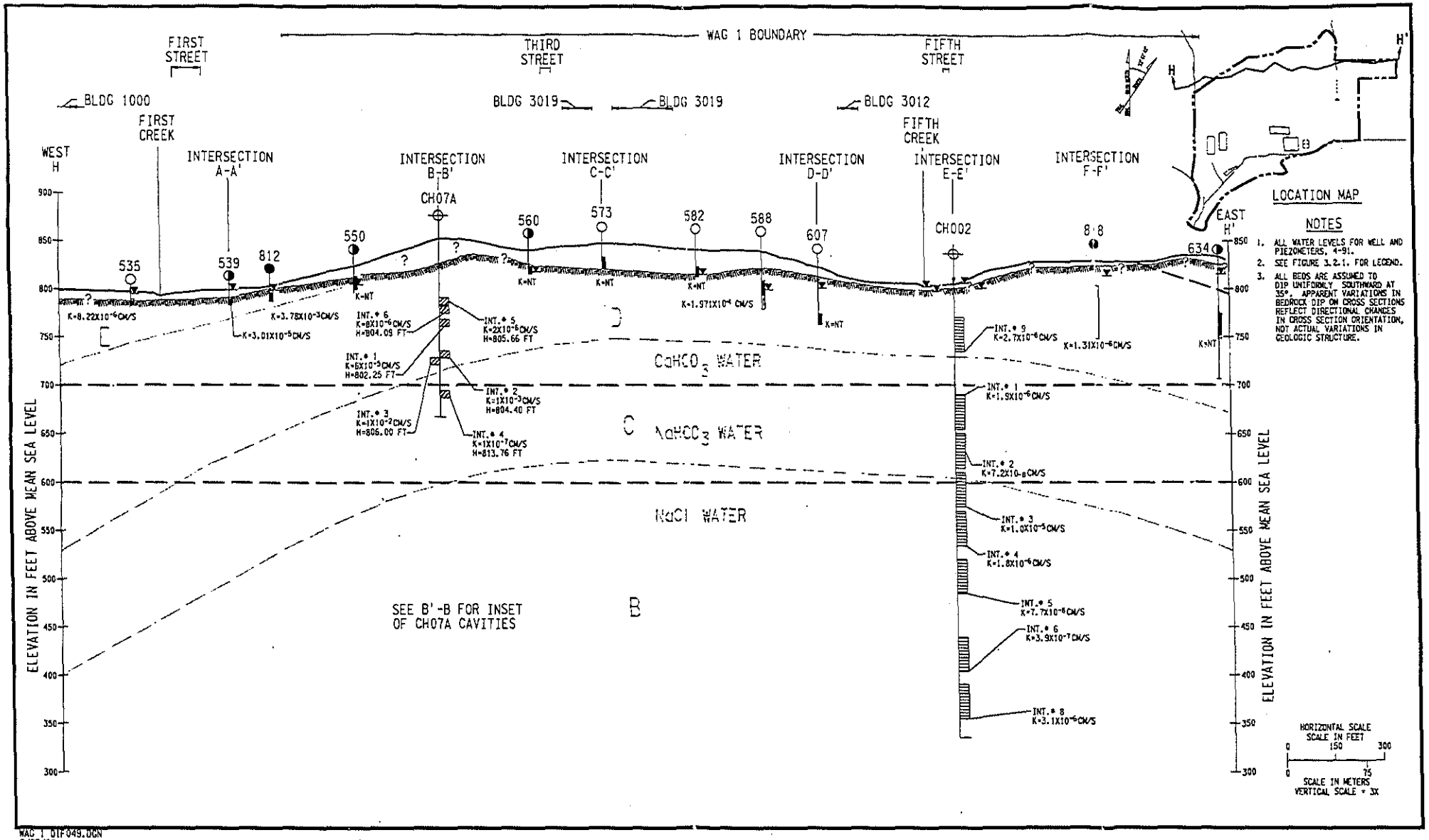
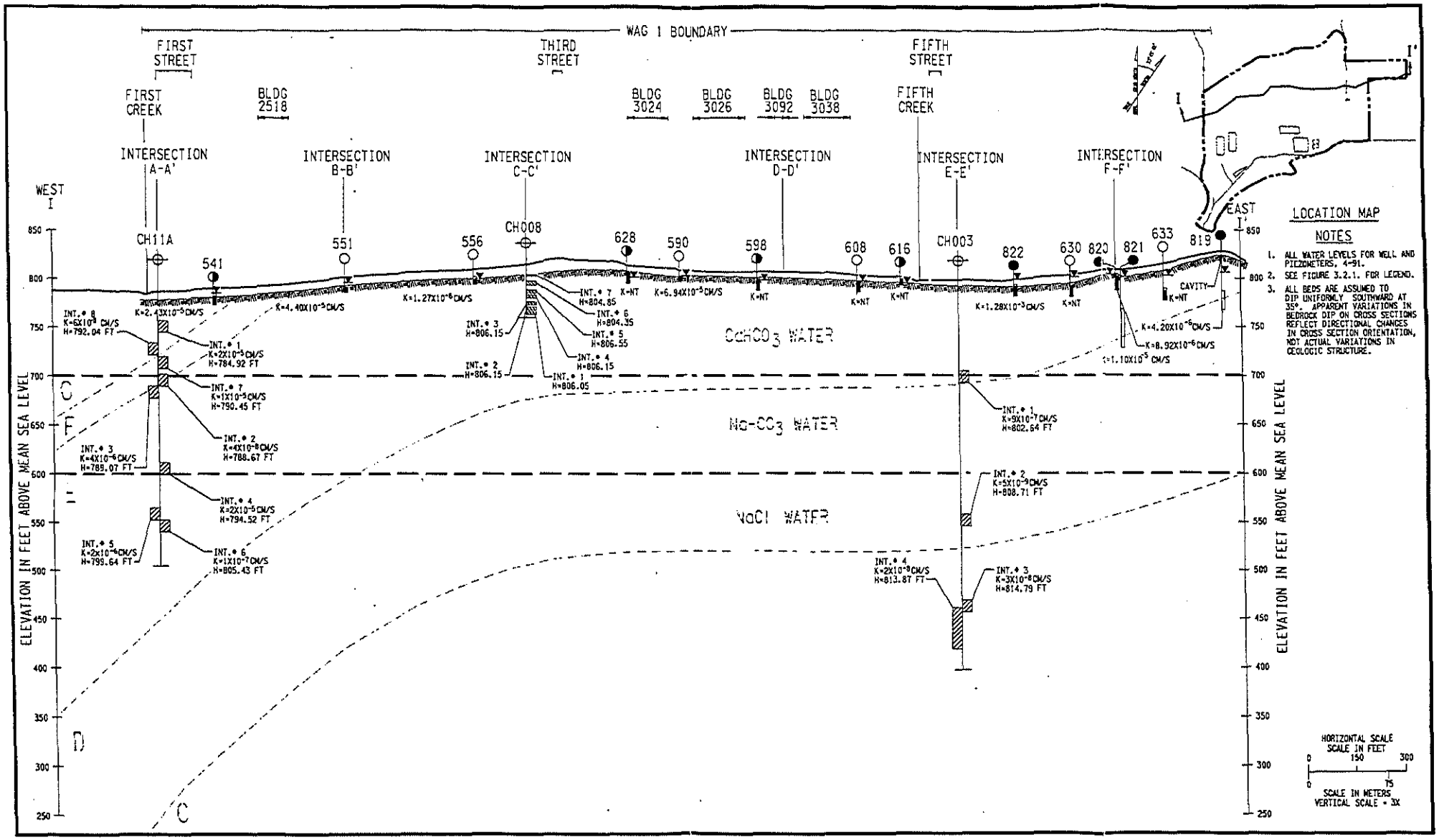
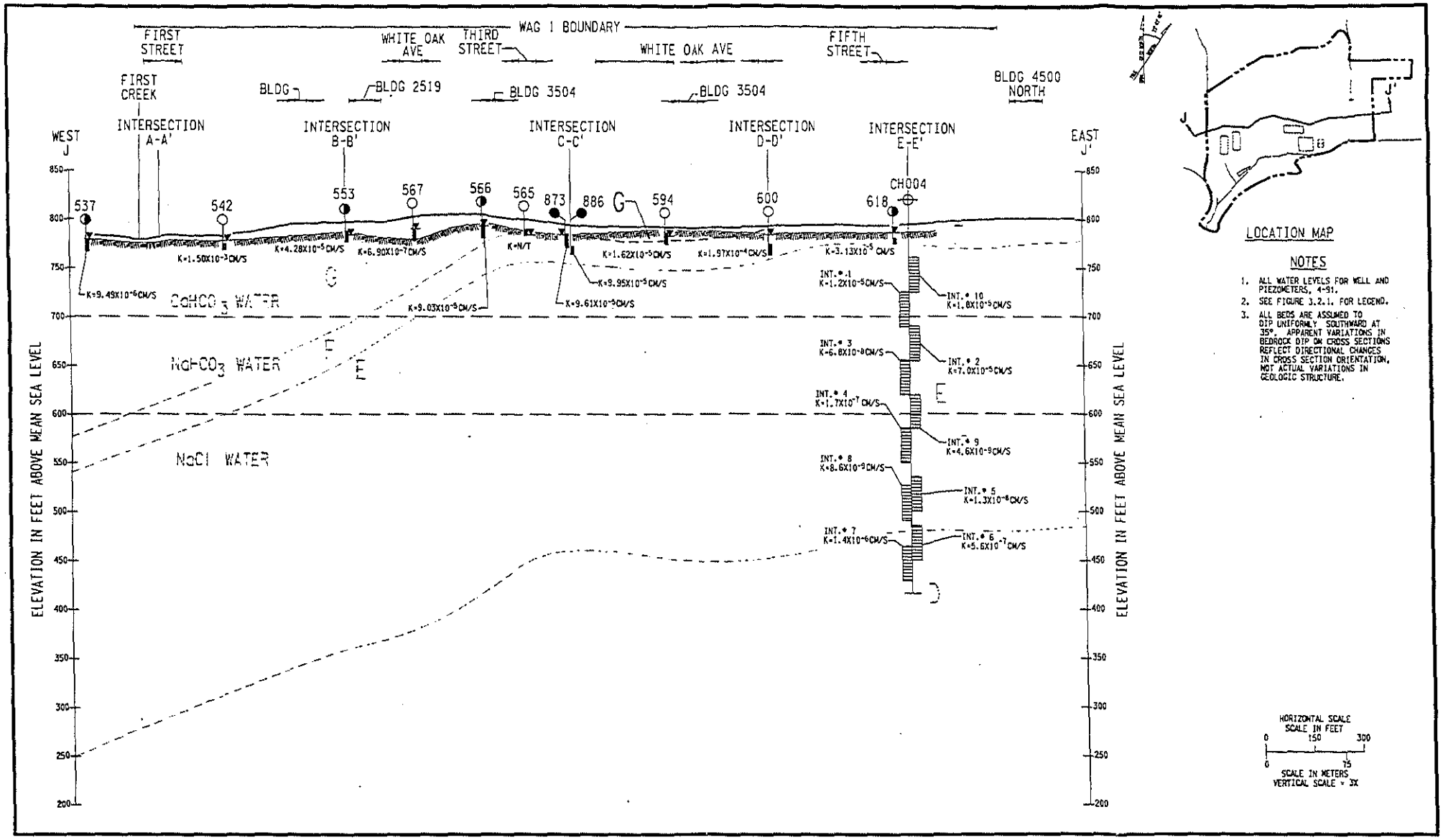


Fig. 3.2.9. Cross section H - H'.



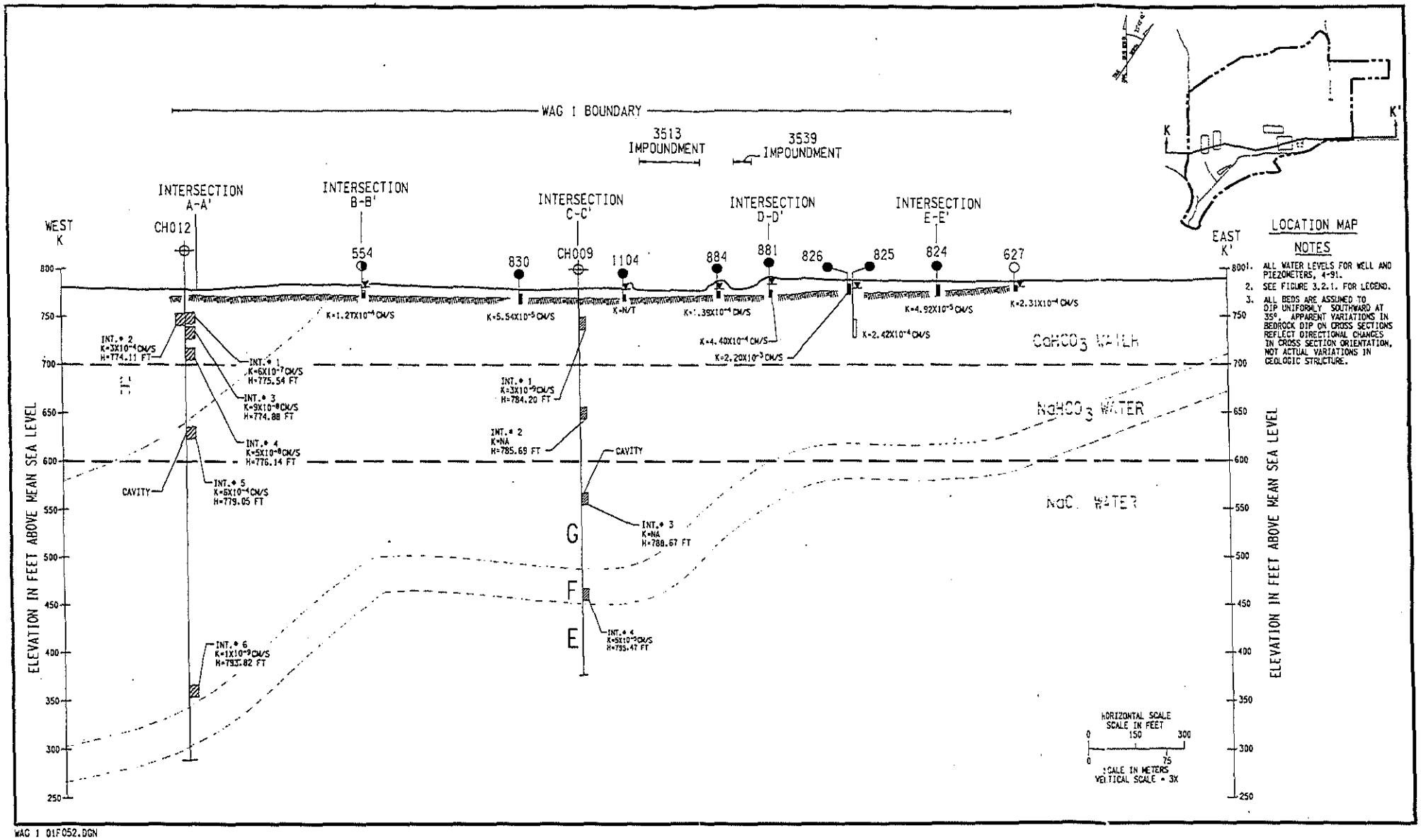
WAG 1 01F050.DGN
9/23/92

Fig. 3.2.10. Cross section I - I'.



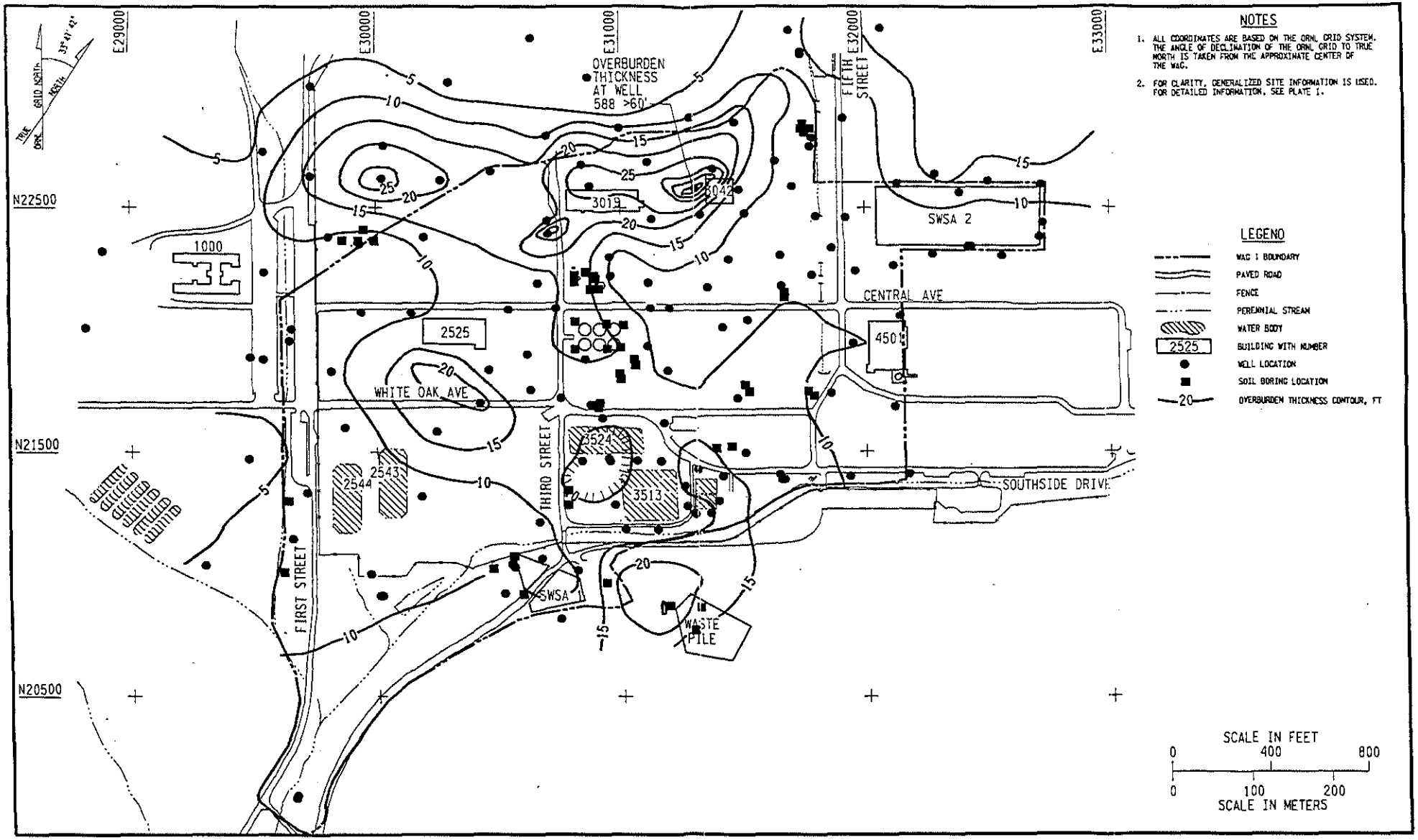
WAG 1 01F051.DGN
9/23/92

Fig. 3.2.11. Cross section J - J'.



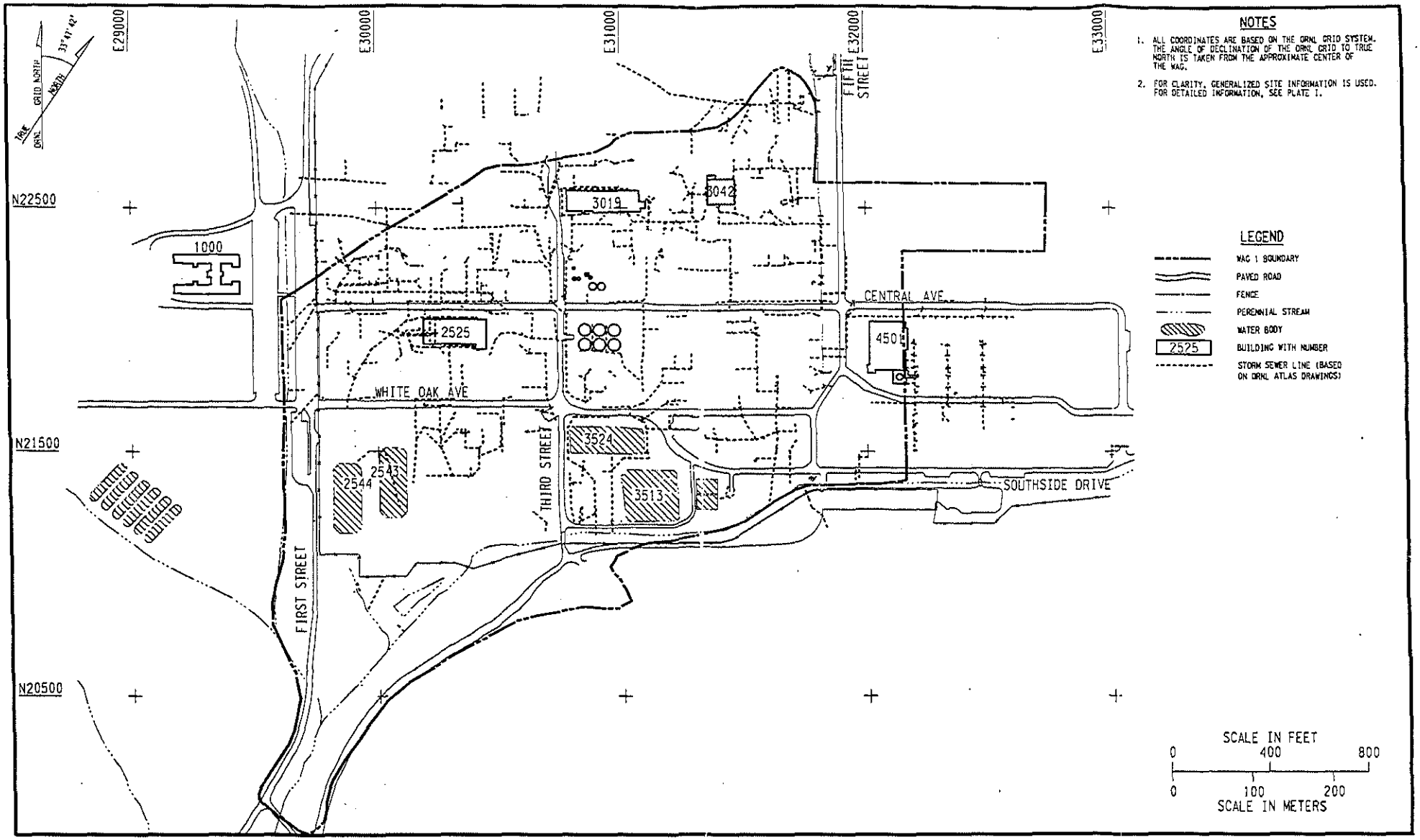
WAG 1 01F052.DGN
9/23/92

Fig. 3.2.12. Cross section K - K'.



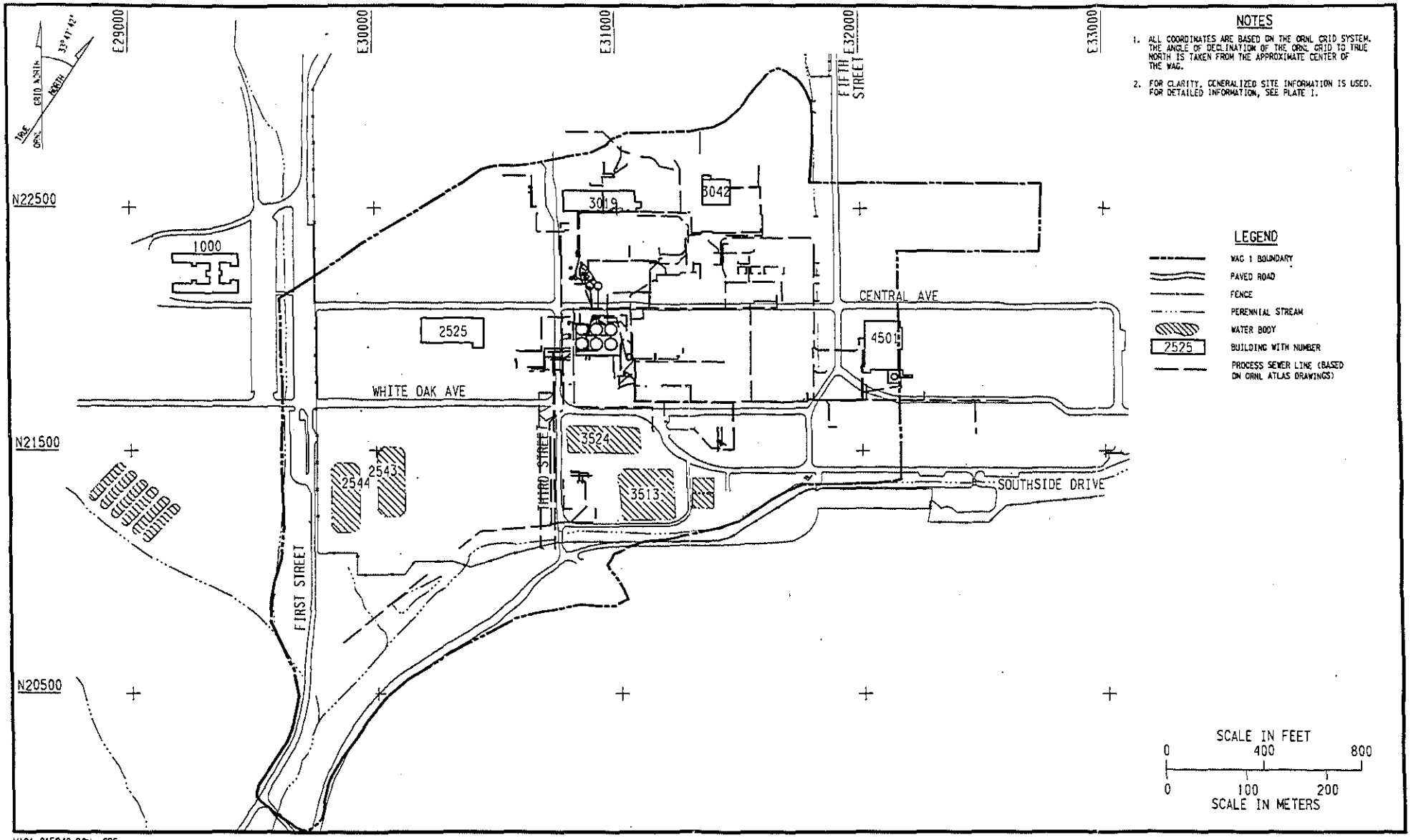
WAG 1 01F236.DGN
9/23/92

Fig. 3.2.13. Map of overburden thickness.



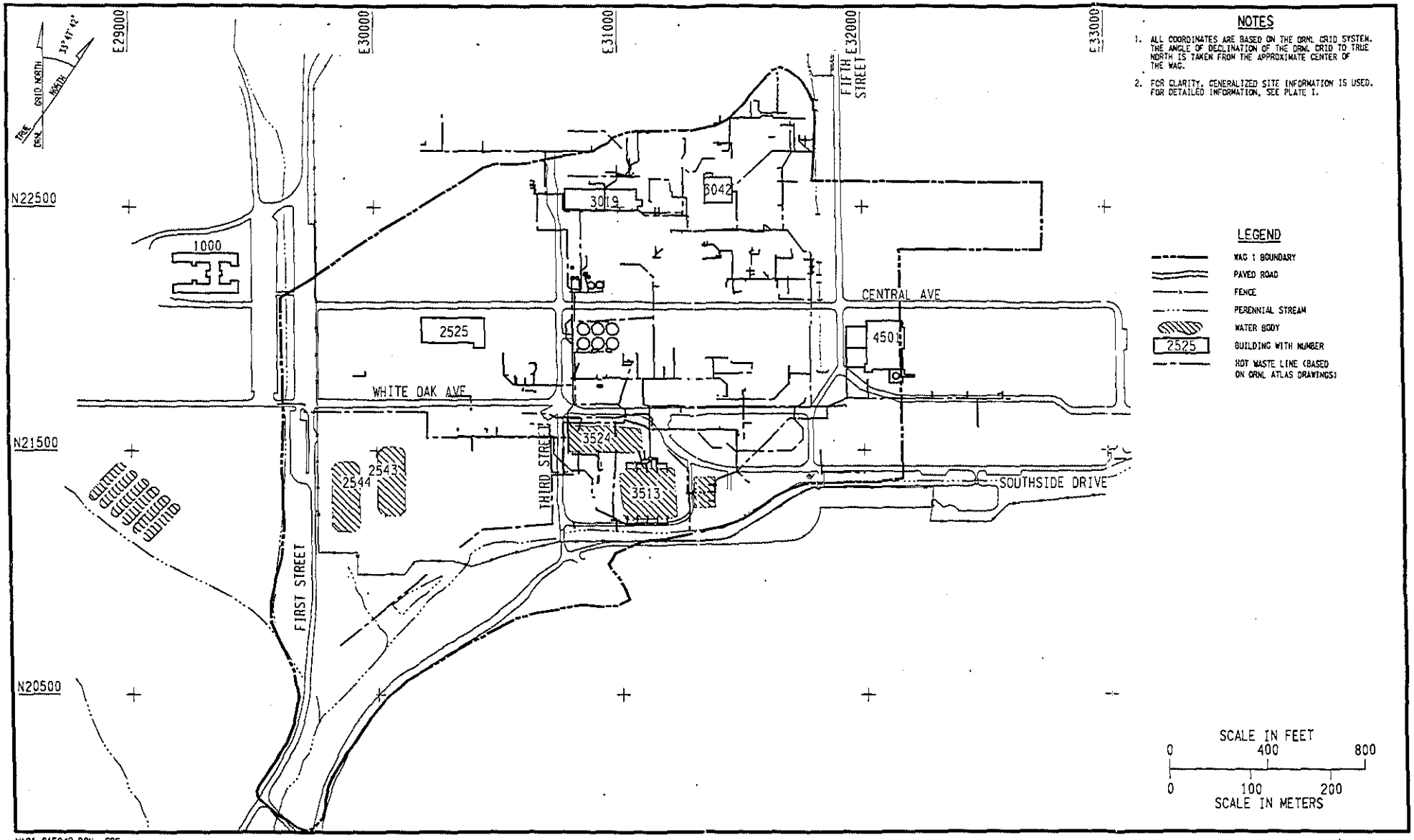
WAG1 01F247.DGN SRF, 6/10/92

Fig. 3.2.14. Storm sewer lines.



WAG1 01F248.DGN SRF, 6/10/92

Fig. 3.2.15. Process sewer lines.



WAG1 01F249.DGN SRF,
6/10/92

Fig. 3.2.16. Hot waste lines.

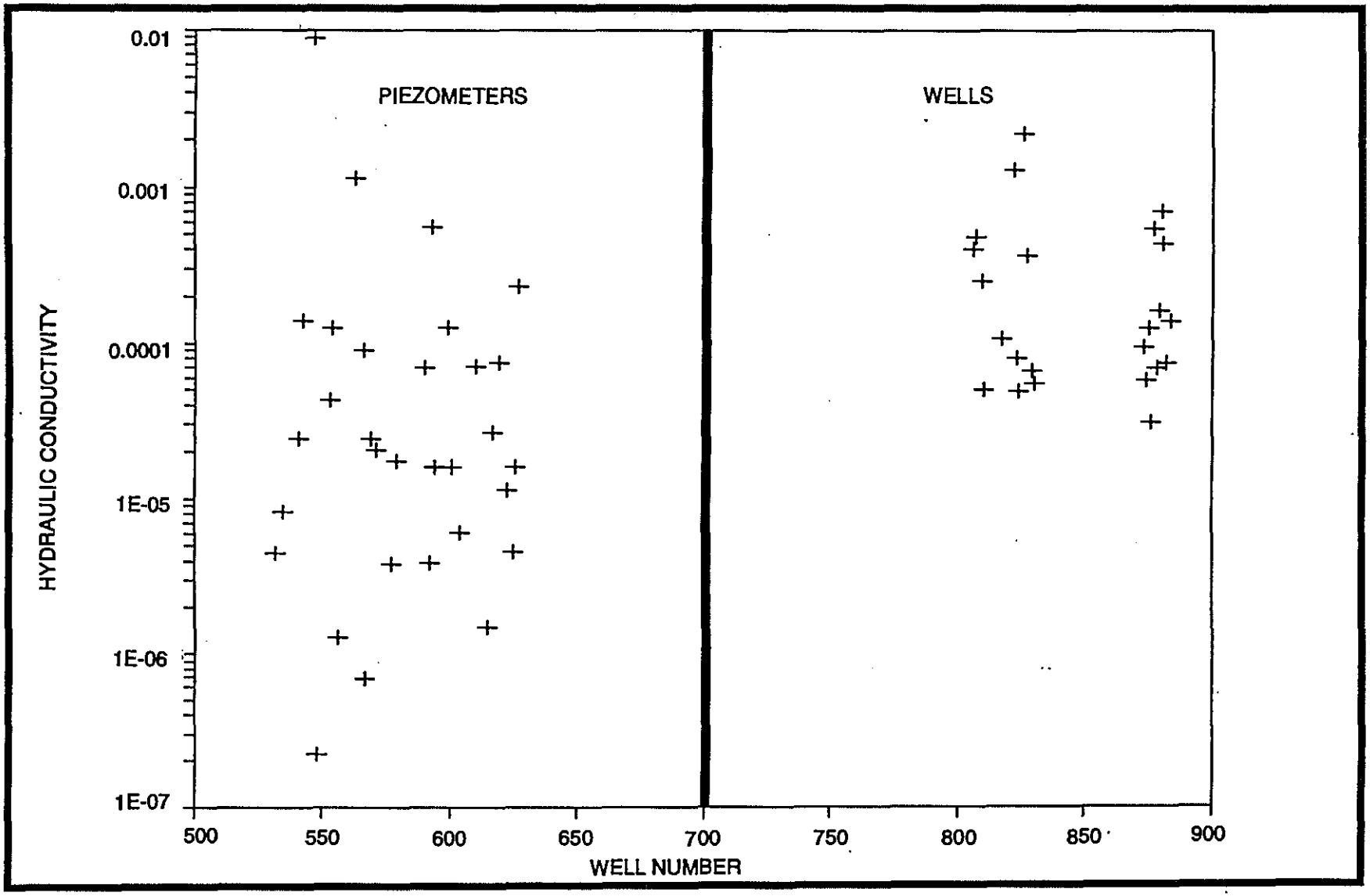


Fig. 3.2.17. Relationship between well construction and hydraulic conductivity values.

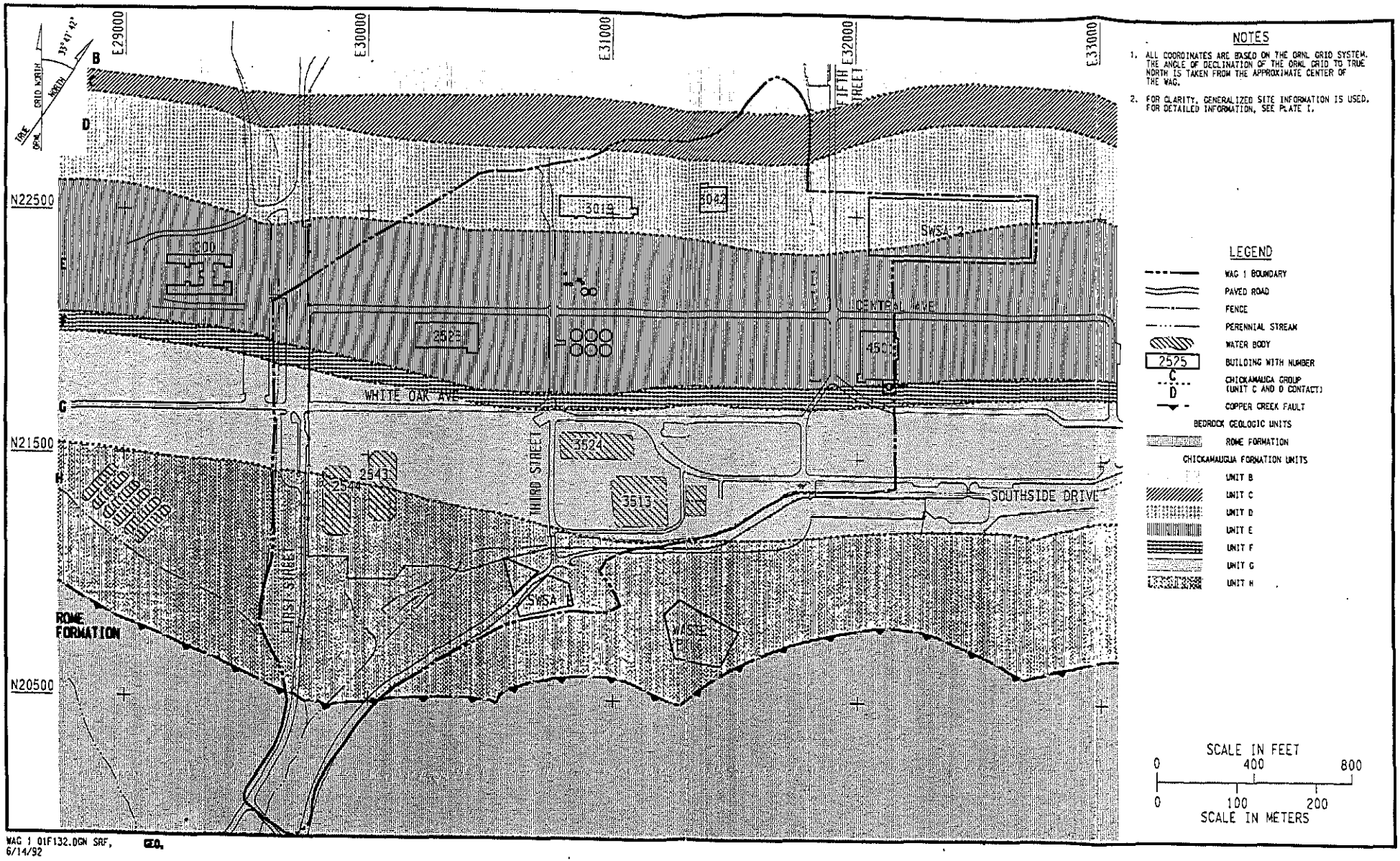


Fig. 3.2.18. Bedrock geology.

