MARTIN MARIETTA

ES/ER-22/V1&D1
ORNL/ER/Sub-87/99053/5/V1

ENVIRONMENTAL
RESTORATION
PROGRAM

RCRA Facility Investigation Report for Waste Area Grouping 6 at Oak Ridge National Laboratory, Oak Ridge, Tennessee

Volume 1
Sections 1 Through 3

ENERGY SYSTEMS

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

UCN-17560 (6 7-91)

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ORNL/ER/Sub--87/99053/5/V1

DE92 007763

53/5/V1

RCRA Facility Investigation Report for Waste Area Grouping 6 at Oak Ridge National Laboratory, Oak Ridge, Tennessee

Volume 1: Sections 1 Through 3

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Date Issued—September 1991

Prepared by
Bechtel National, Inc./CH2M Hill/ERCE/PEER
Oak Ridge,Tennessee
under subcontract 30B-99053C

Prepared for
U.S. Department of Energy
Office of Environmental Restoration and Waste Management
under budget and reporting code EW 20

MARTIN MARIETTA ENERGY SYSTEMS, INC.
managing the
Oak Ridge National Laboratory
Oak Ridge K-25 Site
Oak Ridge Y-12 Plant
Paducah Gaseous Diffusion Plant
under contract DE-AC05-84OR21400
and the
Portsmouth Gaseous Diffusion Plant
under contract DE-AC05-76OR00001
for the
U.S. DEPARTMENT OF ENERGY

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Oak Ridge, Tennessee

contributed to the preparation of this document and should not be considered an eligible contractor for its review.

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ACRONYMS AND INITIALISMS

ACD	Analytical Chemistry Division
AEA	Atomic Energy Act
ALARA	as low as reasonably achievable
ALS	analytical laboratory subcontractor
ARAR	applicable or relevant and appropriate requirement
ASEMP	Active Sites Environmental Monitoring Program
ATDD	Atmospheric Turbulence and Diffusion Division
ATSDR	Agency for Toxic Substances and Disease Registry
BCF	bioconcentration factors
BNAE	base neutral and acid extractable
BNI	Bechtel National, Inc.
BOD	biochemical oxygen demand
BTF	biotransfer factors
BTX	benzene, toluene, and xylene
BUN	blood urea nitrogen
CAG	carcinogen assessment group
CAS	corrective action study
CBER	Center for Business and Economic Research
CEC	cation exchange capacity
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CLP	Contract Laboratory Program
CMI	corrective measures implementation
CMS	corrective measures study
COC	chain of custody
CREAMS	chemicals, runoff, and erosion from agricultural management system
CRDL	contract required detection limit
CRM	Clinch River Mile
CRQL	contract required quantitation limit
CSL	close support laboratory
CT	custody transfer
CWA	Clean Water Act
DCF	dose conversion factor
DOE	U. S. Department of Energy
DQO	data quality objective
EA	Environmental Assessment
EDT	Explosives Detonation Trench
EM	electromagnetic
EMSL-LV	USEPA Environmental Measurements Laboratory-Las Vegas
EPA	U. S. Environmental Protection Agency
ER	Environmental Restoration
ES&H	environmental safety and health

ACRONYMS AND INITIALISMS

ESD	Environmental Science Division
ET	evapotranspiration
ETF	Engineering Test Facility
EWB	Emergency Waste Basin
FB	field blank
FFA	Federal Facilities Agreement
FOF	Field Operations Facility
FS	feasibility study
FSC	field sample coordinator
FSP	field sampling plan
FSS	field services and support
GC	gas chromatograph
GCD	greater confinement disposal
HDPE	high density polyethylene
HEAST	Health Effects Assessment Summary Tables
HFIR	High Flux Isotope Reactor
HHMS	hydraulic head monitoring station
HI	hazard index
HQ	hazard quotient
HSWA	Hazardous and Solid Waste Amendments Act
ICM	Interim Corrective Measure
ICP	inductively coupled plasma
ICRP	International Commission on Radiological Protection
IRIS	Integrated Risk Information System
ISCLT	industrial source complex long term
ISV	in situ vitrification
IWMF	interim waste management facility
LDR	land disposal restrictions
LET	linear energy transfer
LLW	low-level waste
LOAEL	lowest-observed-adverse-effect-level
M&O	management and operating
MCL	maximum contaminant limit
MDA	minimum detectable activity
MS	mass spectrometry
MS/MSD	matrix spike duplicate pairs
MSL	mean sea level
NAAQS	National Ambient Air Quality Standard
NCP	National Contingency Plan
NCRP	National Council on Radiation Protection and Measurement
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NOAA	National Oceanic and Atmospheric Administration
NOAEL	no-observed-adverse-effect-level
NPDES	National Pollutant Discharge Elimination System

ACRONYMS AND INITIALISMS

NPL	National Priority List
NPRM	Notice of Proposed Rulemaking
NRWTP	nonradiological wastewater treatment plant
O&M	operation and maintenance
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OVA	organic vapor analyzer
PARCC	precision, accuracy, representativeness, completeness and comparability
PCB	polychorinated biphenyls
PCE	tetrachloroethylene
PIC	pressurized ionization chamber
PMF	probable maximum flood
PNL	Pacific Northwest Laboratory
PQL	probable quantitation limits
PVC	polyvinyl chloride
PWTP	process wastewater treatment plant
QAPP	quality assurance project plan
QC	quality control
QSAR	quantitative structure activity relationships
RAGS	Risk Assessment Guidance for Superfund
RAP	Remedial Action Program
RCRA	Resource Conservation and Recovery Act
REP	NON-QC Replicated
RFA	RCRA facilities assessment
RFI	RCRA facility investigation
RIC	reconstructed ion chromatogram
ROD	record of decision
RPD	relative percent differences
SARA	Superfund Amendments and Reauthorization Act
SCS	site characterization summary
SDWA	Safe Drinking Water Act
SEG	Scientific Ecology Group
SEIR	sampling event initiation request
SIMS	Sampling Information Management System
SLB	shallow land burial
SMOW	standard mean ocean water
SOP	standard operating procedure
SQL	sample quantitation limit
SPT	standard penetration test
SVOC	semivolatile organic compound
SWIMS	solid waste information management system
SWMU	solid waste management unit
SWSA	solid waste storage area
TAL	target analyte list

ACRONYMS AND INITIALISMS

TARA	Test Area for Remedial Activities
TB	travel blank
TBC	to be considered
TCA	Tennessee Code Annotated
TCE	trichloroethylene
TCL	target compound list
TD	total depth
TDEC	Tennessee Department of Environment and Conservation
TDS	total dissolved solids
TEGD	technical enforcement guidance document
TIC	tentatively identified compound
TKN	total kjeldahl nitrogen
TM	technical memorandum
TOC	total organic carbon
TOX	total organic halides
TRU	transuranic
TSDF	treatment, storage, and disposal facilities
TSP	total suspended particulates
TVA	Tennessee Valley Authority
USGS	U. S. Geologic Survey
VOC	volatile organic compound
WAG	waste area grouping
WLM	working level months
WOC	White Oak Creek
WOL	White Oak Lake
WQC	water quality criteria

EXECUTIVE SUMMARY

This Executive Summary briefly describes the activities and results of the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) of Waste Area Grouping 6 (WAG 6) at the U.S. Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL).

ES.1 OVERVIEW

WAG 6 comprises a shallow land burial facility used for disposal of low-level radioactive wastes (LLW) and, until recently, chemical wastes. As such, the site is subject to regulation under RCRA and the Comprehensive Environmental Response Compensation and Liability Act (CERCLA). To comply with these regulations, DOE, in conjunction with the Environmental Protection Agency (EPA) and the Tennessee Department of Environment and Conservation (TDEC), developed a strategy for closure and remediation of WAG 6 by 1997. A key component of this strategy was to complete an RFI by September 1991. The primary objectives of the RFI were to evaluate the site's potential human health and environmental impacts and to develop a preliminary list of alternatives to mitigate these impacts.

The WAG 6 RFI evaluated ORNL's existing waste disposal records and sampling data and performed the additional sampling and analysis necessary to: describe the nature and extent of contamination; characterize key contaminant transport pathways; and assess potential risks to human health and the environment by developing and evaluating hypothetical receptor scenarios. Estimated excess lifetime cancer risks as a result of exposure to radionuclides and chemicals were quantified for each hypothetical human receptor. For environmental receptors, potential impacts were qualitatively assessed.

Taking into account regulatory requirements and base line risk assessment results, preliminary site closure and remediation objectives were identified, and a preliminary list of alternatives for site closure and remediation was developed. Site objectives and alternatives will be finalized in a Corrective Measures Study (CMS) Report to be completed by February 1992.

ES.2 BACKGROUND

ORNL is one of three principal facilities on DOE's Oak Ridge Reservation (ORR) (Fig. ES.1). ORNL is currently managed and operated for DOE by Martin Marietta Energy Systems, Inc. (Energy Systems).

WAG 6 comprises three solid waste management units (SWMUs). The largest is the 68-acre Solid Waste Storage Area 6 (SWSA 6), which is the current disposal area for solid LLW at ORNL. Prior to May 1986, areas of SWSA 6 also received hazardous chemical wastes, including RCRA-listed wastes, which makes these areas subject to regulation under RCRA. The other two WAG 6 SWMUs are the Emergency Waste Basin (EWB) and the Explosives Detonation Trench (EDT). Constructed as an emergency holding basin for liquid wastes from the ORNL Main Plant Area, the 2-acre EWB has never been used for its intended purpose but does contain water from groundwater discharge and surface water runoff from SWSA 6. The EDT was used to detonate explosives and shock-sensitive chemicals. It is no longer used and has been backfilled.

As required by State of Tennessee hazardous waste regulations, ORNL has prepared a RCRA Closure Plan for SWSA 6, which was approved by the State of Tennessee in September 1988 (BNI 1988a). The SWSA 6 Closure Plan specified a series of activities leading to final closure and corrective action, including an RFI. Because the ORNL SWMUs have been grouped into WAGs, ORNL increased the scope of the RFI to formally encompass all three WAG 6 SWMUs—the EWB and the EDT in addition to SWSA 6.

EPA has recently listed the ORR (including ORNL) on the CERCLA National Priorities List (NPL). Therefore, ORNL conducted the WAG 6 RFI in general conformity with both RCRA and CERCLA guidelines and in accordance with requirements of the National Environmental Policy Act.

ES.2.1 Site Description and History

SWSA 6 is the principal source of environmental contamination in WAG 6. Approximately 19 acres of this 68-acre site have been used for waste disposal. It was opened for limited disposal operations in 1969 and began full-scale operation in 1973. At SWSA 6, LLW, chemical, biological, and mixed wastes have been disposed of in a variety of waste disposal units, including unlined trenches and auger holes, silos, and tumulus waste disposal pads (Fig. ES.2).

For most shipments of waste disposed of at SWSA 6, records generally include estimates of the radionuclides present and their respective activities at the time of disposal. Figure ES.3 illustrates the SWSA 6 disposal log inventory (in curies) by radionuclide and by unit type. Inventory records indicate that isotopes of europium account for approximately 80% of the radioactivity at SWSA 6. These isotopes are associated with reactor control plates buried in the high-activity auger hole area. The europium is relatively well contained by the plates' aluminum cladding. (Europium isotopes were not detected in environmental samples.)

ES.2.2 Demography

Because SWSA 6 is an active facility, ORNL workers (typically less than a dozen) are on-WAG daily during the work week. WAG 6 is approximately 1 mile from the ORNL Main Plant Area, where the majority of ORNL's approximately 5000 employees work. Within 1/2 mile of the boundary of WAG 6, all land is federally owned and there are no residents. Within a 1-mile boundary extension of WAG 6, there are approximately 25 residents, all located to the southwest across the Clinch River. Within a 5-mile radius of WAG 6, there are an estimated 580 residents.

ES.3 PHYSICAL CHARACTERISTICS OF WAG 6

ES.3.1 Site Geology

The overall geology of WAG 6 is highly complex—a result of the original depositional environment, severe and variable structural deformation, variable degrees of weathering, and on-WAG activities such as cut and fill grading, trenching, and waste disposal operations. Because of this geologic complexity, it is unlikely that hydrogeologic processes can be characterized on a local scale with any certainty. Detailed characterization of flow paths from a particular source to a well would be impracticable without intensive study of that particular area.

ES.3.2 Groundwater Hydrology

The majority of groundwater flow in the saturated zone is local rather than regional. Groundwater flows from recharge areas at higher elevations of WAG 6 and discharges to intervening surface water drainages on-WAG and at the site boundary. United States Geological Survey modeling indicates that 90 to 98% of groundwater flow at WAG 6 occurs in the upper 50 to 100 ft of the aquifer, with virtually no flow occurring below 250 ft. Geochemical analysis, age-dating, contaminant sampling, and hydraulic conductivity data all support the model results.

Potentiometric mapping indicates that, to a depth of approximately 65 ft in the bedrock, groundwater flow on a large scale is generally in the direction of mapped hydraulic gradients. On a smaller scale, flow is affected by the orientation, density, and degree of weathering and fracturing. Testing indicates that bedrock aquifer well yields are generally too low (< 1 gpm) to encourage use as a potable water supply.

Shallow subsurface storm flow is highly variable and discontinuous due to the extensive removal or reworking of surficial soils and due to physical features such as waste disposal trenches, the 49 Trench area French Drain, ICM caps, and numerous wells and piezometers. Transient storm flow paths are short from point of infiltration to discharge—generally along streams or seeps within WAG 6.

ES.3.3 Surface Water Hydrology

The four principal drainageways originating on WAG 6 are generally dry during summer months except during storm events. Contributions to stream flow include surface runoff (overland flow, saturated overland flow, subsurface storm flow) and base flow (groundwater discharge). Hydrographs at the stream outlets at the site boundary exhibit storm peaks occurring within one hour of the peak intensity of the storm rainfall. This indicates that overland flow and saturated overland flow dominate the storm hydrograph shape and the storm volume.

ES.4 NATURE AND EXTENT OF CONTAMINATION

Data collected at WAG 6 clearly indicate that contaminants have been released from source areas to the environment on-WAG, and that some of these contaminants are likely migrating off-WAG. Table ES.1 lists radionuclides and chemicals detected at least once during WAG 6 RFI sampling. Although many contaminants were detected in WAG 6 samples, most were detected only once or were detected at low concentrations. Tables 4.2 through 4.8 list ranges of concentrations detected for each contaminant, by media.

ES.4.1 On-WAG Contamination

RFI data indicated very little contamination of surface soils at WAG 6. This is consistent with site waste disposal methods, in which wastes were buried beneath the surface, mostly in trenches and auger holes. Contaminants released from these areas have produced zones of contamination that lie between the soil cover and the top of bedrock. Sampling did not indicate zones of gross soil contamination around the perimeter of waste disposal areas, and the subsurface contamination decreases dramatically with depth. This trend is well illustrated by the vertical concentration profile of tritium, which is by far the most ubiquitous and mobile contaminant at WAG 6.

The RFI identified no temporal trends and no relationships between contaminant concentrations and seasonal variations in the hydrogeologic system. Contaminant concentrations show apparently random fluctuations from sampling event to sampling event.

RFI data indicated widespread contamination of shallow groundwater on-WAG, generally at low concentrations. Within this shallow groundwater system, there are discernible areas where particular contaminants predominate and there are other areas where contaminant concentrations are particularly elevated. However, the complex hydrogeology of WAG 6 renders the precise delineation of plumes impracticable. Contaminant transport along fractures means that contamination detected in a given monitoring well may not be detected at all in adjacent wells. Should groundwater collection be considered as part of remediation, interceptor trenches rather than wells would be most effective.

ES.4.2 Off-WAG Migration Patterns

The primary media by which contaminants are transported off-WAG are groundwater and surface water. Figure ES.4 and associated Table ES.2 identify areas of the site perimeter where off-WAG migration of radionuclides is most likely. Figure ES.5 and Table ES.3 present the same information for chemicals. Detailed discussion of contaminant migration is provided in Sect. 4.

ES.5 FATE AND TRANSPORT

Contaminant fate and transport modeling was conducted to support the base line human health evaluation and to aid in developing remedial alternatives. The base line human health evaluation considered hypothetical present day and future on-WAG and off-WAG receptors.

For on-WAG receptors, predictions of contaminant concentrations in groundwater, surface water, sediment, soil, and air were required. For predictions regarding the off-WAG receptor, an estimate of contaminant flux via surface water to White Oak Lake was required. This flux was used to calculate a resulting contaminant concentration downstream in the Clinch River (where the off-WAG receptor was assumed to be located).

Modeling to predict future variations in concentrations and fluxes was performed only for radionuclides. Such modeling was not appropriate for hazardous chemicals detected at the site because inventory information for chemicals does not exist. However, fluxes representing current conditions were computed.

Water was identified as the major transport mechanism for off-WAG migration of contaminants, with most radionuclide flux occurring via surface water. In groundwater, tritium, cobalt-60, strontium-90, and cesium-137 were predicted to occur in most of the wells in WAG 6. (These radionuclides were detected in a number of locations during the RFI.) Peak future concentrations of these radionuclides in groundwater were predicted to be within two orders of magnitude of present-day concentrations. Europium and uranium were predicted to first occur in groundwater in years 1998 and 2025, respectively.

Air modeling, which was performed conservatively, indicated that the air pathway contributed negligible amounts of exposure-point concentrations of contaminants on-WAG and off-WAG.

ES.6 BASE LINE HUMAN HEALTH EVALUATION

As part of the RFI, a base line risk assessment was performed to assess potential impacts contaminants at WAG 6 would have on human health and the environment if no remedial actions were taken. The base line risk assessment comprises a base line human health evaluation (described below) and a base line environmental evaluation (Sect. ES.7).

The methodology for the human health evaluation involved: selecting potential contaminants of concern; identifying receptor scenarios and associated exposure pathways; estimating representative contaminant concentrations at receptor locations; collecting toxicity information; and finally, estimating risks for each receptor. Hypothetical receptors and associated risks are summarized below.

ES.6.1 Exposure Assessment

Two hypothetical scenarios were assumed for WAG 6—a no action scenario and an institutional control scenario. Each is described below.

ES.6.1.1 No action scenario

The no action scenario assumed that DOE's current access restrictions for the site become ineffective immediately. Site fencing, warning signs, patrols, and institutional controls are assumed to disappear. This scenario is highly unlikely—if not impossible.

However, evaluation of a no action scenario is required under Section 300.430(e)(6) of the National Contingency Plan. In accordance with CERCLA methodology, when risks associated with a no action scenario prove unacceptable, then the need for remedial action is established.

For the WAG 6 no action scenario, risks were evaluated for a hypothetical receptor who homesteads on-WAG over the next 30 years. Risks for the homesteader were evaluated for contaminant concentrations representing an average for the entire site and concentrations representing an average for the high-activity auger hole area. This 2-acre area contains greater than 85% of the WAG's radioactivity and represents an upper bound for exposure to radionuclides.

It is emphasized that the no action scenario is not a realistic scenario and was evaluated solely to define a base line against which to compare alternatives for site closure and remediation. The location of WAG 6 on the U.S. government-owned ORR, its proximity to an operating facility (ORNL), and the existence of site fencing and security patrols, all make it highly unlikely that a member of the public could occupy the site and remain undetected.

ES.6.1.2 Institutional Control Scenario

The institutional control scenario assumed that DOE would continue to use WAG 6 as an LLW disposal site for the next 10 years and that this operational period would be followed by a 100-year institutional control period. This scenario corresponds to DOE's operational and institutional control plans for WAG 6 for the next 110 years with the exception that, for assessment purposes only, the scenario assumed that DOE would not perform site closure or remediation other than to maintain the existing soil cover and vegetation over the disposal units.

For the institutional control scenario, risks were evaluated for hypothetical receptors for two different periods. For the next 30-year period (1990-2020), four receptors were evaluated—one an occupational-risk receptor (an ORNL employee) and the remaining three public-risk receptors (a hunter, a boundary receptor, and an off-WAG homesteader resident downstream along the Clinch River.)

For the period corresponding to the release of institutional controls and other access restrictions in 2100, an on-WAG homesteader was evaluated.

Associated with each hypothetical receptor were a variety of pathways by which that individual could potentially be exposed. Exposure pathways evaluated are identified in Fig. ES.6.

ES.6.2 Risk Characterization Results

ES.6.2.1 Carcinogenic Risks

Excess lifetime cancer risk was quantified for radionuclides and chemicals of concern. Excess lifetime cancer risk is the probability that an individual will develop cancer as a result of exposure to the carcinogen(s) being evaluated. For convenience, this probability is typically presented in exponential notation. For example, a risk of 0.000002 (or 2 in 1,000,000) is represented as 2×10^{-6}. Fig. ES.7 summarizes results for each receptor evaluated. For radionuclides, radiation dose was also computed separately for each receptor, these results are summarized in Table ES.4.

As illustrated in Fig. ES.7, under the toxicological and exposure assumptions used in the evaluation, the lower limit of EPA's target range for risk to the public (10^{-6} to 10^{-4}) was exceeded for the following receptors:

- No action scenario
  - On-WAG homesteader (1990-2020)

- Institutional control scenario
  - On-WAG ORNL employee (1990-2020)
  - Off-WAG (Clinch River) homesteader (1990-2020)
  - On-WAG homesteader (2100-2130)

Risks to these receptors are briefly discussed in the following paragraphs.

ES.6.2.1.1 Receptor for No Action Scenario

On-WAG homesteader (1990-2020). The estimated radionuclide and chemical risks for the hypothetical on-WAG adult homestead receptor evaluated for site average concentrations were 1 (unity) and 3×10^{-4} respectively. Because these risks exceed the upper limit of EPA's target risk range, the need for continued DOE control of the site has been demonstrated.

Ninety nine percent of the radiological risk was associated with external exposure, with the majority of the dose resulting from isotopes of europium associated with the reactor control plates disposed in the high activity auger hole area. Although the computed radionuclide risks and doses were high, they were almost exclusively the result of worst case assumptions regarding the homesteader excavating deep into the wastes and spreading the waste across the ground surface. If the homesteader did not exhume wastes, estimated radionuclide risk would be orders of magnitude less (9×10^{-3}).

The majority of the chemical risk was due to ingestion of groundwater and inhalation of water vapor while showering. Vinyl chloride, carbon tetrachloride, and trichloroethene were the predominant contributors to the groundwater risk.

ES.6.2.1.2 Receptors for Institutional Control Scenario

Employee (1990-2020). The estimated radionuclide risk for the hypothetical maintenance worker receptor was 10^{-3}. This risk was almost exclusively attributable to a hypothetical external radiation dose of 2 rem accumulated over 30 years. Although risk to the employee exceeded the upper limit of EPA's target risk range, dose to the employee was well below the 5 rems per year recommended in federal guidance for maximum occupational exposure. The estimate is conservative due to the assumption that the worker spends 8 hours a day for 30 years working directly over SWSA 6 waste disposal areas.

Off-WAG homesteader (1990-2020). The estimated radionuclide risk for the off-WAG homesteader was 6×10^{-5}. This risk was primarily a result of external exposure from decay of cobalt-60 and cesium-137 that were assumed to accumulate in soils as a result of crop irrigation over a period of decades. The risk contribution from assumed ingestion of surface water was 3×10^{-6}. Because heavy irrigation is highly unlikely given the abundant rainfall in the region, and because a homesteader is more likely to use groundwater as a drinking water source rather than untreated surface water, this scenario is very conservative.

On-WAG homesteader (2100-2120). The estimated radionuclide risk for the future on-WAG receptor evaluated for site average concentrations was 3×10^{-1}. As described for the no action scenario homesteader, the majority of the radionuclide risk was associated with external exposure resulting from conservative scenario assumptions. Estimated chemical risks were the same as for the no action scenario homesteader due to the assumption of steady state conditions for chemicals. Because risks exceed EPA's target risk range, the need for remedial actions effective beyond the year 2100 has been demonstrated.

ES.6.2.2 Noncarcinogenic Risks

The potential for noncarcinogenic effects on health was evaluated by comparing an exposure level with a reference dose. This ratio of exposure to toxicity is called a hazard quotient. If the hazard quotient exceeds one, then the potential exists for noncarcinogenic effects. Noncarcinogenic risks are summarized in Fig. ES.8.

Of all the receptors evaluated, the critical effect specific hazard index exceeded one for only the on-WAG homesteader receptors. The target organ of greatest concern for these effects was the liver. These results support the demonstrated need for continued DOE control of the site.

ES.7 BASE LINE ENVIRONMENTAL EVALUATION

The base line environmental evaluation was the second component of the base line risk assessment. The purpose of the evaluation was to assess potential risks to the environment from selected contaminants at WAG 6.

Field surveys conducted to support this evaluation indicated the following: No rare plant species are present in SWSA 6. SWSA 6 stream drainages contain essentially no wetland community development. No threatened or endangered bird or mammal species listed by the U.S. Fish and Wildlife Services are present at WAG 6. SWSA 6 streams contain no invertebrate species listed as threatened or endangered by the State of Tennessee or the U.S. Fish and Wildlife Service. One of the streams lacks adequate habitat for fish; the other has habitat suitable for native minnows, but none were found during an electroshocking survey. During a survey of the EWB, five bass were collected.

ES.7.1 Methodology

Large areas of WAG 6 have been cleared for waste disposal such that very little natural wildlife habitat remains. Wildlife that might be expected to occupy cleared land is discouraged by regular mowing and maintenance and by the frequent traffic associated with ongoing site operations. To assess potential environmental impacts under a no action scenario, hypothetical target species were selected. For each species, impacts were qualitatively addressed to the extent feasible given the available data.

The target species selected were the tulip poplar, representing terrestrial flora; the white-tailed deer, red-tailed hawk, and raccoon, representing terrestrial fauna; bluegills and fathead minnows, representing aquatic vertebrates; and benthic macroinvertebrates representing aquatic invertebrates.

ES.7.2 Potential Impacts

ES.7.2.1 Terrestrial flora

The evaluation indicated that terrestrial flora (tulip poplar tree) would uptake contaminants, in particular, strontium-90. The combined high levels of strontium-90 in groundwater, surface water, and soils may cause toxic effects on vegetation growing in areas of these concentrations. WAG 6 soils may be marginally phytotoxic due to cadmium, and chromium may accumulate in the roots of vegetation but should not cause effects in plant foliage.

ES.7.2.2 Terrestrial fauna

Deer can ingest strontium-90 from contaminated vegetation, as was evidenced at SWSA 5, where contaminant levels in honeysuckle and blackberry were sufficiently high that strontium-90 levels in the bone of a 45-kg deer could easily exceed the confiscation limit of 30 pCi/g if the deer browsed on such contaminated vegetation for a period of 1 week to 1 year (Garten and Lomax 1987). As part of the Biological Monitoring and Abatement Program, Loar et al. (1988) found that all field-collected mammals from SWSA 4 and the WOC floodplain had detectable levels of strontium-90 in bone tissue. Because of the large inventory of strontium-90 at WAG 6, species from the lower tropic levels such as voles, shrews, and rabbits may suffer adverse effects themselves, bioconcentrate strontium-90 in their bone tissue, and subsequently cause adverse effects in the red-tailed hawk and raccoon that prey upon them.

Cadmium levels in surface water exceeded the SDWA MCL and the suggested standard from the U.S. Fish and Wildlife Service. This metal is also known to bioconcentrate in liver and kidney tissues of shrews by factors ranging from 15 to 33 times the levels found in the soil. Not only can cadmium adversely affect the soft tissue of shrews but also those of the red-tailed hawks that prey upon them. The greatest potential for adverse effects to raccoons is through ingestion of contaminated surface water by the raccoons themselves and by voles upon which they prey and from ingestion of contaminated aquatic organisms. Although cadmium is taken up by plants when the soils are acidic, ingestion of vegetation is not expected to be a major source of contamination to the deer. Incidental ingestion of soil may provide an additional pathway.

ES.7.2.3 Aquatic environment

Although no fish were collected from streams in WAG 6 during surveys in 1990, Drainage FA does provide adequate habitat for native minnows and could, therefore, support fish populations that could potentially be impacted by contaminants from WAG 6 under a no action scenario. Cadmium and copper exceed both the acute and chronic ambient water quality criteria for protection of aquatic organisms. The maximum concentration of strontium-90 detected in surface water at WAG 6 was 10,222 pCi/L.

ES.8 PRELIMINARY DEVELOPMENT AND SCREENING OF ALTERNATIVES

As specified in the SWSA 6 closure plan, DOE/ORNL is conducting a CMS to develop and evaluate alternatives for site closure and remediation. This section briefly summarizes the preliminary development of alternatives; the alternatives listed here will be defined and evaluated in detail in the CMS. Alternatives were developed consistent with CERCLA, RCRA, and NEPA guidance and requirements.

ES.8.1 Remedial Action Objectives

The general goal of WAG 6 closure and remedial action is to protect human health and the environment by closing the site to segregate wastes from the environment for as long as the wastes remain a threat and by remediating unacceptable levels of environmental contamination. Based on (1) this general goal, (2) the nature and extent of contamination, and (3) the results of the base line risk assessment, it is concluded that closure and remedial action at WAG 6 are required for source areas and groundwater, respectively. Specific remedial objectives for each of these waste media are:

- Sources: protect public health and the environment by limiting direct contact/emissions, surface runoff, and leachate generation from on-WAG sources and associated contaminated leachate and soil.
- Groundwater: protect public health and the environment by controlling the migration of contaminants off-WAG and by protecting against future use of contaminated groundwater on-WAG.

ES.8.2 Closure and Corrective Action Alternatives

Using the methodology recommended in *EPA's Guidance for Conducting Remedial Investigation and Feasibility Studies Under CERCLA* (EPA 1988a), a range of seven alternatives was developed for addressing source areas and groundwater. The alternatives, which were developed to span a range of cost and permanence, are summarized in Table ES.5.

ES.9 SUMMARY AND CONCLUSIONS

As a key component of DOE's strategy for closure and remediation of WAG 6 under RCRA and CERCLA, an RFI was completed to evaluate potential human health and environmental impacts of the site, and to develop a preliminary list of alternatives to mitigate these impacts.

Physical characteristics and the nature and extent of contamination were evaluated to develop a conceptual model of the site. Using contaminant data and the site conceptual model as a basis, potential risks to human health and the environment were assessed through development and evaluation of hypothetical receptor scenarios.

Risks computed for a no action scenario on-WAG homesteader exceeded EPA's target risk range of 1×10^{-6} to 1×10^{-4}, and therefore demonstrated the need for continued site controls and continued progress toward site closure and remedial action.

For the institutional control scenario, which assumes DOE maintains and controls access to the site for 110 years, risks computed for receptors representing potential current public exposures did not exceed the upper limit of EPA's target risk range. The risk computed for the hypothetical off-WAG (Clinch River) receptor fell within the range; however, due to conservative, worst-case scenario assumptions, this estimate alone should not be used as the basis for actions beyond those already inherent in the scenario (e.g., access restrictions, site maintenance).

Computed risks for the hypothetical institutional control homesteader who moves on-WAG following the release of site controls in 2100 exceeded EPA's target risk range. This demonstrated the need for site closure and remedial actions that are effective beyond the year 2100.

For both the no action and institutional control homesteader scenarios, computations showed that the majority of the risk was due to isotopes of europium associated with reactor control plates disposed of in a relatively small area of the site. If these control plates were removed, risks would be substantially reduced. However, risks associated with remaining radionuclides, which are more broadly distributed, still were predicted to exceed EPA's target risk range. Consequently, remedial action beyond removal of the control plates still would be required.

Based upon regulatory requirements, the nature and extent of contamination, and results of the base line risk assessment, source areas and groundwater were identified as media that must be addressed in the CMS. Seven alternatives (including a no action alternative) were developed to address preliminary remedial action objectives established for these waste media.

Executive Summary Tables

Table ES.1. Summary of contaminants detected[a]

Analyte	CAS number	Groundwater	Surface water	Sediment	Soil
Volatile Organic Compounds					
1,1,2,2-Tetrachloroethane	79-34-5	S[b]	S	--[c]	--
1,1,1-Trichloroethane	71-55-6	S	S	--	--
1,1,2-Trichloroethane	79-00-5	S	--	--	--
1,1-Dichloroethane	75-34-3	S	S	--	--
1,1-Dichloroethene	75-35-4	S	S	--	R[d]
1,2-Dichloroethane	107-06-2	S	S	--	--
1,2-Dichloroethene	540-59-0	S	S	S	S
1,2-Dichloropropane	78-87-5	--	--	S	--
1,3-Dichloropropene	10061-01-5	--	--	S	--
1,4-Dioxane	123-91-1	S	--	--	--
2-Butanone	78-93-3	S	S	S	S/R
2-Hexanone	591-78-6	--	S	--	S
4-Methyl-2-Pentanone	108-10-1	R	S	--	--
Acetone	67-64-1	S/R	S	S	S
Benzene	71-43-2	S	S	--	R
Carbon Disulfide	75-15-0	S/R	S	--	S
Carbon Tetrachloride	56-23-5	S	--	--	--
Chlorobenzene	108-90-7	--	S	--	S
Chloroethane	75-00-3	S	--	--	--
Chloroform	67-66-3	S	S	S	S/R
Chloromethane	74-87-3	S	--	--	--
Dichlorodifluoromethane	75-71-8	--	S	--	--
Ethylbenzene	100-41-4	S/R	--	--	S
Isobutyl Alcohol	78-83-1	--	--	S	--
Methylene Bromide	74-95-3	--	--	S	--
Methylene Chloride	75-09-2	S/R	--	S/R	S/R
Styrene	100-42-5	--	--	S	--
Tetrachloroethene	127-18-4	S	S	S	S
Toluene	108-88-3	S	S	S	S/R
Trichloroethene	71-55-6	S	S	S	S/R
Trichlorofluoromethane	75-69-4	S	--	S	R
Vinyl Acetate	108-05-4	--	S	--	--
Vinyl Chloride	75-01-4	S	S	--	--
Xylene, total	1330-20-7	S	--	S	S

Table ES.1. (continued)

Analyte	CAS number	Groundwater	Surface water	Sediment	Soil
Semivolatile Organics					
2-Chlorophenol	95-57-8	--	--	--	S
2-Methyl-1,3 DIN Benzene	606-20-2	--	--	S	--
2-Methyl-Phenol	95-48-7	S	--	--	--
Benzo(a)Anthracene	56-55-3	--	--	--	S
Benzo(a)Pyrene	50-32-8	--	--	--	S
Benzoic Acid	65-85-0	--	--	S	S/R
Bis(2-Ethylhexyl)Phthalate	117-81-7	S/R	S	S/R	S
Butyl Benzyl Phthalate	85-68-7	--	--	S	S
Chrysene	218-01-9	--	--	--	S
Di-N-Butyl Phthalate	84-74-2	S/R	S	R	S
Di-N-Octyl Phthalate	117-84-0	S	--	--	S
Diethyl Phthalate	84-66-2	S/R	--	--	--
N-Nitroso N-Phenyl Benzamine	86-30-6	--	--	S/R	S/R
N-Phenyl Benzamine	122-39-4	--	--	R	R
Naphthalene	91-20-3	S	S	--	S
Pentachlorophenol	87-86-5	--	--	--	S
Phenol	108-95-2	--	--	S	S
2,4,5-T	93-76-5	S	--	--	--
2,4,5-TP (Silvex)	93-72-1	S/R	--	--	--
2,4-D	120-83-2	S/R	--	--	--
Aroclor-1254	11097-69-1	S	--	--	--
Inorganic constituents					
Aluminum	7429-90-5	S/R	S/R	S/R	S/R
Antimony	7440-36-0	S	--	--	S/R
Arsenic	7440-38-2	S	S	S/R	S/R
Barium	7440-39-3	S	S/R	S/R	S/R
Beryllium	7440-41-7	S/R	S	S/R	S/R
Boron	7440-42-8	S	--	--	--
Cadmium	7440-43-9	S/R	S	S/R	S/R
Calcium	7440-70-2	S/R	S/R	S/R	S/R
Chromium	7440-47-3	S	S	S/R	S/R
Cobalt	7440-48-4	S/R	S	S/R	S/R
Copper	7440-50-8	S/R	S/R	S/R	S/R
Iron	7439-89-6	S/R	S/R	S/R	S/R

Table ES.1. (continued)

Analyte	CAS number	Groundwater	Surface water	Sediment	Soil
Lead	7439-92-1	S/R	S/R	S/R	S/R
Magnesium	7439-95-4	S/R	S/R	S/R	S/R
Manganese	7439-96-5	S/R	S/R	S/R	S/R
Mercury	7439-97-6	S/R	S	S	S/R
Nickel	7440-02-0	S/R	S	S/R	S/R
Osmium	7440-04-2	--	--	S	R
Potassium	7440-09-7	S	S	S/R	S/R
Selenium	7782-49-2	--	S	S	S/R
Silicon	7440-21-3	S/R	--	--	--
Silver	7440-22-4	S	S	S/R	S/R
Sodium	7440-23-5	S/R	S/R	S/R	S/R
Strontium	7440-26-6	S	--	--	--
Thallium	7440-28-0	--	--	--	S/R
Titanium	7440-32-6	S/R	--	--	--
Tin	7440-31-5	--	--	S/R	R
Vanadium	7440-62-2	S/R	S	S/R	S/R
Zinc	7440-66-6	S/R	S/R	S/R	S/R
Gross Radioactivity					
Gross Alpha	12587-46-1	S/R	S/R	S/R	S/R
Gross Beta	12587-47-2	S/R	S	S/R	S/R
Man-made Radionuclides					
Tritium	10028-17-8	S/R	S/R	S	--
Cobalt-60	10198-40-0	S	S	S	S
Strontium-89	14158-27-1	--	--	R	S
Strontium-90	10098-97-2	S	S	S/R	S/R
Cesium-137	10045-97-3	S/R	S	S/R	S/R
Americium-241	14596-10-2	S	--	--	--
Lead-210	14255-04-0	--	--	--	S
Plutonium 238	13981-16-3	S	S	--	--
Plutonium 239/240	0-013	S	S	--	--
Actinium	14952-40-0	--	--	--	S
Curium-244	13981-15-2	S	S	--	--
Curium-242	15510-73-3	--	S	--	--

Table ES.1. (continued)

Analyte	CAS number	Groundwater	Surface water	Sediment	Soil
Naturally Occurring Radionuclides					
Potassium-40	13966-00-2	S	S	S/R	S/R
Uranium Series					
Uranium-238	7440-61-1	S	--	S/R	S/R
Thorium-234	15065-10-8	S	S/R	S/R	S/R
Uranium-234	13966-29-5	S	--	S/R	S/R
Thorium-230	14269-63-7	S	S/R	S/R	S/R
Radium-226	13982-63-3	S	--	S/R	S/R
Thorium Series					
Thorium-232	7440-29-1	S	S	S/R	S/R
Radium-228	15262-20-1	S	S	S/R	S/R
Thorium-228	14274-82-9	S	S	S/R	S/R
Radium-224	13233-32-4	S	S/R	S/R	S/R

[a]Detected at least once in either site or reference (background) unfiltered samples.
[b]S = detected at least once in site samples.
[c]-- = not detected.
[d]R = detected at least once in reference (background) samples.

Table ES.2. Migration of radionuclides off-WAG[a]

Perimeter segment	Medium/ radionuclides	Discussion
	AREAS LIKELY FOR OFF-WAG MIGRATION OF CONTAMINANTS	
H1	Surface Water Tritium Strontium-90	Storm flow sampling identified significant flux of contaminants off-WAG in surface water.
	Groundwater Tritium Strontium-90	Wells upgradient are contaminated.
H2	Surface Water Tritium	Storm flow sampling identified significant flux of tritium off site.
	Groundwater Tritium	Concentrations exceeding MCL detected in several upgradient wells.
H3	Groundwater Tritium Cobalt-60 Strontium-90	Compliance and RFI monitoring data indicate presence of radionuclides in groundwater.
	AREAS NOT LIKELY FOR OFF-WAG MIGRATION OF CONTAMINANTS	
L		Upgradient to waste disposal areas.

[a]This table provides contaminant migration information for WAG perimeter segments identified in Fig. ES.4.

Table ES.3. Migration of chemicals off-WAG[a]

Perimeter segment	Medium/ chemicals	Discussion
	AREAS LIKELY FOR OFF-WAG MIGRATION OF CONTAMINANTS	
H1	Surface water none	No significant VOC concentrations detected during storm flow sampling
	Groundwater VOCs	Upgradient wells contaminated, monitor unconsolidated zone and bedrock zone. Groundwater wells in this vicinity monitor bedrock zone only.
H2	Surface water VOCs	Low concentration detected during storm flow.
	Groundwater None	Well positioned between creeks DA and DB has had relatively low concentrations of VOCs detected in it.
H3	Surface water None	No surface water features in this area.
	Groundwater VOCs	VOCs detected during compliance and RFI monitoring.
	AREAS NOT LIKELY FOR OFF-WAG MIGRATION OF CONTAMINANTS	
L		Upgradient to waste disposal areas.

[a]This table provides contaminant migration information for WAG perimeter segments identified in Fig. ES.5.

Table ES.4. Summary of risk characterization results

Scenarios and associated receptors	Time period[a]	Radionuclide Dose (rem)	Radionuclide Risk	Chemical Risk	Chemical Hazard index[c]
No Action Scenario					
On-WAG homesteader -- adult (WAG-wide)	Current	2E+5	1.0	3E-4	1 (T)
On-WAG homesteader -- child (WAG-wide)	Current	--[d]	--[d]	2E-4	1 (S)
On-WAG homesteader -- adult (auger hole subarea)	Current	1E+6	1.0	3E-4	3 (L)
On-WAG homesteader -- child (auger hole subarea)	Current	--[d]	--[d]	2E-4	7 (L)
<u>Institutional Control Scenario</u>					
ORNL employee	Current	2E+0	1E-3	1E-8	4E-6 (T)
Hunter	Current	3E-5	8E-9	2E-12	2E-5 (T)
Boundary receptor	Current	9E-6	1E-8	2E-7	3E-5 (T)
Off-WAG homesteader -- adult	Current	1E-1	6E-5	1E-7	7E-3 (T)
Off-WAG homesteader -- child	Current	--[d]	--[d]	3E-8	2E-2 (T)
On-WAG homesteader -- adult (WAG-wide)	Future	4E+3	3E-1	3E-4[b]	1 (T)[b]
On-WAG homesteader -- child (WAG-wide)	Future	--[d]	--[d]	2E-4[b]	1 (S)[b]
On-WAG homesteader -- adult (auger hole subarea)	Future	3E+4	9E-1	3E-4[b]	3 (L)[b]
On-WAG homesteader -- child (auger hold subarea)	Current	--[d]	--[d]	2E-4[b]	7 (L)[b]

[a]"Current" time period means receptor risk evaluated using estimated contaminant concentrations for 1990-2020 time period. "Future" time period means receptor risk evaluated using estimated contaminant concentrations for 2100-2130 time period.

[b]Steady state conditions assumed for chemical contaminants; therefore, estimates of future risk and hazard indices are identical to those for "current"-day on-site homesteader.

[c]T= total; L= lower; K= kidney; S= skin; For T$\geq$1.0, effect-specific hazard indexes all less than 1.0

[d]Current state of the art for radionuclide risk assessment does not provide specific tools for estimating dose/risk to children; dose/risks computed for adults are assumed representative for children.

Table ES.5. Preliminary closure alternatives for WAG 6

Alternative	Description
1	**No Action** (required by CERCLA)
2	**Source Areas:** Institutional controls will be implemented. Caps covering individual groups of disposal units will be constructed to control infiltration and access to waste. **Groundwater:** Institutional controls will be implemented to prevent groundwater use on-WAG and groundwater will continue to be monitored; a final decision on groundwater will be deferred to an area wide (multi-WAG) groundwater remediation program for Bethel Valley.
3	**Source Areas:** Same as Alternative 1. **Groundwater:** In those areas where significant off-WAG migration of contaminants is occurring, trench drains will be constructed to collect the contaminated groundwater; if necessary, the groundwater will be treated in the ORNL liquid waste treatment system. Institutional controls will be implemented to prevent groundwater use on-WAG and groundwater will continue to be monitored.
4	**Source Areas:** Caps covering numerous adjacent groups of disposal units will be constructed to control groundwater recharge and access to the waste. Prior to capping, structural stabilization of trench wastes (either by grouting or dynamic compaction) will be performed. Wastes inundated by White Oak Lake will be excavated and relocated on-WAG to minimize leaching. Wastes in outlying areas will be relocated on-WAG to minimize the need for outlying caps. **Groundwater:** Institutional controls will be implemented to prevent groundwater use on-WAG and groundwater will continue to be monitored.
5	**Source Areas:** Same as Alternative 4. **Groundwater:** Institutional controls will be implemented to prevent groundwater use on-WAG and groundwater will continue to be monitored; a final decision on groundwater will be deferred to an area wide (multi-WAG) groundwater remediation program for Bethel Valley.
6	**Source Areas:** Same as Alternative 4. **Groundwater:** In those areas where significant off-WAG migration of contaminants is occurring, trench drains will be constructed to collect the contaminated groundwater; if necessary, the groundwater will be treated in the ORNL liquid waste treatment system. Institutional controls will be implemented to prevent groundwater use on-WAG and groundwater will continue to be monitored.

Table ES.5. (continued)

Alternative	Description
7	**Source Areas:** Same as Alternative 4, except in situ vitrification will be used in selected areas of the site for long-term immobilization of radiological contaminants. **Groundwater:** Same as Alternative 6.

Executive Summary Figures

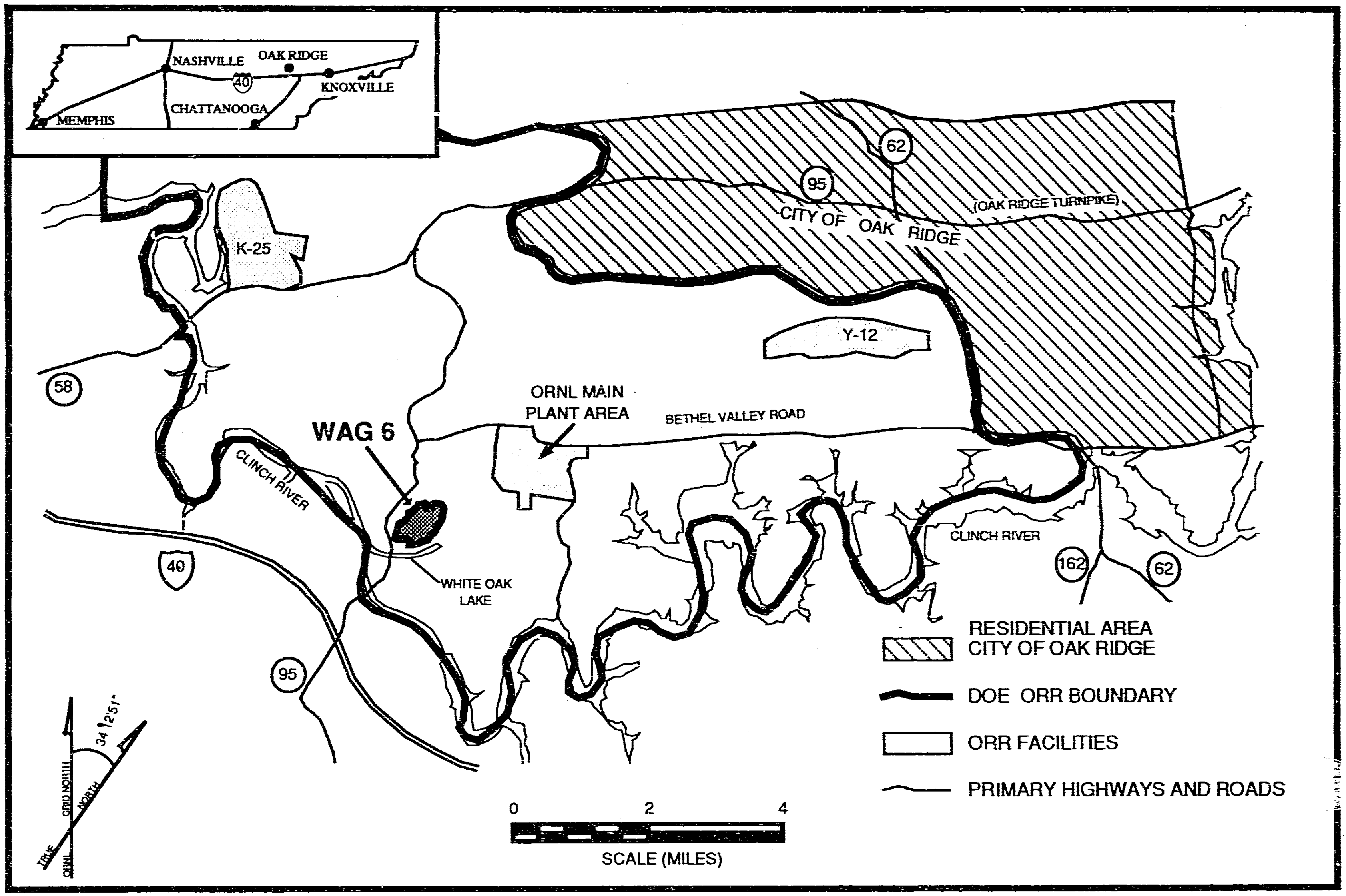
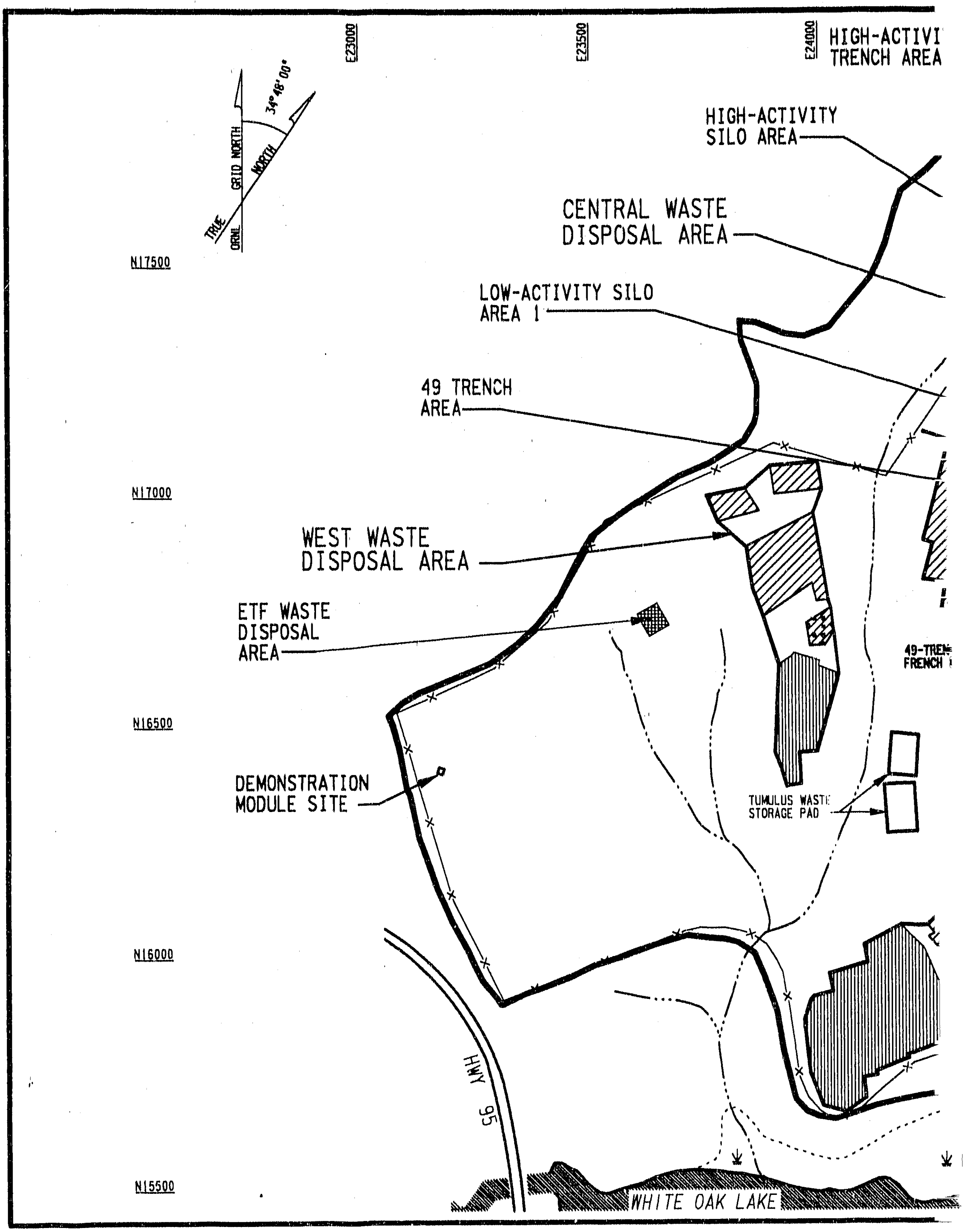


Fig. ES.1. DOE Oak Ridge Reservation.

5.18 4104.7



WAG6 06F366.DGN
9-4

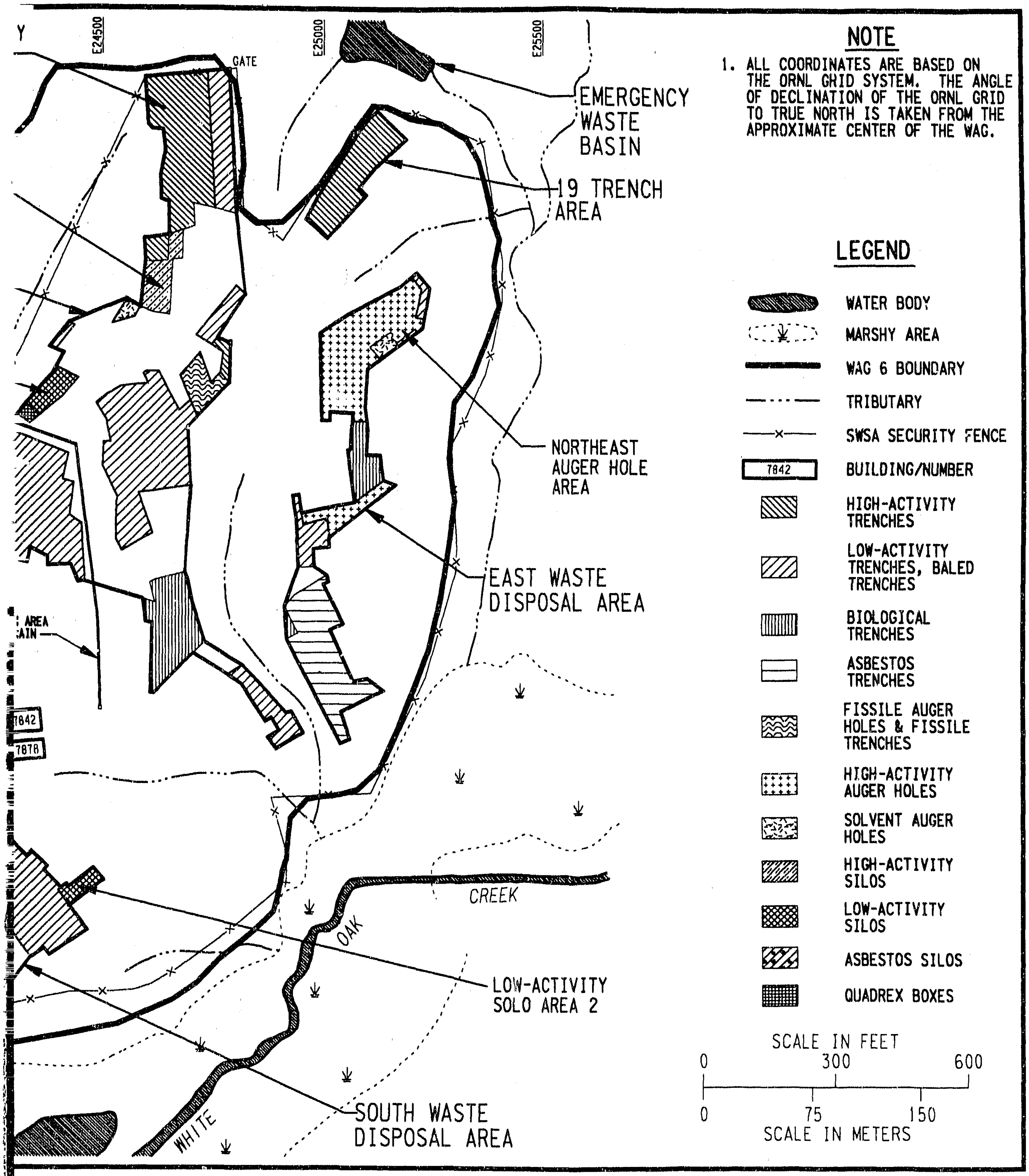
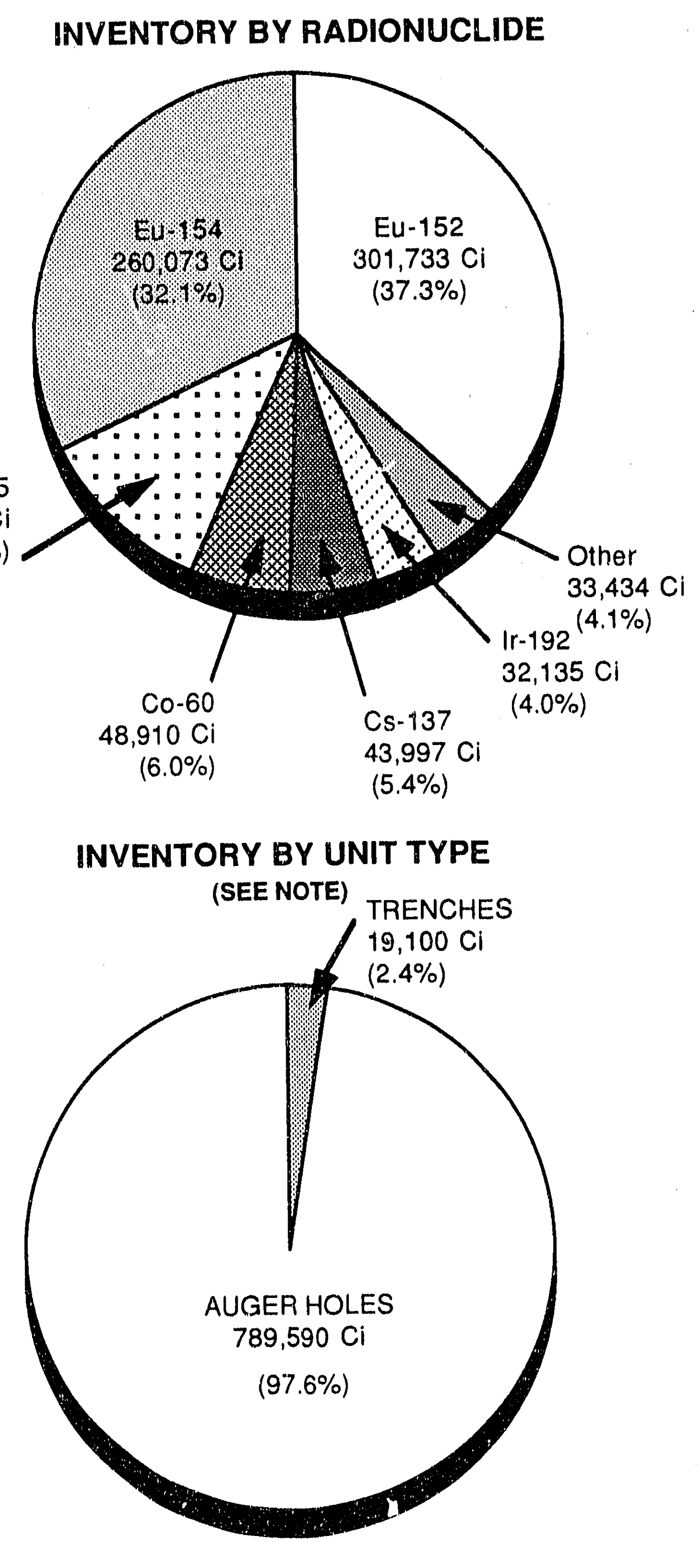


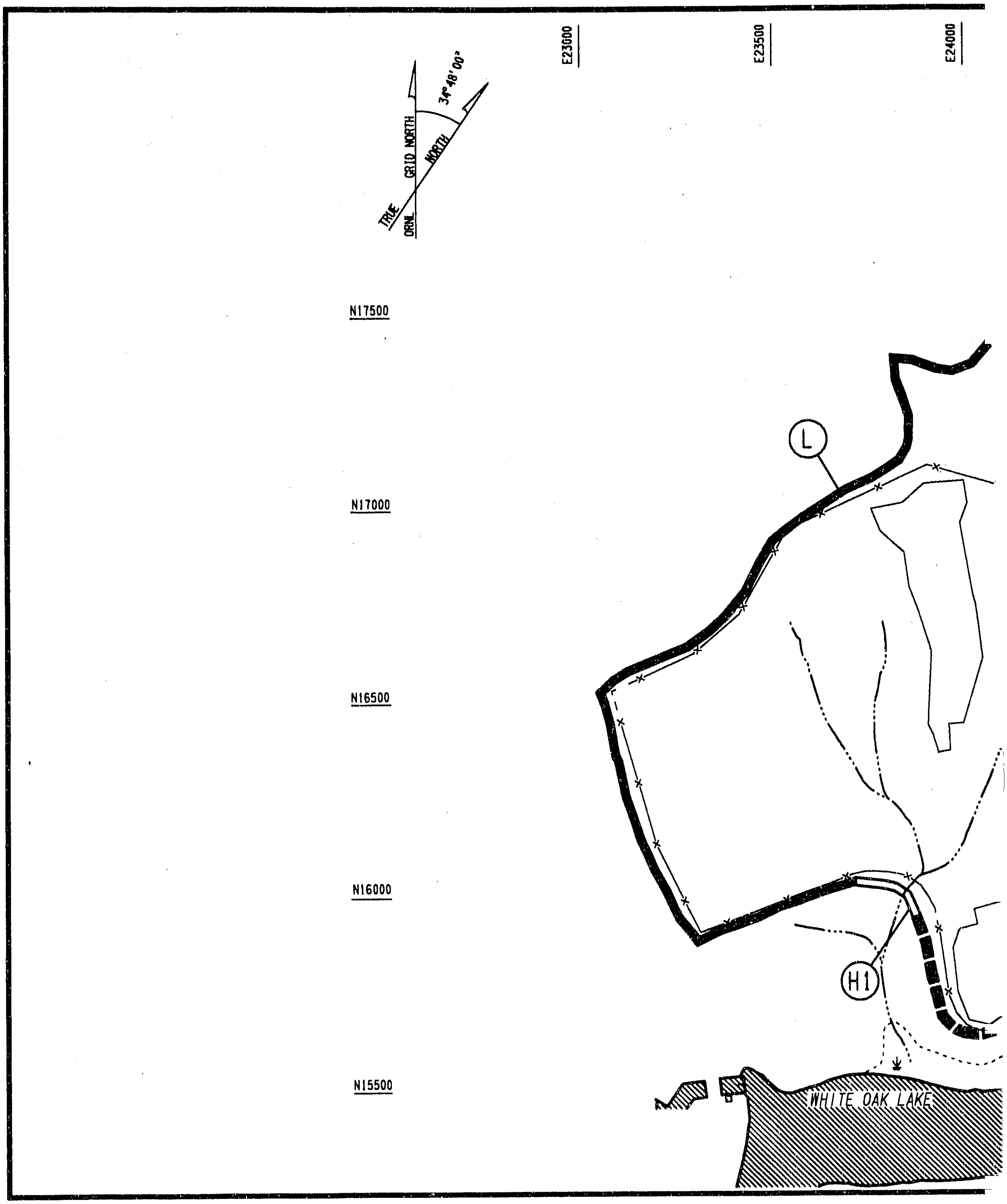
Fig. ES.2. Waste disposal unit locations.



NOTE: Silos 574 Ci (0.1%), Tumulus I & II 83 Ci (0.01%). Records of disposal from 1977 to 1990.

Fig. ES.3. Summary of radioactive waste disposal log for SWSA 6.

5 17 3967.3



WAG6 06F364.DGN
9-9

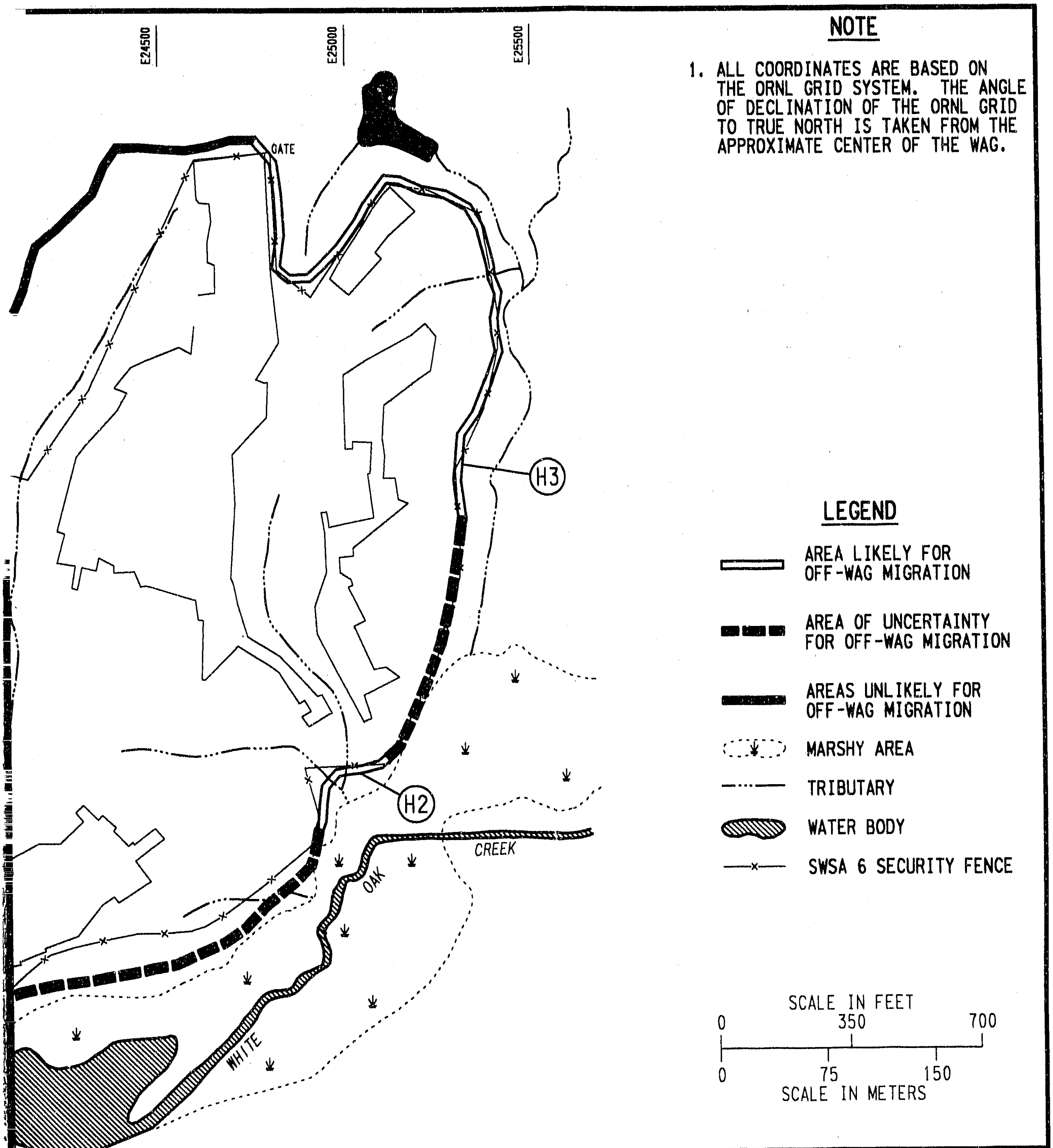
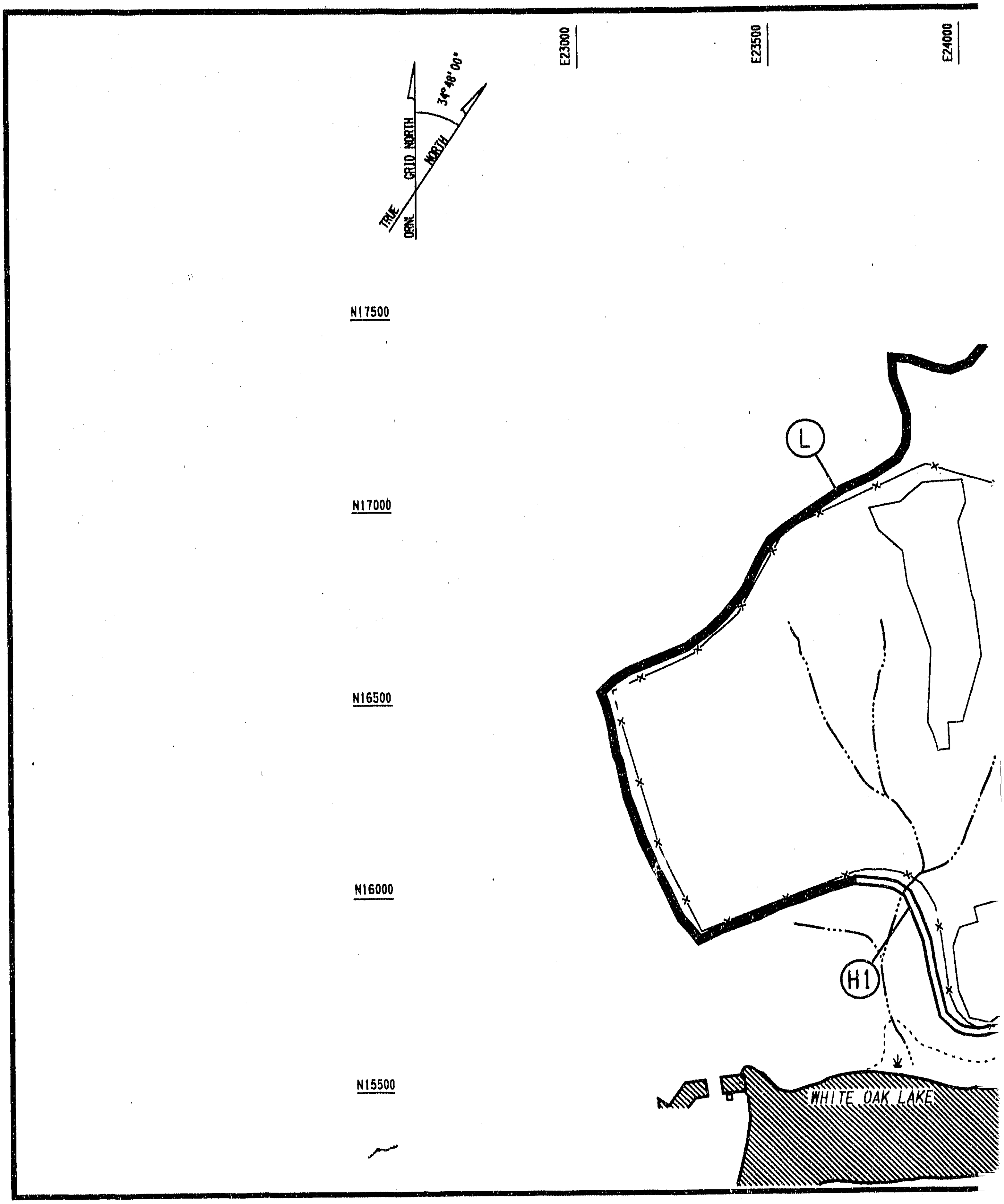


Fig. ES.4. Areas of WAG 6 boundary at which off-WAG migration of radionuclides is likely, uncertain, or unlikely.



WAG6 06F365.DGN
9-9

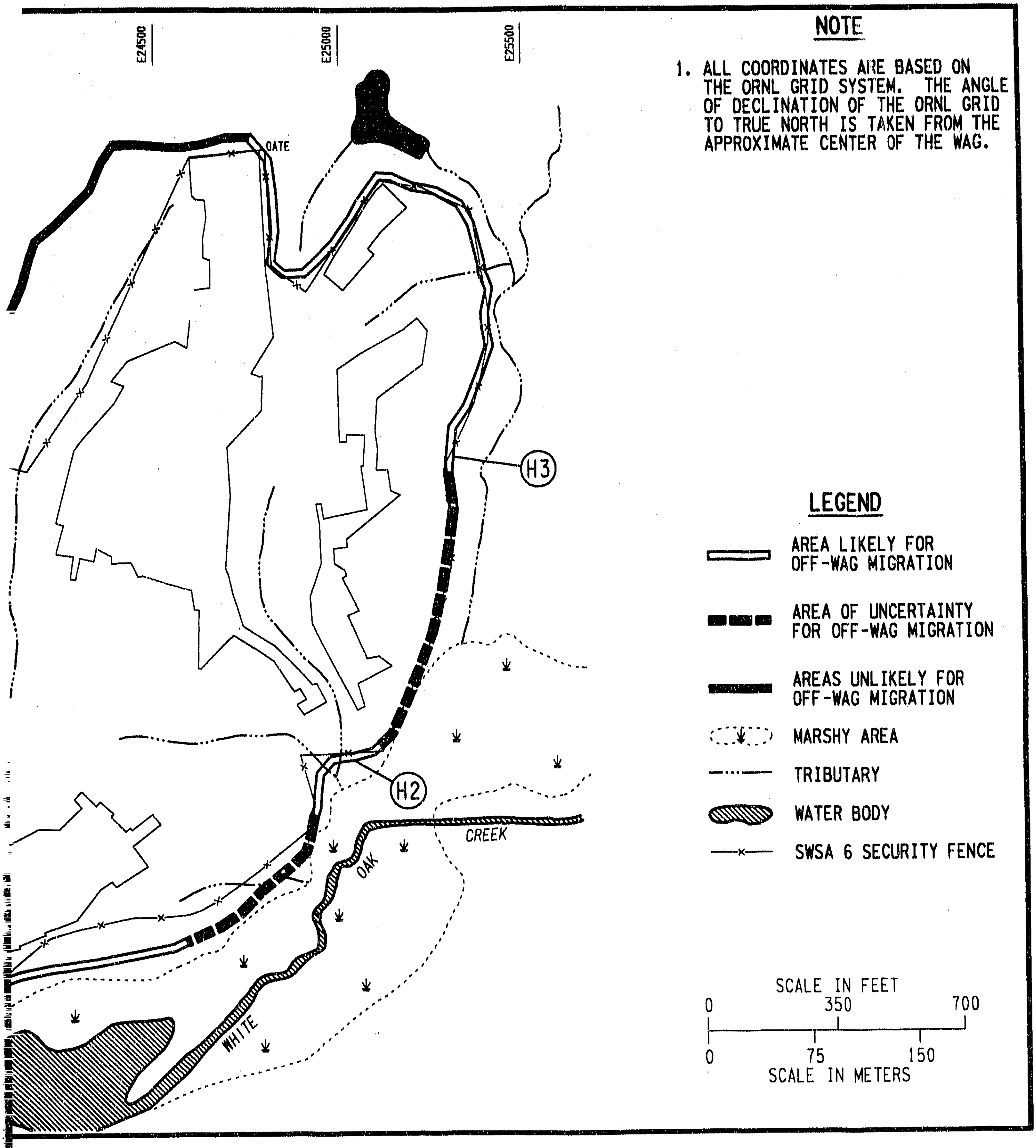


Fig. ES.5. Areas of WAG 6 boundary at which off-WAG migration of chemicals is likely, uncertain, or unlikely.

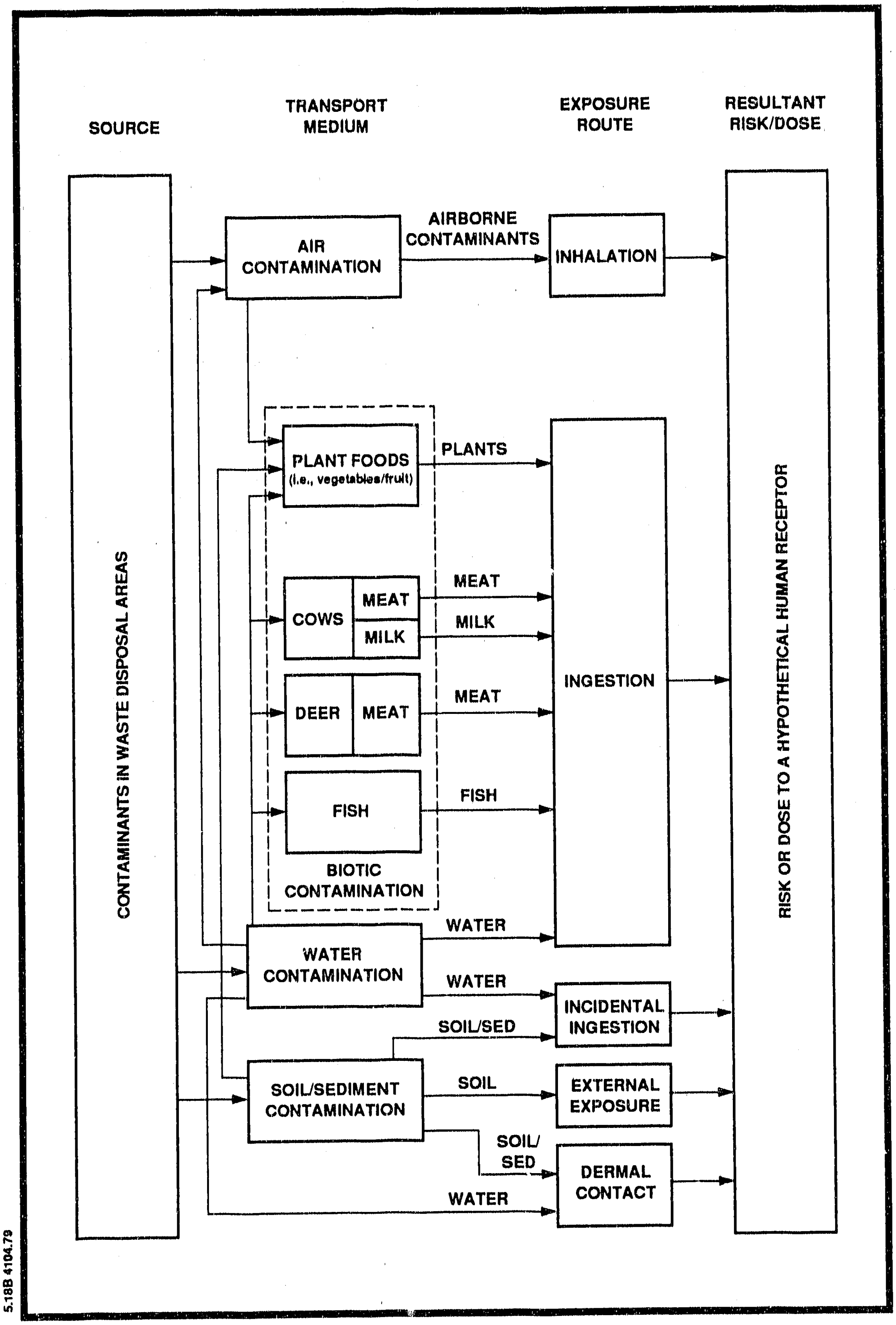


Fig. ES.6. Flow diagram of exposure pathways for WAG 6.

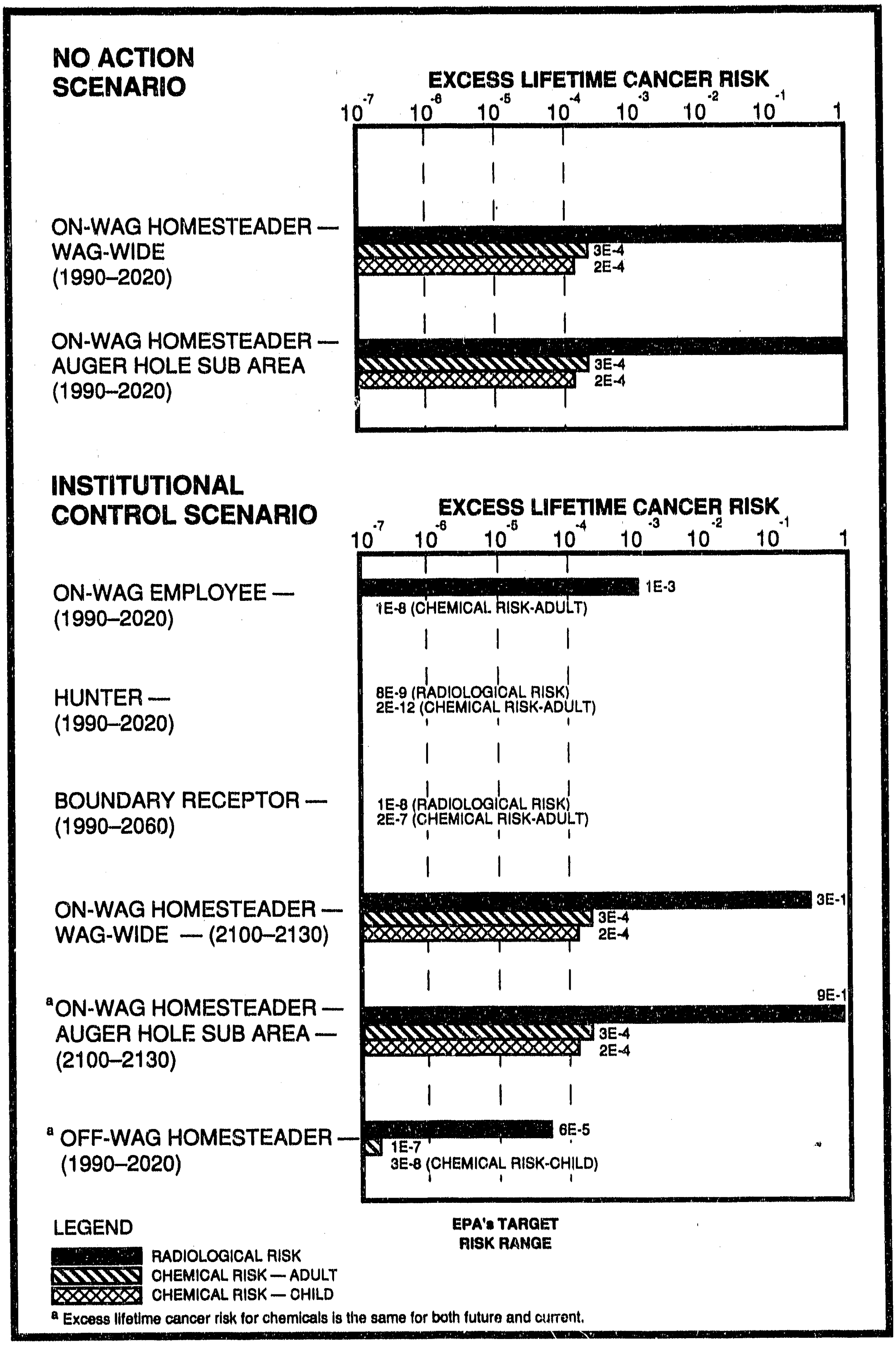
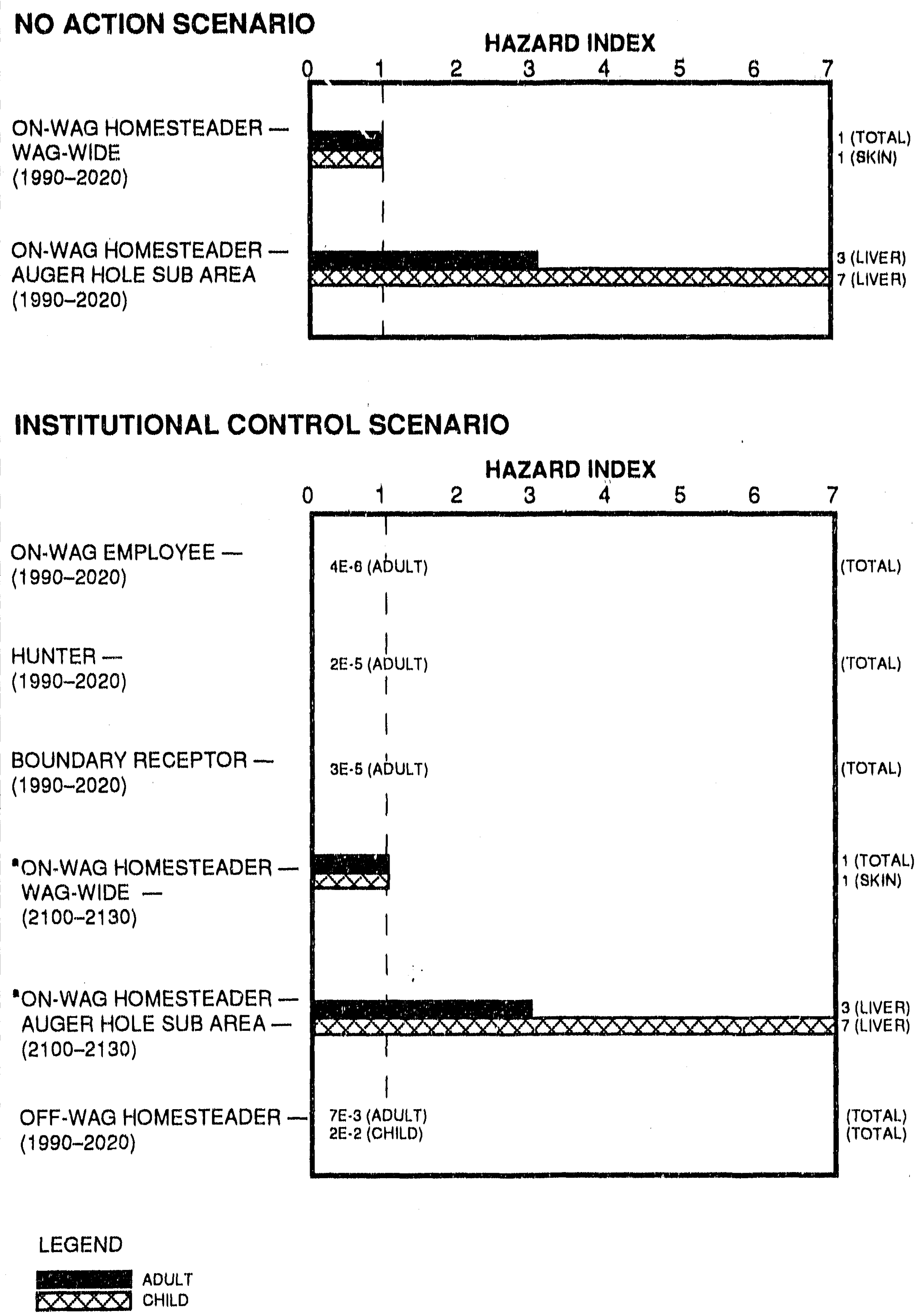


Fig. ES.7. Summary of carcinogenic risk values.

5.18D 4104.104



[a] Hazard index for on-WAG homesteader is the same for both future and current.

Fig. ES.8. Summary of noncarcinogenic effects.

1. INTRODUCTION

This report describes the activities and documents the results associated with the Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) of Waste Area Grouping (WAG) 6 at the U. S. Department of Energy's (DOE) Oak Ridge National Laboratory (ORNL). Section 1.1 provides an overview summarizing organizational, programmatic, regulatory, and site information that is relevant to the development and performance of the WAG 6 RFI. Subsequent sections of the introduction provide more detail on regulatory initiatives (Sect. 1.2), site information and background (Sect. 1.3), purpose and scope of the WAG 6 RFI (Sect. 1.4), and a reader's guide to the organization of the remainder of the RFI report (Sect. 1.5).

1.1 OVERVIEW

ORNL is one of three principal facilities on DOE's Oak Ridge Reservation (ORR), which was established during the World War II "Manhattan" atomic weapons project in 1942 and 1943. ORNL is currently managed and operated for DOE by Martin Marietta Energy Systems, Inc. (Energy Systems). The ORR is shown in Fig. 1.1.

ORNL has maintained a research-oriented mission, and, as a result of the many and varying research projects conducted throughout its operational history, has generated diverse streams of radioactive, hazardous, and mixed (radioactive and hazardous) wastes. Some of these wastes have been disposed of at ORNL by various methods, including shallow land burial (SLB) in trenches and auger holes.

As part of DOE's national Environmental Restoration (ER) Program, ORNL's ER Program addresses the cleanup of areas or facilities potentially contaminated by past activities including waste disposal. Initially, guidance for accomplishing cleanup tasks was provided by DOE orders, one of which, DOE Order 5480.14, set a timetable for bringing DOE facilities into compliance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). However, in April 1986, EPA issued a permit for the DOE/ORNL Hazardous Materials Storage Area, Building 7652. This permit gave the Environmental Protection Agency (EPA) enforcement authority for ORNL corrective action activities through RCRA Section 3004(u).

As the first phase of the RCRA 3004(u) Corrective Action Program, in March 1987 ORNL submitted to EPA a RCRA Facilities Assessment (RFA) (ORNL 1987). The RFA identified approximately 250 solid waste management units (SWMUs). Included among the SWMUs were waste tanks, solid waste storage areas (SWSAs), waste treatment units, impoundments, and leak and spill sites. Because of the large number of sites, ORNL proposed to EPA that SWMUs that were geographically contiguous or within defined hydrologic units be grouped into Waste Area Groupings (WAGs). This concept initially resulted in 20 WAGs.

The subject of this report, WAG 6, comprises three SWMUs. The largest is SWSA 6, which is the current operating disposal area for low-level radioactive waste (LLW) at ORNL. Also, from November 1980 to May 1986, chemically hazardous wastes were disposed within

SWSA 6, which makes it subject to regulation under RCRA. The other two WAG 6 SWMUs are the Emergency Waste Basin (EWB) and the Explosives Detonation Trench (EDT). Greater detail about WAG 6 is provided in Sect. 1.3.

1.2 REGULATORY INITIATIVES AND BACKGROUND

The WAG 6 RFI and all subsequent actions leading to eventual closure and remedial action of SWSA 6 and other portions of WAG 6 are being conducted in accordance with RCRA, as amended by the Hazardous and Solid Waste Amendments Act of 1984 (HSWA). WAG 6 activities also are subject to CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986, and the National Environmental Policy Act (NEPA) of 1969, as amended. The following paragraphs describe these regulatory initiatives and how they apply to the ORNL ER Program and WAG 6.

1.2.1 The ORNL ER Program

When ORNL established its ER Program (formerly called the Remedial Action Program), the ORNL program pursued its mission in accordance with DOE Orders 5820.2, "Radioactive Waste Management," and 5480.14, "Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) Program." DOE orders are the mechanism by which DOE issues formal operational and safety instructions to management and operating (M&O) contractors operating DOE facilities. DOE Order 5820.2 (superseded by 5820.2A in August 1988) establishes policies, guidelines, and minimum requirements for DOE management of radioactive and mixed waste and contaminated facilities. DOE Order 5480.14 provides instructions for implementing a DOE CERCLA program to identify and investigate inactive waste disposal sites and to implement remedial actions where needed. ORNL ER projects mandated by these DOE orders were integrated into a comprehensive long-range environmental plan for the facility.

EPA's enforcement role in ORNL ER activities began in September 1986, when EPA issued its RCRA permit for the ORNL Hazardous Material Storage Area, Bldg. 7652, and invoked Section 3004(u) of RCRA. The primary objective of RCRA 3004(u) is to address releases of hazardous constituents from SWMUs at RCRA-permitted facilities. To achieve the objectives of Section 3004(u), EPA has established the RCRA Corrective Action Program, which requires the following four steps (EPA 1987a):

1. An RFA, which documents SWMUs with actual or potential contaminant releases requiring further investigation

2. An RFI, which characterizes the extent and impact of contaminant releases identified in the RFA

3. A Corrective Measures Study, (CMS), which identifies appropriate remedies for problems identified in the RFI

4. Corrective Measures Implementation (CMI), which includes design, implementation, and monitoring of performance for the corrective measures selected

An RFA submitted to EPA in March 1987 (ORNL 1987) identified 20 WAGs.

On November 21, 1989, EPA placed the DOE ORR on the CERCLA National Priority List (NPL). Because of the number of regulatory programs and regulatory agencies involved, DOE, EPA, and the State of Tennessee are negotiating a three-party Federal Facilities Agreement (FFA) to guide environmental restoration on the ORR. The FFA will likely specify a methodology mirroring the CERCLA process for addressing contamination of facilities and the environment.

1.2.2 WAG 6 Regulatory Background

WAG 6 is unique among the ORNL WAGs in that remediation of the site is conducted primarily under the authority and terminology of RCRA. While waste disposal activities at SWSA 6 are described in detail in Sect. 1.3 and Appendix 1A of this report, a brief summary is provided for understanding the site's regulatory history and status and the impacts the regulatory requirements have had on activities at the site.

SWSA 6 was opened and began receiving limited waste shipments in 1969, and by 1973 was receiving most of ORNL's solid LLW. Although most of the waste disposed of in the SWSA was radioactive waste, hazardous chemical wastes were also disposed of at the site until April 1986. LLW disposal has continued.

For RCRA-regulated facilities ceasing operations under RCRA interim status (as did SWSA 6), State of Tennessee hazardous waste regulations specify that site closure must be initiated no later than November 1988. Consequently, ORNL prepared a RCRA Closure Plan for SWSA 6, which was approved by the State of Tennessee in September 1988 (BNI 1988a). Although RCRA required the closure of only those SWSA 6 disposal units that had received hazardous wastes, ORNL determined that it was technically inappropriate to close these units independently of the adjacent non-RCRA units. In addition, because the nature and extent of radiological and chemical contamination associated with the site was unknown, ORNL proposed that environmental investigations of all of WAG 6 precede final closure of SWSA 6 so that all sources and all environmental contamination could be addressed comprehensively.

Consequently, the SWSA 6 Closure Plan prepared by ORNL specified a series of activities leading to final closure and corrective action. The initial activity was an Interim Corrective Measure (ICM) to reduce releases of contaminants from the RCRA-regulated disposal trenches and auger holes at SWSA 6. The ICM (described in Sect. 1.3.1.1) consisted of a high-density polyethylene (HDPE) interim cap and drainage improvements. Subsequent activities leading to final closure will follow the RCRA Corrective Action Program described above.

At the time the closure plan was prepared, ORNL anticipated that the ORR would be listed on the NPL, so the closure plan also states that SWSA 6 closure activities and WAG 6 investigations will be conducted in general conformance with CERCLA guidance. The second activity specified in the closure plan was an RFI for WAG 6. An RFI Plan was prepared (BNI 1989) and submitted to Tennessee Department of Environment and Conservation (TDEC) and EPA for review. Comments were received and responded to in writing by DOE/Energy Systems (see Appendix 2A). RFI field activities were performed in two parts, referred to as Activity 1 and Activity 2. Activity 1 comprised field activities conducted from December 1988 through fall 1989. Activity 2 field activities were conducted from winter 1989 through summer 1990. Analytical results of Activity 1 were reported and summarized in the ORNL WAG 6 Site Characterization Summary (BNI 1990) prepared for submittal to the Agency for Toxic Substances and Disease Registry (ATSDR). Both Activity 1 and Activity 2 analyses and results are presented in this RFI Report. The purpose and scope of the RFI are described in Sect. 1.4.

1.3 SITE INFORMATION AND BACKGROUND

Site information and background on WAG 6 is presented in four sections. Section 1.3.1 provides a general site description and history of operations. Sections 1.3.2 and 1.3.3 summarize remedial action technology demonstrations and previous investigations conducted at WAG 6, respectively. Relevant demographic information is presented in Section 1.3.4.

1.3.1 Site Description and History

As shown in Fig. 1.1, WAG 6 is located on the ORR, approximately 10 miles southwest of the town center of Oak Ridge, Tennessee. WAG 6 is part of ORNL and is located approximately 2 miles southwest of the ORNL Main Plant Area. The location of WAG 6 in relation to other ORNL WAGs is shown in Fig. 1.2.

WAG 6 lies within Melton Valley, between Haw Ridge on the north and Copper Ridge on the south. WAG 6 is bordered on the south by White Oak Lake (WOL), on the east by a tributary of White Oak Creek (WOC), and on the west by State Highway 95. (Both WOC and WOL lie within WAG 2). The site's topography is gently to moderately sloping, draining to WOL on the south and to an unnamed tributary of WOC on the east (Fig. 1.3).

WAG 6 comprises three SWMUs:

- SWMU 6.1—SWSA 6
- SWMU 6.2—Emergency Waste Basin (EWB)
- SWMU 6.3—Explosives Detonation Trench (EDT)

SWSA 6 is the only SWMU in WAG 6 that includes disposed wastes. The EWB was constructed for emergency storage of ORNL process wastewater but was never used for this purpose. The EDT, which is no longer in use and has been backfilled, lies within the geographic boundary of SWSA 6 and is adjacent to SWSA 6 waste disposal trenches.

Figure 1.4 shows the relative locations of the three SWMUs and summarizes land use within WAG 6.

Access to SWSA 6 is closely controlled. It is enclosed by a 8-ft-high chain link fence topped with barbed wire, and access is controlled by an electronically operated gate activated by controlled personnel badge access cards. Other key surface features include two permanent buildings (7842 and 7878); several temporary (shed-type) structures; overhead power and telephone lines; poles and stanchions; two tumulus pads with stacked concrete vaults; two weather stations; and numerous wells and piezometers. Concrete vaults and large-diameter corrugated pipe used in construction of waste disposal units are also on-site but are moved frequently. Culverts have been constructed where natural or man-made drainages cross site roads. Flumes and weirs installed before, or as part of, the WAG 6 RFI exist on most of the interior drainage channels. In 1990, work began on the construction of the Interim Waste Management Facility (IWMF) in the southwestern portion of WAG 6. To date, the construction has involved clearing and grading an approximately 6-acre area. Other areas of WAG 6 are grass-covered, and these are mowed regularly.

Each SWMU is described in the following paragraphs.

1.3.1.1 SWSA 6 (SWMU 6.1)

SWSA 6 is the principal source of environmental contamination at WAG 6. It was opened for limited disposal operations in 1969 and began full-scale operations in 1973. It has received LLW, chemical, biological, and a variety of other wastes resulting from operations conducted at ORNL (e.g., solvents, scintillation liquids, laboratory glassware and equipment, and protective clothing). Waste packaging has varied from complete lack of containerization to plastic bags to stainless steel drums. Since April 1986, only LLW has been disposed of in SWSA 6. Figure 1.5 summarizes waste disposal operations at SWSA 6.

SWSA 6 covers approximately 68 acres, approximately 19 acres of which are used for waste disposal. The following paragraphs describe the SWSA 6 waste disposal units, waste inventory, planned site operations, and ICMs.

Waste Disposal Units. The variety of waste types and forms, coupled with the evolution of waste disposal regulations and disposal techniques, has resulted in several different types of waste disposal units at SWSA 6, including trenches, auger holes, silos, and aboveground container storage facilities. Table 1.1 summarizes the general types of waste disposal units; cites the approximate number of units, land area occupied, and inventory; and briefly describes how each unit has been used. Information on the type and form of the waste received in each type of disposal unit is provided in Appendix 1A.

Figure 1.6 illustrates the locations of the different types of waste disposal units within SWSA 6.

Waste Inventory. Since SWSA 6 was opened, records have been kept for each shipment of waste disposed there. These records are part of the ORNL Solid Waste Disposal

Log, a computerized data base documenting ORNL waste shipments. Appendix 1A describes data base records for SWSA 6 and provides tables summarizing the records. Figure 1.7 illustrates the inventories (in curies) of various radionuclides disposed in SWSA and the total activity in curies disposed in the unit types.

Planned Site Operations. Site operations ongoing and planned for SWSA 6 fall into three categories: waste disposal operations, preliminary activities leading to closure, and technology demonstrations. Each of these is described below.

- **Waste Disposal Operations**. As illustrated in Fig. 1.5, waste disposal operations at SWSA 6 will continue until September 1996, but current plans project that only the IWMF will receive wastes after approximately 1994. The operation of the IWMF will not impact closure activities for the remainder of SWSA 6. Those areas of the site where waste disposal operations are ongoing (active areas) are shown in Fig. 1.8.

- **Preliminary Closure Activities**. Four site preparation activities must precede final closure of SWSA 6. These are:

  - **Relocation of Tennessee Valley Authority (TVA) Power Lines**. The site is traversed by high-voltage power lines that would interfere with closure and long-term maintenance. The power lines are scheduled to be relocated by April 1994.

  - **Plugging and Abandonment of Wells**. There are approximately 600 observation wells and piezometers in SWSA 6. Because these may act as a route for contaminant migration to groundwater, they are scheduled to be plugged and abandoned by April 1994.

  - **Tumulus Demonstration Cover**. Operational plans for the Tumulus call for its capping. However, to ensure compatibility with other site caps, the Tumulus cap will not be constructed until the final site-wide closure design is complete. An interim soil cover will be placed over the Tumulus by the end of 1993.

  - **Support Facilities**. To expedite closure, ORNL plans to install construction support facilities before completion of closure design. Facilities will include a decontamination pad and trailers for field offices, environmental safety and health support, and lunchrooms. These facilities also will support plugging and abandonment of wells and construction of the Tumulus interim cover.

- **Technology Demonstrations**. Remedial action technology demonstrations are discussed in Sect. 1.3.2. Brief descriptions of past and ongoing technology demonstrations are presented in Table 1.2.

Interim Corrective Actions. Three interim corrective actions have been implemented at SWSA 6: a bentonite seal and a French drain in the 49 Trench area, and geomembrane caps over RCRA-regulated waste disposal units. Each of these is described in the following paragraphs.

- **Bentonite Seal**. To try to alleviate water infiltration in the 49 Trench area of SWSA 6, the area was sealed with a soil-bentonite mixture in 1976. The ground surface was then seeded to prevent erosion. However, water was still observed in the underlying trenches (ORNL 1986).

- **French Drain**. In 1983, a French drain designed to intercept flow of groundwater into trenches was installed in the 49 Trench area (Fig. 1.6). The drain surrounded the trenches on the north and east sides, and was installed at a maximum depth of about 30 ft (Davis and Stansfield 1984). Trenches close to the drain have been dewatered, and there has been a general lowering of the groundwater table. Groundwater table contour maps show significant changes in localized groundwater flow directions. Maximum drawdown of approximately 12 ft occurs where the two drain legs intersect in the northeast corner of the site (ORNL 1986).

- **RCRA ICM**. The Closure Plan for SWSA 6 (BNI 1988a) specified that ICM caps would be installed over areas that had received RCRA-regulated wastes. The caps were installed from November 1988 to May 1989 and were designed to reduce surface water infiltration into the waste disposal areas. Each cap consisted of 80-mil HDPE, which is resistant to ultraviolet light. Cap design life is 5 years. The locations of the capped areas are shown in Fig. 1-9. Performance of the RCRA ICM is discussed in Sect. 3.

1.3.1.2 Emergency Waste Basin (SWMU 6.2)

Constructed in 1961 to 1962 to serve as an emergency holding basin for LLW or process wastes from the ORNL Main Plant Area, the EWB was to be used if ORNL treatment plants were not operational or if treatment plant effluent could not be discharged to WOC. The basin encompasses approximately 2 acres and has a potential storage volume of 15 million gal. It reportedly has never been used for its intended purpose but does contain water from groundwater infiltration and surface water runoff.

The EWB technically is outside the ORNL boundary for WAG 6, which, along this northern edge of the WAG, is marked by the SWSA 6 fence. However, the EWB receives some runoff from the northern portion of WAG 6, and for that reason is considered a WAG 6 SWMU.

1.3.1.3 The EDT (SWMU 6.3)

The EDT is no longer used and has been backfilled. It was located in the southeastern portion of SWSA 6. The trench measured approximately 15 ft long by 5 ft wide by 4 ft deep and was used to detonate explosives and shock-sensitive chemicals such as picric acid, phosphorus, and ammonium nitrate. During operations, wastes were placed in the bottom of the trench and detonated with small plastic charges. Debris from the explosions generally remained in the trench. Table 1.3 lists wastes known to have been detonated at the EDT (ORNL 1985).

The exact location of the EDT is unknown; however, Fig. 1.4 indicates its approximate location based on interviews with personnel who were involved in trench operations. Because the EDT lies inside SWSA 6 and immediately adjacent to numerous SWSA 6 waste disposal trenches, it has been considered a part of SWSA 6 during the RFI. Separate investigations were not conducted specific to the EDT.

1.3.2 Remedial Action Technology Demonstrations

During the past several years, ORNL has demonstrated technologies potentially applicable to remediation and closure of SWSA 6. The general purpose of the demonstrations is to develop reliable, site-specific information regarding technology performance, methods of implementation, and costs. The demonstrations have focused on technologies for decreasing groundwater interaction with trench wastes and on increasing the structural stability of trench wastes to support a multilayer cap without settling. Dynamic compaction of trench wastes and waste grouting with both chemical and particulate grouts have been demonstrated. In addition, an in situ vitrification (ISV) demonstration has been conducted on mock trenches specially constructed to simulate liquid waste seepage trenches at WAG 7. Although the demonstration was designed primarily to support activities planned for WAG 7, considerable performance information resulted that is pertinent to application of the technology to SWSA 6.

Implementation and performance data derived from technology demonstrations are being employed in the WAG 6 CMS. In addition, site characterization data generated in the course of the technology demonstrations are presented in the RFI report, as appropriate. Brief descriptions of past and ongoing SWSA 6 technology demonstrations are presented in Table 1.2.

1.3.3 Previous Environmental Investigations and Ongoing Monitoring Programs

Numerous investigations of site physical characteristics and contamination have been conducted at SWSA 6 over the past 20 years. There also are several ongoing environmental monitoring programs for SWSA 6. Pertinent results from these previous investigations and site monitoring were employed in developing the scope of the WAG 6 RFI and have contributed to the conceptual site model. This section briefly describes the general scope of these investigations and monitoring programs. More detailed descriptions of individual investigations and pertinent results are presented in Appendix 1B; complete results are available in the referenced reports.

1.3.3.1 General programs of site investigation

Most previous investigations and studies performed at WAG 6 have concentrated on SWSA 6 and have been conducted under one of the following programs:

- Study of ORNL contaminant releases to WOC watershed
- SWSA 6 ETF site characterization
- SWSA 6 DOE Order 5820.2A site characterization activities

- SWSA 6 RI preliminary site characterization activities
- ER program technology demonstration

Some of these investigations focused on SWSA 6 or WAG 6 exclusively; others focused on larger areas of ORNL but included all or part of WAG 6 within their scope. The general scope of each program, specific studies conducted under these programs, and data pertinent to the WAG 6 RFI are presented in Appendix 1B.

1.3.3.2 Ongoing monitoring programs

Ongoing monitoring programs for WAG 6 include the ORNL RCRA Compliance Monitoring Program, the RCRA ICM Monitoring Program, and the DOE Order 5820.2A Performance Assessment Monitoring Program. The following paragraphs describe each program.

WAG 6 ORNL RCRA Compliance Monitoring Program. As part of the RCRA 3004(u) assessment of the need for corrective actions at SWMUs, ORNL installed a series of groundwater quality monitoring wells around the perimeter of SWSA 6 and began a contaminant detection monitoring program to determine if the site is a source of continuing releases of hazardous constituents (ORNL 1989). The well installation and sampling are discussed in Sect. 2, and data are discussed in Sects. 3 and 4 of this RFI report.

The RCRA detection monitoring program identified off-site migration of hazardous constituents in groundwater to the east. Four additional RCRA quality wells were installed, and ORNL is now conducting compliance monitoring in this area. Results from this sampling are described in Sect. 4.

WAG 6 RCRA ICM Monitoring Program. As previously described, the RCRA closure plan approved for SWSA 6 specified installation of RCRA ICM caps. Because of the considerable earthwork, pre- and post-implementation monitoring was conducted to determine construction impacts on stream sediment size and distributions and contamination of sediments and surface water. Groundwater monitoring was also performed in the vicinity of the capped areas to aid in assessing the effectiveness of the ICM (Ashwood and Spalding 1990).

DOE Order 5820.2A, Performance Assessment Monitoring Program. DOE Order 5820.2A requires ongoing monitoring to assess the performance of active disposal areas. ORNL's Active Sites Environmental Monitoring Program fulfills these requirements, and includes monitoring of the Tumulus and silos in SWSA 6.

1.3.4 Demography

As illustrated in Fig. 1.1, WAG 6 is located on the federally owned ORR. Because SWSA 6 is an active facility, ORNL workers are on-site daily during the work week and frequently on weekends. Activities performed by these workers include construction of disposal units, waste transportation and disposal, technology demonstrations, and site maintenance and monitoring. All workers are required to have undergone site safety training in accordance with ORNL Environmental Safety and Health (ES&H) Procedures.

At the closest point, WAG 6 is approximately 1 mile from the ORNL Main Plant Area, where the majority of ORNL's approximately 5300 regular employees and 2000 subcontractor personnel work. Within 1/2 mile of the boundary of WAG 6, all land is federally owned, and there are no residents. The two-lane State Highway 95 runs through the ORR and passes along the western side of WAG 6 within 100 ft of its boundary at the closest point. WAG 6 is approximately 0.42 miles from the north bank of the Clinch River, which forms a portion of the boundary of the ORR. The Clinch River, also known as Watts Bar Lake at this location, is open to recreational uses such as boating, fishing, and duck and goose hunting, as permitted by the State of Tennessee.

Within a 1-mile boundary extension of WAG 6, there are approximately 25 residents; all are located across the Clinch River southwest of WAG 6. The closest resident is 0.56 miles from the WAG 6 boundary. Within a 5-mile radius of WAG 6, there are an estimated 580 residents, and within a 10-mile radius, there are an estimated 9900 residents. There are two major residential population centers for the area. The closest, Oak Ridge, is approximately 10 miles from WAG 6 and in 1986 had an estimated population of 26,920. Knoxville, the largest local population center, is approximately 20 miles from WAG 6 and had a 1986 population of 173,210 [Center for Business and Economic Research (CBER) 1989].

1.4 PURPOSE AND SCOPE OF THE WAG 6 RFI

The objectives of the WAG 6 RFI were derived from the goals of the EPA RCRA Corrective Action Program and the EPA CERCLA program. The goals are:

- To characterize the nature and extent of contamination associated with WAG 6 sufficiently to achieve the next two goals
- To assess potential impacts of disposed wastes and environmental contamination on human health and the environment
- To identify preliminary site closure and remediation objectives and perform the initial development and screening of alternatives
- To provide data to support the development of site closure and corrective action alternatives

The WAG 6 RFI addresses existing waste disposal units at WAG 6 and examines contamination of groundwater, surface water, sediment, soil, and air. The baseline human health and environmental evaluations assess the potential health impacts if the site were not closed and remediated. The alternatives assessment includes the preliminary development and screening of alternatives for site closure and for remediation of environmental problems that have been identified through the site characterization and the baseline risk assessment.

1.5 REPORT ORGANIZATION

1.5.1 Main Document Sections and Appendixes

The essential descriptions of WAG 6 RFI activities, results, assessments, and conclusions are presented in Sections 1 through 9, which comprise the main body of this WAG 6 RFI report. Each report section has one or more associated appendixes (e.g., Appendix 1A and 1B; 3A and 3B) that present more detailed descriptions, additional data, or specific, focused discussions. These appendixes may be consulted as desired by the reader.

The contents of each section are briefly described below. Table 1.4 lists each section and its associated appendixes and their titles.

- Section 1, "Introduction," presents essential regulatory background and site information, plus report organization guidance.
- Section 2, "Summary of RCRA Facility Investigation," describes the WAG 6 RFI field activities.
- Section 3, "Physical Characteristics of the Study Area," describes the physical characteristics of the site that most affect or are most pertinent to assessing the nature and extent of contamination and developing and evaluating closure alternatives.
- Section 4, "Nature and Extent of Contamination," presents the results of WAG 6 RFI and previous field investigations conducted to determine the characteristics of the contamination discovered.
- Section 5, "Fate and Transport of Contamination," presents a conceptual hydrogeologic model of the site based on data collected during field investigations and previous investigations and describes fate and transport modeling performed to support the baseline risk assessment.
- Section 6, "Baseline Human Health Evaluation," assesses the potential effects of sources and contamination on the public for the present and in the future.
- Section 7, "Baseline Environmental Evaluation," presents an assessment of potential ecological impacts of WAG 6 contaminants.
- Section 8, "Preliminary Development and Screening of Alternatives," presents preliminary identification of remedial action objectives and development and screening of alternatives.
- Section 9, "Summary and Conclusions," summarizes the results of the investigation.

1.5.2 Treatment of Tables and Figures

As another step to make this report as readable as possible and to prevent the numerous tables and figures from interfering with the flow of the text, tables and figures have been placed at the end of their appropriate sections. Table and figure groupings are marked with dividers so readers can easily refer to them when necessary.

A large-scale foldout map of WAG 6 with groundwater monitoring wells and other key features is included as Figure 1-10.

1.5.3 References

This report contains a separate References section for all source materials cited herein. The References section appears at the end of the main document (after Sect. 9) and contains all references for the entire report, including the appendixes (i.e., the appendixes do not contain separate reference sections).

Section 1 Tables

Table 1.1. WAG 6 waste disposal units

Type of unit	Number as of 12/90	Projected number for period 1/91-5/92	Approximate area (acres)	Inventory[a] (curies)	Description
Trenches	498	3	16	19,054	Trenches were used for disposal of large waste packages and assorted bulky items. Dimensions of trenches, although variable, were generally 50 ft long by 10 ft wide by 13 to 20 ft deep. Beginning in 1975, trench depth was limited to approximately 15 ft or less, with the floor of the trench being at least 2 ft above the documented high water table. Minimum spacing between trenches was 5 ft. When the waste level reached approximately 3 ft below the top, the trench was backfilled with soil, generally from the excavation of the next trench. The cover was then seeded to minimize erosion.
Auger holes	591	0	1.5	208,660	Auger holes were used for disposal of small waste packages with surface activities exceeding 200 mR/hr. Auger holes were generally located in the higher elevations of SWSA 6. Diameters ranged from 1 to 4 ft, with depths up to 20 ft. In April 1986, the use of unlined auger holes was discontinued. Ten auger holes have diameters of 9 ft. Spacing between auger holes was generally at least 3 ft. Three or four disposals were routinely made in each auger hole. Wastes were disposed in various sized containers up to 55-gal drums. After waste disposal, if the radiation reading at the ground surface was greater than 100 mR/h, soil was placed in the auger hole until the radiation reading was reduced.
Greater Confinement Disposal (GCD) Silos	146	118	1.0	575	Silos are concrete-lined waste disposal units and were used after May 1986. They represent the evolution from the shallow land burial techniques described above to greater confinement disposal techniques. A typical concrete silo is constructed of two 15-gauge corrugated steel pipes arranged concentrically. The smaller pipe is approximately 8 ft in diameter and the larger pipe is approximately 10 ft in diameter. The length of the pipes is 14 to 20 ft. The annular space between the two pipes is filled with concrete. The bottom of the silo is a 12- to 18-in. wire-reinforced thick concrete pad. To facilitate even greater confinement of waste in the silo, the inside diameter of some concrete silos have a geometric array of vertically placed cast iron pipes. Usually the silos are placed in the trenches. The majority of silos are equipped with 3-in. diameter monitoring wells for detection and sampling of waste leachate in the silos.
GCD auger holes or silo wells	84	29	0.35	581,777	These auger holes have heavy-wall (3 to 4 in.) cast iron pipe wells or double-walled corrugated steel pipe wells vertically placed in a [illegible]illed auger hole, with the surrounding space backfilled with soil. The pipes are usually 20 ft long with inside diameters of 20 to 25 in. The bottom of the auger holes have a 12 in. thick concrete pad. There are 86 such auger holes in the SWSA 6 area. They were constructed after May 1986.
Quadrex boxes	10	0	0.03	3	Quadrex boxes are large shipping containers that are filled with low-activity compactible wastes and buried.

Table 1.1. (continued)

Type of unit	Number as of 12/90	Projected number for period 1/91-5/92	Approximate area (acres)	Inventory[a] (curies)	Description
Tumulus I-II	486 casks	0	0.6	83	There are two Tumulus disposal units within SWSA 6, referred to as Tumulus I and Tumulus II. Low-activity waste is prepackaged in 55-gal drums or 100-ft^3 metal boxes and then sealed in concrete and epoxy-coated, steel-reinforced casks (5.5 ft x 5.5 ft x 8 ft). The voids between casks are grouted. A precast concrete lid is placed on the vault and it is placed on the concrete Tumulus pad. The entire facility will be covered with a low permeability cap during closure and remediation of WAG 6. The pad is equipped with an underdrain to collect any water that might seep through the pad. Water collected from the pad underdrain is analyzed for contaminants.
Interim Waste Management Facility (IWMF)	Under construction		0.5		The IWMF for low-level radioactive waste is currently under construction and uses the Tumulus technology. The IWMF will consist of 6 to 8 tumulus pads, with an equal extent of ≈32,000 ft^2. Because the IWMF has not yet received any wastes, it is not included within the scope of the WAG 6 RFI.
<u>Experimental</u>					
Hill Cut Test Facility	27 boxes		0.3	50	There are four groups of waste disposal units constructed at SWSA 6 for experimental purposes; these are listed at left. The Hill Cut Test Facility was created as a demonstration project to evaluate the use of hillslope cuts for disposal of high-activity LLW. The ETF was established as a field-scale demonstration site to carry out various investigations for improved shallow land burial (SLB) technology. The EPICORE-II research site is being used to evaluate the long-term leachability of solidified radioactively contaminated ion exchange resin. The Polymer Trenches were created as part of a study to evaluate the application of grouting to trench wastes.
Engineered Test Facility (ETF)	9 trenches		0.25	*b*	
EPICORE				*b*	
Polymer Trenches	4 trenches		0.3	*b*	
Low Hazard Contaminated Waste Landfill			0.4	*c*	The Low Hazard Contaminated Waste Landfill is used for wastes thought to be free of radioactive contamination; however, due to inability to verify this (for example, inability to survey interiors of pipes), the wastes are disposed at SWSA 6.

[a]Inventories are approximate due to ongoing decay and/or incomplete records.
[b]No records.
[c]No records. Expected to be near zero and insignificant with respect to adjacent units

Table 1.2. SWSA 6 technology demonstrations

Demonstration	Description
Trench Grouting "Polymer" trenches (#349, 350, 351)	Field studies of trench grouting have also been conducted in the Polymer Trench Area of SWSA 6. Spalding, Hyder, and Munro (1985) excavated three pilot-scale trenches (349, 350, and 351) measuring 10 ft by 10 ft by 5 ft. Each trench was fitted with eight poly vinyl chloride (PVC) well casings and a central grout injection well. The trenches were filled with suspect solid waste including concrete blocks, tires, pipes, discarded equipment, wooden pallets, shipping cartons, and paper and backfilled with soil. To measure the hydraulic conductivity of the soils, four boreholes were placed around each trench. Trenches 349 and 350 were grouted with sodium silicate in August and September 1982, respectively; Trench 351 was grouted with acrylamide in October 1982. The three trenches were situated so that they had different depths to groundwater. Trench 349 penetrated the water table so wastes were saturated for most of the year; Trench 350 was above the seasonal high point of the water table, and Trench 351 was intermediate between the two.
Trench Grouting Trench 150	In August 1986, particulate grout was injected under pressure into Trench 150 as a remedial action demonstration to assess the effect of this type of grouting on trench subsidence and radionuclide behavior (Spence, Godsey, and McDaniel 1987). Besides the benefit of filling large voids and preventing subsidence, particulate grouts may immobilize and encapsulate most of the radioisotopes close to the waste, may redirect water flow away from the waste, and may offer the advantage of using natural materials that withstand the rigors of weather and time. Components used in this grout were Type I Portland cement (39 percent), Eastern Class C fly ash (55.5 percent), and bentonite (5.5 percent). A concrete mixing truck was used to mix the solids with water and the set retarder/dispersing agent. The grout was pumped through lances driven into the trench. A total of approximately 2,100 gal of grout, with represents about 19 percent of the total trench volume and most of the void volume, was successfully injected into Trench 150.
ISV Demonstration	The ISV demonstration site is located in the northern portion of SWSA 6, southwest of TARA I. The demonstration, which was the second pilot-scale test, used a one-half scale model of trench 7 and pilot-scale ISV equipment from Pacific Northwest Laboratory (PNL). The test was conducted during May 1991. A minimum amount of radioactive waste was placed in the trench to track the behavior of radionuclides when subjected to the new pilot ISV. This new ISV system was intended to demonstrate reduced cesium-137 volatility and evaluate seismic imaging and advanced thermometric methods for monitoring the progression of melting (Jacobs and Spalding 1990). Samples of off-gas scrub solutions were collected during the demonstration and analyzed by ORNL. After vitrification is completed, samples of the solid mass will be analyzed for their leachability and composition.
Hill Cut Test Facility	Described in Appendix 1A.
EPICORE II	Described in Appendix 1A.
Engineered Test Facility	Described in Appendix 1A.
Dynamic Compaction Trench 271	Trench subsidence is a major problem in remediating shallow land disposal sites. Subsidence depressions not only create catchments for surface runoff and precipitation but also channel water into contact with buried waste. Furthermore, surface stability is necessary for almost all infiltration and intrusion barriers. Spalding (1986) conducted a demonstration in SWSA 6 to evaluate the degree of consolidation that could be achieved by dynamic compaction of a closed burial trench in a cohesive soil formation. Trench 271 in the northern portion of

Table 1.2. (continued)

Demonstration	Description
Dynamic Compaction Trench 271 (cont.)	SWSA 6 was selected for this demonstration. Waste disposal records indicate that the trench was operational from March to June 1978, during which time about 880 ft^3 of waste weighing approximately 8,500 lb were disposed. The waste consisted primarily of contaminated equipment, demolition debris, and dry solids, with a small amount of biological waste. Packaging was variable. The inventory of radioisotopes, totaling about 80 Ci, included mostly strontium-90, with smaller amounts of cesium-137, samarium-151, thorium-232, uranium-238, technetium-99, cesium-134, ruthenium-106, cerium-144, iridium-192, cobalt-60, iron-59, manganese-54, californium-252, curium-244, and tin-121. Compaction was accomplished by repeatedly dropping a 4-ton, steel-reinforced concrete cylinder from heights of 12 to 25 ft using the whipline of a 70-ton crane. The ground surface was depressed an average of 2.6 ft. with some areas depressed as much as 6.5 ft. The surveyed volumetric depression totaled 64 percent of the measured trench void space. Neither trench cap bulk density nor permeability was affected by compaction, indicating that the consolidation was primarily subsurface.
Dynamic Compaction/Grouting Test Area for Remedial Actions	The proposed Test Area for Remedial Activities (TARA) Phase 1 involved dynamic compaction and grouting of 19 selected trenches. The area chosen for this demonstration is a hillock of approximately 1 acre in the northeastern part of SWSA 6. This area was selected for several reasons including its hydrologic isolation, the likelihood of its having few containers of liquid hazardous waste, and the ease of monitoring for contaminant release through a suite of perimeter wells (ASG 1987). Experience gained during TARA Phase 1 will be used in the design of TARA Phase 2 to assess the impacts of dynamic compaction on saturated trenches and on the release of contaminants to groundwater. During compaction, downgradient groundwater will be monitored and, as required, extracted and treated.

Table 1.3 Waste items detonated at the explosives detonation trench

Picric acid	Aluminum chloride
Picryl chloride	Aluminum metal
2, 4-dinitrophenyl hydrazine	Magnesium metal
Picramide	Phosphorus pentasulfide
Phosphorous	Methyl acrylate
Zinc peroxide	Titanium trichloride
Nitromethane	Potassium azide
2, 4-dinitrophenol	Phosgene
Hydrazine solution	Zinc metal
Barium peroxide	Phthalic anhydride
Hydrogen peroxide	Cobalt metal
Sodium azide	Chromium metal
Charcoal solution	Niobium powder
Thionyl chloride	Neodymium
Ammonium nitrate	zirconium metal

Source: ORNL. 1985. *Explosives Detonation Trench: Inspection Plan and Schedules*, Oak Ridge, Tennessee.

Table 1.4. WAG 6 RFI report sections and associated appendixes

Section	Appendixes
1. Introduction	1A. SWSA 6 Waste Inventory 1B. Previous Investigation and Ongoing Monitoring Program
2. Summary of RCRA Facility Investigation	2A. Response to the U. S. EPA and TDEC Comments on RFI Plan for ORNL Waste Area Grouping 6
3. Physical Characteristics of the Study Area	3A. Hydrogeologic Data 3B. Bird, Mammal, Reptile, and Amphibian Species Found in the ORR
4. Nature and Extent of Contamination	4A. Data Quality
5. Fate and Transport of Contamination	5A. Surface Water Modeling 5B. Analysis and Results of April to May 1990 Storm Sampling
6. Baseline Human Health Evaluation	6A. Calculation for Determining Relative Dose from Radionuclides in WAG 6 Below-Ground Inventory 6B. Evaluation of Tentatively Identified Compounds 6C. Upper Confidence Limits for Chemicals of Potential Concern at WAG 6 6D. Radiological Risk Assessment Methodology and Results 6E. Calculation of the Accumulation of Contaminants in Soil as a Result of Off-WAG Irrigation 6F. Chemical Risk Assessment Methodology and Results 6G. Toxicity Assessment Factors Used in Risk Characterization
7. Baseline Environmental Evaluation	7A. Results of Surveys for Threatened and Endangered Species and Sensitive Environments
8. Preliminary Development and Screening of Alternatives	8A. Potential ARARs 8B. Worker Exposure Assessment for WAG 6
9. Summary and Conclusions	
References	

Section 1 Figures

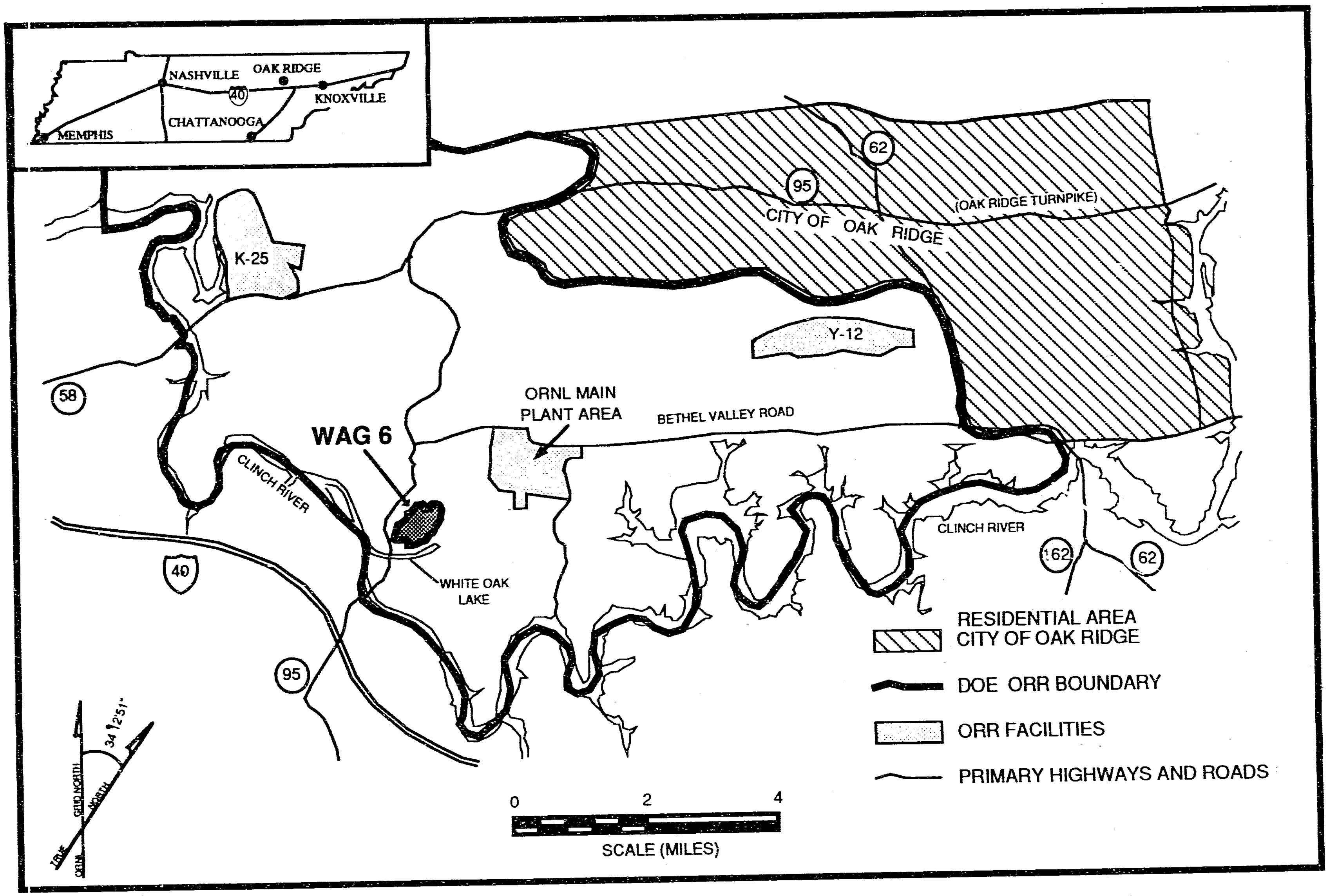


Fig. 1.1. DOE Oak Ridge Reservation.

5.18 4104.7

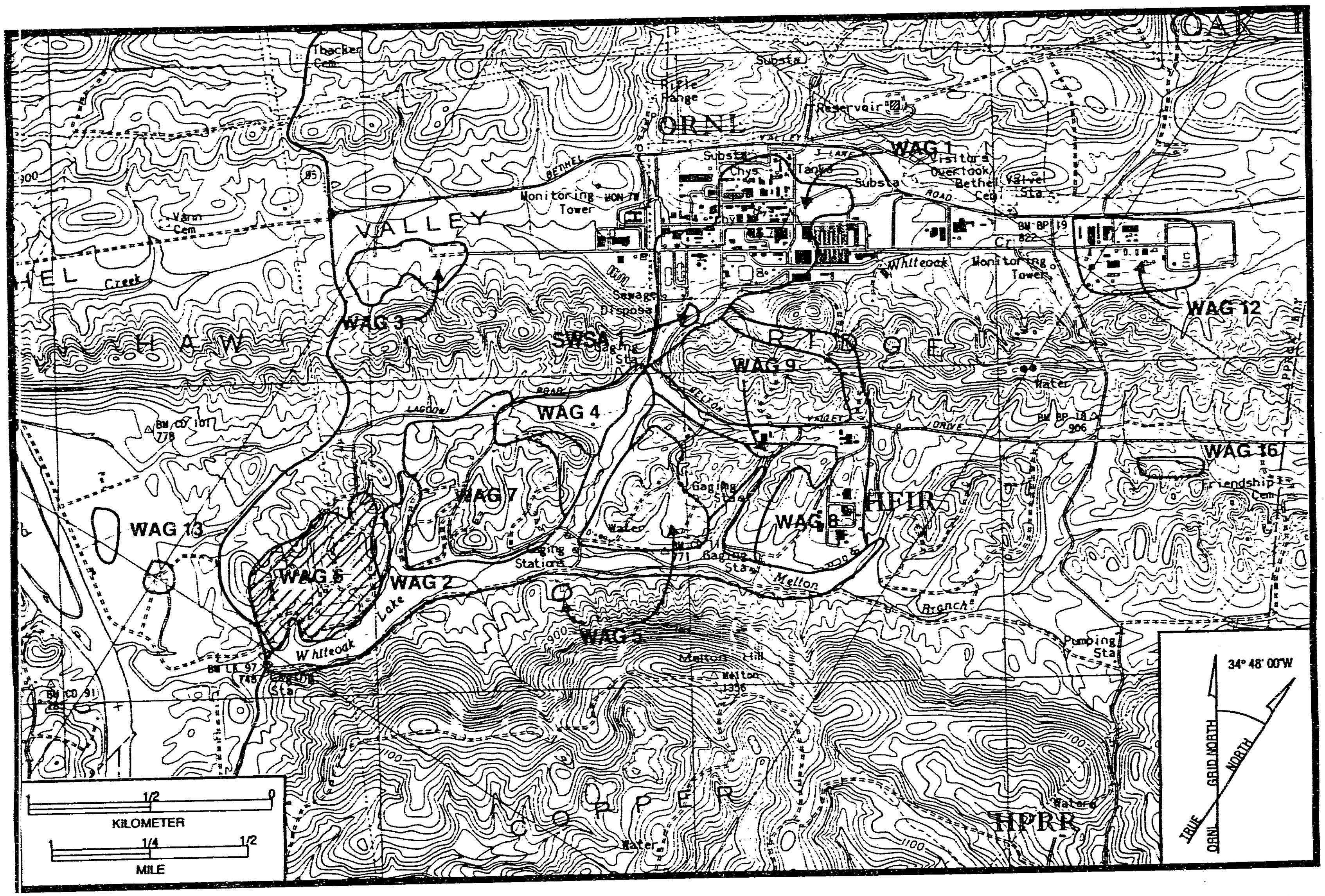
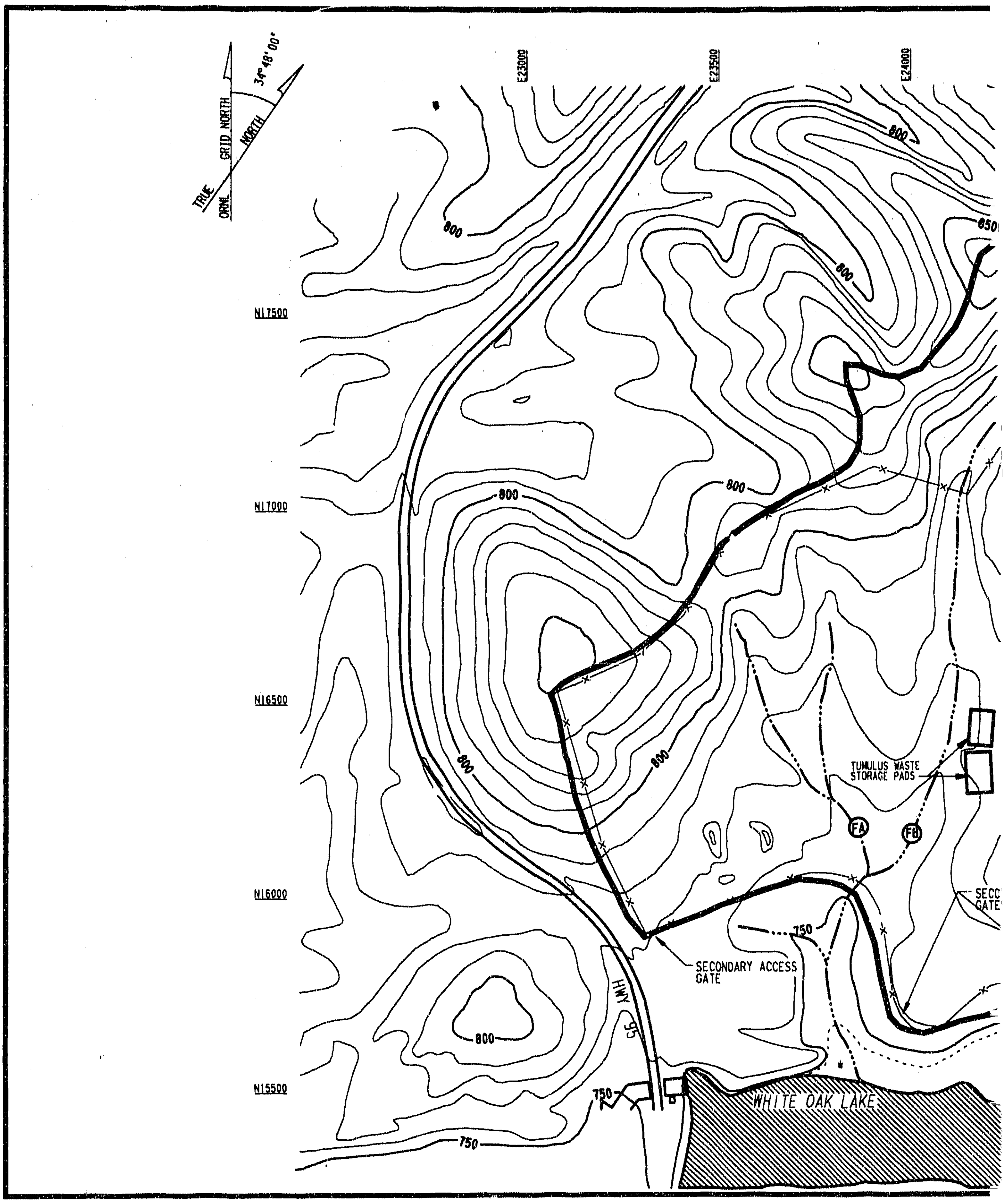


Fig. 1.2. ORNL waste area groupings.



WAG6 06F244.DGN
9-9

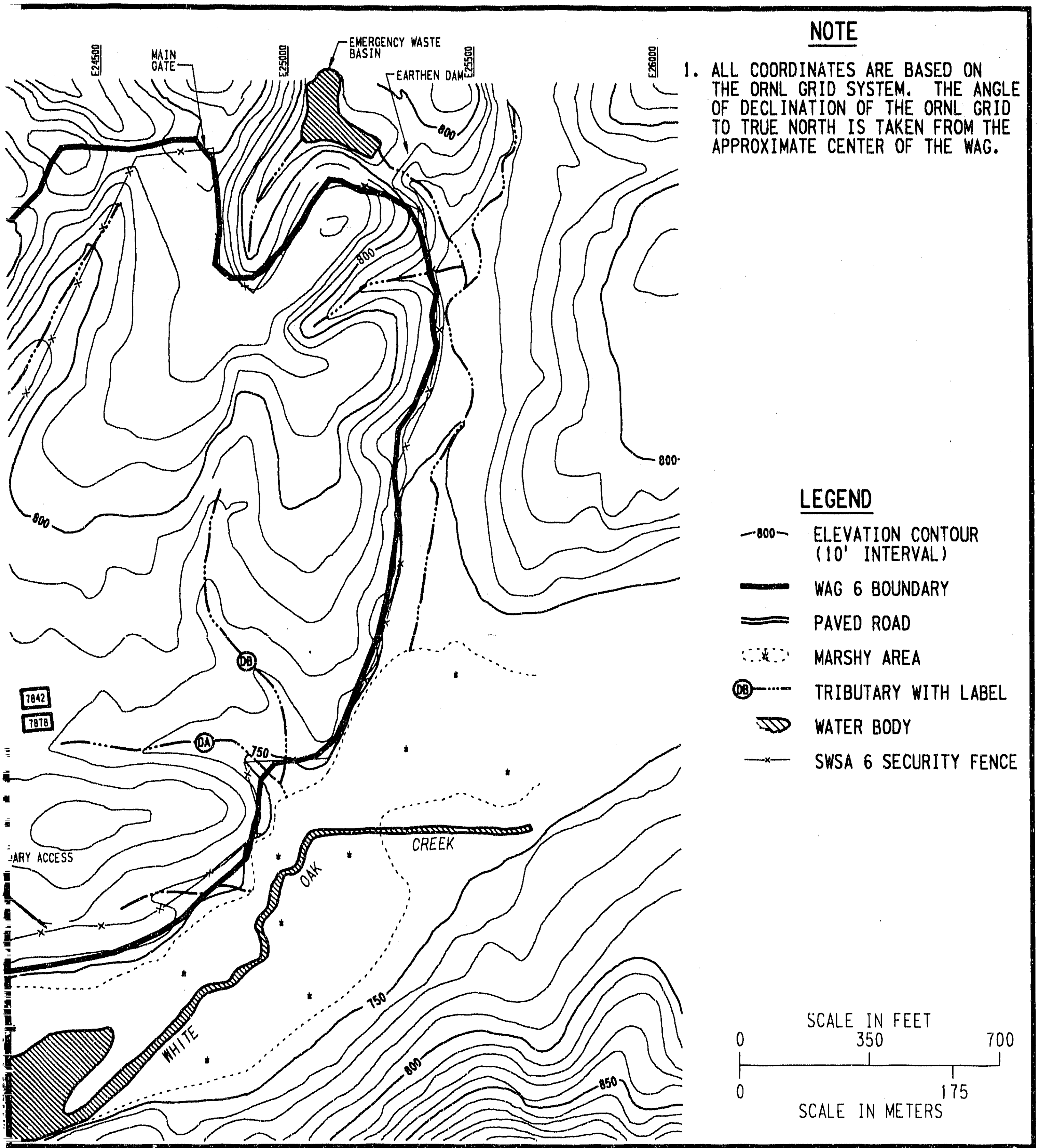


Fig. 1.3. WAG 6 topography and drainage.