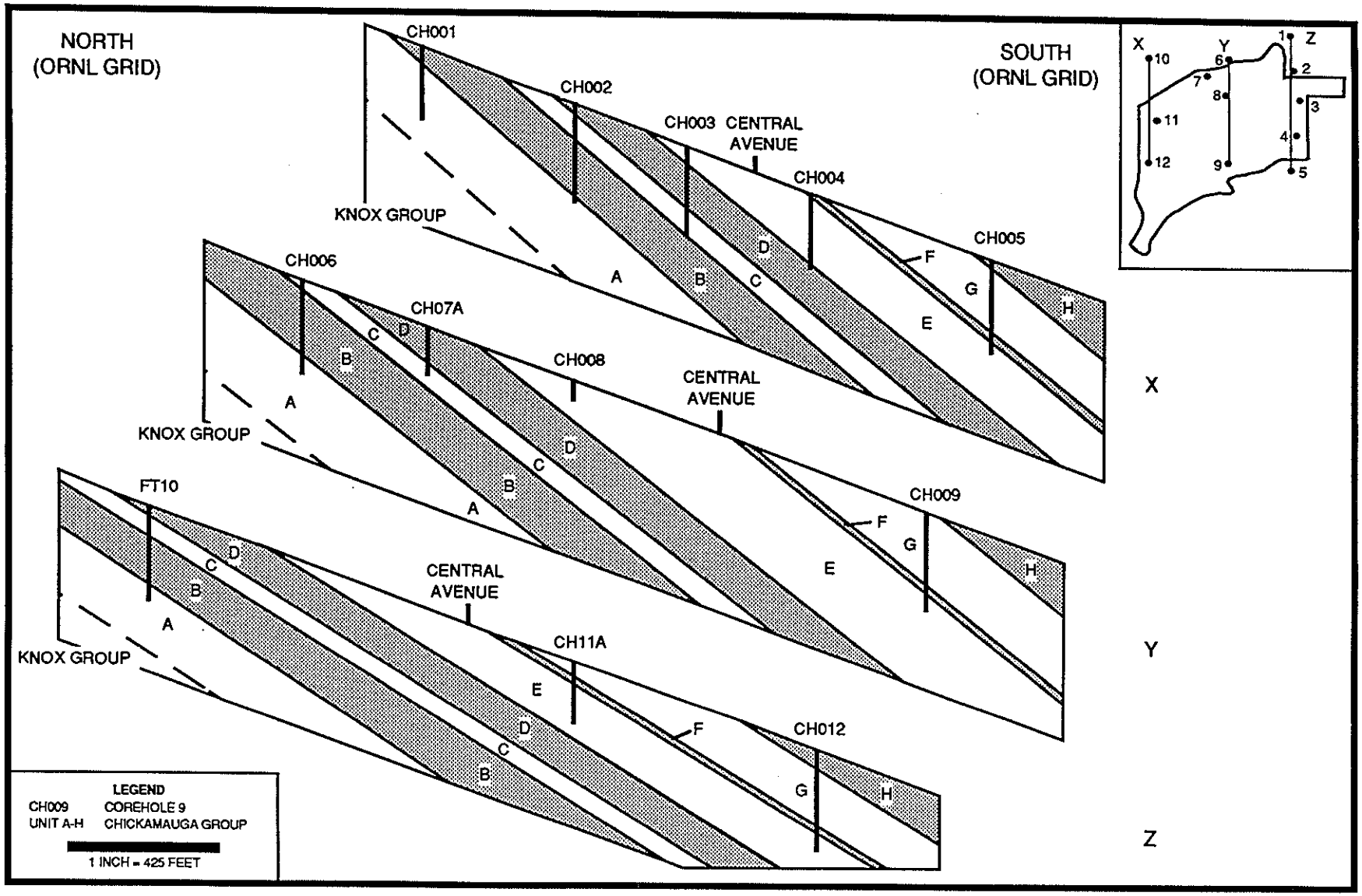
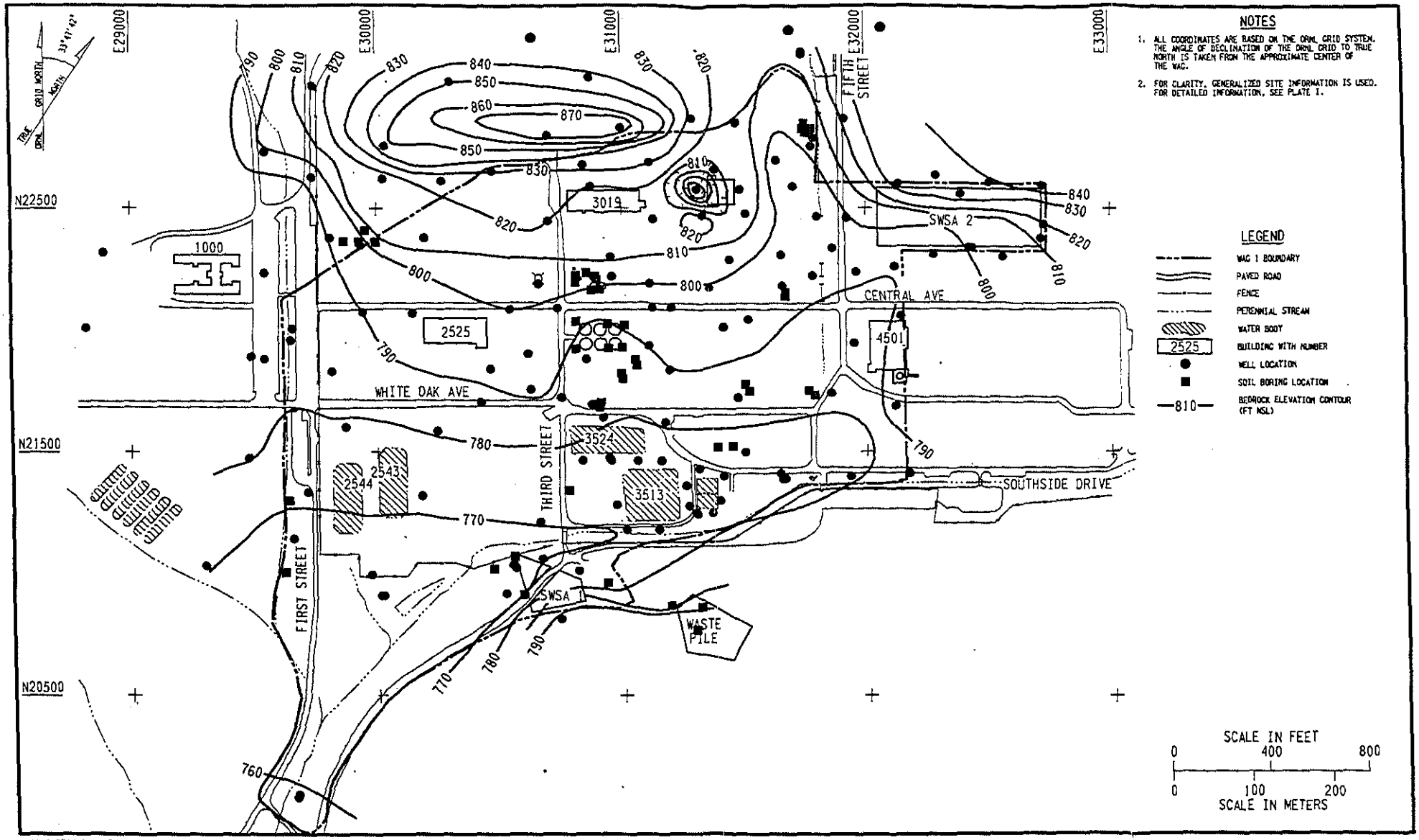


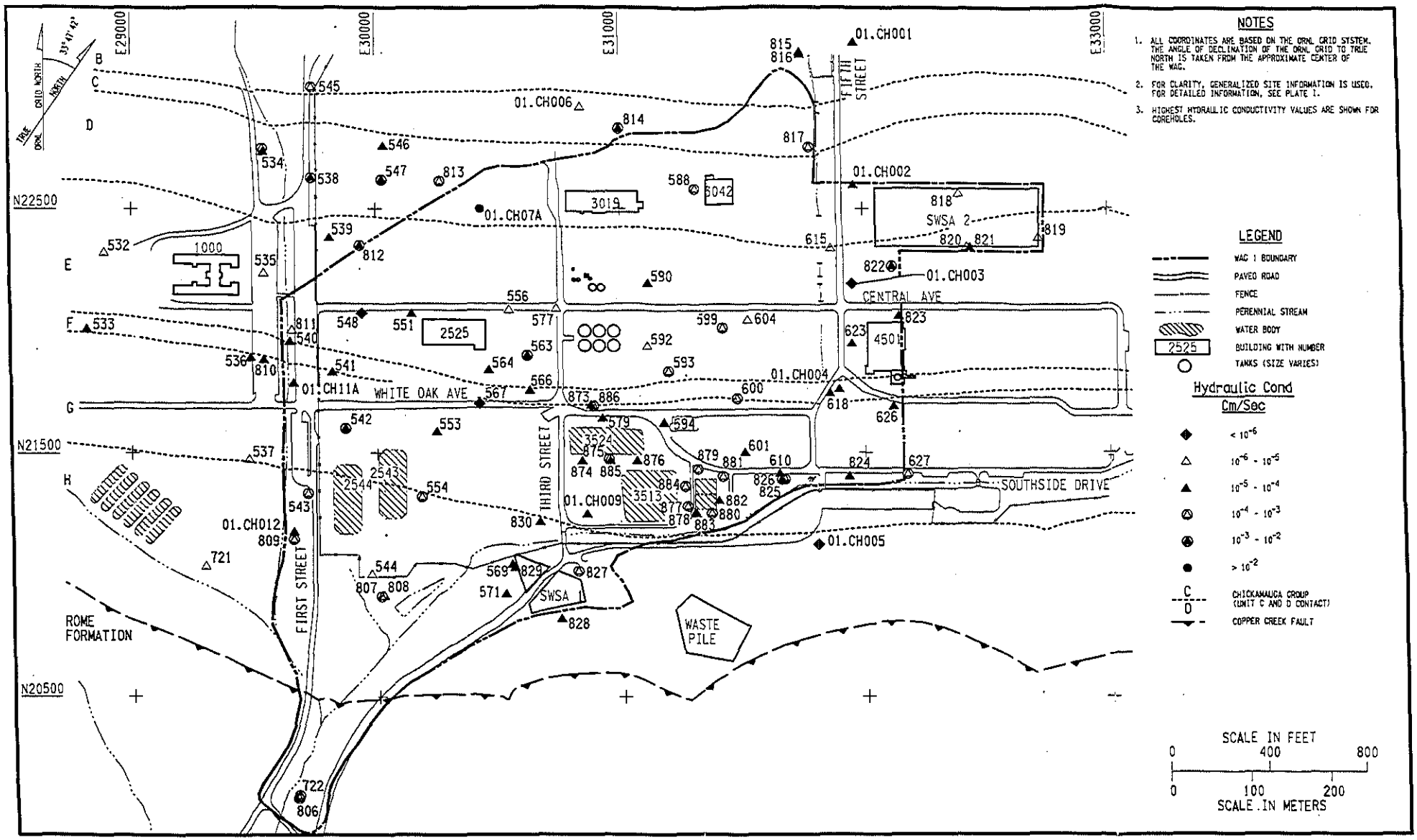
Fig. 3.2.19. Generalized cross section showing bedrock units.

5.31 5922.1A



WAG1 01F314.DGN SRF, 6/14/92

Fig. 3.2.20. Bedrock elevation.



WAG 1 01F226.DGN
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GEO,

Fig. 3.2.21. Distribution of hydraulic conductivity valu for wells and piezometers.

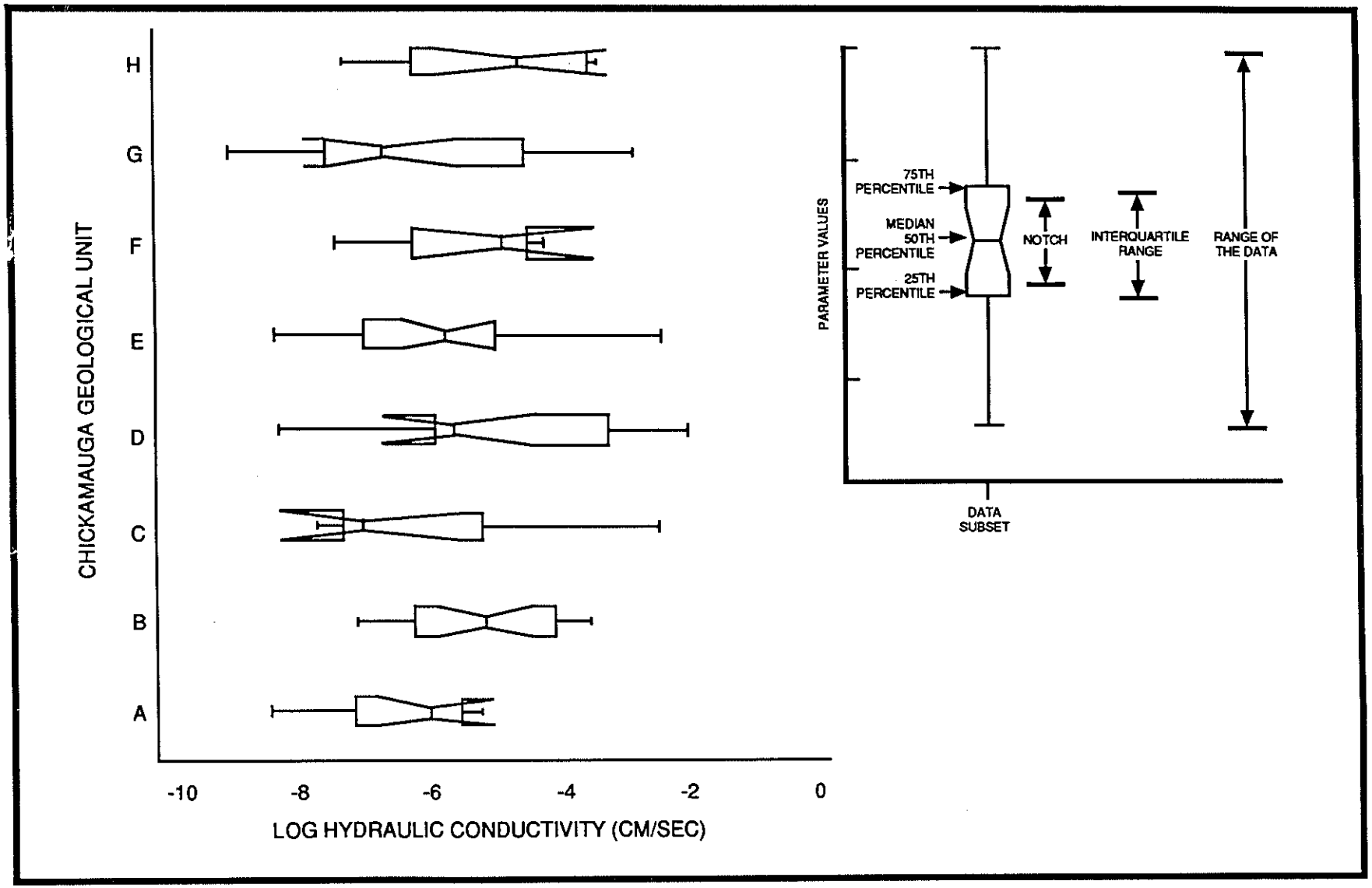


Fig. 3.2.22. Relationship between hydraulic conductivity and Chickamauga bedrock unit.

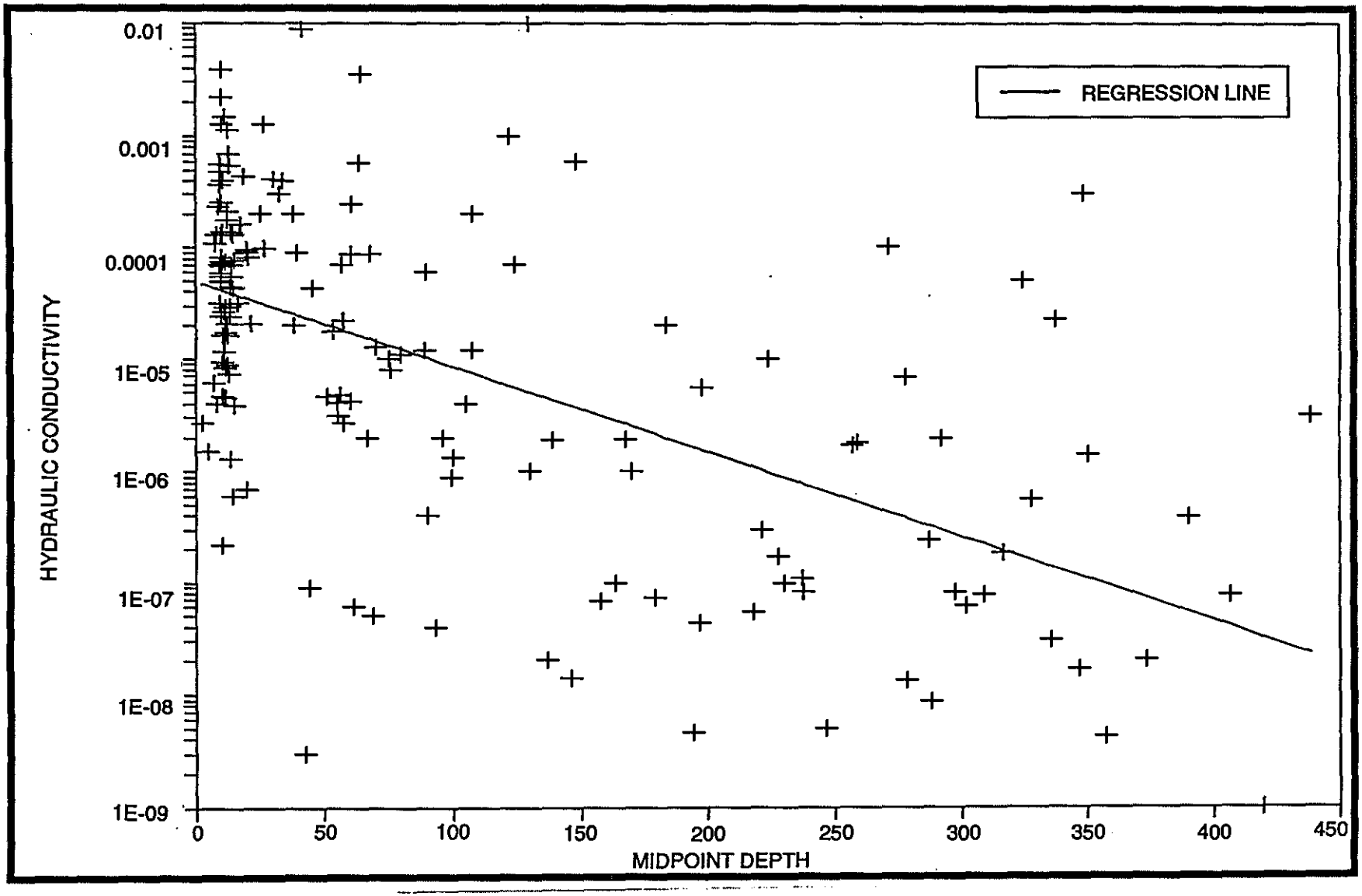


Fig. 3.2.23 Relationship between hydraulic conductivity and depth.

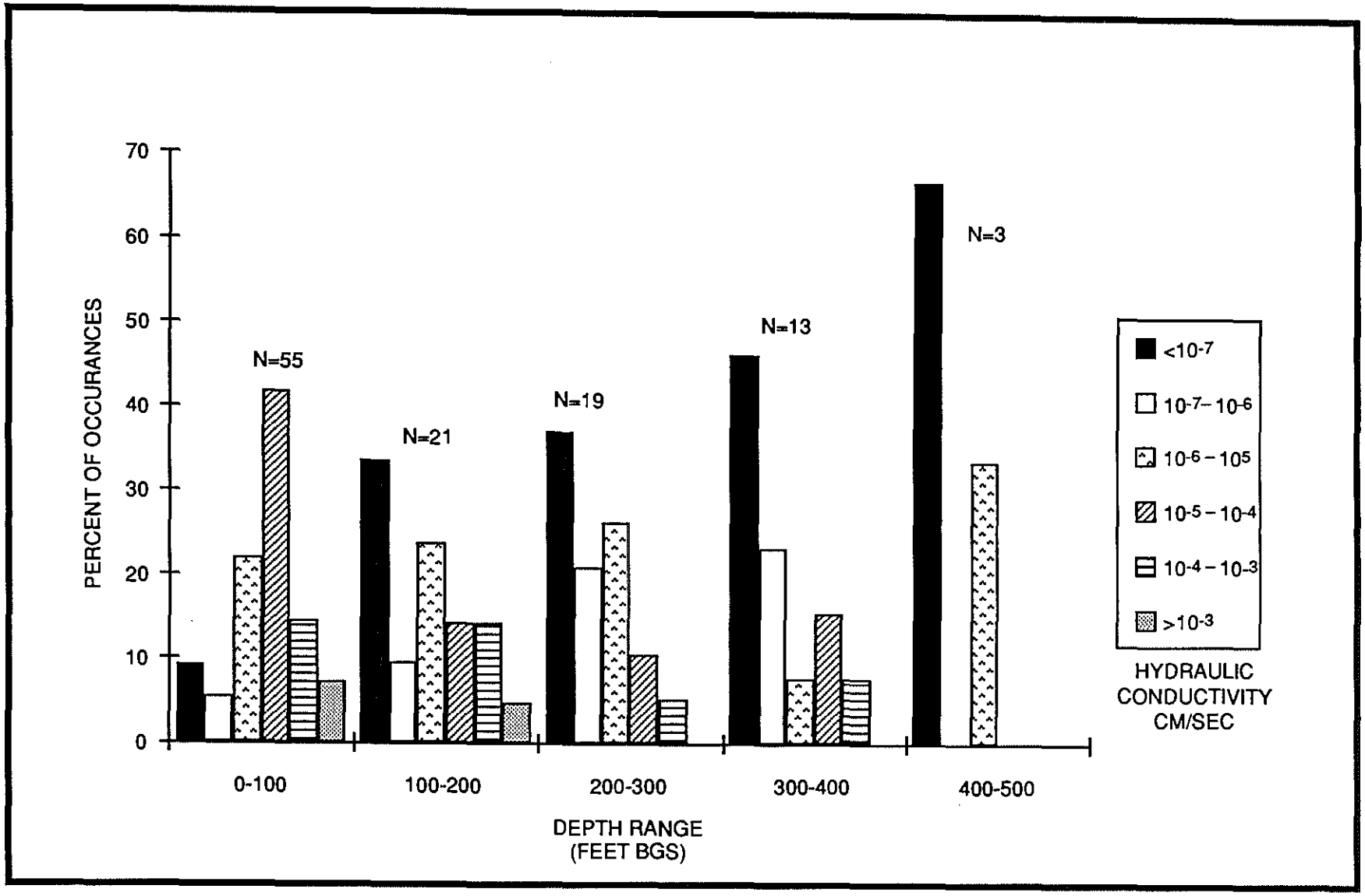


Fig. 3.2.24 Relationship between hydraulic conductivity (cm/sec) and depth.

6066.110

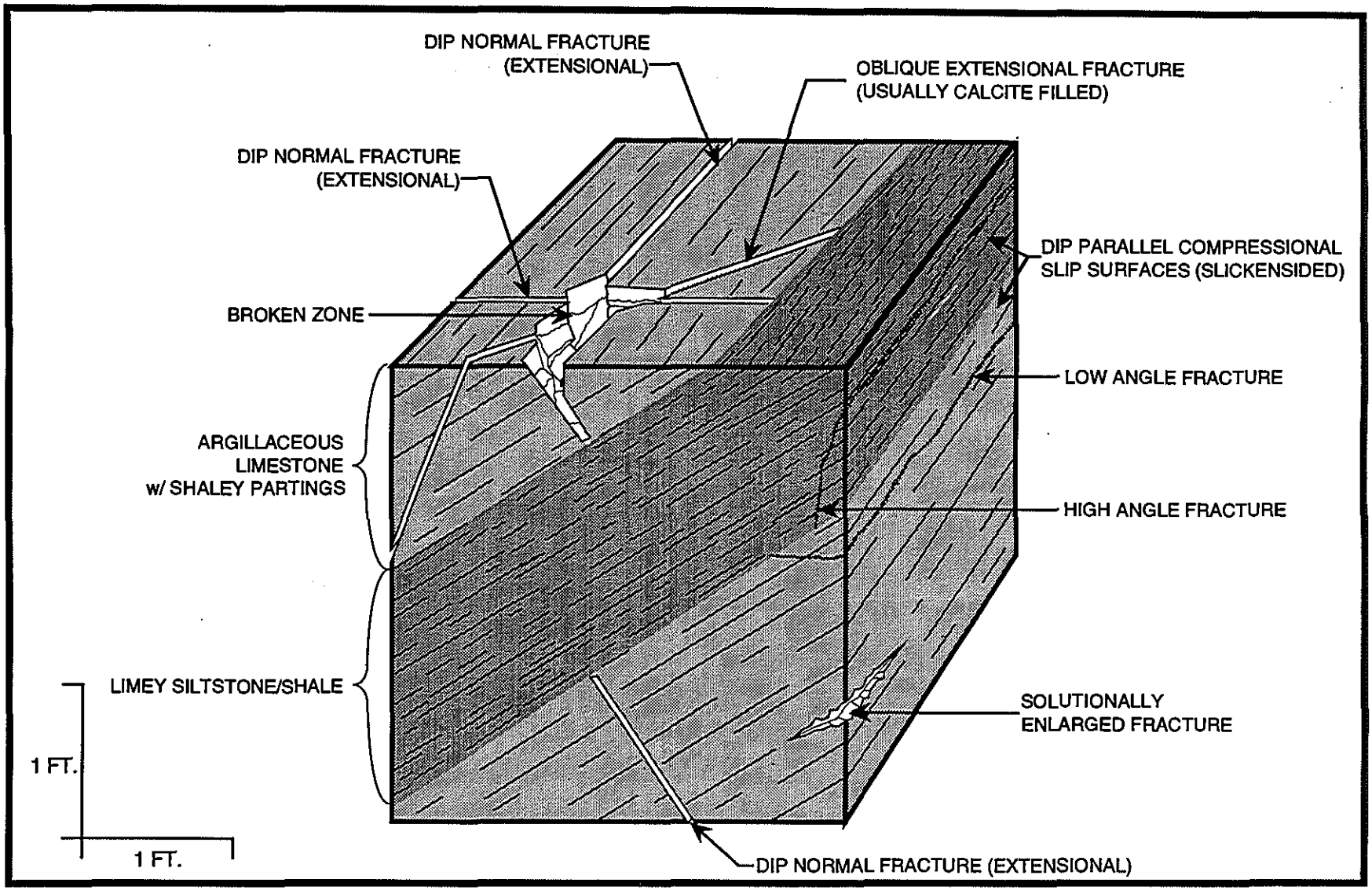


Fig. 3.2.25 Types of fractures in the Chickamauga Group.

5.33G 6066.93

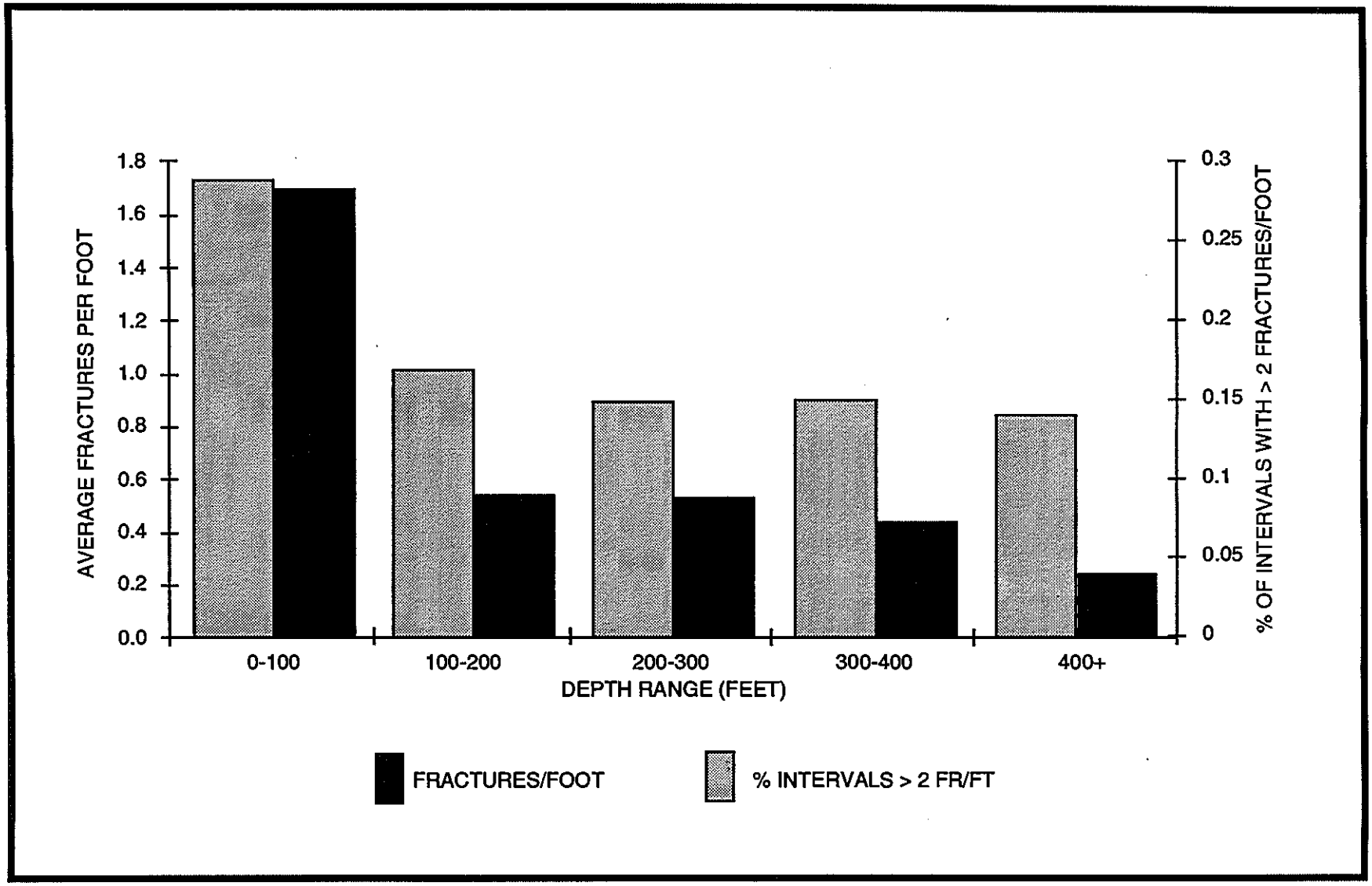
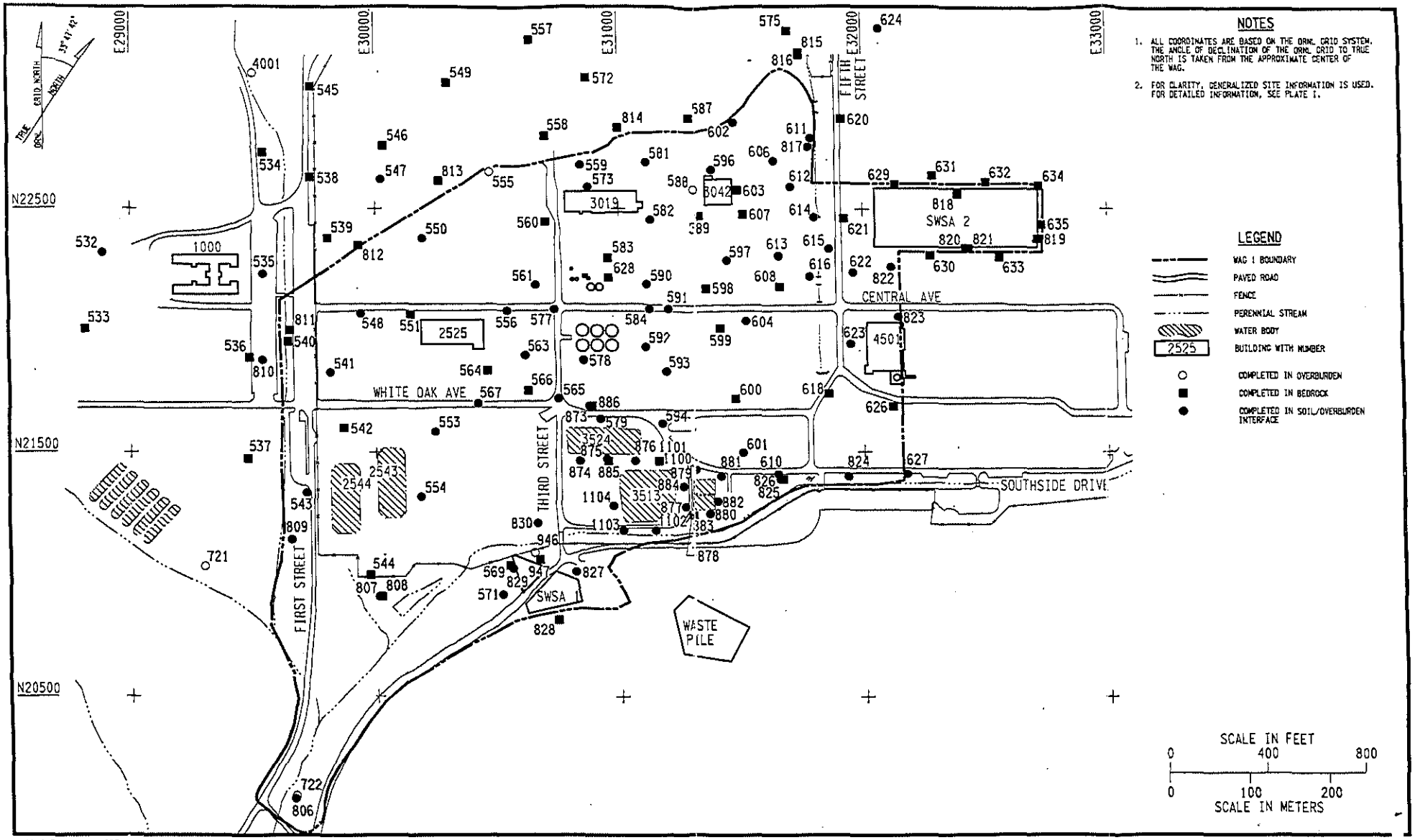
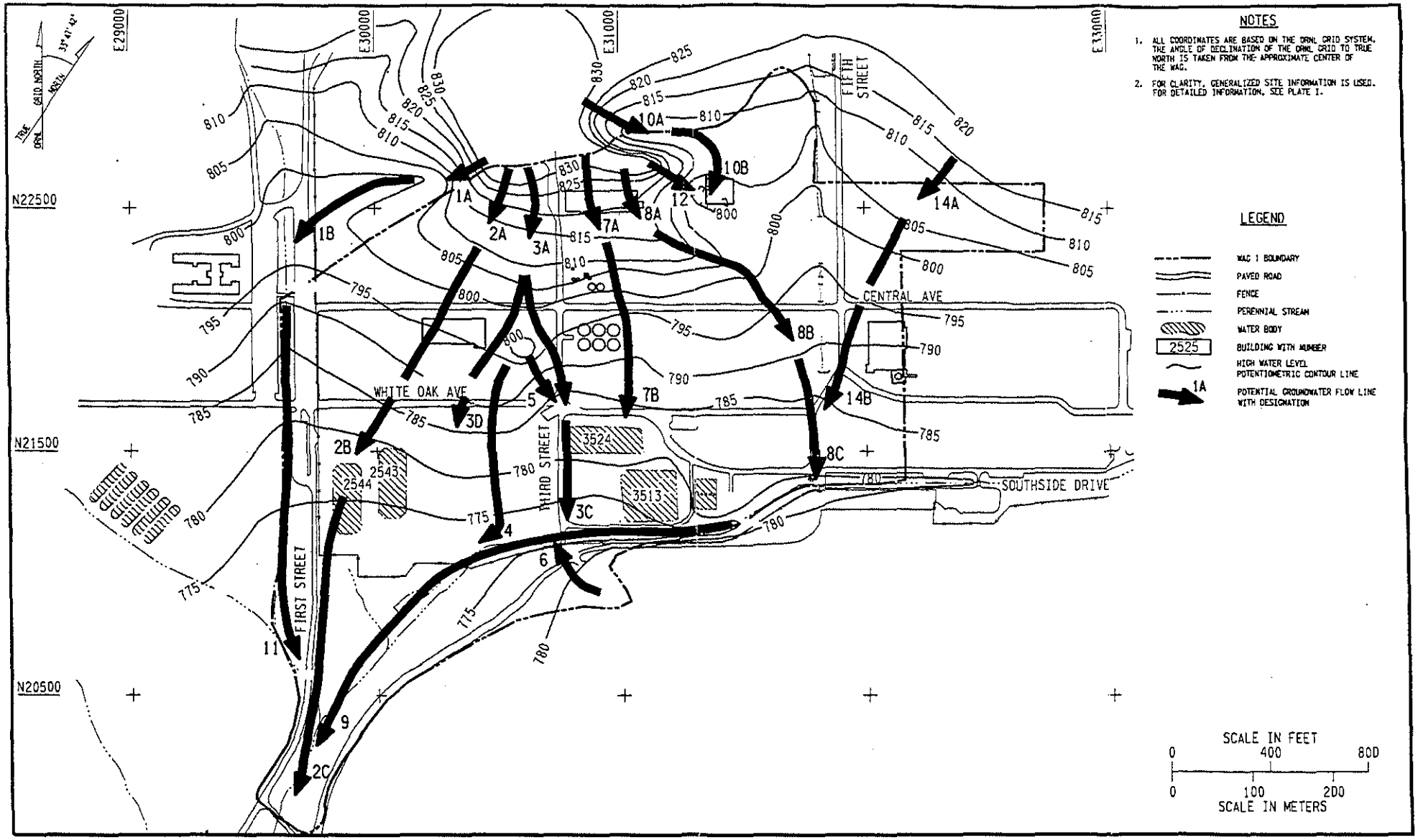


Fig. 3.2.26. Relationship between fracture density and depth for coreholes.