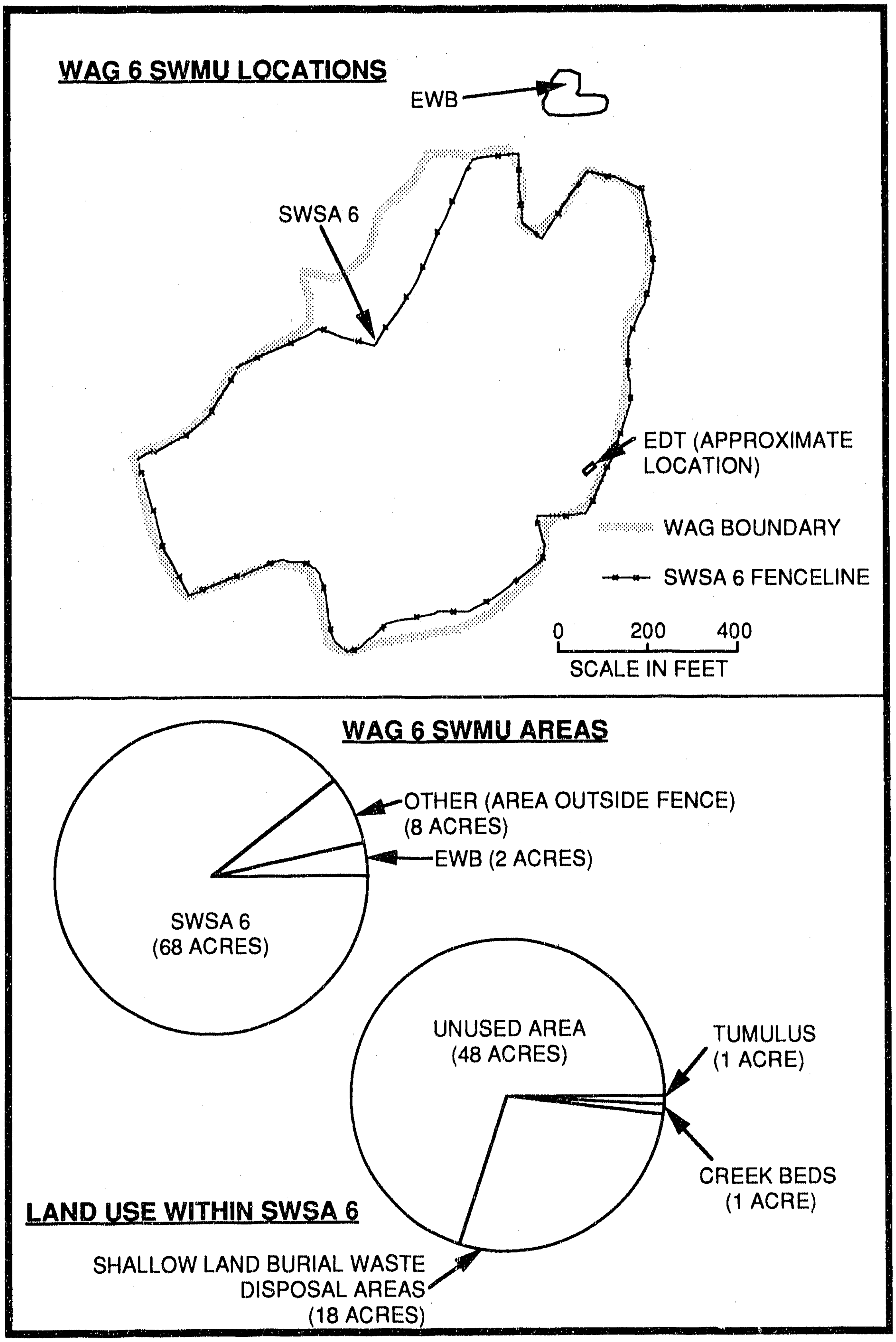
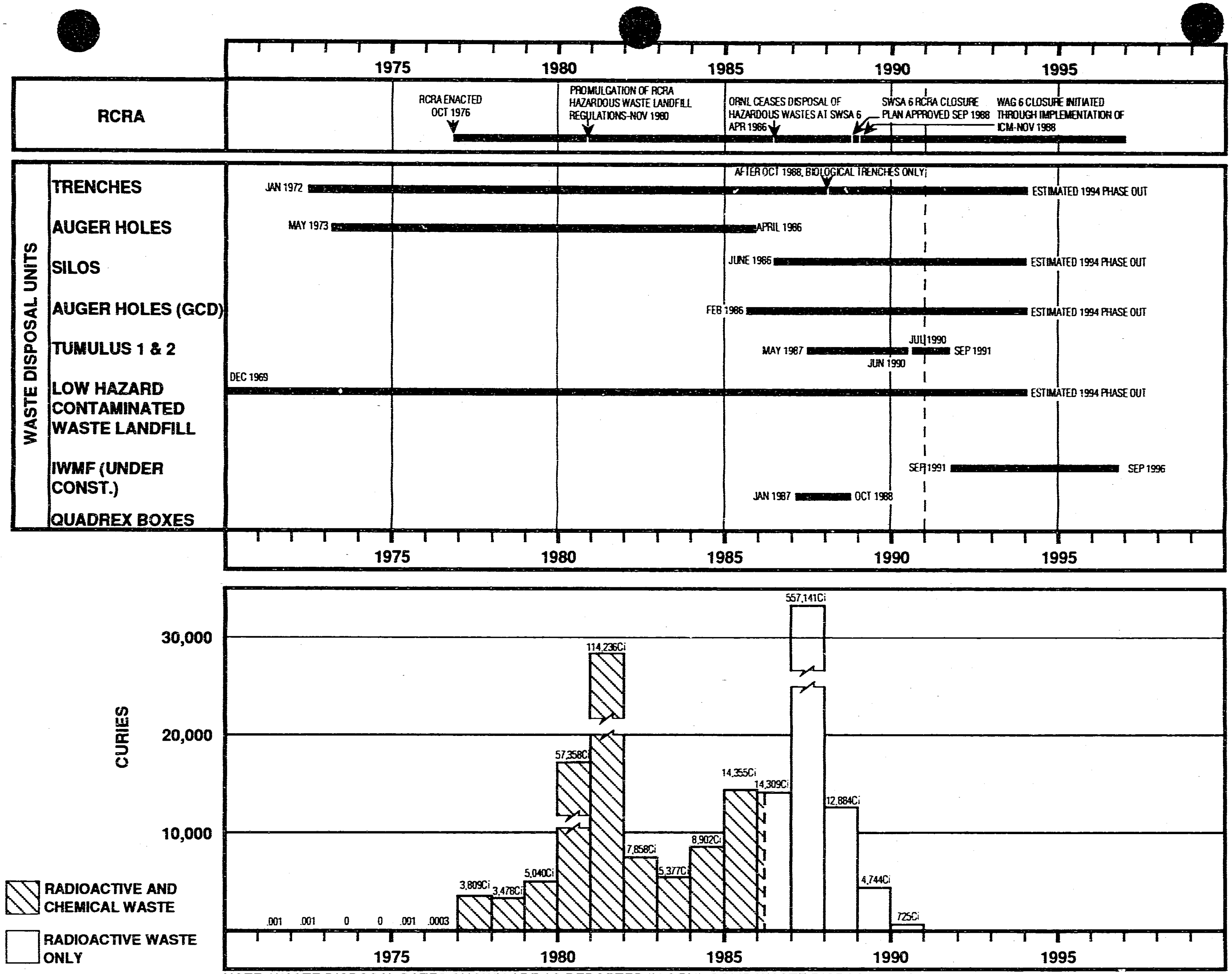


Fig. 1.4. WAG 6 solid waste management units.

5.18 4104.8

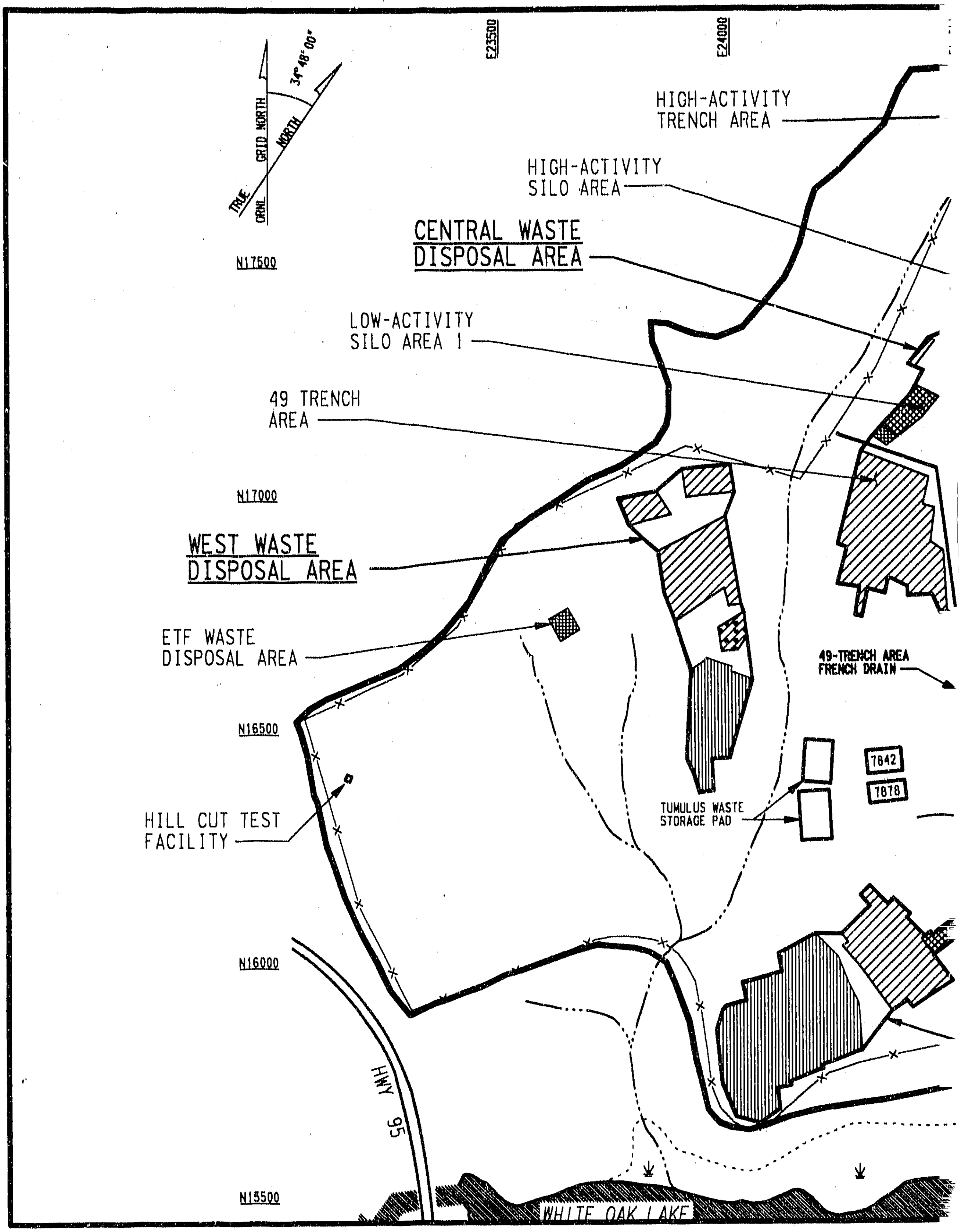
WAG6 06F245.DGN



NOTE: WASTE DISPOSAL DATES SHOWN ARE AS REPORTED IN ORNL SOLID WASTE DISPOSAL LOG.

5.17 ?967.1

Figure 1.5. WAG 6 waste disposal operations.



WAG6 06F340.DGN
08/29/91

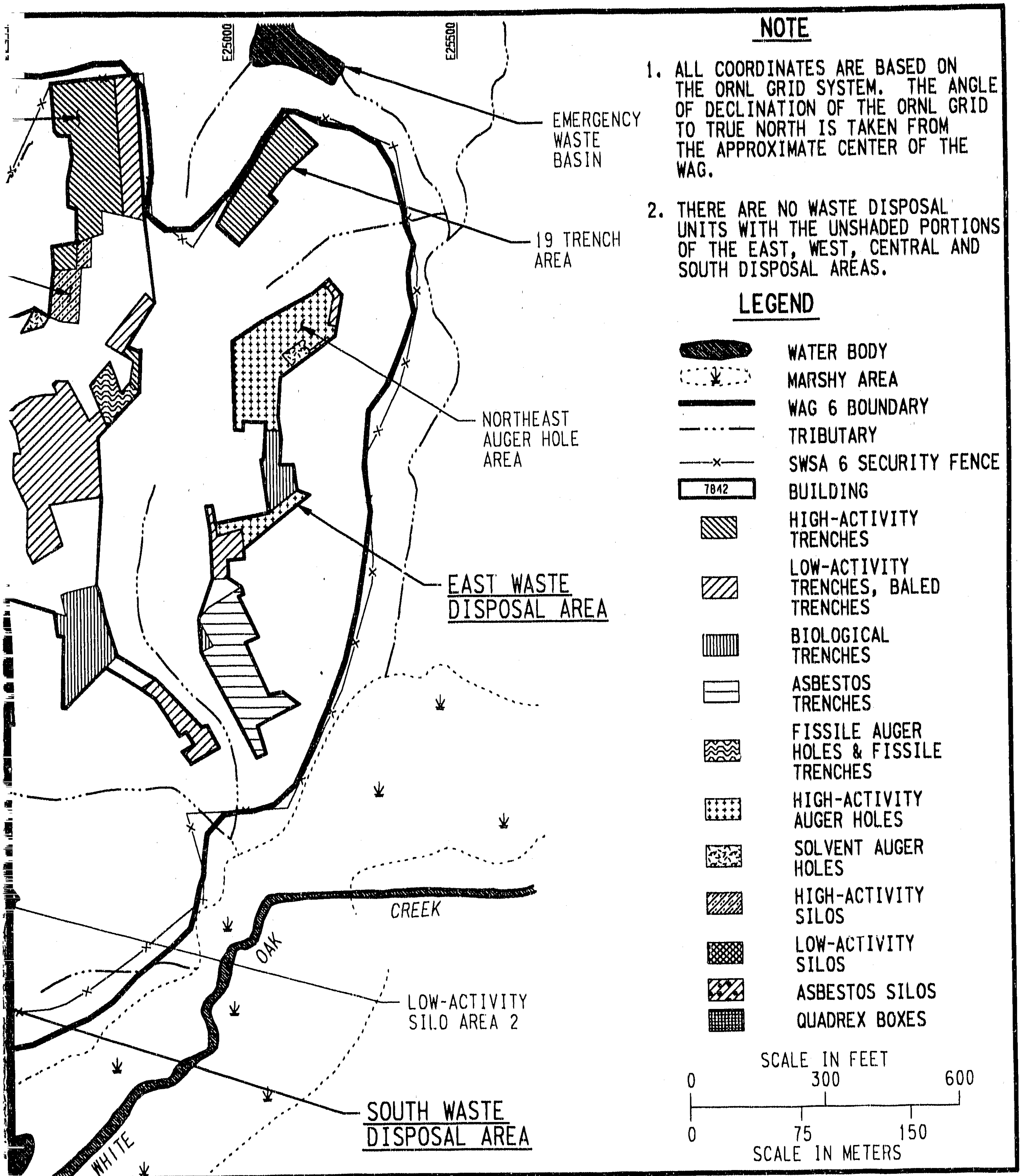
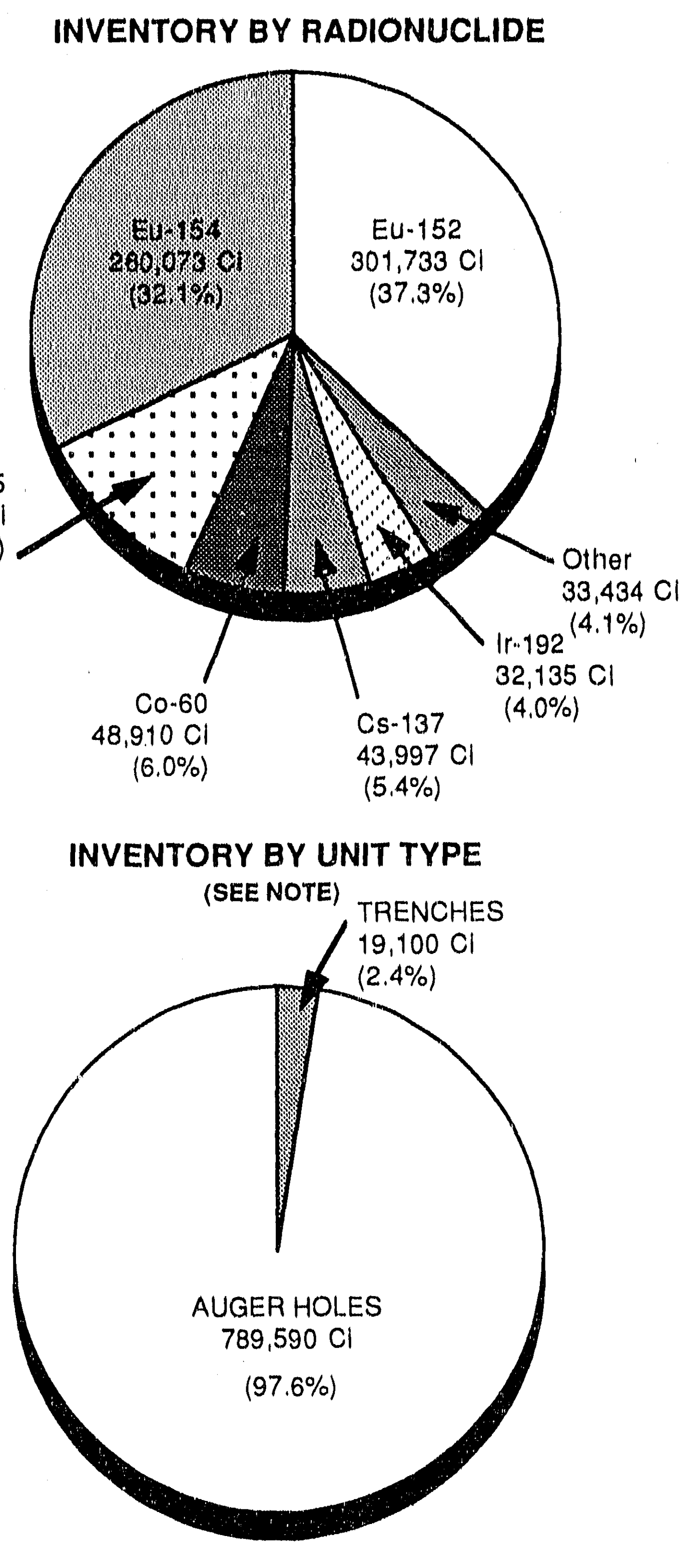


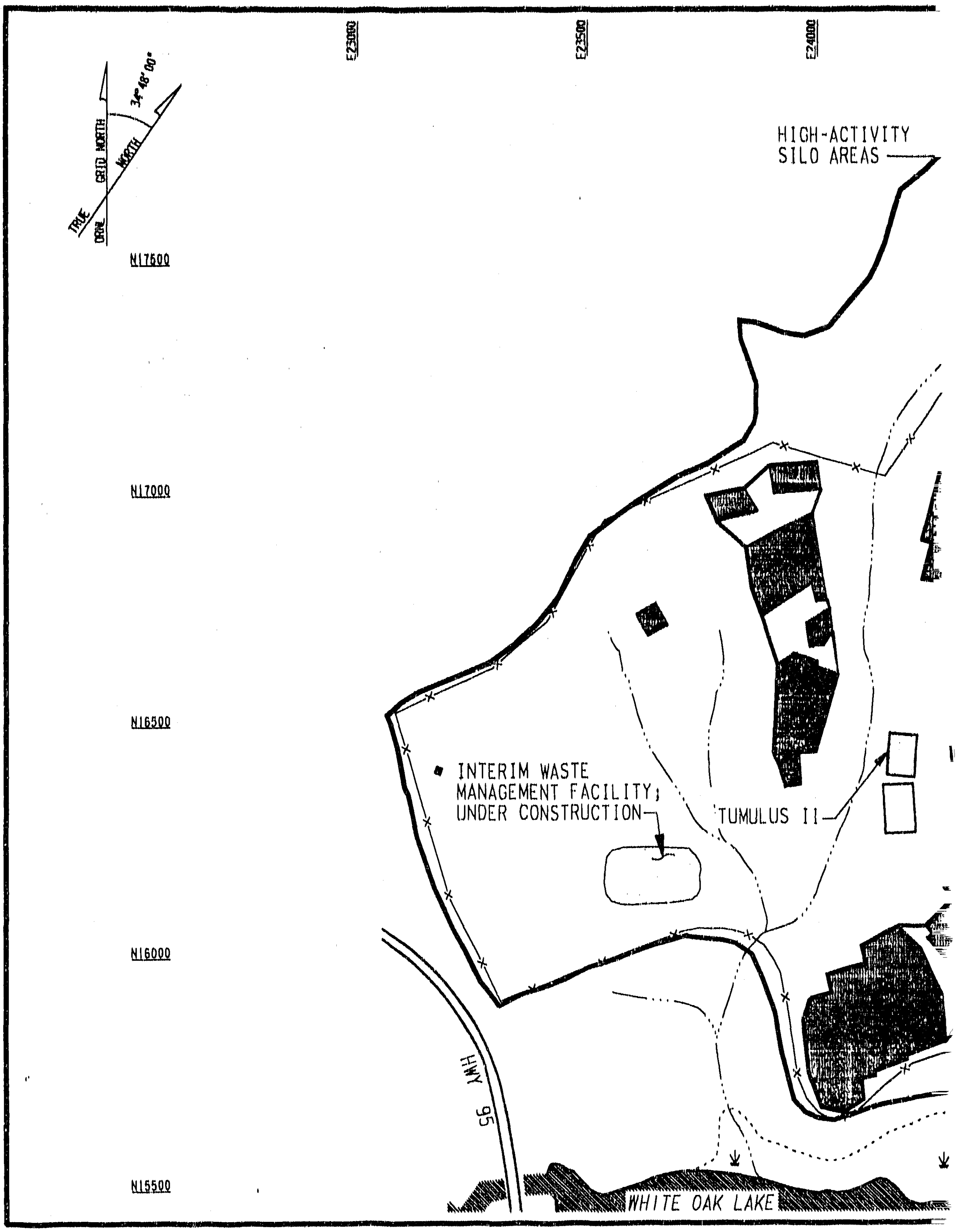
Fig. 1.6. Waste disposal unit locations.



NOTE: Silos 574 Ci (0.1%), Tumulus I & II 83 Ci (0.01%). Records of disposal from 1977 to 1990.

Fig. 1.7. Summary of radioactive waste disposal log for SWSA 6.

5 17 3967.3



WAG 6 06F247.DON
9-9

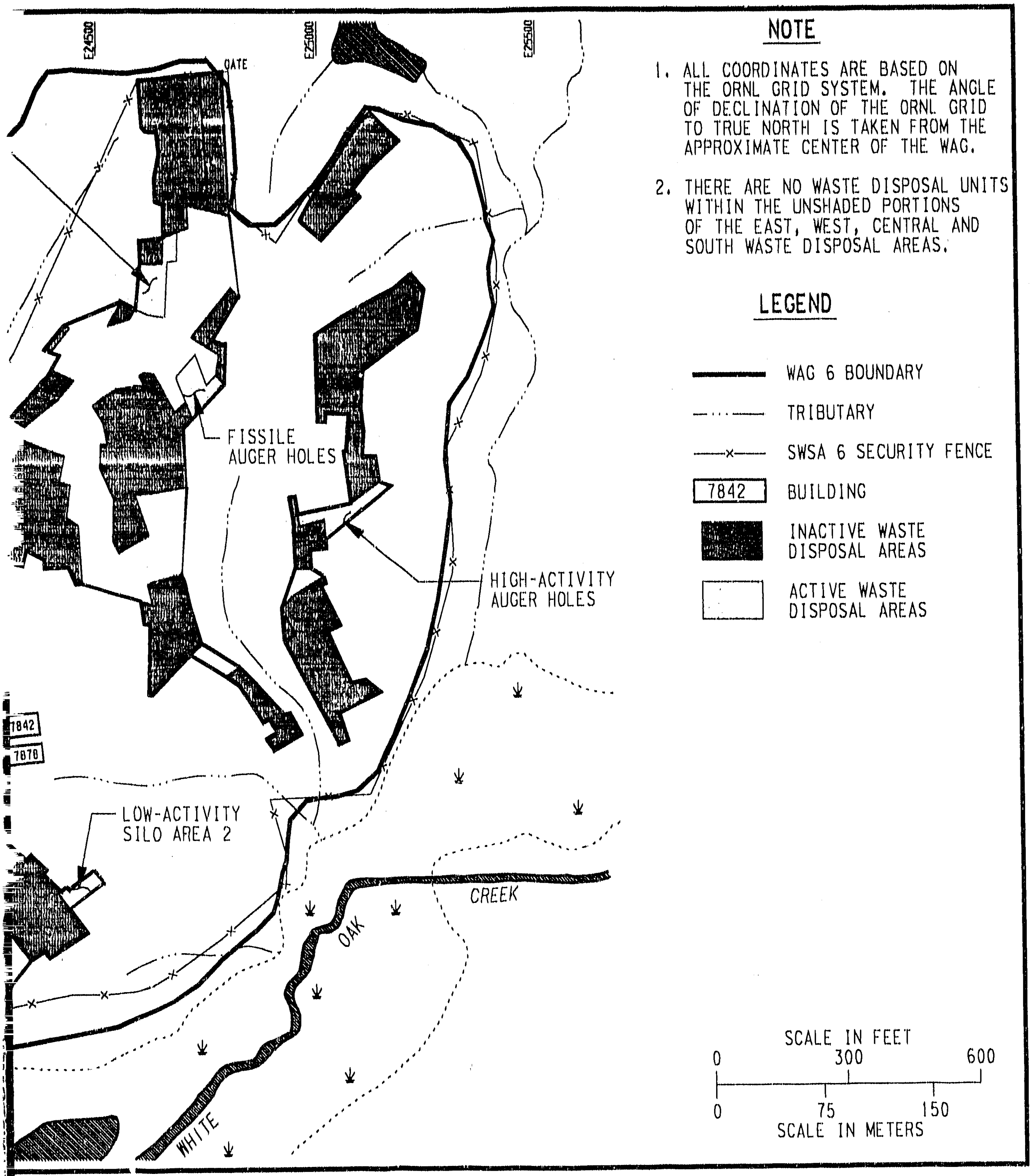


Fig. 1.8. General areas of ongoing waste disposal at SWSA 6.

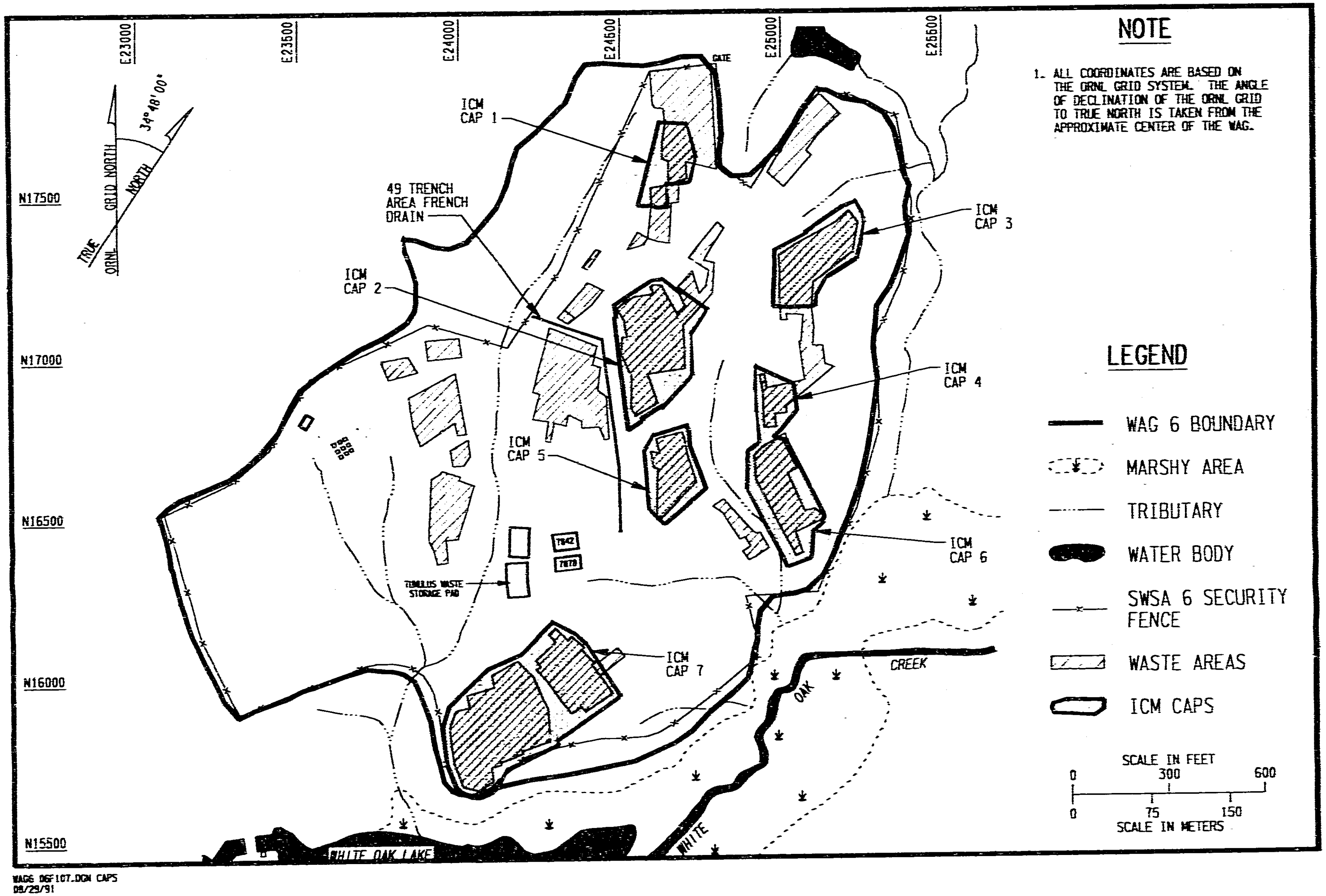
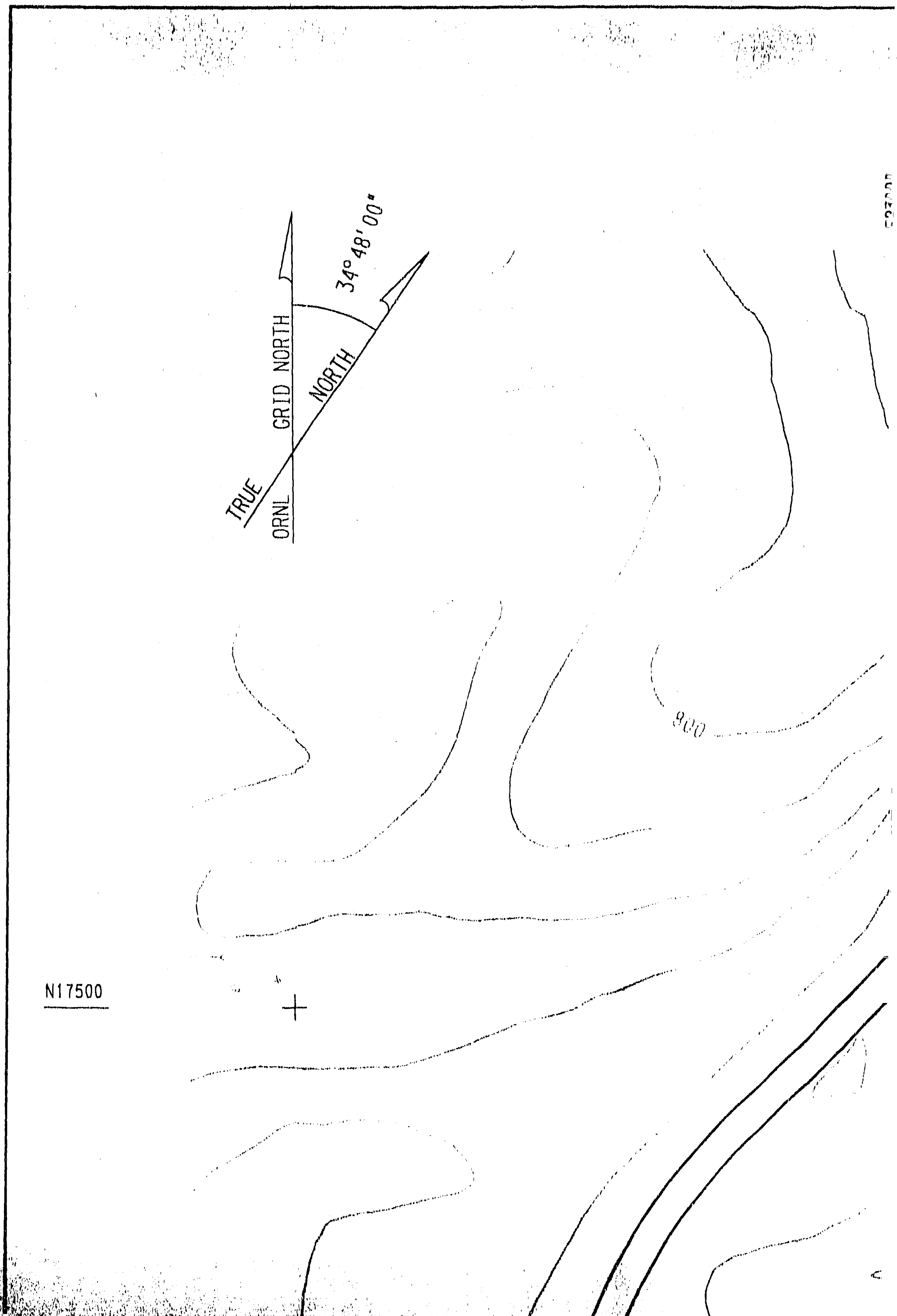
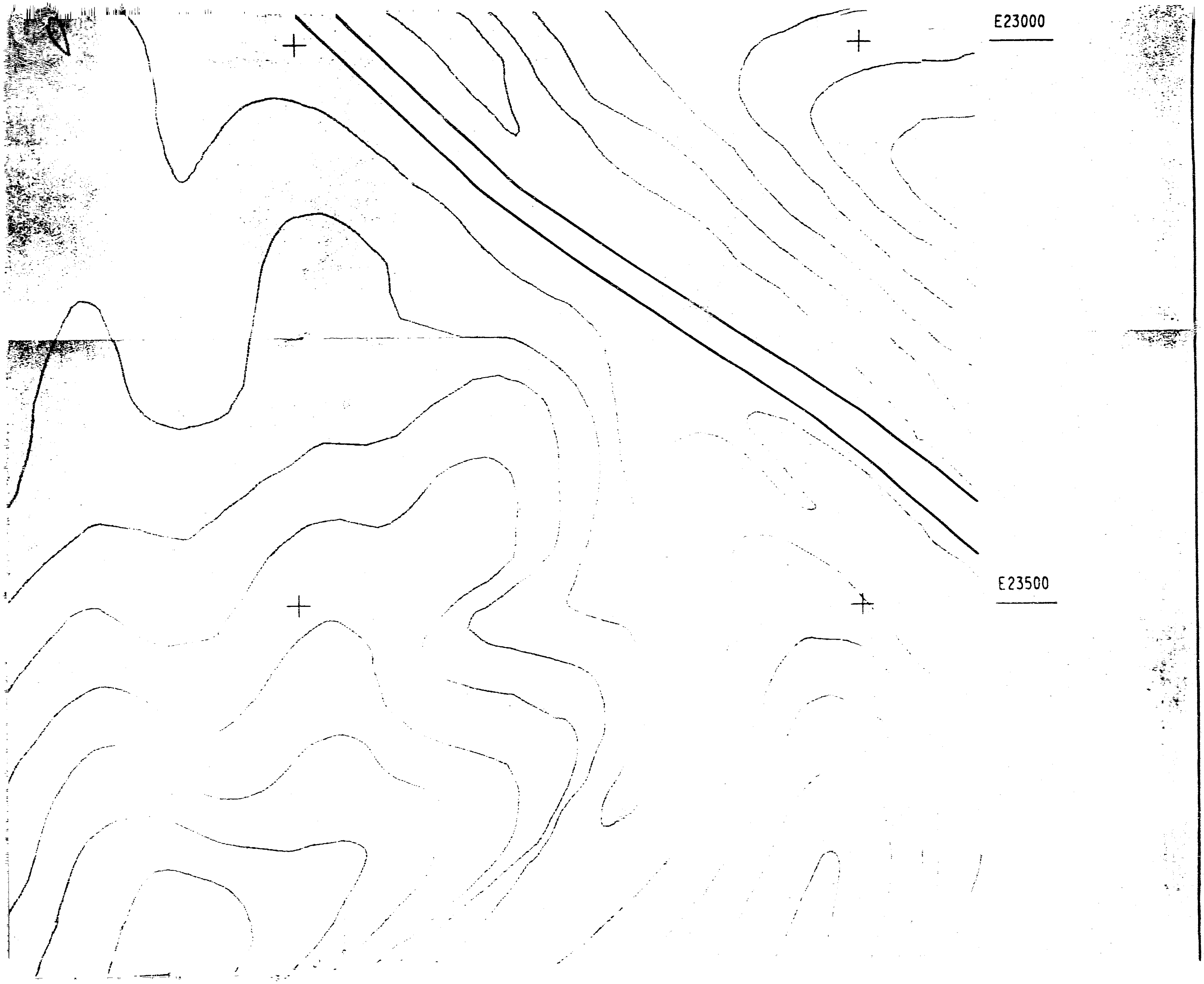
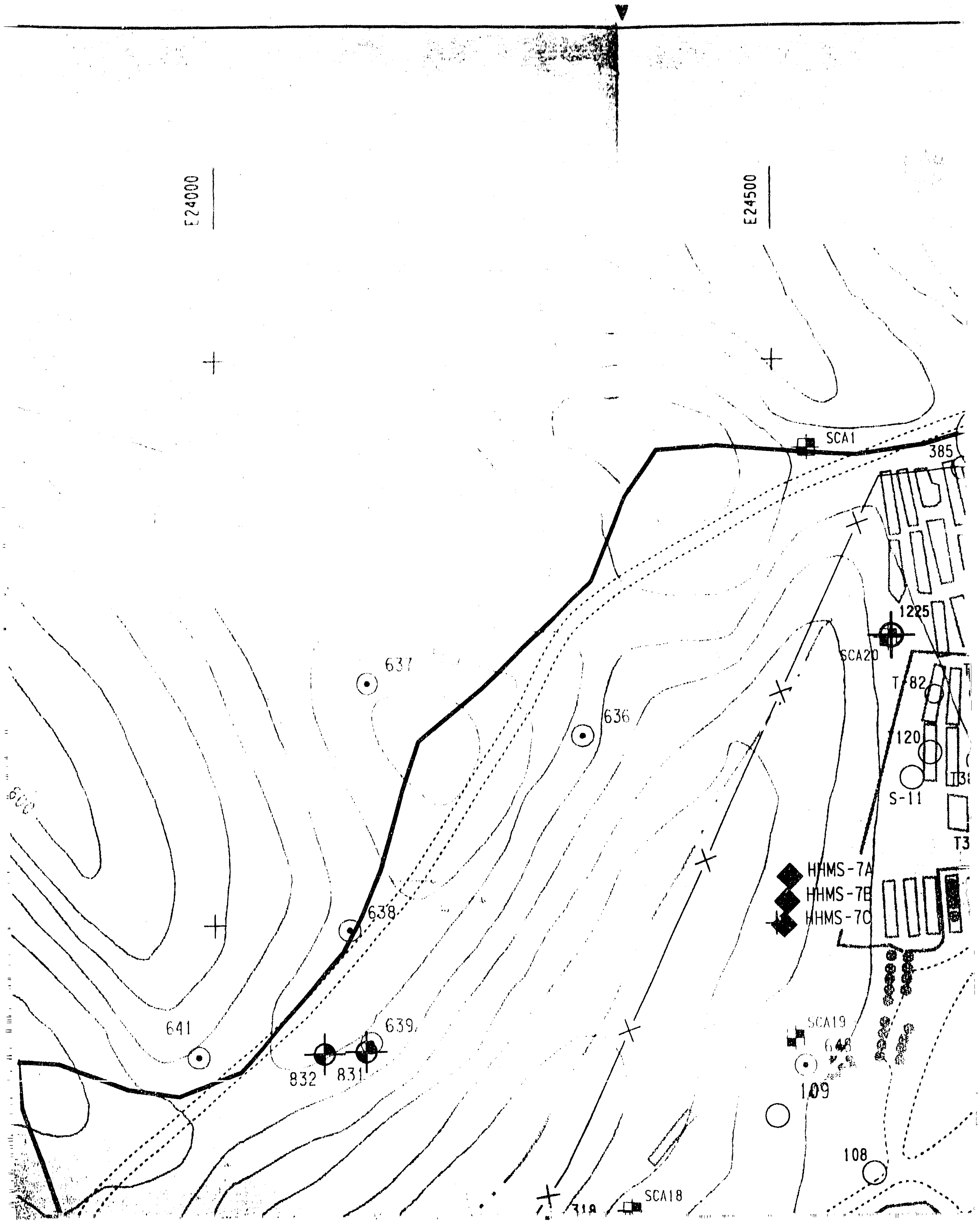
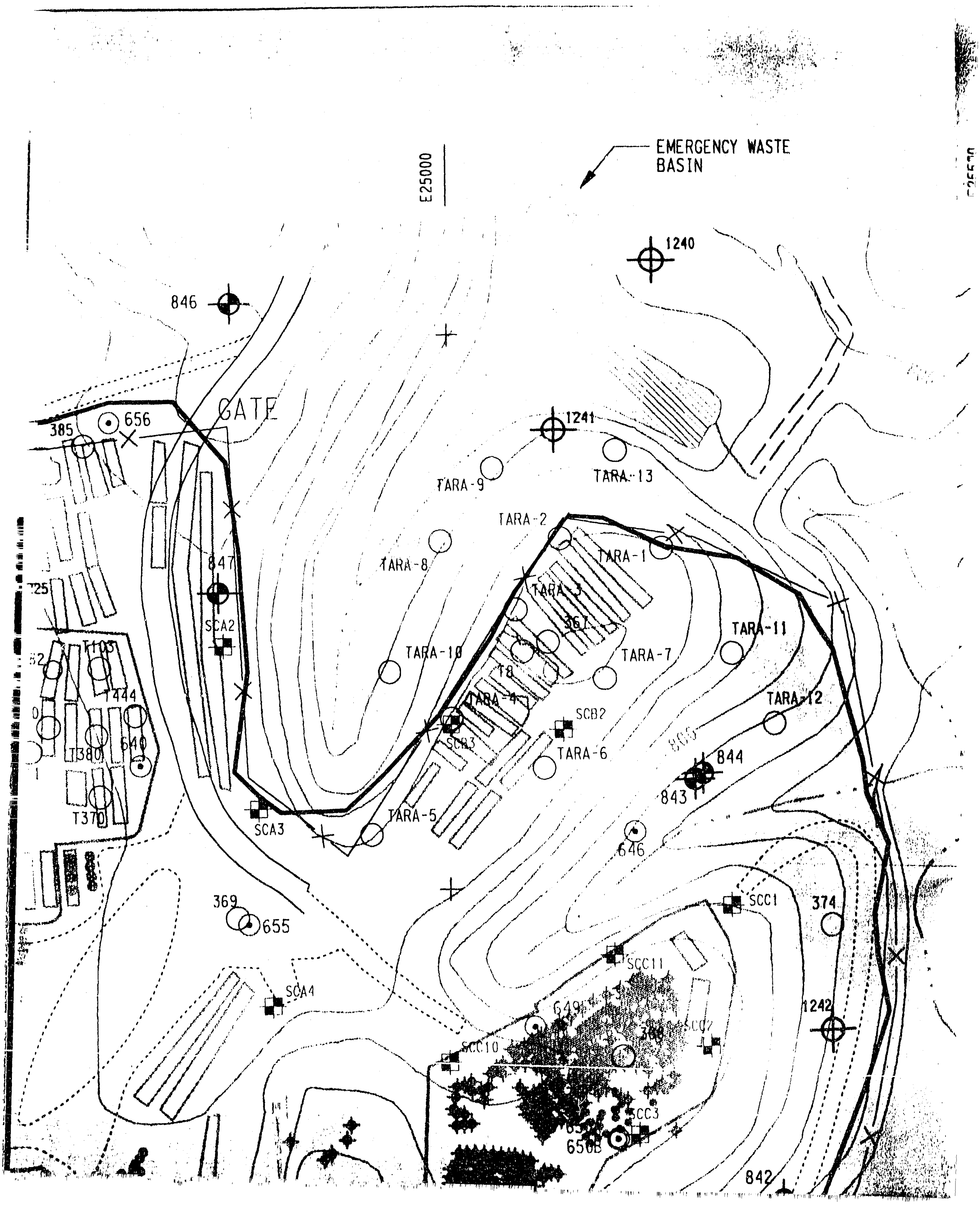


Fig. 1.9. SWSA 6 ICM caps.


TRUE NORTH
ORNL GRID NORTH
34°48'00"
900
N17500


E23000
E23500


E24000
E24500
SCA1
385
1225
SCA20
T-82
T120
S-11
HHMS-7A
HHMS-7B
HHMS-7C
637
636
638
641
639
832
831
SCA19
648
109
108
SCA18


EMERGENCY WASTE BASIN
E25000
1240
846
GATE
656
385
1241
TARA-9
TARA-13
TARA-2
TARA-1
TARA-8
847
TARA-3
SCA2
T103
TARA-10
TARA-7
TARA-11
T444
T8
TARA-4
SCB2
TARA-12
640
SCB3
T380
TARA-6
844
843
T370
TARA-5
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369
655
SCC1
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SCA4
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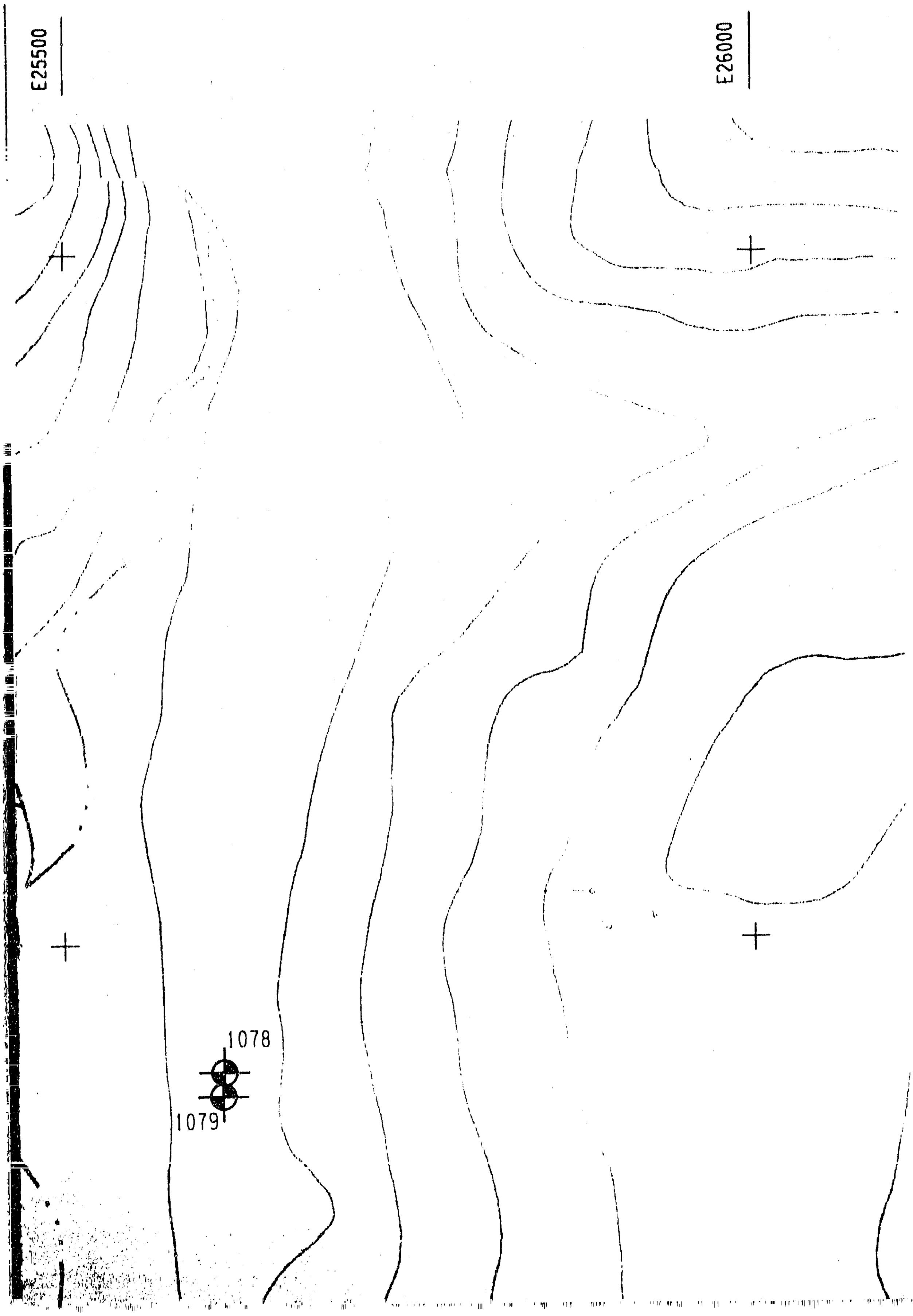
1242
SCC10
SCC3
650B
842

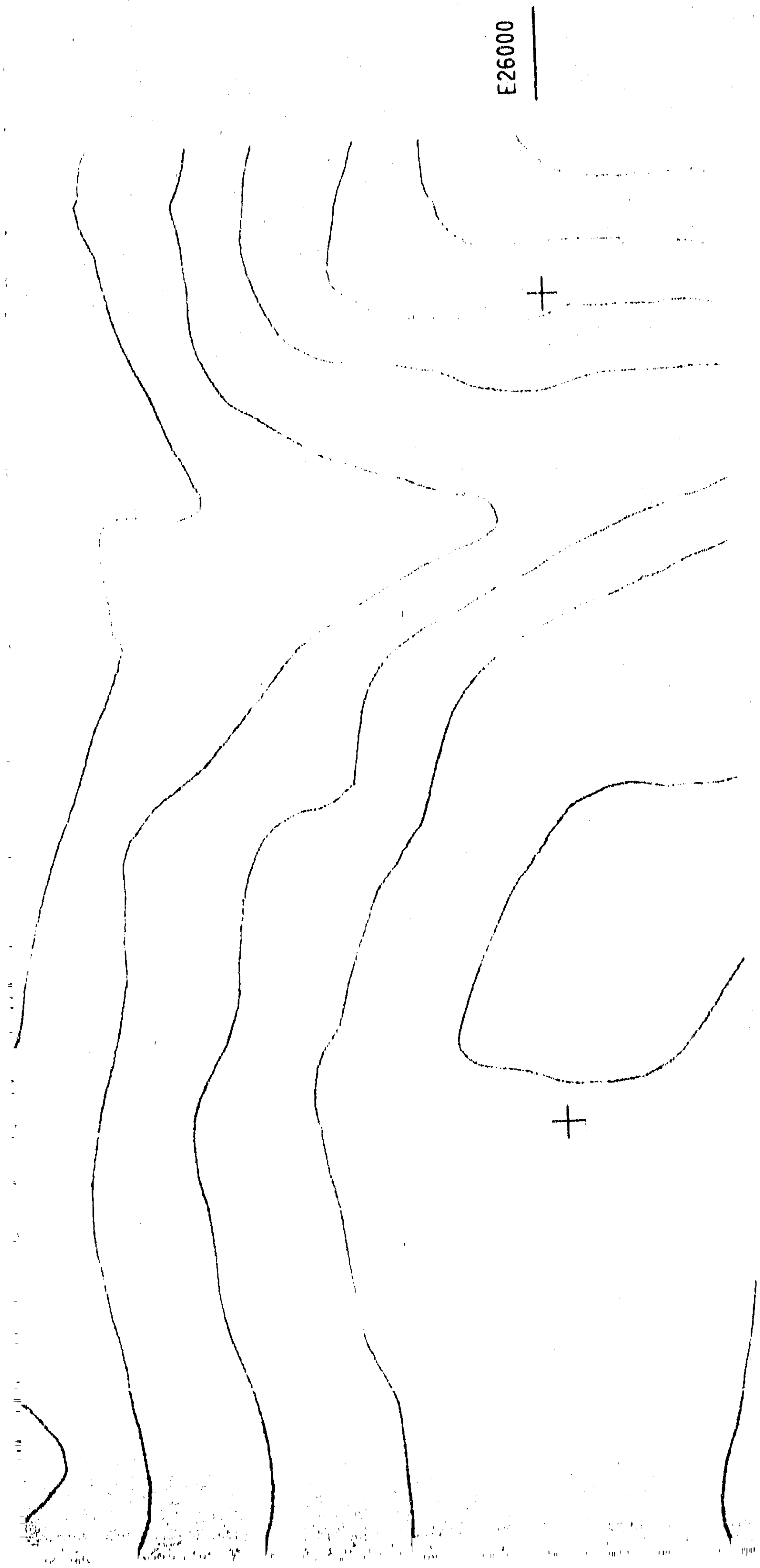


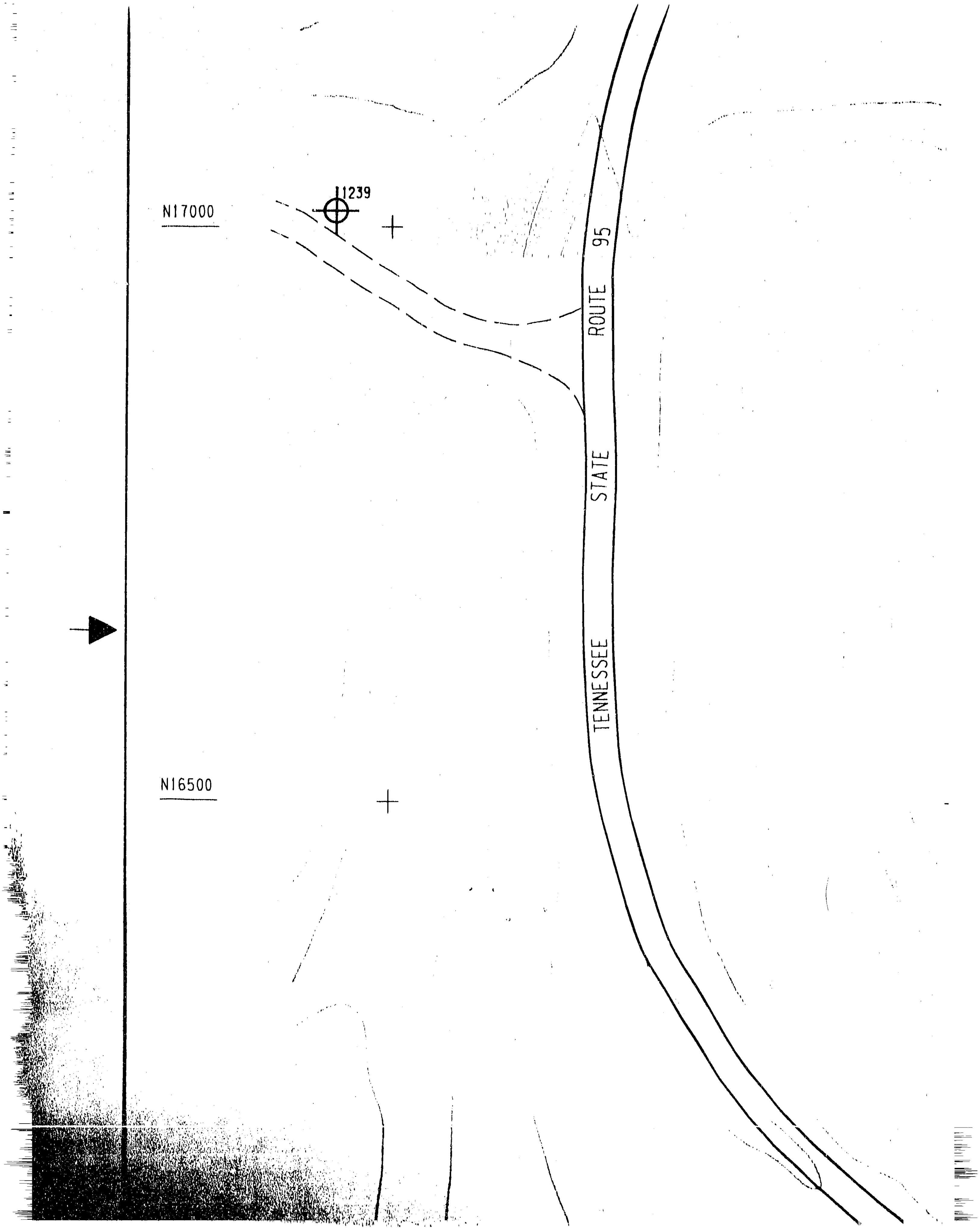
NOTES

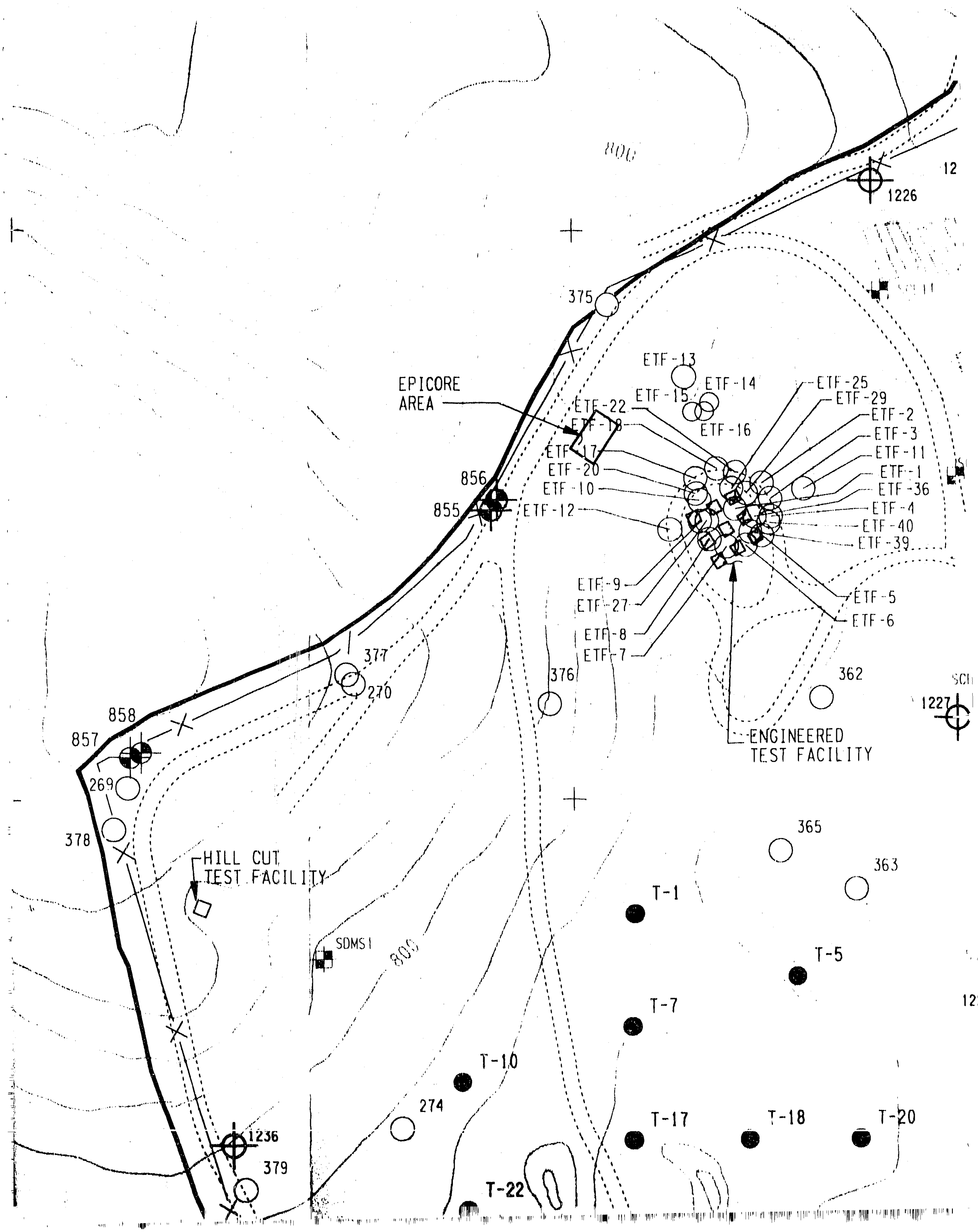
1. ALL COORDINATES ARE
THE ORNL GRID SYSTE
OF DECLINATION OF T
TO TRUE NORTH IS TA
APPROXIMATE CENTER

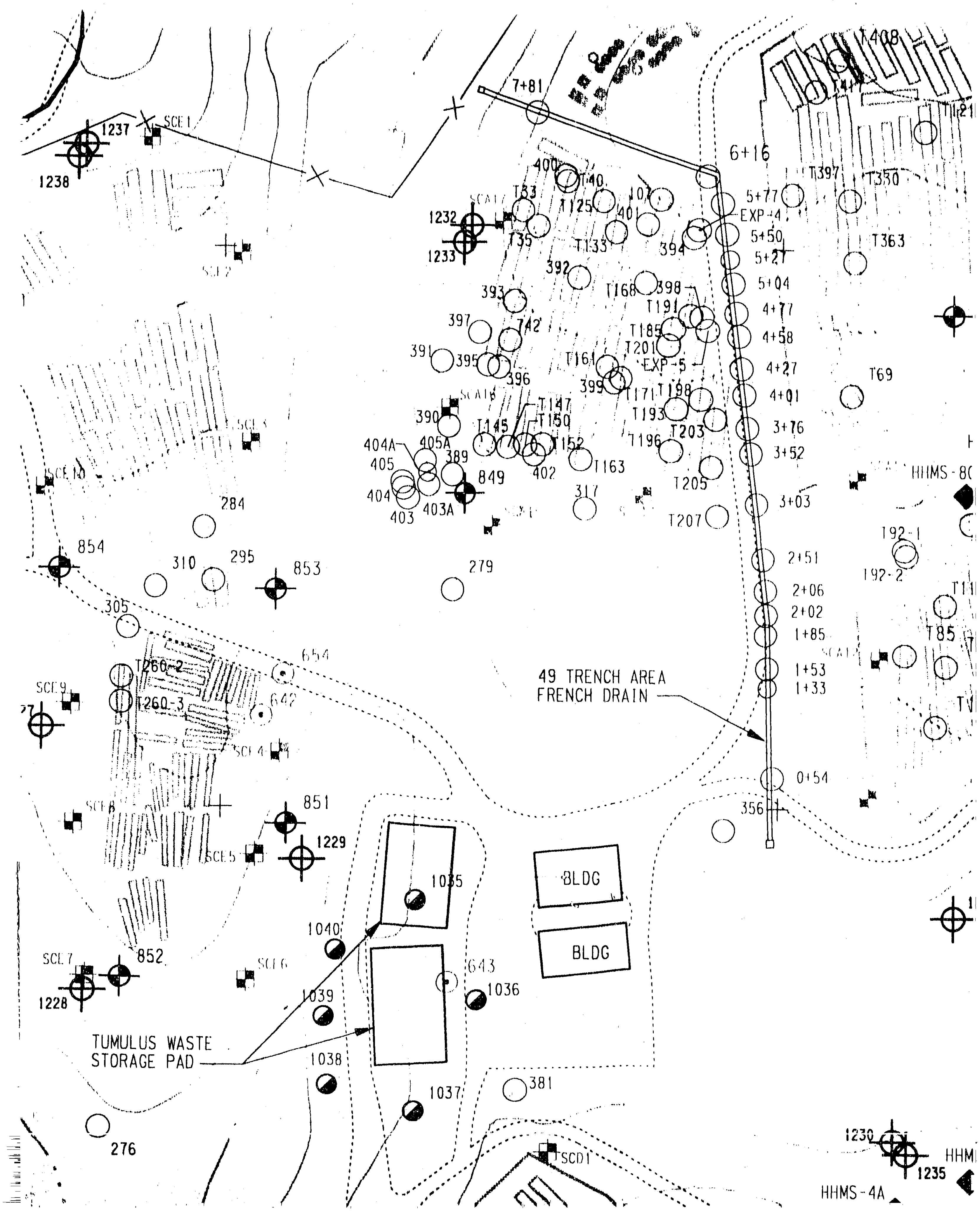
NOTES

1. ALL COORDINATES ARE BASED ON THE ORNL GRID SYSTEM. THE ANGLE OF DECLINATION OF THE ORNL GRID TO TRUE NORTH IS TAKEN FROM THE APPROXIMATE CENTER OF THE WAG.

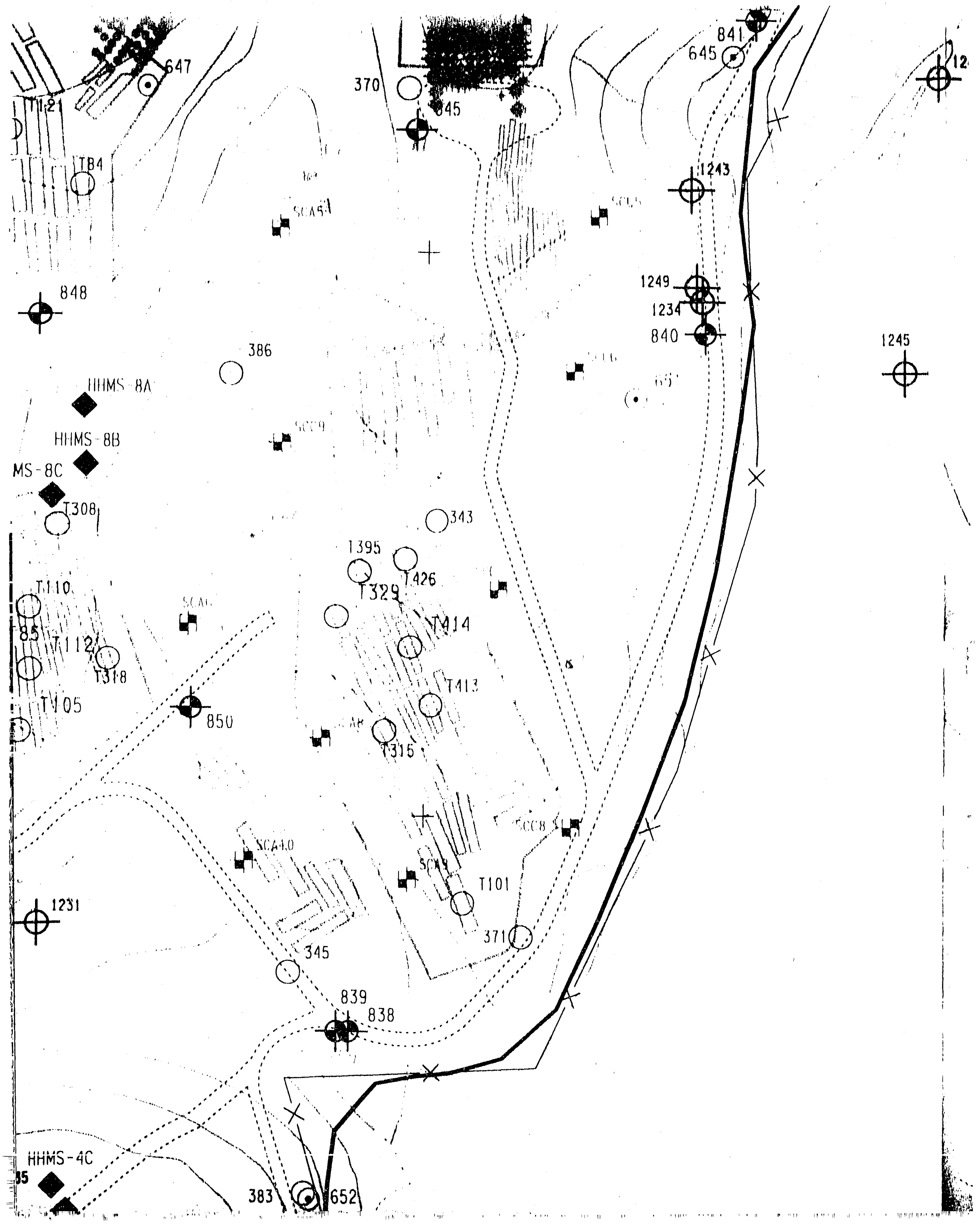


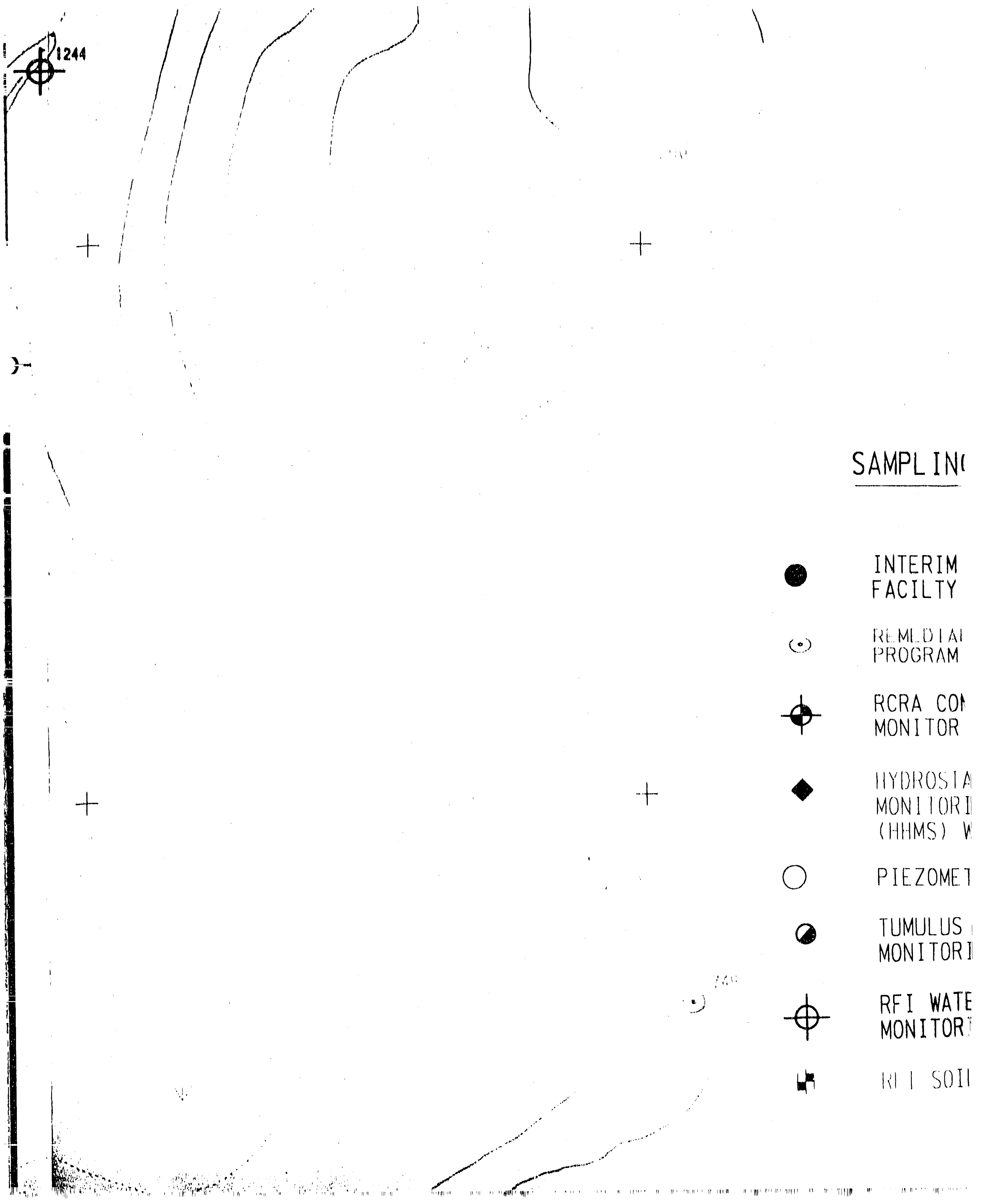

1239
N17000
N16500
TENNESSEE STATE ROUTE 95

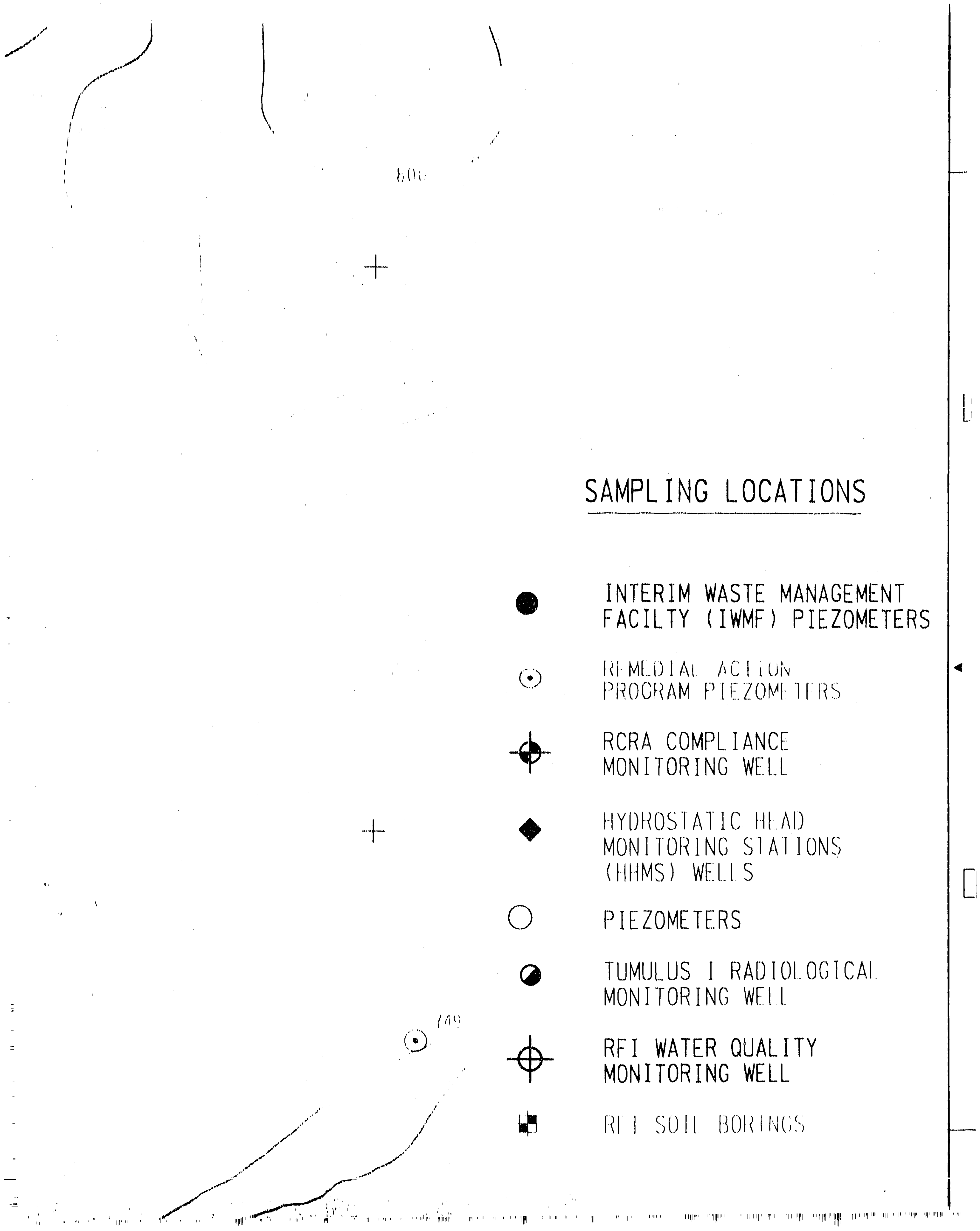

800
12
1226
375
ETF-13
ETF-14
ETF-15
ETF-16
EPICORE
AREA
ETF-22
ETF-18
ETF-17
ETF-20
ETF-10
ETF-12
856
855
ETF-25
ETF-29
ETF-2
ETF-3
ETF-11
ETF-1
ETF-36
ETF-4
ETF-40
ETF-39
ETF-9
ETF-27
ETF-8
ETF-7
ETF-5
ETF-6
377
270
376
362
1227
ENGINEERED
TEST FACILITY
858
857
269
378
HILL CUT
TEST FACILITY
SDMS1
800
365
363
T-1
T-5
T-7
T-10
274
T-17
T-18
T-20
1236
379
T-22

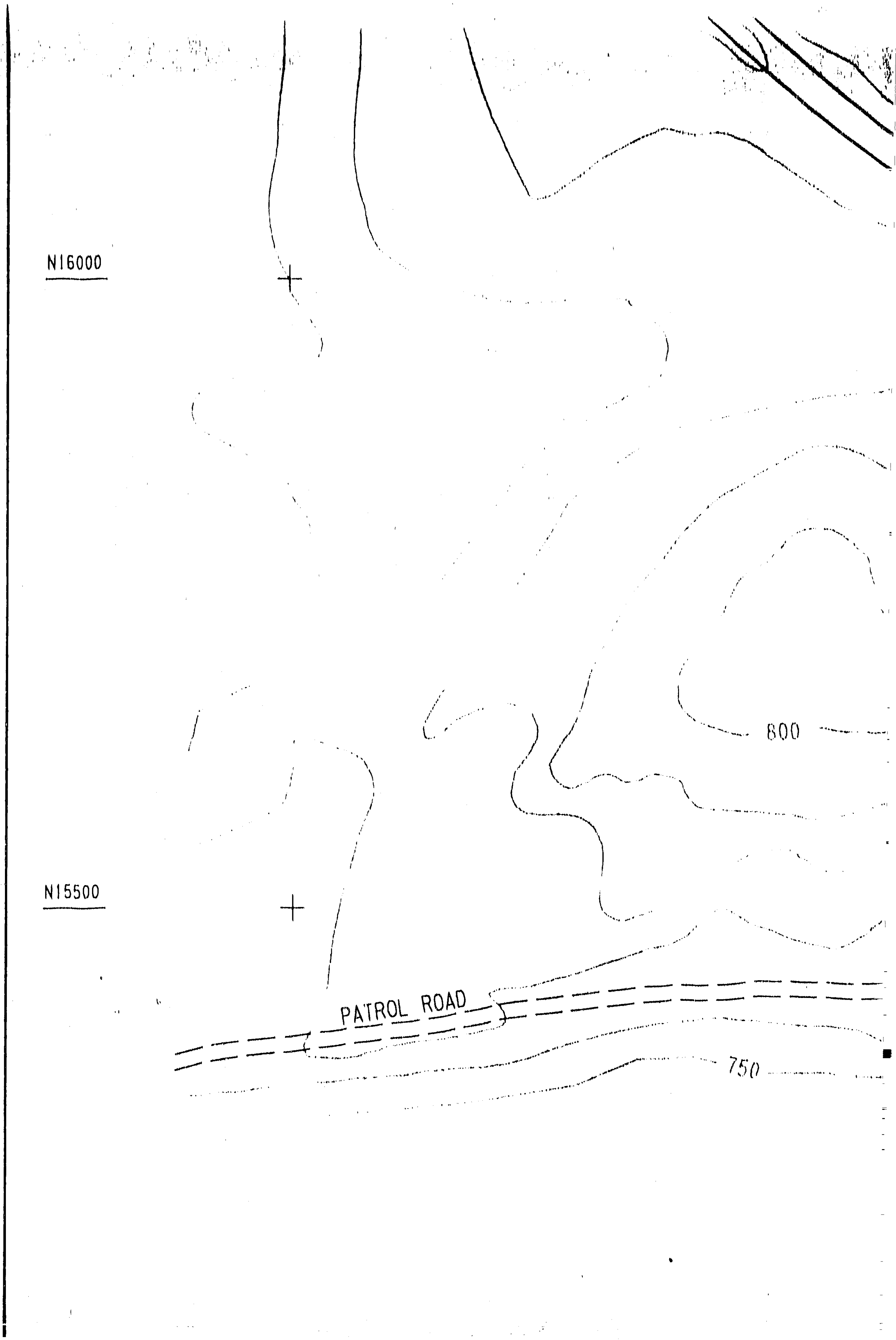


49 TRENCH AREA
FRENCH DRAIN
TUMULUS WASTE
STORAGE PAD
BLDG
BLDG
7+81
6+16
5+77
EXP-4
5+50
5+27
5+04
4+77
4+58
4+27
4+01
3+76
3+52
3+03
2+51
2+06
2+02
1+85
1+53
1+33
0+54
1237
1238
1232
1233
849
854
853
851
1229
1035
1040
1039
1036
1038
1037
852
1228
1230
1235
HHMS-4A
T260-2
T260-3
EXP-5


647
T121
T84
370
845
841
645
1243
1249
1234
840
848
1245
386
HHMS-8A
HHMS-8B
MS-8C
T308
343
1395
T426
T329
T110
T414
85
T112
T318
T413
T105
850
T315
SCC8
SCA10
SCA9
T101
1231
371
345
839
838
HHMS-4C
383
652


1244
SAMPLIN
INTERIM
FACILTY
PROGRAM
RCRA CO
MONITOR
HYDROSTA
MONITORI
(HHMS) W
PIEZOMET
TUMULUS
MONITORI
RFI WATE
MONITOR
RFI SOI


800
749
SAMPLING LOCATIONS
INTERIM WASTE MANAGEMENT FACILTY (IWMF) PIEZOMETERS
REMEDIAL ACTION PROGRAM PIEZOMETERS
RCRA COMPLIANCE MONITORING WELL
HYDROSTATIC HEAD MONITORING STATIONS (HHMS) WELLS
PIEZOMETERS
TUMULUS I RADIOLOGICAL MONITORING WELL
RFI WATER QUALITY MONITORING WELL
RFI SOIL BORINGS



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N15500
800
PATROL ROAD
750

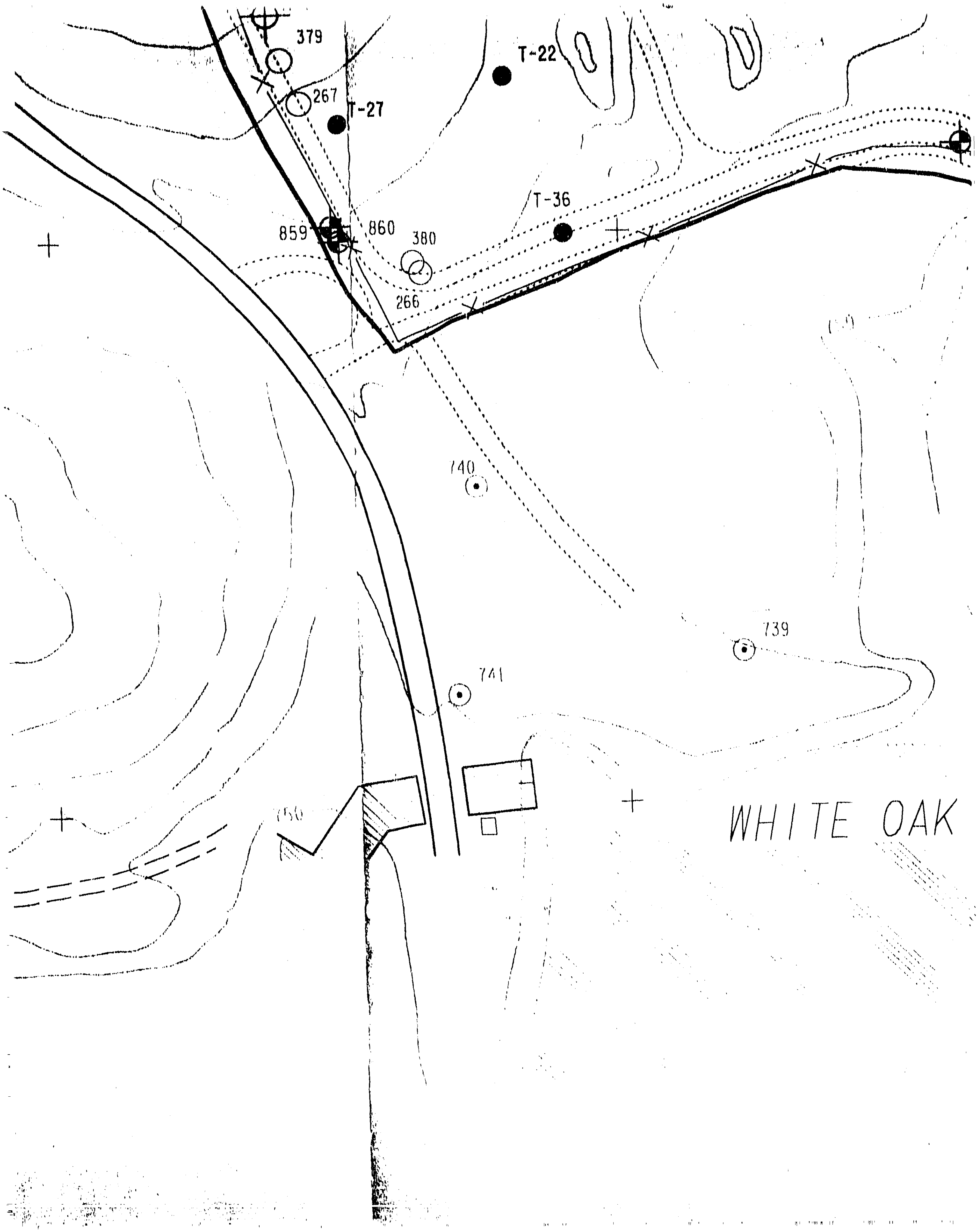
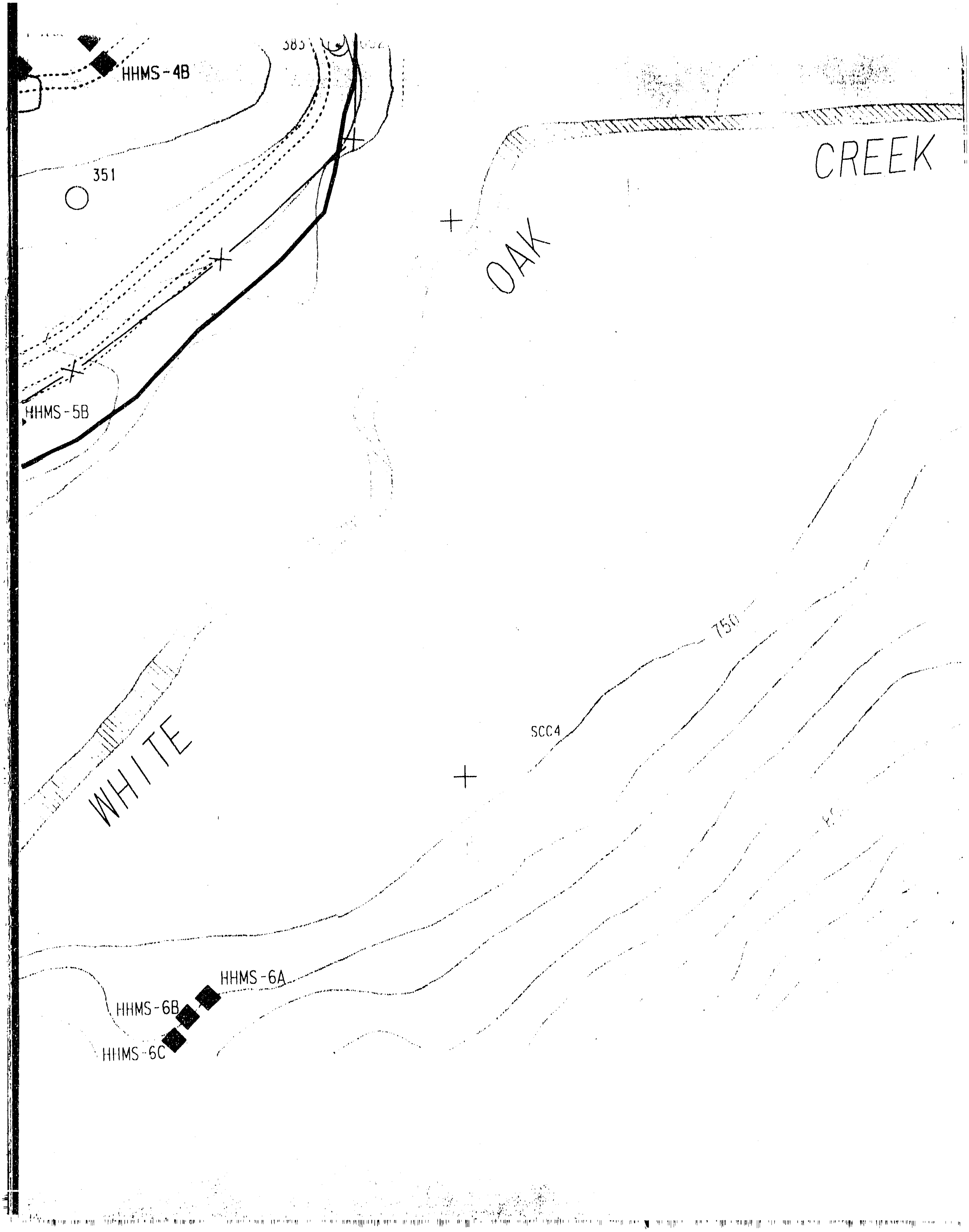
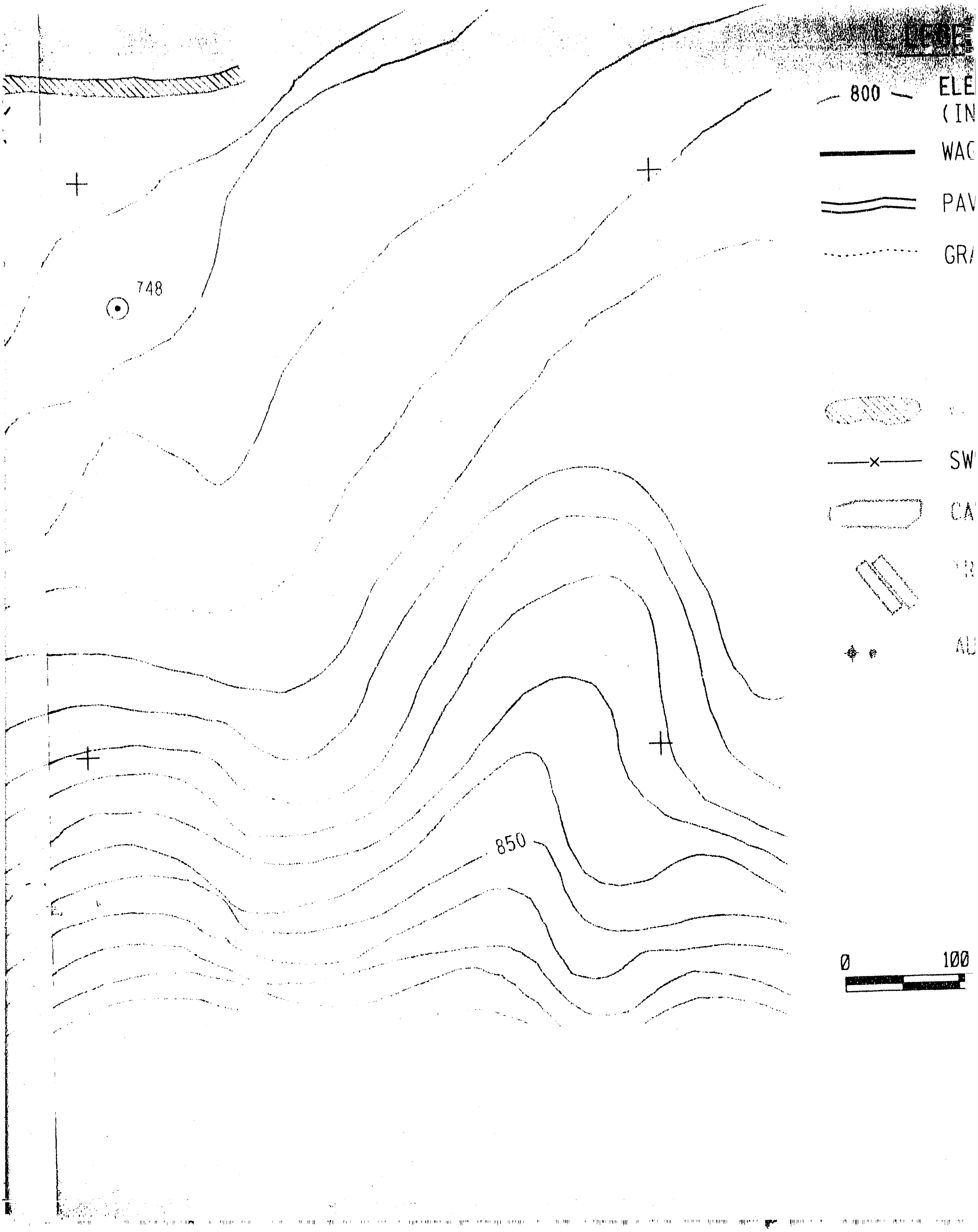

379
267
T-22
T-27
T-36
859
860
380
266
740
739
741
WHITE OAK

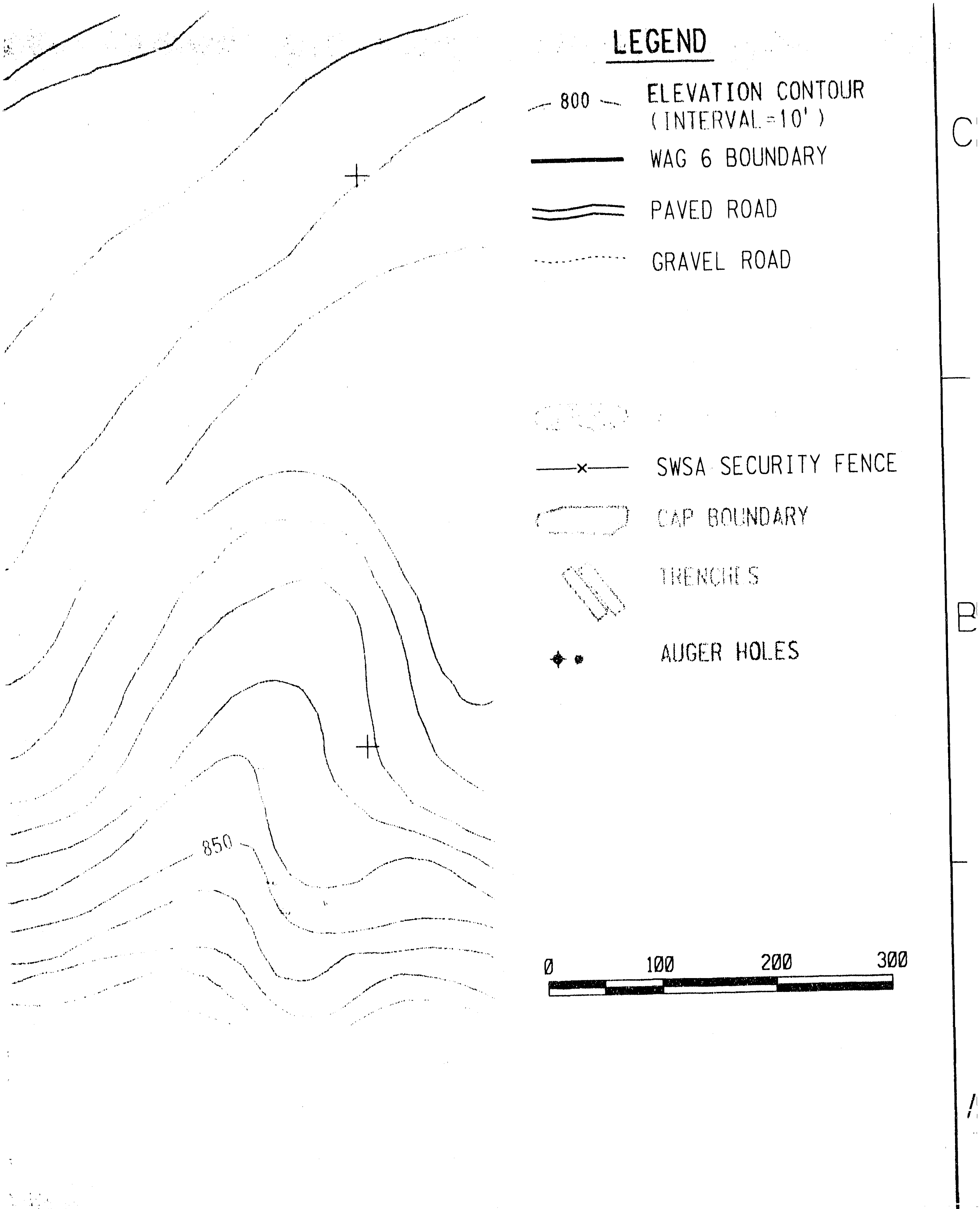
Fig. 1.10 WAG 6 site plan.

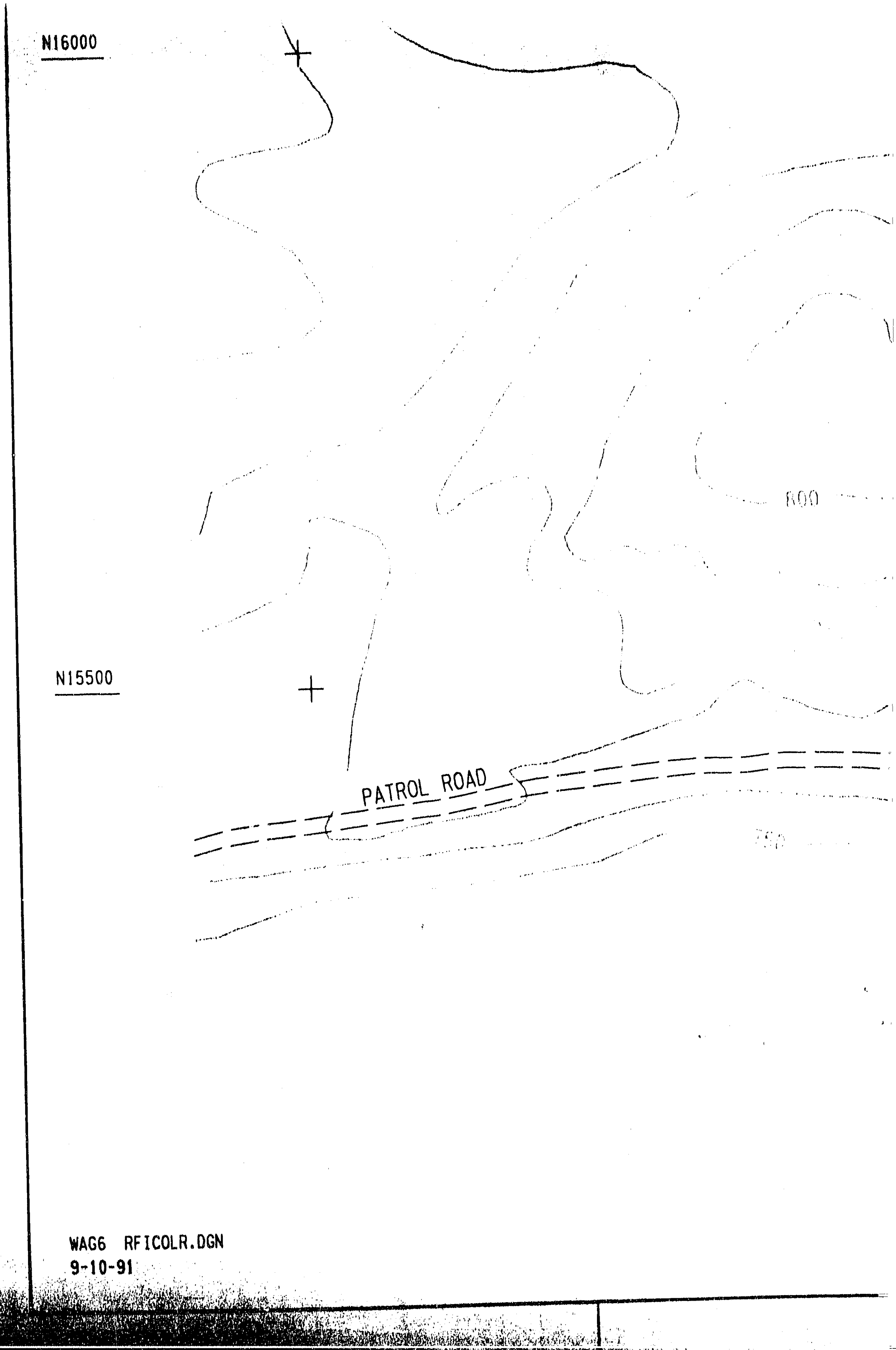


HHMS-4B
351
CREEK
OAK
HHMS-5B
750
SCC4
WHITE
HHMS-6A
HHMS-6B
HHMS-6C

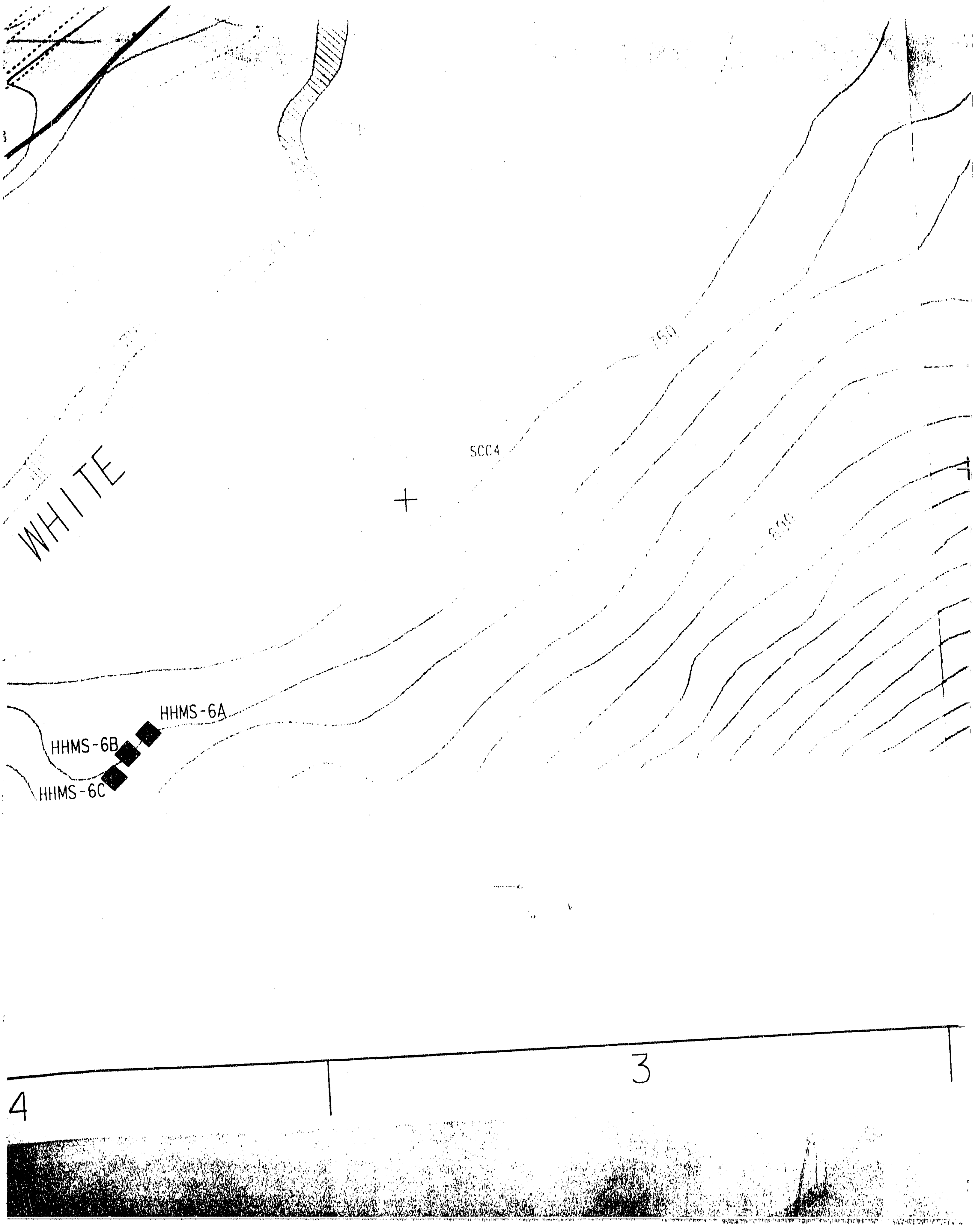


748
800
ELE
(IN
WAG
PAV
GRA
SW
CA
850
0
100


LEGEND
800
ELEVATION CONTOUR
(INTERVAL=10')
WAG 6 BOUNDARY
PAVED ROAD
GRAVEL ROAD
SWSA SECURITY FENCE
CAP BOUNDARY
TRENCHES
AUGER HOLES
0
100
200
300
850



WAG6 RFICOLR.DGN
9-10-91


WHITE
HHMS-6A
HHMS-6B
HHMS-6C
3
4

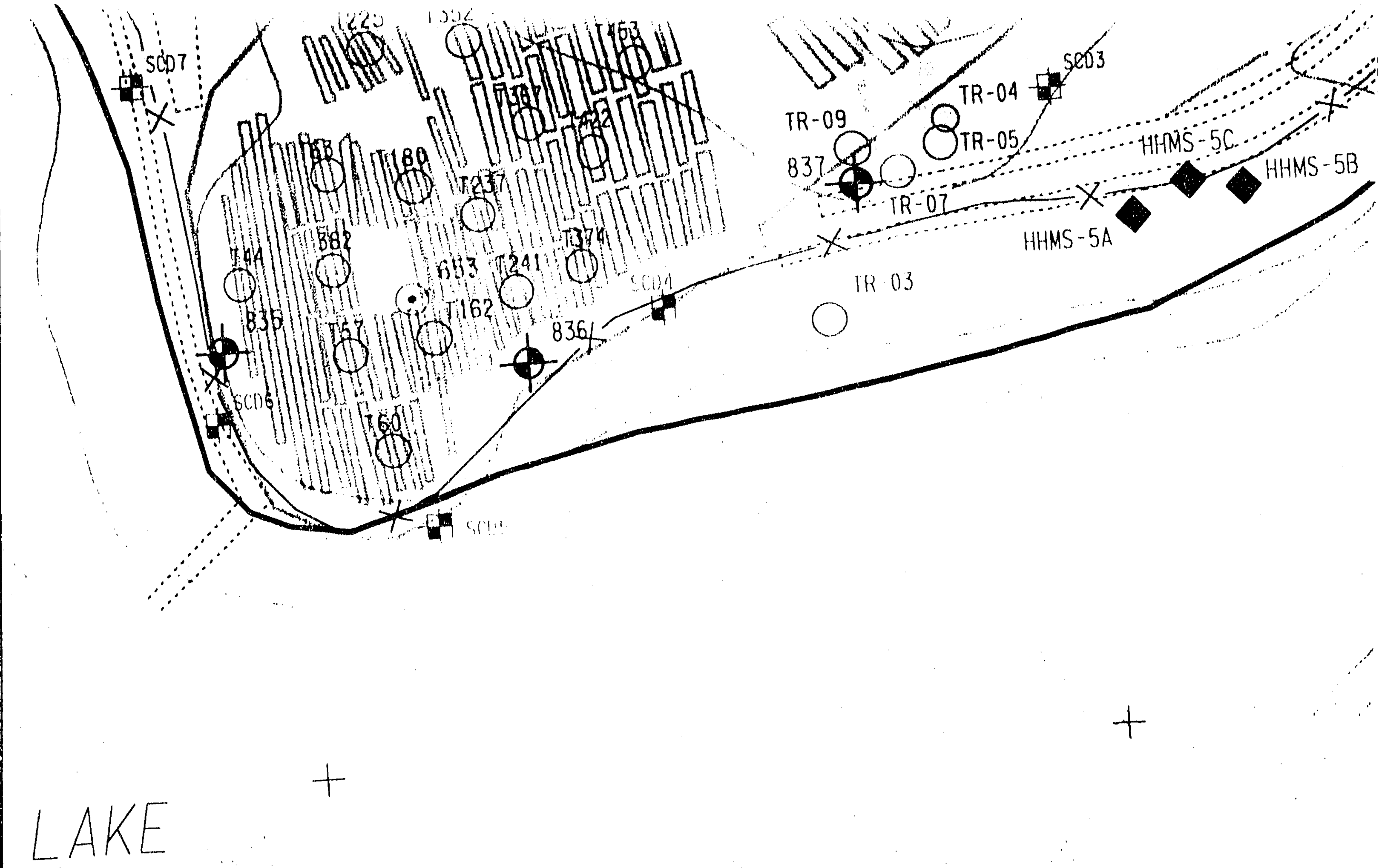
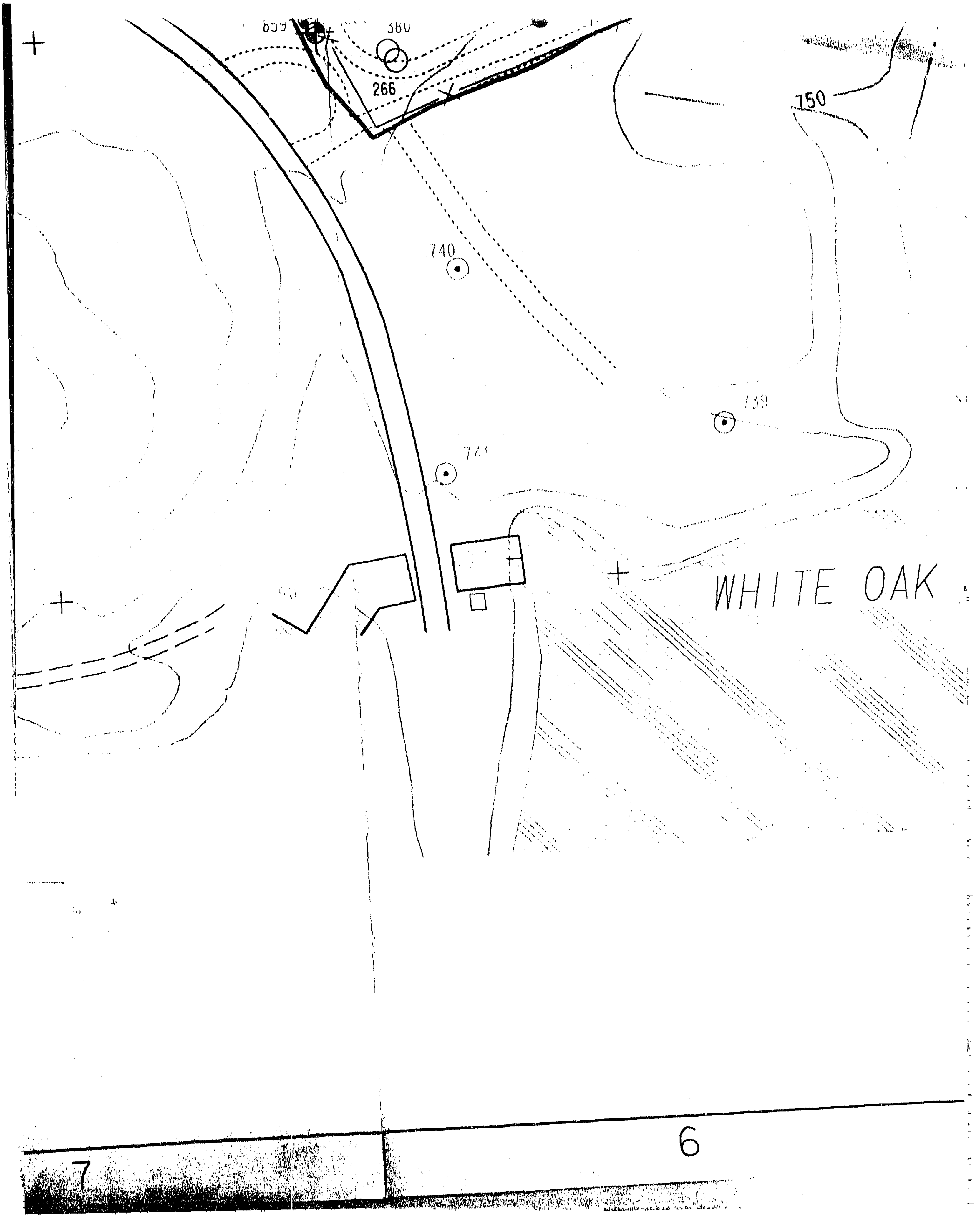
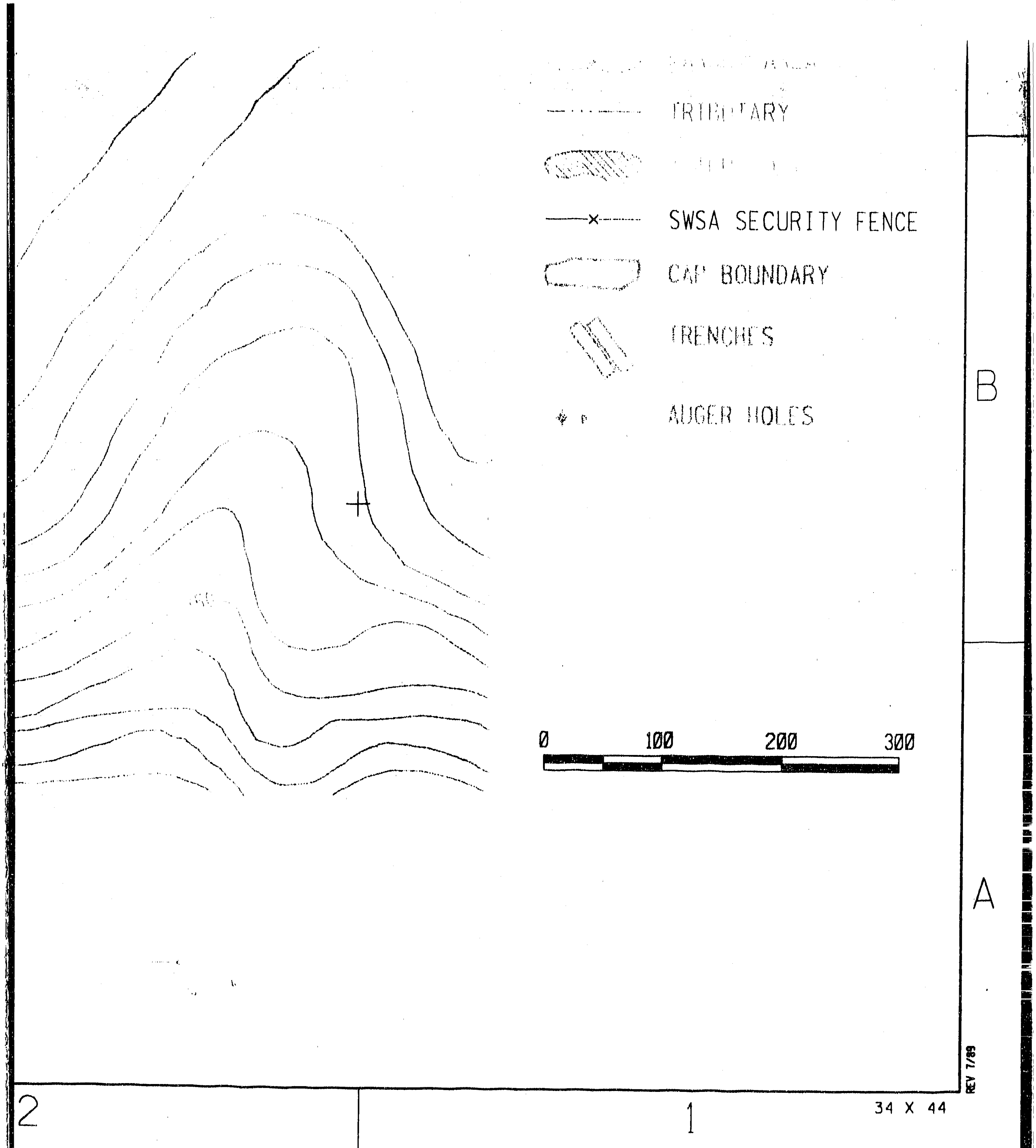


Figure 1.10. WAG 6 site plan.


659
380
266
750
740
739
741
WHITE OAK
6
7


TRIBUTARY
SWSA SECURITY FENCE
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AUGER HOLES
0
100
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B
A
2
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34 X 44
REV 7/89

2. FIELD INVESTIGATION SUMMARY

2.1 INTRODUCTION

This section summarizes the field activities performed specifically for the WAG 6 RFI and outlines pertinent activities from other programs that have contributed to the overall understanding of the site. Interpretations of data collected and descriptions of other, nonfield, activities of the RFI are provided in Sects. 3, 4, and 5.

Field activities to be conducted during the RFI were originally specified in the WAG 6 RFI Plan (BNI 1989). EPA and TDEC reviewed the plan and provided written comments. DOE/Energy Systems responded to these comments in May 1990; comments and corresponding responses are included in Appendix 2A.

A close support laboratory (CSL) was set up at the ORNL RI/FS Program Field Operations Facility (FOF) to permit field radiological screening of environmental samples for gross alpha and gross beta activity. Screening results were used to determine sample shipping and laboratory handling requirements. Health and safety hazardous work permits were prepared for individual work tasks. Workers were briefed on potential hazards, and then each day signed onto and off the appropriate activity-specific hazardous work permits. Investigation-derived wastes were handled according to the ORNL RI/FS Waste Management Plan (BNI 1988b) and approved procedures.

Technical memorandums were prepared for key field activities. These documents summarized sampling and measurement activities (such as equipment used, procedures followed, samples collected, and analyses performed) and analytical results. As described in the introduction, WAG 6 RFI field investigations were conducted in two parts, referred to as Activity 1 and Activity 2. Table 2-1 lists the technical memorandums prepared for WAG 6 RFI field activities and indicates whether they were prepared for Activity 1 or 2. Activity 1 technical memorandums were published in the WAG 6 Site Characterization Summary (BNI 1990a). Activity 2 technical memorandums are published as part of this RFI Report.

2.1.1 Scope

The goals of the WAG 6 RFI were:

- To characterize the nature and extent of contamination associated with WAG 6 sufficiently to achieve the next two goals
- To assess potential impacts of disposed wastes and environmental contamination on human health and the environment
- To identify preliminary site closure and remediation objectives and perform the initial development and screening of alternatives
- To provide data to support the development of site closure and corrective action alternatives

The investigation included compiling and evaluating historical data associated with past waste disposal activities and data from other investigations of site conditions. WAG 6 RFI field investigations were designed specifically to verify and/or fill gaps in the historical data and to thereby accumulate sufficient data to perform base line human health and environmental evaluations and a CMS. The following field activities were conducted by Energy Systems and its subcontractors. Each activity is described in subsequent subsections.

- Surface radiological and gamma radiation exposure rate surveys
- Surface geophysical survey
- Soil gas and well headspace surveys
- Evaluation of existing wells
- Installation of monitoring wells
- Groundwater sampling
- Measurement of groundwater levels
- Installation of flumes on four main drainageways
- Surface water storm flow measurements using flumes and weirs
- Surface water and sediment sampling
- Surface and subsurface soil sampling
- Biohazard investigation
- Borehole geophysical logging
- Survey for threatened and endangered species
- Wetlands survey
- Reference (background) sampling

Unless otherwise noted, RFI sampling was performed in accordance with ORNL procedures for environmental surveillance. When planned activities were not addressed by existing ORNL procedures, special project-specific procedures were prepared and used. Because of their volume, the project procedures are not included in this report, but copies of any or all procedures can be obtained by contacting DOE/Energy Systems.

Analytical protocols for samples collected during the RFI are summarized in Tables 2.2 through 2.8, as follows:

- Table 2.2, "Target Compound List as Defined in 1988 Contract Laboratory Program (CLP) Statement of Work—VOCs"
- Table 2.3, "Target Compound List as Defined in the 1988 CLP Statement of Work—Semivolatiles"
- Table 2.4, "Target Compound List as Defined in 1988 CLP Statement of Work—Pesticides and PCBs"
- Table 2.5, "Target Analyte List as Defined in 1988 CLP Statement of Work"
- Table 2.6, "Radiological Analytical Parameters"
- Table 2.7, "Field Parameters and Major Ions for Water Samples"
- Table 2.8, "RCRA Appendix IX Constituents"

2.1.2 Data Quality Review

To ensure that data quality objectives (DQOs) were achieved for all RFI samples collected, quality control (QC) levels were assigned to all samples submitted for analysis. These QC levels determined the frequency or percentage of QC samples to be evaluated for each analysis. QC levels also determined the amount of supporting documentation, regarding the analysis of the sample, that would be submitted by the laboratory with each sample result package. All data received from the analytical laboratory were reviewed for contract compliance and were submitted for validation. Sample results were qualified (flagged) by the data reviewer to indicate problems or a reduced level of data quality if required as a result of either field or analytical deficiencies. Appendix 4A presents a detailed assessment of the quality of WAG 6 RFI environmental data.

2.1.3 Data Completeness

As part of the evaluation of RFI data quality (Appendix 4A), an assessment of data completeness was performed; this constituted an inventory of the number of samples collected and analyses actually performed for each media compared to those projected in the RFI Plan. Sampling and analytical completeness for each media are summarized below.

Media	Sampling completeness (%)	Analytical completeness (%)
Groundwater	79	97
Surface water	122	99
Sediment	169	99
Soil	65	99

Sampling completeness was assessed by comparing the number of samples that were planned to be collected and analyzed to the actual number collected and analyzed. The percent completeness for each media was calculated for all individual analytical suites (Appendix 4A). These numbers were averaged to derive the numbers presented above. The groundwater sampling completeness of 79% is the result of a lower than projected frequency of analysis for dioxins/furans, herbicides, and organophosphorous/pesticides as well as for miscellaneous parameters including biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), and total organic halides (TOX). The reduced frequency of analysis (relative to plan) for dioxins/furans, herbicides, and organophosphorous/pesticides corresponded to a reduced frequency of Appendix IX analyses relative to Target Compound List (TCL) analyses. For the miscellaneous groundwater parameters, it was determined that the reduced frequency was adequate to meet the data needs of the base line risk assessment and alternative assessment. Sampling completeness percentages for groundwater semivolatile organic compounds (SVOCs), volatile organic compounds (VOCs), and inorganics were 153%, 155%, and 202%, respectively.

The 65% soil sampling completeness is primarily a result of an over-estimate in the RFI Plan of the number of samples that would be determined appropriate for laboratory analyses based on field screening analyses. In addition, soil samples were not collected as projected in the plan at the former EDT. Based on interviews with ORNL operations personnel, the EDT is located immediately adjacent to numerous waste disposal trenches and is covered by the RCRA ICM cap. The EDT was essentially addressed as part of SWSA 6 in the RFI, and was not addressed individually in terms of the base line risk assessment or alternatives assessment.

Analytical completeness is the percentage of useable data derived from the sampling activities performed. As indicated above, analytical completeness exceeded 95% for all media, which was the target completeness goal.

2.2 SURFACE RADIOLOGICAL SURVEY

Surface radiological surveys were performed during both Activity 1 and Activity 2. The survey for Activity 1 was performed over most of SWSA 6, while the Activity 2 survey was performed on a portion of WAG 2 and the EWB. Both surveys consisted of a surface scan and discrete measurements made at locations shown in Fig. 2.1.

For both surveys four types of measurements were made:

- A continuous near-surface gamma radiation measurement, made with a sodium-iodide detector within 15 cm of the ground surface
- Fixed-position gamma radiation measurements, made with a sodium-iodide detector in a cone shield 30 cm above the ground surface
- Total beta-gamma radiation measurements, made with a pancake Geiger-Muller detector contacting the ground surface
- Gamma radiation exposure rate measurements, made with a pressurized ionization chamber (PIC) 1 m above the ground surface

2.2.1 Activity 1 Radiological Survey

Between July 16, 1988, and September 11, 1988, a walkover survey was conducted on approximately 74% of WAG 6 (49 acres). The survey characterized radioactive contamination of surface soils and helped define site-specific worker health and safety requirements for implementation of the RCRA ICM and RFI field activities. The ICM caps were placed over trenches to prevent surface water infiltration. The survey identified a number of locations at which surface radiation levels were higher than three times daily background (which was measured off the WAG). These areas were field marked for remediation during site preparation for placement of the ICM caps. Gamma radiation exposure rate measurements were used to support the base line human health risk assessment.

2.2.2 Activity 2 Radiological Survey

Between December 5, 1989, and February 16, 1990, an additional walkover survey was performed for the EWB area and a portion of WAG 2. Isolated areas of above-normal surface radiation were identified in the northern area of the EWB and in the WOC area. Elevated radiation survey readings were used as input for the selection of soil sampling locations and also were used to determine appropriate health and safety requirements for RFI workers.

2.3 GEOPHYSICAL SURVEY

An electromagnetic terrain conductivity (EM) survey was performed during Activity 1 in November 1988. The survey objectives were to help identify potential contaminant plumes, to guide the siting of groundwater wells and soil borings, and to delineate the trench areas and the areas for surface soil investigation.

Twenty-three survey lines, oriented east-west on the ORNL grid system and spaced 100 ft apart, covered the area inside the SWSA 6 security fence. At 10-ft intervals along the lines, data were collected. A Geonics EM 34 terrain conductivity meter was employed in the survey. Figure 2.2 shows the survey lines and electromagnetic contour lines.

The EM survey data were interpreted based on general conductivity values; locations showing conductivity anomalies were noted. The EM data revealed considerable interferences from fences, power lines, and metallic materials at the ground surface (e.g., piping and debris). Due to this interference, the EM survey was unable to clearly define the trench area boundaries or any contaminant plumes that might have been present.

The RFI Plan specified a specific geophysical investigation to discover the location of a transuranic (TRU) cask that was reportedly buried in a trench at SWSA 6; however, this investigation was not conducted. Discussions with waste management personnel indicated that containers, boxes, and casks containing wastes were buried in many trenches at the SWSA. It was determined that geophysical methods would not be able to discriminate between the TRU cask and the numerous other such containers and other objects (e.g., lead shielding) buried at the site.

2.4 SOIL GAS SURVEY

Soil gas surveys were performed during Activity 1 and Activity 2. Each is discussed separately in the following subsections.

2.4.1 Activity 1 Soil Gas Survey

The Activity 1 soil gas survey was conducted within SWSA 6 to detect the presence of VOCs around the perimeter of selected trench areas. The survey was conducted in three phases. During the first phase, conducted between March 7, 1989, and March 29, 1989, 84 soil and well gas (headspace) samples were collected and measured for VOC concentrations with flame ionization and photo ionization field analytical instruments. In the second phase, conducted between April 3 through 7, 1989, 41 of the earlier sampling locations that had shown elevated VOC concentrations were resampled, and the samples were analyzed with a portable gas chromatograph (GC). In general, soil gas sample depths ranged from 4 to 9 ft. During the third phase, 10 nonintrusive VOC sampling devices were placed, retrieved, and analyzed April 5 through 11, 1989, by Quadrel Services, Inc. Figure 2.3 shows soil gas sampling locations for Activity 1. Results were used (with other data) to identify potential VOC contaminant plumes and to help select locations for soil sampling and installation of groundwater monitoring wells.

2.4.2 Activity 2 Soil Gas Survey

During Activity 2, a soil gas investigation was conducted from December 1989 through January 1990 in the EWB area and in four areas within SWSA 6, as shown in Fig. 2.4. This survey's purpose also was to detect the potential presence of VOCs and, in conjunction with other nonintrusive surveys, to locate soil sampling points.

Because of wet conditions during Activity 2, extraction of soil gas in situ was not feasible. Instead, soil samples were collected from a depth of 12 in. to 18 in. and taken to the CSL for soil headspace GC analysis. The soil headspace samples analytical results indicated the presence of VOCs in the soil, and this information was used to identify additional well locations. Well headspace samples were also collected during Activity 2; after collection and equilibration, these were returned to the CSL for analysis by GC.

2.5 GROUNDWATER INVESTIGATION

This section discusses the groundwater monitoring that was performed during Activity 1 and Activity 2 of the RFI. The groundwater investigation utilized two groups of wells: the 800 series, which are the ORNL RCRA Compliance Program wells, and the 1200 series, which were installed specifically as part of the WAG 6 RFI.

There are 30 RCRA compliance wells and 22 RFI wells. All 52 wells were installed between June 1987 and June 1990. All were constructed with stainless steel screens and casing and were drilled and installed in general conformance with the RCRA Groundwater Monitoring Technical Enforcement Guidance Document (TEGD) (EPA 1986a).

2.5.1 ORNL RCRA Groundwater Compliance Program

The 30 ORNL RCRA compliance wells were installed to sample the shallow portion of the water table aquifer, which, as described in Sect. 3, comprises the majority of active groundwater flow. For compliance purposes, 21 of the 30 wells have been designated to serve as the actual RCRA monitoring network, which consists of 14 perimeter wells and 7 upgradient wells that serve as the reference wells. The remaining nine wells are located within SWSA 6 and are used for characterization purposes only.

With few exceptions, wells designated as part of the compliance monitoring network were installed as well pairs. The shallow well of each pair generally is screened to monitor the zone of fluctuation of the water table, while the deeper well is installed below the water table completely within the zone of saturation. The locations of ORNL RCRA compliance wells are shown in Fig. 2.5.

2.5.2 WAG 6 RFI Monitoring Well Installation

The 22 WAG 6 RFI groundwater monitoring wells were installed to improve upon the definition of groundwater contamination that could be provided by the RCRA compliance network alone. Nine of the RFI wells (1225 through 1233) are shallow wells and were installed in March 1989 as part of Activity 1. The remaining 13 wells, consisting of 4 deep bedrock wells (1234, 1236, 1238, 1239), 6 intermediate-depth bedrock wells (1249, 1237, 1241, 1242, 1244, and 1245) and 3 additional shallow wells (1235, 1240, 1243) were installed as part of Activity 2 between January and May 1990. RFI well locations are shown in Fig. 2.6. Details of the RFI well installations for Activity 1 and Activity 2 are provided in the following subsections.

2.5.2.1 Activity 1 well installation

Eight well points and nine RFI wells were installed in SWSA 6 during Activity 1 of the WAG 6 RFI. The well points were installed before well installation to determine the depths for positioning the well screens. The well points depths ranged from 7.8 to 35.5 ft. The well depths, selected on the basis of water levels measured in the well points, ranged from 7.5 to 24.0 ft. Screened intervals ranged from 2.0 to 22.5 ft.

Three of the first nine RFI wells were installed as storm flow zone wells. (For a discussion of storm flow, see Sect. 3.) The six other wells were installed to allow sampling of the shallowest groundwater.

2.5.2.2 Activity 2 well installation

Thirteen additional RFI groundwater monitoring wells were installed from January through May 1990. Well locations and completion depths were selected based on analysis of data collected during previous investigations. Monitoring well completion depths were 23.6 to 27.2 ft in the shallow overburden (regolith), 27.32 ft in the contact zone, 24.09 to 70.5 ft in the intermediate bedrock, and 147 to 160 ft in the deep bedrock. Screen intervals ranged from 15 to 20 ft. (Rock cores were obtained from Deep Well 1234 and from a portion of Well 1237.)

2.5.3 Geophysical Logging of RFI Bedrock Wells

The four deepest bedrock monitoring wells (1234, 1236, 1238, and 1239) were used to assess the groundwater quality and hydrology of the lower flow component of the shallow aquifer system. Following drilling and before well installation, all four open boreholes were geophysically logged by ORNL. Table 2.10 summarizes the borehole geophysical logging program. The primary objectives of the geophysical logging were: (1) to identify water-bearing fractured bedrock to aid in selecting well screen intervals and depths for future well installations; (2) to further characterize local bedrock geology and hydrogeology; and (3) to allow stratigraphic and structural comparisons with existing geophysical logs for hydraulic head monitoring station (HHMS) wells located within SWSA 6. The geophysically logged wells are shown in Fig. 2.6.

2.5.4 Groundwater Sampling and Analysis

Sampling and analysis of groundwater was conducted to investigate the nature, extent, and concentrations of contaminants present in the groundwater, to evaluate groundwater geochemistry, and to help determine the potential for contaminant migration from WAG 6. Beginning in June 1988, 10 distinct sampling events were conducted among the monitoring wells at WAG 6, either as part of ORNL RCRA compliance monitoring or WAG 6 RFI activities. Table 2.11 indicates the wells that were sampled during each sampling event, and Tables 2.12 and 2.13 indicate analytical suites for each well for each round. Along with the sampling event, water level measurements were collected prior to purging the well.

As indicated in Table 2.11, the first WAG 6 RFI groundwater sampling event occurred in April through May 1989, which coincided with the fourth sampling event of the RCRA compliance monitoring program. The RFI sampling included Activity 1 RFI wells installed in 1989 and the nine interior RCRA compliance program wells not previously sampled by the RCRA Compliance Monitoring Program. During storm events (May 9 through 11 and June 8 through 9, 1989), two sampling rounds were conducted on the RFI wells and selected interior RCRA compliance site characterization wells to assess the effects of precipitation on shallow groundwater chemistry. The nine RFI wells and nine interior ORNL wells were sampled in August of 1989 to assess groundwater quality under seasonal low groundwater conditions.

Following the installation of the additional 13 RFI monitoring wells during Activity 2, an additional sampling round was conducted from May 9 through 30, 1990, on the newly installed wells and on those RFI wells for which samples had not been obtained in previous sampling rounds because the wells were dry. Again, sampling events coincided with the ORNL semiannual compliance monitoring sampling event. WAG 6 RFI project personnel accompanied ORNL sampling crews to collect supplemental samples (geochemical analyses) from select perimeter and upgradient well pairs. Sample splits were also collected from some compliance wells to provide a basis for comparison of laboratory analytical results from the ORNL Analytical Chemistry Division (ACD), which analyzed ORNL RCRA compliance program samples, and IT Corporation, which analyzed RFI samples. Samples were also collected from three existing polyvinyl chloride (PVC) piezometers from the Engineering Test Facility (ETF) area to be analyzed for geochemical parameters only. During the tenth sampling event (June 11 through 20, 1990) wells were sampled for metals (total and dissolved), anions, (carbonate/bicarbonate), and alkalinity. Wells 1226, 1230, and 1232 remained dry during all sampling events and consequently have never been sampled.

2.6 SURFACE WATER INVESTIGATION

This section discusses the surface water sampling events for Activities 1 and 2 of the WAG 6 RFI. The general objectives of the surface water investigation were to characterize surface water contamination, provide data to support evaluation of interactions between surface water and groundwater, and provide flow data and contaminant characterization data to support modeling of contaminant flux at the WAG 6 boundary.

2.6.1 Reference Surface Water Sampling

On May 22, 1990, two reference samples were collected from locations on the headwaters of Melton Branch (Fig. 2.7). This creek is in an area well separated from any waste management areas and represents an uncontaminated area of the ORR. The samples were analyzed for TCL VOCs, base neutral and acid extractables (BNAEs), and pesticides/polychlorinated biphenyls (PCBs), and Target Analytes List (TAL) metals, cyanide, and radionuclides. One sample was analyzed for Appendix IX constituents. WAG 6 contaminants are compared with reference sample constituents collected from uncontaminated areas on the ORR.

2.6.2 Site Surface Water Sampling

Surface water samples and measurements were taken during both Activity 1 and 2. Each is discussed below.

2.6.2.1 Activity 1 surface water sampling

In February, April, and May 1989, surface water samples were collected using ESP procedures at 16 locations on intermittent streams within the WAG, at one location in the EWB, and at one seep (Fig. 2.8). Samples were collected and analyzed for TCL organics, TAL inorganics, radioactive constituents, anions, total dissolved solids (TDS), sulfide, alkalinity, COD, TOC, total kjeldahl nitrogen (TKN), BOD, and fecal coliforms. Conditions existing during each sampling event were as follows:

- February 1989: Base flow during high groundwater level; before installation of the ICM caps
- April 1989: Base flow during high groundwater level; after installation of the ICM caps
- May 1989: Storm event flow during high groundwater level
- September 1989: Under conditions of low base flow and storm flow during low groundwater table.

During the pre-ICM cap sampling, only 11 of the locations contained water enough to obtain a sample; under the high water table conditions, only 6 locations were sampled; during the storm event, 14 of the sites were sampled.

2.6.2.2 Activity 2 surface water sampling

To provide data for calibrating the surface water contaminant transport model, surface water flow measurements were made and samples were collected during two storm events during Activity 2. To allow flow measurements to be taken, Parshall and trapezoidal flumes were installed at the locations shown in Fig. 2.8. For the storm events, eight automatic samplers controlled by the four electronic data loggers were placed on the four main drainages of WAG 6. The ORNL Environmental Science Division's (ESD) Hydrology Group and WAG 6 RFI personnel collected discharge data and operated electronic data loggers and automatic sequential water samplers. At each automatic sampler location, 48 grab samples were collected and analyzed for TAL metals and radioactive constituents.

2.7 SOILS INVESTIGATION

This section discusses the WAG 6 RFI soil investigation, which was conducted during both Activity 1 and Activity 2. The primary objectives of the soil investigation were to help define the extent of soil contamination in WAG 6, aid in defining contaminant migration pathways, and provide soils data to support development of remedial action alternatives. Sampling activities, including reference sampling, are discussed in the following sections.

2.7.1 Reference Soil Sampling

From October through December 1989, 20 reference soil samples were collected from four boreholes (one to four samples per borehole and 10 shallow soil sampling locations) (Fig. 2.7). Samples were analyzed for TCL VOCs, BNAEs, pesticides, PCBs, TAL metals, and radionuclides.