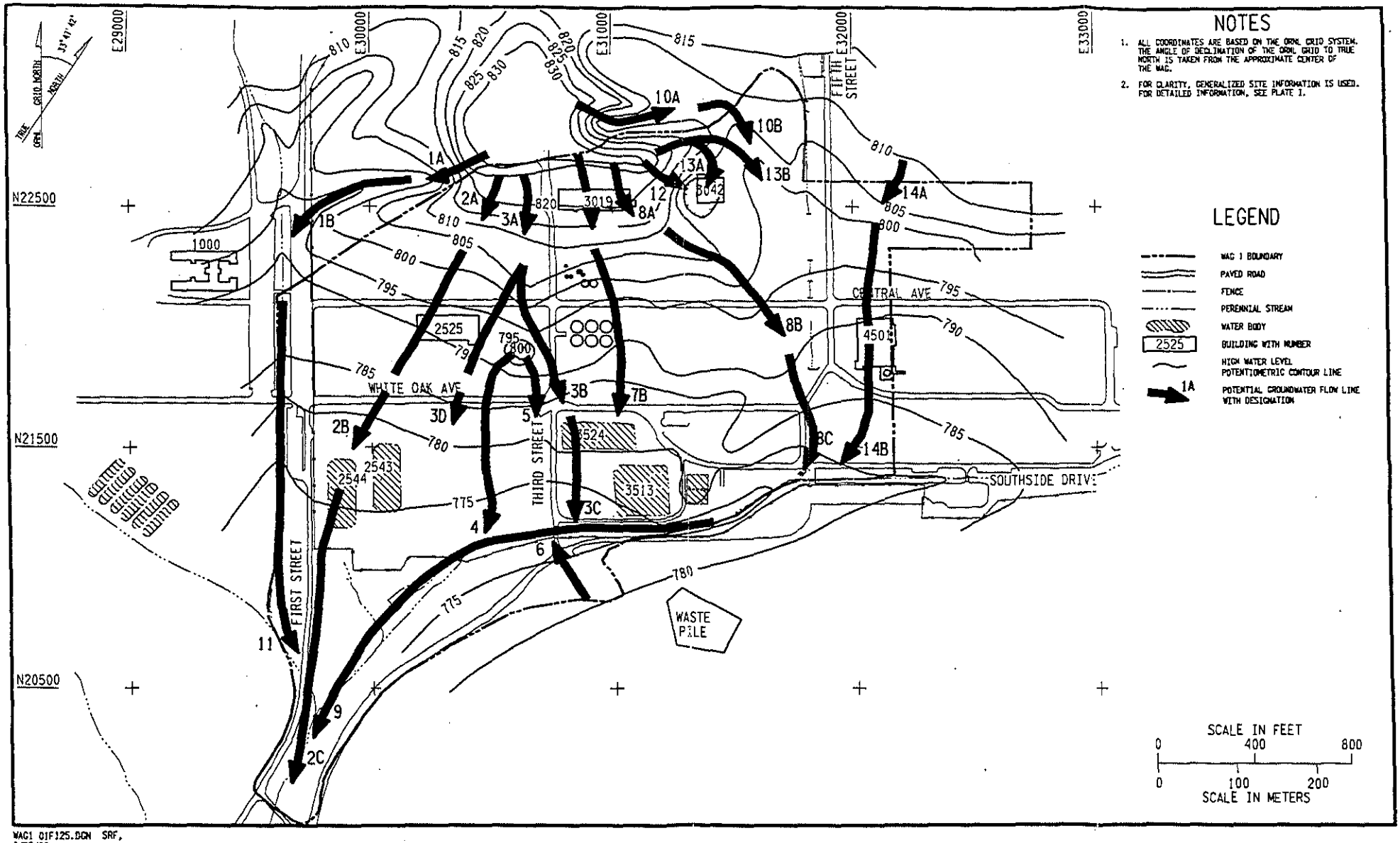
WAG1 01F246.DGN SRF, 6/22/92

Fig. 3.3.1. Distribution of well and piezometer types.



WAG1 01F124.DGN SRF, 8/25/92

Fig. 3.3.2. Map of water table under high base conditions April 1991



WAG1 01F125.DGN SRF, 8/25/92

Fig. 3.3.3. Map of water table condition under low base conditions 9/91.

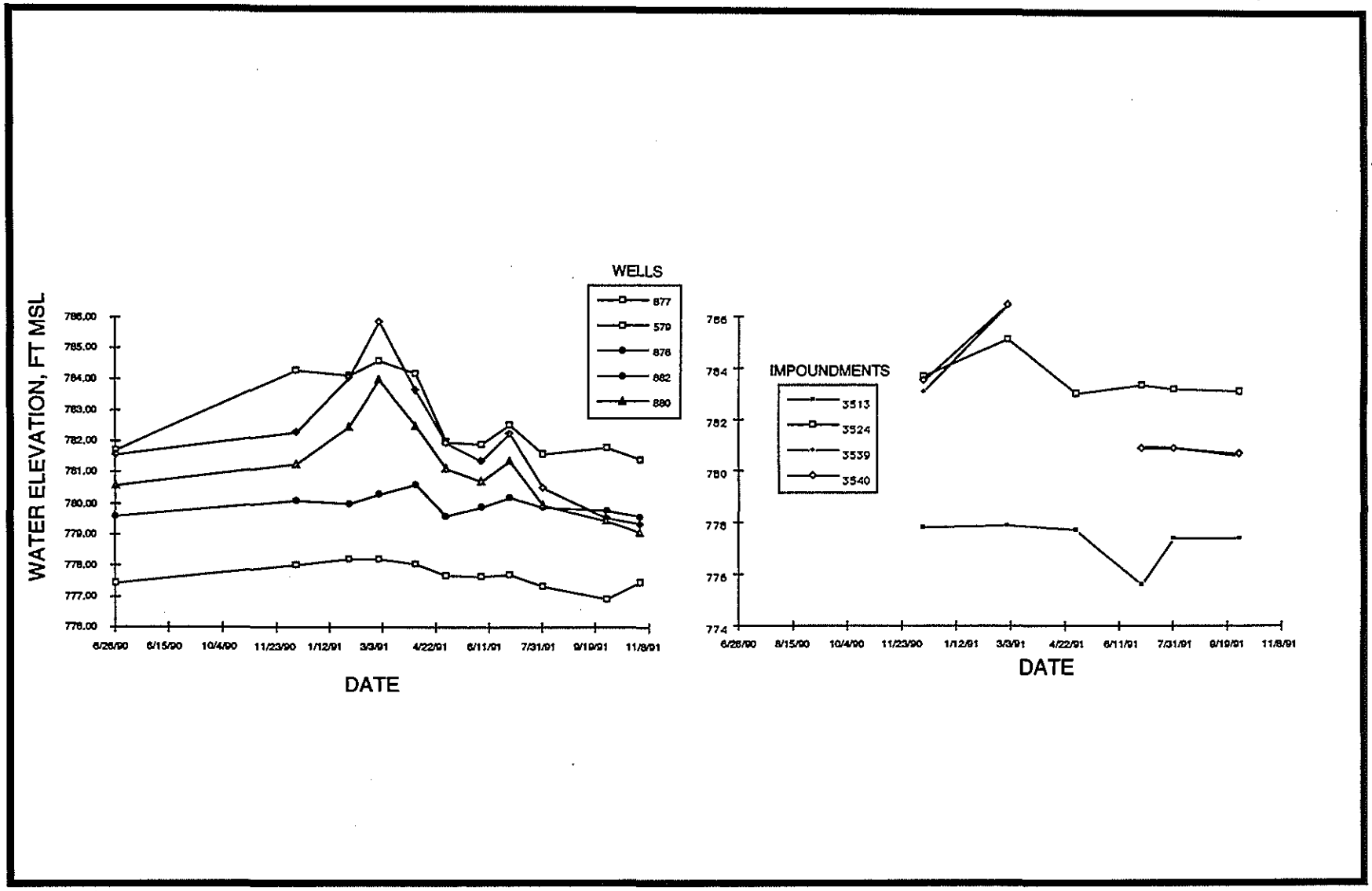


Fig 3.3.4. Hydrographs for surface impoundments and selected nearby wells.

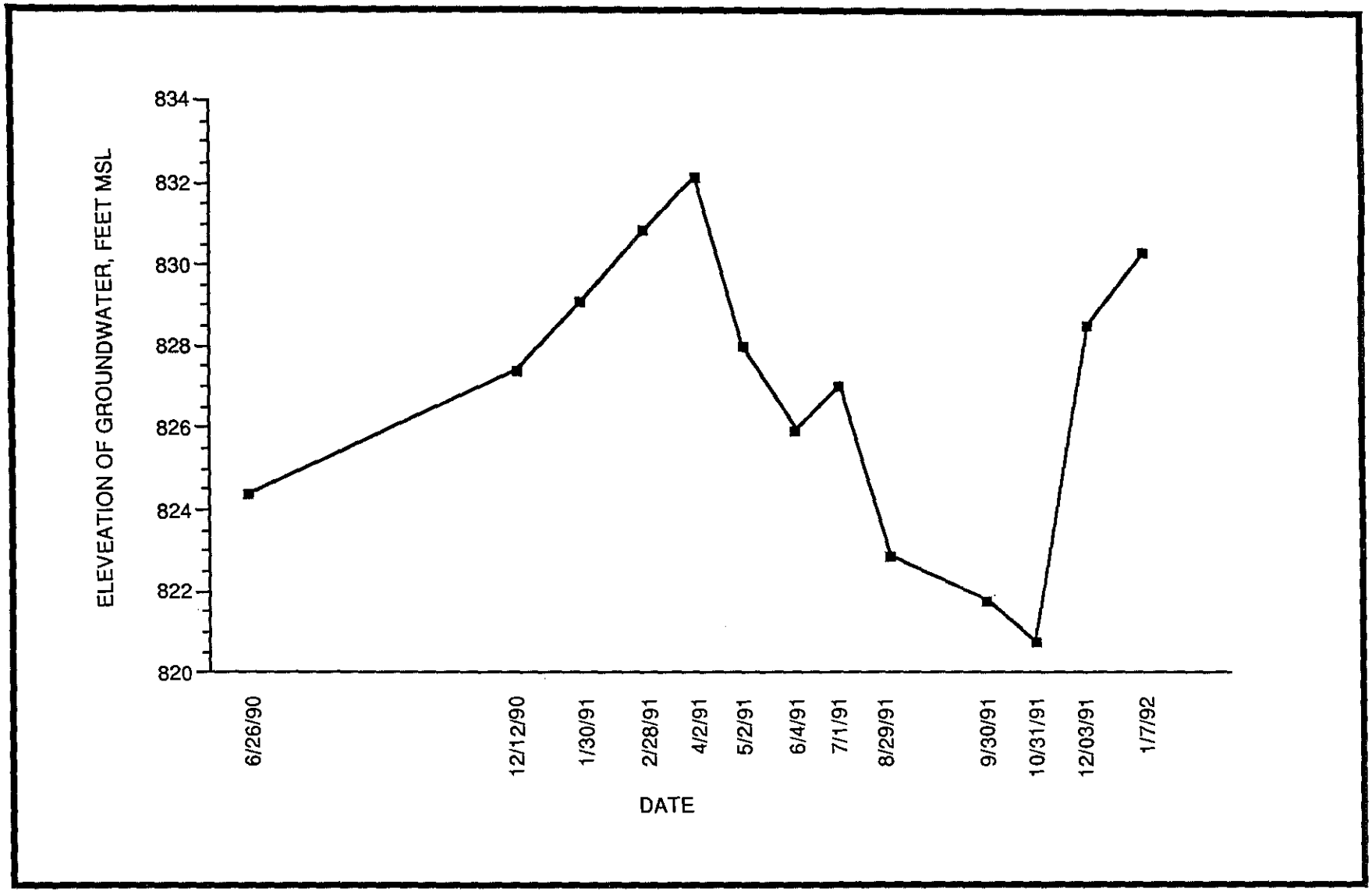


Fig. 3.3.5. Monthly groundwater monitoring data for piezometer 572.

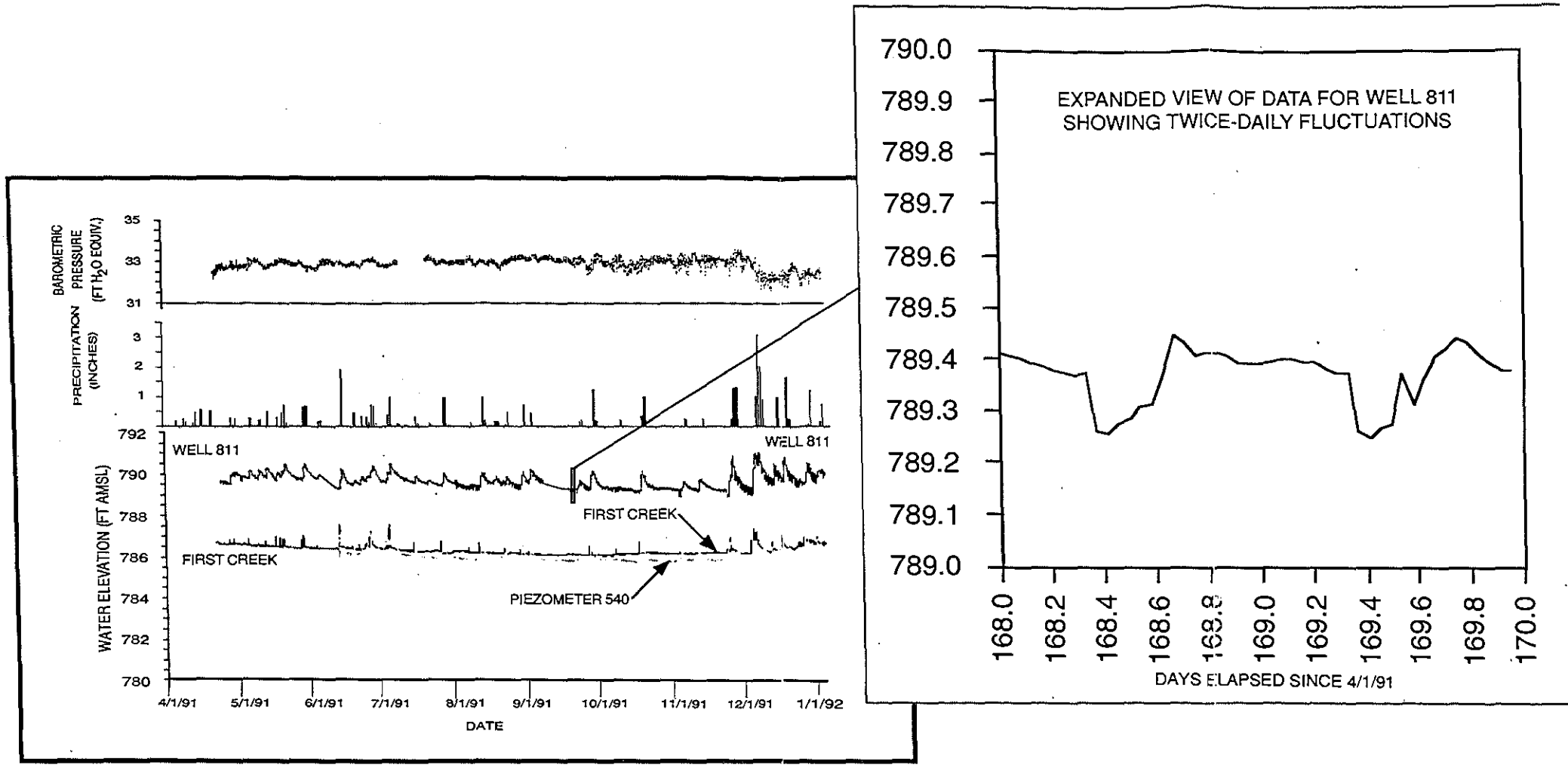


Fig. 3.3.6. Continuous groundwater monitoring data for First Creek, well 811 and piezometer 540.

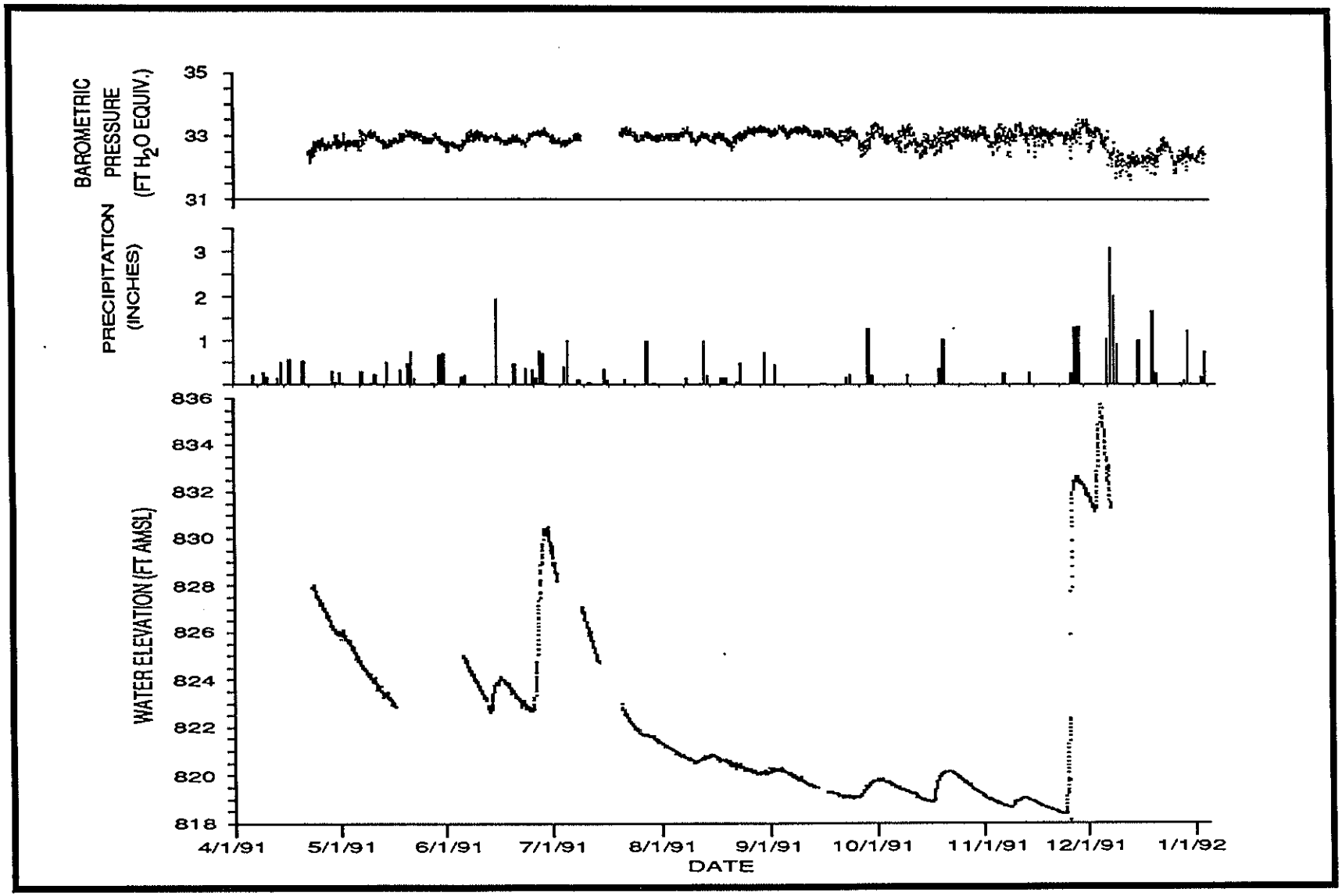


Fig. 3.3.7. Continuous groundwater monitoring data for piezometer 549.

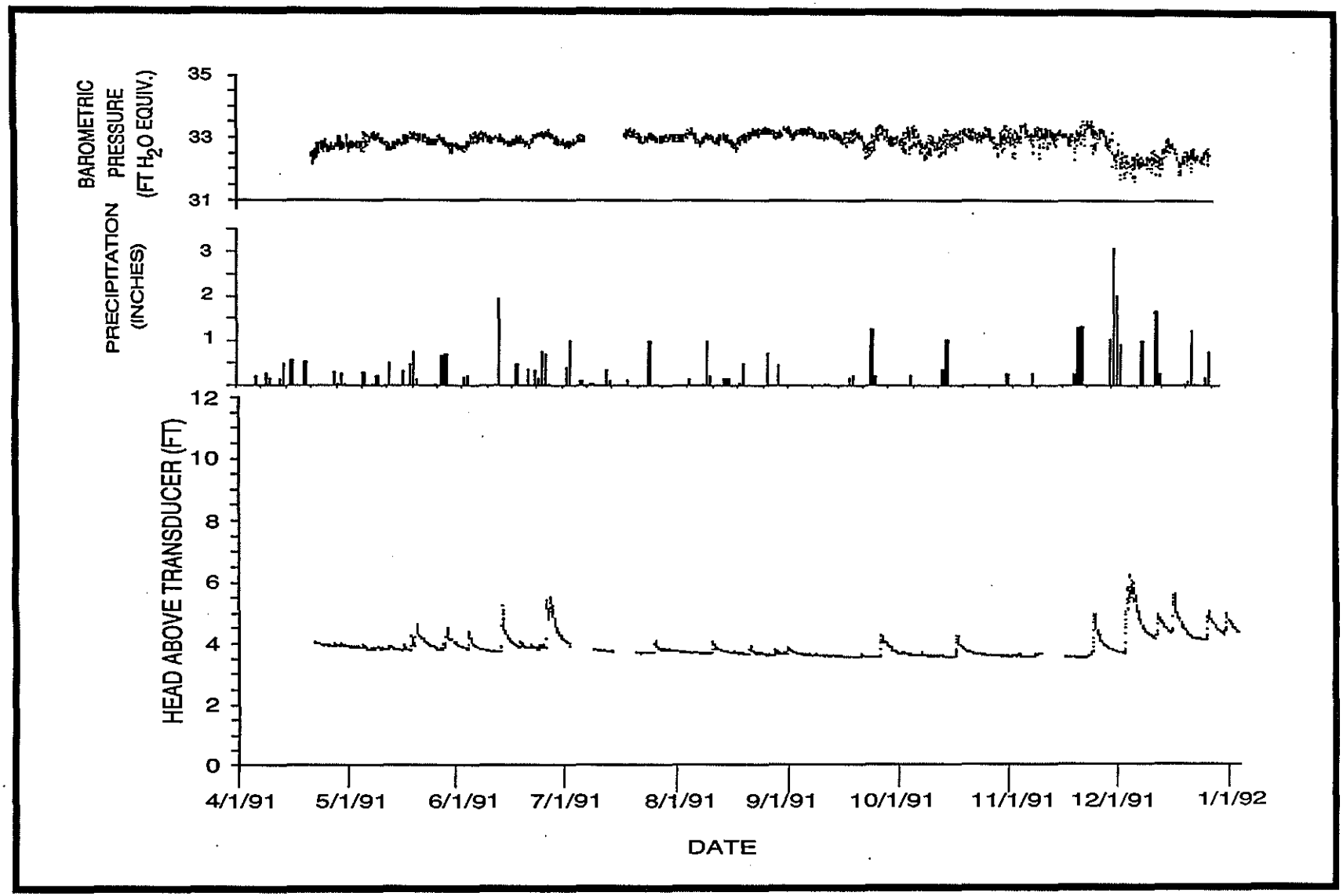


Fig. 3.3.8. Continuous groundwater monitoring data for well 826.

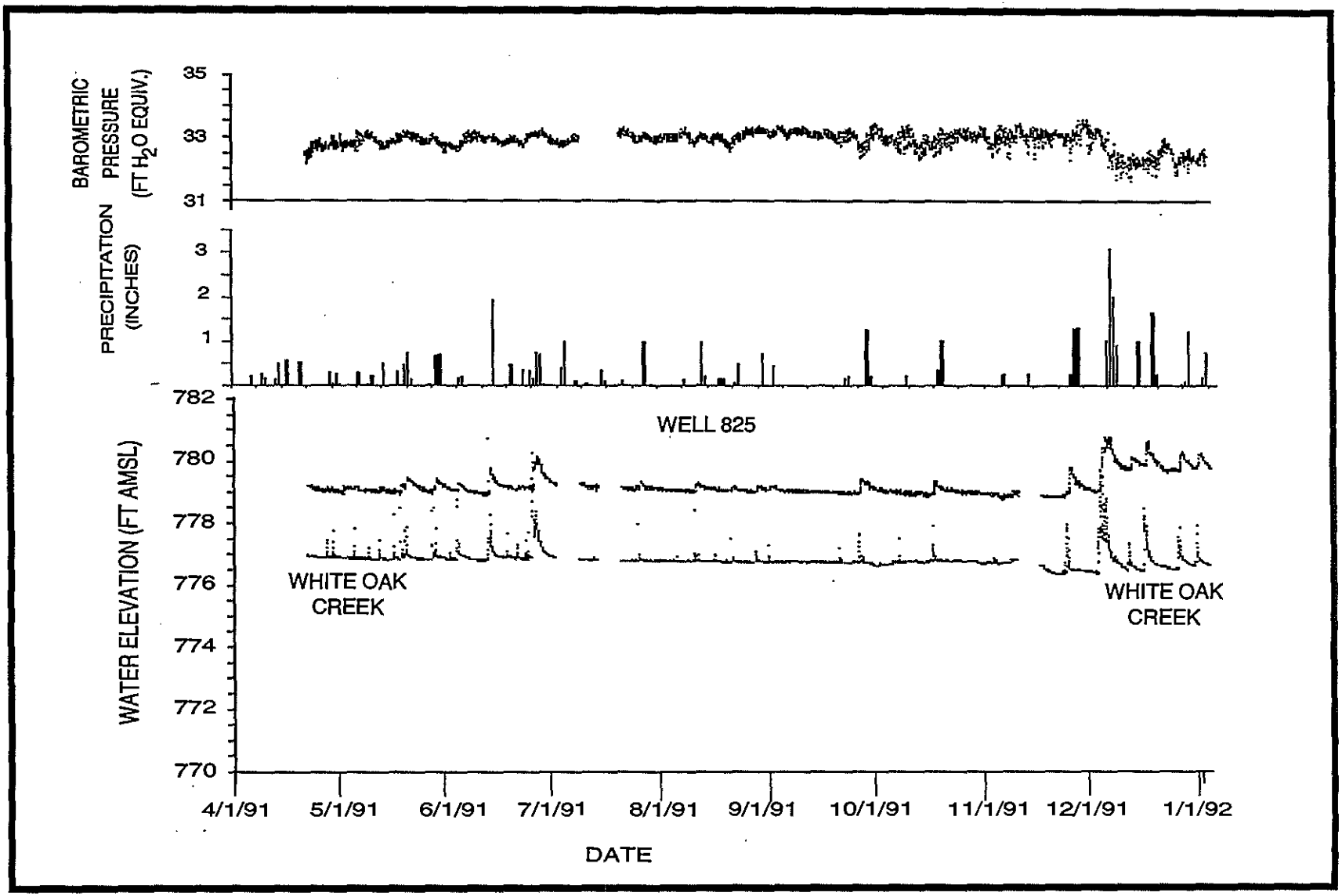


Fig. 3.3.9. Continuous groundwater monitoring data for well 825 and White Oak Creek.

5.33D 6066.49

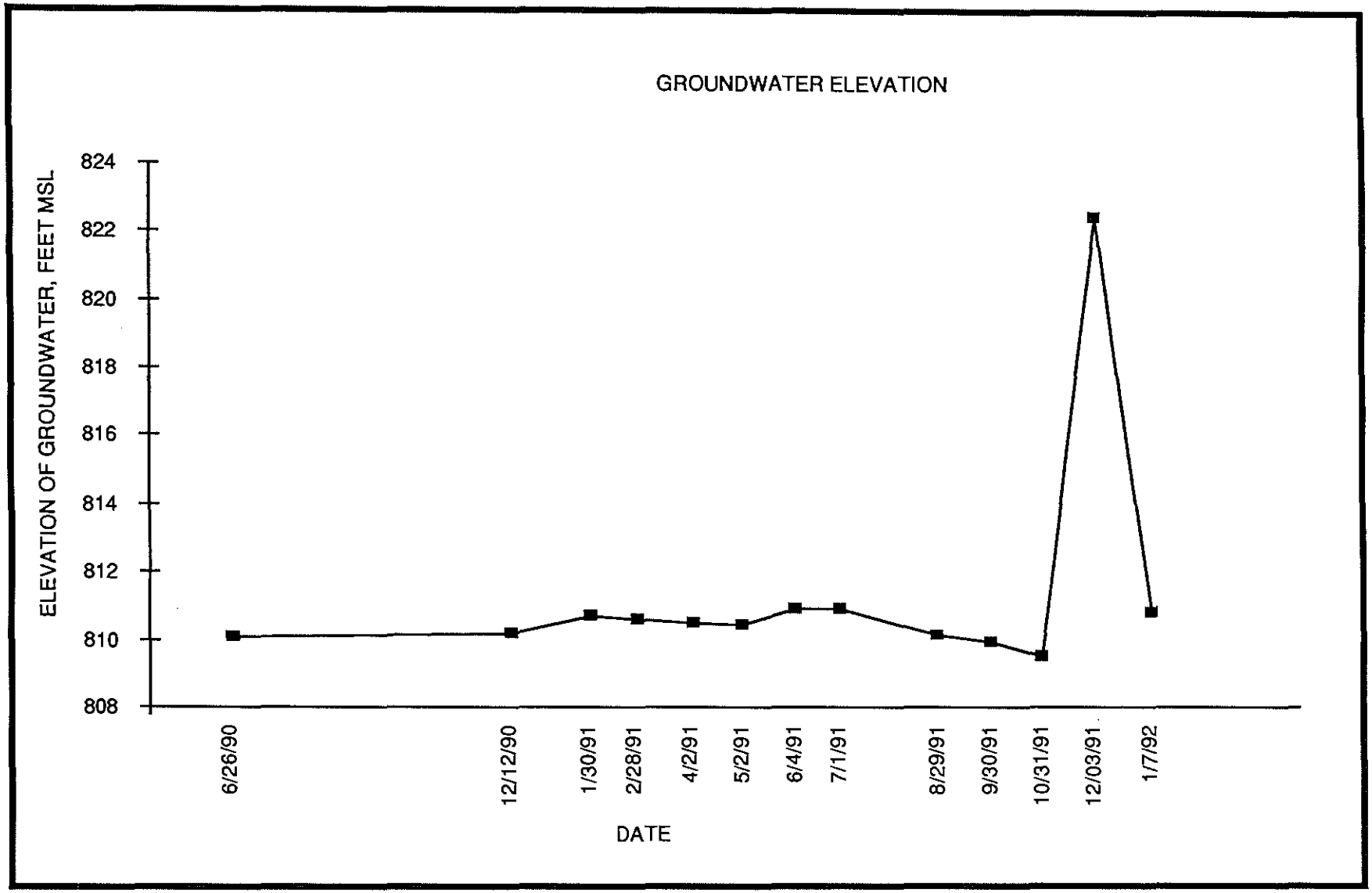


Fig 3.3.10. Monthly groundwater elevation monitoring data for well 814.

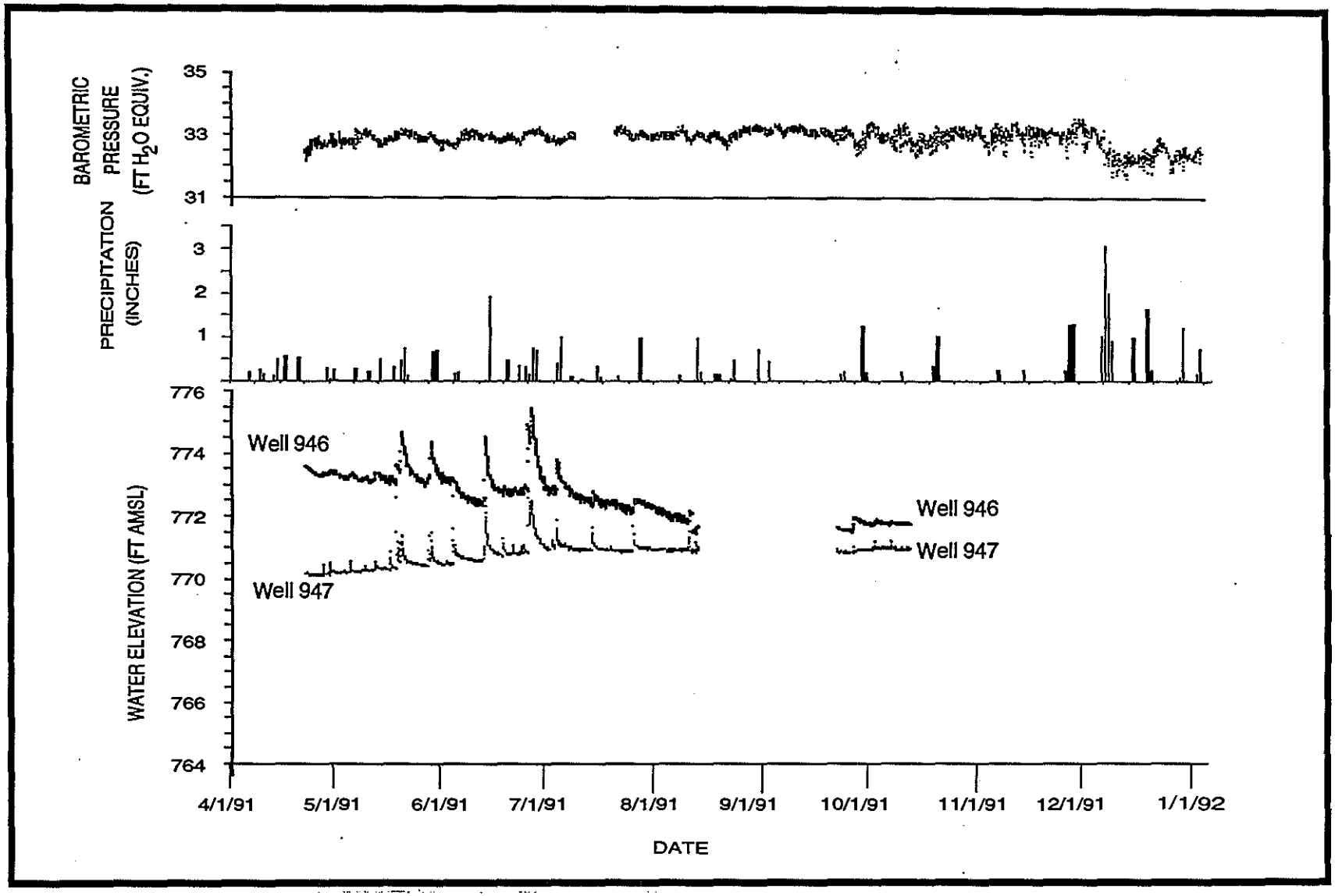
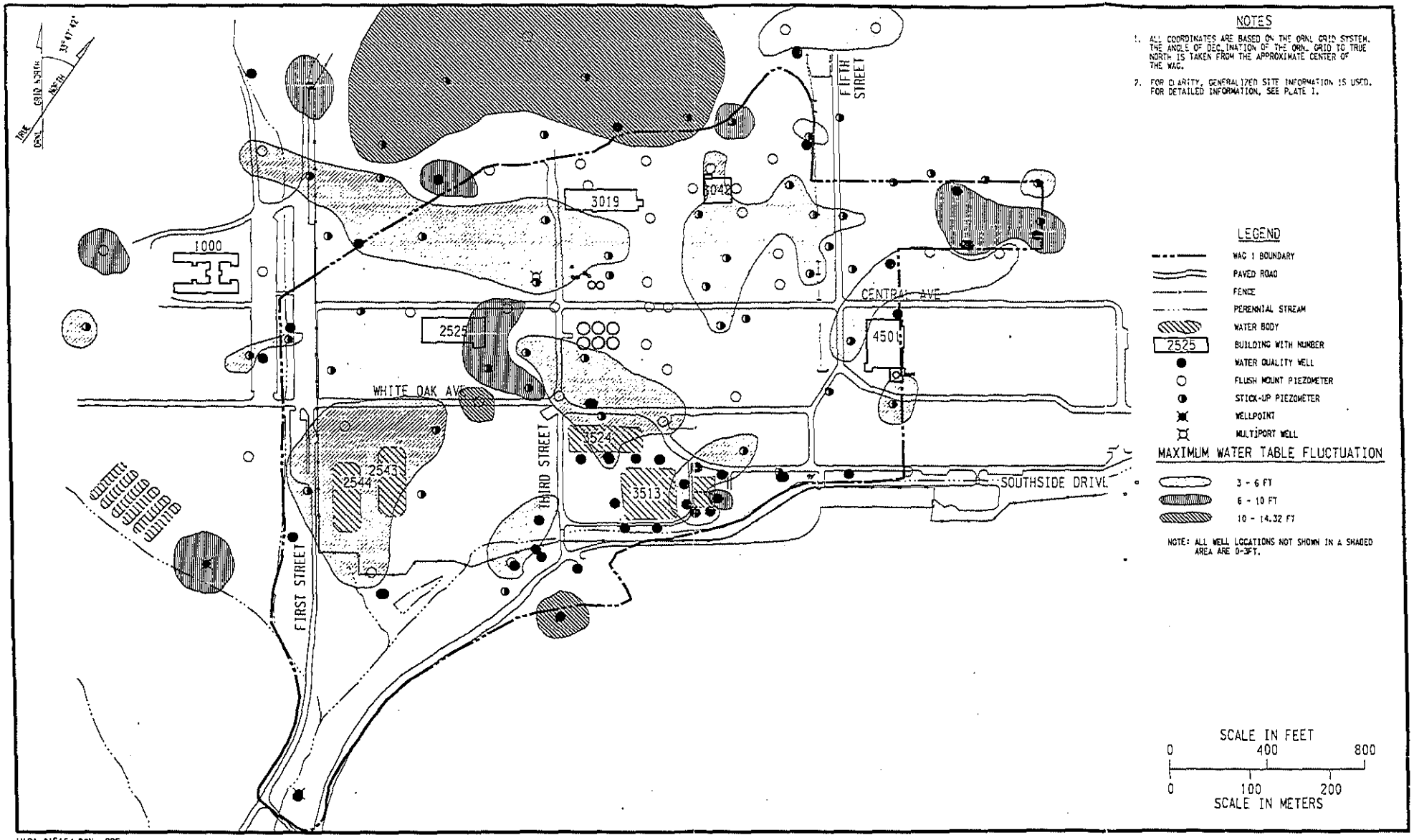


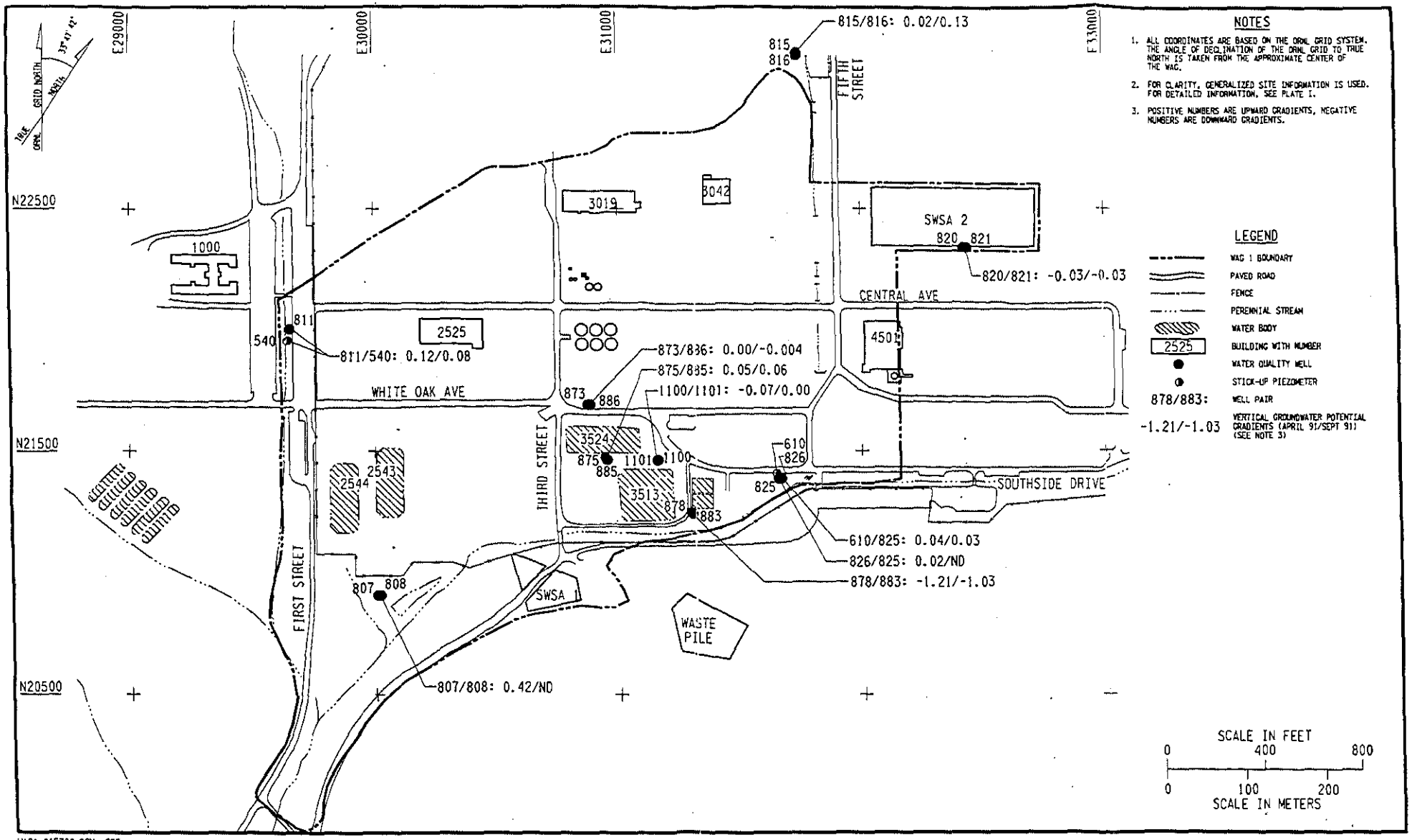
Fig. 3.3.11. Continuous groundwater monitoring data from well pair 946 and 947.

5.33D 6066.62A



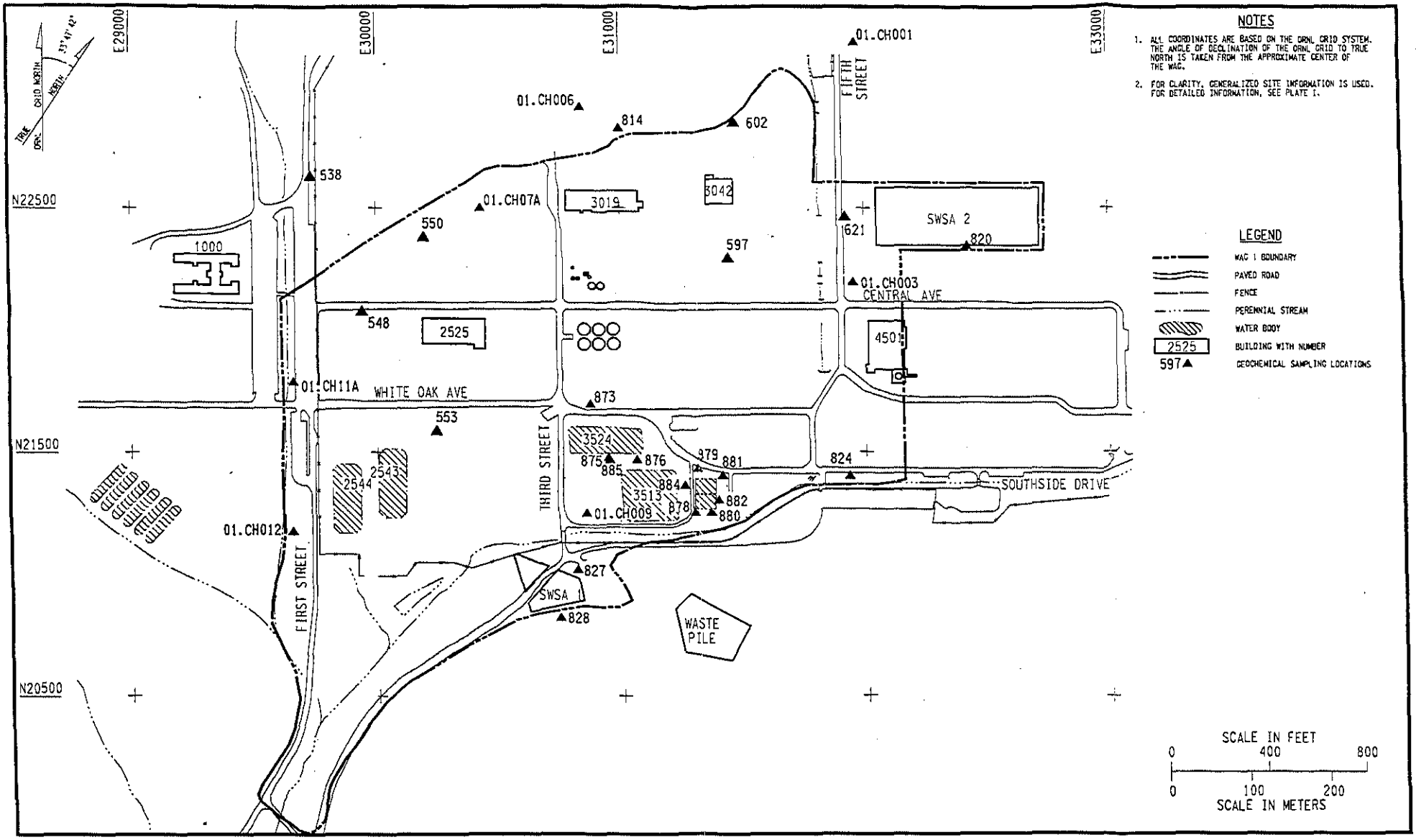
WAG1 01F164.DGN SRF,
6/14/92

Fig. 3.3.12. Maximum groundwater fluctuations.



WAG1 01F360.DGN SRF, 9/11/92

Fig. 3.3.13. Vertical potential gradient data for selected well pairs.



WAG 1 01F227.DGN
6/8/92

Fig. 3.3.14. Sampling locations included in geochemical evaluation.

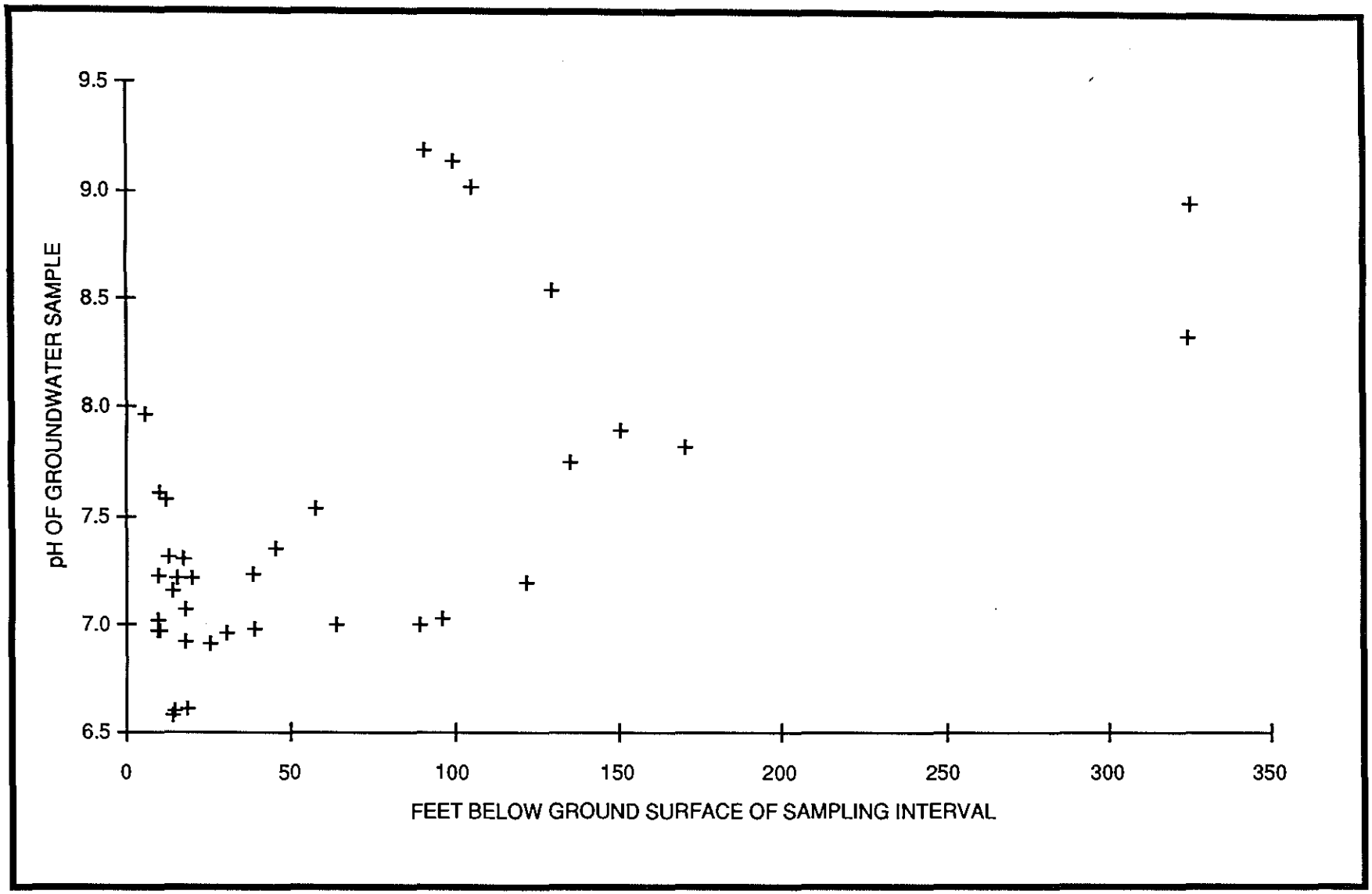


Fig 3.3.15. pH of groundwater vs depth.

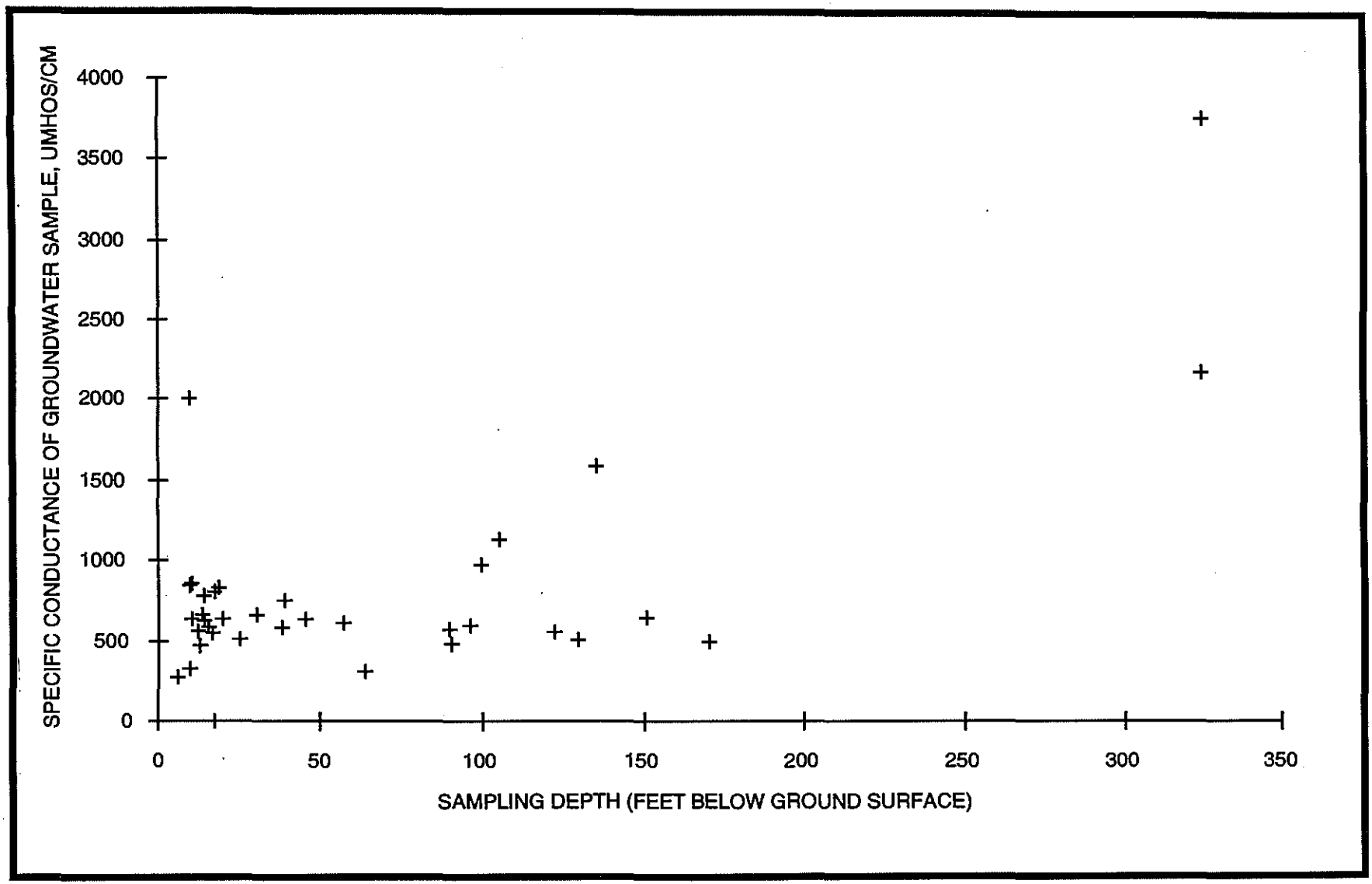
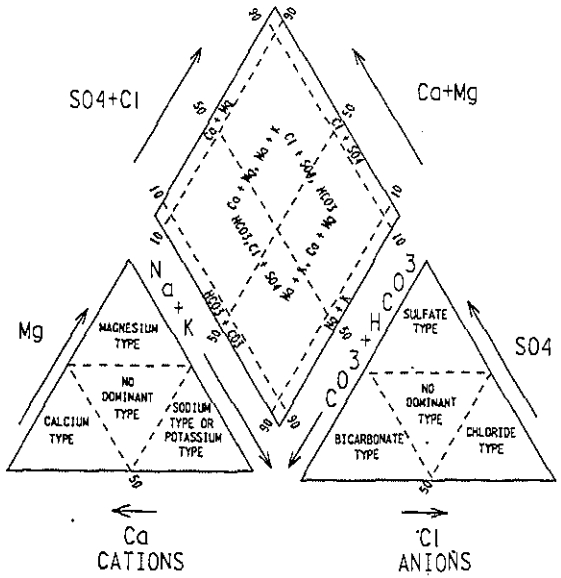
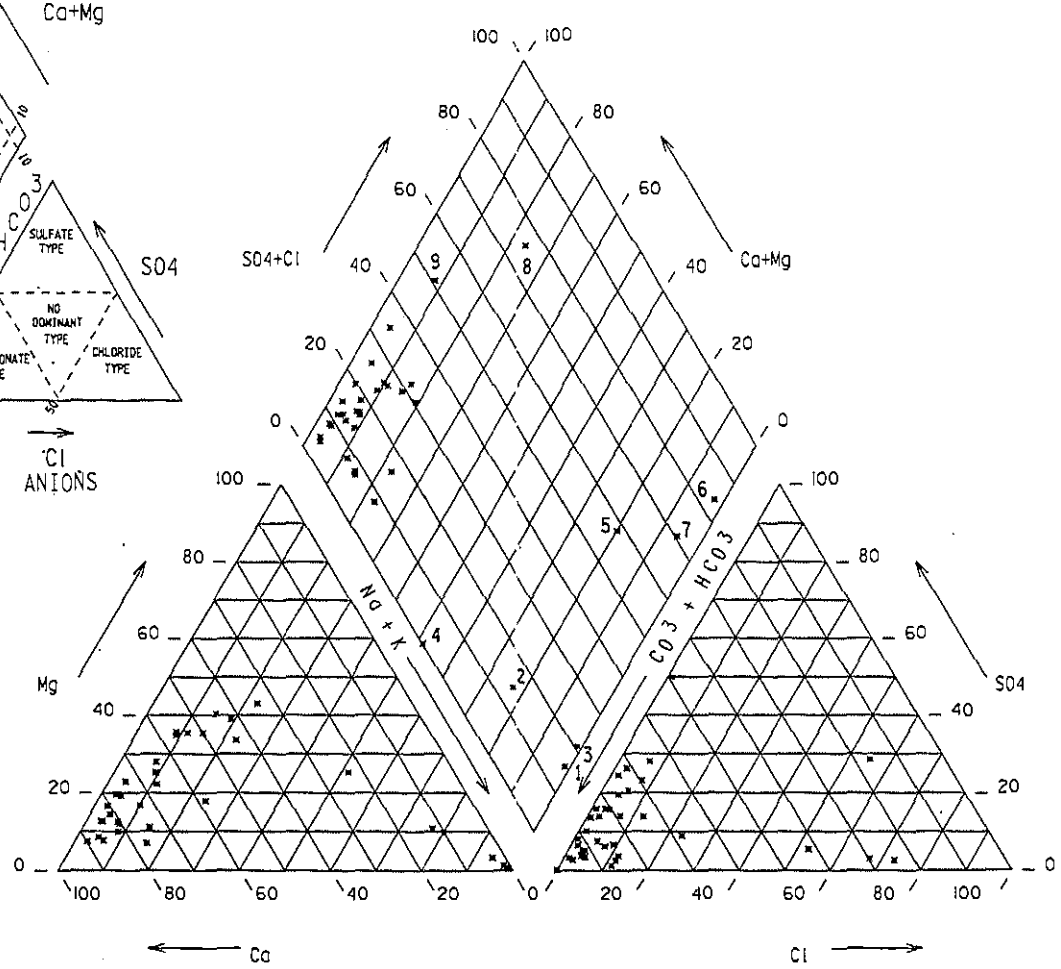


Fig 3.3.16. Specific conductance of groundwater vs depth.





LABEL	WELL IDENTIFIER	ELEV CODE	SAMPLING LOCATION TYPE	GEOLOGIC UNIT
1	CH003I1	M	CH	E
	CH001I1	U	CH	B
	CH001I2	U	CH	B
	CH07AI2	U	CH	D
	CH006I1	U	CH	B
	CH006I2	U	CH	B
2	CH012I5	M	CH	D
6	CH006I4	L	CH	B/A
5	CH009I2	M	CH	G
7	CH009I4	L	CH	F
	CH011I1	U	CH	G
3	CH011I3	M	CH	E
	CH007I1	U	CH	D
4	CH001I3	M	CH	A
	602	U	I	C
	538	U	R	D
8	548	U	I	E
	621	U	R	D
	550	U	I	E
	597	U	I	E
	553	U	I	G
	885	U	R	G
	814	U	R	C
	820	U	R	E
	824	U	I	G
	827	U	I	H
	828	U	R	H
	873	U	I	G
	875	U	I	G
	876	U	I	G
	878	U	I	G
9	879	U	I	G
	880	U	I	G
	881	U	I	G
	882	U	I	G
	884	U	I	G

SAMPLING INTERVAL
ELEV CODE

U = >725 FT MSL
M = 600 - 725 FT MSL
L = <600 FT MSL

WELL TYPE

R = ROCK
I = INTERFACE
CH = COREHOLE

WAC1 01F232.DGN
6/8/92

Fig. 3.3.17. Trilinear plot of groundwater chemistry data.

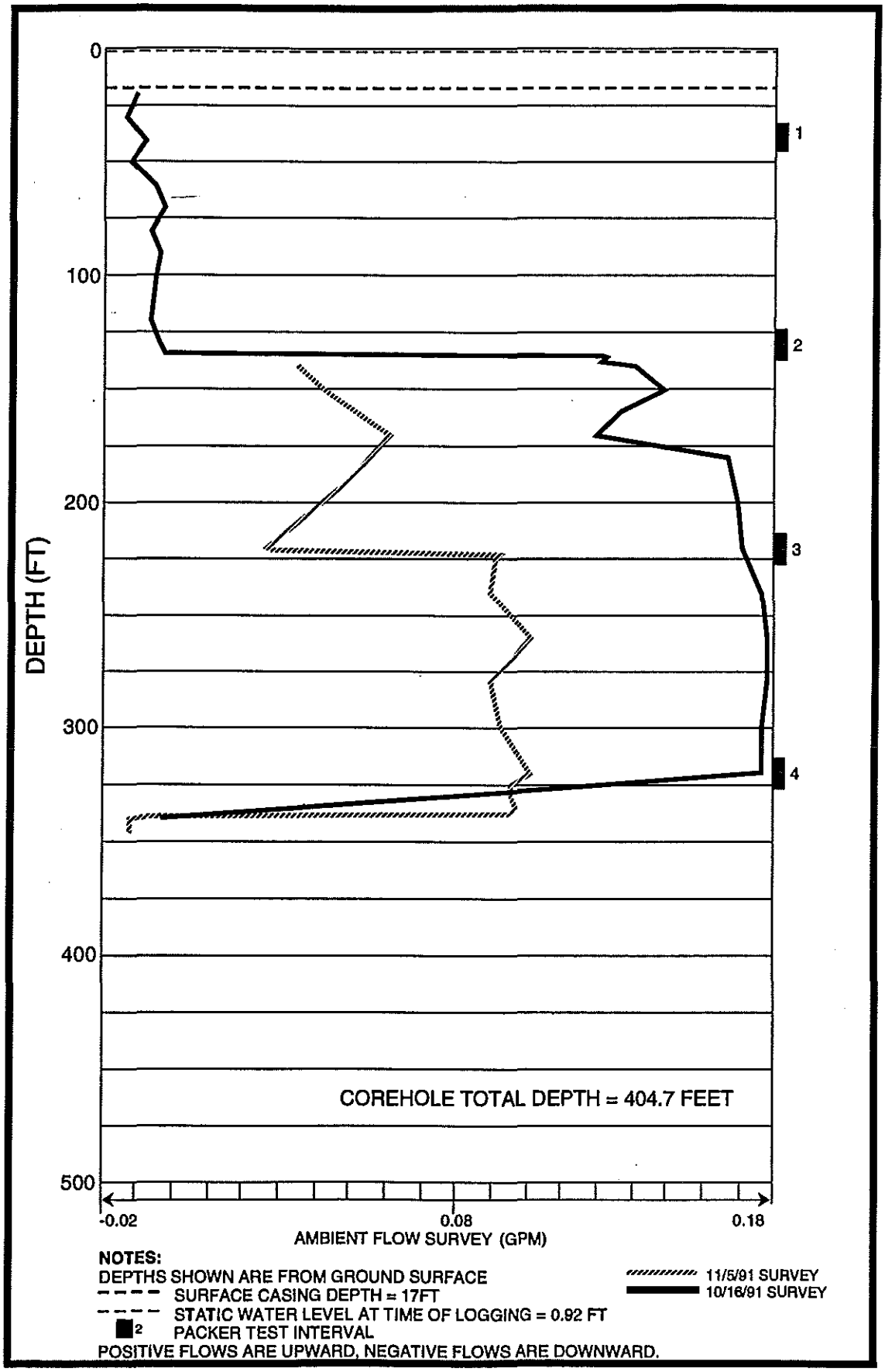


Fig. 3.3.18. Vertical flowmeter data for CH009. *Source:* Moore and Young, 1992.

5.33 6066.37b

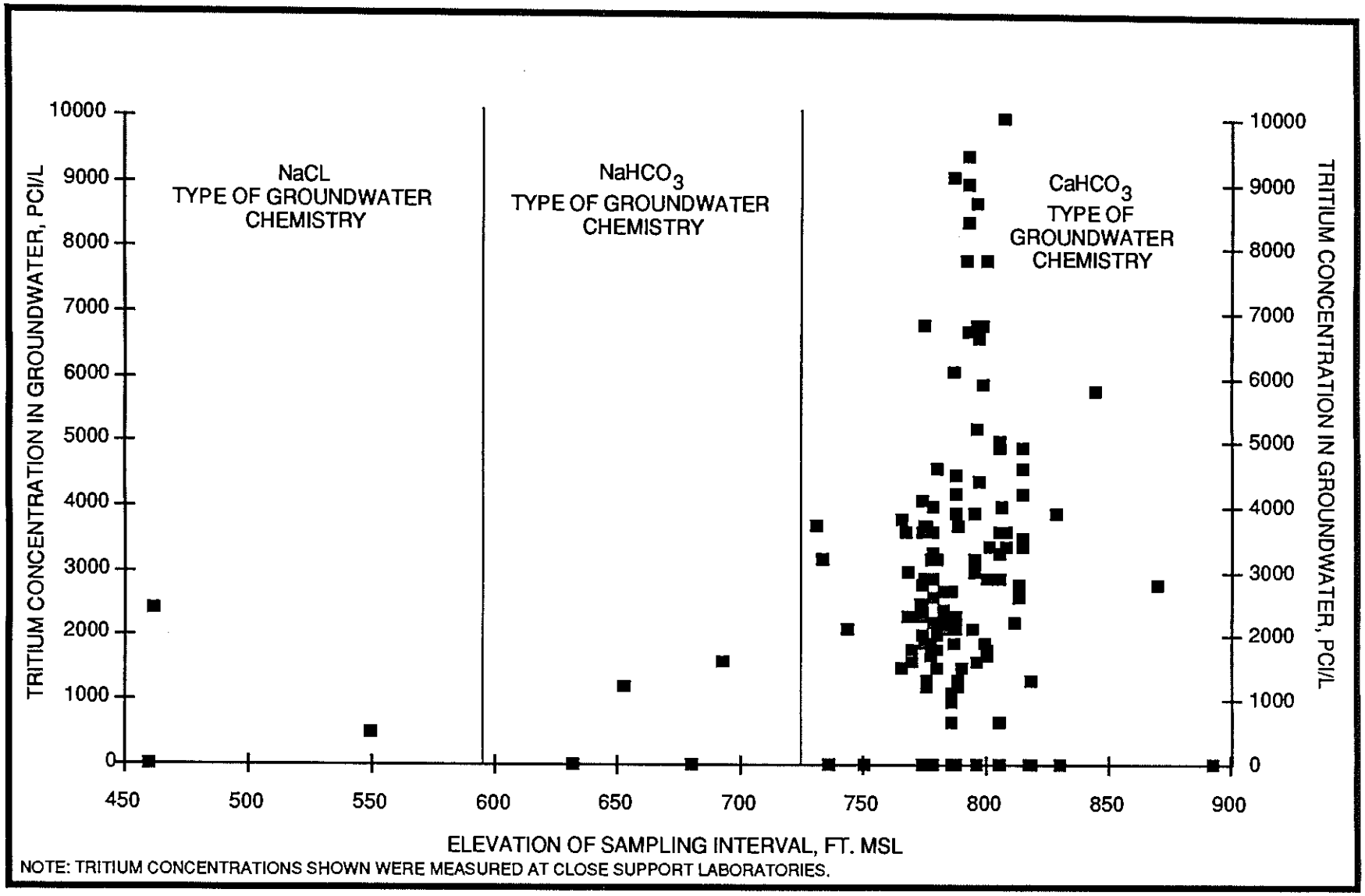


Fig. 3.3.19. Tritium concentrations in groundwater vs sample elevation.

5.33F 6066.92

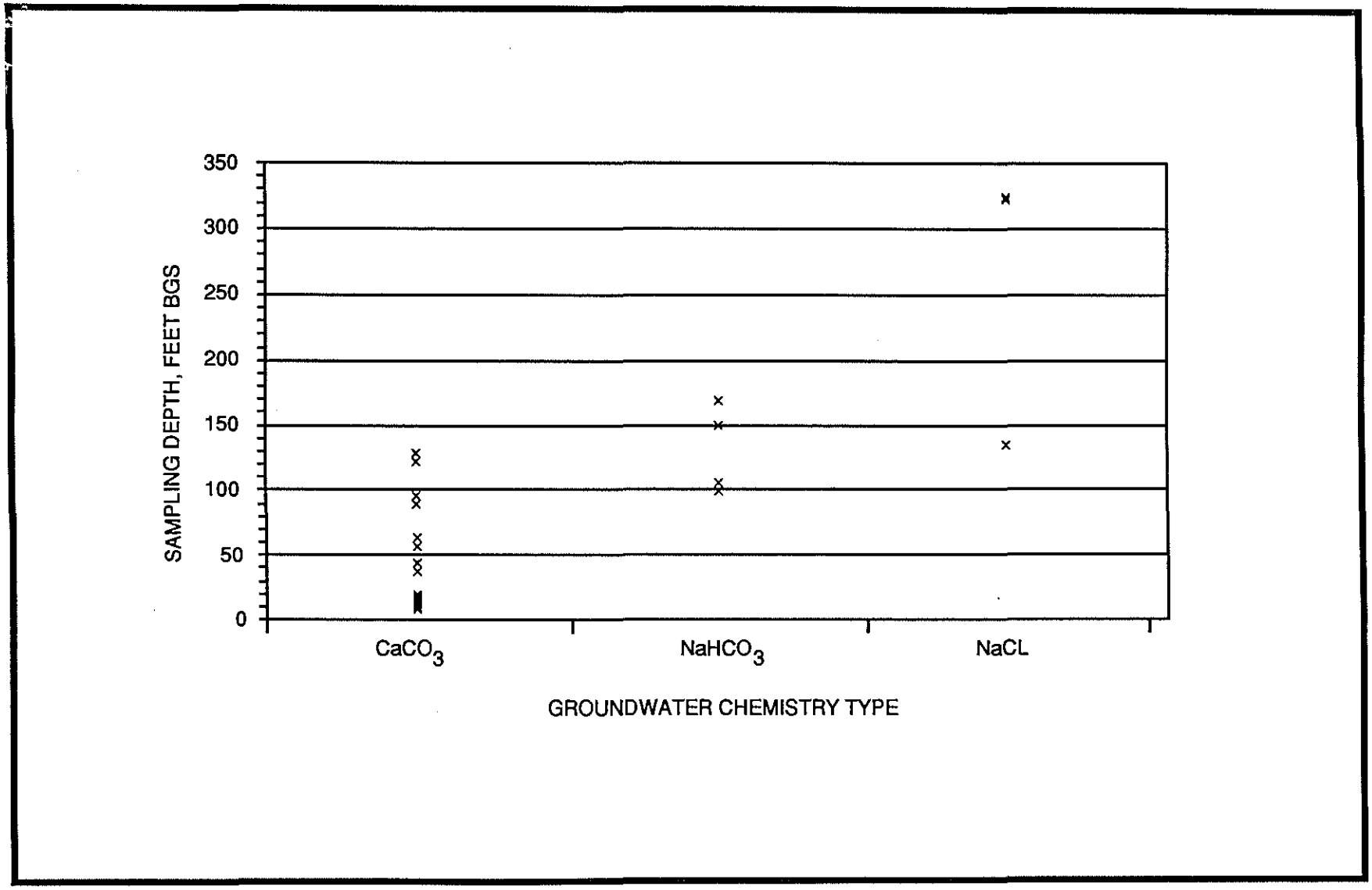


Fig. 3.3.20. Occurrence of groundwater chemistry type with depth.

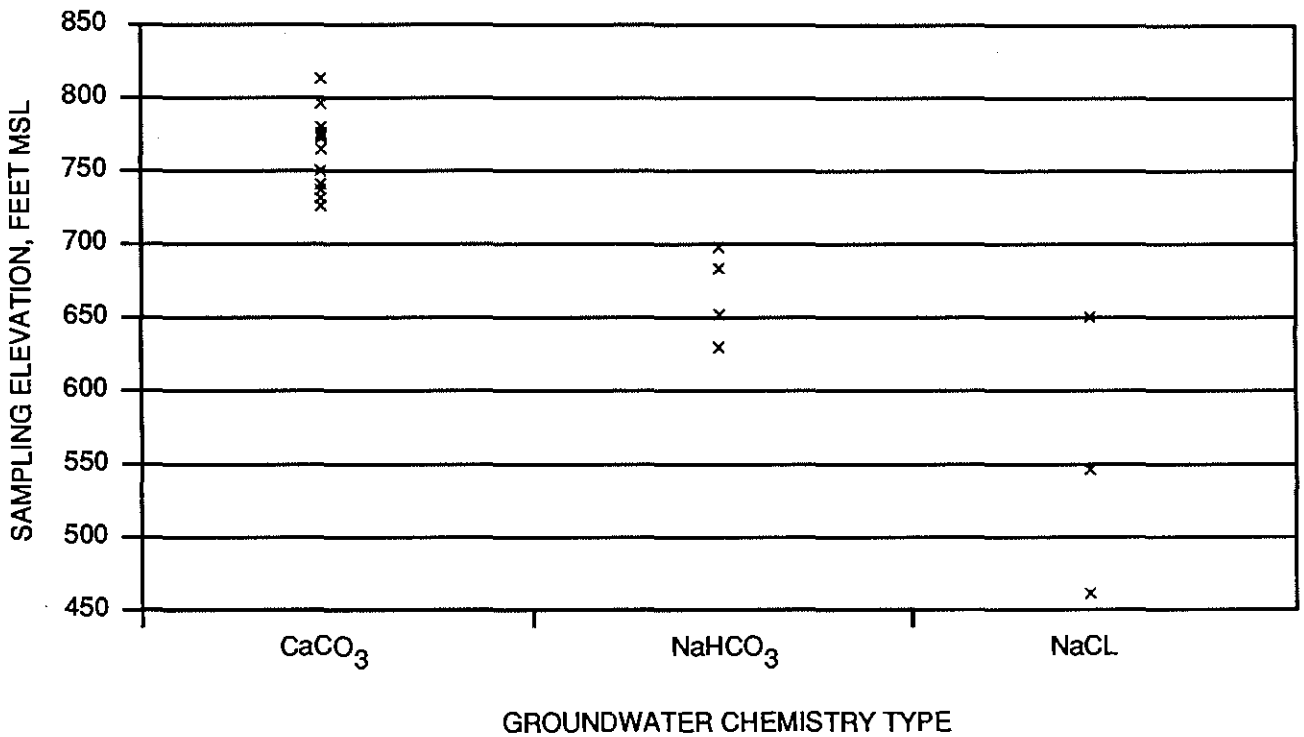
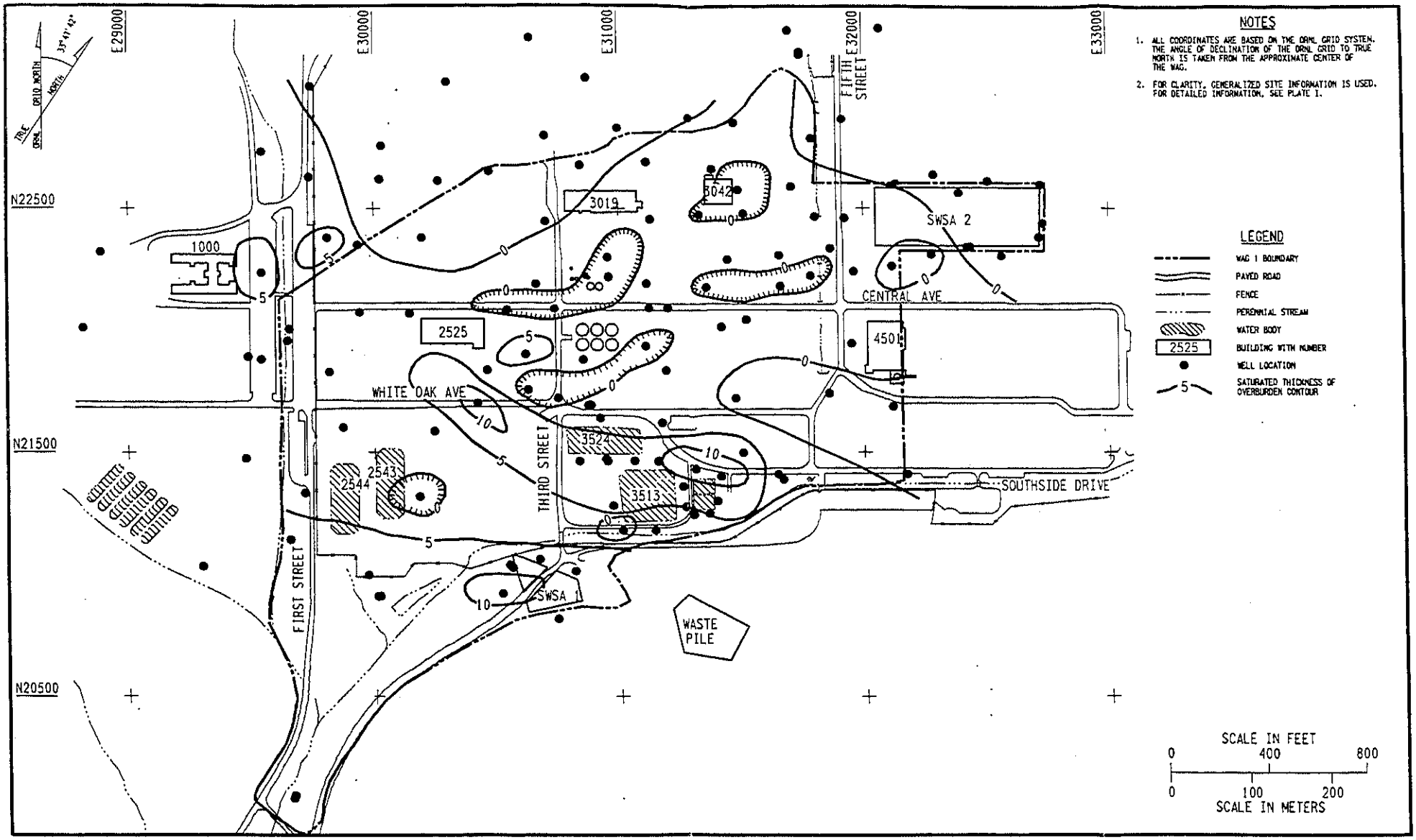
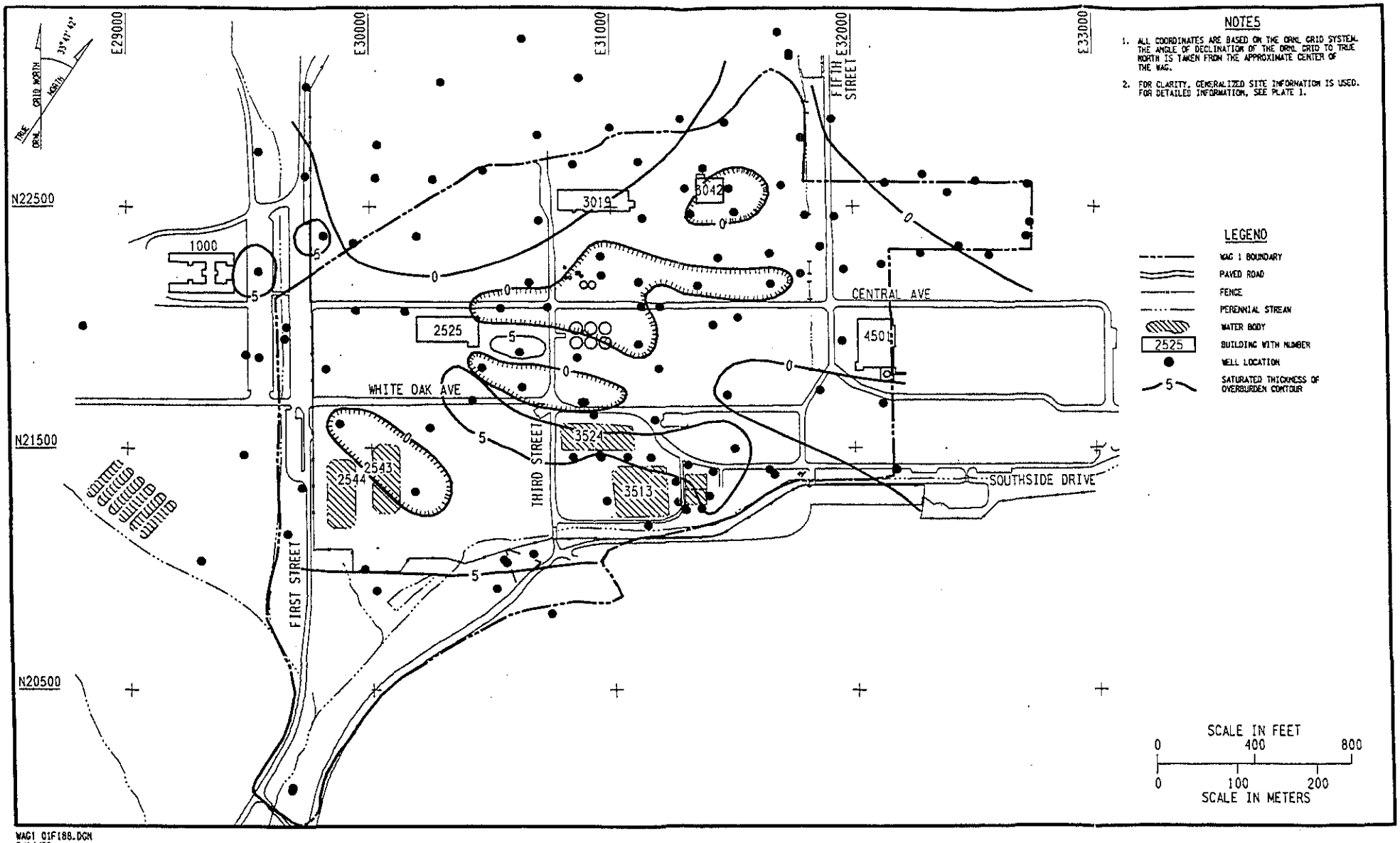


Fig. 3.3.21. Occurrence of groundwater chemistry type with elevation.