2.7.2 Site Soil Sampling

Site soil sampling was conducted during both Activity 1 and Activity 2 of the WAG 6 RFI, as discussed in the following subsections. Figure 2.9 shows soil sampling locations.

2.7.2.1 Activity 1 soil sampling

Between December 1988 and January 1989, 53 borings were drilled to auger refusal. Boring depths ranged from 5.4 to 51.2 ft, and sampling was performed continuously. As samples were collected, they were surveyed for chemical and radiological contamination using field instruments. Based on the results of the field screening, 63 samples were submitted for laboratory analysis of TCL organics, TAL inorganics, and radioactive constituents.

The soil borings were conducted only around the perimeters of the waste disposal areas. There were no attempts to drill into the waste disposal trenches and auger holes themselves, both because of the difficulty in characterizing heterogeneous waste materials and the hazards presented by drilling into unknown waste materials.

2.7.2.2 Activity 2 soil sampling

Between December 1989 and March 1990, in conjunction with well installation, eight soil borings were drilled and continuously sampled until auger refusal. Boring depths ranged from 16.3 to 48.25 ft. As samples were collected, they were surveyed for chemical and radiological contamination using field instruments. Based on the field screening results, 17 samples were submitted for full TCL and TAL analysis and for selected radiological analyses.

2.8 SEDIMENTS INVESTIGATION

Sediment sampling was performed during both Activity 1 and Activity 2 to define the nature and extent of sediment contamination on WAG 6. The following sections summarize sediment sampling activities, including reference sampling.

2.8.1 Reference Sediment Sampling

Reference samples are used to determine site contamination at WAG 6. Reference sediment samples were collected under base flow conditions May 24 and 25, 1990, from four locations chosen because they are hydrologically separated from ORNL waste management activities yet contain sediments derived from Conasauga Group material. Samples were analyzed for TCL VOCs, BNAEs, pesticides/PCBs, TAL metals, cyanide, and radionuclides. Reference sampling locations are shown in Fig. 2.10.

2.8.2 Site Sediment Sampling

Sediment sampling was conducted during Activity 1 and Activity 2 at locations shown in Fig. 2.11. During the Activity 1 period, sediment samples were collected by ORNL in conjunction with the ICM cap construction. During Activity 2, in February and March 1990, sediment samples were collected at 31 locations within WAG 6, including 16 samples from the EWB. The objective of this sampling was to collect contaminant and concentration level data to support the baseline risk assessment. Samples were analyzed for the full TCL and TAL regime and for radionuclide constituents. Select samples were analyzed for the full suite of Appendix IX chemicals.

2.9 ECOLOGY INVESTIGATION

ORNL's ESD conducted surveys for threatened and endangered species and sensitive environments in WAG 6. From May through September 1990, surveys were conducted for fish, invertebrates, birds, mammals, plants, and wetlands. No threatened or endangered species or sensitive environments were found. No other ecological investigation was performed as part of the RFI field sampling activities.

2.10 BIOHAZARD INVESTIGATION

The biohazard investigation was conducted during both Activity 1 and Activity 2 to determine if the microbiological contents of the soils, surface water, and groundwater at WAG 6 are of normal character (e.g., standard plate, total coliforms, fecal coliform, colony morphology). Samples were analyzed primarily for bacteria content. Activities are described in the following sections.

2.10.1 Activity 1 Biohazard Sampling

Sixteen soil samples, all downgradient of the biological waste trench areas, were taken at depths up to 3 ft. Forty-four water samples were taken. Groundwater samples were taken from existing RCRA monitoring wells, and surface water samples were taken at the gaging stations existing in August and November 1988 and at the WOL control structure. Soil sampling locations are shown in Fig. 2.12. Groundwater and surface water sampling locations are shown in Fig. 2.13.

2.10.2 Activity 2 Biohazard Sampling

The Activity 2 biohazard investigation was a follow-up to biohazard sampling conducted during Activity 1, during which an unidentified bacteria was noted in SWSA 6 groundwater. The objective of Activity 2 sampling was to:

- Confirm the continued presence of the unidentified bacteria in SWSA 6 groundwater
- Determine if the organism was present in areas immediately adjacent to SWSA 6
- Determine if the organism was present in other ORR and ORNL areas

Surface water samples were collected from four locations outside ORNL and the ORR to determine if the organism were generally present in local waterways (Fig. 2.14). At one location, a sediment sample was collected. In addition, during July 1990, groundwater samples were collected from 49 wells located throughout ORR. These sampling locations are shown in Fig. 2.15.

The sampling program indicated the presence of an unidentified bacteria in the natural environment in locations remote from the ORNL area. Tentative identification of the organism by 16SRNA analysis indicated that the organism is not representative of a genera with abnormal human health concern. It was consequently concluded that the biohazard sampling program revealed no abnormal biological hazard at SWSA 6.

Section 2 Tables

Table 2.1. WAG 6 RFI Technical Memorandums

Technical memorandum	Subject
Activity 1[a]	
06-01	Review of Analytical Data Quality and Qualification of Analytical Results
06-02	Existing Well Investigation
06-03	Waste Area Grouping 6 RFI Soil Gas Survey
06-04	Radiation Walkover Survey Results for WAG 6 SWMU 6.2, SWSA 6
06-05	Interim Surface Water Sampling for the ORNL WAG 6 RFI
06-06	WAG 6 Electromagnetic Survey
06-07	Validation of ORNL Groundwater Data
06-08	WAG 6 RFI Well Installation
06-09	Groundwater Sampling at SWSA 6
06-10	Biohazard Investigation Results for WAG 6 SWMU 6.1, SWSA 6
06-11	WAG 6 Waste Management
06-12	PHASE I Soil Sampling for the ORNL WAG 6 RFI
Activity 2	
06-03A	Soil Gas Survey (Phase 1, Activity 2)
06-04A	Surface Radiological Investigation for WAG 6, SWMU 6.2, Emergency Waste Basin (EWB) (Phase 1, Activity 2)
06-05A[b]	Surface Water and Sediment Sampling for the ORNL WAG 6 RFI (Phase 1, Activity 2)
06-08A	WAG 6 RFI Well Installation (Phase 1, Activity 2)
06-09A[b]	Groundwater Sampling at WAG 6
06-10A[b]	WAG 6 Biohazard Investigation Results (Phase 1, Activity 2)
06-12A	Soil Sampling for the ORNL WAG 6 RFI (Phase 1, Activity 2)
06-13	WAG 6 Borehole Geophysical Logging
06-14	Demographic Data to Support WAG 6 RFI
06-15	Reference Sampling for the ORNL WAG 6 RFI

[a]These Activity 1 TMs were included in *WAG 6 Site Characterization Summary* (BNI 1990a).
[b]These TMs summarize Activity 1 and Activity 2 data.

Table 2.2. Target compound list as defined in 1988 CLP statement of work—VOCs

VOCs	CAS number	Quantitation limits[a] soil (μg/kg)[b] water (μg/L)
Chloromethane	74-87-3	10
Bromomethane	74-83-9	10
Vinyl chloride	75-01-4	10
Chloroethane	75-00-3	10
Methylene chloride	75-09-2	5
Acetone	67-64-1	10
Carbon disulfide	75-15-0	5
1,1-Dichloroethene	75-35-4	5
1,1-Dichloroethane	75-35-3	5
1,2-Dichloroethene (total)	540-59-0	5
Chloroform	67-66-3	5
1,2-Dichloroethane	107-06-2	5
2-butanone	78-93-3	10
1,1,1-Trichloroethane	71-55-6	5
Carbon tetrachloride	56-23-5	5
Vinyl acetate	108-05-4	10
Bromodichloromethane	75-27-4	5
1,1,2,2-Tetrachloroethane	79-34-5	5
1,2-Dichloropropane	78-87-5	5
cis-1,3-Dichloropropene	10061-01-5	5
Trichloroethene	79-01-6	5
Dibromochloromethane	124-48-1	5
1,1,2-Trichloroethane	79-00-5	5
Benzene	71-43-2	5
trans-1,3-Dichloropropene	10061-02-6	5
Bromoform	75-25-2	5
2-Hexanone	591-78-6	10
4-Methyl-2-pentanone	108-10-1	10
tetrachloroethene	127-18-4	5
Toluene	108-88-3	5
Chlorobenzene	108-90-7	5
Ethyl benzene	100-41-4	5
Styrene	100-42-5	5
Xylenes (total)	133-02-7	5

[a]Quantitation limits are highly matrix dependent. The quantitation limits listed are provided for guidance and may not always be achievable.

[b]Quantitation limits for soil are based on wet weight. The quantitation limits calculated by the laboratory for soil sediment are calculated on a dry-weight basis.

Source: EPA. 1988i. *Contract Laboratory Program Statement of Work: Multi-Media, Multi-Concentration*, Appendix 2 to OWSER 9240.0-1, Washington, D.C.

Table 2.3 Target compound list as defined in 1988 CLP statement of work—semivolatiles

Semivolatiles	CAS number	Quantitation limits[a]	
		water (μg/L)	soil (μg/kg)[b]
Phenol	108-95-2	10	330
bis(2-Chloroethyl)ether	111-44-4	10	330
2-chlorophenol	95-57-8	10	330
1,3-Dichlorobenzene	541-73-1	10	330
1,4-Dichlorobenzene	106-46-7	10	330
Benzyl alcohol	100-51-6	10	330
1,2-Dichlorobenzene	95-50-1	10	330
2-Methylphenol	95-48-7	10	330
bis(2-chloroisopropyl)ether	39638-32-9	10	330
4-Methylphenol	106-44-5	10	330
N-Nitroso-Dipropylamine	621-64-7	10	330
Hexachloroethane	67-72-1	10	330
Nitrobenzene	98-95-3	10	330
Isophorone	78-59-1	10	330
2-Nitrophenol	88-75-5	10	330
2,4-Dimethylphenol	105-67-9	10	330
Benzoic acid	65-85-0	50	1600
bis(2-chloroethoxy)methane	111-91-1	10	330
2,4-Dichlorophenol	120-83-2	10	330
1,2,4-Trichlorobenzene	120-82-1	10	330
Naphthalene	91-20-3	10	330
4-Chloroaniline	106-47-8	10	330
Hexachlorobutadiene	87-68-3	10	330
4-Chloro-3-methylphenol (para-chloro-meta-cresol)	59-50-7	10	330
2-Methylnaphthalene	91-57-6	10	330
Hexachlorocyclopentadiene	77-47-4	10	330
2,4,6-Trichlorophenol	88-06-2	10	330
2,4,5-Trichlorophenol	95-95-4	50	1600
2-Chloronaphthalene	91-58-7	10	330
2-Nitroaniline	88-74-4	50	1600
Dimethyl phthalate	131-11-3	10	330
Acenaphthylene	208-96-8	10	330
2,6-Dinitrotoluene	606-20-2	10	330
3-Nitroaniline	99-09-2	50	1600
Acenaphthene	83-32-9	10	330
2,4-Dinitrophenol	51-28-5	50	1600
4-Nitrophenol	100-02-7	50	1600
Dibenzofuran	132-64-9	10	330
2,4-Dinitrotoluene	121-14-2	10	330

Table 2.3 (continued)

Semivolatiles	CAS number	Quantitation limits[a] water (μg/L)	soil (μg/kg)[b]
Diethylphthalate	84-66-2	10	330
4-Chlorophenyl phenyl ether	7005-72-3	10	330
Fluorene	86-73-7	10	330
4-Nitroaniline	100-01-6	50	1600
4,6-Dinitro-2-methylphenol	534-52-1	50	1600
N-nitrosodiphenylamine	86-30-6	10	330
4-Bromophenyl-phenylether	101-55-3	10	330
Hexachlorobenzene	118-74-1	10	330
Pentachlorophenol	87-86-5	50	1600
Phenanthrene	85-01-8	10	330
Anthracene	120-12-7	10	330
Di-n-butylphthalate	84-74-2	10	330
Fluoranthene	206-44-0	10	330
Pyrene	129-00-0	10	330
Butyl benzyl phthalate	85-68-7	10	330
3,3'-Dichlorobenzidine	91-94-1	20	660
Benzo(a)anthracene	56-55-3	10	330
Chrysene	218-01-9	10	330
bis(2-ethylhexyl)phthalate	117-81-7	10	330
Di-n-octyl phthalate	117-84-0	10	330
Benzo(b)fluoranthene	205-99-2	10	330
Benzo(k)fluoranthene	207-08-9	10	330
Benzo(a)pyrene	50-32-8	10	330
Indeno(1,2,3-cd)pyrene	193-39-5	10	330
Dibenz(a,h)anthracene	53-70-3	10	330
Benzo(g,h,i)perylene	191-24-2	10	330

[a]Quantitation limits are highly matrix dependent. The quantitation limits listed are provided for guidance and may not always be achievable.

[b]Quantitation limits for soil are based on wet weight. The quantitation limits calculated by the laboratory for soil sediment are calculated on a dry-weight basis.

Source: EPA. 1988i. *Contract Laboratory Program Statement of Work: Multi-Media, Multi-Concentration*, Appendix 2 to OWSER 9240.0-1, Washington, D.C.

Table 2.4 Target compound list as defined in 1988 CLP statement of work—pesticides/PCBs

Pesticides/PCBs	CAS number	Quantitation limits[a] water (μg/L)	Quantitation limits[a] soil (μg/kg)[b]
alpha-BHC	319-84-6	0.05	8.0
beta-BHC	319-85-7	0.05	8.0
delta-BHC	319-86-8	0.05	8.0
gamma-BHC (lindane)	58-89-9	0.05	8.0
Heptachlor	76-44-8	0.05	8.0
Aldrin	309-00-2	0.05	8.0
Heptachlor epoxide	1024-57-3	0.05	8.0
Endosulfan I	959-98-8	0.05	8.0
Dieldrin	60-57-1	0.10	16.0
4,4'-DDE	72-55-9	0.10	16.0
Endrin	72-20-8	0.10	16.0
Endosulfan II	33213-65-9	0.10	16.0
4,4'-DDD	72-54-8	0.10	16.0
Endosulfan sulfate	1031-07-8	0.10	16.0
44'-DDT	50-29-3	0.10	16.0
Endrin ketone	53494-70-5	0.10	16.0
Methoxychlor	72-43-5	0.5	80.0
alpha-chlordane	5103-71-9	0.5	80.0
gamma-chlordane	5103-74-2	0.5	80.0
Toxaphene	8001-35-2	1.0	160.0
Aroclor-1016	12674-11-2	0.5	80.0
Aroclor-1221	11104-28-2	0.5	80.0
Aroclor-1232	11141-16-5	0.5	80.0
Aroclor-1242	53469-21-9	0.5	80.0
Aroclor-1248	12672-29-6	0.5	80.0
Aroclor-1254	11097-69-1	1.0	160.0
Aroclor-1260	11096-82-5	1.0	160.0

[a]Quantitation limits are highly matrix dependent. The quantitation limits listed are provided for guidance and may not always be achievable.

[b]Quantitation limits for soil are based on wet weight. The quantitation limits calculated by the laboratory for soil sediment are calculated on a dry-weight basis.

Source: EPA. 1988i. *Contract Laboratory Program Statement of Work: Multi-Media, Multi-Concentration*, Appendix 2 to OWSER 9240.0-1, Washington, D.C.

Table 2.5. Target analyte list as defined in 1988 CLP statement of work

Metals	CAS number	Quantitation limits[a] water (μg/L)	soil (μg/kg)[b]
Aluminum	7429-90-5	200.0	40,000
Antimony	7440-36-0	60.0	12,000
Arsenic	7440-38-2	10.0	2,000
Barium	7440-39-3	200.0	40,000
Beryllium	7440-41-7	5.0	1,000
Cadmium	7440-43-9	5.0	1,000
Calcium	7440-70-2	5000.0	1,000,000
Chromium	7440-47-3	10.0	2,000
Cobalt	7440-48-4	50.0	10,000
Copper	7440-50-8	25.0	5,000
Iron	7439-89-6	100.0	20,000
Lead	7439-92-1	5.0	1,000
Magnesium	7439-95-4	5000.0	1,000,000
Manganese	7439-96-5	15.0	3,000
Mercury	7439-97-6	0.2	40,000
Nickel	7440-02-0	40.0	8,000
Potassium	7440-09-7	5000.0	1,000,000
Selenium	7782-49-2	5.0	1,000
Silver	7740-22-4	10.0	2,000
Sodium	7440-23-5	5000.0	1,000,000
Thallium	7440-28-0	10.0	2,000
Vanadium	7440-62-2	50.0	10,000
Zinc	7440-66-6	20.0	4,000
Other			
Cyanide	57-12-5	10.0	--

[a]Quantitation limits are highly matrix dependent. The quantitation limits listed are provided for guidance and may not always be achievable.
[b]Quantitation limits for soil are based on wet weight. The quantitation limits calculated by the laboratory for soil sediment are calculated on a dry-weight basis.

Source: EPA. 1988i. *Contract Laboratory Program Statement of Work: Multi-Media, Multi-Concentration*, Appendix 2 to OWSER 9240.0-1, Washington, D.C.

Table 2.6. Radiological analytical parameters

Analyte	Detection limit goals
Americium-241	(1.0 pCi/L)
Cadmium/indium-115	
Calcium-45	(6 pCi/L)
Carbon-14	(100 pCi/L)
Curium isotopic	(1 pCi/L)
Gamma isotopic	(20 pCi/L Cs-137)
Gross alpha - total	(pCi/L - <500 ppm solids)
Gross beta	total (4 pCi/L - <500 ppm solids)
Iodine-129	(10 pCi/L)
Iodine-131	(1 pCi/L)
Iron-55	(100 pCi/L)
Lead-210	(20 pCi/L)
Neptunium-237	(1.0 pCi/L)
Nickel-63	(100 pCi/L)
Plutonium isotopic	(1 pCi/L)
Plutonium isotopic (including Pu-241)	(Pu 241: 10 pCi/L)
Polonium-219	(1 pCi/L)
Promethium-147	(50 pCi/L)
Radium-226	(1.0 pCi/L)
Radium-226,228	(1.0 pCi/L, 3.0 pCi/L)
Radon-220	(volume dependent)
Radon-220/222	(10 pCi/L)
Ruthenium-106	(150 pCi/L)
Strontium-89/90	(10 pCi/L, 5 pCi/L)
Strontium-90	(5 pCi/L)
Technitium-99	(30 pCi/L)
Thorium isotopic	(1.0 pCi/L)
Thorium isotopic (including Th-234)	(10 pCi/L, Th-234)
Tritium	(500 pCi/L)
Uranium-total (fluorometric)	(5 ug/l)
Uranium isotopic	(1.0 pCi/L)
Uranium isotopic (including U-232)	(1 pCi/L, U-232)
Gross alpha/beta (total)	

Source: EPA. 1988i. *Contract Laboratory Program Statement of Work: Multi-Media, Multi-Concentration*, Appendix 2 to OWSER 9240.0-1, Washington, D.C.

Table 2.7. Field parameters and major ions for water samples

Field parameters	Major ions
Eh[a]	Alkalinity
pH	Bicarbonate (from alkalinity)
Specific electrical conductance	Carbonate (from alkalinity)
Temperature	Calcium
DO[b]	Chloride
	Magnesium
	Nitrate
	Potassium
	Sodium
	Sulfate
	Sulfide

[a]Oxidation-reduction potential was not always measured as part of the field parameters.
[b]Dissolved oxygen was measured only in surface water samples.

Source: EPA. 1986f. *Test Methods for Evaluating Solid Waste, Volume 1C: Laboratory Manual Physical/Chemical Methods*, SW-846, Office of Solid Waste and Emergency Response, Washington, D.C.

Table 2.8. RCRA Appendix IX Constituents

Compounds/elements	CAS number	Water CRDLs[a] (µg/L)
VOLATILES		
Acetone	67-64-1	10
Acetonitrile (methyl cyanide)	75-05-8	1000
Acrolein	107-02-8	10
Acrylonitrile	107-13-1	10
Ally chloride (3-chloropropene)	107-05-1	5
Benzene	71-43-2	5
Bromodichloromethane	75-27-4	5
Bromoform	75-25-2	5
Carbon disulfide	75-15-0	5
Carbon tetrachloride	56-23-5	5
Chlorobenzene	108-90-7	5
Chloroethane	75-00-3	10
Chloroform	67-66-3	5
Chloroprene	126-99-8	5
Dibromochloromethane	124-48-1	5
1,2-Dibromo-3-chloropropane	96-12-8	10
1,2-Dibromoethane	106-93-4	5
trans-1,4-Dichloro-2-butene	110-57-6	100
Dichlorodifluoromethane	75-71-8	200
1,1-Dichloroethane	75-34-3	5
1,2-Dichloroethane	107-06-2	5
1,1-Dichloroethylene	75-35-4	5
trans-1,2-Dichloroethylene	156-60-5	5
1,2-Dichloropropane	78-87-5	5
cis-1,3-Dichloropropene	10061-01-55	5
trans-1,3-Dichloropropene	10061-02-65	5
1,4-Dioxane	123-91-1	5000
Ethylbenzene	100-41-4	5
2-Hexanone	591-78-6	10
Isobutyl alcohol	78-83-1	3000
Methacrylonitrile	126-98-7	10
Methyl bromide (bromomethane)	74-83-9	10
Methyl chloride (chloromethane)	74-87-3	10
Methylene bromide (dibromomethane)	74-95-3	10
Methylene chloride (dichloromethane)	75-09-2	5
Methyl ethyl ketone	78-93-3	10
Methyl iodide (iodomethane)	74-88-4	5
Methyl methacrylate	80-62-6	10
4-Methyl-2-pentanone (methyl isobutyl ketone)	108-10-1	10
Pentachloroethane	76-01-7	20
Propionitrile (ethyl cyanide)	107-12-0	100
Pyridine	110-86-1	20,000

Table 2.8. (continued)

Compounds/elements	CAS number	Water CRDLs[a] (μg/L)
VOLATILES (continued)		
Styrene	100-42-5	5
1,1,1,2-Tetrachlorethane	630-20-6	5
1,1,2,2-Tetrachlorethane	79-34-5	5
Tetrachloroethylene	127-18-4	
Toluene	108-88-3	5
1,1,1-Trichloroethane	71-55-6	5
1,1,2-Trichloroethane	79-00-5	5
Trichloroethylene	79-01-6	5
Trichlorofluoromethane	75-69-4	5
1,2,3-Trichloropropane	96-16-4	5
Vinyl acetate	108-05-4	10
Vinyl chloride	75-01-4	10
Xylene (total)	1330-20-7	5
SEMIVOLATILES		
Acenaphthene	83-32-9	10
Acenaphthylene	208-96-8	10
Acetophenone	98-86-2	10
2-Acetylaminofluorene	53-96-3	10
4-Aminobiphenyl	92-67-1	50
Aniline	62-53-3	50
Anthracene	120-12-7	10
Aramite	140-57-8	10
Benzo(a)anthracene	56-55-3	10
Benzo(b)fluoranthene	205-99-2	10
Benzo(k)fluoranthene	207-08-9	10
Benzo(g,h,i)perylene	191-24-2	10
Benzo(a)pyrene	50-32-8	10
Benzyl alcohol	100-51-6	20
bis(2-Chloroethoxy)methane	111-91-1	10
bis(2-Chloroethyl)ether	111-44-4	10
bis(2-Chloroisopropyl)ether	108-60-1	10
bis(2-Ethylhexyl) phthalate	117-81-7	10
4-Bromophenyl phenyl ether	101-55-3	10
Butyl benzyl phthalate	85-68-7	20
4-Chloroaniline	106-47-8[b]	20
4-Chloro-3-methylphenol	59-50-7	10
2-Chloronaphthalene	91-58-7	10
2-Chlorophenol	95-57-8	10
4-Chlorophenylphenyl ether	7005-72-3	10
m-Cresol	108-39-4	10
o-Cresol	95-48-7	10
p-Cresol	106-44-5	10

Table 2.8. (continued)

Compounds/elements	CAS number	Water CRDLs[a] (μg/L)
SEMIVOLATILES (continued)		
Chrysene	218-01-9	10
Diallate	2303-16-4	10
Dibenzo(a,h)anthracene	53-70-3	10
Dibenzofuran	132-64-9	10
Di-n-butyl phthalate	84-74-2	10
1,2-Dichlorobenzene	95-50-1	10
1,3-Dichlorobenzene	541-73-1	10
1,4-Dichlorobenzene	106-46-7	10
3,3-Dichlorobenzidine	91-94-1	20
2,4-Dichlorophenol	120-83-2	10
2,6-Dichlorophenol	87-65-0	10
Diethyl phthalate	84-66-2	10
p-Dimethylaminoazobenzene	60-11-7	30
7,12-Dimethylbenz(a)anthracene	57-97-6	20
3,3'-Dimethylbenzidine	119-93-7	80
a,a-Dimethylphenethylamine	122-09-8	10
2,4-Dimethylphenol	105-67-9	10
Dimethyl phthalate	131-11-3	10
m-Dinitrobenzene	99-65-0	10
4,6-Dinitro-o-cresol (2-Methyl-4,6-dinitrophenol)	534-52-1	50
2,4-Dinitrophenol	51-28-5	50
2,4-Dinitrotoluene	121-14-2	10
2,6-Dinitrotoluene	606-20-2	10
2-Sec-butyl-4,6-dinitrophenol (dinoseb)	88-85-7	20
Di-n-octyl phthalate	117-84-0	10
Diphenylamine	122-39-4	10
Ethyl methacrylate	97-63-2	10
Ethyl methanesulfonate	62-50-0	10
Fluoranthene	206-44-0	10
Fluorene	86-73-7	10
Hexachlorobenzene	118-74-1	10
Hexachlorobutadiene	87-68-3	10
Hexachlorocyclopentadiene	77-47-4	10
Hexachloroethane	67-72-1	10
Hexachlorophene	70-30-4	500
Hexachloropropene	1888-71-7	20
Indeno(1,2,3-cd)pyrene	193-39-5	10
Isophorone	78-59-1	10
Isosafrole	120-58-1	10
Methapyrilene	91-80-5	40
3-Methylcholanthrene	56-49-5	30
Methyl methanesulfonate	66-27-3	10
2-Methylnaphthalene	91-57-6	10
Naphthalene	91-20-3	10

Table 2.8. (continued)

Compounds/elements	CAS number	Water CRDLs[a] (μg/L)
SEMIVOLATILES (continued)		
1,4-Naphthoquinone	130-15-4	10
1-Naphthylamine	134-32-7	120
2-Naphthylamine	91-59-8	170
o-Nitroaniline	88-74-4	50
m-Nitroaniline	99-09-2	50
p-Nitroaniline	100-01-6	50
Nitrobenzene	98-95-3	10
o-Nitrophenol	88-75-5	10
p-Nitrophenol	100-02-7	50
4-Nitroquinoline-1-oxide	56-57-5	10
N-Nitrosodi-n-butylamine	924-16-3	20
N-Nitrosodiethylamine	55-18-5	10
N-Nitrosodimethylamine	62-75-9	10
N-Nitrosodiphenylamine	86-30-6	10
N-Nitroso-di-n-propylamine	621-64-7	10
N-Nitrosomethylethylamine	10595-95-6	10
N-Nitrosomorpholine	59-89-2	10
N-Nitrosopiperidine	100-75-4	10
N-Nitrosopyrrolidine	930-55-2	10
5-Nitro-o-toluidine	99-55-8	20
Pentachlorobenzene	608-93-5	20
Pentachloroethane	76-01-7	20
5-Nitro-o-toluidine	99-55-8	20
Pentachlorobenzene	608-93-5	20
Pentachloroethane	76-01-7	20
Pentachloronitrobenzene	82-68-8	20
Pentachlorophenol	87-86-5	50
Phenacetin	62-44-2	10
Phenanthrene	85-01-8	10
Phenol	108-95-2	10
p-Phenylenediamine	106-50-3	50
2-Picolone	10-96-8	70
Pronamide	23950-58-5	30
Pyrene	129-00-0	10
Safrole	94-59-7	10
1,2,4,5-Tetrachlorobenzene	95-94-3	10
2,3,4,6-Tetrachlorophenol	58-90-2	10
Tetraethyldithiopyrophosphate	3689-24-5	20
o-Toluidine	95-53-4	20
1,2,4-Trichlorobenzene	120-82-1	20
2,4,5-Trichlorophenol	95-95-4	50
2,4,6-Trichlorophenol	88-06-2	10
O,O,O-Triethylphosphorothioate	126-68-1	10
sym-Trinitrobenzene	99-35-4	10

Table 2.8. (continued)

Compounds/elements	CAS number	Water CRDLs[a] (μg/L)
ORGANOCHLORINE PESTICIDES		
Aldrin	309-00-2	0.050
alpha-BHC	319-84-6	0.050
beta-BHC	319-85-7	0.050
gamma-BHC (lindane)	58-89-9	0.050
delta-BHC	319-86-8	0.050
Chlorobenzilate	510-15-6	0.10
Chlordane	57-74-9	0.50
4,4'-DDD	72-54-8	0.10
4,4'-DDE	72-55-9	0.10
4,4'-DDT	50-29-3	0.10
Dieldrin	60-57-1	0.10
Endosulfan-I	959-98-8	0.050
Endosulfan II	33213-65-9	0.10
Endosulfan sulfate	1031-07-8	0.10
Endrin	72-20-8	0.10
*Endrin aldehyde	7421-93-4	
*Endrin ketone	53494-70-5	0.10
Heptachlor	76-44-8	0.050
Heptachlor epoxide	1024-57-3	0.050
Isodrin	465-73-6	0.050
Kepone	143-50-0	0.10
Methoxychlor	72-43-5	0.50
Toxaphene	8001-35-2	1.00
PCBs		
Aroclor-1016	12674-11-2	0.50
Aroclor-1221	11104-28-2	0.50
Aroclor-1232	11141-16-5	0.50
Aroclor-1242	53469-21-9	0.50
Aroclor-1248	12672-29-6	0.50
Aroclor-1254	11097-69-1	1.00
Aroclor-1260	11096-82-5	1.00
ORGANOPHOSPHORUS PESTICIDES		
O,O-Diethyl-O-(2-pyrazinyl)(thionazin)	297-97-2	1.0
Dimethoate	60-51-5	1.0
Disulfoton	298-04-4	1.0
Famphur	52-85-7	2.0
Parathion	56-38-2	1.0
Parathion methyl	298-00-0	1.0
Phorate	298-02-2	1.0

Table 2.8. (continued)

Compounds/elements	CAS number	Water CRDLs[a] (μg/L)
CHLORINATED HERBICIDES		
2,4-D (2,4-dichlorophenoxyacetic acid)	94-75-7	0.16
Dinoseb	88-85-7	0.04
2,4,5-TP (silvex)	93-72-1	0.04
2,4,5-T (2,4,5-trichlorophenoxyacetic acid)	93-76-5	0.04
DIOXINS		
2,3,7,8-Tetrachlorodinbenzo-dioxin (TCDD)	1746-01-6	0.36
Tetrachlorodibenzo-dioxins (TCDDs)		0.26
Pentachlorodibenzo-dioxins (PeCCDs)		0.49
Hexachlorodibenzo-dioxins (HeCDDs)		0.55
FURANS		
Tetrachlorodibenzo-furans (TCDFs)		0.42
Pentachlorodibenzo-furans (PeCDFs)		0.16
Hexachlorodibenzo-furans (HxCDFs)		0.14
MISCELLANEOUS PARAMETERS		
Cyanide	57-12-5	10
Sulfide	18496-25-8	100

[a]There are no Contract Required Detection Limits (CRDLs) for Appendix IX constituents for soils/sediments.

[b]IT analyzes for endrin ketone rather than endrin aldehyde.

Source: EPA. 1986g. *Test Methods for Evaluating Solid Waste, Volume 1B: Laboratory Manual Physical/Chemical Methods*, SW-846, Office of Solid Waste and Emergency Response, Washington, D.C.

Table 2.9 RCRA Appendix IX constituents—metals

Metals	CAS number	CRDLs water (μg/L)	CRDLs soil (μg/kg)[b]
Aluminum	7429-90-5	200	40,000
Antimony	7440-36-0	60	12,000
Arsenic	7440-38-2	10	2,000
Barium	7440-39-3	200	40,000
Beryllium	7440-41-7	5	1,000
Cadmium	7440-43-9	5	1,000
Calcium	7440-70-2	5000	1,000,000
Chromium	7440-47-3	10	2,000
Cobalt	7440-48-4	50	10,000
Copper	7440-50-8	25	5,000
Iron	7439-89-6	100	20,000
Lead	7439-92-1	5	1,000
Magnesium	7439-95-4	5000	1,000,000
Manganese	7439-96-5	15	3,000
Mercury	7439-97-6	0.2	40,000
Nickel	7440-02-0	40	8,000
Osmium	7440-40-2	500	100,000
Potassium	7440-09-7	5000	1,000,000
Selenium	7782-49-2	5	1,000
Silver	7740-22-4	10	2,000
Sodium	7440-23-5	5000	1,000,000
Thallium	7440-28-0	10	2,000
Tin	7440-31-5	50	10,000
Vanadium	7440-62-2	50	10,000
Zinc	7440-66-6	20	4,000

Source: EPA. 1986h. *Test Methods for Evaluating Solid Waste, Volume 1A: Laboratory Manual Physical/Chemical Methods*, SW-846, Office of Solid Waste and Emergency Response, Washington, D.C.

Table 2.10. WAG 6 borehole geophysical logging program summary

Log type	Well 1234	1236	1238	1239	CH-2[a]
Natural gamma ray	*b*	C	C	C	C
Caliper	*b*	C	C	C	C
Temperature	*b*	C	C	C	C
Differential temperature	*b*	C	C	C	C
Spontaneous potential (SP)	*b*	C	C	C	C
Borehole televiewer (BHTV)	*c*	O	O	O	O
Variable density acoustic log (VDL)	*d*				
Short guard resistivity	O	C	C	C	C
Short/long normal resistivity	*b*	C	C	C	C
Fluid resistivity	C	C	C	C	C
Lateral log resistivity	C	C	C	C	C
Single point resistance (SPR)	*b*	C	C	C	C
Deviation survey	*c*	B	B	B	B
Gamma-gamma density	*d*				
BHC density	C	C	C	C	C
Epithermal neutron	*d*				
BHC neutron	C	C	C	C	
Sonic	*d*				
BHC sonic	C	C	C	C	

[a]Quality control well located in the ORNL Main Plant Area.
[b]ORNL logged the original corehole; Century Geophysics logged the reamed/deepened borehole.
[c]ORNL originally logged corehole and subsequently logged the entire reamed/deepened hole.
[d]Original Well 1234 corehole logging by ORNL.

O - Logging performed by ORNL.
C - Logging performed by Century Geophysics.
B - Logging performed by both ORNL and Century Geophysics.

Table 2.11. WAG 6 groundwater sampling program summary

	Sampling event									
	1	2	3	4	5	6	7	8	9	10
Well no.	1st quarter RCRA monitoring 5/5-7/2/88	2nd quarter RCRA monitoring 10/4-11/4/88	3rd quarter RCRA monitoring 1/12-2/13/89	4th quarter RCRA monitoring 4/11-5/11/89	Storm event 5/9-11/89	Storm event 6/8-9/89	Dry season 8/28-9/5/89	Dry season 9/26-28/89	Semi-annual RCRA monitoring 5/9-30/90	Semi-annual RCRA monitoring 6/11-20/90
1225				B	B	B	B	B		
1226				Dry	Dry	Dry	Dry	Dry		
1227				B	B	B		B		
1228				B	B	B	B	B	B	B
1229				B	B	B	B	B	B	B
1230				Dry	Dry	Dry	Dry	Dry	Dry	Dry
1231				B	B		B	B		
1232				Dry	Dry	Dry	Dry	Dry	Dry	Dry
1233				B	B	B	B	B		
1234									B	B
1234A[a]									O/B	
1235									Dry	Dry
1236									B	B
1237									B	B
1238									B	B
1239									B	B
1240									B	B
1241									B	B
1242									B	B
1243									B	B
1244									B	B
1245									B	B
745	O	O	O	O					O/B	B
831	O	O	O	O					O/B	B
832	O	O	O	O					O/B	B
833	O	O	O	O					O/B	B
835	O	O	O	O					O	
836	O	O	O	O					O	
837	Dry	Dry	O	O					O	
838	O	O	O	O					O/B	B

Table 2.11. (continued)

	Sampling event									
	1	2	3	4	5	6	7	8	9	10
Well no.	1st quarter RCRA monitoring 5/5-7/2/88	2nd quarter RCRA monitoring 10/4-11/4/88	3rd quarter RCRA monitoring 1/12-2/13/89	4th quarter RCRA monitoring 4/11-5/11/89	Storm event 5/9-11/89	Storm event 6/8-9/89	Dry season 8/28-9/5/89	Dry season 9/26-28/89	Semi-annual RCRA monitoring 5/9-30/90	Semi-annual RCRA monitoring 6/11-20/90
839	O	O	O	O					O/B	B
840	O	O	O	O					O/B	B
841	O	O	O	O					O/B	B
842	O	O	O	O					O/B	B
843	O	O	O	O					O/B	B
844	O	O	O	O					O/B	B
845	O	O	O	B			B			
846	O	O	O	O						
847	O	O	O	O						
848	O	O	O	B			B			
849	O	O	O	B	B		B			
850	O	O	O	B			B			
851	O	O	O	B	B		B			
852	O	O	O	B	B		B			
853	O	O	O	B	B		B			
854	O	O	O	B	B		B			
855	O	O	O	O					O/B	B
856	O	O	O	O					O/B	B
857	O	O	O	O					O/B	B
858	O	O	O	O					O/B	B
859	Dry	Dry	O	O					O/B	B
860	O	O	O	O					O/B	B
ETF-13									B	B
ETF-14									B	B
ETF-15									B	B

NOTES:
O Sampled by ORNL crews as part of compliance monitoring.
B Sampled by RFI personnel.
O/B Well sampled by ORNL crew as part of compliance monitoring; additional samples collected at time of sampling by RFI personnel for geochemical parameters.

[a]Well 1234A has subsequently been redesignated No. 1249 by ORNL.

Table 2.12. WAG 6 groundwater analytical program summary

		Sample event									
		1	2	3	4	5	6	7	8	9	10
Well no.	Date installed	1st quarter RCRA 6/5-7/2/88	2nd quarter RCRA 10/4-11/4/88	3rd quarter RCRA 1/12-2/13/89	4th quarter RCRA 4/11-5/11/89	Storm event 5/9-11/89	Storm event 6/8-9/89	Dry season 8/28-9/5/89	Dry season 9/26-28/89	Semi-annual RCRA monitoring 5/9-30/90	Semi-annual RCRA monitoring 6/11-19/90
1225	3/24/89				A	A	A	A	B1		
1226	3/27/89				Dry	Dry	Dry	Dry	Dry		
1227	3/28/89				A	A	A		B		
1228	3/28/89				A	A	A	A	B	C	F
1229	3/29/89				A	A	A	A	B	C	F
1230	3/17/89				Dry	Dry	Dry	Dry	Dry	Dry	Dry
1231	3/22/89				A	A		A1	B		
1232	3/16/89				Dry	Dry	Dry	Dry	Dry	Dry	Dry
1233	3/15/89				A	A	A	A	B		
1234	5/14/90									D	F
1234A[a]	5/1/90									C,F	
1235	1/12/90									Dry	Dry
1236	5/3/90									C1	F1
1237	4/5/90									C	F
1238	4/30/90									C	F
1239	5/7/90									C	F
1240	3/19/90									C	F
1241	4/12/90									C	F
1242	4/18/90									C	F
1243	4/18/90									C	F
1244	4/9/90									C1	F1
1245	4/13/90									D	F
745	8/5/87	G	G	G	G					H,F	F
831	2/26/87	G	G	G	G					H,F	F
832	6/16/87	G	G	G	G					H,F	F
833	8/5/87	G	G	G	G					H,F	F
835	9/30/87	G	G	G	G					H	
836	9/15/87	G	G	G	G					H	
837	7/29/87	Dry	Dry	G	G					H	
838	7/29/87	G	G	G	G					H,F	F
839	7/31/87	G	G	G	G					H,F	F
840	10/20/87	G	G	G	G					H,F	F

Table 2.12 (continued)

		Sample event 1	2	3	4	5	6	7	8	9	10
Well no.	Date installed	1st quarter RCRA 6/5-7/2/88	2nd quarter RCRA 10/4-11/4/88	3rd quarter RCRA 1/12-2/13/89	4th quarter RCRA 4/11-5/11/89	Storm event 5/9-11/89	Storm event 6/8-9/89	Dry season 8/28-9/5/89	Dry season 9/26-28/89	Semi-annual RCRA monitoring 5/9-30/90	Semi-annual RCRA monitoring 6/11-19/90
841	7/17/87	G	G	G	G					H,F,E2	F
842	7/17/87	G	G	G	G					H,F,E2	F
843	7/28/87	G	G	G	G					H,F	F
844	7/2/87	G	G	G	G					H,F	F
845	10/30/87	G	G	G	A			A			
846	10/14/87	G	G	G	G						
847	12/11/87	G	G	G	A						
848	11/20/87	G	G	G	A			A			
849	11/5/87	G	G	G	A	A		A			
850	11/20/87	G	G	G	A			A			
851	11/23/87	G	G	G	A	A		A			
852	11/23/87	G	G	G	A	A		A			
853	8/3/87	G	G	G	A	A		A			
854	9/28/87	G	G	G	A	A		A			
855	6/22/87	G	G	G	G					H,F,E2	F
856	11/23/87	G	G	G	G					H,F,E2	F
857	11/23/87	G	G	G	G					H,F	F
858	11/23/87	G	G	G	G					H,F	F
859	8/17/87	Dry	Dry	G	G					H,F	F
860	8/11/87	G	G	G	G					H,F	F
ETF-13	?/86									F	F
ETF-14	?/86									F	F
ETF-15	?/86									F	F

[a]Well 1234A has subsequently been redesignated # 1249 by ORNL.

NOTES: Sample analytical suites A-F are associated with WAG 6 RFI sampling. Samples analyzed by IT Corporation.

Sample analytical suites G and H are the parameters analyzed by ORNL in RCRA detector monitoring. Suite H reflects the reduced parameter as specified for semi-annual RCRA assessment monitoring in the GWQAP. Samples analyzed by the ORNL ACD laboratory.

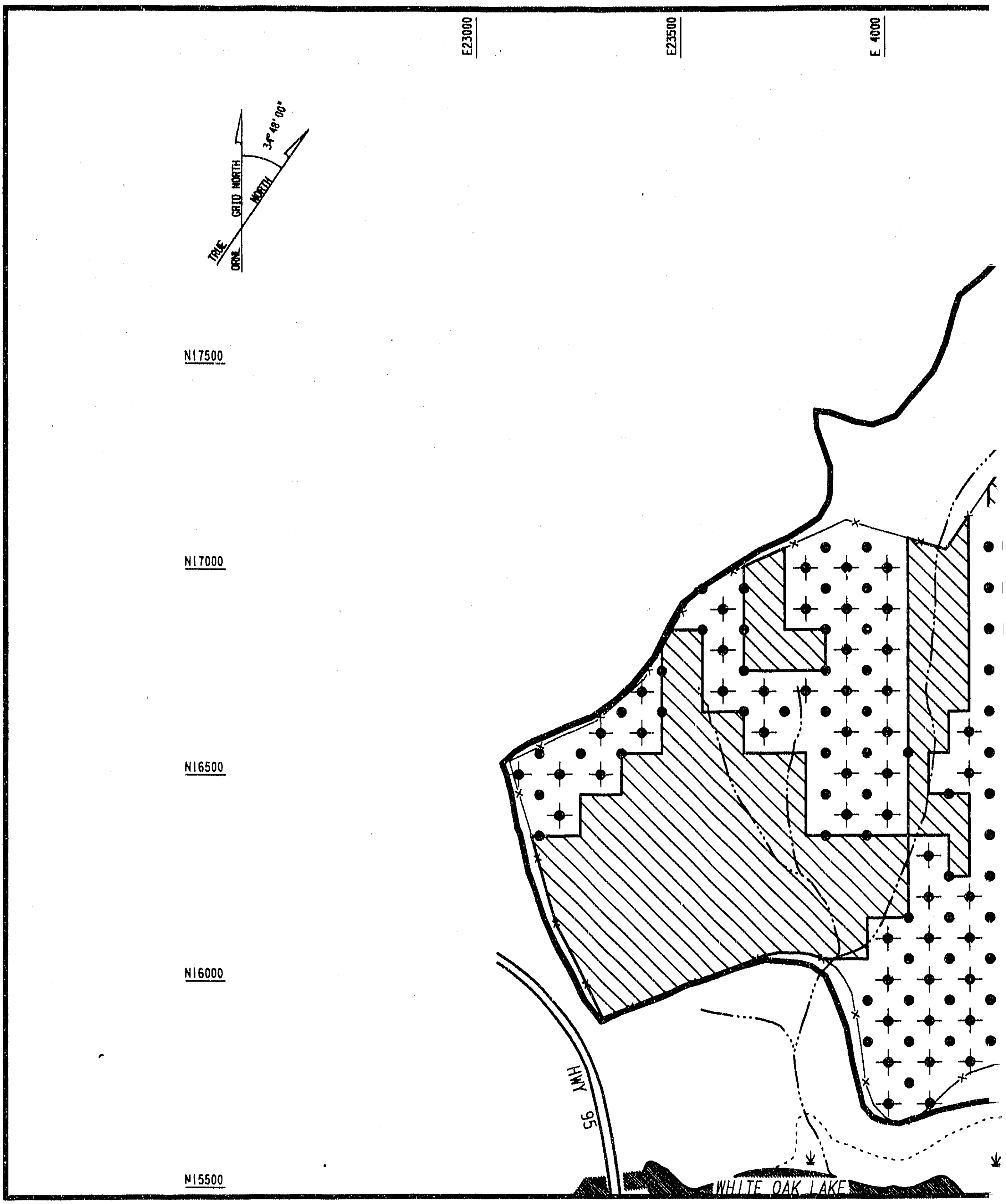
1–Denotes duplicate samples collected at a rate of 10%.
2–Denotes sample splits analyzed by both ORNL ACD laboratory and WAG 6 RFI contract laboratory (IT Corporation).

Table 2.13. Analytical suite summary

Parameter	A[a]	B[a]	C[a]	D[a]	E[a]	F[a]	G[b]	H[b]
TCL VOCs	X	X	X		X		X	X[c]
Appendix IX VOCs				X				
TCL BNAEs	X	X	X				X	
Appendix IX BNAEs				X				
Phenols							X	
TCL pesticides, PCBs	X	X	X				X	
Appendix IX pesticides, PCBs				X				
Appendix IX (OP) pesticides				X				
TCL chlor. herbicides							X	
Appendix IX chlor. herbicides				X				
Appendix IX dioxins/furans				X				
TAL metals	X	X	X			X		
Appendix IX metals				X				
ICP metals					X		X	X
TCL cyanide	X	X	X					
Appendix IX cyanide				X				
Sulfides	X							
Anions	X		X	X		X	X	X
Carbonate/bicarbonate	X		X	X		X		
Alkalinity (as CaCO3)			X	X		X		X
COD	X							
BOD	X							
TKN	X							
TDS	X							
TOX	X						X	
TOC	X						X	
Fecal coliform	X						X	
Turbidity							X	
Gross alpha	X	X	X	X[d]	X		X	X
Gross beta	X	X	X	X[d]	X		X	X
Gamma isotopic	X	X	X		X		X	X
Tritium	X	X	X	X	X		X	X
Ra-226/228	X	X	X				X	
Sr-90	X	X	X		X		X	X
Am-241		-	X					
Th isotopic	X	X	X	X				
Pu isotopic		-	X					
U isotopic	X	X	X					
Co60								X

[a]Analyses performed by IT Corporation as part of the WAG 6 RFI.
[b]Analyses performed by ORNL ACD laboratory as part of RCRA Compliance Monitoring Program for SWSA 6.
[c]Samples analyzed for VOCs using Method SW8240. Only nine target compounds identified in the RCRA Groundwater Quality Assessment Plan for Solid Waste Storage Area 6 (ORNL 1989).
[d]Samples analyzed for gross alpha and gross beta at the field CSL.

Section 2 Figures



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9-5

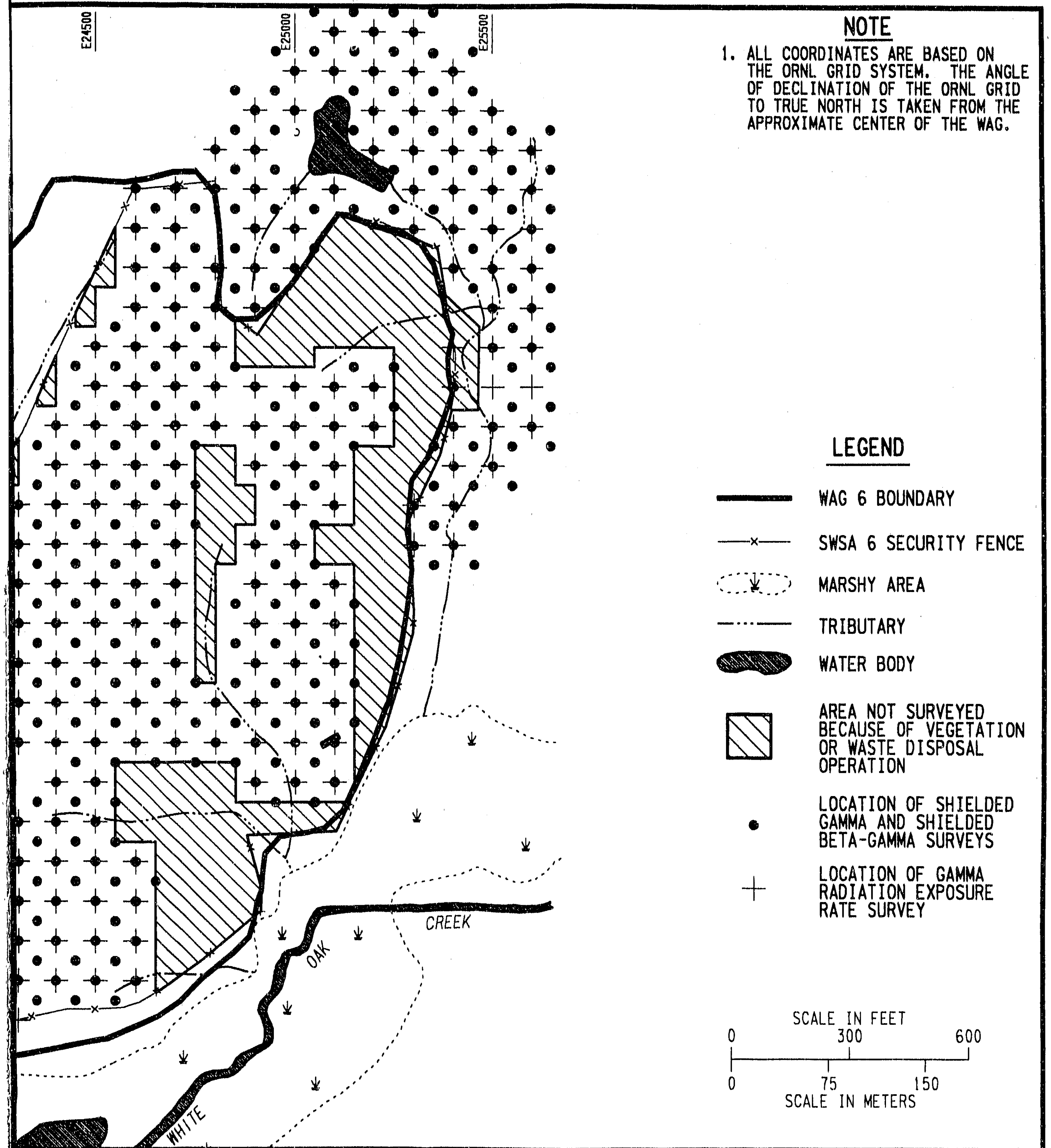
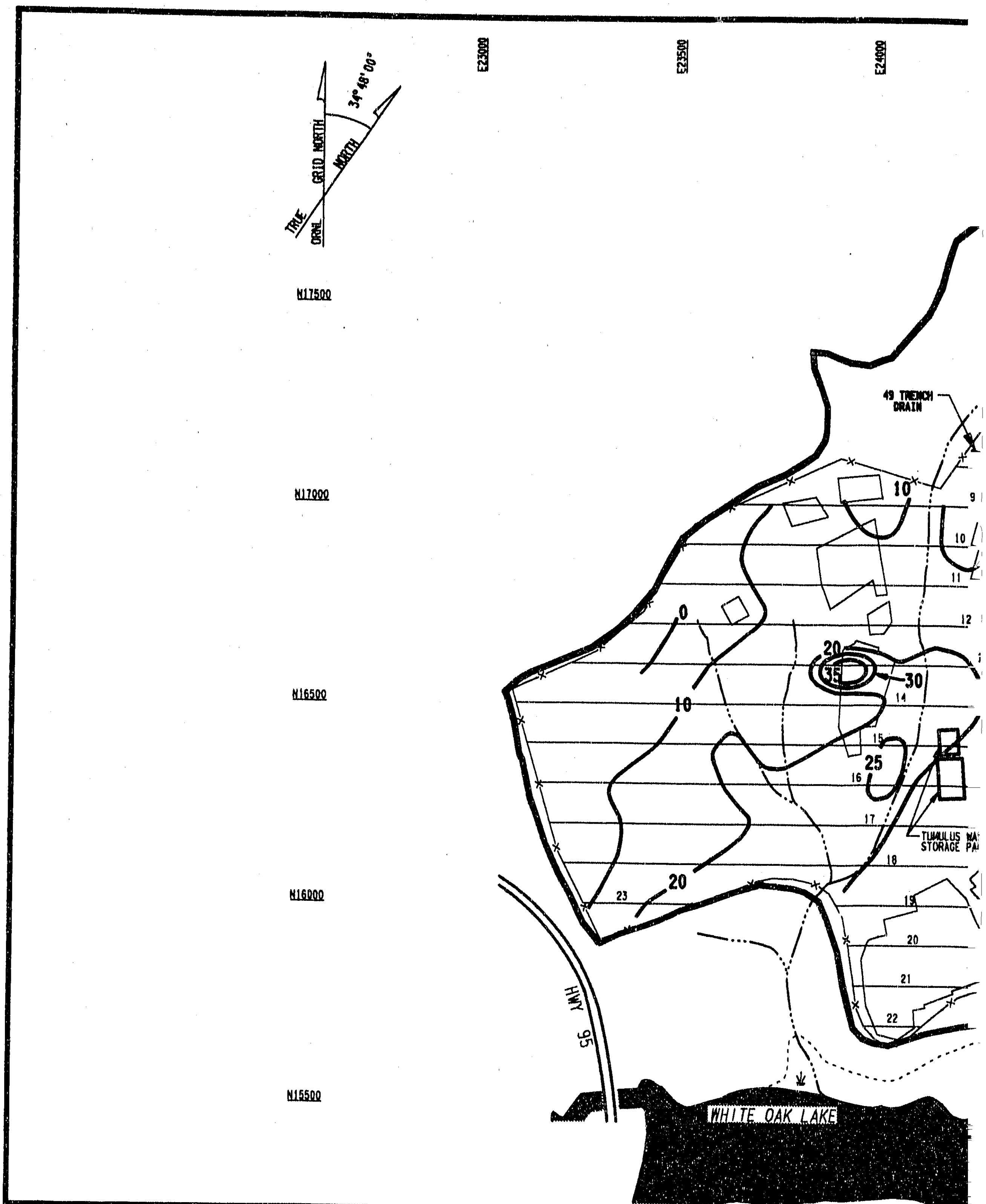


Fig. 2.1. Radiation walkover survey.



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9-5

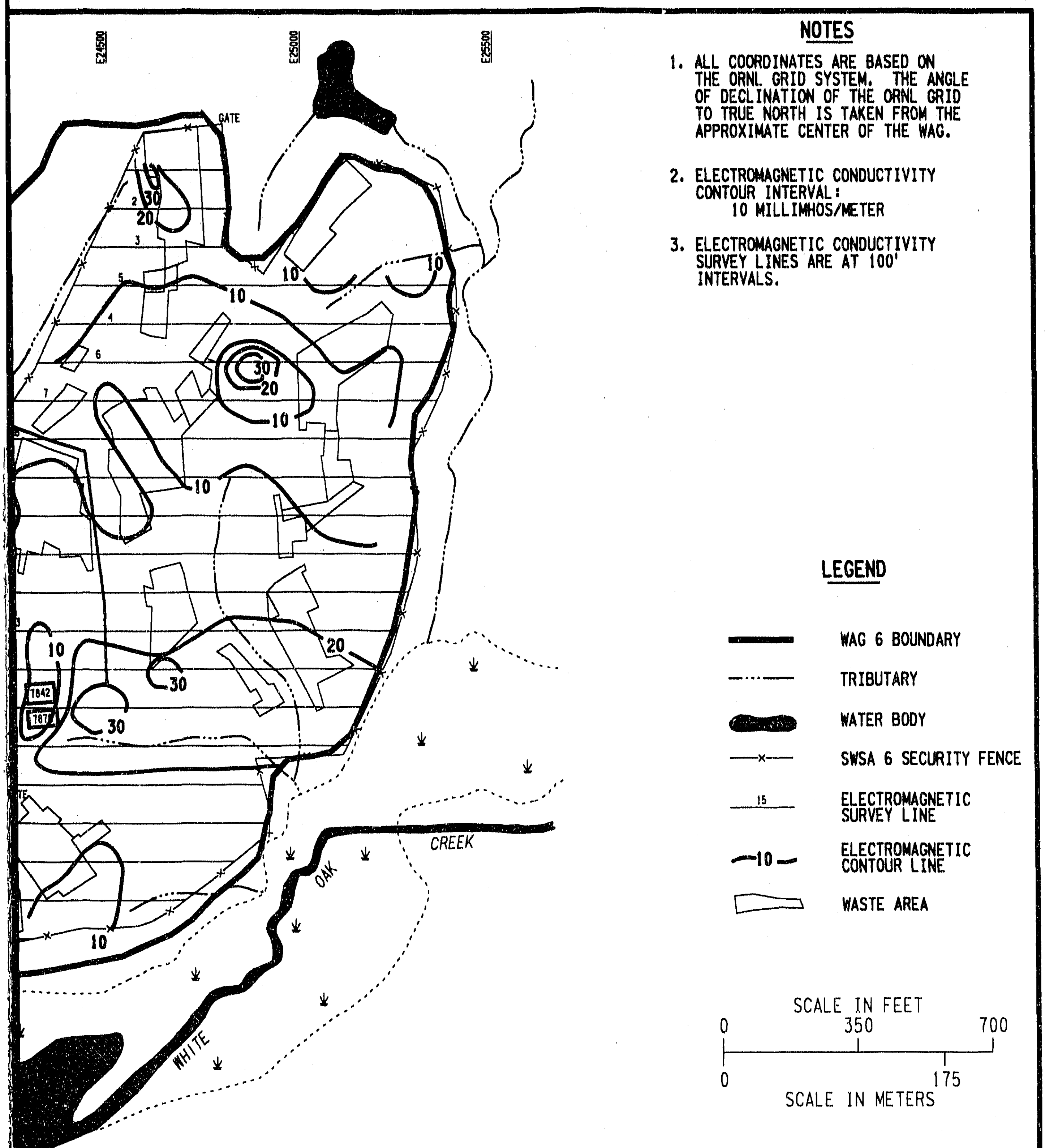
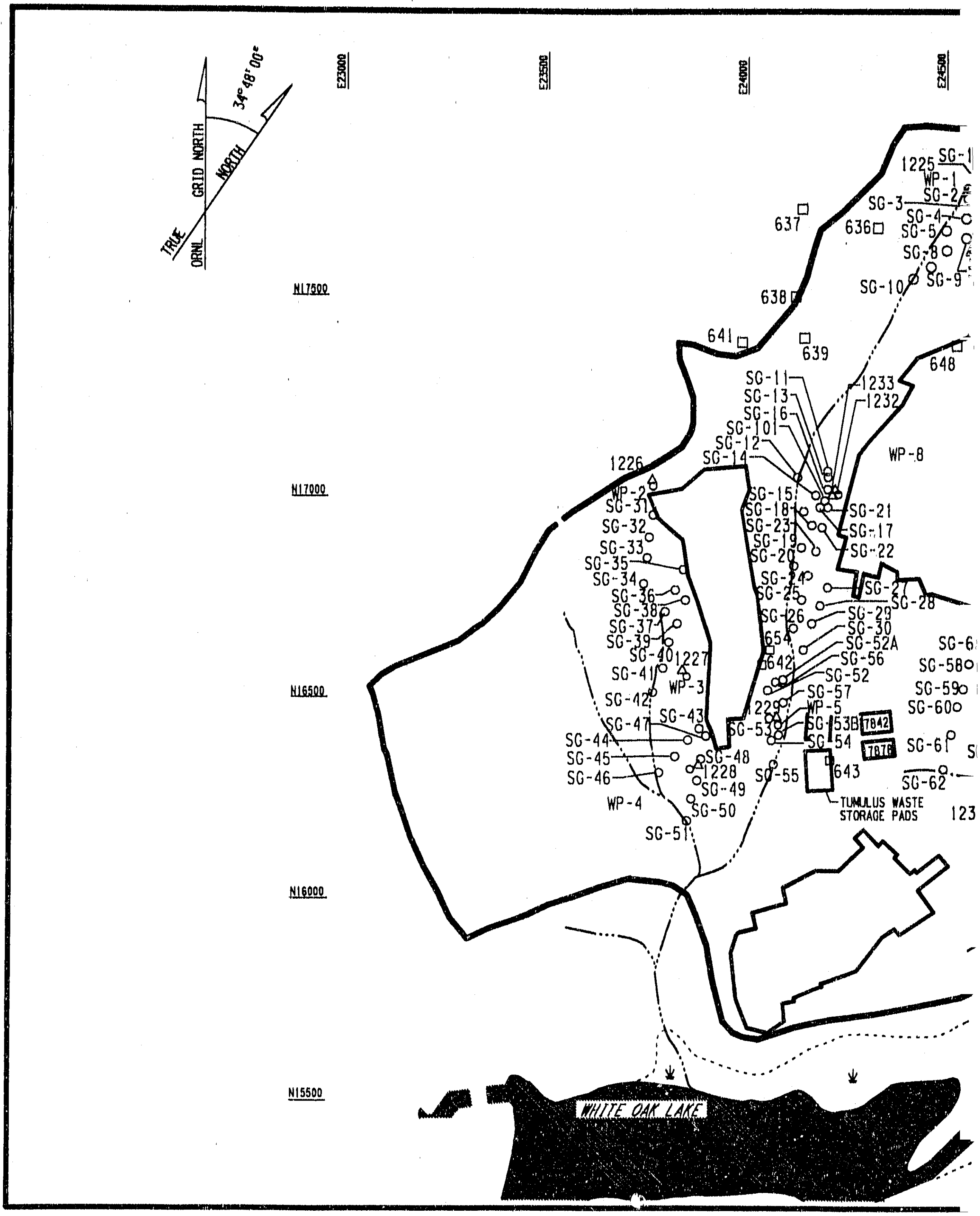


Fig. 2.2. Electromagnetic conductivity survey contour map.



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9-5

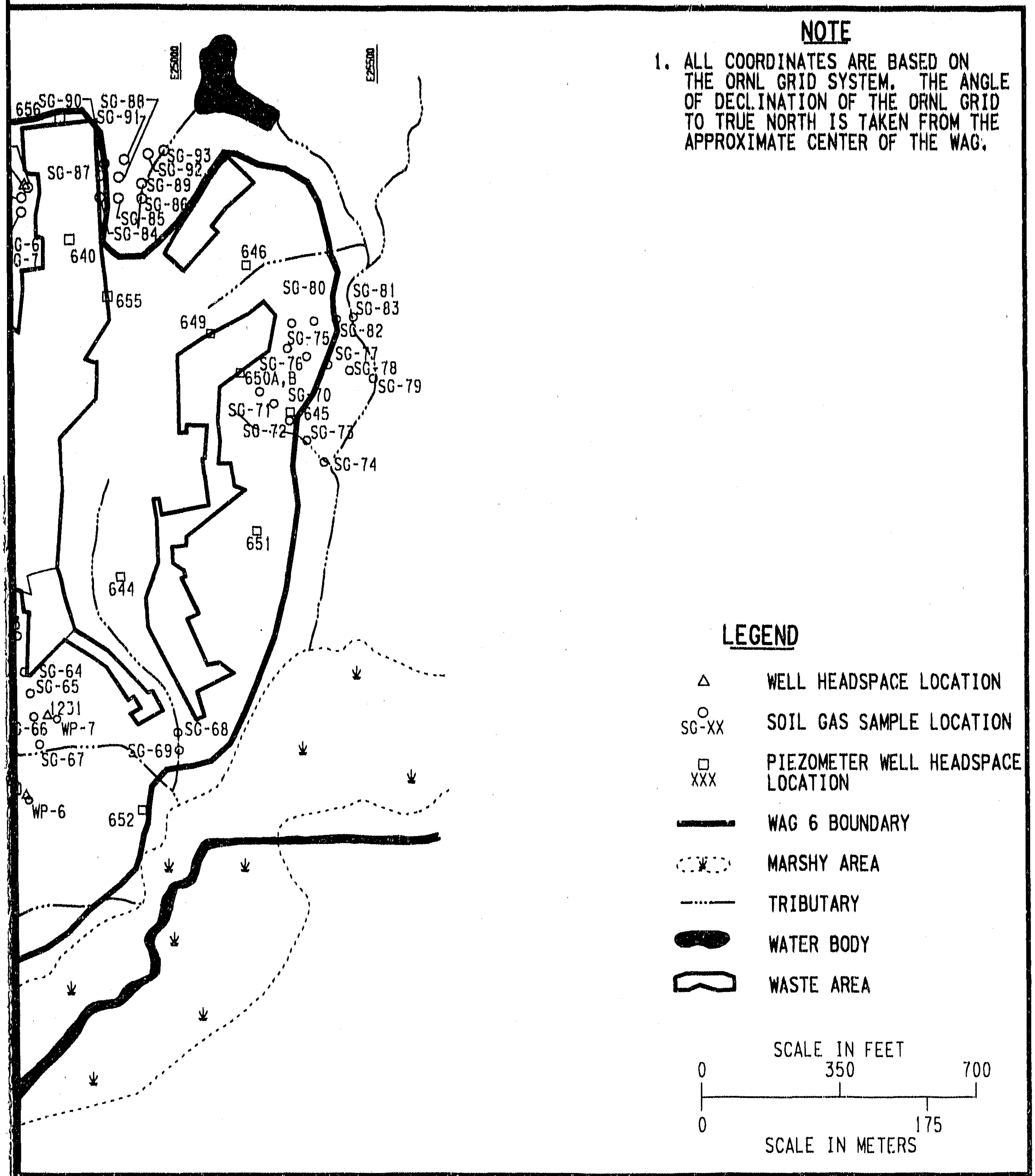
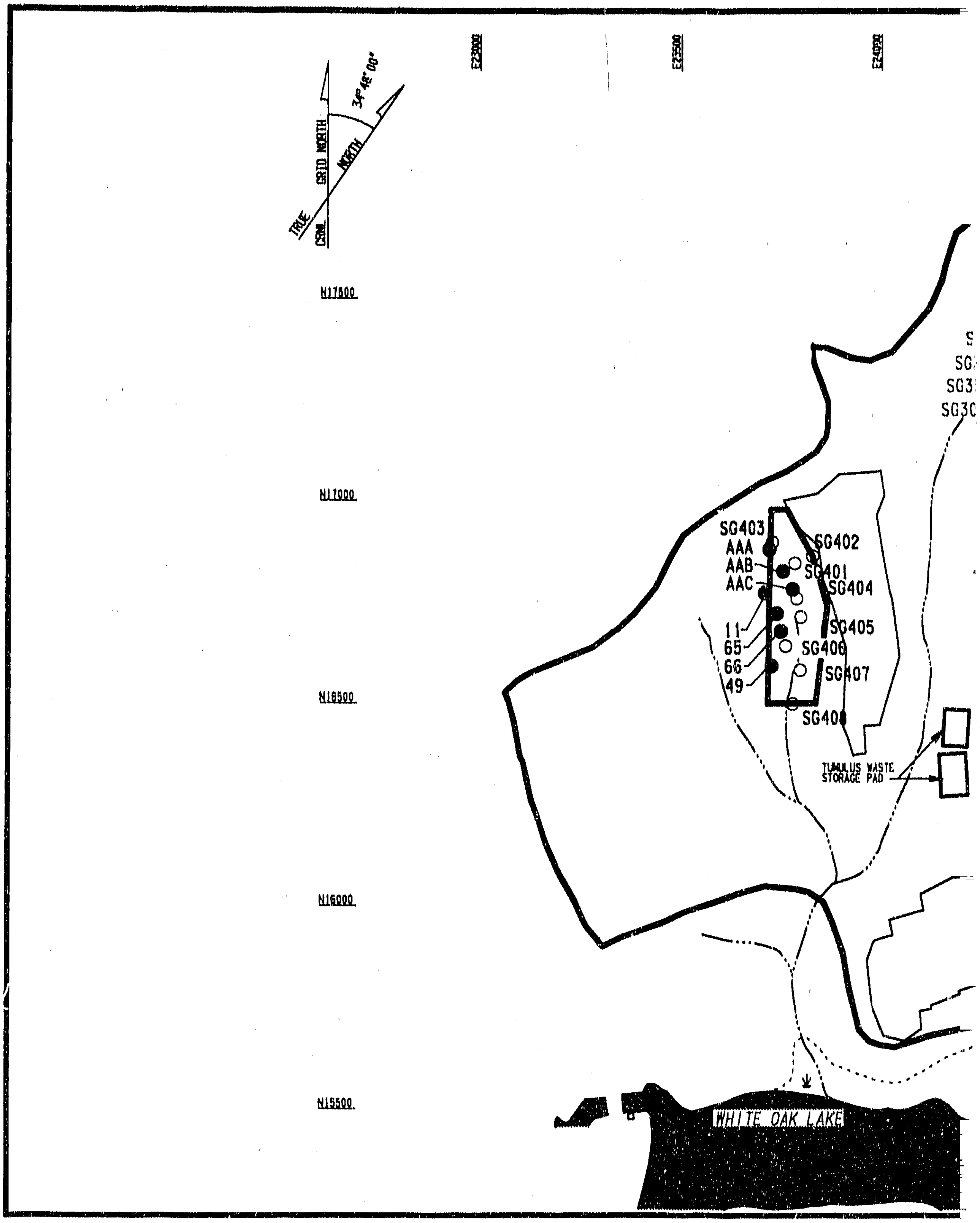


Fig. 2.3. Soil gas and well headspace locations, Activity 1.



WAG 6 06F260.DGN
9-5

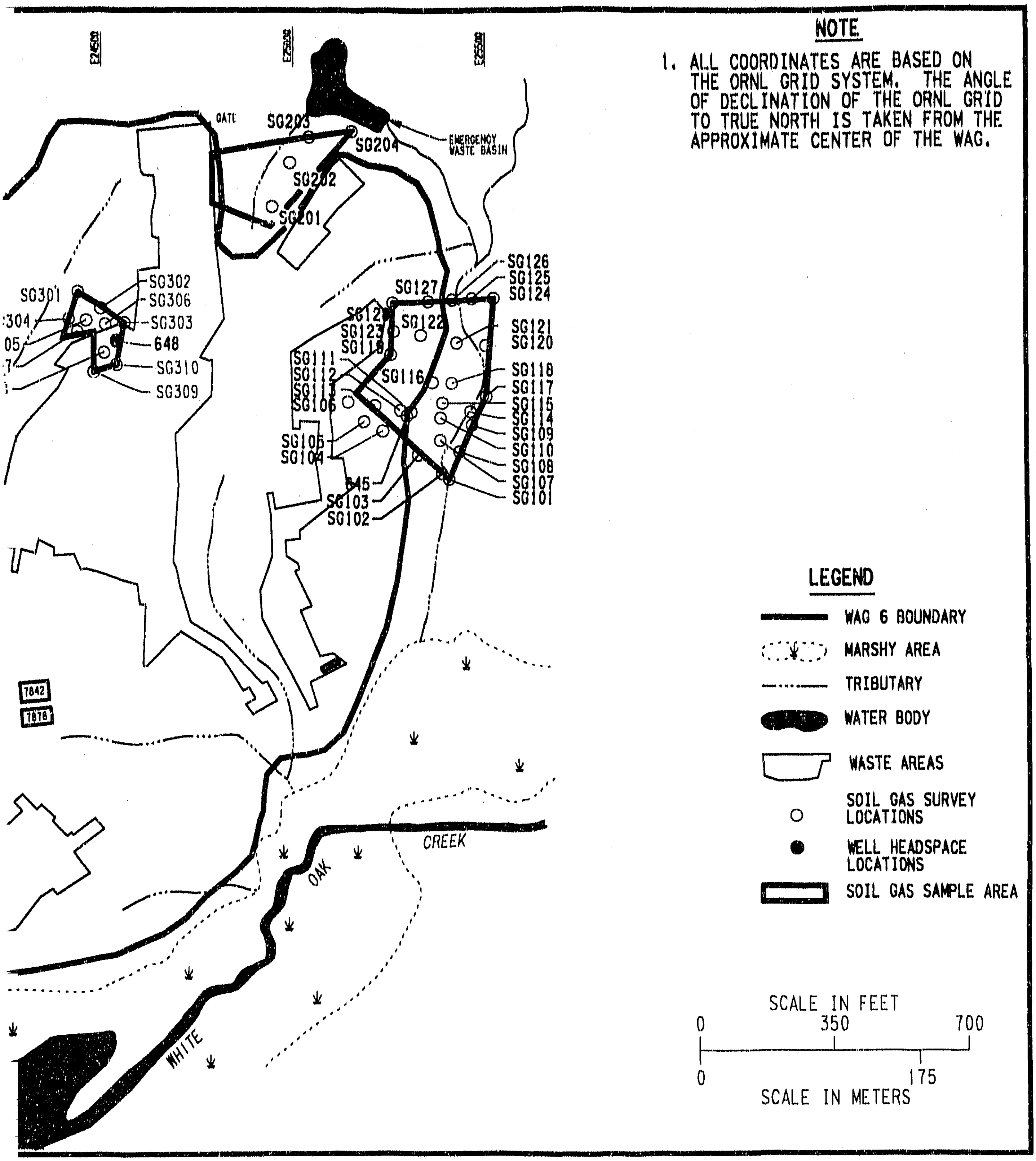
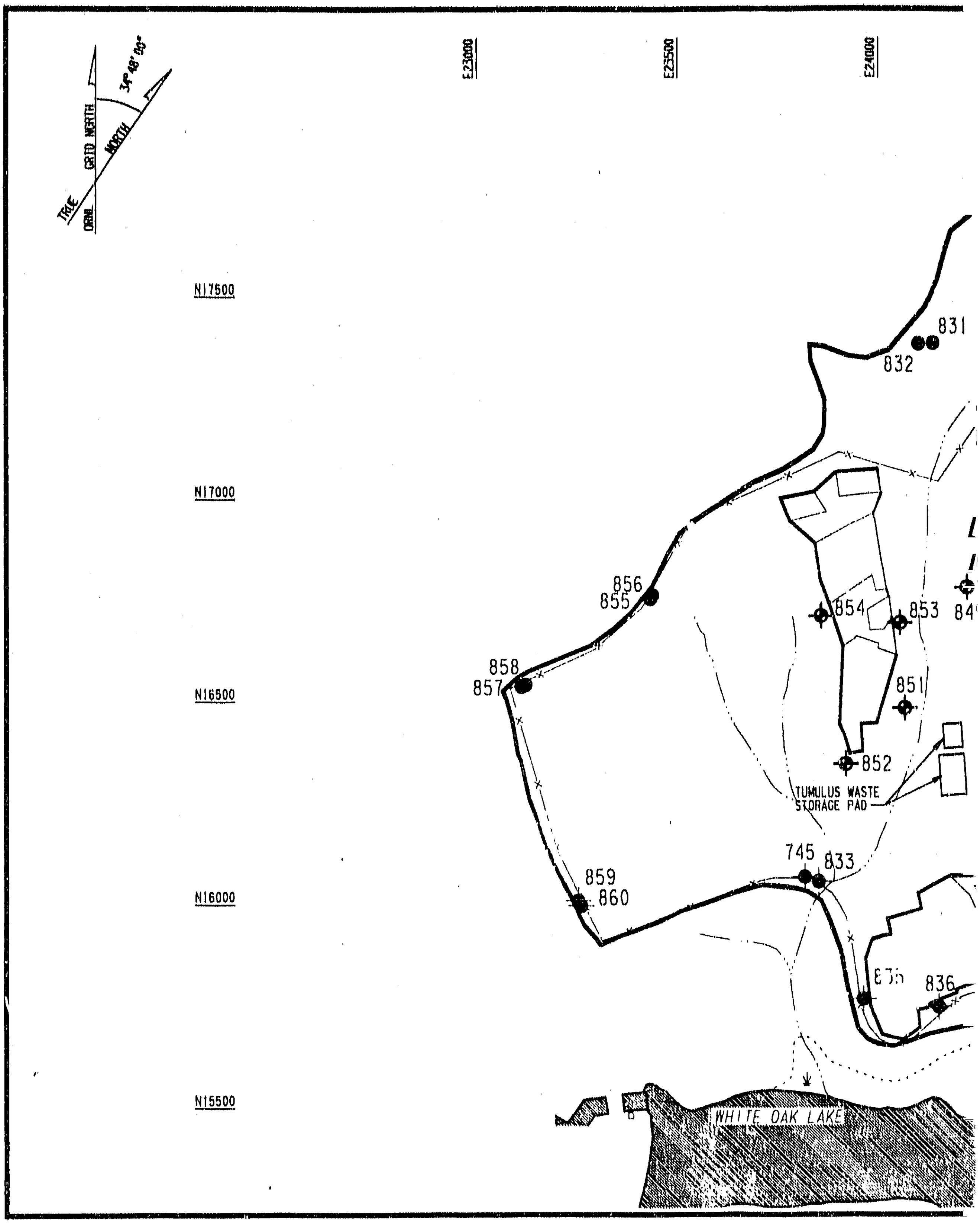


Fig. 2.4. Soil gas and well headspace locations, Activity 2.



WAG6 06F259.DGN
9-5

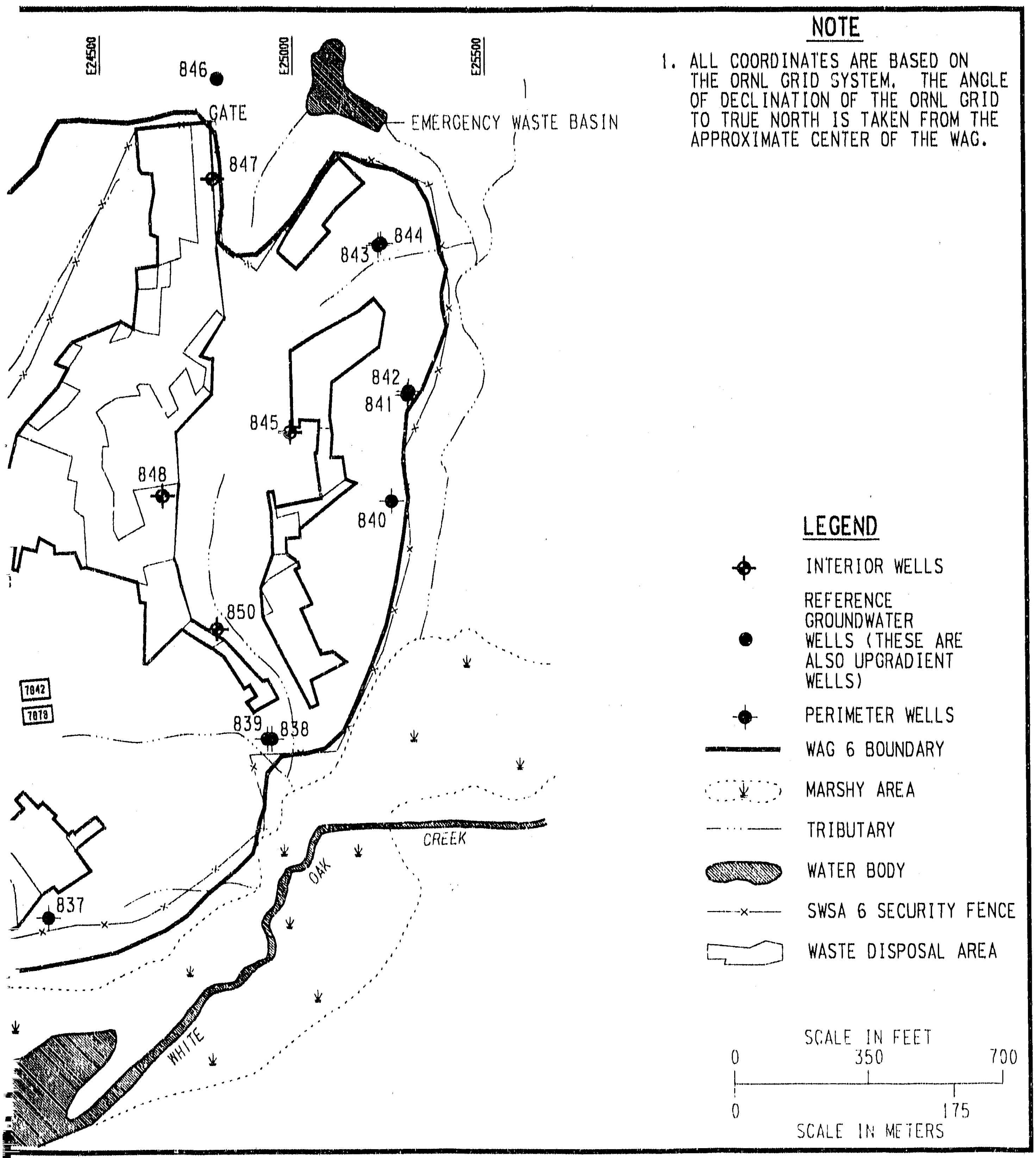
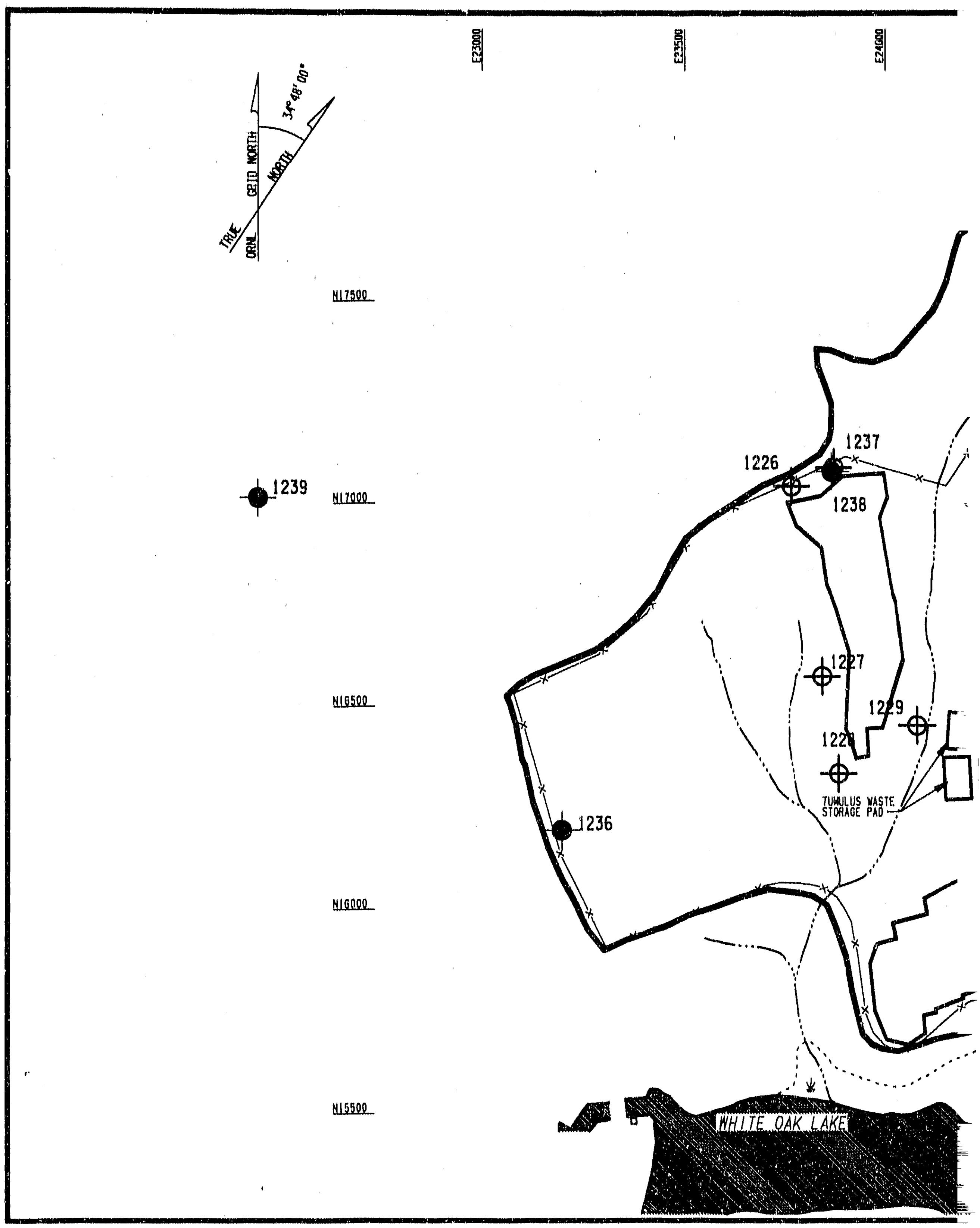


Fig. 2.5. ORNL RCRA compliance well locations.



WAG6 06F256.DGN
9-6

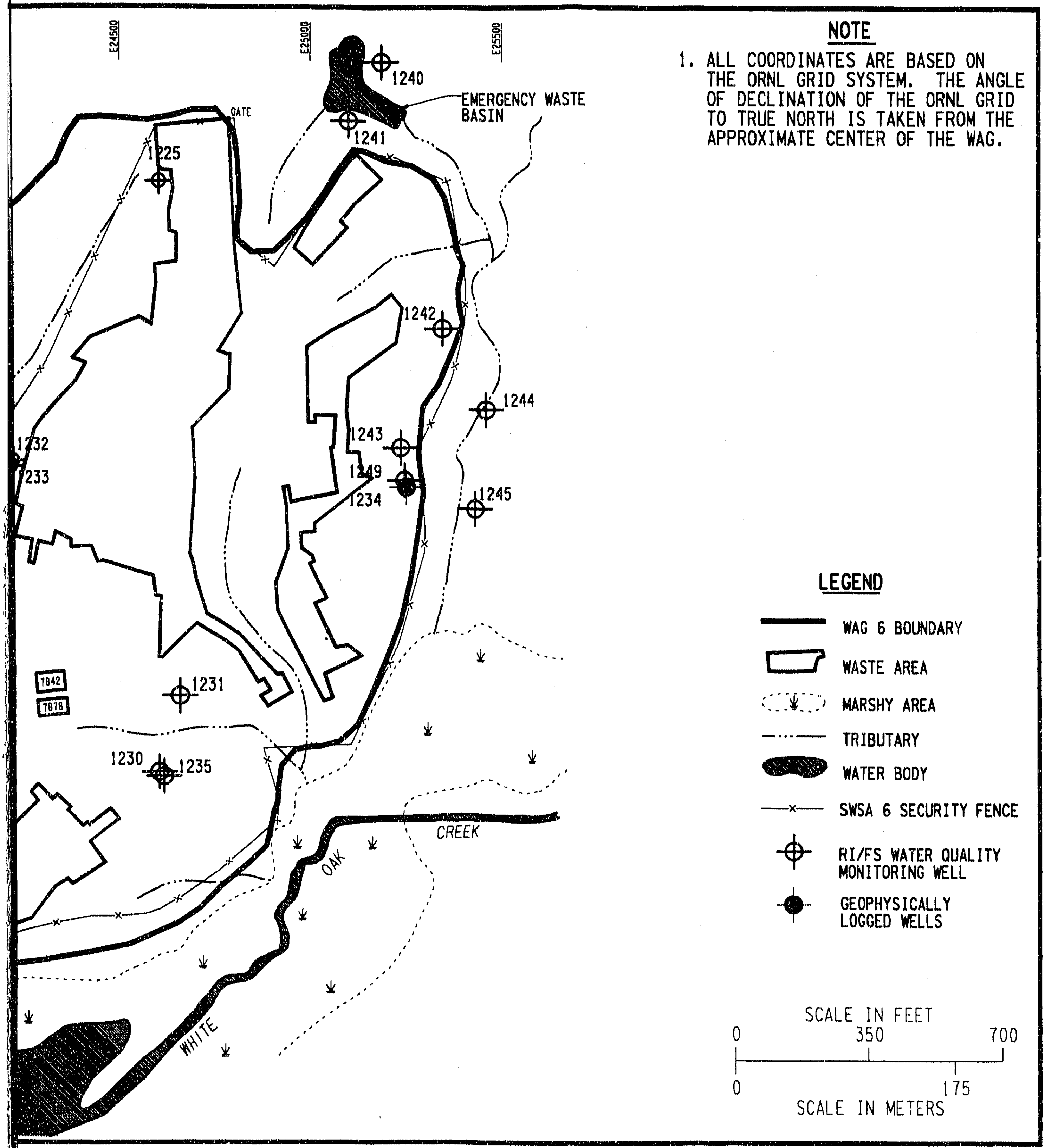
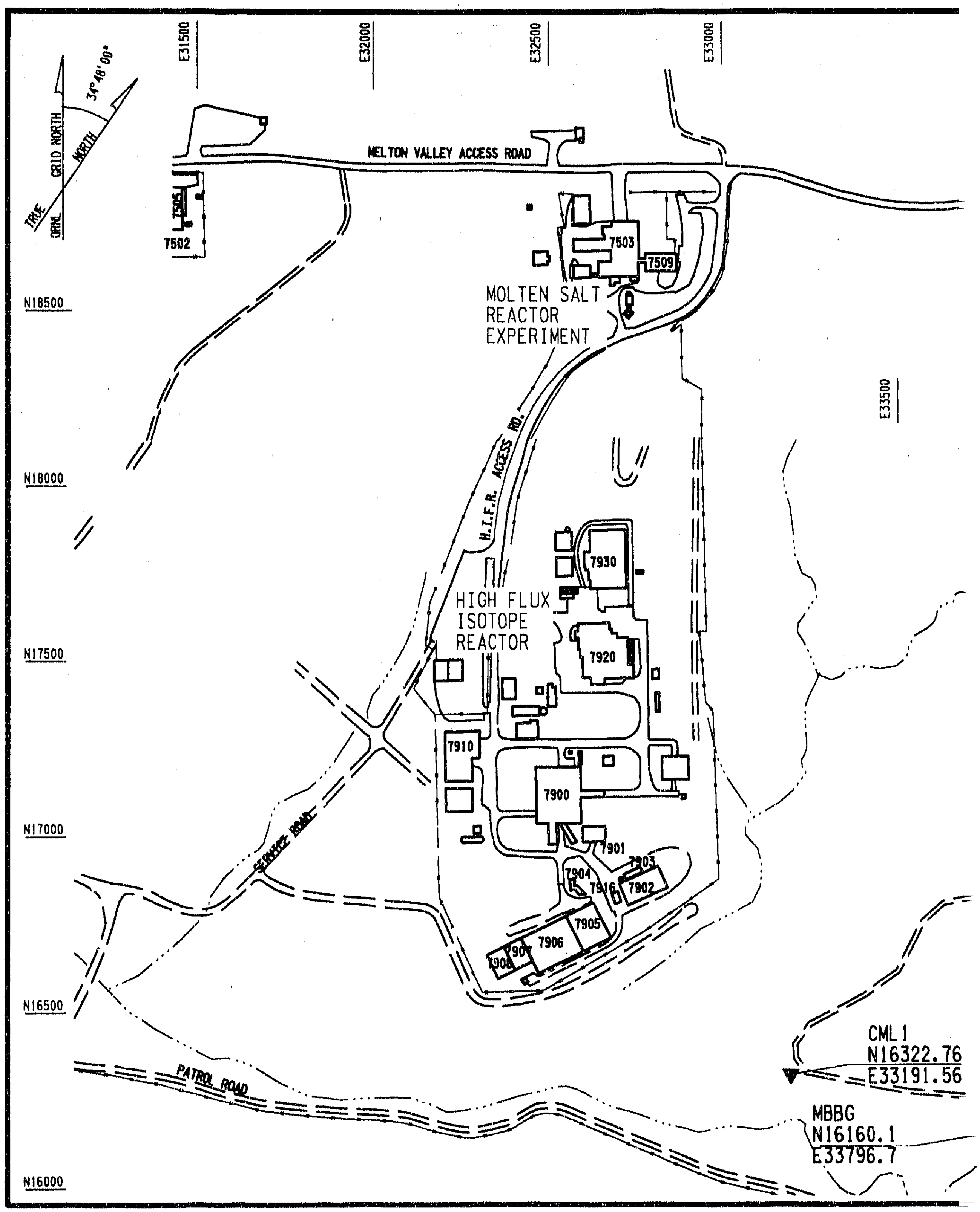


Fig. 2.6. WAG 6 RFI groundwater well locations.



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9-6

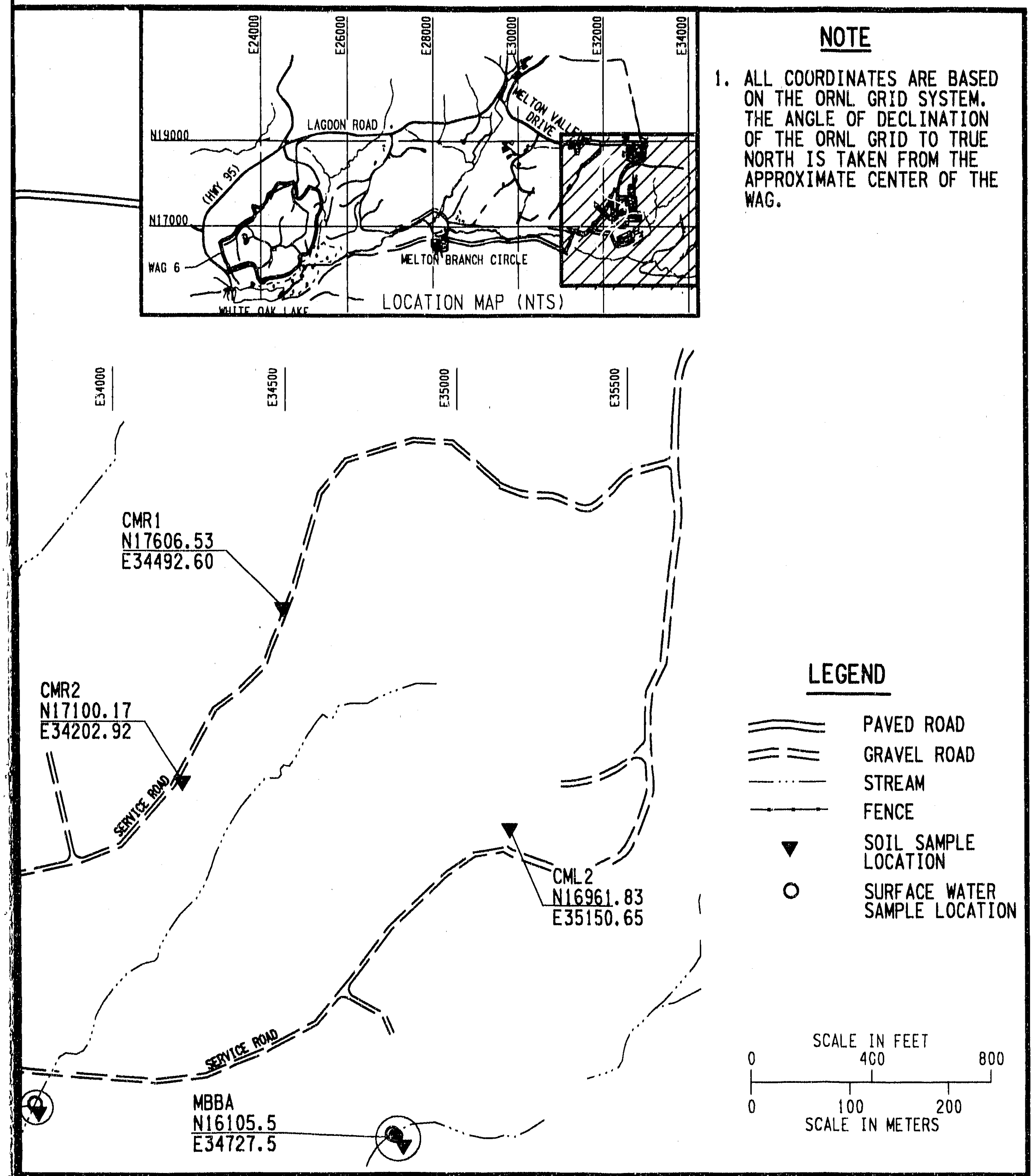
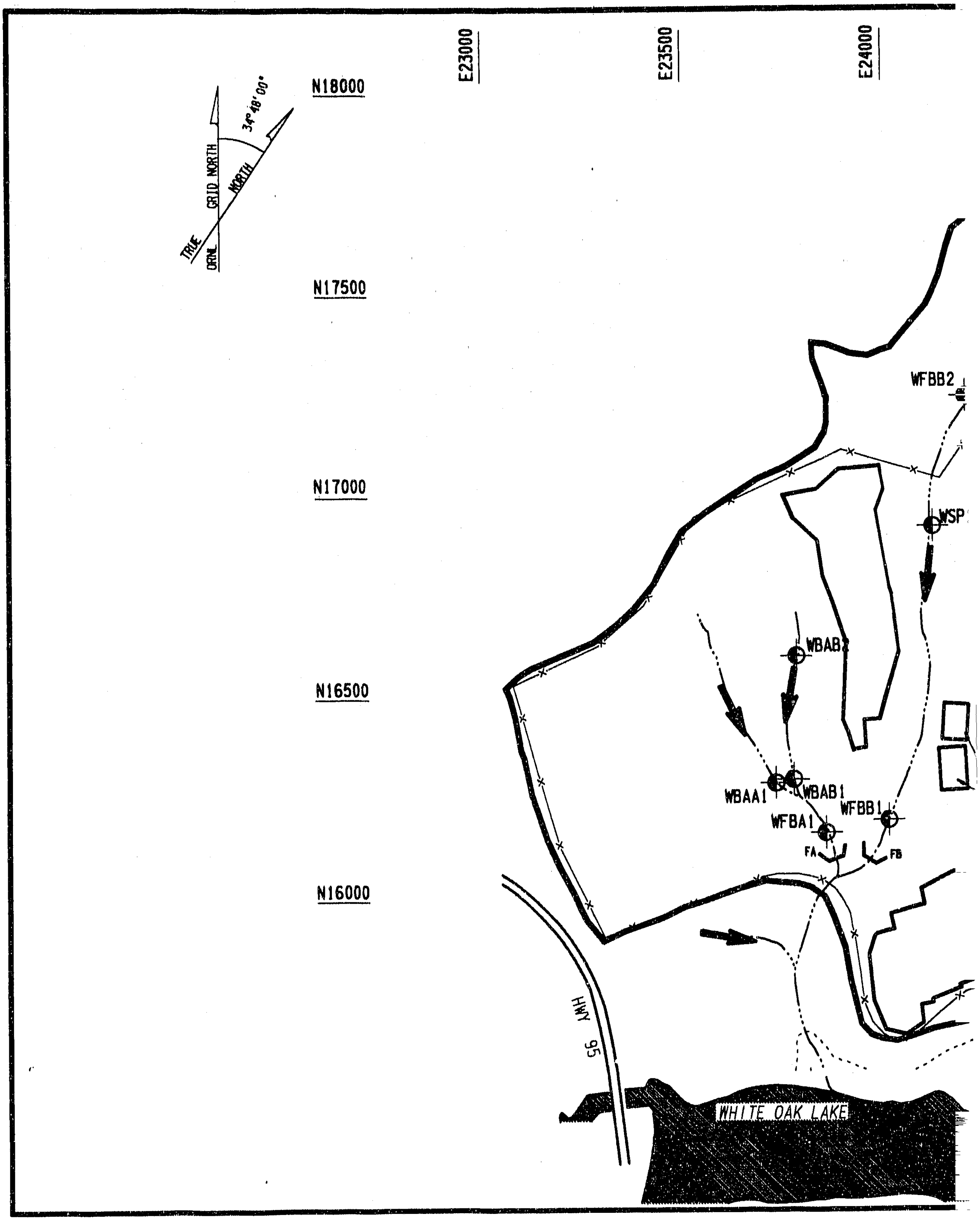


Fig. 2.7. WAG 6 reference surface water and soil sampling locations (in proposed SWSA 7).



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9-6

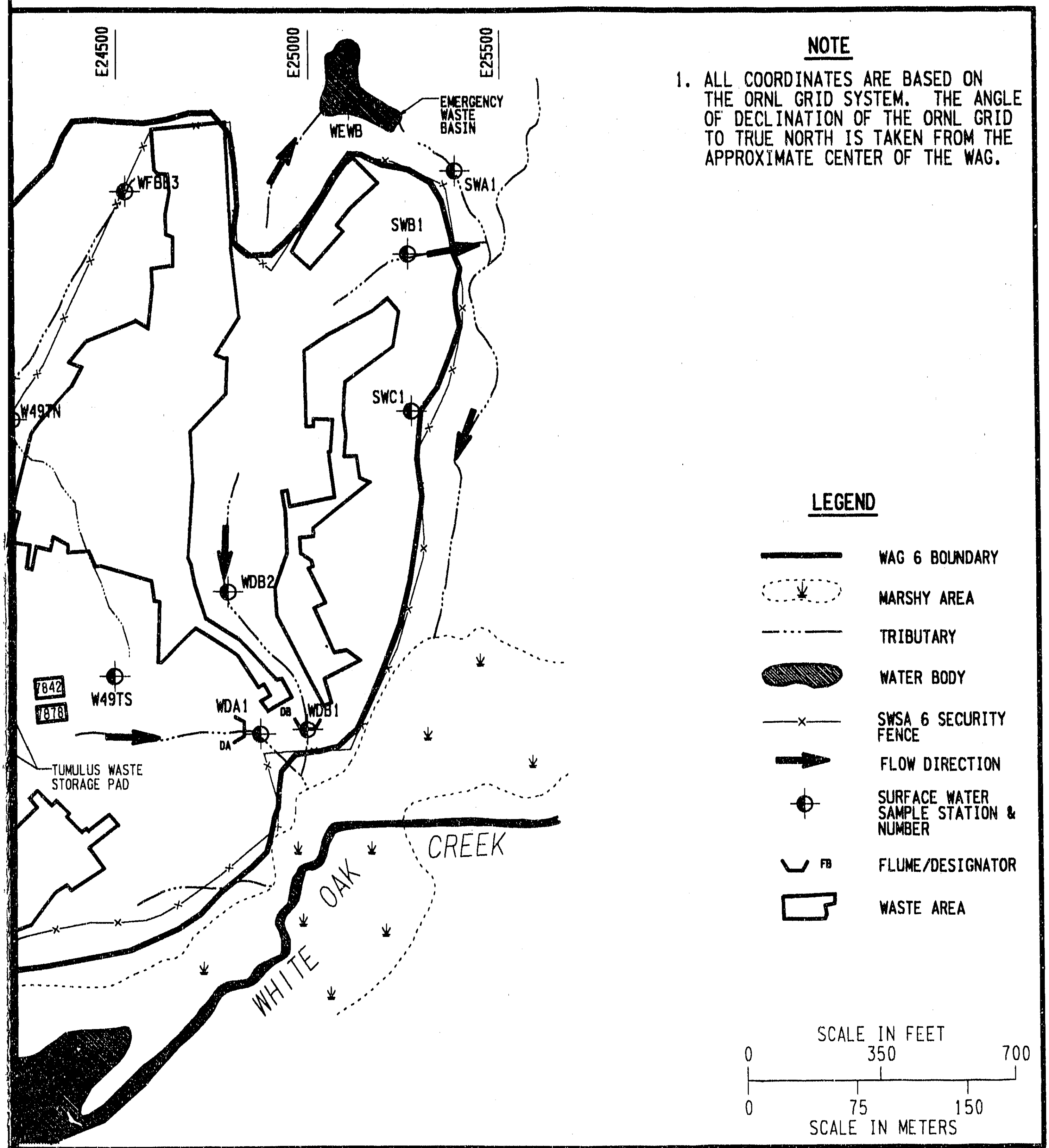
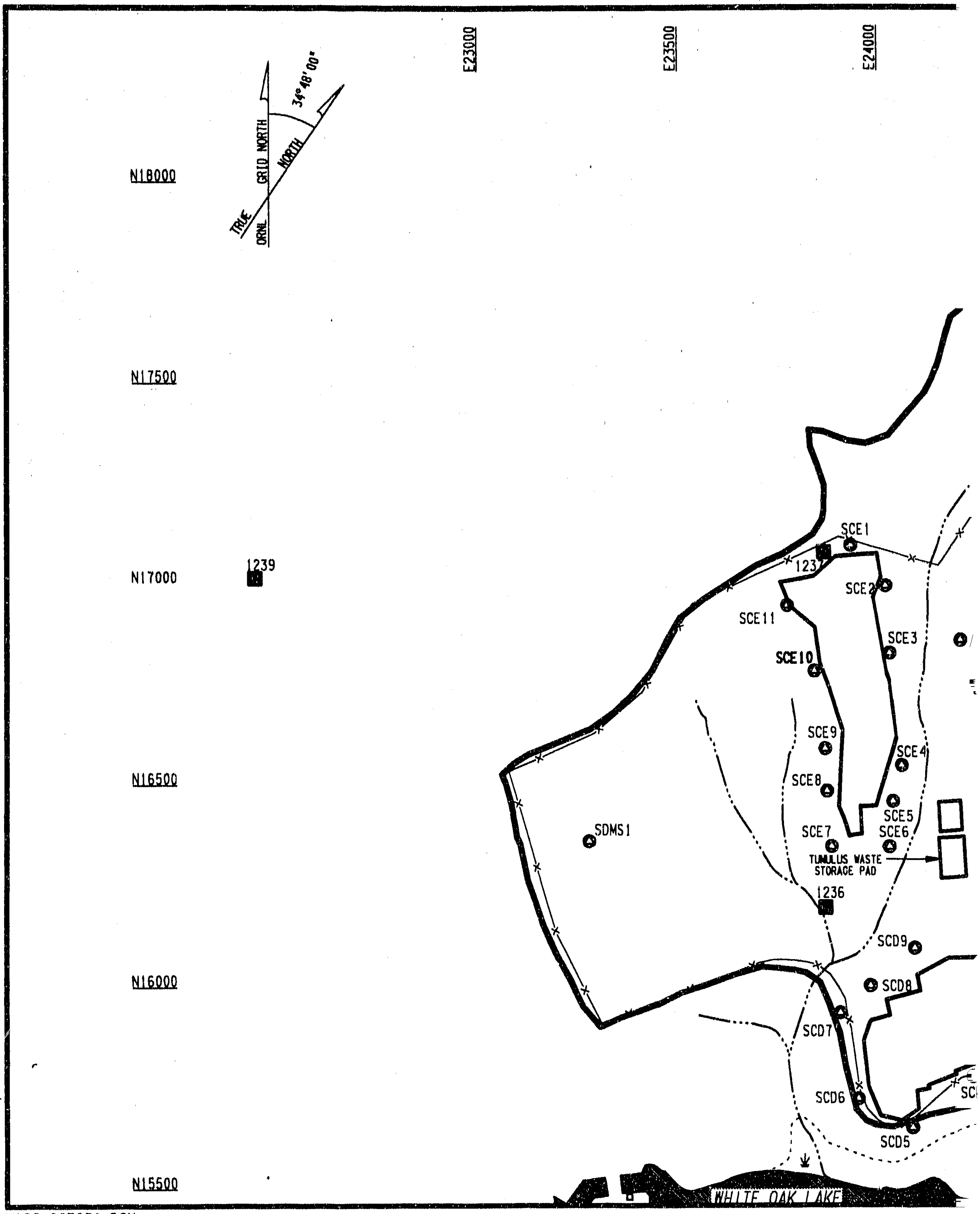


Fig. 2.8. Surface water sampling locations.



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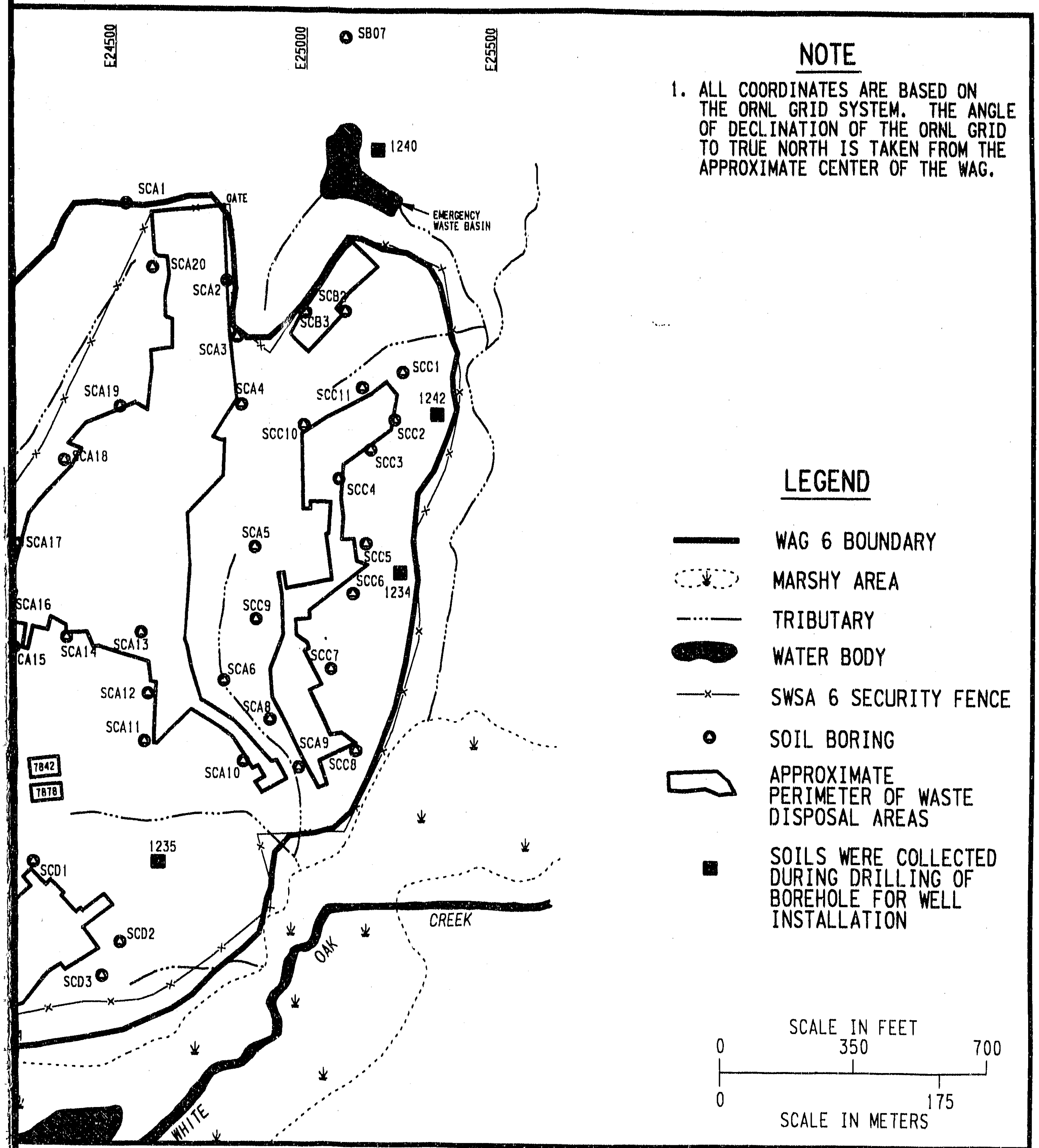


Fig. 2.9. Soil sampling locations.

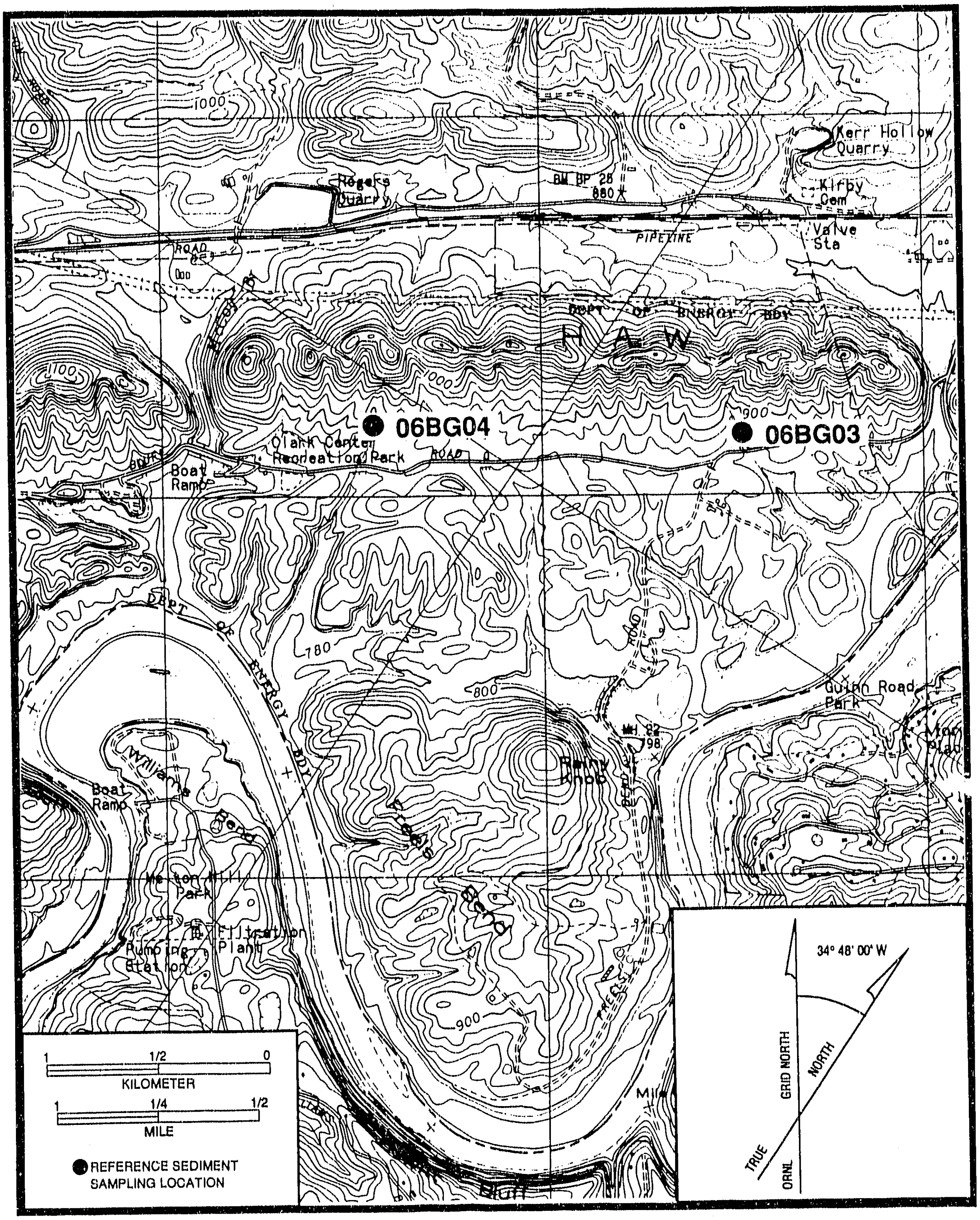
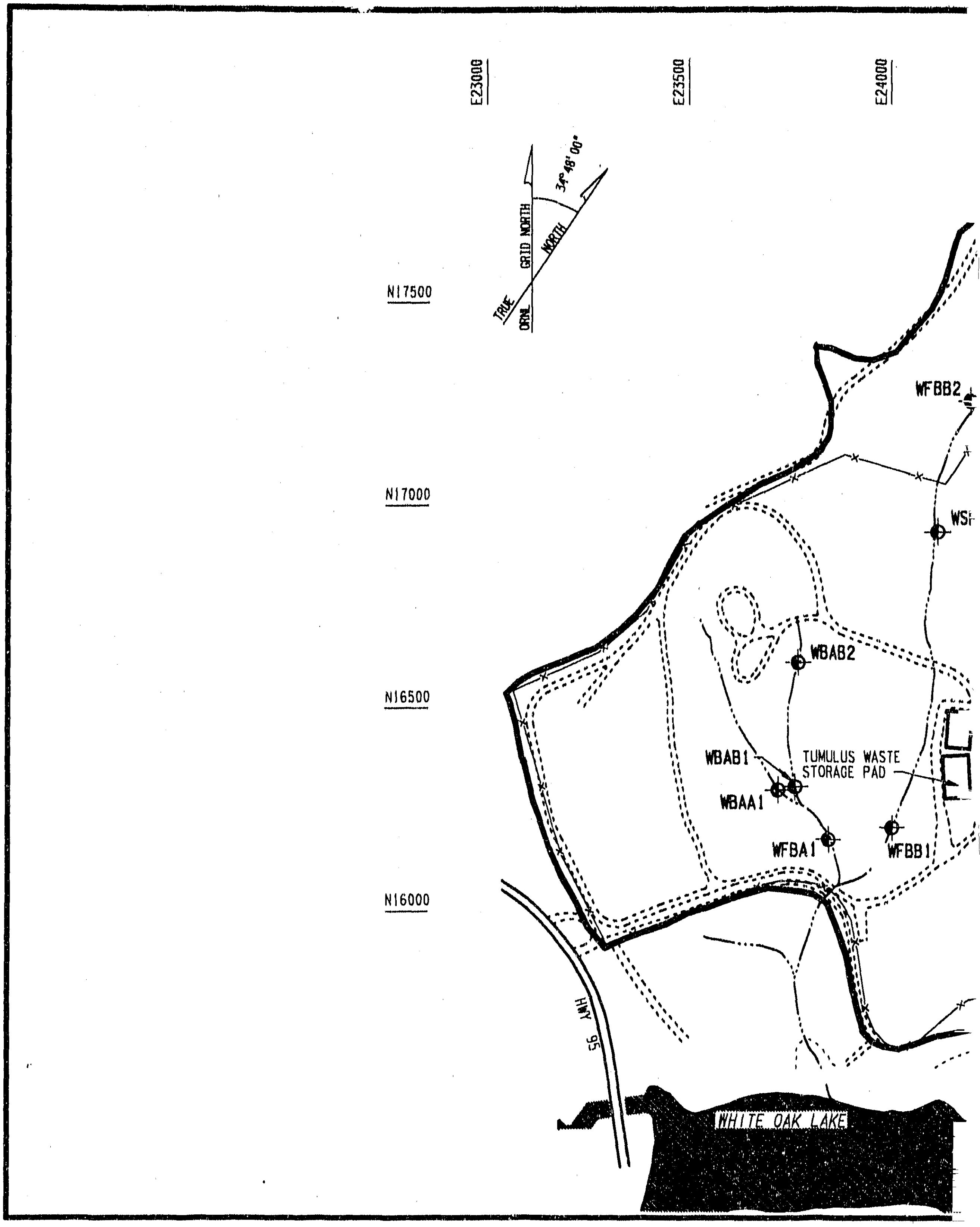


Fig. 2.10. Reference sediment sampling locations in Melton Valley north of Park Road. Map prepared by Tennessee Valley Authority for U.S. DOE (1986).



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9-6

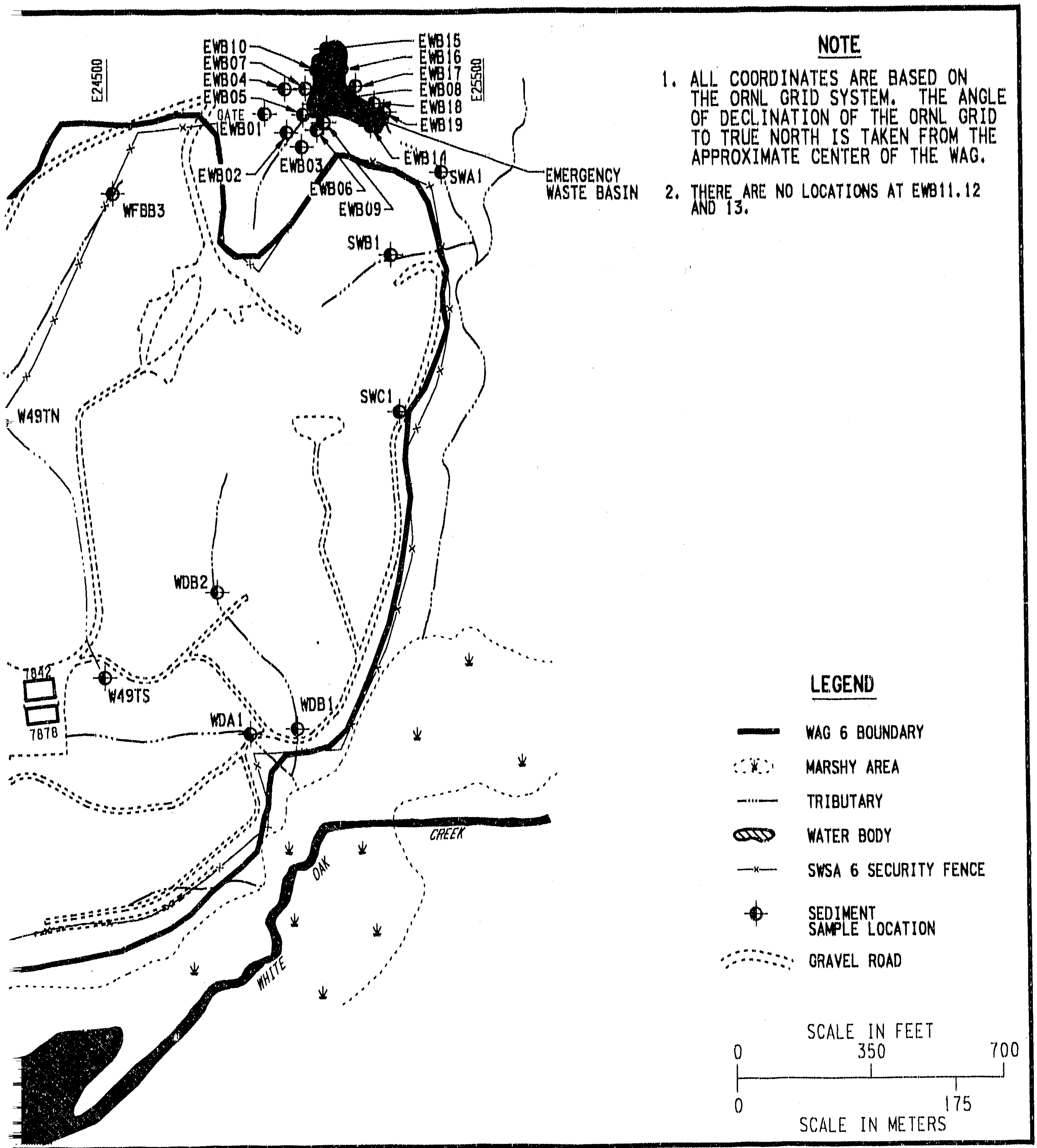
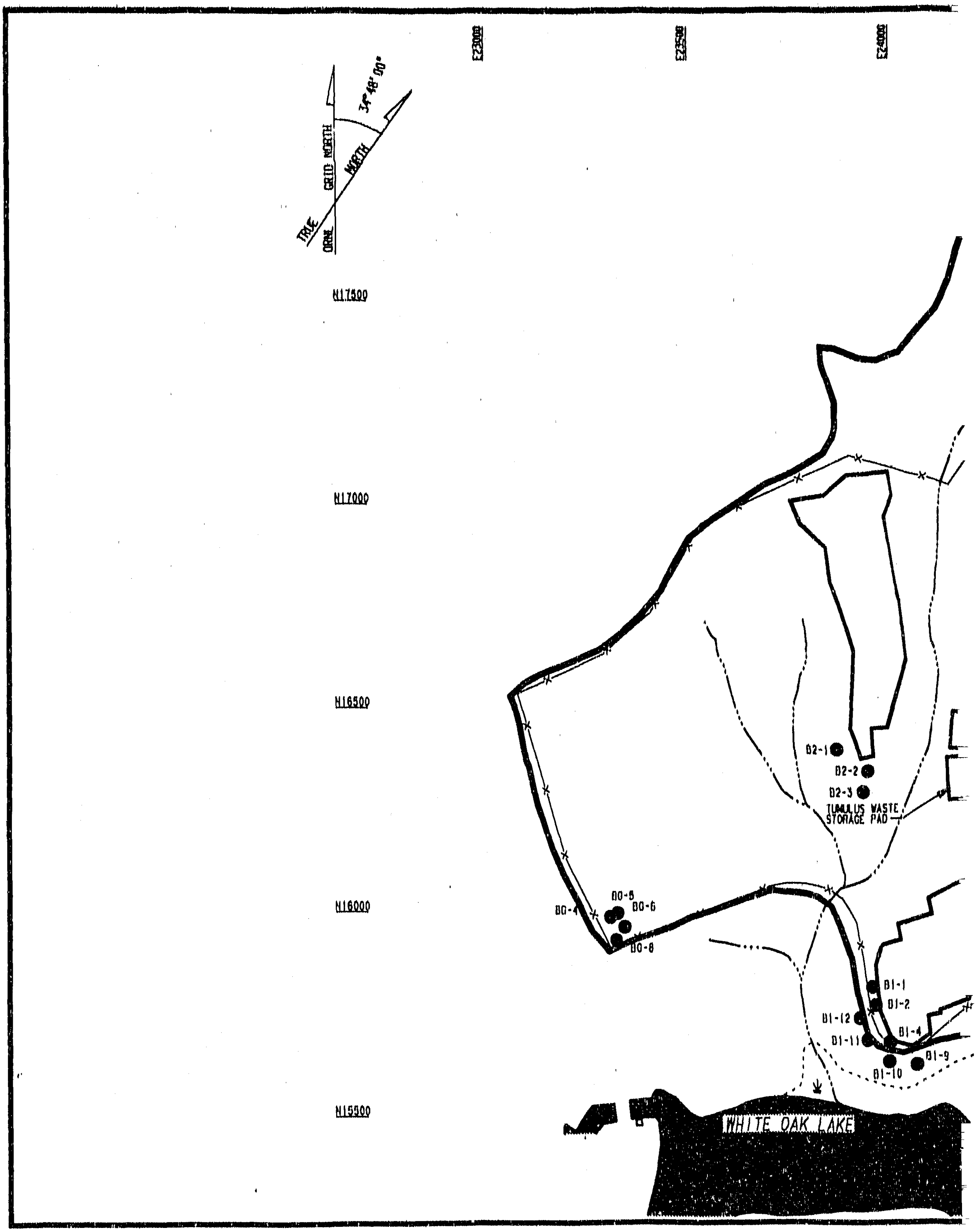


Fig. 2.11. WAG 6 sediment sampling locations.



WAG6 06F020.DGN
9-6

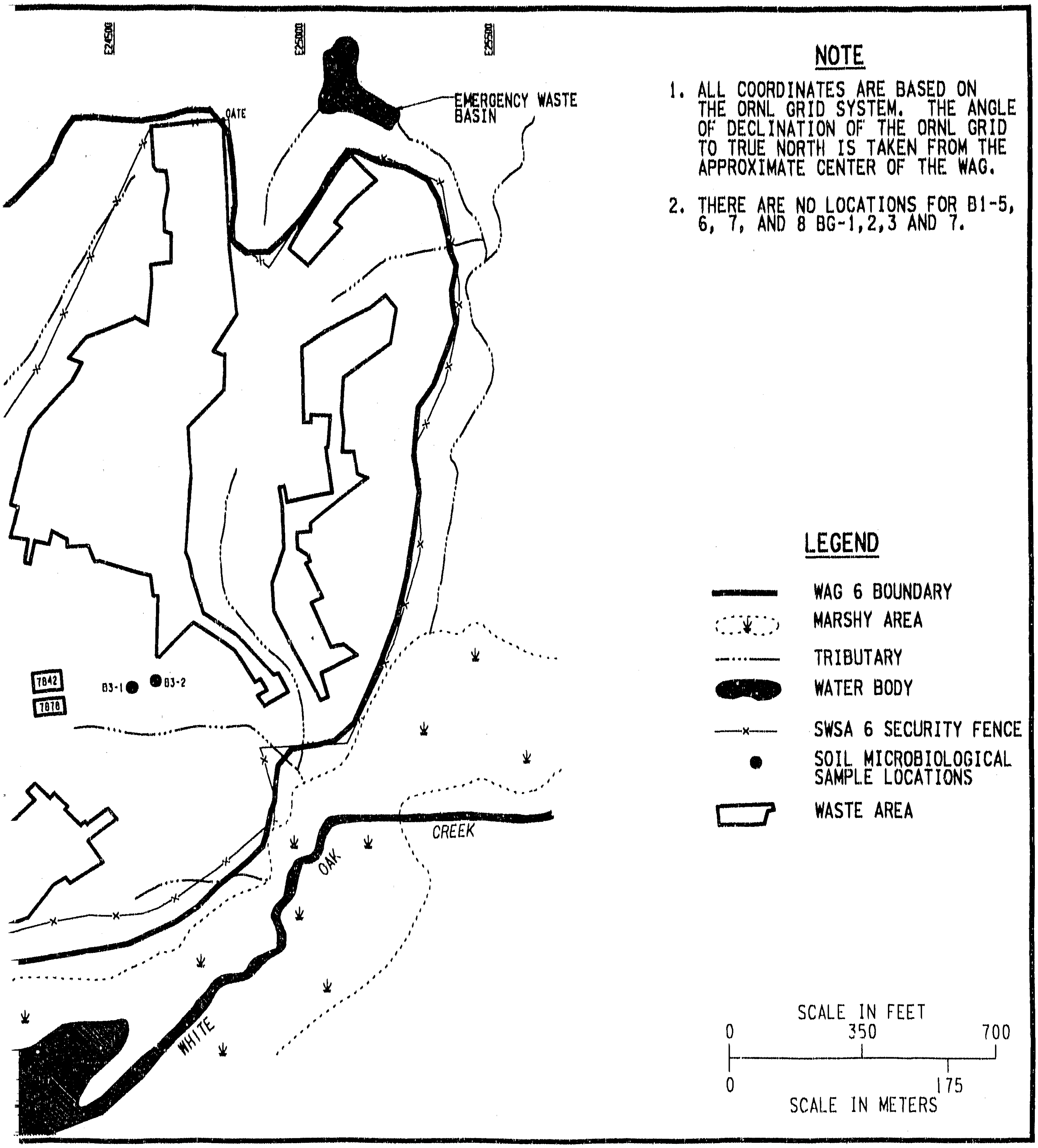
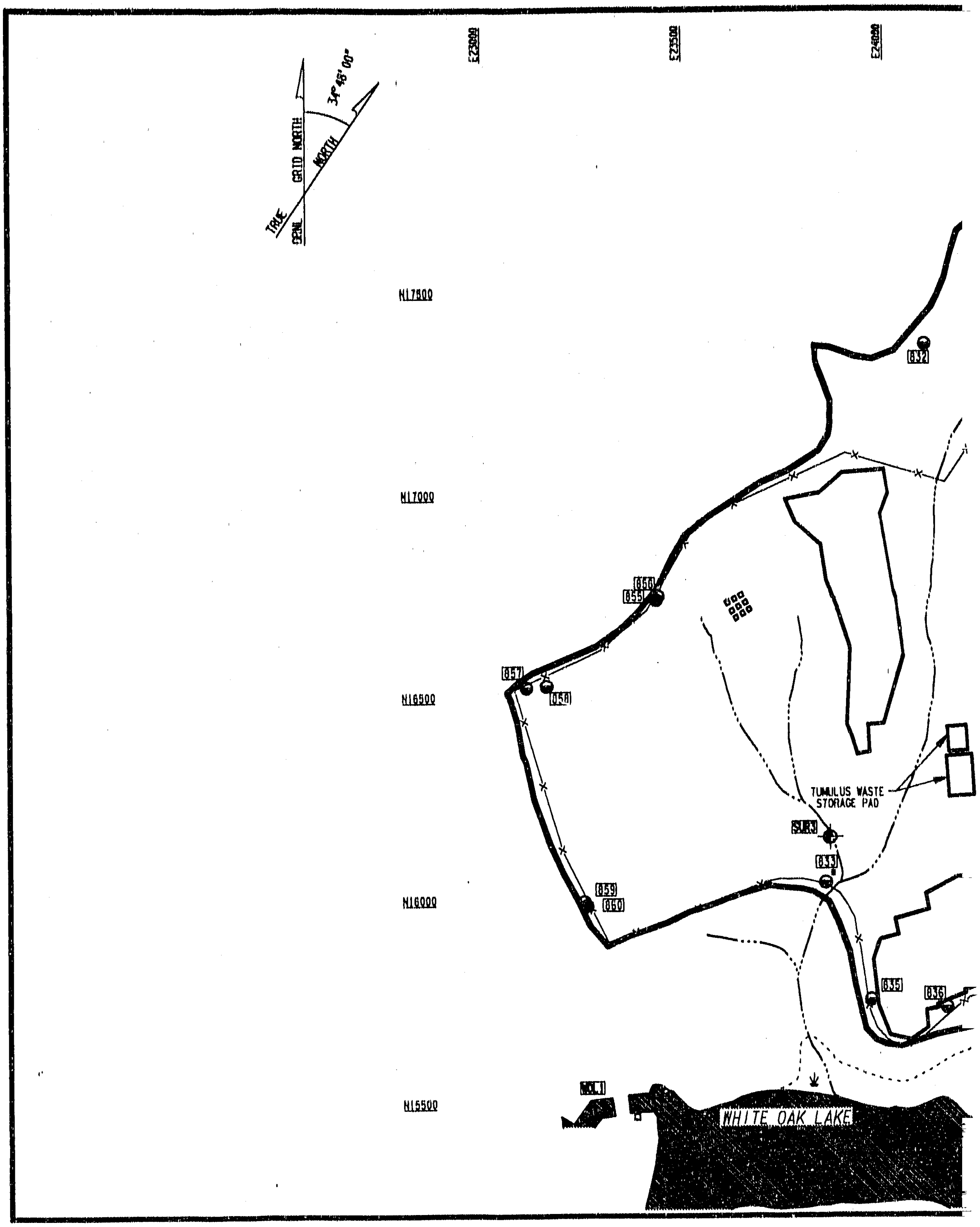


Fig. 2.12. Soil microbiological sampling locations Activity 1.



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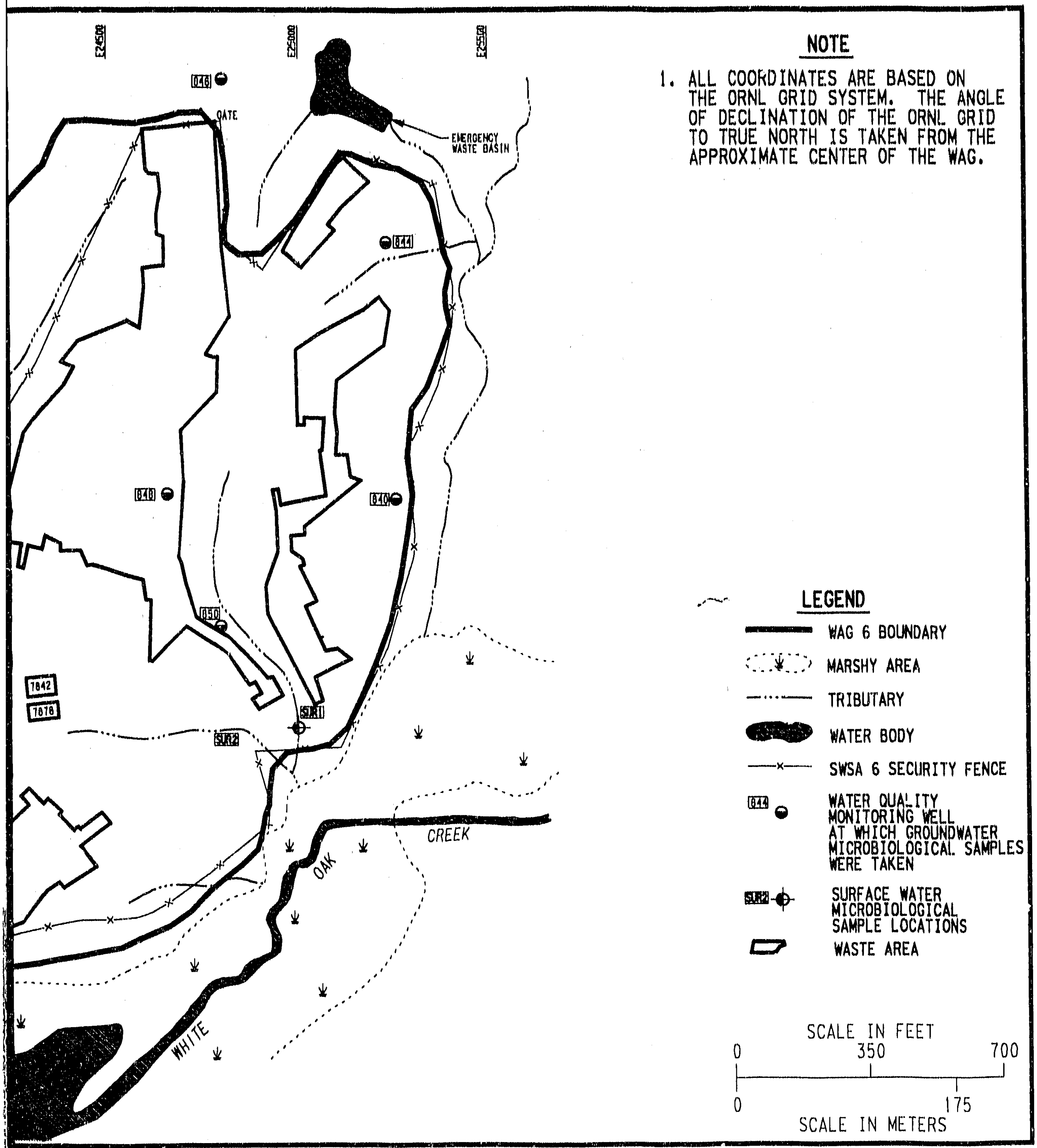


Fig. 2.13. Groundwater and surface water microbiology sampling locations, Activity 1.