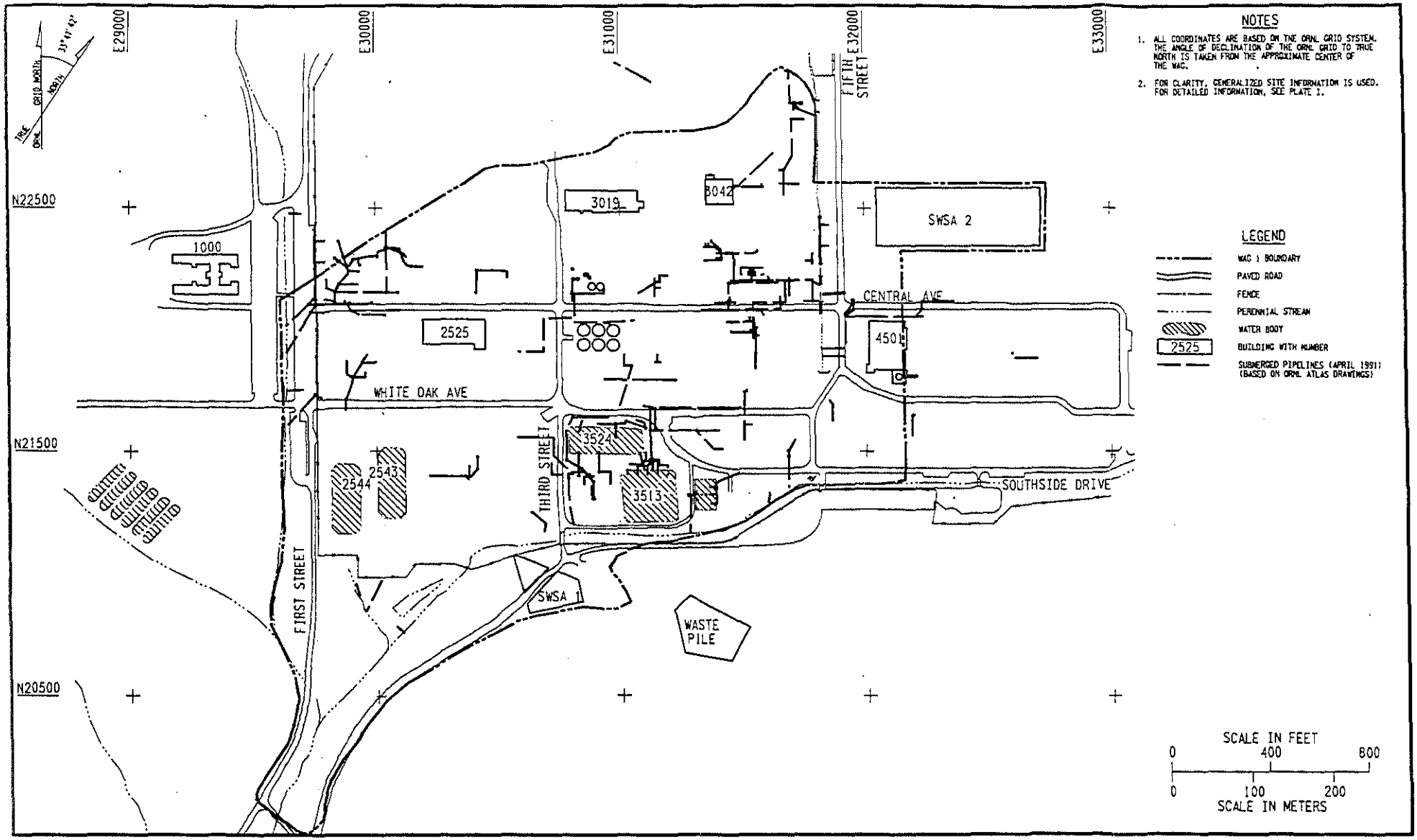
WAG1 01F189.DGN
6/14/92

Fig. 3.3.22. Saturated thickness of overburden, April 199



WAG1 01F188.DGN
6/14/92

Fig. 3.3.23. Saturated thickness of overburden, September-October 1991.



WAG1 01F244.DGN
6/14/92

Fig. 3.3.24. Locations of pipelines (process sewer, hot waste, or storm sewer lines) that were below groundwater tables, April 1991.

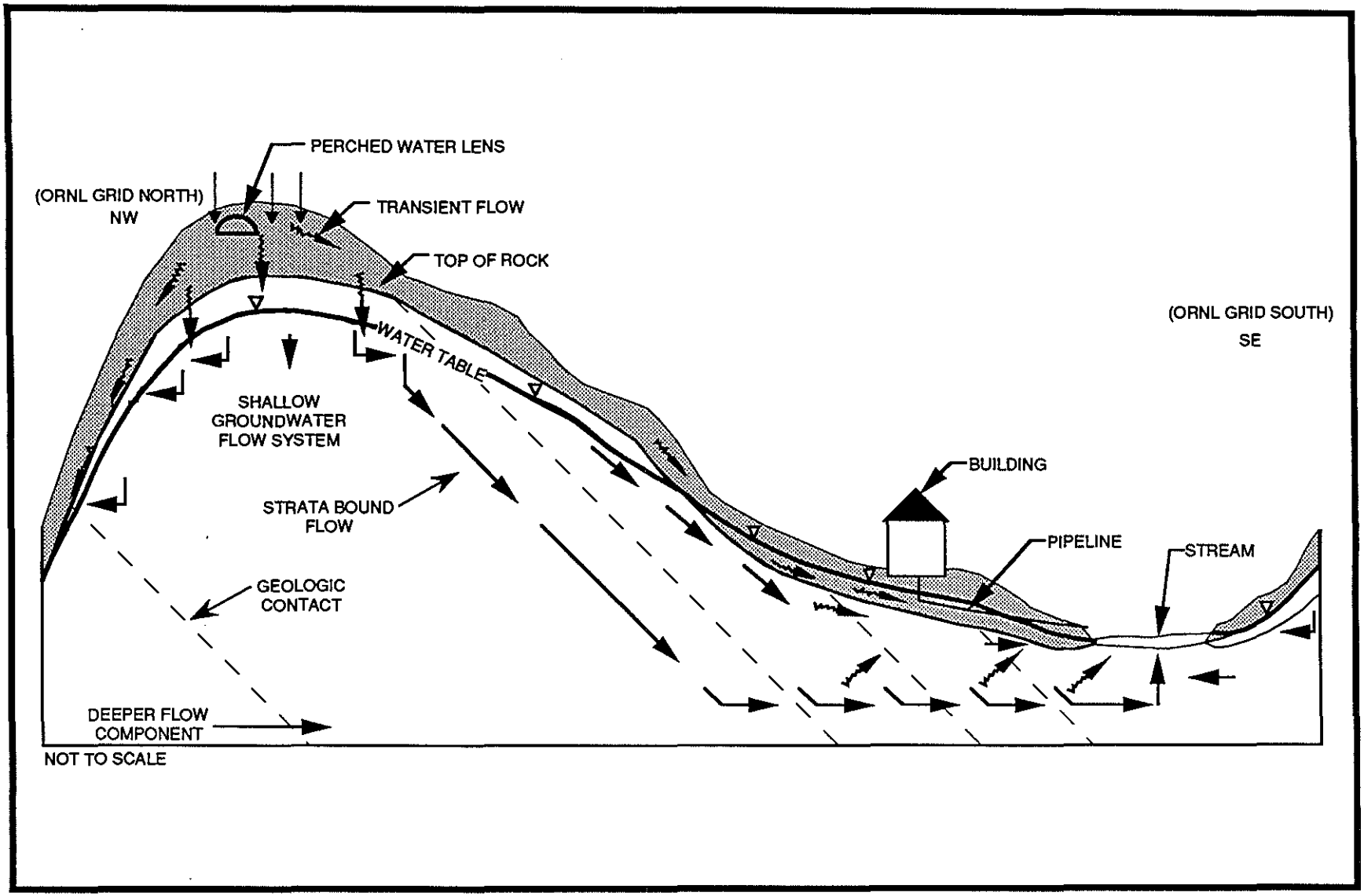
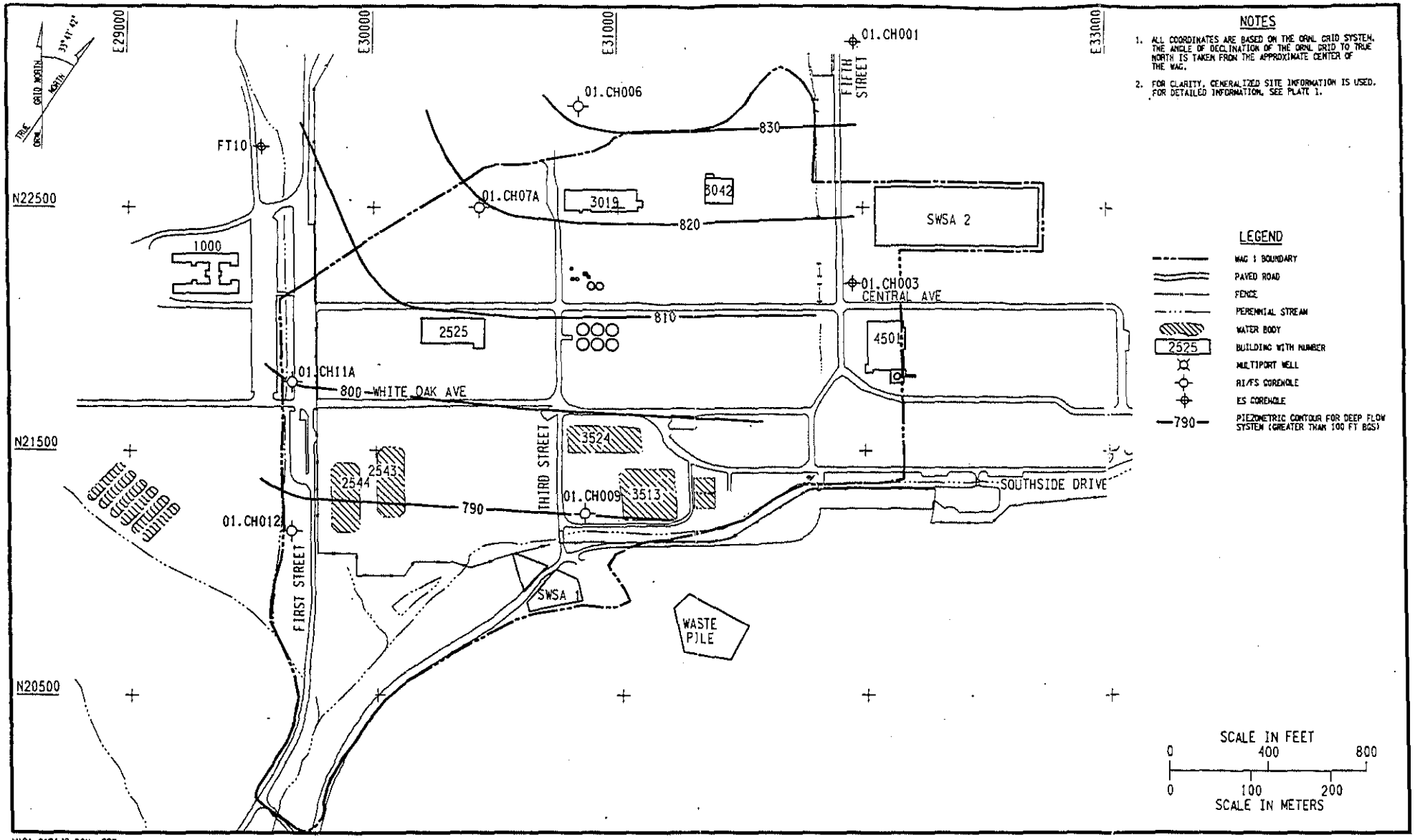


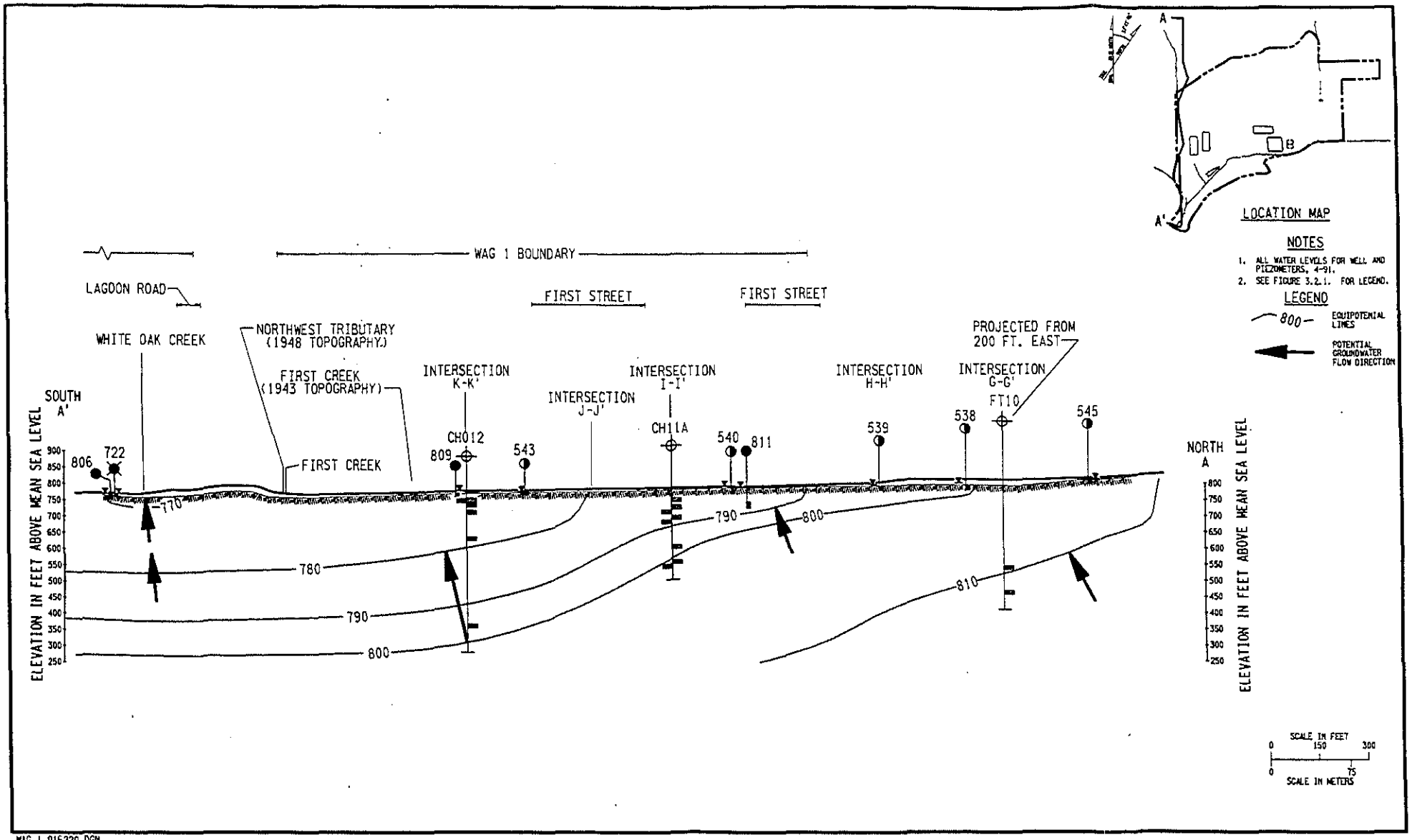
Fig. 3.3.25. Conceptual groundwater occurrence (modified from Moore 1989).

5.33B 6066.31
Adapted from WAG6 06F257.DGN



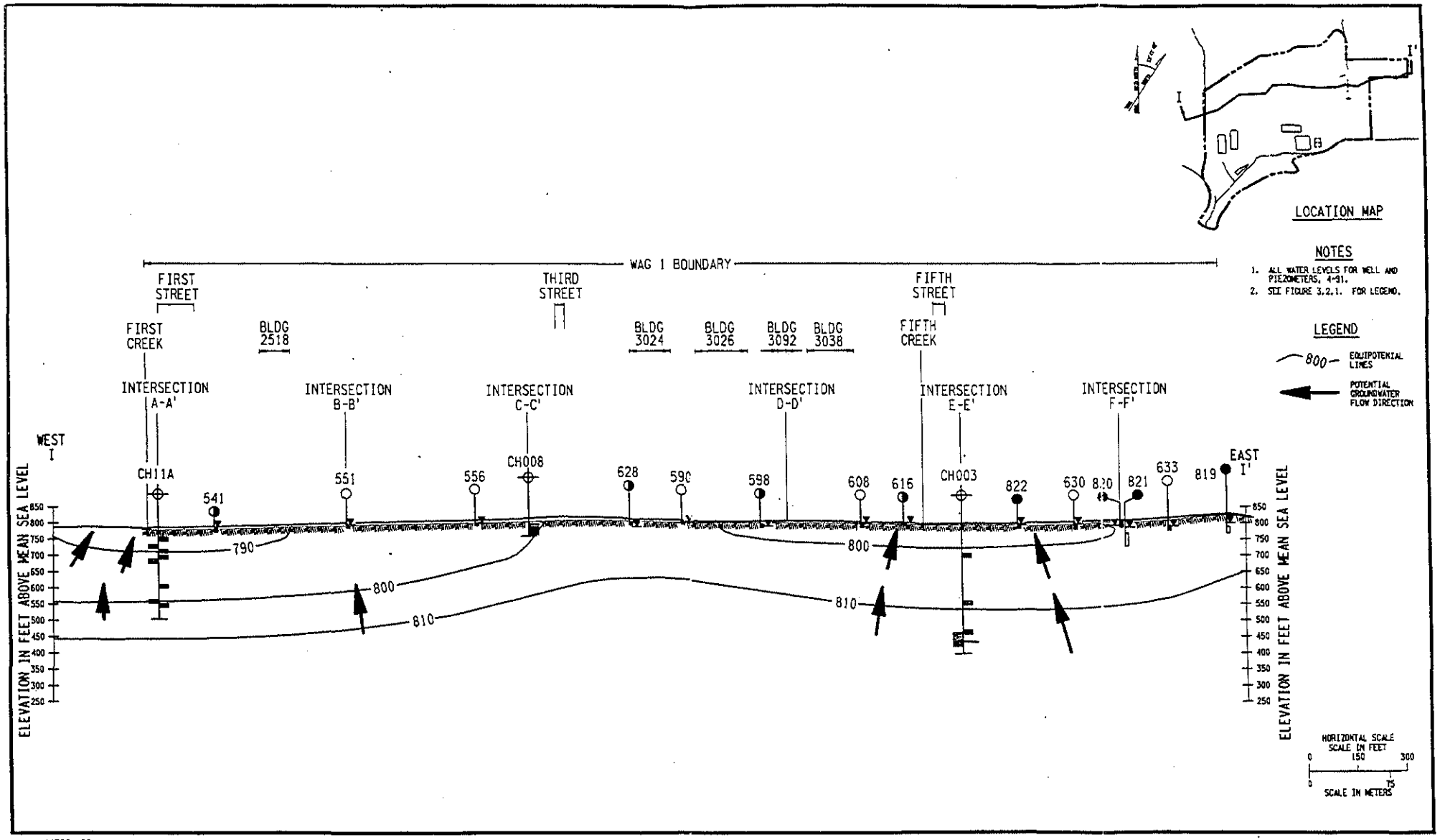
WAG1 01F149.DGN SRF, 6/14/92

Fig. 3.3.26. Potentiometric surface for deep bedrock.



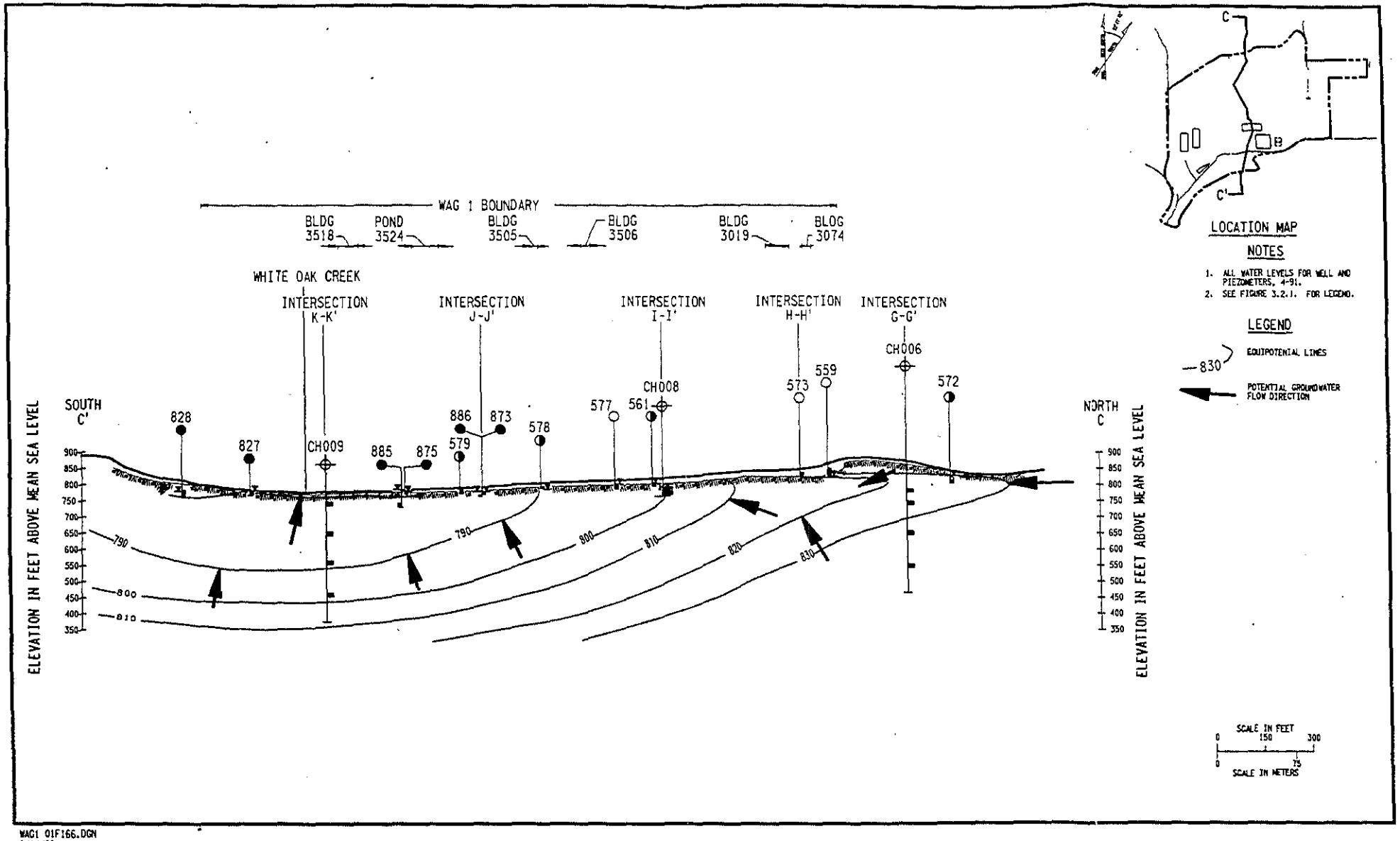
WAG 1 01F22C.DGN
6/14/92

Fig. 3.3.27. Conceptual groundwater flow system, cross section A-A'.



WAG 1 01F221.DGN
6/14/92

Fig. 3.3.28. Conceptual groundwater flow system, cross section I-I'.



WAG1 01F166.DGN
6/14/92

Fig. 3.3.29. Conceptual groundwater flow system, cross section C-C'.

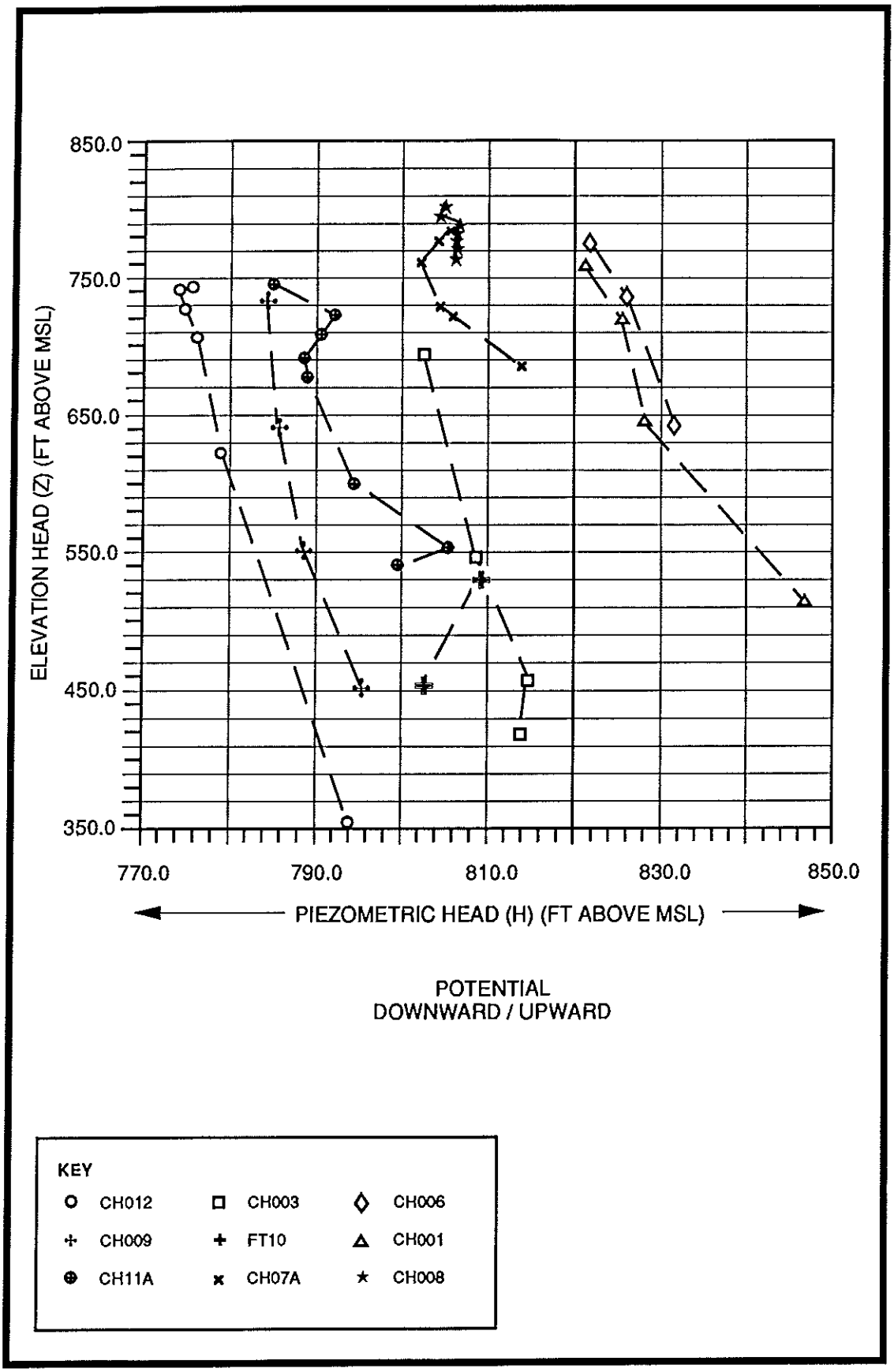


Fig. 3.3.30. Piezometric heads vs elevation heads in coreholes.

5.33A 6066.10

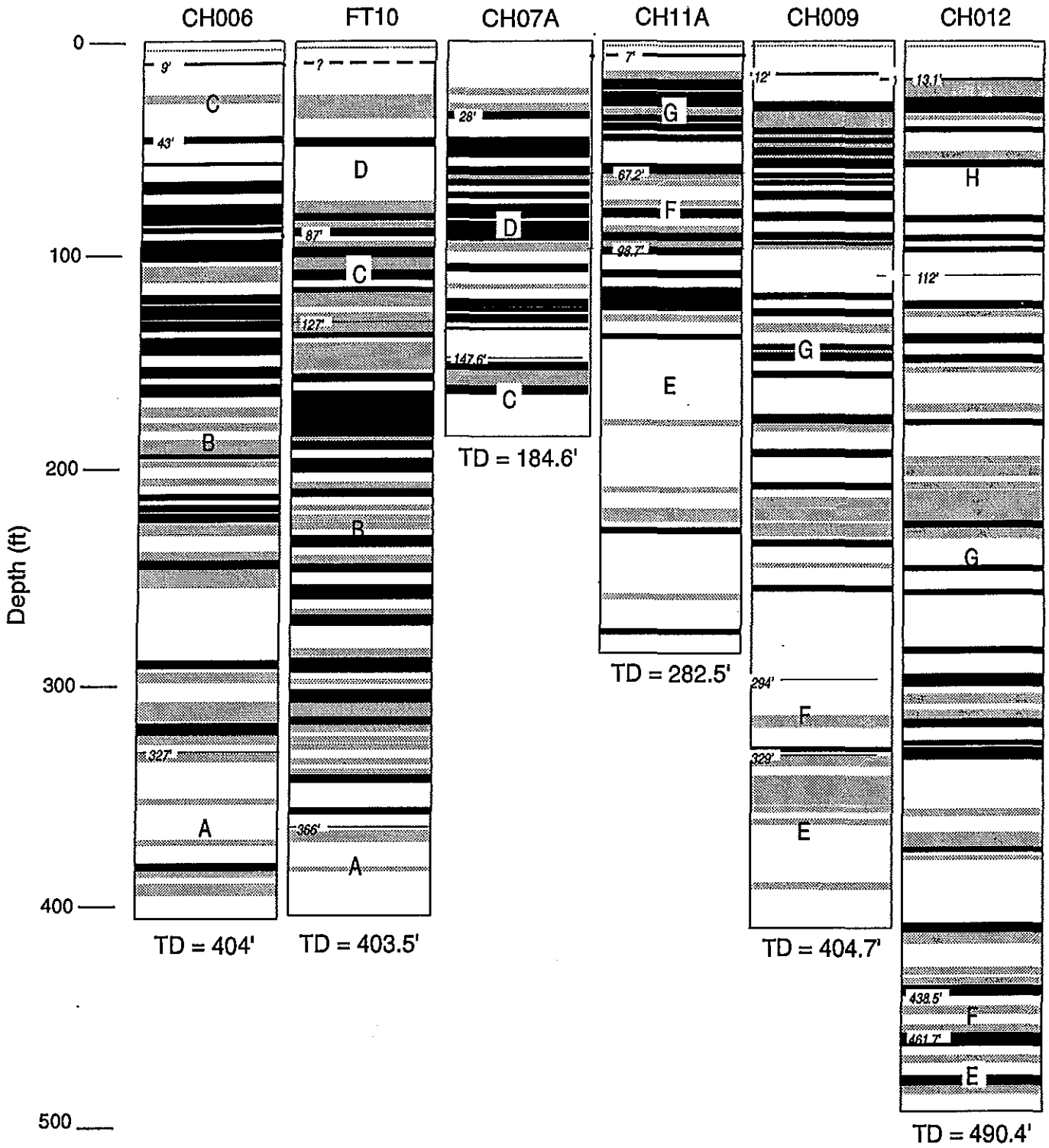


Fig. 3.3.31. Location of water transmitting fractures at coreholes.

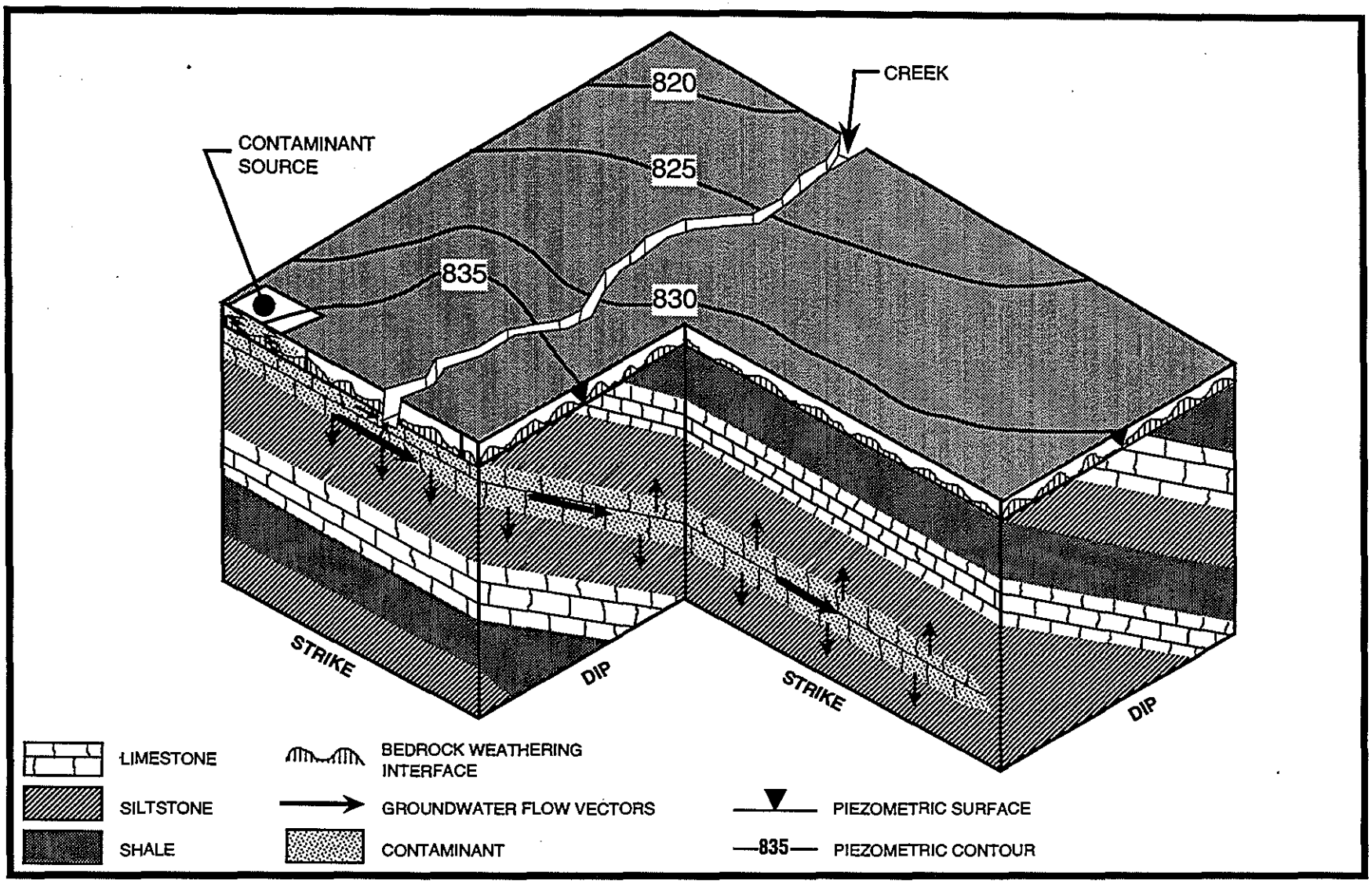


Fig. 3.3.32. Idealized block diagram of the strata-bound flow concept. *Modified from:* Ketelle and Lee, 1992.

5.18 6068.151

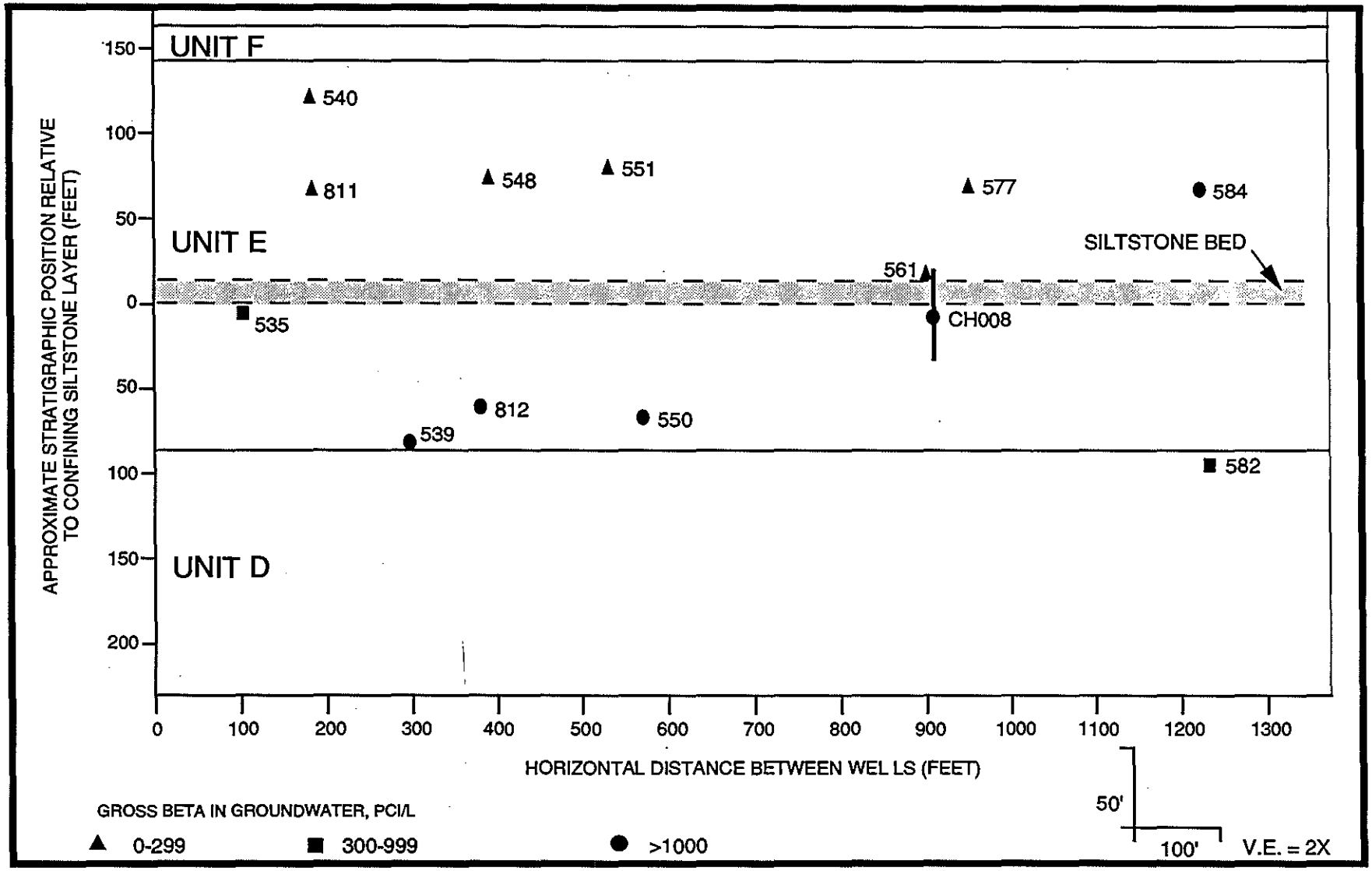
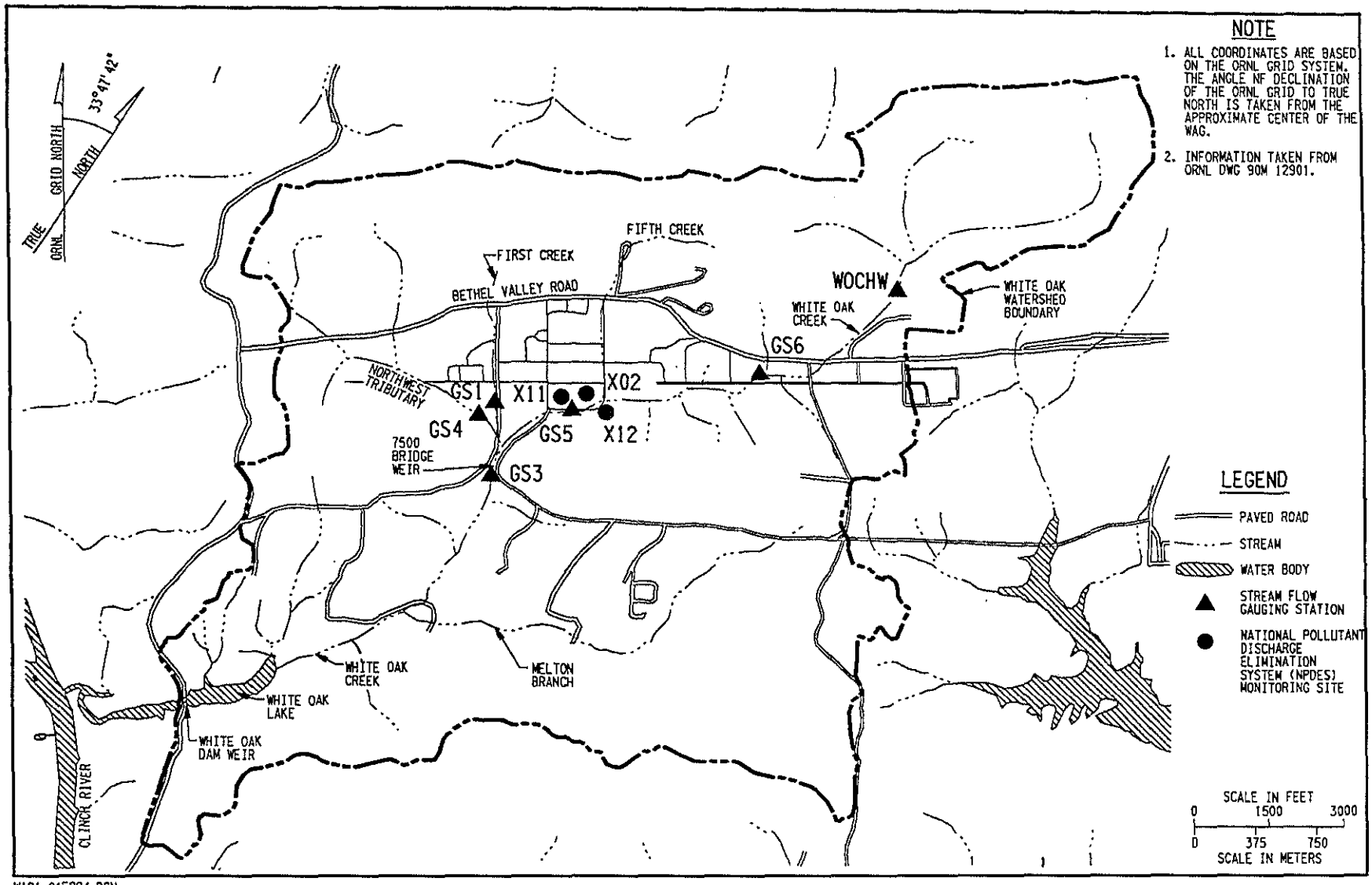


Fig. 3.3.33. Distribution of gross beta activities in geologic strata between CH008 and First Creek (shown in stratigraphic cross section).

5.33A 6066.11



WAG1 01F294.DGN
6/10/92

Fig. 3.4.1. WOC drainage basin with locations of stream flow gauging stations and NPDES outfalls.

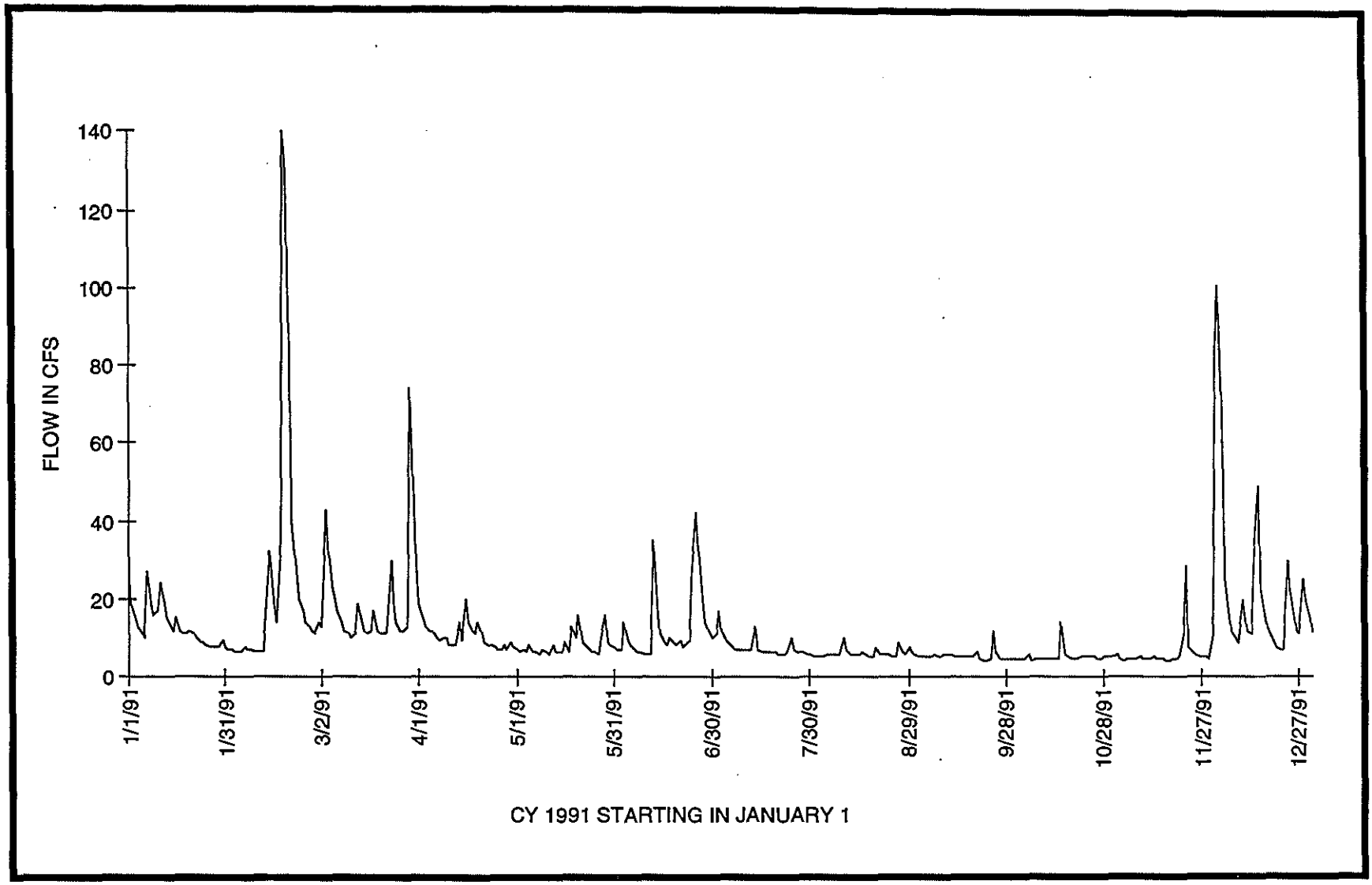


Fig. 3.4.2. Mean daily flows in White Oak Creek at 7500 bridge (GS3, USGS #356550).

5.33F 6066.100

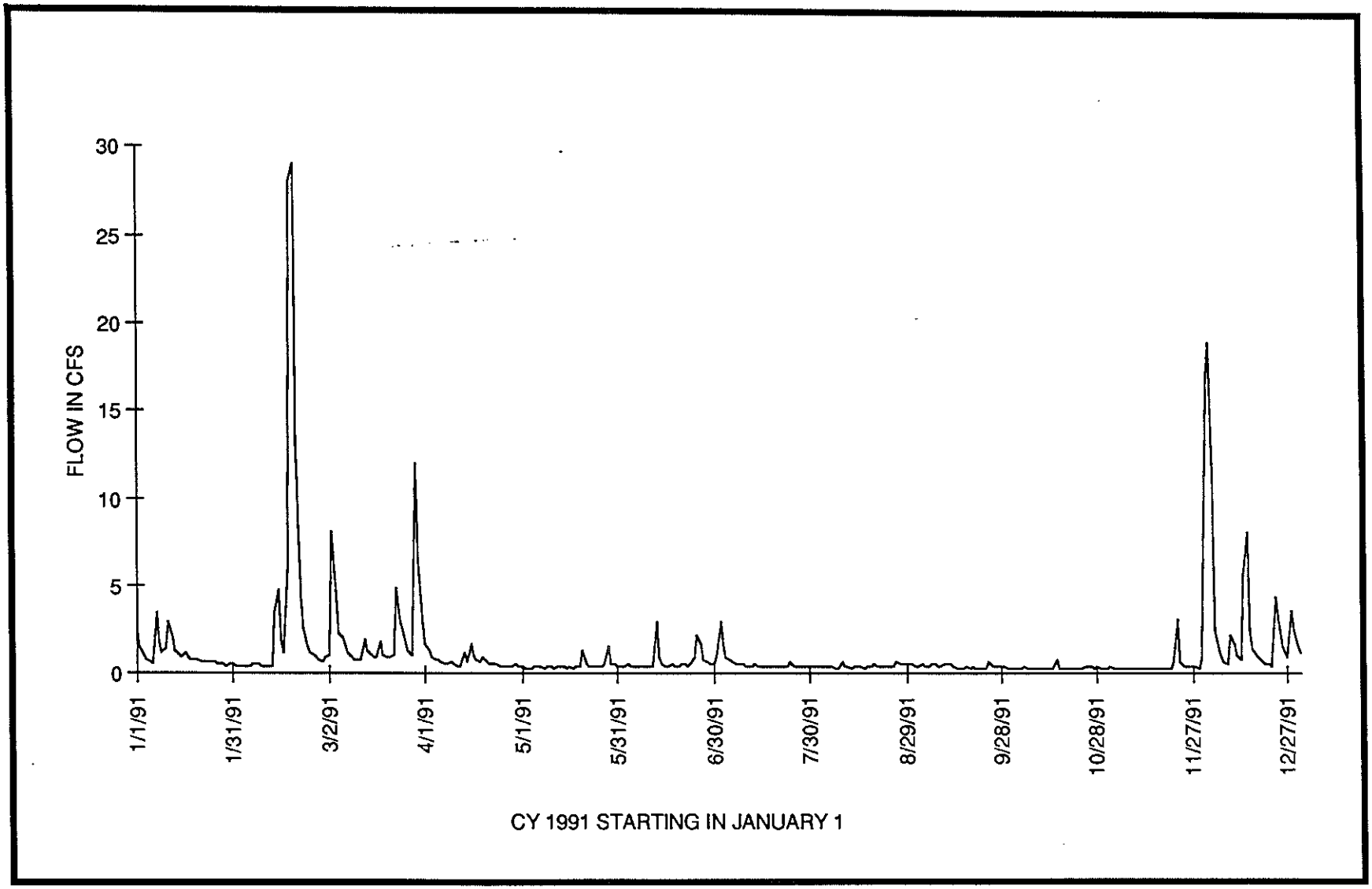


Fig. 3.4.3. Mean daily flows in Northwest Tributary (GS4, USGS # 3536440).

5.33F 6066.101

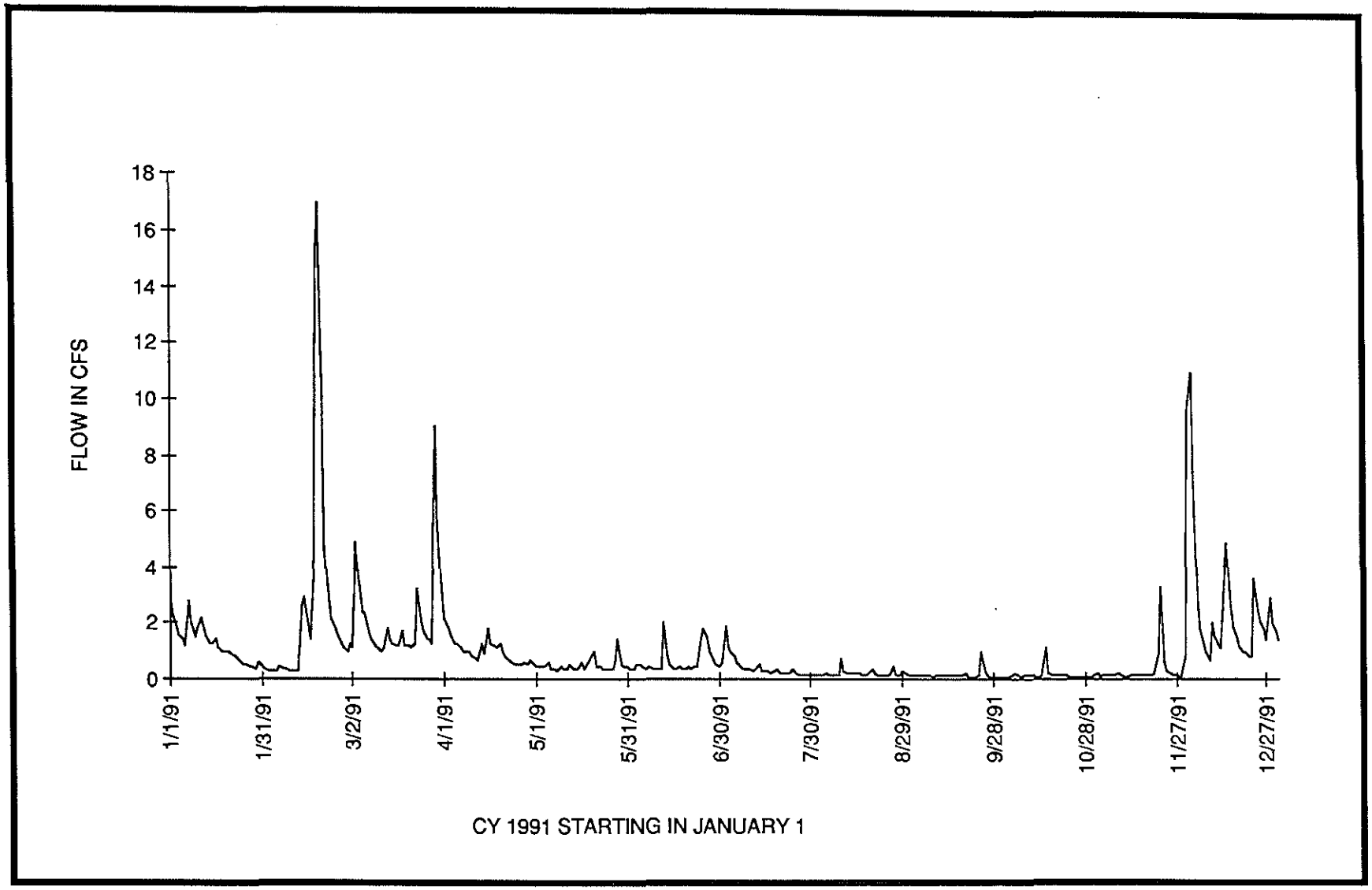


Fig. 3.4.4. Mean daily flows in First Creek (GS1, USGS# 3536450).

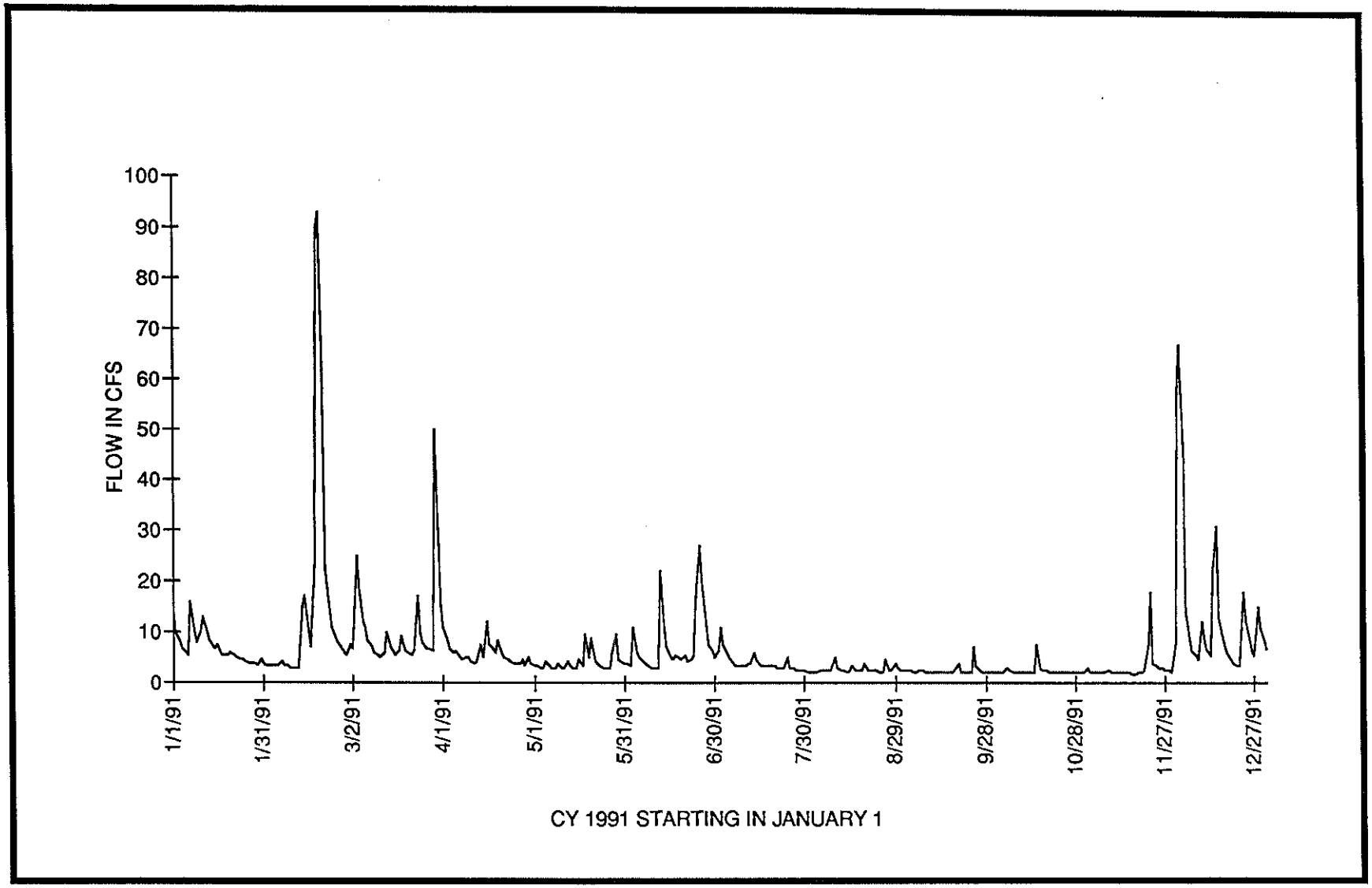


Fig. 3.4.5. Mean daily flows in White Oak Creek Parshall flume (GS5, 3536380).

5.33F 6066.103

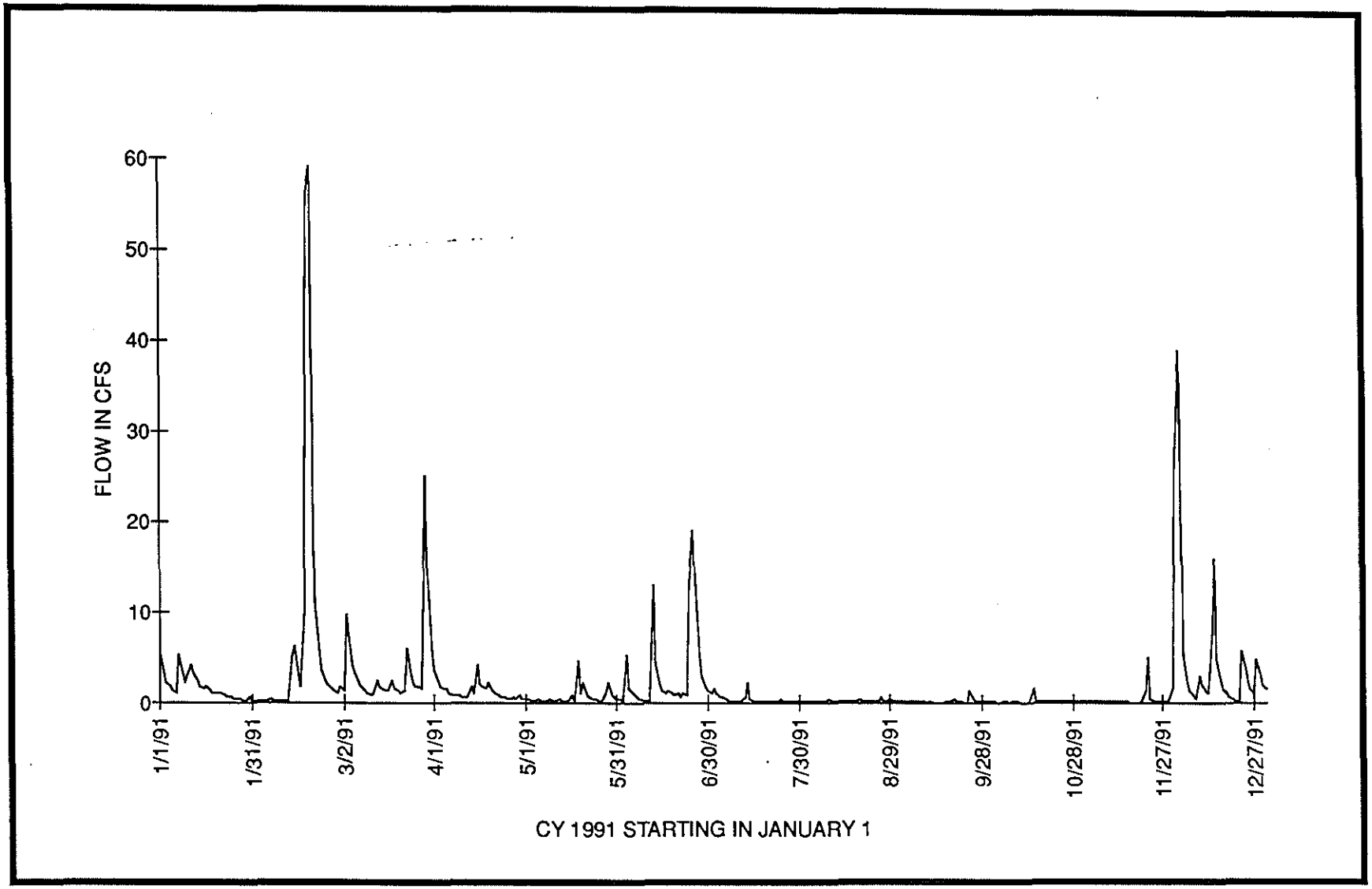


Fig. 3.4.6. Mean daily flows in upper White Oak Creek (GS6, 3536320).

5.88F 6066.104

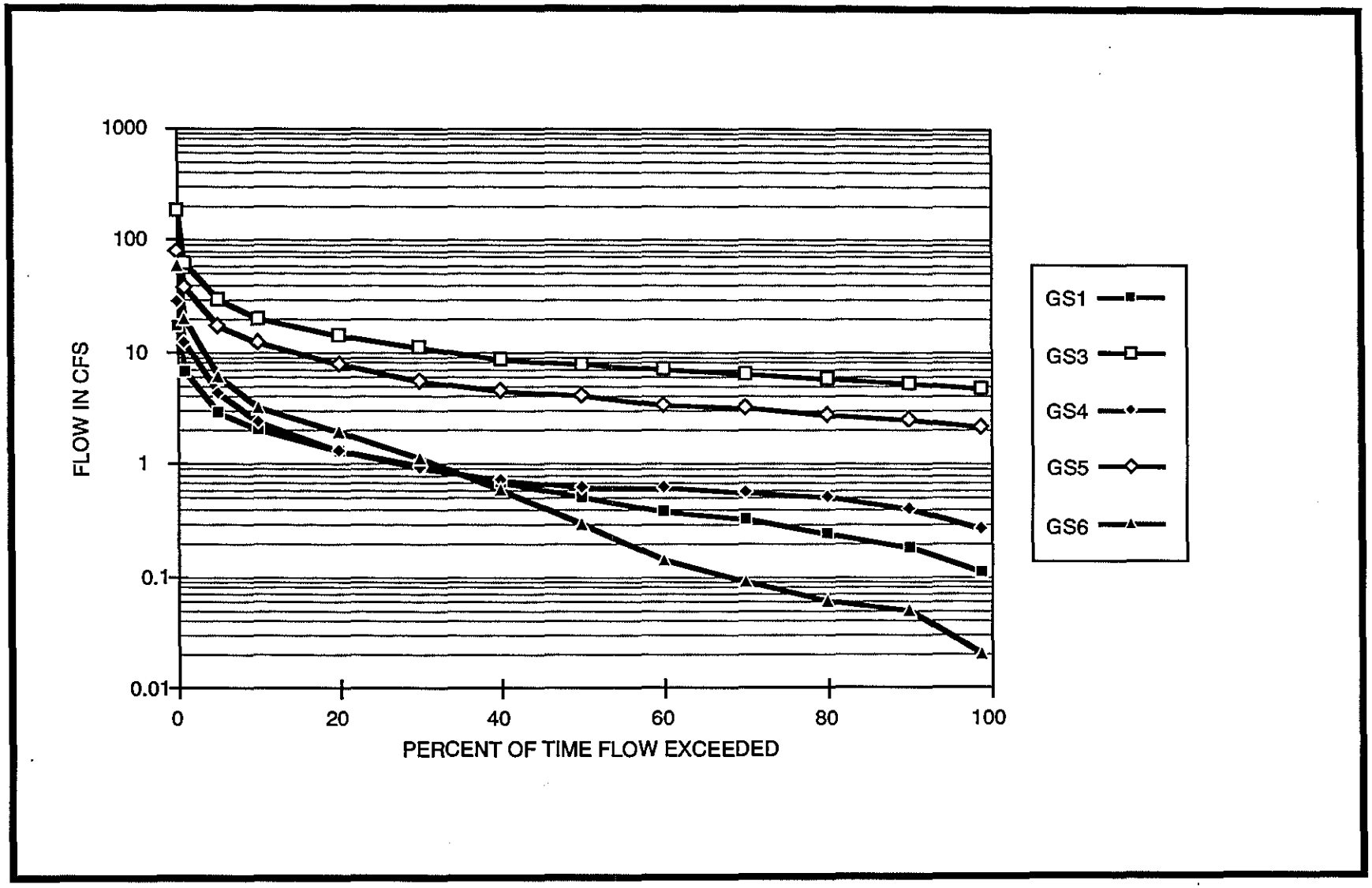


Fig. 3.4.7. Flow duration curves at USGS stations near WAG 1 (Oct. 1987 - Mar. 1992 daily flows).

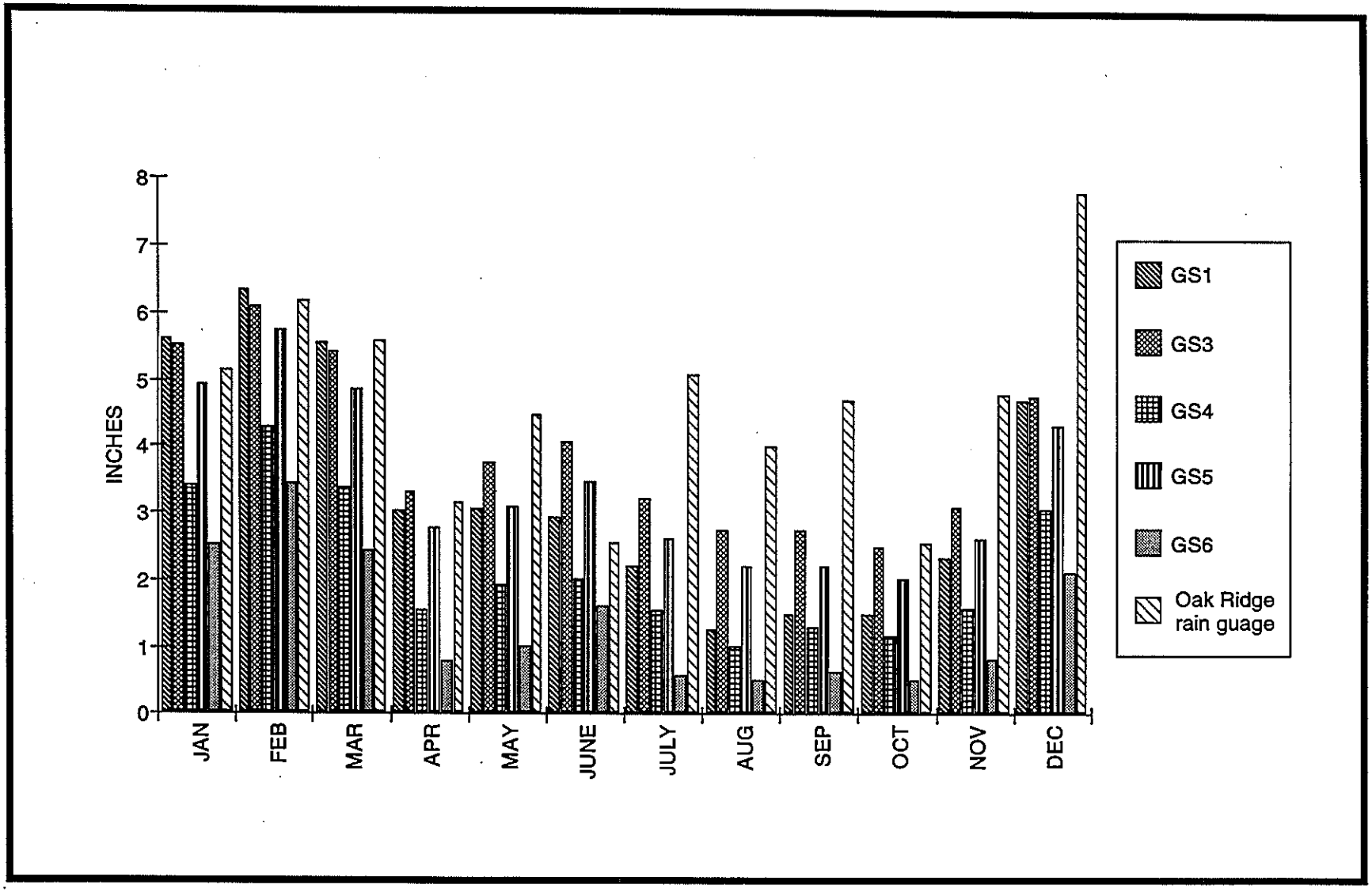


Fig. 3.4.8. Average monthly runoff and rainfall (1988-1991).

5.33F 6066.107

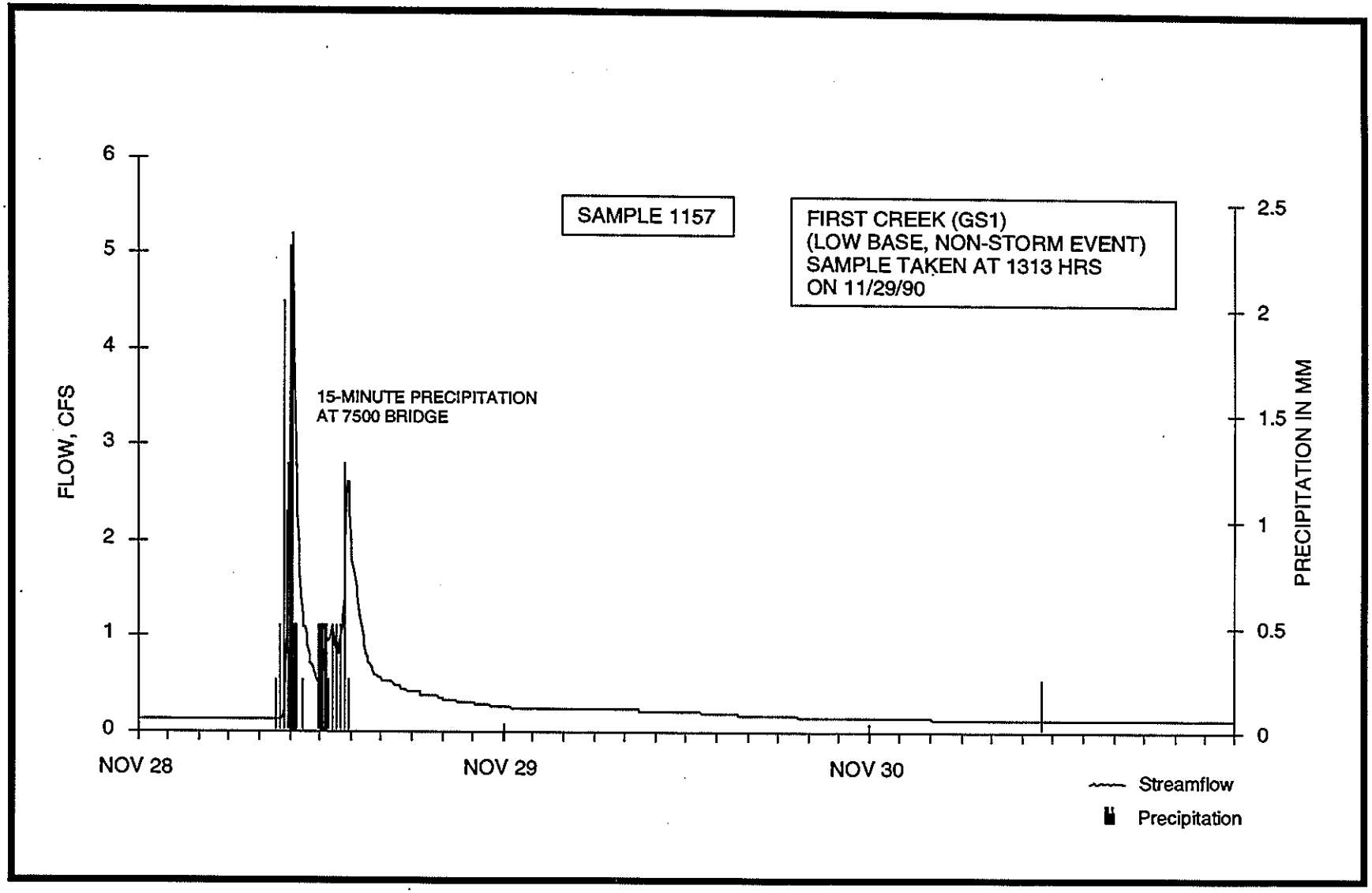


Fig. 3.4.9. November 28-30, 1990 hydrograph at SW-7.