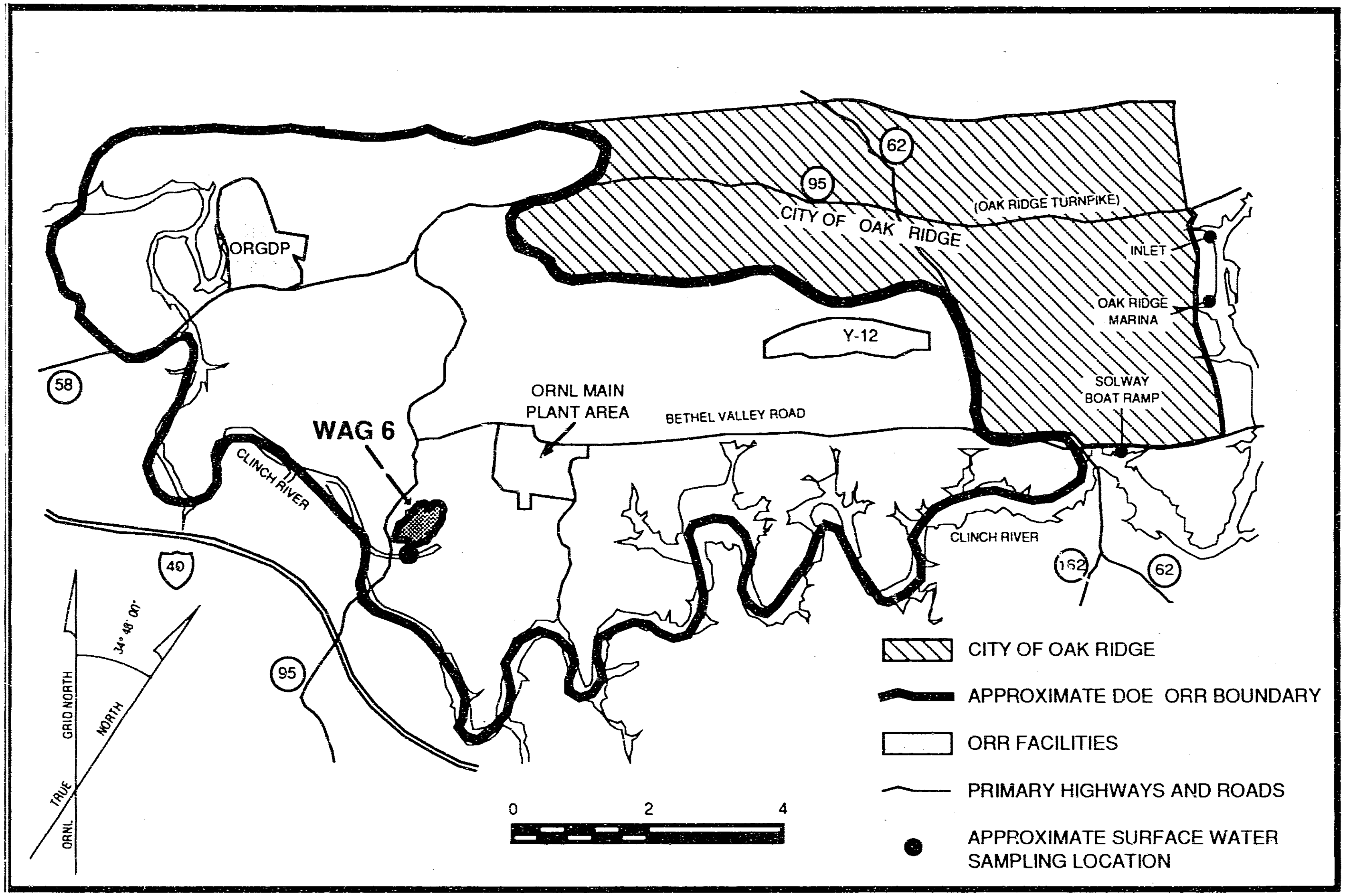
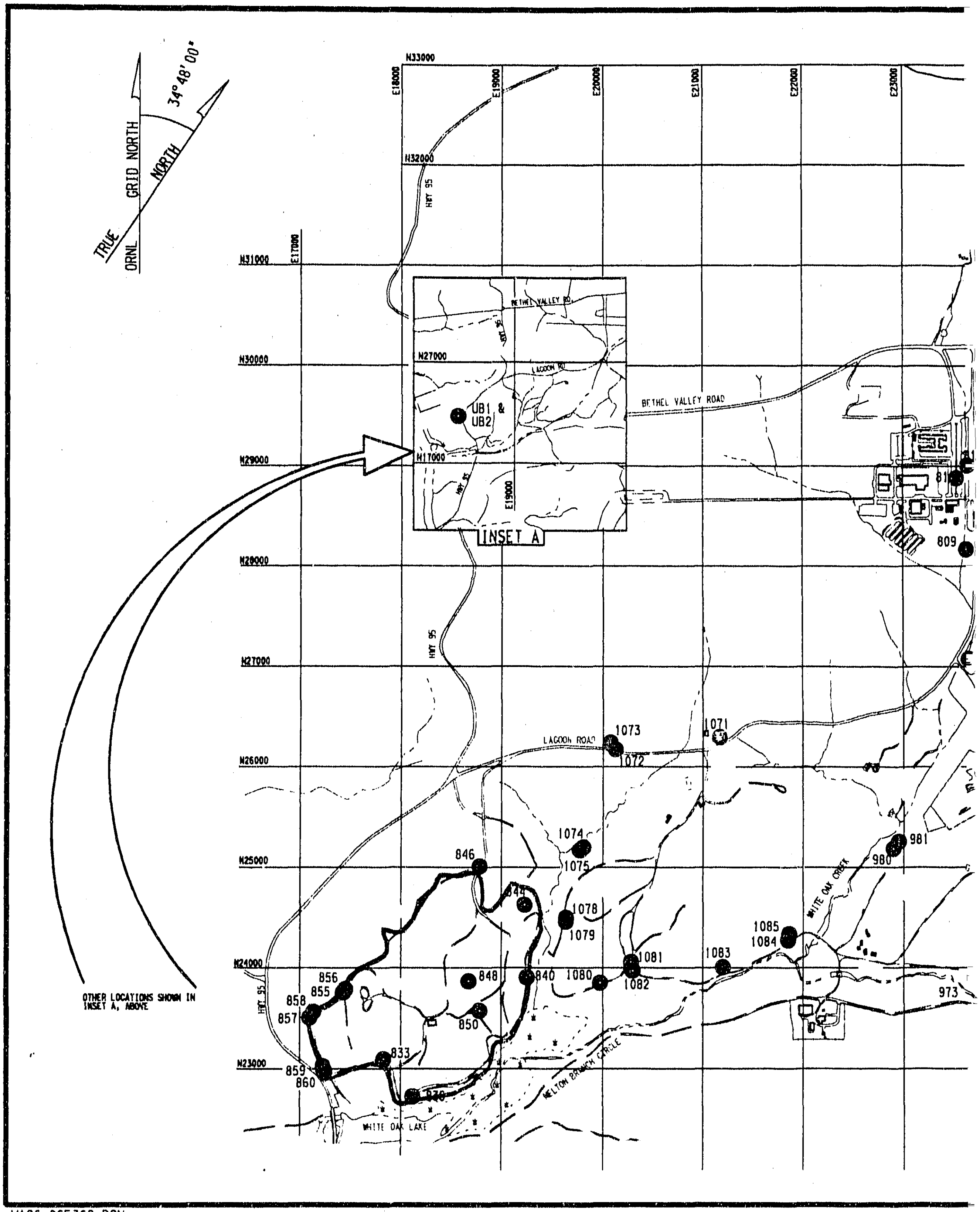


Fig. 2.14. Approximate microbiological surface water sampling locations, Activity 2.

5 18F 4104 177A



WAG6 06F369.DGN
9-6

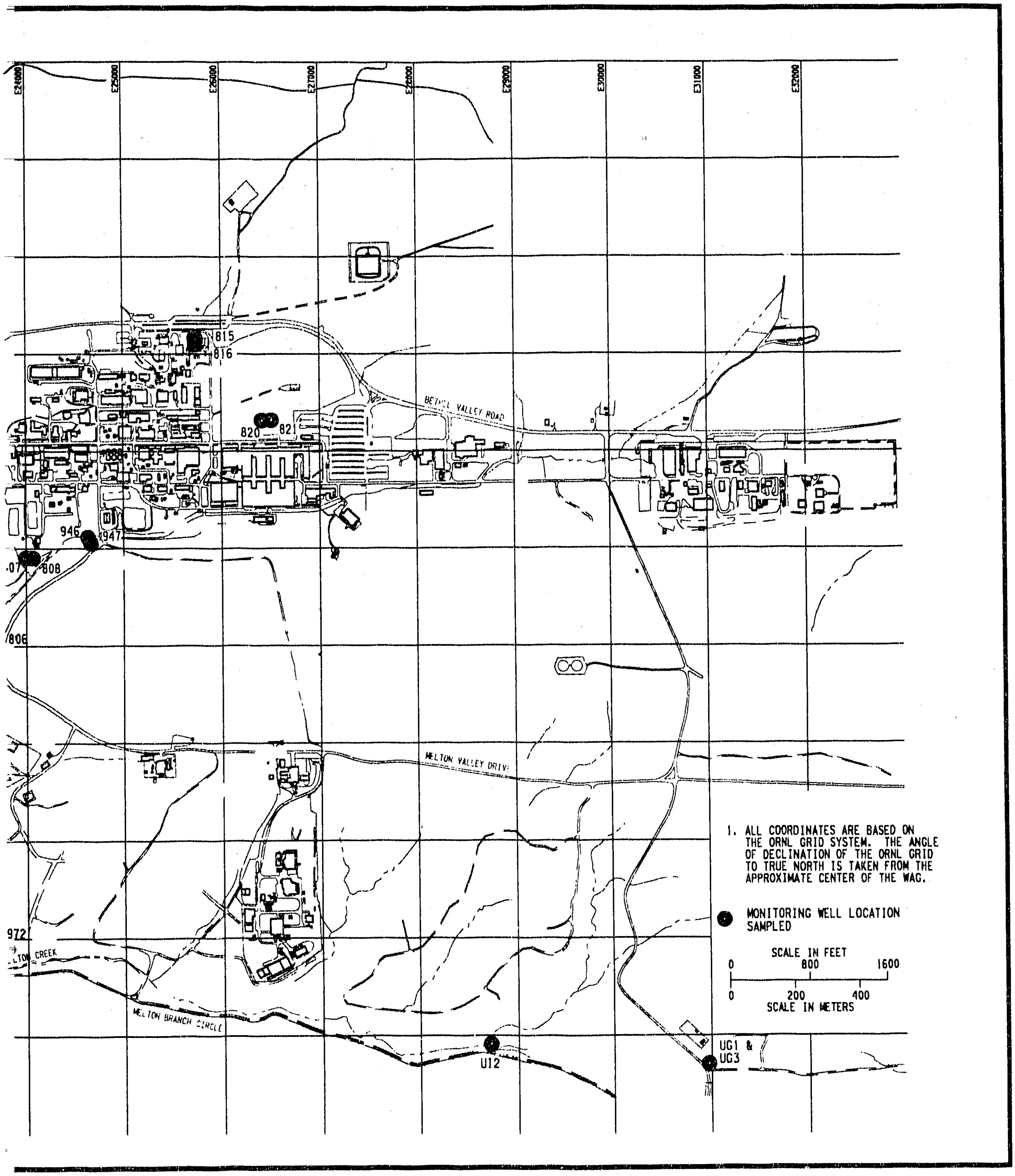


Fig. 2.15. Groundwater microbiological sampling locations, Activity 2.

3. PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section of the WAG 6 RFI Report describes the physical characteristics of the site that are relevant to identifying and evaluating potential transport pathways, mechanisms, and receptors. This information supports subsequent sections that pertain to nature and extent of contamination and contaminant fate and transport (Sects. 4 and 5, respectively). Additionally, key findings relevant to development and screening of potential remedial action alternatives are included.

This section is organized into five subsections: Sect. 3.1, Site Topography, Climate and Meteorology; Sect. 3.2, Site Geology; Sect. 3.3, Groundwater Hydrology; Sect. 3.4, Surface Water Hydrology; Sect. 3.5, Ecology. A summary of key findings is presented at the conclusion of each section.

Appendix 3A presents a summary tabulation of WAG 6 subsurface and hydrogeologic data, and Appendix 3B presents data in support of Sect. 3.5.

3.1 SITE TOPOGRAPHY, CLIMATE, AND METEOROLOGY

This section discusses the topography, climate, and meteorology of WAG 6. Section 3.1.1 describes the topography and physical features of the site; Sect. 3.1.2 discusses climate and meteorology and the interplay among precipitation, ambient air temperatures, evapotranspiration, and winds. Section 3.1.3 summarizes the key information presented in this section.

3.1.1 Topography and Site Features

WAG 6 is located at the southwestern end of Melton Valley, a northeast-southwest trending valley roughly 1.2 miles wide that lies between Haw Ridge to the north and Copper Ridge to the south. Crest elevations along Haw Ridge and Copper Ridge reach 1000 ft and 1356 ft, respectively. A line of lower hills with crest elevations of approximately 850 ft occurs near the center of Melton Valley. WAG 6 is situated on the southeast flank of one of these hills.

Ground surface elevations within WAG 6 range from about 745 ft (MSL) adjacent to WOL at the southern WAG boundary and eastern perimeter of the site to greater than 850 ft (MSL) at the crest of the series of knobs along the northwest boundary. Maximum topographic relief across the site is 105 ft. Slopes within WAG 6 are variable and range from 10 to 57%. The greatest irregularity of terrain and the steepest slopes occur in the northern and northeastern parts of the site adjacent to the SWSA 6 access road and along the eastern perimeter road.

As Fig. 3.1 shows, the WAG 6 topography is dissected by four principal surface water drainages—FA, FB, DB, and DA. With the exception of stream DA, which trends grid east-west, streams .. 'AG 6 are oriented roughly grid north-south. The resulting undulating topography and relief plays an important role in the hydrogeologic framework of WAG 6 (Sect. 3.3).

Comparisons of historical (pre-ORNL) and recent air photographs of the site reveal that modifications of the land surface for waste disposal have not significantly altered the original surface drainage patterns or slope configuration. However, site records do indicate that the thin site soils have been highly disturbed, reworked, or removed over much of the site during past waste trench excavation, construction activities (involving cut and fill operations), and site grading. Air photographs from 1935 indicate the WAG 6 area was originally cleared and used for agriculture; several farmhouses existed on or adjacent to the present-day site. Old growth timber remained along the low-lying or steep areas not suited for agriculture. By 1952, following acquisition of the land by the Atomic Energy Commission (later DOE), the farmhouses had been removed and the site had become overgrown by secondary growth timber—to the extent that prior to waste disposal operations, the WAG 6 area was heavily wooded. Following initiation of waste disposal operations, trees were removed from waste disposal areas. Stands of trees remained along the principal drainage paths until the ICM capping work, which was completed in 1989. This work required removal of the trees along the eastern two interior drainages (DA and DB). Dense stands of mixed deciduous and conifer timber still exist along the northern boundary and in the western portions of WAG 6. Historical air photographs indicate that the area immediately north and northwest of WAG 6 (outside the SWSA 6 fence) has never been used for waste disposal purposes.

3.1.2 Climate and Meteorology

The WAG 6 climatic and meteorological information a' pertinent in characterizing the potential for atmospheric transport of contaminants in the ... assessment and are integral factors in the dynamics of site hydrogeology.

The nearby Cumberland and Great Smoky mountains have a moderating influence on the climate of the area. In general, this results in warm, humid summers and cool winters, with no noticeable extremes in precipitation, temperature, or winds.

3.1.2.1 Precipitation

Abundant site-specific precipitation data are available from the gaging stations established at three locations within SWSA 6 (at the ETF, the EPICORE facility, and in the 49 Trench area). Rainfall has been recorded at these stations since 1981. Additional dat: are available from four meteorological towers established at ORNL in 1982 (in particula: MET Tower 4, located in Melton Valley). Long-term records are available from th National Oceanic and Atmospheric Administration (NOAA) weather station at Norris Da (1947 to present) and the Atmospheric Turbulence and Diffusion Division (ATDD) L located in Oak Ridge (1959-present). Generally, rainfall records for individual precipitati events recorded at different stations are similar (within 0.5 in.), although the Valley and Ridge topography yields some variation from location to location.

Precipitation for WAG 6 for the period 1988 through January 1990 as recorded at the ETF station is shown in Fig. 3.2. The area's climate is humid with frequent rain; periods of 5 days or more without precipitation occur on average only 4 to 5 times per year (Boegly 1984). Maximum monthly precipitation occurs January through March and is associated with winter storms that are generally of low intensity but long duration. Light snow occurs November through March, but most snowfalls amount to only a trace. Average annual snowfall for the period 1951–1988 was 9.8 in. (MMES 1989). A second peak in rainfall occurs in July, when short, heavy rainfalls associated with thunderstorms are common (Davis et al. 1984). The driest period of the year normally occurs from September through October, when, typically, slow-moving high pressure cells suppress rain and provide clear, dry weather. However, as shown in Fig. 3.2, monthly total rainfall was unusually high in September 1989.

The long-term average annual precipitation recorded at the NOAA Oak Ridge station for the period 1948–1990 was 54 in. An estimate of the long-term average annual precipitation at WAG 6 was determined by using the long-term Oak Ridge station data (1948 to 1990) to extend the existing 1981–1990 record for the ETF station (see Sect. 5). The average annual precipitation for the extended record was computed to be 51.2 in. Consequently, a reasonable estimate of the long-term average annual precipitation for WAG 6 can be considered to be 52 in.

Annual precipitation actually recorded at the ETF station for each year from 1981 through 1988 (excluding 1982) was below the estimated long-term average for WAG 6, indicating drought conditions prevailed. During these years, the drought conditions resulted in reduced stream flows and depressed water levels. The lowest annual precipitation occurred in 1986, when the annual precipitation (38.5 in.) was 26% below the estimated average reference value for WAG 6. However, annual precipitation for the 1989 and 1990 water years measured 64.5 and 63.5 in., respectively, exceeding the estimated WAG 6 average annual precipitation by 12.78 and 11.45 in., respectively. This suggests that 1989 and 1990 were wet years relative to the historical average.

3.1.2.2 Temperature

The mean annual temperature for the Oak Ridge area is 58°F (Webster and Bradley 1988). The coldest month is usually January, with temperatures averaging approximately 38°F but occasionally dipping as low as 0°F. However, differences between December through February are minor. Although there is little difference between June and August, July is the hottest month, with temperatures averaging 77°F but occasionally peaking at over 100°F. Average daily temperatures fluctuate 53.6°F over the course of the year (Davis et al. 1984). Figure 3.3 shows the temperature fluctuation recorded at the ATDD station in Oak Ridge from 1988 through June 1990.

3.1.2.3 Evapotranspiration

Regionally, annual evaporation has been estimated to range from 32 to 35 in., or 60 to 65% of rainfall (Farnsworth et al. 1982). Evapotranspiration in the Oak Ridge area is 29 to 30 in., or 55 to 56% of annual rainfall (TVA 1972; Moore 1988; Hatcher et al. 1989). These estimates may be high for WAG 6, because much of the site's vegetation has been removed. Boegly (1984) reports that actual values are more likely 20 to 23 in. per year or 36 to 42% of annual precipitation.

Although evapotranspiration rates are probably reduced due to recent clearing of site vegetation, soil evapotranspiration is occurring. As part of the RFI effort, water balance calculations for WAG 6 were performed for the period 1981–1990 and indicated an average annual evapotranspiration of 29.4 in. (see Sect. 5 for details), the majority of which occurs during the growing season (average 220 days from April through September). Moore (1988) suggests 75% of evapotranspiration occurs during this period and often exceeds the rate of precipitation, such that soil moisture levels are lowest during this time.

3.1.2.4 Winds

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, while nighttime winds usually blow down-valley. This pattern is apparent in Fig. 3.4, which is a wind rose representing winds measured at the 300-ft level of MET station 4 in Melton Valley for the period January 1988 through June 1990. This figure shows the relative frequency (as a percentage) of occurrence of winds by compass orientation and wind speed. Wind speeds are represented by the telescoping bar scale. Tornadoes and high-velocity winds are rare; wind speeds are less than 7.4 mph 75% of the time, and wind speeds exceeding 18.5 mph are rare.

3.1.3 Summary of Key Findings

Pertinent findings regarding WAG 6 topography, climate, and meteorology are summarized below.

- WAG 6 displays up to 105 ft of topographic relief across the site; four internal streams dissect the site, forming an undulating topography with slopes that range from 10 to 57% (i.e., vertical grades of 10 to 57 ft per 100 ft horizontally).

- Historical air photographs indicate that the areas immediately north and northwest of WAG 6 (outside the SWSA 6 fence) have never been used for waste disposal purposes.

- Site records indicate that the thin site soils have been highly disturbed, reworked, or removed over much of the site during past waste trench excavation, construction activities (involving cut and fill operations), and site grading.

- Maximum precipitation occurs during January to March, with a secondary peak in rainfall in July; the driest period of the year is September to October.

- The mean annual precipitation from 1948 to 1990 was 54 in. Drought conditions prevailed from 1981 through 1988, with 1986 being the driest year. Annual precipitation for 1989 and 1990 exceeded the 1948-1990 mean, indicating relatively wet years.

- Evapotranspiration at WAG 6 ranges from 20-30 in. annually (37 to 56% of annual rainfall).

- Maximum evapotranspiration occurs during the growing season (April through September) and is lowest during the winter.

- Seasonal patterns of evapotranspiration and precipitation have a pronounced effect on soil moisture levels and groundwater levels. The water table and soil moisture levels are highest from January to March, when precipitation is high and evapotranspiration is minimal. Water table and soil moisture levels are lowest from August through October, when precipitation is low and evapotranspiration is high.

- Prevailing winds at WAG 6 are northeasterly during the day and southeasterly during the night; speeds are generally less than 7 mph.

3.2 SITE GEOLOGY

The geology of the site has a controlling influence on the occurrence of groundwater and contaminant transport and impacts the selection and design of remedial action alternatives. This section provides a description of site geology and identifies key features and aspects that affect the fate and transport of contaminants and bear on potential remedial action alternatives.

This section is organized into three subsections. Section 3.2.1 presents WAG 6 in the context of its regional geologic setting. Section 3.2.2 describes the site-specific geology, providing detailed discussion of the stratigraphy, structural geology, and physical and chemical properties of geologic materials of WAG 6. Section 3.2.3 summarizes the key geologic findings that aid in understanding the aquifer skeleton and that support the needs of the RFI.

3.2.1 Regional Setting

WAG 6 is situated in the Tennessee 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 siltstones, 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 Site Geology

WAG 6 is situated in Melton Valley on the Copper Creek Thrust Sheet above the Copper Creek Thrust Fault (Fig. 3.5). Motion along this fault has placed the middle to late Cambrian Conasauga Group and underlying Rome Formation rocks above the younger Ordovician Chickamauga Group rocks. Subsequent erosional processes and varying degrees of in-place weathering of bedrock have produced a geologic sequence above the Copper Creek Fault at WAG 6 that consists of, in ascending order:

- Unweathered, consolidated bedrock (lower Conasauga Group and Rome formations)
- Regolith
  - An interval of weathered, unconsolidated bedrock or "saprolite" overlain by:
  - A veneer of alluvial (water deposited), colluvial (transported by gravity), or residual (formed in-place by physical/chemical weathering) soils.

Because saprolite and soils are weathering products of the underlying bedrock, this section is organized to provide a detailed description of WAG 6 bedrock parent material, followed in ascending order by descriptions of WAG 6 saprolite and soils.

3.2.2.1 Bedrock

Bedrock has been encountered at depths ranging from 2.5 to 51 ft below grade in WAG 6. The average depth to bedrock observed was 19 ft. Generally, bedrock is encountered at shallow depths in topographically lower areas and along drainages and at greater depths on hilltops. Bedrock occurs at depths of 20 to 25 ft below grade in the vicinity of the WAG 6 main gate; 2.5 to 21 ft (10 ft on average) below grade along the eastern perimeter of WAG 6; 7 to 8 ft below grade along the drainage bounding WAG 6 on the east; and at depths generally greater than 23 ft (ranging up to 39 ft) along the southern boundary of WAG 6 in the vicinity of the biological trenches.

Figure 3.6 shows the bedrock surface configuration generated using available subsurface information, including bedrock tops from boring logs, auger refusal depths, and actual elevations of bedrock exposed in trenches. Data sources include subsurface control provided in Davis et al. 1984; Davis et al. 1986; Davis et al. 1987; Davis et al. 1989; Davis and Stansfield 1984; Spalding 1990; Morrissey 1990; Dreier and Toran 1989; Mortimore 1987; Mortimore and Ebers 1988; and information from the 54 soil borings and 22 wells installed during the WAG 6 RFI [TM 06-12, *Phase 1 Soil Sampling for the ORNL WAG 6 RFI;* TM 06-12A, *Soil Sampling for the ORNL WAG 6 RFI (Activity 1, Activity 2)*; TM 06-08, *WAG 6*

RFI Well Installation, and TM 06-08A, WAG 6 RFI Well Installation (Phase 1, Activity 2)]. Depths to bedrock are tabulated in Appendix 3A.

Given the available subsurface data, the bedrock surface shown is a reasonable approximation. However, due to the variety in types and sources of bedrock surface information, the bedrock configuration shown is only an approximation and in any single location may show more or less relief than is actually present.

In an attempt to better define the bedrock surface, ORNL performed a shallow refraction seismic survey across WAG 6 (Dreier, Selfridge, and Beaudoin 1987). However, after processing two test lines (2A-2G and 1A-1G), the study was terminated short of completion, and the remainder of the data were not processed. The test line data showed good correlation with bedrock depths observed in wells. Figure 3.7 shows the location of the seismic lines. If necessary to support the corrective measures study, an improved definition of the bedrock surface could be provided through further processing and evaluation of these data.

The bedrock geology underlying WAG 6 is complex, owing to patterns of initial deposition and highly variable subsequent structural deformation. The following sections describe in detail the stratigraphy, structural geology, and chemical properties of bedrock underlying WAG 6 based upon existing and RFI data. Bedrock geologic features are shown in Fig. 3.8, the WAG 6 Geologic Map. Figures 3.9 through 3.19 present hydrogeologic cross sections that depict site-specific geologic conditions at WAG 6.

3.2.2.1.1 Stratigraphy

The Conasauga Group is composed of a sequence of clastic-rich formations alternating with carbonate-rich formations deposited as part of a major marine transgression over a subsiding carbonate-rimmed tidal flat. This depositional setting is believed to mark the regional transition from the shallow shelf environment to the northwest to the deeper marine environment to the southeast (Hasson and Haase 1988; Haase, Walls, and Farmer 1985).

The Conasauga Group within Melton Valley ranges up to 1800 ft thick (Boegly 1984) and comprises six distinct formations. These are, in ascending order: the Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Limestone, Nolichucky Shale, and Maynardville Limestone. Lithologic descriptions for each of the Conasauga Group formations are presented in Table 3.1. Site-specific stratigraphic control is afforded by rock cores and borehole geophysical logs from deep wells within or adjacent to WAG 6. These deep borehole and core control points are indicated in Fig. 3.8. Borehole geophysical logs for the four deep wells drilled and logged at WAG 6 as part of the RFI are presented and evaluated in TM-06-13.

Of the six Conasauga Group formations, only the Maryville Limestone and Nolichucky Shale bedrock occur in the near surface underlying WAG 6. The Maryville Limestone underlies the northern half of the site, while the overlying Nolichucky Shale underlies the southern half of the site. Bedrock is generally not exposed at the surface. However, the

Maryville Limestone does outcrop in the extreme northeastern part of WAG 6 in the embankment on the north side of the TARA area (shown on Fig. 3.8).

The Nolichucky Shale is the youngest formation underlying WAG 6 and has been observed to be approximately 550 ft thick in the ORNL-JOY #2 corehole, located roughly 3.5 miles east-southeast of WAG 6 (Haase, Walls, and Farmer 1985). However, a complete Nolichucky section was not encountered in the southern half of WAG 6, and from site stratigraphic control it appears that only the lower Nolichucky underlies WAG 6. Borehole geophysical logs (in particular, borehole televiewer logs) from the HHMS-series deep wells and from WAG 6 RFI Well 1236 are the principal source of lithologic information for the Nolichucky within WAG 6; rock cores have not been obtained from the Nolichucky Shale within WAG 6. The geophysical logs indicate that the Nolichucky within WAG 6 consists of thin shaley limestone beds interbedded with carbonate shales and mudstones. Similar lithologies were observed in lower Nolichucky cores from USGS coreholes UG2 and UF2, located further up Melton Valley in an equivalent stratigraphic position (Tucci and Withington-Hanchar 1989). Based upon these lithologies, the Nolichucky was deposited either as a marine transgressive pulse or in a deeper marine setting.

The contact between the Maryville Limestone and Nolichucky Shale is shown on Fig. 3.8. The contact between the Nolichucky and underlying Maryville is gradational, marked by an increase in limestone content in the lower Nolichucky (Haase, Walls, and Farmer 1985). Consequently, there is some range of error associated with this interpretation. Further, individual beds within the Nolichucky are difficult to correlate laterally between wells using logs and cores due to a combination of rapid lateral facies changes and post-depositional structural deformation.

The Maryville Limestone beneath WAG 6 ranges up to approximately 415 ft thick, as shown by deep borehole geophysical log correlations. Descriptions of the lithology of the Maryville Limestone are provided by rock cores from the ETF area (wells ETF-1, -3, -4, -5, -6, -11, -13, and the 240-ft deep ETF-16); USGS corehole UB-2 (located immediately west of Highway 95 and WAG 6); and two cores from Wells 1234 and 1238 (drilled as part of the WAG 6 RFI). Generally, the Maryville within WAG 6 is characterized by massive to ribbon-bedded silty, intraclastic (flat pebble), oolitic and pelloidal limestones up to 1 ft thick, interbedded with silty, calcareous mudstones and dark shales (Vaughan et al. 1982; Tucci and Withington-Hanchar 1989; Haase, Walls, and Farmer 1985; and TM-06-08A). Limestone lenses are more abundant and pure in the upper portion of the Maryville in the northern half of the site, whereas mudstone units are more prevalent in the Lower Maryville, as noted in cores and geophysical logs.

The Maryville stratigraphy observed in site cores shows rapid lithologic changes vertically and laterally. As reported in Haase, Walls, and Farmer (1985) and observed in WAG 6 RFI rock cores, the limestones within the upper Maryville display upward-coarsening cycles that are indicative of a higher energy environment within a subtidal setting, possibly associated with storm deposition. This setting commonly yields laterally discontinuous depositional patterns and may contribute to the difficulty encountered in correlating individual beds from well to well. Further, structural deformation within the Maryville formation produces wide variations in formation and internal stratigraphic interval thicknesses from one location to another. Consequently, it is difficult to correlate individual or groups of limestone beds between wells, even using borehole geophysical logs.

The Rogersville Shale, although not exposed near the surface at WAG 6, was encountered at depths between 297 and 352 ft below land surface in deep wells HHMS-7A and -8A, respectively, located in the northern half of WAG 6.

3.2.2.1.2 Structural geology

Generally, the bedrock in Melton Valley strikes N55°E, parallel to the trend of the Copper Creek Thrust Fault (roughly grid east-west), and dips 20-25° to the southeast (grid south). However, within WAG 6, dips are generally steeper, on the order of 30-40°, but highly variable due to complex local structural deformation (Webster and Bradley 1988). Rock cores and deep well borehole televiewer logs show dips changing frequently in relatively short vertical distances in association with small-scale kink and drag folds and minor faults (Tucci and Withington-Hanchar 1989, Dreier and Toran 1989, and TM 06-13, *WAG 6 Borehole Geophysical Logging*). Dips observed in cores and logs range from 30° to near vertical, oriented in nearly all directions.

Due to the absence of surface bedrock exposures, structural mapping has been limited to mapping structures observed in saprolite zones exposed in shallow trenches. Dreier and Beaudoin (1986) documented structural complexity through shallow trench mapping on a scale of 1:125. In that study, 10 shallow (4-ft deep) trenches were excavated in a band trending roughly north-south across the central portion of WAG 6. The trenches were aligned to allow for mapping structures and fracture densities in the saprolite perpendicular and parallel to overall formation strike. In general the study revealed that formation strike is variable (N35-70°E) across the site but is approximately oriented grid east-west. Conversely, formation dips reflect increasing structural complexity from north to south across the site. In the northern part of WAG 6, bedding was found to dip 22° to 33° to the southeast with gentle warping of the beds. In the central part of the site, small folds and faults have been identified. In the southern part of the site (on the hill adjacent to WOL), the trenches revealed more intense deformation marked by small-scale thrusting and overturned folds.

Structural mapping in saprolite above the Maryville formation was also performed during excavation and construction of the 49 Trench French Drain. Davis and Stansfield (1984) found that the bedding dips locally from horizontal up to 60° to the southeast due to folding of the strata.

Structural measurements from all of these studies are presented in Fig. 3.8, which shows that structural complexity increases from north to south across the site.

Faulting. The principal regional structural feature controlling much of the subsidiary structure and stratigraphy within Melton Valley is the Copper Creek Thrust Fault, which is exposed at the surface on the north flank of Haw Ridge north of WAG 6. It then dips relatively gently to the southeast, so that at WAG 6 the fault zone lies roughly 1000 ft below the ground surface. At this depth, the fault does not likely impact WAG 6 groundwater flow or contaminant transport.

Other localized faulting is widespread in the subsurface at WAG 6. Rock cores from WAG 6 and surrounding areas display four types of faults: bedding plane faults, high angle normal and reverse faults, and intraformational thrust faults. However, none of the faults at WAG 6 are active faults.

Bedding plane faults are ubiquitous throughout the Conasauga Group bedrock but are generally small-scale, with only slight horizontal displacement. They characteristically occur at contacts between different lithologies and are most abundant in thin- to medium-bedded intervals of limestone or siltstone and mudstone (Haase, Walls, and Farmer 1985).

High angle normal and reverse faults have been identified in cores from the nearby ORNL-JOY #2 and WOL-1 coreholes (Davis et al. 1987; Haase, Walls, and Farmer 1985). These faults typically show small vertical displacements (30-40 ft) and are accompanied by minor drag folds and a zone of deformation up to 5 ft thick. Many high angle faults were observed in shallow trenches in SWSA 6 and during the French Drain construction (Davis and Stansfield 1984), suggesting that such faults are quite common in the subsurface at WAG 6.

Intraformational thrust faults have been encountered in cores from within Melton Valley. Within WAG 6, Dreier and Toran (1989) identified two low-angle intraformational thrust faults in two of the four deep HHMS well clusters (wells HHMS-5A and HHMS-8A). Fault identification was based upon stratigraphic thickening, abrupt dip changes in televiewer logs, temperature log anomalies, and other supporting borehole geophysical log evidence.

Figure 3.20 depicts a structural cross section oriented grid north-south across the central part of WAG 6. This cross section is based upon deep well control afforded by the HHMS well clusters and shows the two thrust faults, "A" and "B", identified in HHMS well 8A and 5A, respectively. Dreier and Toran (1989) report displacements of approximately 250 ft for Fault A and 20 to 75 ft for Fault B. The fault zone associated with Fault A in well HHMS-8A ranges up to 23 ft thick. Neither of these faults are exposed at the surface.

During the WAG 6 RFI, four deep (150 to 170 ft) wells were located and installed to assess the extent of these faults and evaluate the potential impact on groundwater flow at WAG 6. Continuous rock cores were obtained from RFI Well 1234, located on the eastern perimeter of WAG 6, and from the upper 20 ft of Well 1237, located in the northwest portion of the site. Evaluations of the core from these two wells and the full suite of borehole geophysical logs subsequently run on all four boreholes (TM 06-13, *WAG 6 Borehole Geophysical Logging*, and TM 06-08A, *WAG 6 Well Installation, Phase 1, Activity 2*) revealed faulting in only one deep borehole, Well 1234. The fault plane in this well was encountered at a depth of 56 ft below land surface; an accompanying 20-ft thick fault zone occurred from 50 to 70 ft. The fault is evidenced in the core by a brecciated zone straddled by intervals of chaotic bedding on either side. Further evidence includes temperature and fluid resistivity anomalies noted in borehole geophysical logs. A repeated stratigraphic section typical of thrust faults was not observed, but the fault was encountered just below the base of surface casing, thereby precluding acquisition of adequate geophysical logs above that point. It is believed this fault correlates with Fault A observed in Well HHMS-8A.

Although it can not be proven, because of the limited deep well control and structural complexity at WAG 6, it is likely that other faults may exist. Faulting results in either thickened stratigraphic sections (in the case of reverse and thrust faults) or a loss of section (as in normal faults), making correlations of individual beds between wells problematic.

Based upon available data, is it not possible to evaluate the effects of a given fault on site hydrology (i.e., groundwater flow and contaminant transport) without uncertainty. A fault may act as a conduit (facilitating groundwater flow along the fault plane or fault zone) at one location while at another location, the same fault may act as a barrier to flow.

Figure 3.8 shows the subcrop leading edge of the two principal thrust faults identified. Figures 3.9 through 3.19 present hydrogeologic cross sections that depict the generalized structural framework underlying WAG 6 and incorporate the faults identified.

From examination of Fig. 3.8, it appears that the structural complexity noted in the southern half of WAG 6 can be attributed to the imbricate thrust faulting. North of the mapped edge of Fault A, the degree of complexity diminishes and bedding orientations are more consistent.

Folding. Minor folding is common, particularly in thin-bedded shale and mudstone intervals, and is highly variable in continuity and intensity. Davis et al. (1984) observed two sharp folds in the bedrock at the ETF site. The fold axes are roughly 18 ft apart and trend north-northeast. The folds are asymmetric (dips ranging from 12° to 65°), with steeper dips observed on the southeast flanks.

Generally, individual structures cannot be correlated with any certainty from well to well. Overall, as shown in Fig. 3.8, the folding is most common in the southern half of the site and appears to coincide with the leading edge of the two identified thrust faults, A and B.

Fractures. Conasauga Group bedrock has little or no matrix (i.e., bulk rock) porosity but is highly fractured throughout Melton Valley. Consequently, fractures form the most significant element controlling groundwater flow in the bedrock. Fractures may have developed at any time from the Cambrian (associated with compaction during or immediately after deposition) to the present. However, the present fracture network was principally developed in response to the Alleghenian Orogeny.

At least two, but as many as five, fracture sets have been identified in cores from the Maryville and Nolichucky bedrock within and around WAG 6. The most prominent fracture orientations are parallel to local geologic strike and include bedding plane parallel and strike-parallel fractures. Less-prominent and less-penetrative fractures are oriented perpendicular and oblique to local strike and bedding.

Based upon extensive outcrop mapping in Melton Valley, Sledz and Huff (1981) documented two major fracture orientations in weathered lower Conasauga Group shales. From statistical analysis of fracture orientations, Sledz and Huff (1981) identified one principal set of fractures/joints oriented parallel to formation strike (N54°E) dipping roughly parallel to bedding, and a second principal set oriented normal to formation strike (N45°W) but oblique to bedding, dipping at angles up to 82°. Similar fracture patterns were encountered in coreholes at the ETF site (Davis et al. 1984 and 1987), WOL-1 and ORNL-JOY #2 (Haase, Walls, and Farmer 1985), and in WAG 6 RFI cores.

Shallow trench mapping (Dreier and Beaudoin 1986; Davis and Stansfield 1984) in WAG 6 has identified two near-vertical extensional fracture sets present in saprolite in addition to bedding plane fractures. The extensional fractures are oriented roughly perpendicular to each other. Dreier and Foreman (1990) report extensional fracture orientations of N35°W and N55°E in the northern part of WAG 6 and N5°E and N85°W in the southern portion of the site. Other fractures were observed in the ETF area parallel to local folding. It is expected that additional fracture trends associated with local structural features (folds and faults) may be encountered throughout WAG 6.

Fracture density varies with lithology but generally decreases with depth (Sledz and Huff 1981). The highest bedding plane fracture density occurs in intervals of interbedded silty shales and limestones (Davis et. al. 1987). Coarse limestone breccia zones had the lowest fracture density; the few present were oblique to bedding. Further, high-angle fractures observed in limestone units appear to terminate abruptly at the contact with shale or mudstone units. Detailed fracture mapping in the shallow saprolite (Dreier et al. 1987) showed that fracture densities appear to be locally independent of fracture type and average 20 to 30 fractures per foot. Although fractures are widespread, they are generally short, being less than 3 ft long (Moore 1988), such that distinct fractures or groups of fractures cannot be correlated between wells with any certainty.

Open fractures are most common in the upper 150 ft of bedrock and decrease with depth (Dreier et al. 1987). Sledz and Huff (1981) reported that fracture porosity decreases roughly 8.2% for every 50 ft below land surface. Dreier and Foreman (1990) suggest that two systems of fractures exist in Melton Valley: an older tectonic system that generally occurs below depths of 150 ft and that is characterized by abundant healed fractures; and a younger system generally occurring at depths less than 150 ft that contains more open fractures (formed in response to erosional unloading).

Fractures (some chemically widened) range up to 6 in. diameter, although most are less than 0.01 in. wide. Solution enlargement of fractures is most common in carbonate-rich portions of the Nolichucky Shale, particularly parallel to bedding planes. However, no large-scale solution (or karst) features were noted in WAG 6 cores or televiewer logs, although some small-scale (less than 0.9 in.) solution cavities have been documented in shallow bedrock cores from the ETF area.

Figure 3.21 schematically portrays the fracture network prevalent at WAG 6 and illustrates the interconnection of various fracture orientations with an overall decrease in fracture density with depth.

3.2.2.1.3 Bedrock physical and chemical properties

The migration of radionuclides and other contaminants through bedrock is controlled in large part by the physical properties of the rock matrix or secondary porosity features and chemical interactions between the contaminants and the rock. Calcium carbonate cements in the Nolichucky and Maryville formations generally preclude any primary matrix porosity. Therefore fluids move through bedrock principally along secondary porosity features (fractures and solution cavities). Consequently, the key physical and chemical properties of bedrock that affect radionuclide and other contamination transport include bulk rock properties (porosity, open fracture density, hydraulic conductivity, etc.) impacting flow and retardation associated with ion exchange and sorption reactions caused by interaction with the rock along fracture planes.

Physical and chemical properties of bedrock vary with the depth and degree of rock weathering. In general, porosity, pH, and the capacity for ion exchange and sorption decrease with depth as the bedrock becomes more 'ndurated (i.e., less weathered) with depth. Porosity in bedrock is caused by solution of calcium carbonate cements (Table 3.2) in the upper portion of the bedrock. Porosity development decreases sharply with depth as the pH of infiltrating acidic waters are buffered and the water is in equilibrium with calcium-carbonate. Bedrock pH also changes with depth. As shown in Table 3.2, at a depth of 5 feet, the pH of shallow bedrock is acidic (pH <6), but increases to 7 to 8. The change in pH reflects the depth of weathering.

Kds[1] for five radionuclides, CEC[2], and other physical properties were determined for rock cuttings from the 115-ft deep Maryville borehole and a 25-ft deep Nolichucky borehole in SWSA 7 (Rothschild et al. 1984b). Bedrock in SWSA 7, located further east in Melton Valley, is representative of conditions at WAG 6. Mean physical and chemical properties of bedrock are summarized in Table 3.3. Figure 3.22 relates the analyses for the Maryville Limestone to depth.

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[1]The relative sorption (adsorption and/or absorption) of a given compound or radionuclide by a rock or soil matrix is expressed as the distribution coefficient, Kd. The Kd is related to overall retardation as follows:

$$\text{Retardation factor } (R_f) = 1 + \text{Kd} \times (\text{bulk density/porosity})$$

[2]The cation exchange capacity (CEC) is the sum of the exchangeable cations within a rock or soil profile. The CEC represents the degree of anticipated ion exchange between radionuclides and other ionic substances and the rock or soil matrix.

As shown on Fig. 3.22, CEC decreases with depth as a result of decreased rock weathering. The decrease in Kds for strontium-85 with depth parallels a similar decrease in total hardness (calcium + magnesium) Kds and exchangeable calcium with depth. Strontium sorption is principally by ion exchange in competition with calcium and magnesium in solution. The parallel decrease in Kds for calcium + magnesium and the increase in calcium-carbonate content with depth suggests that the Maryville bedrock is increasingly indurated and inert to radionuclide sorption at depth.

X-ray diffraction studies of selected Maryville rock cores from the ETF area (Davis et al. 1984) indicate that illite, chlorite, and mixed layer illite/vermiculite are the dominant clay minerals present. Webster (1976) noted that cesium-137 interacts with illite clays and is readily sorbed into the illite lattice structure, while cobalt-60 is commonly adsorbed to manganese oxide coatings in fractured or weathered rock. The decreasing Kds for cesium-134 and cobalt-58 observed with depth in the deep Maryville borehole may reflect a decrease in illite content and manganese oxide coatings related to the depth and degree of weathering. No observable pattern was noted for iodine-125 or americium-241 (Davis et al. 1984; Rothschild et al. 1984b). Rock cuttings from the 25-ft deep Nolichucky borehole suggest similar trends, but these remain unsubstantiated due to the limited sampling performed.

It should be noted that the reported Kd values are derived from bulk analysis of disaggregated rock cuttings. However, most transport of radionuclides through the bedrock underlying WAG 6 is via fractures and other secondary porosity features. Sorption in the bedrock would occur where fluids are in contact with the rock. As the surface area of the bedrock is limited to that exposed along the fractures (with some slight matrix interaction), the actual sorptive capacity of the system is finite and is somewhat less than that described by laboratory Kds derived from pulverized material.

3.2.2.2 Saprolite

Saprolite formed from in situ weathering of bedrock directly overlies competent bedrock and is a significant component of the aquifer system where saturated. Under unsaturated conditions, the saprolite is further significant in that this is the interval in which, by design, the majority of waste disposal trenches terminate. This section provides a detailed description of the saprolite based upon existing and RFI data. This section describes saprolite occurrence and thickness within WAG 6, its significant characteristics, and its physical/chemical properties.

Saprolite occurrence. Throughout Melton Valley, the Maryville and Nolichucky bedrock weather to form a saprolite indicative of the lithologies of the individual parent formations. Saprolite in areas underlain by limestone-rich bedrock, (as in the northern part of WAG 6), is principally a brownish-yellow illitic clay (Vaughan et al. 1982). The transition from saprolite to bedrock commonly is abrupt in these areas. Silty limestone or siltstone/shale bedrock weathers to a porous, brown or dull olive-brown siltstone saprolite, with a gradational transition to competent bedrock noted by an increase in rock fragments with depth. Bedrock consisting of interbedded limestone and shale yields a saprolite with alternating hard and soft beds, such as was encountered in drilling in the TARA area at the northern end of WAG 6.

The overall thickness of the saprolite layer throughout WAG 6 is proportional to the depth of bedrock weathering and varies with topographic position. The 54 soil borings and 22 boreholes drilled during the WAG 6 RFI revealed that the saprolite ranged up to 45 ft thick. Saprolite is generally thicker on hilltops and thinner along surface water features in topographically low-lying areas.

Within WAG 6, the upper portion of the saprolite is further weathered to form a silty clay soil layer that ranges from less than 1 ft to 13.5 ft thick (BNI 1990c,d; TM-06-08A, *Well Installation Phase 1, Activity 2*; TM-06-12A, *Soil Sampling for the ORNL WAG 6 RFI, Phase 1, Activity 2*). This silty clay soil is equivalent to the "C" soil horizons. The contact between the silty clay and saprolite is gradational, marked by an increase in shale fragments and decreased weathering with depth. Contact generally occurs between 5 to 10 ft below grade. Six RFI soil borings (SCA-10, SCA-17, SCC-2, SCC-3, SCE-5, and SCE-6) that were terminated at refusal in limestone bedrock encountered no weathered shale zone; the silty clay directly overlaid the limestone bedrock.

The original bedrock structural fabric is preserved in the saprolite. Consequently, fractures and minor faults are commonplace, particularly in the southern half of WAG 6. Saprolite exposures along the east perimeter road (in the vicinity of RFI Well 1234) show considerable kink folding and relict fracturing. As discussed previously, from mapping exploratory trenches within WAG 6, Dreier and Beaudoin (1986), Davis and Stansfield (1984), and others have found the saprolite to be highly folded and fractured. Weathering and differential movement of water through the saprolite fractures has in some cases enhanced these relict features in siltstones and shales. In other cases, fracture faces are coated with manganese or iron oxides (Ammons et al. 1987), thereby reducing fracture openings.

Physical and chemical properties of saprolite. The physical and chemical properties of the saprolite have been studied at WAG 6 and in similar settings at SWSA 7 and have been reported in Ammons et al. (1987) and Rothschild et al. (1984a). Table 3.4 summarizes the findings of these studies.

Porosity in saprolite is a combination of matrix and secondary porosity, developed through weathering and leaching of carbonate cements and enlargement of fractures. The degree of weathering in the saprolite is variable but decreases with depth as evidenced by the following:

- Illitic clays increase with depth and there is an abundance of iron and manganese oxide clay complexes caused by downward percolation of water through the saprolite.
- The calcium carbonate equivalents are low and decrease with depth.

- Clay content in the saprolite is high in the upper portions but decreases with depth in less weathered saprolite.

- The saprolite becomes less acidic with depth (the contact with unweathered bedrock can sometimes be distinguished by a sharp change to pHs greater than 7.5).

The chemical properties of in-place saprolite are controlled by iron-manganese clay and oxide complexes coating most fracture and grain surfaces (where weathering has sufficiently enhanced primary matrix porosity). Laboratory Kds have not been determined for WAG 6 saprolite but are available from saprolite developed from Maryville Limestone at SWSA 7 (Rothschild et al. 1984a). Kds are not available for saprolite derived from Nolichucky bedrock, but are expected to be similar to those reported for Maryville saprolite from SWSA 7.

Kds for strontium-85 are higher than observed for unweathered Maryville bedrock, but there is increased competition for exchange sites with calcium and magnesium in solution, which are leached from the saprolite. Kds for cesium-134 are also higher, perhaps related to the increase in illitic clays and extractable manganese and iron over bedrock. (Cesium-134 sorption is higher in the presence of illitic clays, manganese, and iron.) SWSA 7 Kds suggest that there is little difference between the sorption capacity of Nolichucky and Maryville saprolite.

3.2.2.3 Soils

This section provides a description of the distribution and physical/chemical properties of WAG 6 soils.

Soil types and distribution. Detailed soil mapping at WAG 6 was performed by Lietzke and Lee (1986) and Ammons et al. (1987) using eight test pits, one deep trench, and soil/saprolite cores from two HHMS-series wells; 11 distinct soil types were identified. Figure 3.23 depicts these soil types and their distribution at WAG 6 and shows the locations of the test pits and trenches.

WAG 6 soils are principally residual soils developed in situ as weathering products of Maryville Limestone and Nolichucky Shale saprolite. In addition, alluvial (water deposited) soils occur along drainage paths and low-lying areas adjacent to WOL. Colluvial (transported by gravity) soils also mantle some hillslopes, particularly in the northwest and southwest portions of WAG 6. Recent alluvial and colluvial soils are developing in low areas and along drainageways in WAG 6 as a result of gradual widening and slope retreat of the surface water drainages. In the northwest corner of WAG 6, ancient alluvial soils are evidenced by well-rounded quartzite from the distant Unaka Mountains as well as sub-rounded Knox chert fragments. These alluvial deposits indicate that, during the past, the Clinch River flowed across the site (Ammons et al. 1987; Davis et al. 1984).

Soil development is related to parent rock and/or saprolite composition, degree of weathering, and topographic position. As noted previously, weathering persists to greater depths on hilltops than in low-lying areas. Consequently, thin residual soils occur on the ridges but are absent in the low areas, where thick alluvial deposits are found. The descriptions of eight test pits presented in Lietzke and Lee (1986) revealed total soil thickness ranging from 1.3 to 9.8 ft. Generally WAG 6 soils are less than 3 ft. thick.

As described in Sect. 3.2.2.2, the C-Horizon soils at WAG 6 are typically composed of silty clay, with increasing shale content marking the transition to the underlying weathered shale saprolite (where present). The silty clay ranges from less than 1 to 13.5 ft thick.

Thin, highly acidic A- and B-horizon soils overlie the silty clay C-Horizon. The A-Horizon soil (soil exposed at ground surface) is typically a gray to yellowish-brown silt loam or shaley silt loam with less than 20% rock fragments. A-Horizon soil ranges from less than 1 in. to 1 ft thick (with a mean of 8.5 in.). The B-Horizon underlies the A-Horizon soil and averages 34.5 in. thickness. It is comprised of yellowish-brown or orange-brown shaley silt loam to silty clay and clay loam, with manganese oxide nodules and coatings and an overall increase in rock fragments with depth. The pH of the B Horizon soils ranges from acidic to alkaline (pH 5 to 8). Between 50 and 100% of the relict bedrock structure is preserved in the B-Horizon (Ammons et al. 1987).

As reported in Section 3.1, native soils have been removed or reworked and fill materials imported during operational and disposal activities within most areas of WAG 6. Soils have been considerably altered or removed in association with construction of the 49 Trench French Drain, Tumulus pads, and most recently the widespread grading in conjunction with construction of the IWMF in the southwest part of WAG 6. Ammons et al. (1987) report that during clearing activities, most of the soils in trenched areas were pushed off into the drainage ways or buried under leached/unleached saprolite excavated from the waste disposal trenches. Vaughan et al. (1982) further reports that most of the A- and B-Horizon soils were removed in the ETF area in 1975. In these and other cases, activities at WAG 6 have altered the natural fabric, mineralogy, and distribution of soils, creating zones of variable and unpredictable permeability both laterally and vertically.

Several soils or conditions identified in WAG 6 test pits have physical characteristics that may impact local saturated or unsaturated zone groundwater movement:

- Soil unit 5, which typically occurs in foot-of-slope positions, commonly has a fragipan horizon that tends to perch water above it. Flow zones associated with the fragipan layer were evident at depths of 2.3 to 3 ft in test pit V in the vicinity of the biological trenches (Lietzke and Lee 1986). Soils of this type underlie the Tumulus area and biological disposal trenches in the southern part of WAG 6.

- Lietzke and Lee (1986) encountered a relatively impermeable bedrock underlying soil unit 10, as observed in test pit X, and suggest that at this location, water evidently flows laterally along the soil/rock interface, discharging to the stream.

Soil physical and chemical properties. Information regarding the physical and chemical nature of WAG 6 soils is principally provided by Ammons et al. (1987) and Davis et al. (1984). Additional soil properties information is presented in Rothschild et al. (1984a) for soils in SWSA 7. Table 3.5 summarizes the soil properties from these sources.

WAG 6 soils are thin, acidic, and highly leached. Organic content is typically low (less than 4.3 percent) and decreases with depth; clay content increases with depth in the soil horizons and clay-filled upper saprolite. Consequently, soil bulk density generally increases with depth; porosity correspondingly decreases, in part because of the clay plugging and also because of manganese and iron oxide precipitation. CEC was high, averaging 208 meq/kg, and displayed no observable trends either laterally, vertically, or in relation to other properties.

Bulk Kd analyses were performed on 24 Maryville soil samples collected from three 6.5-ft deep trenches within WAG 6 (Davis et al. 1984). Additional laboratory-measured Kds for soil from a shallow trench in the northern part of WAG 6 and for other WAG 6 soils sampled and described by Lietzke and Lee (1986) were determined by Friedman and Kelmers (1990). In general, these studies found:

- No observable patterns or correlations were identified between Kd values and depth, soil physical properties, or each other.
- Kds measured varied widely according to soil type. For instance, the Kd for cesium ranged from 151 L/kg for mixed sandstone/shaley clay to 5035 L/kg for claystone soils.
- Organics (EDTA, napthalene, toluene, chloroform, and phthalates) had no effect on the Kd for europium.
- The Kds for europium and uranium increased with increasing pH, but above pH 5.5 the Kds for uranium began to decline.
- Although thin, WAG 6 soils have a high sorption capacity and are thus capable of retaining appreciable concentrations of cobalt, strontium, and uranium.

3.2.3 SUMMARY OF FINDINGS REGARDING SITE GEOLOGY

The distribution and physical characteristics of the geology saprolite, (bedrock, saprolite, and soils) at WAG 6 constitute the aquifer skeleton and in large part control the site's groundwater hydrology (discussed in Section 3.3). The following key findings about site geology are fundamental to understanding groundwater hydrology at WAG 6 and recognizing the limitations the site geology imposes on defining contaminant fate and transport.

- **Bedrock**

- The Maryville Limestone and Nolichucky Shale bedrock underlie the northern and southern parts of the site, respectively. These formations were deposited in an environment whereby rapid lateral and vertical variations in lithology are common. Consequently, correlations of individual beds within these formations from well to well are uncertain.

- Although bedrock generally strikes grid east-west and dips towards grid south (i.e., true northeast strike and southeast dip), due to local structural complexities a wide range in bedding strike and dip has been documented at WAG 6. Site borehole televiewer logs and rock cores show that strikes and dips change rapidly in relatively short vertical distances.

- Minor folding (i.e., kink folds) and normal, reverse, and thrust faults are widespread. Two principal thrust faults have been identified trending roughly east-west across WAG 6. Other faults and fault splays are also possible. Faults may act as either conduits or impediments to groundwater flow (i.e., a given fault or fault zone may in one location facilitate groundwater flow and in another, serve as a barrier to flow). However, faults at WAG 6 are not active faults.

- Structural complexity increases from north to south across WAG 6 and is likely related to the occurrence of the two principal thrust faults.

- Little or no primary porosity exists in the bedrock. However, fractures (secondary porosity) are widespread. As many as five distinct fracture sets may be encountered at a given location at WAG 6. Principal fracture orientations include strike parallel and bedding plane parallel fractures (generally trending ORNL grid east-west) and a high-angle fracture set oriented perpendicular to bedding.

- Most fractures are short (less than 3 ft long) but interconnected so as to form a complicated network (i.e., stair-stepping patterns in all directions) for groundwater flow.

- Open fracture density decreases with depth.

- Depth to bedrock varies with topography, ranging from 2.5 to 51 ft below land surface. Along the perimeter of WAG 6 the depth to bedrock was found to be 20–25 ft below grade; an average 10 ft below grade along the eastern perimeter (ranging from 2.5 to 21 ft); and greater than 23 ft along the southern boundary adjacent to WOL.

- **Saprolite**

- Saprolite overlies bedrock throughout the site and is formed in place from weathering of underlying bedrock.

- Saprolite thickness varies across the site with degree and depth of weathering; it is generally thicker on hilltops.

- Relict bedrock structural fabric is preserved, and in some cases (owing to movement of fluids through the saprolite), porosity associated with the structural feature is either enhanced or occluded.

- Weathering has further resulted in dissolution of calcium carbonate cements such that the saprolite shows considerably more matrix (primary) porosity than underlying unweathered bedrock.

- **Soils**

- Eleven different soil types have been delineated at WAG 6.

- WAG 6 soils are typically thin and acidic. In many areas, soils have been removed, reworked, or otherwise altered during site operations. This has created discontinuous zones of variable and somewhat unpredictable permeability, both laterally and vertically.

- Although thin and variable, WAG 6 soils have high sorptive capacities for retaining cobalt, strontium, and uranium.

- **Overall**

- The geology of the site is complex, being a product of original depositional patterns in the bedrock, severe and variable structural deformation, weathering, and human activities. Consequently, there is considerable uncertainty in determining hydrogeologic processes on a local scale, such as assessing specific flow paths from a particular trench source to a well or surface water.

3.3 GROUNDWATER HYDROLOGY

Groundwater is a significant pathway for transport of contaminants at WAG 6. Consequently, a thorough understanding of site groundwater hydrology is relevant to support risk assessment, evaluate the nature and extent of contamination, and develop remedial action alternatives.

This section summarizes the groundwater hydrology of WAG 6. Section 3.3.1 discusses prior groundwater investigations conducted at WAG 6 and describes the existing network of wells and piezometers used to evaluate WAG hydrology. Section 3.3.2 describes groundwater occurrence at WAG 6 and discusses trench hydrology, the effects of ICM capping, aquifer geochemistry, aquifer hydraulic properties, and groundwater flow. Key findings related to groundwater hydrology at WAG 6 are summarized in Sect. 3.3.3. Hydrogeologic data for wells identified within WAG 6 are summarized in Appendix 3A.

3.3.1 Prior Investigations/Monitoring Network

SWSA 6 has long been the focus of ORNL and USGS investigations, site characterization research, remedial technology demonstrations, and regulatory compliance monitoring. The first groundwater wells and/or piezometers were installed in 1954 as part of the initial characterization of SWSA 6, 15 years prior to the site's use for disposal. Since then, available records indicate a total of 355 groundwater wells and/or piezometers have been drilled and installed within WAG 6. Additionally, as many as 600 trench piezometers have been installed in and between most of the waste disposal trenches in SWSA 6 to monitor trench water levels and trench water/leachate chemistry. The RFI identified 226 WAG 6 groundwater wells or piezometers and 72 WAG 6 intratrench piezometers for which records are available. Well construction data for these wells and piezometers are summarized in Appendix 3A.

Table 3.6 summarizes the history of groundwater well or piezometer installations through June 1990, and identifies those still existing when the WAG 6 RFI was conducted. Figure 3.24 shows the locations of all identified wells or piezometers within or immediately adjacent to WAG 6.

Since completion of WAG 6 RFI field activities (June 1990), approximately 50 additional monitoring wells, well points, or piezometers have been installed or were to be installed within WAG 6 by ORNL as part of the ongoing Active Sites Monitoring Program. These include 31 intratrench wells installed next to the LLW silos; 8 wells installed next to the high activity auger holes; 2 wells installed near the active fissile wells; a well installed adjacent to both asbestos silos; 4 wells planned in the Hill Cut Test Facility area; and 6 new wells around Tumulus Pad 2 (Ashwood 1990a; Ashwood 1990b; Wickliff, Morrissey, and Ashwood 1991). Figure 3.24 and Appendix 3A do not include wells installed after June 1990. Also, since June 1990, grading activities associated with the IWMF construction in the southwest part of WAG 6 have resulted in the destruction or abandonment of the 10 IWMF piezometers as well as several other pre-RAP piezometers (piezometers 266, 267, 380, 274, 276, 379 and 380).

Most of the still-existing wells and piezometers were constructed using methods or materials that predate current standards for use in regulatory compliance water quality monitoring. However, they provide valuable information regarding groundwater potentiometric levels, and these data have been used to the extent practical in the RFI. Limited groundwater sampling has been performed on many of the piezometers in conjunction with research projects conducted in WAG 6 over the years. Analytical results are presented in Appendix 1B, and have been incorporated as appropriate in the assessment of the nature and extent of contamination (Sect. 4).

The present groundwater quality monitoring network consists of the 22 RFI monitoring wells (BNI 1990c; TM-06-08A, Well Installation) and 30 ORNL RCRA compliance monitoring wells (Mortimore and Ebers 1988). Figure 3.25 shows the locations of these 52 water quality monitoring wells. The 22 RFI wells were installed at depths ranging from 3 ft to 170 ft to monitor the shallow storm flow zone, saturated regolith, and shallow and deep bedrock. Details regarding well construction and rationale for well location selection are provided in WAG 6 RFI TM 06-08, *WAG 6 Well Installation, Activity 1* (BNI 1990c) and TM 06-08A, *WAG 6 Well Installation, Activity 2*. Of the 22 wells installed, 3 wells (1226, 1232, and 1235) have remained consistently dry throughout the investigation period.

The ORNL compliance monitoring network consists of upgradient, interior site characterization and perimeter wells and well pairs. Generally, well pairs were constructed to monitor both the water table and the deeper bedrock (i.e., less than 110 ft deep) and are screened in both regolith and/or shallow bedrock. Deep potentiometric control within WAG 6 is afforded by: four HHMS three-well clusters that monitor 20-ft open intervals at three distinct depths to 400 ft; by a four-well cluster at the ETF site to depths of 240 ft; RFI well pair 1237 and 1238; RFI wells 1236 and 1239; and a three-well cluster on the east side of WAG 6 (RFI wells 1234, 1249, and ORNL Well 840).

Following completion of the WAG 6 RFI, wells not required to support activities leading to site closure will be plugged and abandoned to eliminate them as possible sources of cross-contamination. ORNL is preparing a detailed well plugging and abandonment plan, and plugging and abandoning will be conducted as an activity separate from the remedial action prior to completion of the Record of Decision (ROD).

3.3.2 Groundwater Occurrence

Groundwater at WAG 6 occurs principally under unconfined, water table conditions in the regolith and shallow bedrock. No major confining layers or aquitards have been identified, such that groundwater occurs as a continuum from the water table surface depth in bedrock. Perched water conditions occur locally in WAG 6 within the unsaturated zone, or vadose zone. Transient saturated conditions associated with shallow subsurface storm flow in the uppermost unsaturated zone also occur. Figure 3.26 illustrates the various elements of groundwater occurrence at WAG 6. As shown, near surface water features and in low-lying areas, the storm flow zone and shallow water table are indistinguishable.

3.3.2.1 Saturated zone

The water table marks the top of the saturated zone and occurs at depths ranging from less than 1 ft below grade in low-lying topographic areas and along surface water drainages to as much as 55 ft below grade on hilltops. The water table fluctuates in response to episodic and longer-term seasonal patterns of precipitation and evapotranspiration. Water levels are generally highest from January to March (peaking in February), when precipitation is high and evapotranspiration is minimal; water levels are lowest from August through October, when precipitation is low and evapotranspiration is high.

Historical water level data are plentiful for existing wells and piezometers at WAG 6. However, there have been few occasions during which a large number of wells were measured simultaneously, such that it is not possible to construct a potentiometric map for the whole site for a given date using this data. Therefore, in February 1990, water levels were measured at nearly 300 wells and piezometers in existence at that time in and adjacent to WAG 6. These water level measurements are tabulated in Appendix 3A. Additional water level data recorded in association with quarterly sampling of the 30 ORNL compliance monitoring wells and the 22 RFI monitoring wells from 1988 through June 1990, are summarized in TM-06-09A, *Groundwater Sampling Phase 1, Activity 2*.

A water table potentiometric map for February 1990 is presented in Fig. 3.27. It is believed this map reflects both seasonal as well as long-term high water table conditions (1990 was a wet year with above-average precipitation). Although the majority of WAG 6 wells do not straddle the water table, potentiometric maps constructed using data from wells screened at or within 50 ft of the water table provide a reliable approximation of the water table. Potentiometric head differences were noted in well pairs consisting of deep and shallow bedrock or regolith wells. Therefore, in preparing Fig. 3.27, care was exercised to exclude potentiometric data from deeper bedrock wells, deep wells in well pairs or well clusters, and wells encountering obvious perched water conditions. As Fig. 3.27 shows, the water table surface appears to be a subdued replica of site topography (see Fig. 3.1), and water table gradients suggest local flow to WAG 6 surface water drainages and overall southerly flow towards WOL. The potentiometric map further indicates the line of topographic highs along the northwest boundary of WAG 6 forms a groundwater divide.

A complete round of water level measurements from all existing wells representing dry season conditions (i.e., September 1990) was not obtained during the WAG 6 RFI field effort. However, existing historic water level data for 118 site wells were evaluated collectively to assess the mean maximum annual water level fluctuation at each location. This information is summarized in Appendix 3A. The maximum historic water level fluctuations recorded in these wells were contoured and are presented as Fig. 3.28. Typically, water level fluctuations are more pronounced in higher topographic areas; in low-lying areas (particularly along surface water drainages), water table elevations are maintained at more consistent levels. Because of this, hydraulic gradients are generally steepest during the wet season, becoming more subdued during the dry season. As Fig. 3.28 confirms, the least amount of fluctuation was observed in low-lying areas, while greater than 20 ft of maximum fluctuation occurs in localized areas of generally higher topography in the northern portion of WAG 6. Because Fig. 3.27 represents seasonal (as well as long-term) high water table conditions, the hydraulic gradients shown represent expected maximums; hydraulic gradients during the dry season would be somewhat less. Evaluation of historical data indicated a mean maximum water table fluctuation of 6.67 ft. Consequently, water level elevations for low water table conditions would be expected to average 6.7 ft lower than those presented for February 1990.

Shallow wells screened in either the bedrock or regolith show rapid response to precipitation events, whereas deep wells show little or no response. Figure 3.29 presents daily rainfall hyetographs and hydrographs for three shallow WAG 6 wells for which continuous water level data were available. The hydrographs show water level responses from several hours up to 12 hours. Davis et al. (1984) and Davis and Marshall (1988) report response times of 5 to 7 hours with 11.5 hours to peak water level and up to 170 hours for reequilibration. Hydrographs and hyetographs for other wells (Ashwood and Spalding 1990) show similar trends, although water level data generally were recorded biweekly to weekly and aquifer response to individual precipitation events could not always be measured.

Figure 3.30 presents hydrographs for two 400-ft deep HHMS-series piezometers for which continuous water level data were available. Two significant features of these hydrographs are noted. First, water levels for both wells indicate these wells have yet to reach equilibration following drilling and installation in 1987. In fact, all but one of the four deep HHMS-A wells (HHMS-7A) are still equilibrating. (This is related to the low storativity of the aquifer associated with decreased secondary permeability and hydraulic conductivity at depth in the bedrock.) Second, these hydrographs show a lack of water level fluctuation in response to precipitation events. Although some minor pressure fluctuations are noted in these wells, they cannot readily be correlated to precipitation events.

Alternatively, due to the low hydraulic conductivity prevalent in wells of this depth, it is possible that the lag in aquifer response is so great that the minor fluctuations observed are responses to recharge (i.e., precipitation) events occurring prior to the period for which data was recorded. No explanation can be offered for the erratic hydrograph response shown for HHMS-6A, which is located outside the WAG 6 boundary on the south side of WOL.