5.33F 6066.79

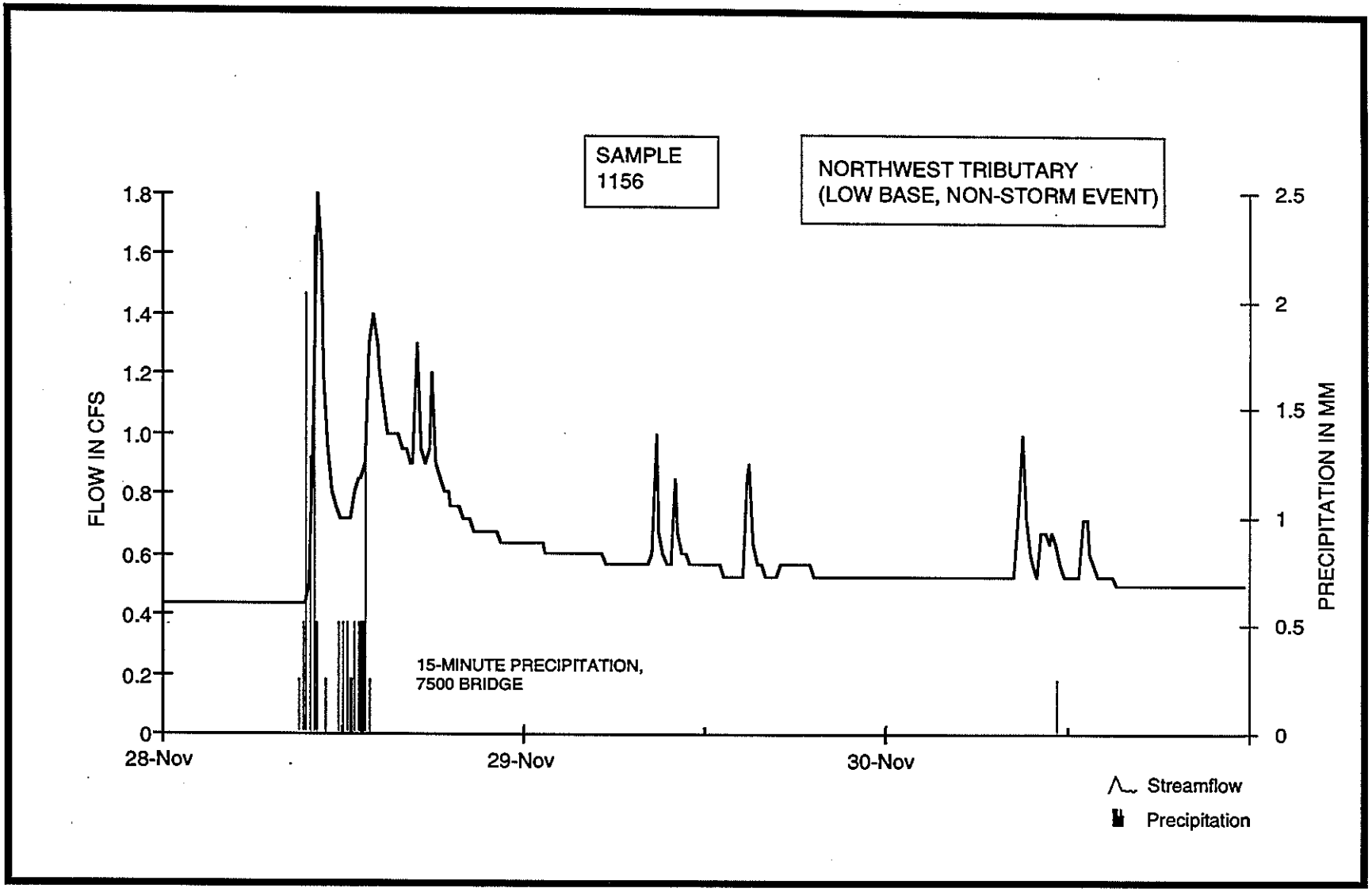


Fig. 3.4.10. November 28-30, 1990 hydrograph at SW-8.

5.33F 6066.105

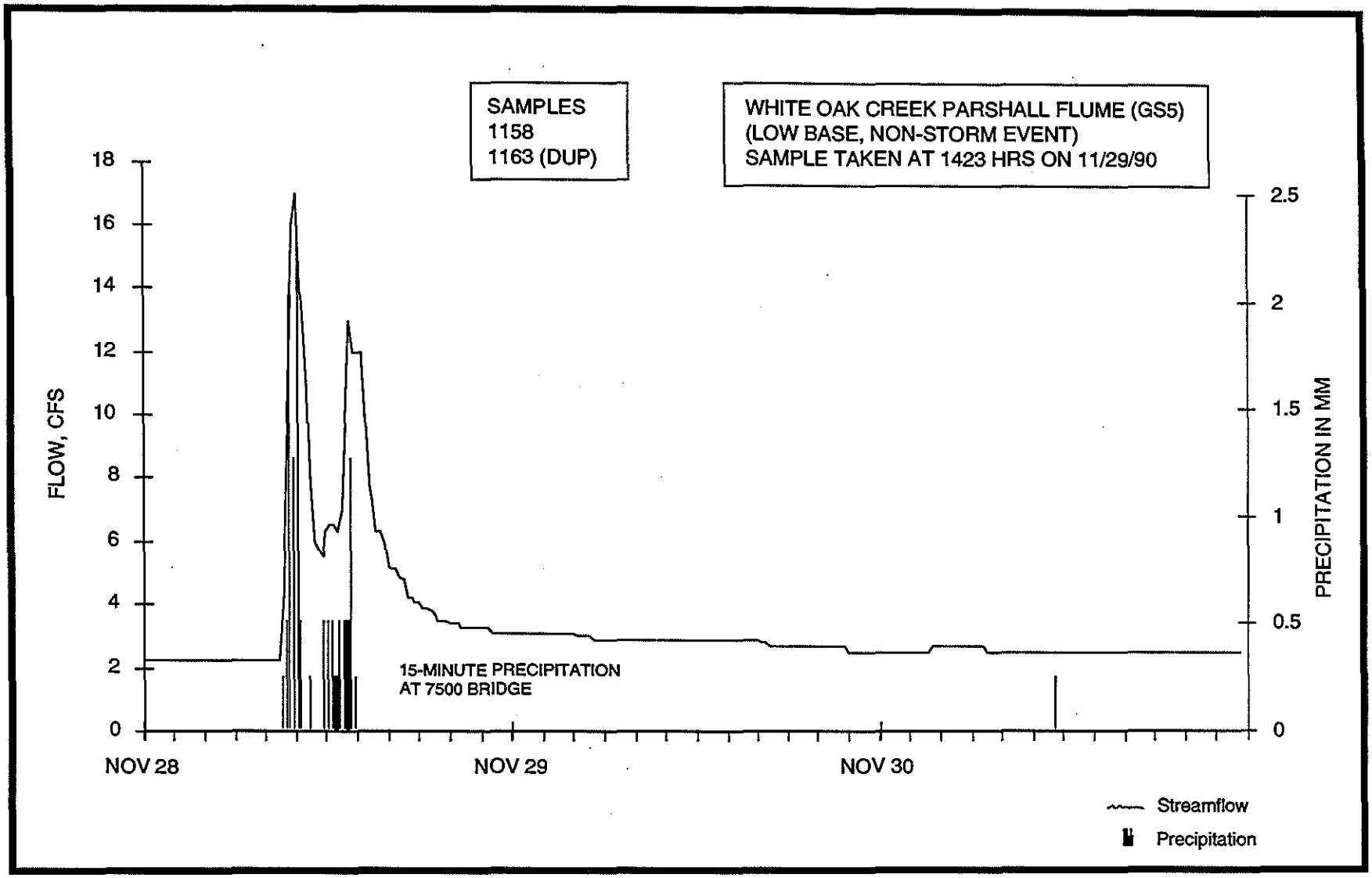


Fig. 3.4.11. November 28-30, 1990 hydrograph at SW-5.

5.33F 6066.71

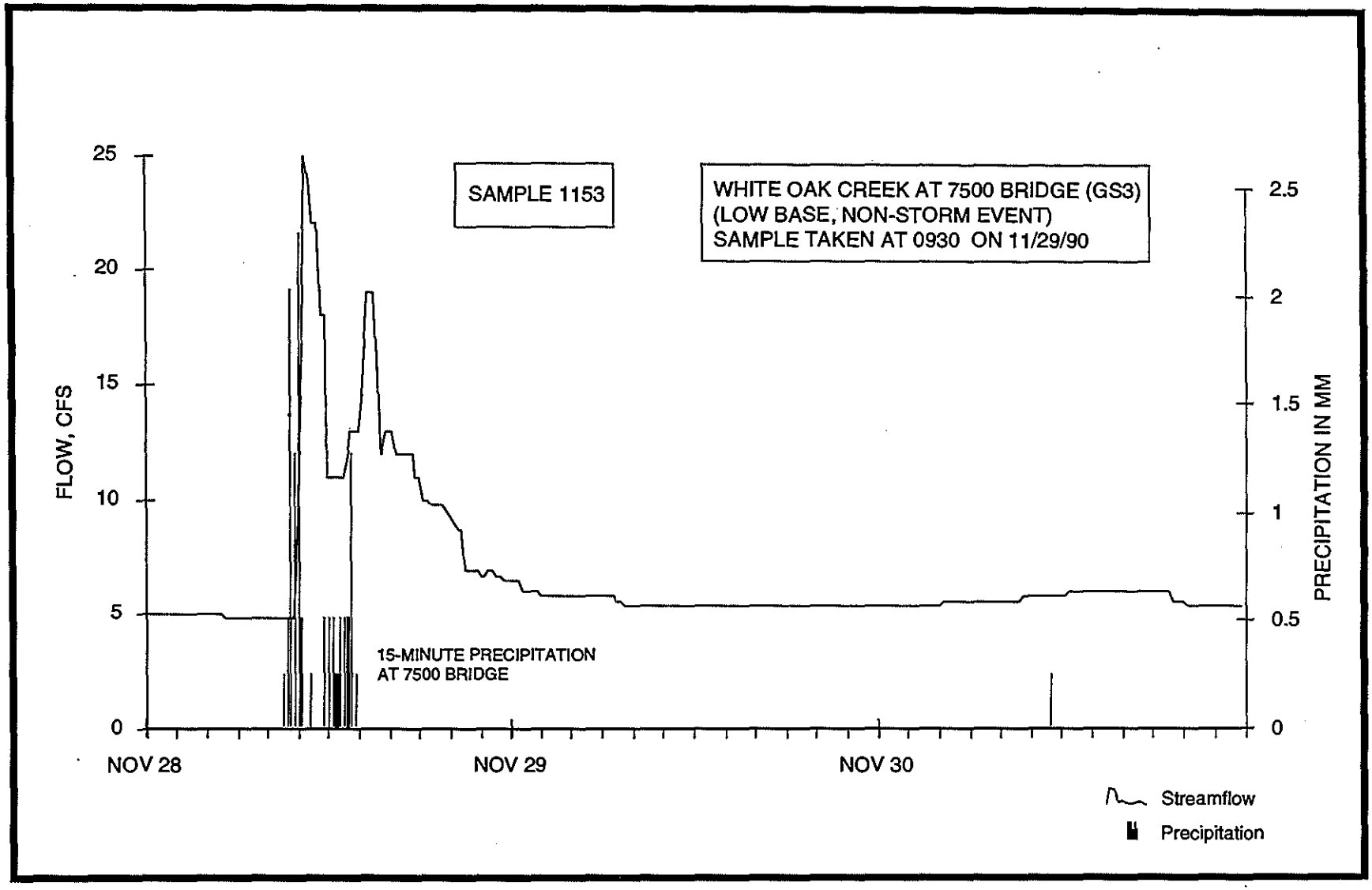
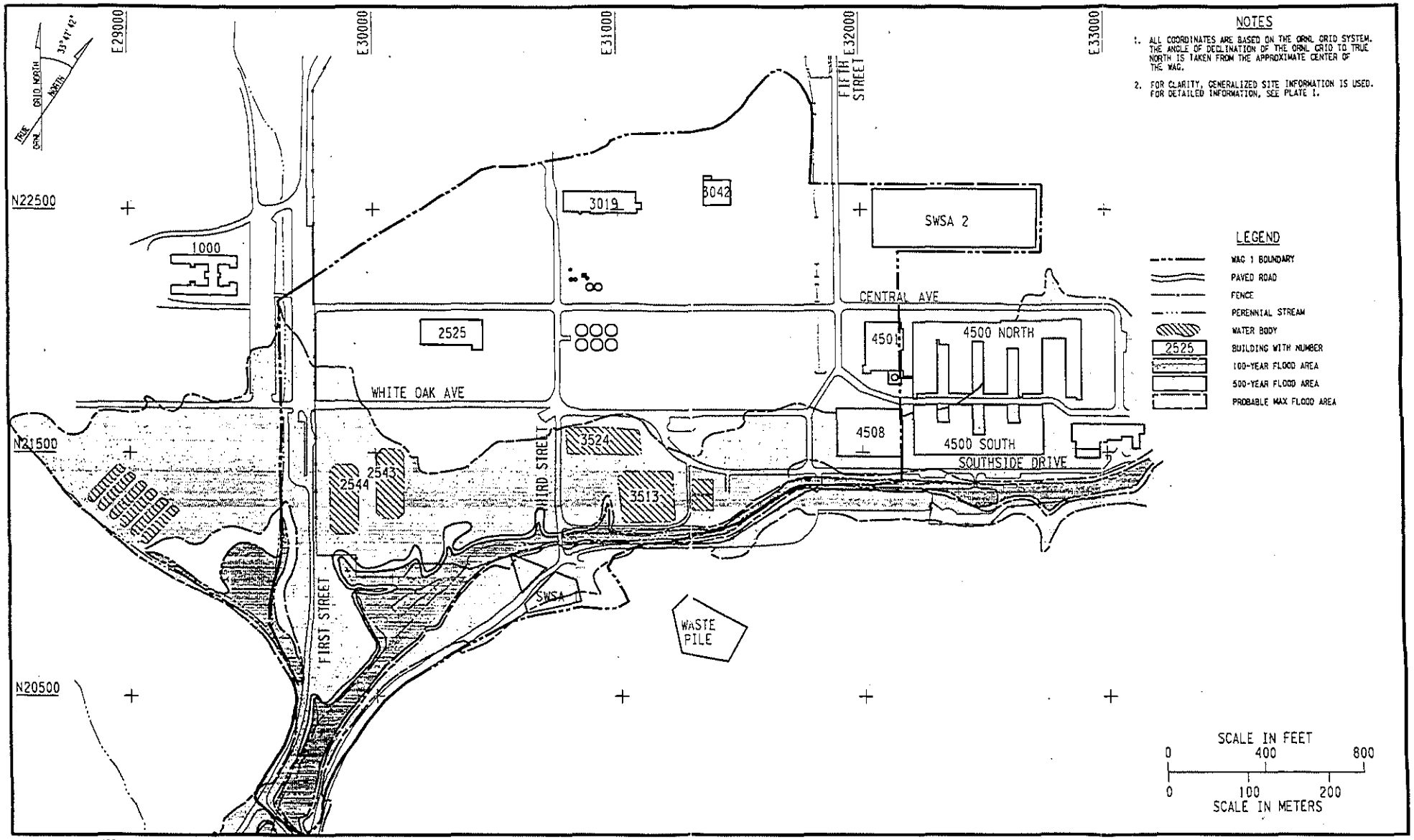


Fig. 3.4.12. November 28-30, 1990 hydrograph at SW-6.

5.33F 6068.75



WAG1 01F251DGN SRF,
6/12/92

Fig. 3.4.13. White Oak Creek floodplain area.

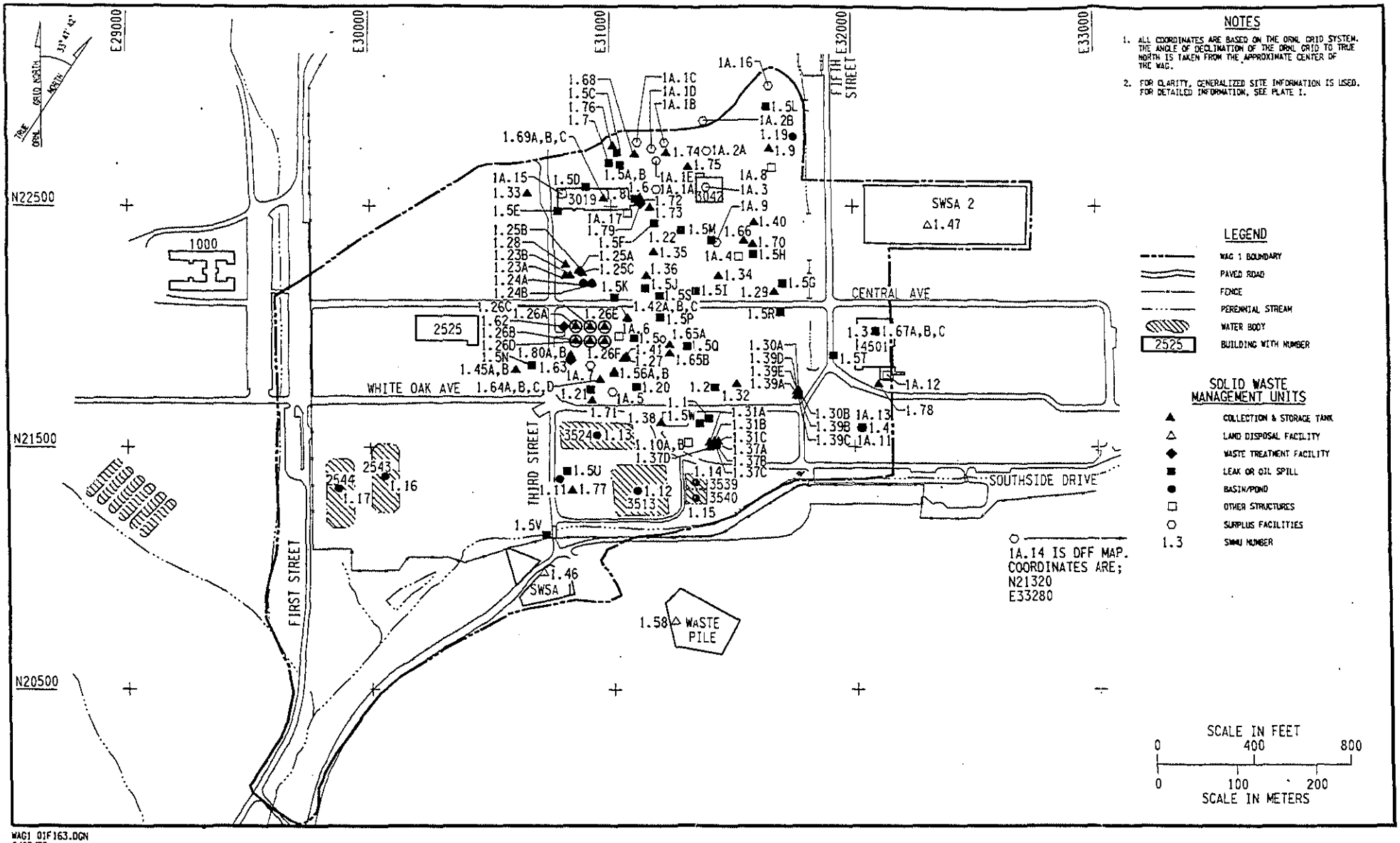
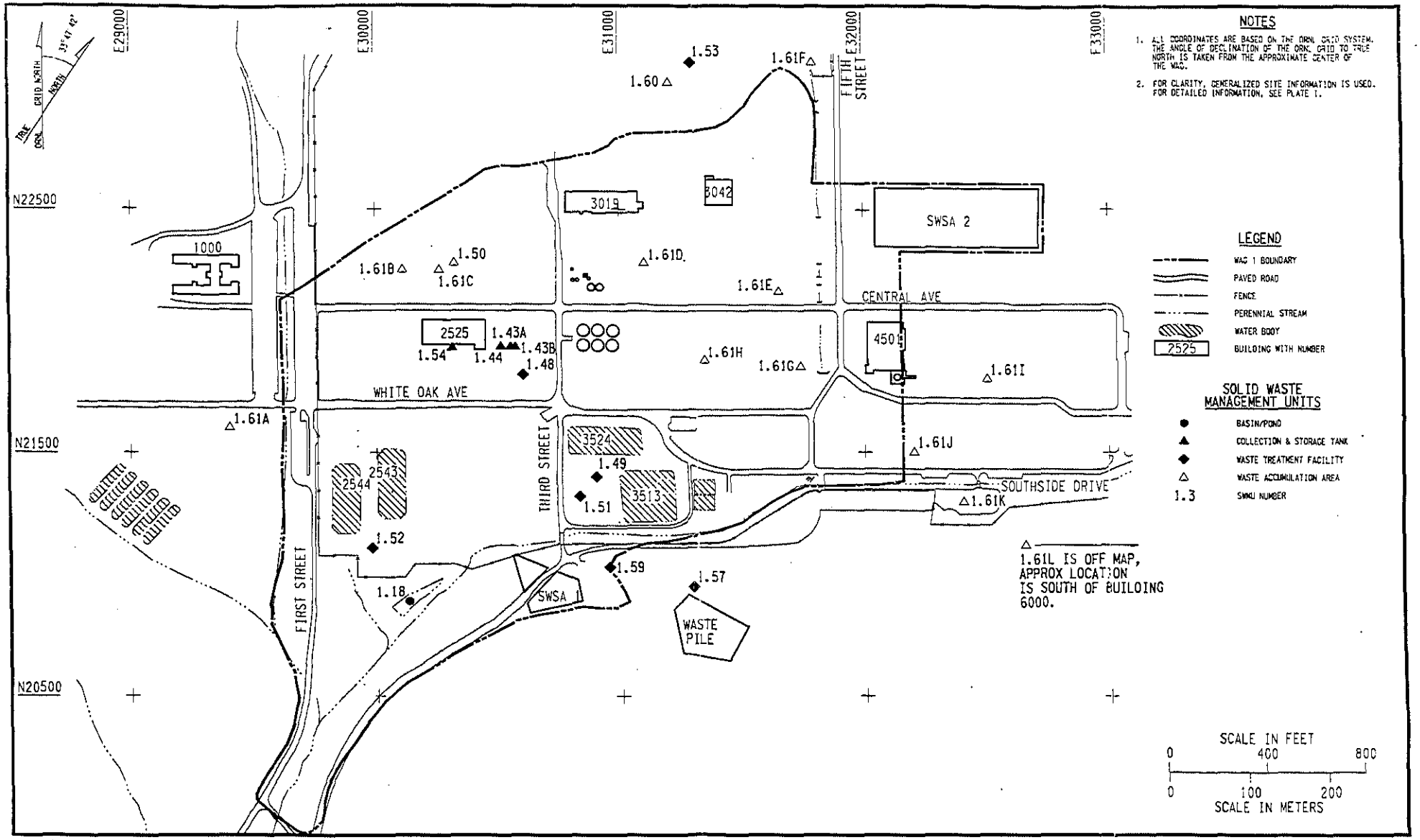


Fig. 3.5.1. Solid waste management units.



WAG1 01F250.DGN SRF, 6/11/92

Fig. 3.5.2. SWMU waste storage and treatment facility.

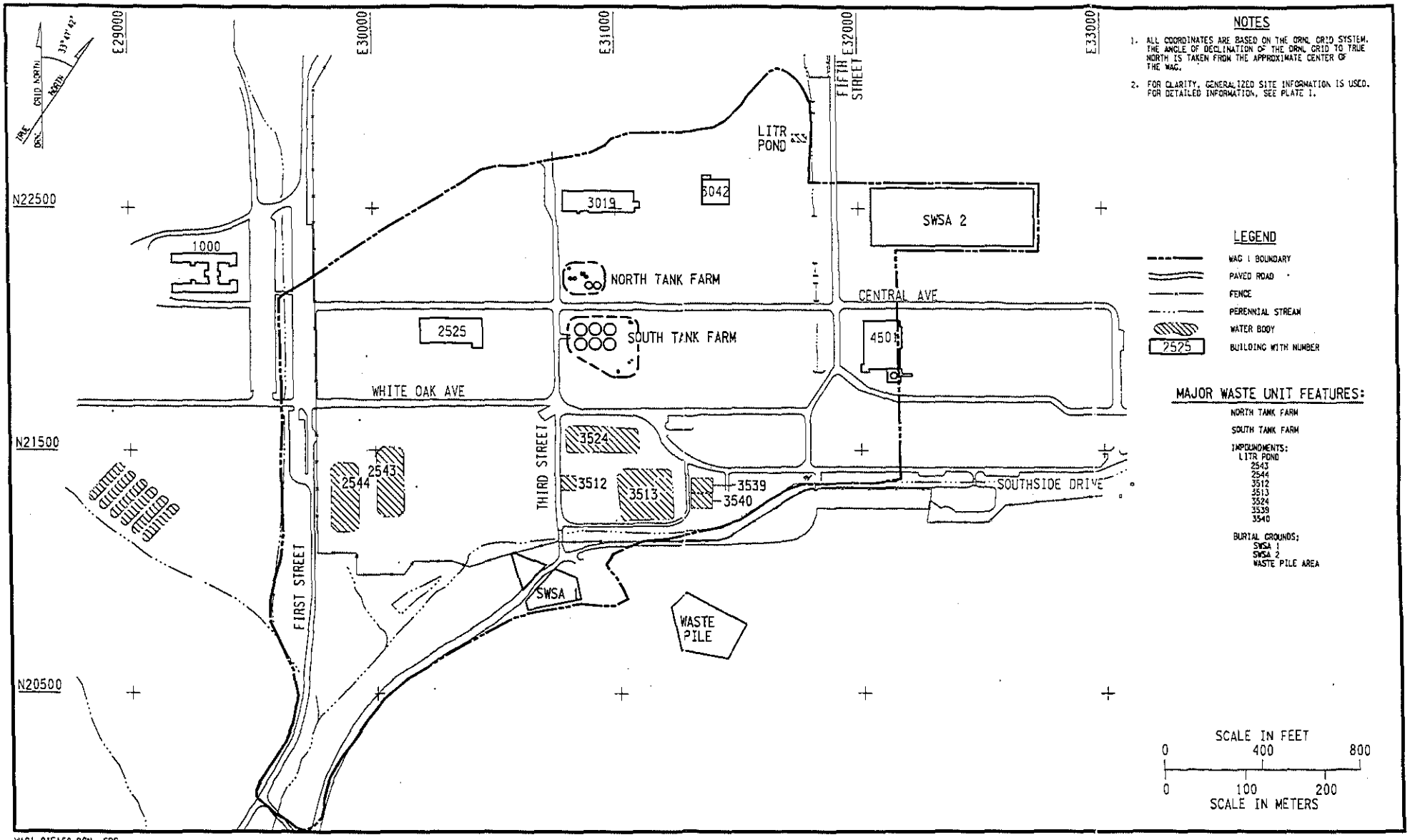


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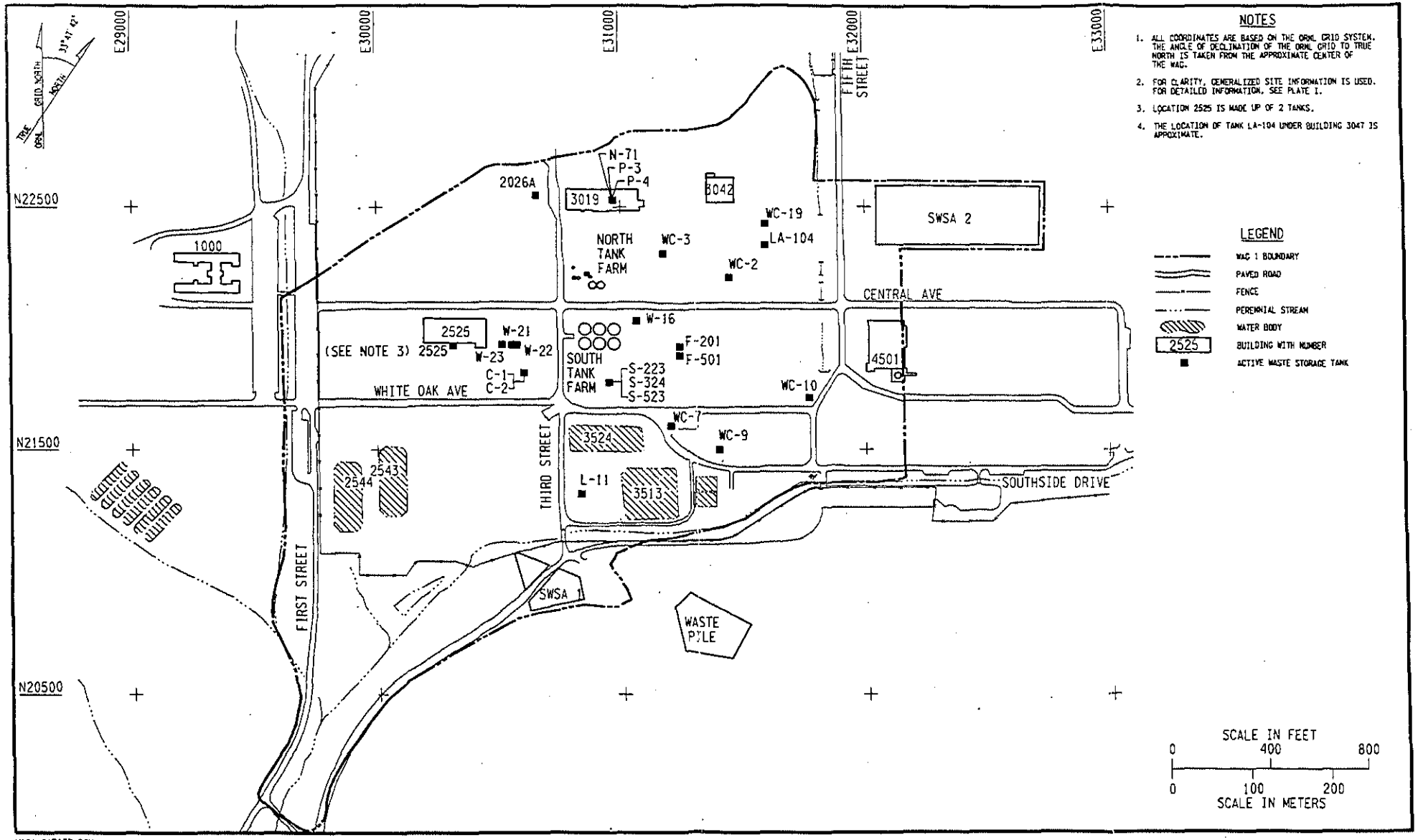
Fig. 3.5.3. Waste unit physical setting.



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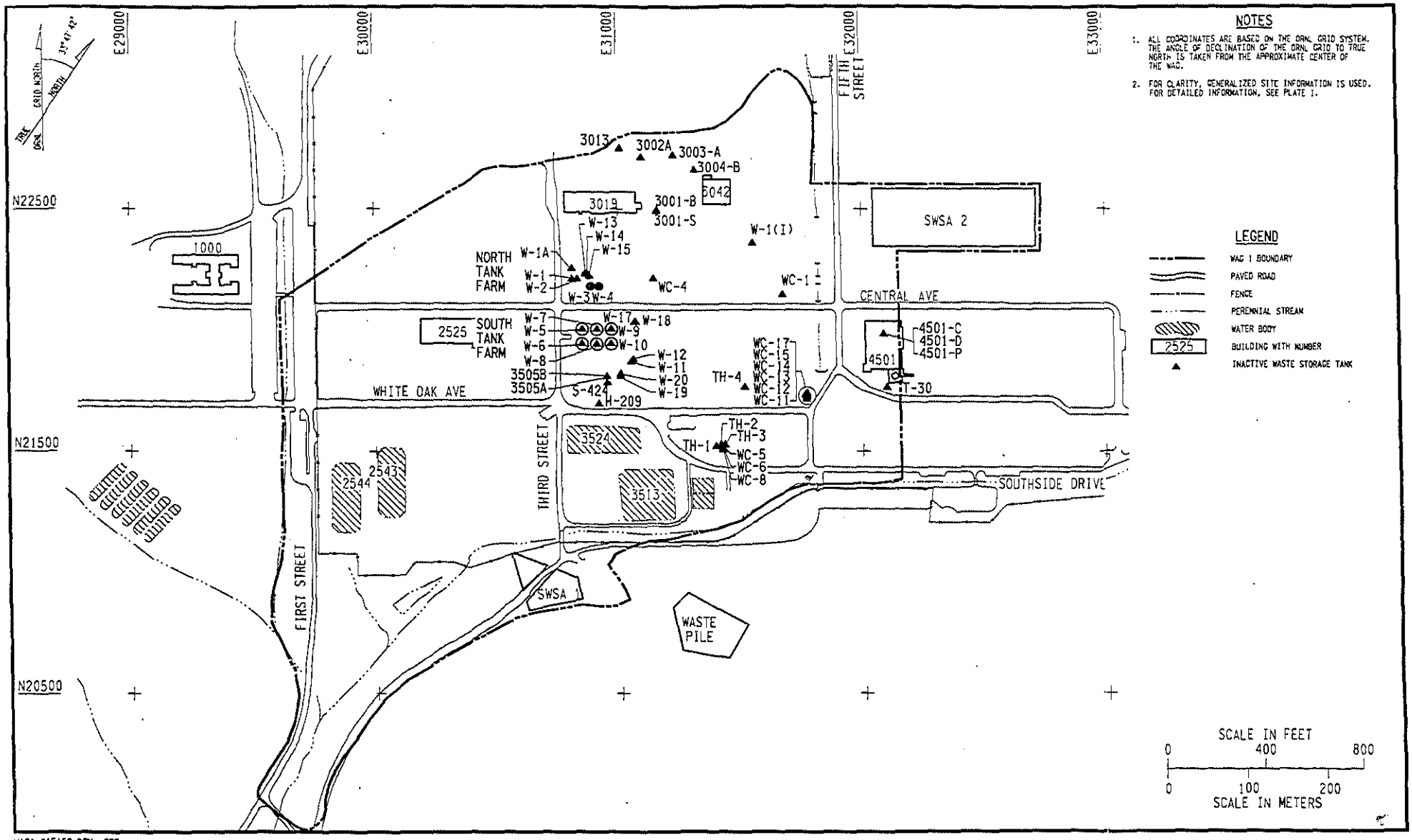
9/23/92

Fig. 3.5.4. Active waste storage tanks.



WAG1 01F152.DGN SRF, 6/11/92

Fig. 3.5.5. Inactive waste storage tanks.

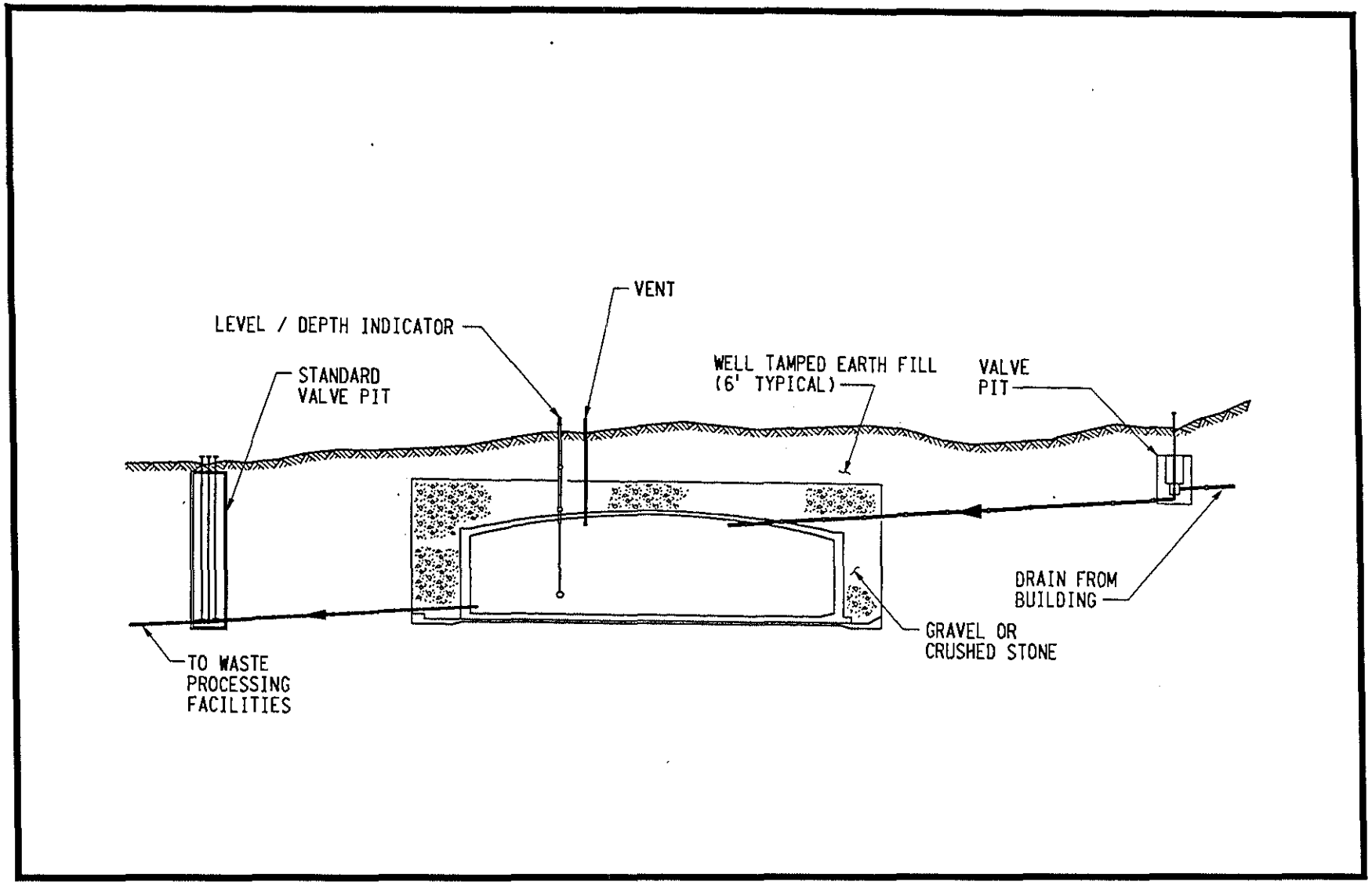


Fig. 3.5.6. Typical concrete (Gunite) waste tank installation.

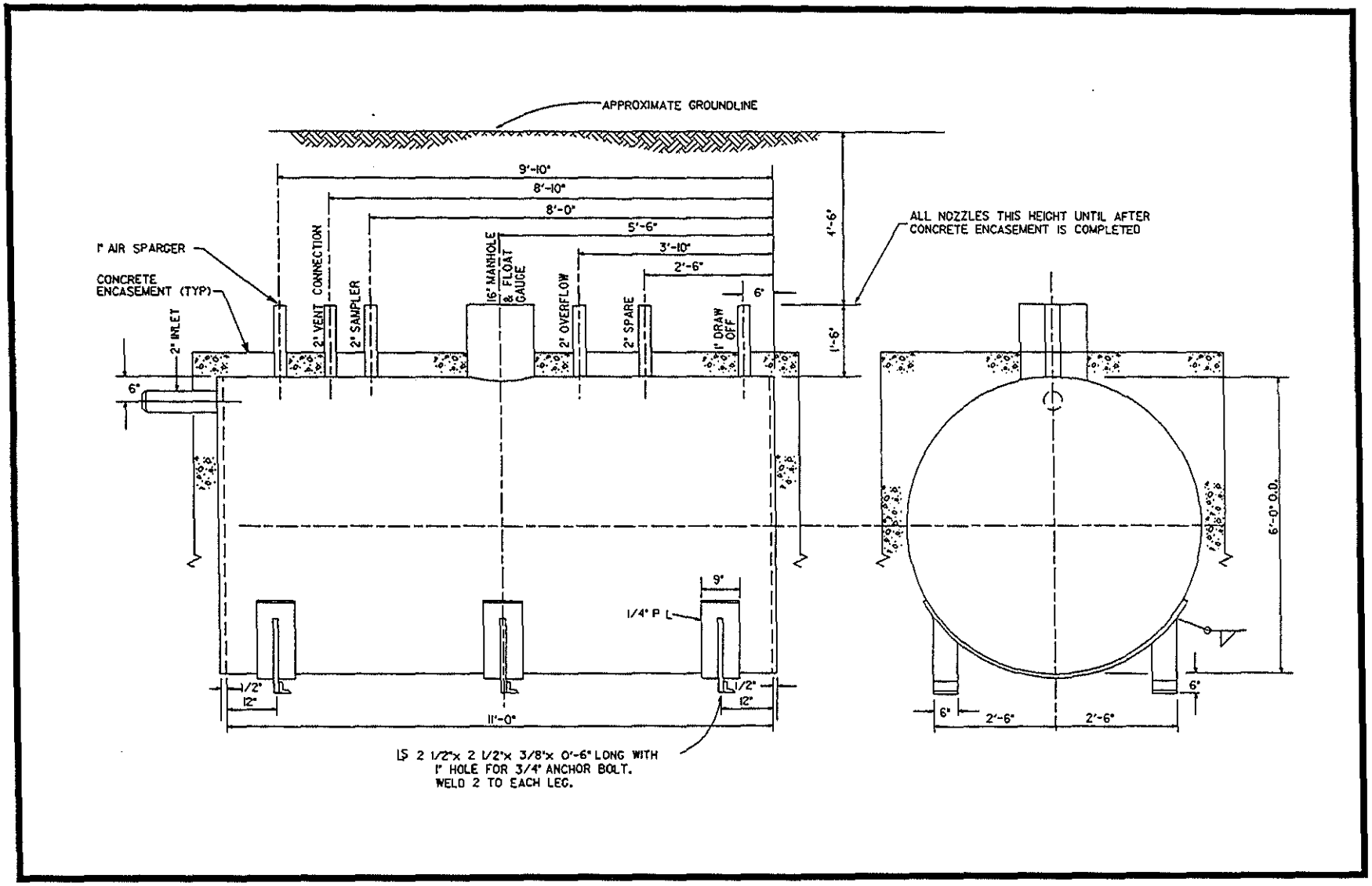


Fig. 3.5.7. Typical horizontal stainless steel waste tank installation.

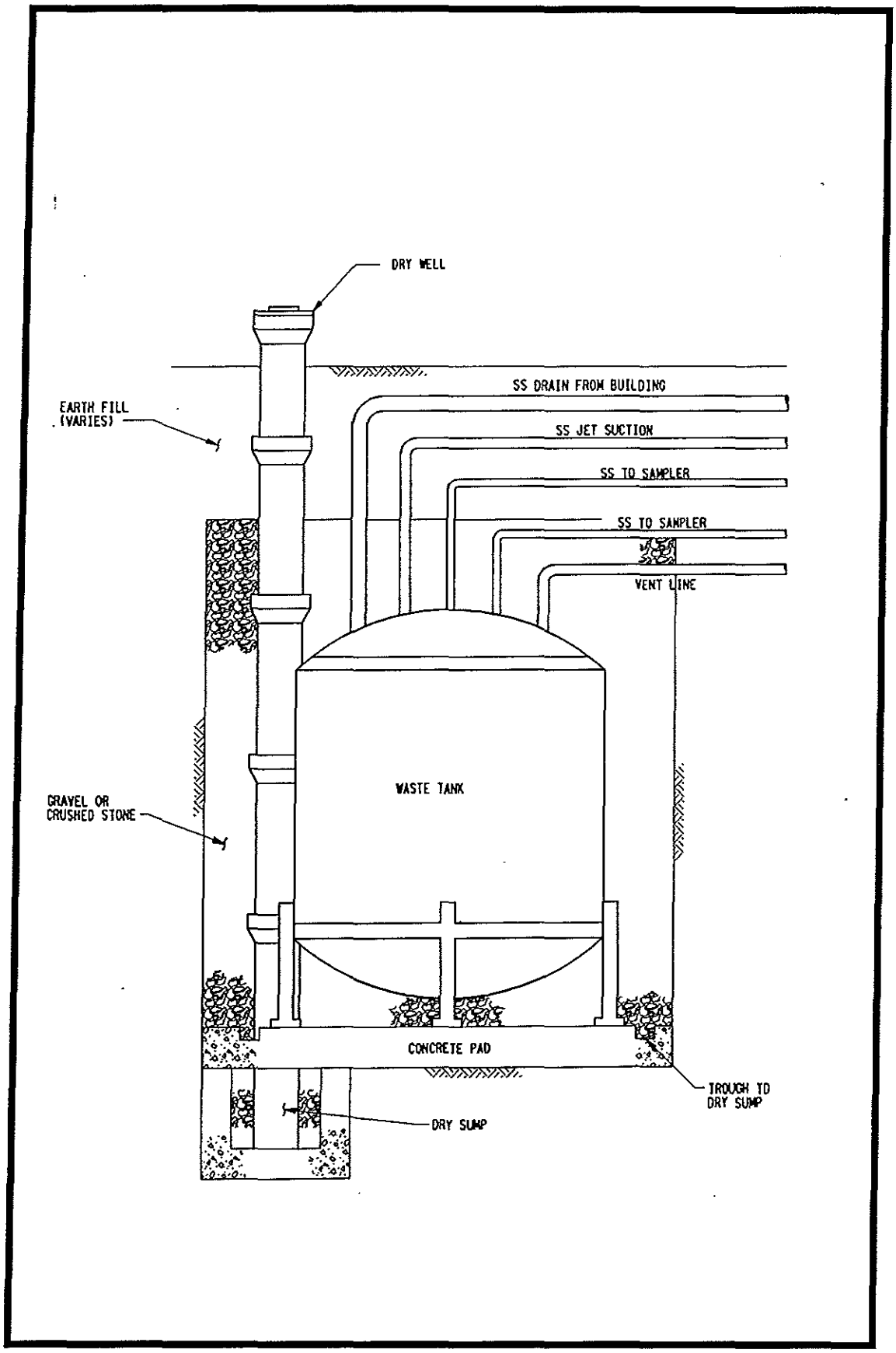


Fig. 3.5.8. Typical vertical stainless steel waste tank installation.

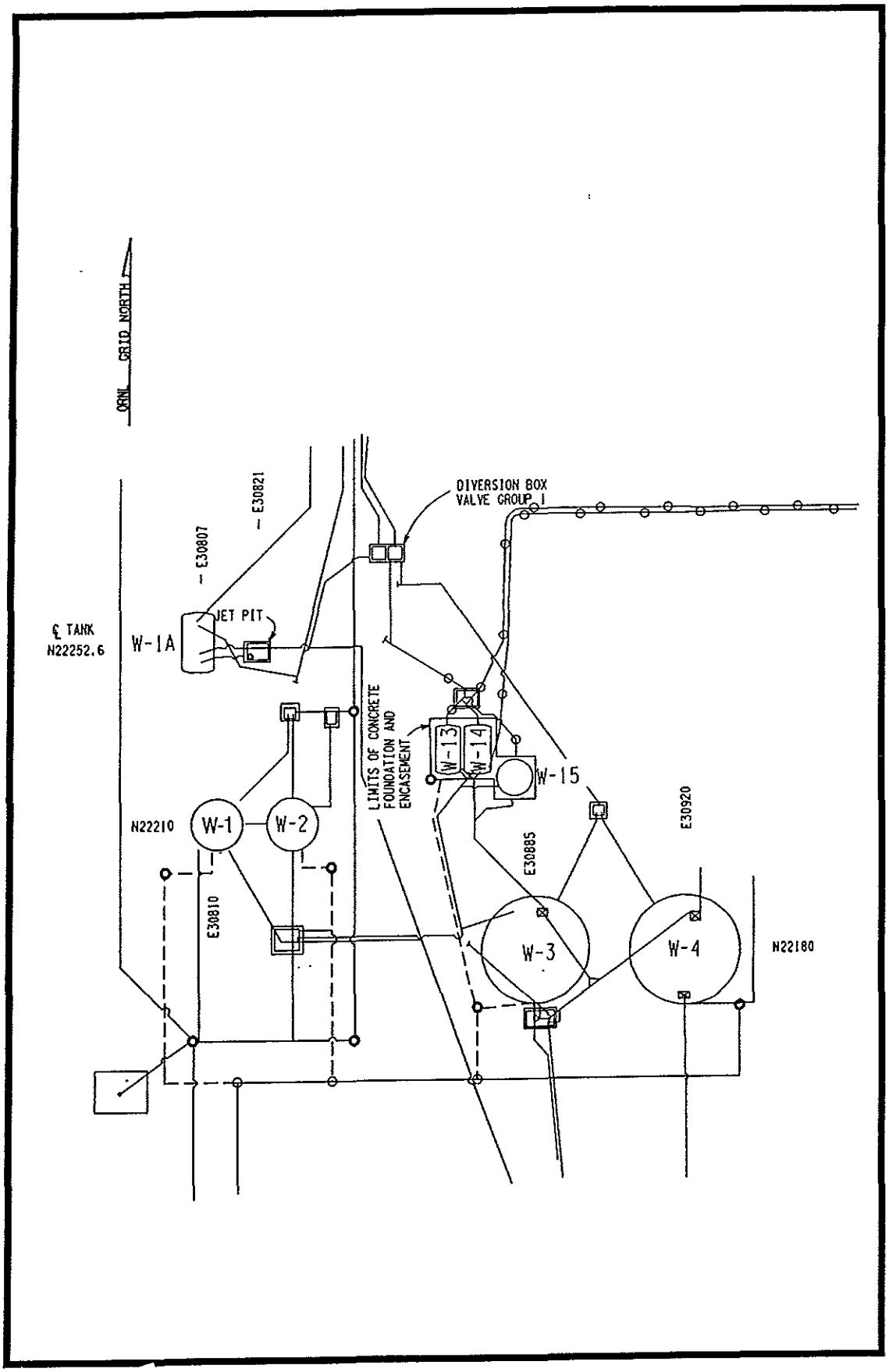
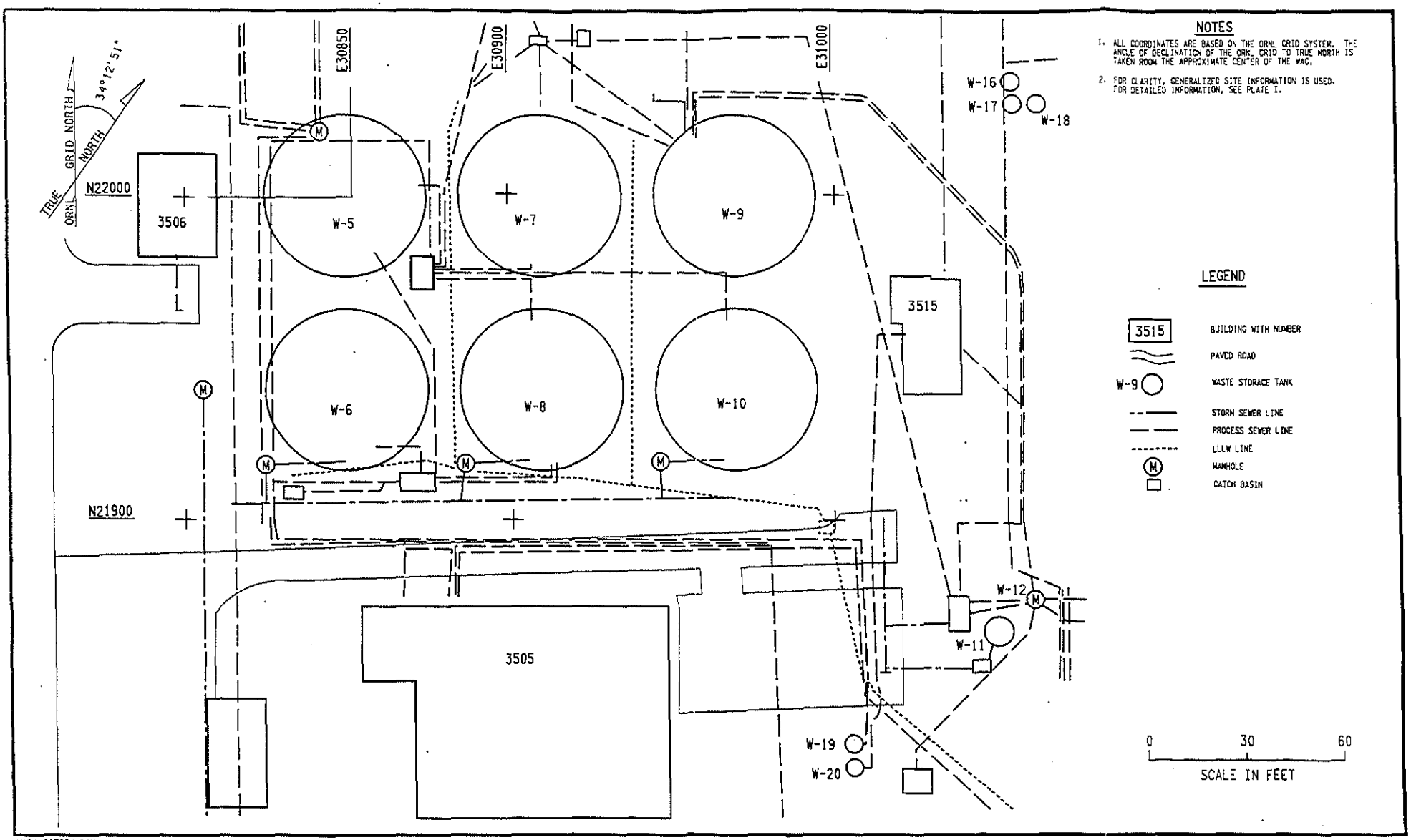


Fig. 3.5.9. North Tank Farm.



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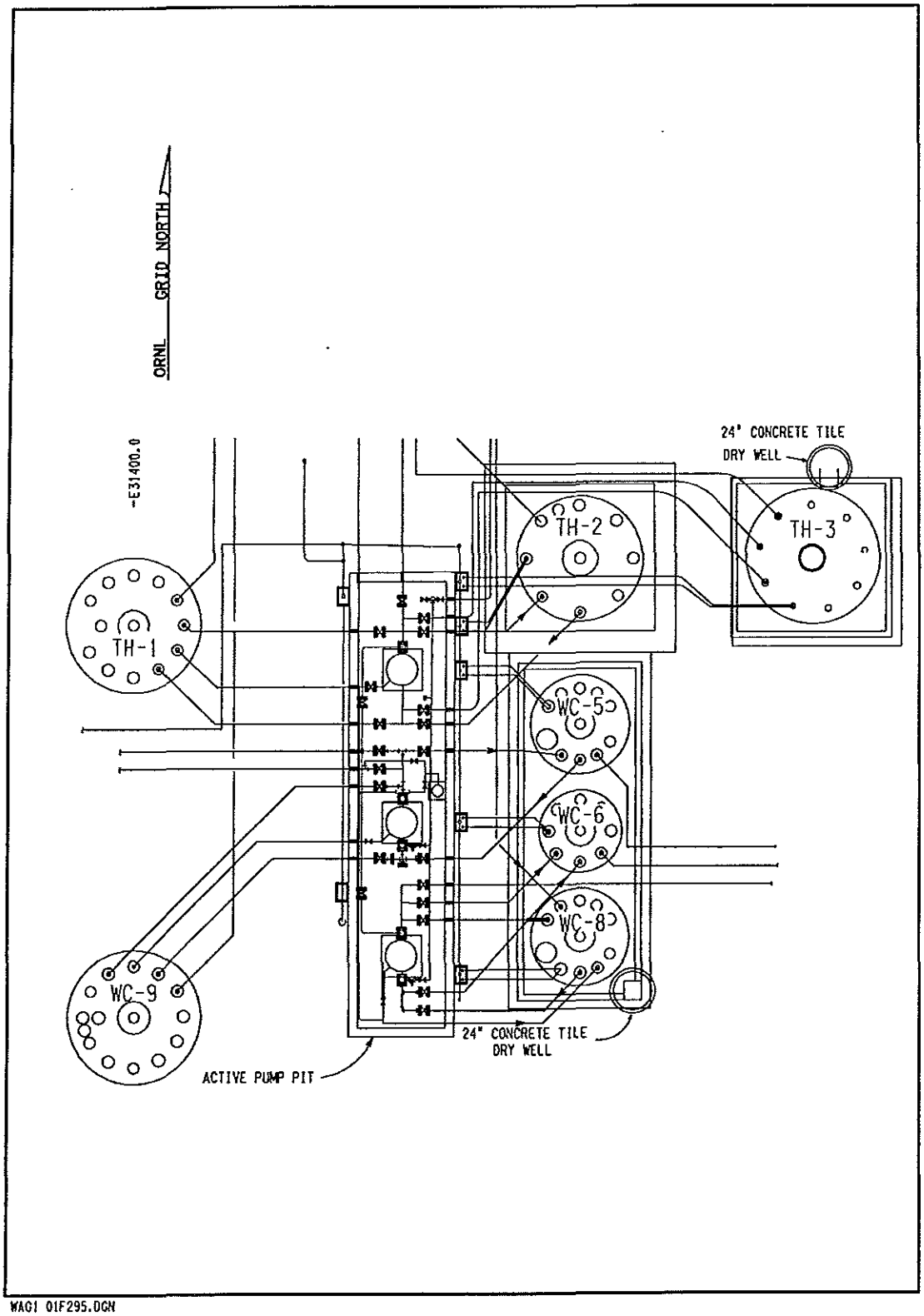
6/22/92

Fig. 3.5.10. South Tank Farm.



WAG1 01F295.DGN
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Fig. 3.5.11. Thorium tank farm.

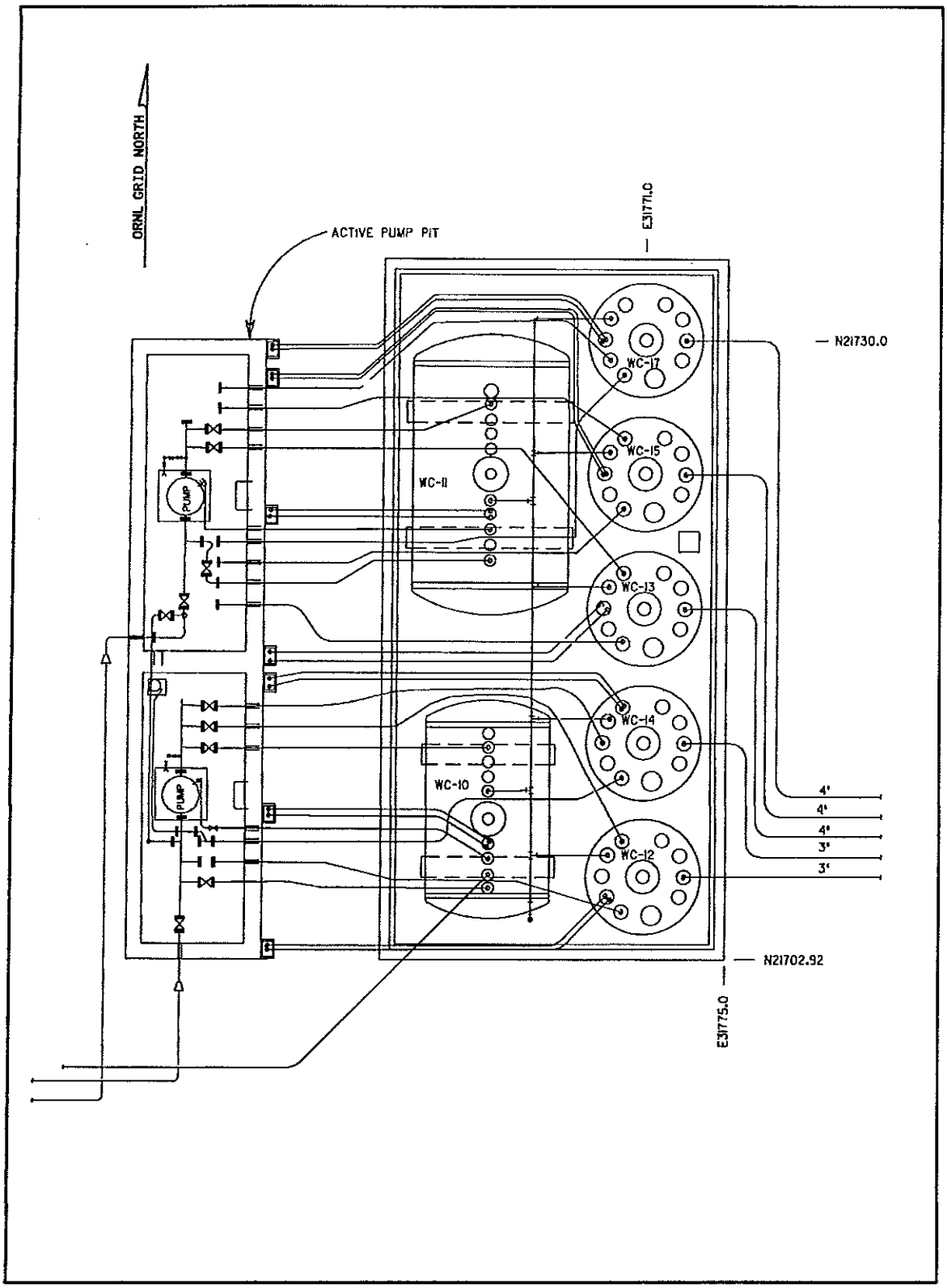

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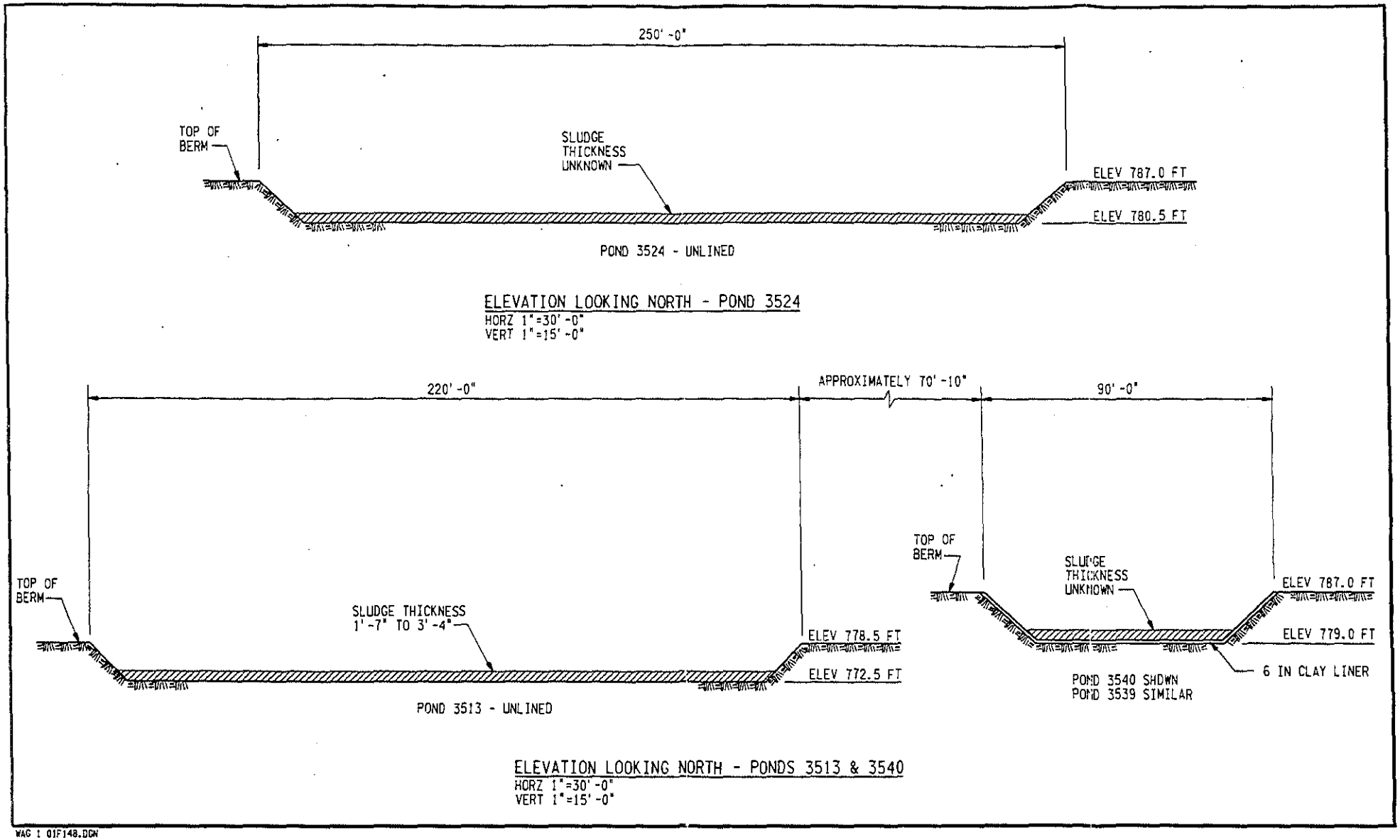
Fig. 3.5.12. Building 4500 area tank farm.



WAG 1 01F148.DGN
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Fig. 3.5.13. Cross-sectional view of surface impoundments.

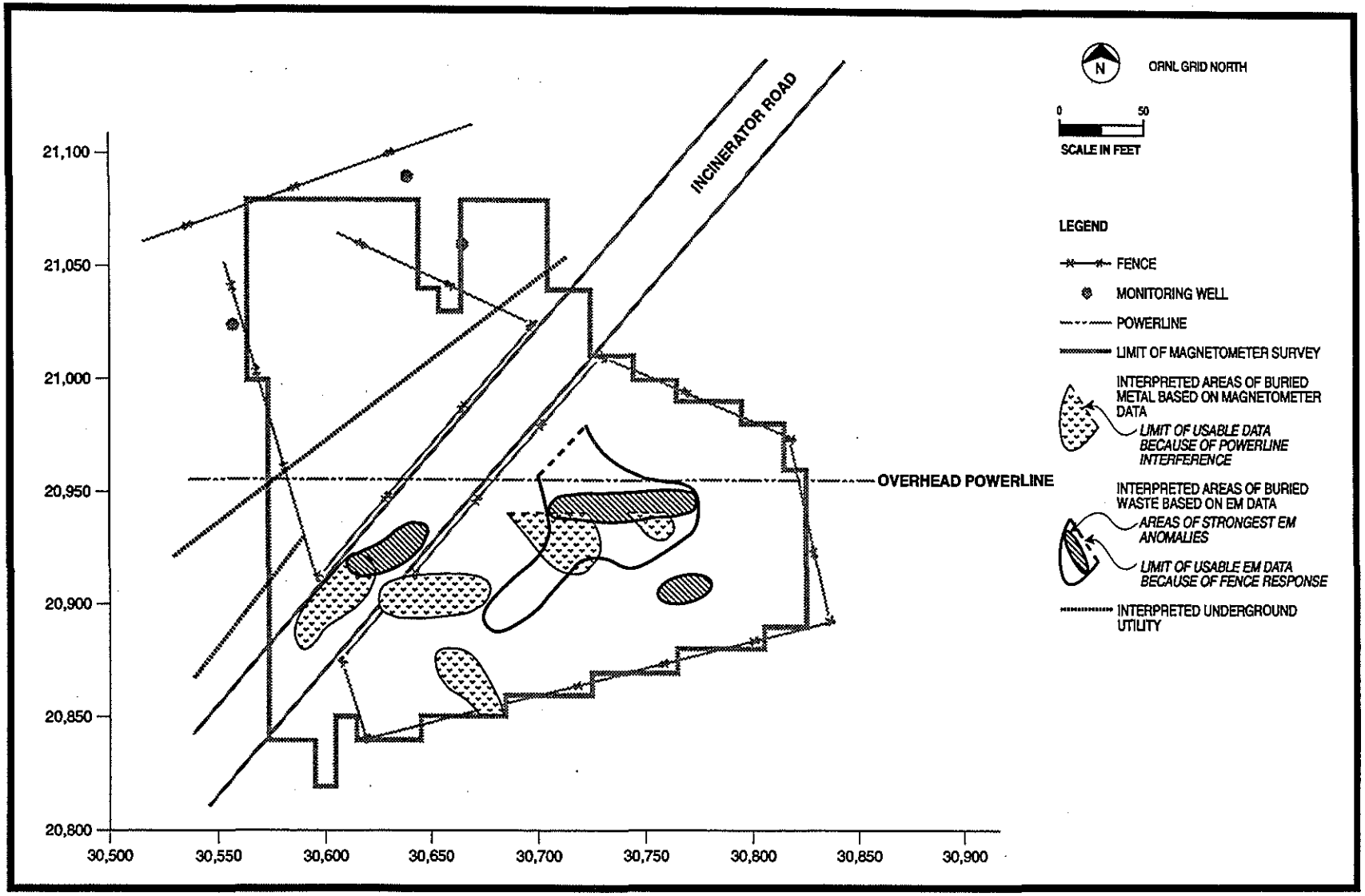


Fig. 3.5.14 Interpreted locations of buried wastes (SWSA 1), from geophysical survey data.

5.33A 6066.21

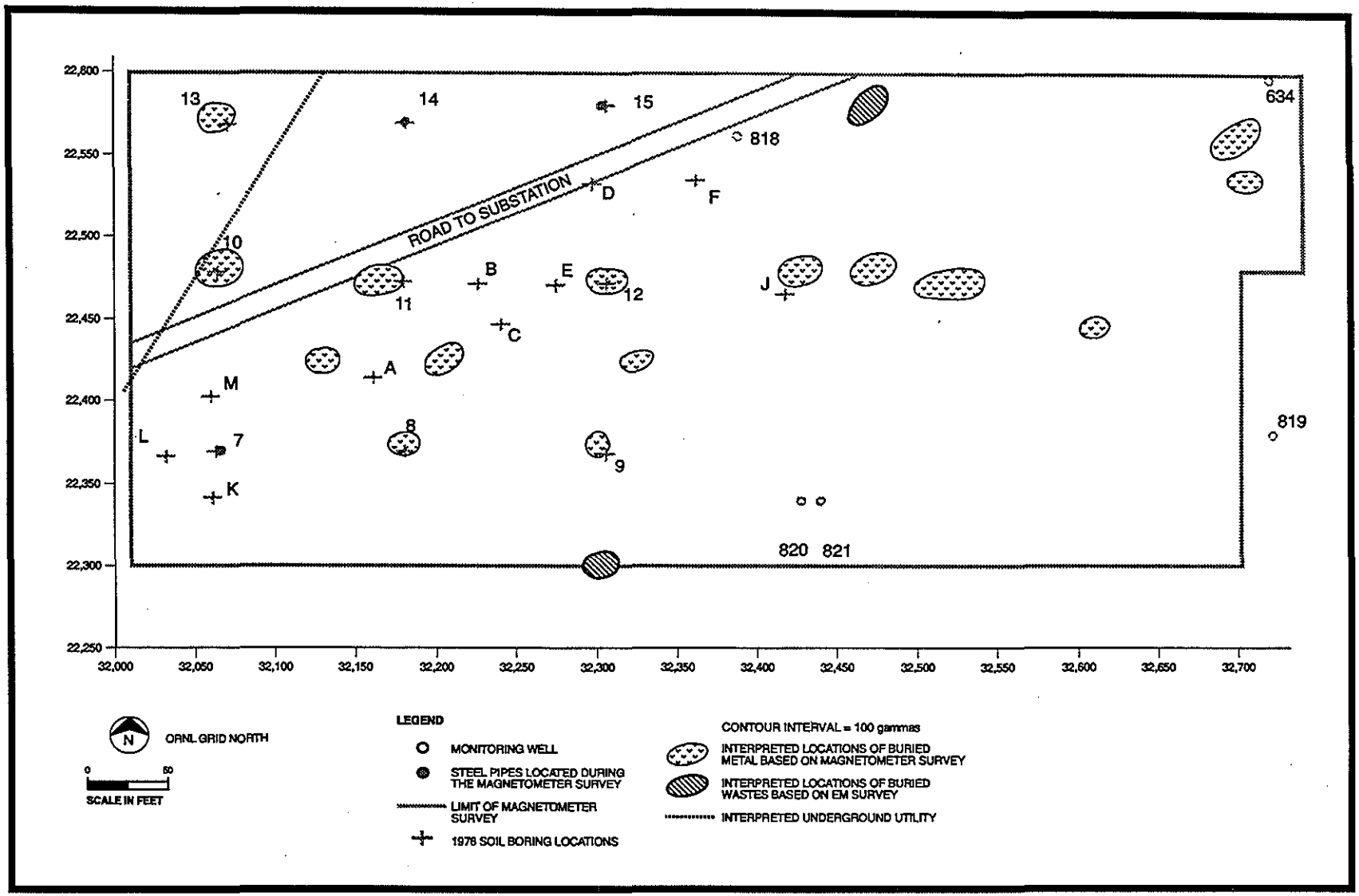
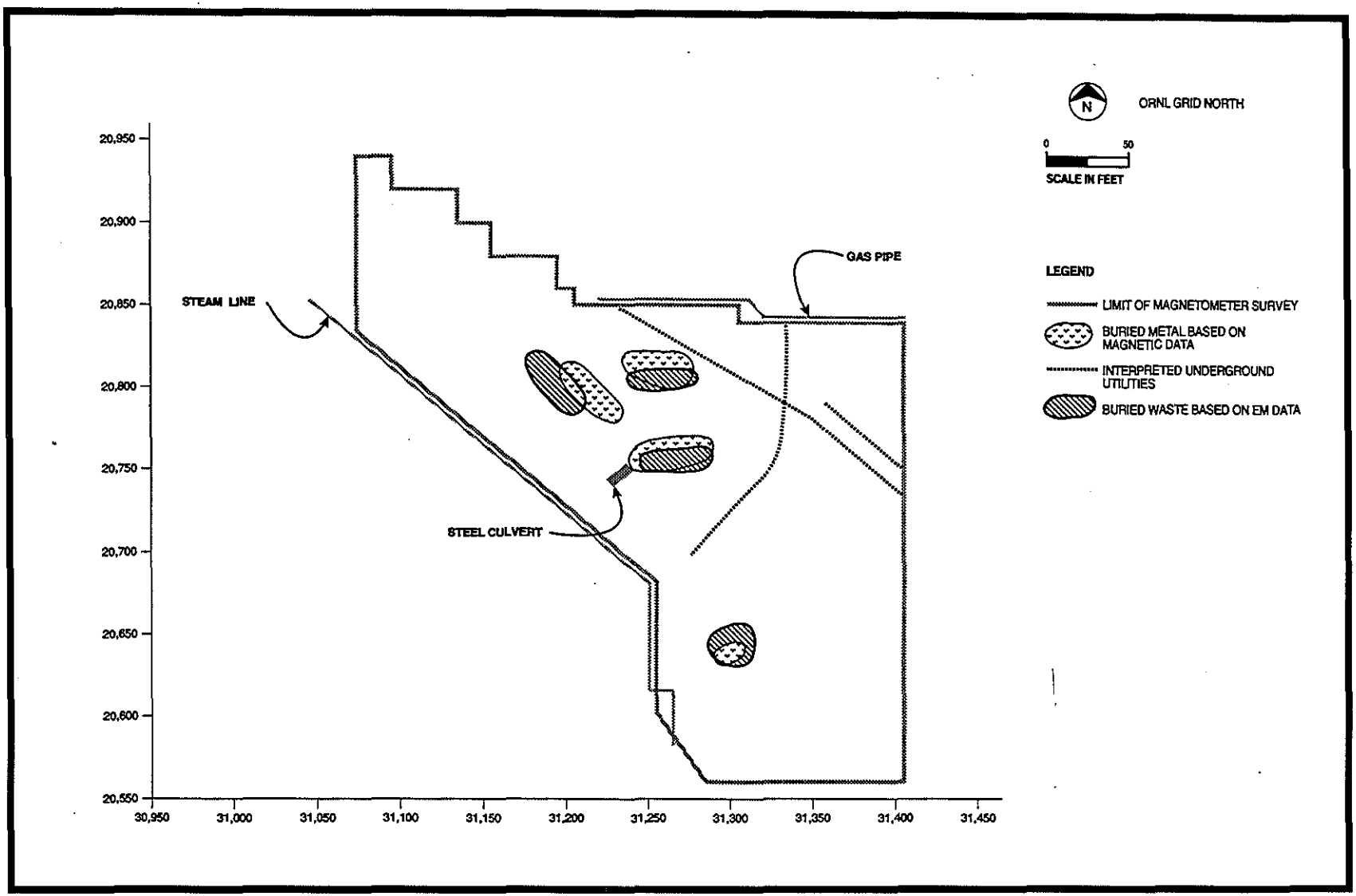


Fig. 3.5.15 Interpreted locations of buried wastes (SWSA 2), from geophysical survey data.

5.33A 6066.22



5.33A 6066.23

Fig. 3.5.16. Interpreted locations of buried wastes (waste pile area), from geophysical survey data.

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