Comparing measured water level elevations with bedrock elevations in wells and piezometers shown in the hydrogeologic cross sections (Figs. 3.9 through 3.19), it is clear that the water table in some areas in WAG 6 occurs in the regolith and in other areas occurs in the bedrock. To separate those areas where water table occurs in bedrock from those where it occurs in the regolith, the top of bedrock elevation map (Fig. 3.6) was subtracted from the February 1990 potentiometric map (Fig. 3.27). The resulting intercept values were contoured to represent the regolith-saturated thickness map presented in Fig. 3.31. Figure 3.31 also shows areas where, during seasonal high water table conditions, the water table occurs in the bedrock and the overlying regolith is unsaturated.

As shown in Fig. 3.31, in much of the northern portion of WAG 6 the water table occurs below bedrock at depths ranging up to 30 ft below the regolith/bedrock contact. In areas where the water table occurs above bedrock, the saturated thickness of the regolith ranges up to 30 ft, but is generally less than 20 ft thick throughout the site. Because the water table declines seasonally, it can be assumed that the extent and thickness of saturated regolith will also decline as more bedrock is exposed above the water table. The anticipated areal extent of saturated regolith and/or bedrock under low water table conditions, as shown on Fig. 3.31, was interpreted by assuming a 6.7 ft decline in the seasonal high water table elevation (the mean maximum fluctuation observed from historical data), which would expose an additional 6.7 ft of bedrock above the water table. As shown in Fig. 3.31, during the dry season, a much larger area exists where the water table occurs below the bedrock surface. (The implications of this finding on groundwater flow is pursued further in Sect. 3.3.2.5). Because Fig. 3.28 shows areas where water table fluctuations could be less than or exceed the assumed average (6.67 ft), the actual extent of areas where the water table occurs below bedrock during dry season conditions could vary from that shown in Fig. 3.31.

Groundwater recharge and discharge. Groundwater recharge is principally from precipitation (estimated to range from 7 to 9% of annual precipitation at WAG 6) and as such, occurs throughout WAG 6. The undulating topographic relief and presence of intervening surface water drainages results in very localized shallow flow systems with classic proximal recharge and discharge areas all within WAG 6. As shown in Fig. 3.27, recharge areas coincide with topographically higher areas, while discharge appears to occur along drainages and to WOL. Head differences observed in well pairs and clusters for the most part confirm this assessment. In recharge areas, the shallow well of the pairs typically (though not always) show higher potentiometric head than the deeper well indicating downward components of flow associated with recharge. Conversely, in discharge areas, such as along the unnamed surface water drainage bounding WAG 6 on the east, potentiometric head observed in the deep well of the pair exceeds that of the shallow well. indicating an upward vertical flow component characteristic of groundwater discharge areas. This is further confirmed by the artesian conditions observed in RFI wells 1244 and 1245 installed directly adjacent to this drainage. Well pairs installed in hillslope positions somewhere between the hilltop recharge areas and lower relief discharge areas show typical mixed upward and downward vertical gradients depending on location relating to the imaginary line separating recharge and discharge (i.e., where measured heads would be equal in deep and shallow wells).

Head differences observed in well pairs and clusters represent either upward or downward vertical gradients that can be related to the recharge-discharge relationship discussed. Table 3.7 summarizes average vertical gradients and directions for WAG 6 well clusters and well pairs based upon available water level data. Figure 3.32 displays the average vertical gradients and indicated gradient direction. Vertical gradients observed range from 0.008 to 0.23 ft/ft and reflect the potential for both upward and downward components of flow. A downward component of flow is indicated at the HHMS-7 and ETF-14/15/16 well clusters. At HHMS-7, the vertical gradient increases with depth while the ETF cluster shows a decrease in gradient with depth. Upward vertical gradients were observed between the intermediate and shallow wells at the HHMS-5 well cluster, which is located adjacent to WOL in a groundwater discharge location. Vertical gradients could not be determined between intermediate and deep wells for HHMS clusters -4, -5, -6, and -8 because potentiometric data indicate the deep wells have not yet equilibrated following drilling and installation (as shown in Fig. 3.28). It must be noted that the occurrence of vertical gradients does not imply flow in a vertical sense, only the potential for vertical components of flow. However, as will be discussed further, site data suggest there is little or no vertical groundwater flow from shallow to deep zones, and the high degree of topographic relief is sufficient to induce virtually all of WAG 6 recharge to remain in the shallow, upper portion of the aquifer.

Effects of the 49 Trench area French Drain. A key feature recognizable on Fig. 3.27 is the linear drawdown pattern in the central part of WAG 6 associated with the 49 Trench area French Drain. This drain, installed into bedrock in late 1983, was designed to intercept groundwater from upgradient areas and lower the water table below the base elevation of the 49 Trench area trenches, thereby decreasing the generation and potential mobilization of leachate. The French Drain is lined with a filter fabric and consists of a 226-ft-long north leg, which discharges to a catch basin at the western outfall, and a 600-ft long east leg, which discharges to a catch basin at its southern end. Discharge from the east leg ultimately drains to surface water drainageway DA.

Early post-construction performance monitoring by Davis and Stansfield (1984) showed the French Drain effectively suppressed the water table to a depth of 16 ft below ground surface over 50% of the 49 Trench area. (Previously the water table occurred at a depth of 6 ft below grade.) Drawdown was observed to extend 164 to 196 ft from the trench centerline (out to intertrench Well 400), with a maximum 13-ft suppression at the deepest point in the drain (Davis and Marshall 1988). As a result, 29 of 49 trenches had dried up.

Davis and Marshall (1988) report that discharge from the east leg of the drain during steady state conditions is 0.32 to 0.50 gpm but ranges up to 20 gpm during storm events. Davis and Marshall (1988) report a total of 1,137,909 and 695,903 gal of water were discharged from the east leg during 1984 and 1985, respectively. Discharge from the north leg is intermittent and was observed only five times during Davis and Marshall's 3-year study, and then at a peak discharge of 1 gpm associated with a storm.

Figure 3.27 clearly shows that the French Drain is effective in intercepting groundwater, particularly in the immediate vicinity of the drain. However, an evaluation of precipitation and well hydrographs for the period 1984 to 1988 shows that the French Drain effectiveness is decreasing, probably as a result of clogging of the filter fabric lining (Black 1989). Wells within 40 ft of the drain show 4 to 11 ft of sustained water table suppression, whereas wells beyond 50 ft of the drain centerline now show no drawdown effects.

3.3.2.2 Unsaturated zone

The unsaturated zone at WAG 6 extends from ground surface to the water table and primarily consists of soil and saprolite, although, as shown in Fig. 3.31, the uppermost competent bedrock is also locally unsaturated when it protrudes above the water table. This interval is significant because, by design, the majority of waste burial trenches terminate in the unsaturated zone. Groundwater occurs within the unsaturated zone as localized lenses of perched water and as transient water in the storm flow zone. This section describes groundwater occurrence in the unsaturated zone and discusses active processes related to waste disposal trench hydrology (bathtubbing, trench-groundwater interactions, effects of ICM capping.)

Perched water. Perched conditions have been observed locally within the unsaturated zone in wells and piezometers, specifically in the northwest corner of WAG 6 (in piezometers 269, 267, and 270) and in the 49 Trench area in the central part of WAG 6 (in Well 1232 and Piezometer 317). Perched conditions are not unexpected due to the nature of the regolith (for example, the occurrence of a clayey C-horizon as previously described) and the number of waste disposal trenches that commonly retain infiltrating water, creating a bathtubbing effect. Perched water may also occur in areas of WAG 6 underlain by soil unit 5 (see Fig. 3.23), which commonly displays a fragipan horizon that could act to perch water.

Well control suggests these perched zones are of limited extent (generally only in the vicinity of the well where encountered) and are relatively insignificant. For example, perched water identified in Piezometer 269 in the western part of the site was not observed in Piezometer 378 or wells 857 and 858, which are located within 40–50 ft of Piezometer 269.

Storm flow. Recent research efforts at ORNL have emphasized the significance of the subsurface storm flow or interflow zone as a mechanism and pathway for shallow transport of infiltrating water and contaminants in the unsaturated zone to surface streams. The storm flow zone consists of the macropores and mesopores in the root zone of shallow soil horizons and, depending on local conditions, comprises the shallow interval from ground surface to a depth of up to 6 ft (see Fig. 3.26). Conceptually, storm flow may occur wherever the infiltration rate and capacity of surficial soils exceeds the peak rainfall intensity. Consequently, flow in this zone is transient (lasting only hours or days), generated in response to precipitation events of sufficient duration and intensity to saturate this interval and produce a transient perched zone in the storm flow zone. Infiltrating water is then transmitted laterally downslope in response to gravity, following short flow paths towards adjacent drainages. Because the base of the zone is not impermeable, recharge to the water table occurs along the length of the saturated storm flow zone. Near perennial streams, the water table is considerably higher; in these areas, the storm flow zone and water table are indistinguishable. The storm flow zone and water table may also be connected locally on steep hillsides where wet-weather seeps can occur.

The occurrence of storm flow is dependant on the infiltration rate of surface soils exceeding both the peak rainfall intensity and permeability of the underlying saprolite such that the majority of precipitation will infiltrate and remain perched in the storm flow zone. Moore (1988) compared hydraulic conductivity data from slug tests conducted in nearly 400 piezometers at ORNL (including 60 piezometers at WAG 6) to limited soil infiltration data for undisturbed, forested soils in SWSA 7 and determined that the shallow surface soils have significantly higher permeability than the underlying saprolite. Further, Moore reported the infiltration capacity of undisturbed forested soils exceeds the maximum rainfall intensity for the area, such that practically all incident rainfall infiltrates into the soils with little or no overland flow component. From results of storm flow monitoring at SWSA 7, Moore (1988 and 1989a), postulated that in undisturbed areas on the ORR, 90 to 95% of the rain water actually infiltrating into the subsurface (approximately 39 to 41% of annual rainfall) is conducted through this zone to surface water drainages, with only 5 to 10% of precipitation actually recharging the shallow groundwater.

Other studies (Solomon et al. 1989) conducted in a localized study area similar to WAG 6 at nearby SWSA 5 have shown that storm flow only accounts for an estimated 44% of the total discharge (i.e., groundwater discharge plus storm flow) to adjacent Melton Branch during "dry" years. Further, in this study, tritium detected in soil pore water strongly suggests that the flow path between the waste disposal trenches and the stream may be partially in the storm flow zone, but the contamination is discharged to the stream as groundwater.

During the WAG 6 RFI, three shallow storm flow wells were installed to assess the storm flow zone at locations where it was expected to be present. All three wells were constructed using RCRA monitoring well construction standards. Wells were screened from 3 to 14 ft below ground surface to intercept the storm flow zone. However, throughout the investigation, two of the three wells (Wells 1226 and 1230) have remained consistently dry during rainfall events monitored. The third well, RFI Well 1232, consistently had water both during periods of precipitation and during dry periods; it likely monitors a localized perched water lense. These results highlight the logistical problems associated with monitoring this zone and the difficulty in predicting the occurrence of the storm flow zone.

As previously discussed, the surface soils at WAG 6 have been highly disturbed, reworked, or removed as a result of site clearing and grading, waste disposal trench excavation, and cut and fill work associated with the construction of the ICM caps, Tumulus pads, and IWMF area. Additionally, over 1000 piezometers, wells, auger holes, and disposal trenches perforate the storm flow zone, providing infiltration galleries that bypass lateral storm flow. Approximately 15% of the WAG 6 surface area is covered by impermeable ICM caps preventing direct recharge to the storm flow zone. Consequently, the surficial soils at WAG 6 are not representative of undisturbed, forested conditions elsewhere in Melton Valley and the storm flow zone, where prevalent, is likely laterally discontinuous.

Available WAG 6 soil infiltration data suggest that overall, there is little difference in permeability between site soils and underlying saprolite at the locations where data were collected. Further, site soil infiltration rates (ranging from 1.8 x 10^{-3} to 6 x 10^{-6} cm/sec) are less than the peak rainfall intensity of 2.3 cm/sec reported by McMaster (1967) for the area. This suggests that once the infiltration capacity of the soils is reached and soils are saturated, the majority of precipitation would be conducted away as overland runoff. However, as discussed in Section 3.2 and shown on Fig. 3.23, 11 distinct soil units have been identified at WAG 6, and physical and hydraulic properties likely vary laterally within a given soil type as well as between different soil units. Nonetheless, although site soils may display higher infiltration rates elsewhere in WAG 6, in the areas where data were collected it is unlikely that storm flow is a significant factor.

Hydrographs for shallow water table wells at WAG 6 show rapid responses to precipitation events (up to 3.5 ft peak increase in water level). If the majority of infiltrating water was attenuated in the storm flow zone, such rapid increases would not be expected to occur. This suggests that the storm flow component may not be present in these locations.

From the preceding discussion, the storm flow zone at WAG 6 is believed to be highly variable and discontinuous, resulting in discrete flow pathways where present. However, as will be discussed in the following section, storm flow does appear to be occurring at WAG 6 as evidenced by trench hydrology data in the vicinity of capped areas, and may be of significance in contaminant transport at WAG 6. Nonetheless, due to the inherent heterogeneity of the storm flow zone at WAG 6, site-wide characterization of this component is neither practical nor feasible. Consequently, considerable uncertainty exists regarding the impact of storm flow on the hydrologic system and contaminant fate and transport at WAG 6. Due to these uncertainties, simple recognition of the potential for storm flow is sufficient to support the remedial alternatives selection process (i.e., although monitoring the storm flow is impractical, remedial strategies should include components that address storm flow).

3.3.2.2.3 Trench hydrology

Unlined waste trenches at WAG 6 are typically 10 ft wide by 50 ft long by 15 ft deep. However, in the biological trenches, trench depths are shallower, ranging from 7 to 12 ft deep. Unlined auger holes are typically up to 5 ft in diameter and up to 23 ft deep. Although they were initially designed so that their bottoms would be above the water table, an interesting consequence of shallow trench waste burial operations is that precipitation tends to infiltrate into trenches either directly or via storm flow, creating bathtubbing conditions wherein water is perched in the trenches above the water table. In other areas of WAG 6, the water table intersects the trenches perennially and/or when seasonal or episodic high water table conditions persist, causing further inundation of the trenches.

Trench bathtubbing occurs when inflow from these sources along fractures, mesopores, and macropores exceeds outflow through the trench bottoms and side walls, which have lower permeability. Bathtubbing trenches act as infiltration galleries allowing for mobilization of leachate. In the case where trenches are completely filled, outflow can potentially occur via the storm flow zone, where it exists.

Bathtubbing is most pronounced during the winter wet season. During this time, precipitation is at a maximum, evapotranspiration is minimal, water table elevations and soil moisture contents are highest, and water infiltrates into waste disposal trenches faster than it seeps out of the bottom (Tamura et al. 1980).

Pre-ICM cap trench hydrologic conditions. Davis et al. (1987) reported on a study conducted by Davis and Solomon to identify the interaction between the shallow water table and trenches. A total of 20 intratrench monitoring wells and 6 water table wells were monitored over an extended period to define the hydrologic conditions of the trenches in WAG 6. A combination of continuous and manual water level measurements were made beginning in February and March 1986. Existing data from 1985 to 1987 were also included in the study. The water level data showed that trenches could be classified hydrologically according to one of the following five criteria.

(1) **Unsaturated**—the water table outside the trench was consistently below the trench bottom and standing water was not observed in the trench monitoring well
(2) **Inundated**—the water level elevation in the trench monitoring well is above the trench bottom and equal to the water level elevation observed in adjacent water table monitoring wells
(3) **Intermittently Inundated**—a combination of 1 and 2, due to a fluctuating water table
(4) **Bathtubbing**—the water table elevation adjacent to the trench was consistently less than the water level inside the trench and is below the trench bottom and measurable standing water was observed in the trench monitoring well
(5) **Intermittently Bathtubbing**—the trench bottom is about the seasonal high water table and trench water is only encountered sporadically

The hydrologic condition of trenches in WAG 6 during the study are shown in Fig. 3.33. Solomon et al. (1988) report only 10% of trenches monitored were either bathtubbing or inundated during the entire monitoring period. Eighty-four percent of SWSA 6 trenches showed either intermittent bathtubbing or were intermittently inundated during this period. Further monitoring of 14 trench wells from 1986-1987 identified only 6 trenches in which bathtubbing occurred for more than one month. Davis et al. (1987) found that only those trenches with water levels within 1.5 ft of the adjacent water table showed any significant response to storm events. When trench well water levels are greater than 1.5 ft above the local water table elevation, the majority of infiltration can be attributed to direct infiltration through the cap or storm flow. However, when the water level difference is less than 1.5 ft, as much as 90% of the total trench influx may occur through pathways other than direct infiltration through the cap, namely, interaction with the water table.

Water level data from 1976 to 1987 indicate that the auger holes are not inundated by a high water table, although standing water was observed during construction of several auger holes (Solomon et al. 1988). The existence of bathtubbing auger holes was not explored because piezometers do not exist in auger holes.

Effects of ICM capping on trench hydrology. In 1989, eight HDPE caps were constructed in WAG 6 as an ICM. The caps presently cover over 15% of the surface area of WAG 6. Solomon et al. (1988) reported on the hydrologic condition of trenches prior to placement of the caps (Fig. 3.33). An attempt was made as part of the RFI to evaluate the current state of trench/groundwater interaction.

To accomplish this, it was assumed that across the site the average trench is 15 ft deep. Based on this assumption (which is consistent with operational records, which indicate that, with the exception of the biological waste trenches, most trenches range from 14 to 18 ft deep) an elevation map was created to show the elevation of the bottom of the trenches in the vicinity of the capped areas. This map was created by subtracting 15 ft from the topographic surface (Fig. 3.1). For the biological trenches, a trench depth of 10 ft was assumed (records indicate trenches in these areas range form 7 to 12 ft deep). The February 1990 potentiometric map (Fig. 3.27), which illustrates high seasonal water table conditions, was then subtracted from the trench bottom map to identify areas where the water table is intersecting the trenches. Using this method, a number of trench areas were determined to be inundated during high seasonal water table conditions, whereas others appear to be unsaturated as a result of interaction with the water table. Figure 3.34 displays the resulting hydrologic conditions of trenches in February 1990. Because the high seasonal potentiometric surface map was used, it is believed this figure represents a worst case scenario.

From examination of surface topography (ground surface elevations ranging from 810 to 820 ft) and the February 1990 potentiometric map (elevations 785-800 ft), and assuming all auger holes are at least 20 ft deep (records support this), it appears the auger holes are not in contact with the water table.

To determine the degree of groundwater and trench interaction under dry conditions, the mean maximum water table fluctuation of 6.7 ft was considered. If a trench area is unsaturated during high water table conditions, it should also be unsaturated during the dry season, when the water table would be on average approximately 6.7 ft lower. Conversely, a trench area where mapping indicates wet season inundation of greater than 6.7 ft should remain inundated during the dry season. Trenches where mapping indicates 6.7 ft of intercept or less should be inundated during the wet season but unsaturated during the dry season (intermittently inundated). Figure 3.35 depicts these scenarios.

Further, trench water elevations measured February 20, 1990, for 59 intratrench wells were compared to the mapped water table elevation for the same date, as shown on Fig. 3.27. Bathtubbing trenches are those in which the trench water elevations exceed the mapped water level elevation at that location. Inundated trenches show trench water elevations that are equivalent to the mapped water table elevations. Dry trenches are noted by dry intratrench wells. From examination of Fig. 3.34, some trenches appear to be either bathtubbing or unsaturated in areas designated as inundated. This is related to depths of individual trench piezometers and indicates that trench hydrologic conditions shown on Fig. 3.34 are a reasonable approximation, but actual conditions in individual trenches may vary from those shown.

Of the 59 trench wells, 21 were dry, 18 were inundated, and 20 displayed bathtubbing. The individual trench well conditions are also shown on Fig. 3.34. The results suggest that in the uncapped 49 Trench area, the French Drain has been effective in lowering the water table to preclude groundwater/trench interactions, but the trenches commonly display bathtubbing conditions resulting from either storm flow or direct precipitation infiltration. Apart from two trench wells (T44 and T63) that reflect trench/groundwater interaction, Cap 8 has apparently been effective in preventing infiltration. As shown on Fig. 3.33, trenches in the Cap 8 area were found to be intermittently bathtubbing prior to cap placement (Davis et al. 1987). Comparing pre- and post-cap mapping, the construction of Caps 4, 5, and 6 have apparently had little effect on dewatering trenches or preventing bathtubbing and/or inundation of the trenches.

Ashwood and Spalding (1990) have recently summarized the results of monitoring the effects of the ICM caps on groundwater levels and trench water levels. In this study, conducted from 1988 (pre-Cap) through October 1990, water level data were manually and, in some cases, continuously recorded for 25 shallow groundwater wells or piezometers outside the trench areas and 45 intratrench piezometers. Their findings support the previously stated conclusion that the ICM caps have only been effective in preventing bathtubbing for two cap areas, Caps 2 and 8. It is believed that in these two areas the caps significantly reduced the recharge area of the storm flow zone, thereby preventing infiltration to the bathtubbing trenches. Conversely, in other capped areas (most of which were constructed on hillslopes) bathtubbing conditions persisted although direct infiltration by precipitation was precluded by the caps. This indicates that storm flow does occur and should be addressed in closure alternatives intended to prevent bathtubbing.

Ashwood and Spalding (1990) also concluded that recharge to the shallow groundwater was not affected by placement of the caps. Shallow wells monitored still displayed responses to precipitation that are consistent with the range of pre-cap responses.

Ashwood and Spalding (1990) noted that in the Cap 8 area, only two trench wells (T44 and T63) displayed inundated conditions. They found that the lake and trench water elevations in these two trenches are the same, and that the trench water levels fluctuate proportionately with changes in lake stage in response to precipitation events (Fig. 3.36). In these two cases, the trenches are slightly deeper than the average trench depth near WOL, and the trench bottoms are below the lake stage level of WOL. Other trenches located closer to WOL are typically less than 15 ft deep and would not be impacted by lake stage fluctuations because the trench bottoms are well above the 100-year flood stage elevation (754 ft). It is possible that there may be other deep trenches present in this area. Therefore, closure alternatives may need to address means of preventing interactions with the groundwater in these low-lying areas.

3.3.2.3 Aquifer Geochemistry

Groundwater geochemistry data acquired either as part of the WAG 6 RFI or prior research indicates the groundwater at WAG 6 is stratified. Groundwater age-dating studies provide support of the geochemical stratification observed.

The combination of geochemical stratification and groundwater age dating results indicates there is little or no circulation or mixing between the shallow, active flow component and deeper, more stagnant groundwater zones. From these results, it is believed that active groundwater flow at WAG 6 is limited to the upper 150 to 170 ft of the aquifer.

Aquifer stratification. During the RFI, groundwater analytical data for samples from 86 WAG 6 wells or piezometers were evaluated to assess the aquifer geochemistry. Existing groundwater data from 40 piezometers were integrated with data from 46 groundwater samples collected and analyzed as part of the RFI. Samples were collected from all of the ORNL RCRA well pairs, the well 840/1234/1249 cluster, and the ETF-13/14/15 piezometer cluster, as well as all other WAG 6 RFI monitoring wells and selected ORNL interior site characterization monitoring wells. Table 3.8 summarizes the data sources for existing WAG 6 groundwater geochemical data used. Figure 3.37 shows the locations of all 86 wells.

Groundwater geochemical data were plotted on a trilinear diagram (Piper plot) and are presented as Fig. 3.38. Further, plots of pH versus depth, specific conductance versus depth, and pH versus specific conductance were prepared and are presented as Figs. 3.39, 3.40, and 3B.41, respectively. There are apparent increases in pH and specific conductance with depth in the aquifer that appear directly related to the aquifer geochemistry. Specific conductance and pH form a linear relationship, both increasing with depth. Dreier and Toran (1989) noted 1 to 2 orders of magnitude higher specific conductances for the deep HHMS A wells versus the shallower B and C wells. The increase in specific conductance with depth observed suggests a more highly mineralized groundwater at depth, which is usually related to higher residence time in the bedrock and/or longer flow path lengths.

Field measured pH was found to range up to 12.5, but a pH greater than 11 must be considered suspect. Dreier and Toran (1989) suggest that the elevated pH (i.e., above 9) are related to grout contamination. While this may be the case in the two HHMS wells where pH = 12.5, elevated pH values above 10 were observed in other than HHMS wells and other locations within Melton and Bear Creek Valleys. It is unlikely that all of these wells are contaminated with grout. It is believed that with the exception of wells HHMS-5A and 6A and ETF-13, wells with pH of 9-11 are not grout contaminated, but reflect a natural evolution of groundwater. Details are provided in TM-06-09A, *Groundwater Sampling*

Phase 1, Activity 2. Further, the elevated sodium and chloride concentrations observed in the two deep HHMS-series wells are far in excess of levels representative of grout, and are equivalent to concentrations reported for deep (i.e., >600 ft deep) saline groundwater encountered in the hydrofracture rock cover wells elsewhere in Melton Valley.

As Fig. 3.38 shows, the aquifer appears to be stratified into three distinct zones: a shallow, neutral to acidic, calcium-bicarbonate type water; an intermediate zone of alkaline (pH > 8.5) sodium-carbonate or bicarbonate water; and a deep zone of alkaline to neutral, sodium-chloride type water. The sodium-chloride chemistries are interpreted as representing the upper extent of the deep saline groundwater component observed by Haase et al. (1987) and Switek et al. (1987) in deep hydrofracture wells in Melton Valley. Further, concentrations of lithium, bromide, and fluoride are comparable to deep saline water chemistries.

Eighty-six percent of the wells studied are shallow and displayed the calcium-bicarbonate chemistries. As seen from Fig. 3.38, some of the calcium-bicarbonate type waters show elevated percentages of magnesium. This is likely due to a localized increase in dolomite in the vicinity of these wells. The only two outliers to the observed stratification are wells HHMS-5C and RFI well 1244 (data points 49 and 17 on Fig. 3.38, respectively). Well 1244 is located along the eastern drainage, screened below the water table in an area where depth to bedrock is very shallow (exposed in the stream bed), and potentiometric data indicate artesian conditions prevail at this location.

Groundwater from Well 1244 plots midway between the shallow calcium-bicarbonate and intermediate sodium-carbonate/bicarbonate chemistries. It is unclear whether the resulting geochemistry is indicative of either upward flow from depth (which is consistent with the both the recharge-discharge relationships discussed earlier and the artesian conditions observed) or mixing of shallow groundwater with potentially contaminated surface water. Similarly, groundwater from well HHMS-5C, the shallow well of this cluster (screened interval is from 42 to 62 ft), consistently plots outside the remainder of the data in all three fields of the trilinear diagram. As shown on Table 3.7, upward vertical gradients are prevalent between the intermediate and shallow wells at this cluster. This suggests there is some mixing of intermediate and shallower groundwater at this location, due to either the indicated upward flow component; alternatively, it may be an artifact of well installation or related to interaction with WOL surface water.

By comparing the different water chemistries to screened interval (as shown in Fig. 3.42 and summarized in Table 3.9), the transition between the shallow calcium-bicarbonate type water and the intermediate sodium-carbonate/bicarbonate water is seen to occur in WAG 6 at an elevation of approximately 665 ft. This transition can also be identified in borehole geophysical logs for several of the deep RFI wells for which high quality fluid resistivity borehole geophysical logs are available (TM-06-13A, *Borehole Geophysical Logging*). The transition between the intermediate zone and the underlying sodium-chloride type waters is observed only in the vicinity of WOL in wells HHMS-6A and -5A, and appears to occur at an elevation of 385 ft. The stratification observed is consistent with the findings of Webster and Bradley (1988) for groundwater elsewhere in Melton

Valley. Geraghty and Miller (1990) and Haase and King (1988) observed similar stratification of groundwater in the Conasauga Group bedrock aquifer in Bear Creek Valley, although the transition depths between zones varied. These transitions are noted on all WAG 6 RFI hydrogeologic cross sections (Figs. 3.9 through 3.19).

Depth to these transitions varies across the site owing to topographic relief and it is unlikely that the transitions are totally planar features. They probably fluctuate somewhat across the site perhaps mimicking the structural configuration of Melton Valley. The transitions are significant in that they appear to be distinct, indicating little or no circulation or mixing of waters between zones (except perhaps in the two wells previously noted). Further, as can be seen in Figs. 3.9 through 3.19, the aquifer stratifications observed transect both structural and stratigraphic features. Groundwater geochemical zones are consistent across mapped thrust faults and the three distinct Conasauga Group formations underlying WAG 6.

Tritium is ubiquitous in the shallow groundwater at WAG 6 and within Melton Valley in general (Poreda, Cerling, and Solomon 1988). Therefore, tritium can be used as both a tracer for contaminant migration and for age dating because it moves at the same rate as groundwater. Dreier and Toran (1989) reported tritium concentrations near or below detection limits in the WAG 6 HHMS intermediate and deep wells. Tritium was not detected in the four deep RFI monitoring wells. Conversely, in the shallow flow system near waste disposal trenches, tritium has been reported in groundwater at levels ranging up to 10,000,000 pCi/L. Tritium was reported at 1243 pCi/L in well HHMS-4C, the shallow well of the cluster (which displayed calcium-bicarbonate chemistry indicative of the active flow system), but was not detected in the deeper wells in this cluster in spite of the downward vertical gradients indicated by potentiometric data. The overall lack of deep groundwater contamination by tritium further suggests that little or no circulation (or mixing) occurs between the different geochemical zones, and active flow is restricted to the uppermost parts of the aquifer.

Heavy isotope studies and age dating. Dreier and Toran (1989) analyzed samples from WAG 6 wells HHMS-5A, -5B, -5C, -6A, -6B, and -6C for deuterium and oxygen-18 isotopes to fingerprint the aquifer flow components.[3] Generally, oxygen-18 and deuterium

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[3]The hydrogen and oxygen isotope values in groundwater are in general determined from the environment in which the groundwater recharged (entered the aquifer). Specifically, temperature, latitude, and elevation influence the isotope values. Thus, if these conditions are different for separate flow systems, the hydrogen and oxygen isotopes will fingerprint water from each system. The isotopes studied are deuterium (^{2}H or D) and ^{18}O, which have additional neutrons making them heavier than the more common isotopes, ^{1}H and ^{16}O. Because the heavy isotopes occur in very small quantities, the δ notation is used to report isotope ratios:

$$\delta = (^{R}\text{sample}/^{R}\text{standard}^{-1}) \times 1000\ ^{o}/oo$$

ratios decreased with depth indicating the groundwater is heavier at depth (the more negative values indicate lighter water and less negative values indicate heavier waters). The deep A wells, which displayed sodium-chloride type chemistries, display subtle differences in isotopic signatures when compared with the sodium-carbonate/bicarbonate type waters of the B and C wells. This suggests relatively stagnant, older waters. The deep wells showed deuterium ratios ranging from -23 to -27 o/oo (per mil; analogous to percent) and oxygen-18 ranging from -2.6 to -4.1 o/oo. Conversely, the B and C wells, which have sodium-carbonate geochemical signatures, showed deuterium ranging from -34.5 to -35 o/oo and oxygen-18 ranging from -5.5 to -6.1 o/oo. HHMS-5C, which displayed a geochemical signature indicative of mixing of intermediate and shallow water chemistries, and which has been shown to have upward vertical gradients, displayed deuterium results comparable to the other B and C well results but had the lowest oxygen-18 ratios (-6.1 o/oo).

The oxygen-18 and deuterium results further indicate that there is stratification between the intermediate and deeper water chemistries and suggest a subtle difference between the intermediate zone and shallow, active flow zone chemistry (although the shallowest well analyzed monitors an apparent mixing zone). However, no samples were analyzed from waters displaying calcium-bicarbonate chemistries indicative of the active flow component.

Tritium, with a half-life of 12.3 years, decays radioactively to helium, an inert gas. Consequently, the measurement of relative ratios of helium and tritium can be used to date groundwater. Poreda, Cerling, and Solomon (1988) sampled 13 WAG 6 wells (108, 109, 345, 347, 370, 371, 373, 374, 381, 382, 383, 386, and 388) in July and September 1986, and analyzed samples for tritium and helium to date the shallow (less than 126 ft deep) groundwater at WAG 6. Poreda, Cerling, and Solomon (1988) found that all groundwater samples analyzed ranged from 0.1 to 6.0 years in age, indicative of the very short residence times in the aquifer as well as the short flow path lengths. Since residence time is a function of depth and hydraulic gradient, WAG 6 groundwater was found to be younger in areas with higher hydraulic gradients and shallow depths and older (i.e., at the high end of the age range reported) in areas of low gradient and greater depths. Poreda, Cerling, and Solomon (1988) reported several wells that did not fit this trend but suggest that the lower residence times indicated by age dating results reflected localized zones of preferential flow.

Additional age dating of WAG 6 groundwater was performed by Solomon (1988) using tritium, helium and krypton-35 techniques. Samples from RAP piezometer 741 in the southwest corner of WAG 6 indicate the groundwater in that well is approximately 1.5 years old. This finding agrees with the results of the Poreda, Cerling, and Solomon (1988) study and further confirms the short residence times in the shallow, active flow component of the aquifer at WAG 6. Conversely, carbon-14/carbon-13 age dating (Toran et al. 1991) of

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where R is the ratio of the heavy isotope to the light isotope. The sample is reported as a ratio to standard mean ocean water (SMOW) for D and ^{18}O). This ratio has 1 subtracted from it to make the standard value 0, and it is multiplied by 1000 to make the number larger and use units of per mil (°/oo, analogous to percent).

deeper groundwater indicates groundwater at depth is very old (on the order of 10,000 to 40,000 years old), indicative of extremely long residence time and little movement.

3.3.2.4 Aquifer hydraulic properties

As previously noted, considerable site characterization research has been conducted at WAG 6, much of which has contributed information regarding site aquifer hydraulic properties. Other studies within similar geologic settings in Melton and Bear Creek valleys have provided further information. Within WAG 6, a total of 109 individual well slug tests, four tracer tests, and one pump test have been performed. Because of the extent of available information, aquifer testing was not conducted as part of the RFI. Rather, the existing data have been incorporated to form the basis of understanding of site hydraulic properties. Because of the nature of the geologic materials comprising the aquifer skeleton, aquifer properties vary between the regolith (soil and/or saprolite) and bedrock, and with depth. This section summarizes pertinent information regarding aquifer hydraulic properties. Table 3.10 summarizes the aquifer hydraulic properties reported from available sources. Slug test hydraulic conductivities are tabulated in Appendix 3A.

Soil hydraulic properties. As noted in Sect. 3.3.2.2.3, in uncapped areas, precipitation tends to infiltrate into trenches either directly or via storm flow, creating "bathtubbing" conditions. Therefore, the infiltration rates of site soils are of significance in efforts to model the unsaturated zone. For purposes of comparison, infiltration rates and hydraulic conductivities are both presented in units of cm/sec.

Soil infiltration data have been collected at several locations within the ORR and Melton Valley. Moore (1988) reports that soil infiltration rates for the ORR range from 1.0×10^{-2} to 2.3×10^{-3} cm/sec (14.3 to 3.3 in./h). Site-specific infiltration data for WAG 6 has been acquired by Davis et al. (1984) in the ETF area, and by Clapp (1990) for three 482-ft^2 test plots within SWSA 6. Their results, which showed infiltration rates lower than suggested by Moore, ranged from 1.8×10^{-3} cm/sec (Clapp 1990) to 5.6×10^{-6} cm/sec (Davis et al. 1984) cm/sec (2.6 to 0.008 in./hr, respectively). Their site-specific data are within ranges reported by Luxmoore, Spalding, and Munro (1981) and Rothschild et al. (1984a) for undisturbed soils in similar geologic conditions at SWSA 5 and SWSA 7, respectively. The three orders-of-magnitude range is not unexpected, as soils vary widely as a result of both natural (such as degree of weathering, slope position, and vegetation) and demographic factors (such as soil removal, trenching, etc.). Soil macropores and mesopores together total only 0.2% of the soil volume but account for 96% of the infiltration (Watson and Luxmoore 1986).

Ammons et al. (1987) determined that the total porosity of WAG 6 soils ranges from 42 to 49%, which is within the 30% to 60% range reported by Davis et al. (1984) for undisturbed A and B-Horizon soils in the ETF area. Both ranges reported are typical of clayey and silty clay soils. Davis et al. (1984) report a mean total porosity of 50% (0.5) for ETF area soils. They further suggest that in the 0 to 8-in. shallow soil interval, soil effective porosity is roughly equivalent to total porosity (i.e., effective porosity = 0.5), but for deeper soils, the effective porosity probably approaches 0.05 or less. The RCRA RFI Guidance

(EPA 1989d) suggests effective porosities of 0.01 to 0.15 (depending on degree of secondary porosity) could be expected for clayey and silty clay soils typical of WAG 6.

Saprolite hydraulic properties. Because groundwater occurs in the saprolite over much of WAG 6, aquifer properties including hydraulic conductivity and effective porosity, are important factors in assessing the rate of groundwater movement through the saprolite in the saturated zone. Physical properties of saprolite are also significant as the majority of waste disposal trenches terminate in saprolite in the unsaturated zone. Values for these properties for WAG 6 have been determined from slug test data and from several aquifer tests that have been conducted at WAG 6 within the saprolite portion of the regolith.

Of the 109 slug tests performed in WAG 6, 25 were conducted in the saturated saprolite. These tests determined that hydraulic conductivities range from 3.7×10^{-3} to 9.6×10^{-6} cm/sec (10.5 to 0.027 ft/day), with a geometric mean hydraulic conductivity of 2.0×10^{-4} cm/sec (0.6 ft/day). Table 3.11 summarizes the distribution of WAG 6 regolith hydraulic conductivity data from slug tests. Using the geometric mean hydraulic conductivity and mapped saturated thickness of the regolith from Fig. 3.31, the transmissivity of the regolith ranges from 0 (where unsaturated) to 0.21 cm^2/sec (19.5 ft^2/day).

The majority of the regolith slug tests were performed in saprolite derived from the underlying Nolichucky bedrock. From Table 3.11 it can be seen that the saprolite formed from Nolichucky bedrock has a geometric mean hydraulic conductivity that is ten times that observed for saprolite derived from Maryville bedrock. This may be related to the nature of the host rock, in that the Maryville is more carbonate-rich and tends to weather to a clayey saprolite whereas the Nolichucky saprolite is more silty in nature.

Figure 3.43 shows the distribution of hydraulic conductivity across WAG 6 by hydrogeologic unit. There is little difference between WAG 6 soil infiltration rates and hydraulic conductivities for the underlying saprolite.

From a tracer test conducted in 1976 in the vicinity of the biological trenches near the southern boundary of WAG 6, Tamura et al. (1980) observed that initial and maximum tracer breakthrough occurred in an observation well downgradient to the injection well. Using tracer breakthrough time and known distance between the wells, an average linear velocity of 0.4 to 0.6 m/day and an effective porosity of 2% to 3% was calculated for the saprolite at this location. These values are consistent with the range reported in Webster and Bradley (1988).

Additional constant head tracer tests were performed in unsaturated saprolite at two test sites near the southwest end of the 49 Trench area (Dreier et al. 1987) adjacent to previously mapped exploratory trenches. Aquifer properties were not determined, but the tracer results showed strong asymmetric distribution in a preferred direction perpendicular to hydraulic gradient. The orientation of the tracer plume was found to be influenced by the intersection of mapped bedding plane fractures and extensional fractures, but did not approximate the vector sum of the bedding plane fracture orientations as expected. This suggests that flow in the regolith is controlled by a combination of secondary permeability features and hydraulic gradient. These test sites were revisited later in 1987, and new tests were performed using improved techniques in somewhat deeper pits. Results indicated faster tracer travel times, with the highest tracer concentrations observed in strike-parallel observation wells. However, subsequent excavation of the test site to identify the structural fabric affecting the results revealed a tree root that had grown along and enlarged a relict fracture in the saprolite. This indicates the difficulties involved in confidently predicting groundwater flow paths in the regolith on a local scale. From a larger perspective, however, groundwater flow can be expected to be primarily gradient dominated with secondary control exerted by structural fabric.

Bedrock hydraulic properties. There is virtually no primary matrix porosity in bedrock of the Conasauga Group; therefore, groundwater flow within bedrock is principally along secondary permeability features such as fractures and solution cavities. Consequently, aquifer properties determined from aquifer testing primarily describe the fracture network.

Sixty-eight slug tests performed in bedrock at WAG 6 revealed a consistent trend of decreasing hydraulic conductivity with depth, a trend unrelated to stratigraphy (Fig. 3.44). WAG 6 bedrock hydraulic conductivities are summarized in Table 3.12 and are presented on Fig. 3.43, and are also included on the WAG 6 hydrogeologic cross sections (Figs. 3.11 through 3.15). The slug test results show that hydraulic conductivity for the bedrock as a whole at WAG 6 ranges from 1.8×10^{-3} to 1.9×10^{-9} cm/sec (5.1 to 5.4×10^{-6} ft/day), with a geometric mean of 3.1×10^{-5} cm/sec (0.09 ft/day).

Little difference can be seen between geometric mean hydraulic conductivities for Nolichucky and Maryville bedrock although Maryville bedrock, appears to exhibit a wider range of values. As Figs. 3.41 and 3.42 show, hydraulic conductivities vary several orders of magnitude at any given depth as well as laterally. Both formations display a decrease in hydraulic conductivity with depth. This decrease is related to the depth of active circulation of groundwater and the density of open fractures which are limited to depths less than 150 feet (Dreier and Foreman 1990). Consequently, active groundwater flow is limited to depths less than 150 ft; groundwater flow is increasingly precluded with depth.

Both a tracer test and a pump test have been performed in the shallow Maryville bedrock at the ETF site. The results for both showed nonradial responses with both tracer and drawdown patterns that approximate the trend of fractures associated with two minor folds. Results of the tracer test showed initial tracer breakthrough as well as peak concentrations in a direction along strike. However, although the highest tracer concentration was detected along strike from the injection well, it was not detected in the nearest along-strike well (Vaughan et al. 1982). It was found that tracer patterns were controlled by a combination of matrix porosity and, principally, by strike-parallel fractures associated with two sharp anticlinal structures trending approximately along formation strike. This suggests that primary flow in groundwater at WAG 6 is along fractures, but bulk transport via intergranular flow is also a factor. Fractures are important and dominate quick movement, but volumetrically, fractures may be less significant than the surrounding rock matrix.

Similar patterns of drawdown were observed in observation wells during a pump test in the same ETF area. Smith and Vaughan (1985a,b) analyzed the pump test data using nonradial solutions and calculated a geometric mean transmissivity of 0.16 cm^2/sec (14.8 ft^2/day) for the Maryville Limestone at this location. Using the (nonradial) geometric mean transmissivity of Smith and Vaughan (1985a, 1985b) and the geometric mean hydraulic conductivity reported by Davis et al. (1984) for the ETF area (6.31×10^{-5} cm/sec or 0.18 ft/day), the aquifer appears to be on the order of 82 ft thick. This thickness is consistent with the depth of active groundwater flow indicated from the geochemical results. Assuming an aquifer thickness of 100 to 150 ft for the active flow component of the aquifer and the geometric mean hydraulic conductivity for WAG 6 bedrock reported earlier (3.1 x 10[illegible] cm/sec) transmissivity of the bedrock ranges from 0.09 to 0.14 cm^2/sec (9 to 13.5 ft^2/d).

Storativity[4] for the bedrock is low, ranging from 0.01 to 0.001, with a geometric mean storativity of 0.005. Anisotropy has been reported to range from 3:1 to 23:1 (Kx:Ky) elsewhere in Melton Valley. In the ETF area pump test, Smith and Vaughan (1985a,b) reported 5:1 anisotropy.

Combining the results of the slug tests, pump tests, and tracer tests at the ETF site, Davis et al. (1984) calculated an effective porosity of 0.03 for the shallow Maryville bedrock at this location. Although this effective porosity is higher than default values suggested in the RFI Guidance (EPA 1989d) for fractured carbonate rocks (0.001) and assumed ranges of 0.0001 to 0.007 presented in various reports (Moore 1988; Vaughan et. al. 1982; Sledz and Huff 1981), this effective porosity was empirically derived using actual WAG 6 aquifer testing data. Therefore, it is believed this value is representative.

No pump tests were performed in the Nolichucky bedrock within WAG 6. However, Smith and Vaughan (1985a, 1985b) and Law Engineering, Inc. (1983) have reported on aquifer tests performed in similar bedrock in areas of Bear Creek Valley. The separate studies found comparable results in terms of response to pumping and parameter values.

The transmissivities, storativities, and effective porosities reported indicate a low-yield (successful pump tests in the Maryville Limestone bedrock at the ETF area required pumping at a rate of less than 0.9 gpm; higher rates dewatered the aquifer) aquifer with limited storage capacity principally related to fractures. Although the Conasauga Group bedrock aquifer does supply a few area domestic wells, the hydraulic conductivity of the aquifer is generally too low to encourage extensive use as a water-supply aquifer.

Overall, the nonradial responses to pumping, somewhat unpredictable tracer responses, and low aquifer yield (based upon pump test rates) reflect the complexity of the aquifer system and suggest that pump and treat remedial strategies likely would not be feasible.

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[4]The volume of water an aquifer releases from or takes into storage per unit surface area of the aquifer per unit change in hydraulic head. In unconfined aquifers such as occurs at WAG 6, storativity and is equal to the specific yield.

3.3.2.5 Groundwater flow

The portion of precipitation that is not accounted for by surface runoff or evapotranspiration infiltrates into the subsurface and follows complex pathways in both the unsaturated and saturated zones, as described below. Figure 3.45 illustrates combined unsaturated and saturated flow paths at WAG 6.

Unsaturated zone flow. Except in areas of SWSA 6 where wastes are in direct contact with the water table, a portion of the contaminant travel pathway occurs in the unsaturated zone. Due to the "bathtubbing" effect discussed earlier, contaminated fluids exiting waste disposal trenches or auger holes are generally under positive pressure. Thus the downward hydraulic gradients will cause much of the existing contaminated water to be delivered to the water table, although some of the water would move down inclined surfaces (such as bedding planes) to discharge to streams or swales, or as seeps. In intersecting the water table, flow in trenches or along a series of trenches may vary from flow in the intervening area between trenches as water particles would move along the trench and exit at any point of lower head along the trench bottom and/or sidewalls (Webster and Bradley 1988). Once exiting the trench, contaminated fluids flow through the unsaturated zone following discrete but established features such as fractures, relict bedding planes, and soil fragipan horizons (Ammons et al. 1987). Unsaturated flow is generally transient and therefore slower than flow under saturated conditions. This allows for more contact between fluids and geologic materials, and contaminant retardation (i.e., related to sorption processes) is increased (Ammons et al. 1987).

Where prevalent at WAG 6, flow along the storm flow zone would follow surface topography. Storm flow paths are consequently short, on the order of 160 to 330 ft from points of infiltration to discharge at streams or seeps (Moore 1988). Also, because storm flow is transient, perched water in the storm flow zone will infiltrate downward in the unsaturated zone all along the storm flow path during and after precipitation events.

Saturated zone flow. Although the groundwater at WAG 6 is a continuum from the regolith to depth in bedrock, groundwater flow is complex, as the geologic materials comprising the saturated zone (i.e., regolith and bedrock) are distinctly different.

Groundwater flow in the regolith occurs through porosity (resulting from weathering) and along fractures and relict bedrock structures, which may be either locally enhanced by solution enlargement or occluded due to clay plugging or precipitation of iron and manganese oxides. Groundwater flow in the regolith is largely gradient dominated, particularly in the upper more weathered portion of the regolith, where the degree of weathering is greater and the regolith behaves more like an isotropic media. Anisotropy increases with depth in the regolith as the degree of weathering decreases and the significance of relict bedrock structural fabric becomes more prevalent. Nonetheless, Webster and Bradley (1988) suggest that anisotropy in the regolith is probably not great enough to impair flow rate and directions on a larger scale using hydraulic gradients derived from potentiometric mapping.

Conversely, due to the lack of primary matrix porosity, groundwater flow in the unweathered bedrock is principally along secondary permeability features such as fractures, solution cavities, and possibly, faults. Bedrock flow paths are associated principally with strike-parallel and bedding plane fractures (trending generally east-west across the site) or with the intersection of bedding plane fractures with other conjugate fracture sets. As explained in Section 3.2, up to five distinct fracture sets have been identified in WAG 6 bedrock.

Whereas flow in the regolith is generally controlled by the hydraulic gradient and follows topography, groundwater flow in bedrock is strike-parallel and along bedding, except where crossing secondary fractures with different orientations and lower heads. The result is a tortuous, stair-stepping flow path in three dimensions that may vary with depth (Webster and Bradley 1988).

Depending on the local orientation of fractures and the hydraulic gradient, bedrock groundwater flow may occur directly between two points. However, features that control flow in the bedrock (folds, faults, fractures) are so variable laterally that flow prediction between two points cannot be determined precisely.

Small-scale folds, such as those identified in the ETF area at WAG 6, have been shown to effect significant control on flow direction and rate, generally owing to the increased hydraulic conductivity associated with these features. Depending on orientation, other such features present but not identified at WAG 6 may serve as either conduits or impediments to strike-parallel flow (Boegly et al. 1985).

Groundwater flow at WAG 6 is local rather than regional and appears to occur predominantly in the shallow subsurface, where groundwater flow follows short flow paths from points of recharge to points of discharge, all within WAG 6. Groundwater discharges to nearby intermittent streams, which ultimately discharge to WOL (Webster and Bradley 1988; Lomenick and Wyrick 1965). However, along the southern boundary of WAG 6, surface and groundwater flow is directly to the lake (Boegly et al. 1985). Moore (1988) suggests the shallow flow system has flow paths on the order of 1300 ft long, while Webster and Bradley (1988) report the maximum flow path length in the deeper aquifer is 3300 ft long.

Three conceptual groundwater flow diagrams were constructed across WAG 6 using potentiometric data for February 1990 (Figs. 3.46, 3.47, and 3.48). Two of the flow diagrams are oriented north-south across the site while the third is oriented east-west across WAG 6. The two north-south flow diagrams, A-A' and C-C', show discharge to WOL and shallow flow from points of recharge in WAG 6. Conceptual flow diagram C-C' includes three deep HHMS-series wells (HHMS-4A, -5A, and -8A), which have not yet reached equilibrium following their installation. Consequently, flow at depth in the vicinity of these wells cannot be determined using potentiometric data for these wells. The east-west flow diagram, F-F', demonstrates that within WAG 6 flow is local, with discharge to drainages within or adjacent to WAG 6. USGS modeling results further support the conclusion that groundwater flow is towards the intervening streams (Tucci 1984). The conceptual flow diagrams illustrate the recharge/discharge relationships observed in individual well pairs or clusters across WAG 6.

Pressure tests conducted in the Conasauga Group in Melton Valley indicate that secondary openings in bedrock are limited to the upper 100 ft of bedrock, restricting active flow to this interval (Webster, 1976; Lomenick and Wyrick, 1965). Further, USGS modeling efforts to date (Tucci 1991; Zehner and Tucci 1991) suggest 90% to 98% of all groundwater flow at WAG 6 occurs in the upper 50 to 100 ft of the aquifer, with virtually no flow occurring below 250 ft. From site characterization data presented in this report, a preponderance of evidence exists to indicate that active groundwater flow is limited to the upper 150 ft of the aquifer.

- Geochemical data indicate the aquifer at WAG 6 is distinctly stratified, suggesting little or no circulation occurs between zones. These data indicate the shallow active flow system is limited to the upper 150-170 ft of the aquifer.
- Groundwater age dating results show that shallow groundwater is young, on the order of 0.1 to 6.0 years, which indicates short residence times and short flow paths. Within the range given, the age increased with depth. This suggests that most active groundwater circulation occurs at shallow depths.
- Heavy isotope data suggest that deeper groundwater is older and relatively stagnant.
- Hydraulic conductivitie decrease dramatically with depth such that active circulation at depth is improbable.
- Hydrographs suggest that only shallow wells show demonstrable response to precipitation.
- Tritium analytical results for wells at WAG 6 show a lack of tritium contamination below a depth of 100 ft, further supporting a lack of active circulation at depth.

Some vertical flow component is possible, as indicated by the vertical gradients discussed previously. However, topographic relief at WAG 6 is great enough to induce virtually all of WAG 6 recharge to remain in the shallow, local flow system. Therefore, if deep flow does occur within WAG 6, it probably involves only a very small fraction of WAG 6 groundwater (Boegly et al. 1985).

As shown in Fig. 3.31, during the wet season the water table occurs in the regolith over most of the southern half of WAG 6, and below the regolith/bedrock interface in the shallow bedrock in much of the northern half of the site. During the dry season, the area of regolith saturation decreases and groundwater flow through bedrock is more significant. Likewise, hydraulic gradients decrease during periods of seasonal low water table conditions. Therefore, groundwater flow rates calculated from seasonal high water table potentiometric data represent maximum expected flow rates and provide a conservative estimate of groundwater discharge from WAG 6. Groundwater flow velocities during low water table conditions would be somewha s.

Flow directions and rates saturated regolith and upper bedrock to a depth of 100 ft are the product of hydraulic gradient and the orientation, density, and interconnection of fractures. While it is accepted that strike-parallel flow dominates, it can be assumed that, to a depth of 65 ft in bedrock, flow is in the direction of hydraulic gradient, as determined from a water table potentiometric map (ORNL 1990).

To provide an estimate of groundwater flow rates in both saturated regolith and bedrock in various areas of WAG 6, average linear groundwater velocities (or seepage velocities) were calculated along 20 major and secondary flowlines labeled A through J, as shown on Fig. 3.49. Average linear velocity was determined by:

$$\text{Velocity} = \frac{(\text{hydraulic conductivity x hydraulic gradient})}{\text{effective porosity}}$$

An effective porosity of 0.03 was used for both regolith and bedrock as equivalent values were obtained from aquifer testing conducted in the regolith and bedrock within WAG 6. Geometric mean hydraulic conductivities for regolith or bedrock were determined by using the appropriate hydraulic conductivities along or near each flowline from Fig. 3.49. The hydraulic gradient was determined from the February 1990 potentiometric map (Fig. 3.25). In areas where mapping indicates flow is solely in the shallow bedrock, only bedrock velocities are calculated. Conversely, in areas where mapping indicates saturated regolith conditions exist, flow rates were determined for both hydrologic units. The resulting average linear velocities are summarized on Table 3.13.

As shown on Table 3.13, groundwater flow rates in the regolith range from 0.10 m/day (flowline B_1) to 2.28 m/day (flowline C_2). The overall geometric mean linear velocity for the regolith is 0.33 m/day (395 ft/year). This value compares well with the average mid-season flow rate of 0.25 m/day (Webster and Bradley 1988) and the WAG 6 tracer test flow rate of 0.40 to 0.60 m/day (Tamura et al. 1980). The tracer test was conducted in the area of flowline I_2, where the average linear velocity was determined to be 0.31 m/day.

Average linear velocities calculated for the shallow bedrock ranged from 0.04 m/day (flowline F) to 0.49 m/day (flowline J_2). The overall geometric mean linear velocity for the shallow bedrock is 0.15 m/day (180 ft/year). This value compares well with the 0.18 m/day flow rate from the tracer test performed in the ETF area (Davis et al. 1986).

As shown on Table 3.13, flow velocities in the regolith are approximately twice those in the bedrock, owing to the order of magnitude difference in hydraulic conductivities between the two hydrologic units. However, flow in the bedrock actually may be considerably faster or slower than the velocities shown, because flow in bedrock follows tortuous paths, and rates between two points are not directly proportional to the heads measured at any two points (Moore 1988). In areas where hydraulic gradient direction is parallel to strike, flow rates may be significantly faster than areas where the hydraulic gradient is normal to strike, because in the latter case flow paths would be longer and more tortuous.

Groundwater flow in deeper portions of the aquifer in WAG 6 is estimated to be towards the south or southeast based upon mapping using WAG 6 deep well potentiometric data (Fig. 3.50). As explained earlier, flow rates through deeper bedrock in the active zone of circulation would be slower because of longer flow paths, lower hydraulic gradients, and increasing confinement with depth.

3.3.3 SUMMARY OF FINDINGS REGARDING GROUNDWATER HYDROLOGY

Key findings and conclusions regarding the groundwater hydrology at WAG 6 are presented below.

- **Groundwater Occurrence and Flow**

- In the saturated zone, groundwater occurs under water table conditions in the regolith and/or shallow bedrock. No major aquitards or confining layers are present, so that groundwater is a continuum from the water table to depth in bedrock.

- Perched water occurs in the unsaturated zone at WAG 6 but appears to be of limited extent and significance.

- Transient storm flow occurs in the unsaturated zone at WAG 6. However, the storm flow zone is highly variable and likely discontinuous due to considerable removal or reworking of surficial soils, the lack of vegetative cover, ICM capping over approximately 15% of the site, and other physical features resulting from waste disposal activities. Therefore, storm flow paths are likely discrete and short from point of infiltration to discharge along streams or seeps within WAG 6.

- Considerable uncertainty exists with respect to the impact of the storm flow zone on WAG 6 hydrology, and it is neither feasible nor practical to characterize storm flow in detail on a site-wide basis. However, storm flow can serve as a transport mechanism for contamination, and consequently remedial alternatives must address uncertainties associated with subsurface storm flow.

- The water table configuration mimics topography, indicating groundwater flow towards WAG 6 surface water features and in an overall southerly direction towards WOL.

- The water table occurs below the top of unweathered bedrock over much of the northern half of WAG 6 for all or most of the year. Groundwater flow in these areas is solely through fractured bedrock. Conversely, the water table occurs in the regolith in the southern half of the site, such that shallow groundwater flow occurs both in the saturated regolith and uppermost fractured bedrock.

- The water table adjacent to WOL fluctuates proportional to lake stage fluctuations. Disposal trenches greater than 15 ft deep adjacent to WOL are inundated, and water levels in these trenches also fluctuate with lake levels. Shallower trenches are apparently unaffected.

- Groundwater flow diagrams (analogous to flownets) indicate groundwater flow is local rather than regional. Groundwater follows short flow paths within WAG 6, flowing from higher elevation points of recharge to discharge along intervening surface water drainages.

- Hydraulic conductivity in the regolith or bedrock varies by several orders of magnitude laterally and at any given depth, but shows a marked decrease with depth. The decrease in hydraulic conductivity is related to the decreasing density of open fractures with depth.

- Aquifer testing results indicate the bedrock aquifer is a low yield aquifer (less than 1 gpm), with limited storage capacity principally related to fractures; well yields are generally too low to encourage use as a potable water supply.

- Aquifer testing (pump and tracer tests) in bedrock showed considerable nonradial, anisotropic response, which illustrates the difficulty in predicting groundwater flow between two points with confidence and suggests that remedial alternatives involving groundwater extraction by pumping are likely to prove ineffective.

- A preponderance of evidence exists to support the conclusion that a majority of groundwater flow at WAG 6 occurs in the upper 50 to 100 ft of the aquifer with virtually no flow occurring below 250 ft.

- Groundwater flow in the regolith, where saturated, is through a combination of matrix porosity and secondary porosity features and generally is expected to follow mapped hydraulic gradient on a larger scale. However, the degree of anisotropy increases with depth in the regolith in inverse proportion to the degree of weathering. Consequently, some uncertainty remains in predicting local groundwater flow between two points.

- In the unweathered bedrock, groundwater flow occurs along secondary permeability features, principally fractures. Principal groundwater flow directions in bedrock follow strike-parallel and bedding plane fractures except where crossing secondary fractures with different orientations and lower heads. This results in tortuous, stair-stepping flow paths in three dimensions.

- Flow directions and rates in the saturated regolith and upper bedrock are controlled by a combination of the hydraulic gradient, and the orientation, density, and degree of interconnecting fractures. While strike-parallel flow dominates in the bedrock, it can be assumed that on a larger scale flow is in the direction of hydraulic gradient, as determined from potentiometric mapping, particularly in areas where the water table occurs above the top of competent bedrock. Nonetheless, there is considerable uncertainty in predicting flow between two given points at WAG 6.

- Groundwater flow rates (average linear velocities) in the regolith range from 0.10 m/day to 2.28 m/day, with an overall geometric mean linear velocity of 0.33 m/day (395 ft/year). Flow rates in the shallow bedrock range from 0.04 to

0.49 m/day, with a geometric mean linear velocity of 0.15 m/day (180 ft/year). The difference is largely related to the order of magnitude difference in hydraulic conductivities between the two.

- **Existing Remedial Measures Performance**

– The 49 Trench French Drain installed in 1983 has been effective in intercepting groundwater and lowering the water table below trench bottoms over portions of the 49 Trench disposal area.

– Comparing pre- and post-ICM capping maps, the construction of ICM caps 4, 5, and 6 have apparently had little effect on dewatering trenches or preventing bathtubbing and/or inundation of the trenches (largely due to the position on slopes and limited size). Conversely, Ashwood and Spalding (1990) report that ICM caps 2 and 8 are effective due to the significant reduction of the storm flow recharge area upgradient of the trenches. None of the caps had any effect on groundwater levels.

3.4 SURFACE WATER HYDROLOGY

Surface water at WAG 6 is significant because, as described in Section 3.3, the majority of contaminant transport, either via storm flow or groundwater discharge, is to the surface water features within and surrounding WAG 6. Because of this, surface water is a principal pathway for contaminant transport off of WAG 6 and is of concern with respect to potential health risks associated with exposure. Consequently, an understanding of surface water dynamics at WAG 6 is integral to delineation of the nature and extent of contamination, fate and transport of contaminants, and assessment of risk to receptor populations.

This section presents a summary description of the surface water hydrology of WAG 6 and the water bodies that receive surface water drainage. The section is organized into four subsections. Section 3.4.1, Surface Water Features, details the drainage features of WAG 6 and characterizes the receiving waters impacted by contaminants released from WAG 6. Section 3.4.2, Stream Flow Data, summarizes the available WAG 6 stream flow data, including the continuous measurements of flow, storm events, and sporadic measurements of dry-weather flows. Section 3.4.3, Precipitation and Runoff Relationships, summarizes the runoff characteristics of the WAG 6 basins based on analyses of available stream flow data and results of previous studies. This section also describes WAG 6 runoff processes, storm response, and stream base flow characteristics.

Section 3.4.4 summarizes the effects of ICM capping on stream flow. Section 3.4.5, Elements of Water Balance, provides estimates of average annual precipitation evapotranspiration, surface runoff, and groundwater discharge. Section 3.4.6, Surface Water Quality, describes the quality of the surface waters in WAG 6 based on the results of the 1989 WAG 6 RFI surface water sampling activities. Section 3.4.7 provides a summary of key findings regarding surface water hydrology at WAG 6.

3.4.1 Surface Water Features

WAG 6 is situated on a hillside within the WOC basin, as shown in Fig. 3.51. The site is just north of WOL, which is an impounded segment of WOC. Outflow from WOL is controlled at a dam located about 0.6 miles upstream of the confluence of WOC and the Clinch River. All of the WAG 6 area drains to the WOL floodplain either directly or via the several drainages located within the WAG 6 boundary and along its eastern boundary. White Oak Creek joins the Clinch River at Clinch River Mile (CRM) 21.0.

3.4.1.1 Key local surface water features

The receiving waters of WAG 6 are the EWB, an unnamed tributary to WOC that flows along the eastern side of WAG 6, WOL and the WOC embayment, WOC, and the Clinch River. Each of these is described below.

Emergency Waste Basin. The EWB is located just north of the SWSA 6 fence. Runoff from a small area north of the northern drainage divide drains into a natural channel leading to the EWB, which is approximately 40 ft below the level of the WAG 6 boundary.

The bowl-shaped basin has a surface area of 2 acres and a storage capacity of 46 ac-ft (15 million gallons). The surrounding area is generally marshy and covered mostly with high grass and briar. An earth-filled dam on the eastern side controls outflow from the EWB, and any discharge (or seepage) enters a narrow stream draining the area southeast of the dam. Eventually this stream joins the unnamed tributary of WOC that parallels the eastern boundary of WAG 6.

Unnamed tributary of WOC. An unnamed tributary parallels the eastern boundary of WAG 6 and runs south into a marshy area that marks the approximate high-water level of WOL. This stream is sometimes referred to as the "West Seep Tributary" in other documents (the "west" refers to its position relative to WAG 7). This unnamed tributary receives groundwater and surface water runoff from a 161-acre drainage basin that includes the southeast slopes of Haw Ridge, a portion of the pits and trenches of WAG 7, the EWB, and the eastern flank of WAG 6.

White Oak Creek. WOC drains a 6.53 mi^2 basin that contains the ORNL Main Plant (WAG 1) in Bethel Valley and all the other WAGs within Melton Valley and Bethel Valley. Elevations in the basin range from 741 ft at the Clinch River confluence to 1356 ft at the crest of Copper Ridge on the southeastern drainage divide. WOC originates at several springs along Chestnut Ridge. The main branch of WOC is 4 miles long, and its major tributaries are the Melton Branch, which drains the Melton Valley, and an unnamed tributary in the northwest part of Bethel Valley.

The WOC flow consists of natural surface runoff, groundwater discharge, and discharge of imported waters. ORNL imports water from outside the WOC basin and discharges an estimated 3.5 cfs of process and waste water into WOC annually (Webster and Bradley 1988). According to Tennessee's water quality criteria and stream use classification for interstate and intrastate streams, WOC's water is intended for freshwater use, for livestock watering, and for wildlife.

Flow characteristics of the streams in the WOC basin vary according to local geology, soils, and vegetative cover. Table 3.14 shows flow statistics from four USGS flow gaging stations shown in Fig. 3.51.

White Oak Lake and White Oak Creek embayment. WOL, located just south of WAG 6, is formed by a low-head earthen dam located 0.6 miles upstream of the confluence of WOC and the Clinch River. Since September 1986, ORNL has recorded water level measurements for WOL at two locations along the upstream side of the dam. Lake stage data are recorded in 15-minute increments by a Stevens (chart) recorder installed in a stilling well mounted to the dam on the south side of the lake. In addition, since May 1988, ORNL has recorded lake stage data using two pressure transducers mounted to a staff gage in a stilling well affixed to the dam on the north side of the lake. Lake level elevations for May 1988 through January 1991 are shown in Fig. 3.52. The data show a mean lake level for this period of 745.36 ft, which is only 3 ft above the bank-full level of the Clinch River. The maximum flood level recorded to date for WOL is 751.28 ft; it occurred on December 23, 1990, associated with a high-intensity rainstorm. The lowest lake level, 744.81 ft, was recorded November 10, 1990. Daily fluctuations of several feet associated with short-duration rainstorms are not uncommon. From May 1988 to January 1991, the lake level exceeded the mean 25% of the time, but reached elevations above 747 ft only 2.7% of the time. The cumulative frequency distribution of lake levels is shown in Fig. 3.52.

At mean pool level, the lake has a 35.5 ac-ft (1,550,000 ft^3) storage capacity. Outflow from the lake is through a weir and a concrete-box culvert located at the dam. The present outlet capacity is estimated to be 2000 cfs (Tschantz 1987). Fitzpatrick (1982) estimated the levels of WOL for 100 and 500 year floods and for the probable maximum flood (PMF), to be 754, 754.9, and 761.4 ft, respectively. The PMF would inundate the animal waste trenches located in the southern part of WAG 6. Changes in the lake level have been shown to impact the water table elevation in the southern part of WAG 6 (Ashwood and Spalding 1990). As discussed previously in Section 3.3 and shown in Fig. 3.36, lake level fluctuations are evidenced in water levels recorded in several of the deeper trench piezometers (Wells T44 and T63) adjacent to WOL, which fluctuate in response to lake stage elevation. Shallower trenches showed no response. Generally in the deeper trenches, a response to WOL fluctuation is only observed when lake levels exceed an elevation of 747 ft.

WOL is the sink for all the contaminants transported in runoff and sediments generated in the WOC basin, and accumulated sediments in the lake contain tritium, cobalt-60, and cesium-137. The lake dynamics greatly impact radionuclide releases into the Clinch River. Resuspended sediments are released from the lake during heavy storms. Dye studies conducted in 1987 by ORNL indicated that travel time through the lake is approximately 27 hours (Borders et al. 1987). The major flow paths appeared to be the old channel beds.

Discharge and water levels below the WOL dam are controlled by the operation of the Melton Hill Dam, which is located on the Clinch River, 2.3 miles upstream of the WOC embayment and Watts Bar Dam, 21 miles downstream of the confluence of WOC and the Clinch River.

Clinch River. The Clinch River is the major surface water body receiving discharges from WOC. Three TVA dams, Melton Hill, Norris, and Watts Bar, control the flow of the Clinch River. White Oak Creek discharges to the Clinch River at a point downstream of Melton Hill Dam, but upstream of Watts Bar Dam. Norris Dam is about 32 miles from the site and is upstream of Melton Hill Dam.

At the Melton Hill Dam gaging station, the Clinch River has a drainage area of 3343 mi^2. The average annual discharge of the river is about 4600 cfs. The record since 1936 shows extremes ranging from the maximum of 39,600 cfs recorded February 18, 1937, to several zero-flow days recorded since Melton Hill Dam was completed in August 1962 (USGS 1990).

River stages below Melton Hill Dam are affected by a combination of discharge from Melton Hill Dam and Watts Bar Lake backwater when not generating power. Since power generation began at Melton Hill Dam in the summer of 1964, the Clinch River flow has corresponded to the power generation pattern. During the peak power generation days, Monday through Friday, releases are made for a 10-to-16 hour period; no releases are made for the remaining off-peak hours. The peak releases vary between 16,000 to 21,000 cfs. Table 3.15 shows the monthly flows of the Clinch River recorded at the Melton Hill Dam tailwaters for the 1988-1989 water year.

According to the State of Tennessee stream use classification, the Clinch River water is used for domestic water supply, industrial water, aquatic life, recreation, irrigation, livestock watering, wildlife, and navigation.

3.4.1.2 Site drainage characteristics

The number of streams in WAG 6 result in short overland flow lengths. Land slopes vary from 20 to 57% around the ridges and fr m 2 to 12% in the topographic low areas. Despite the modifications to the site vegetation, soils, and surfaces related to the site's use for disposal, site streams and overall topography have not been altered. Gross topographic features remain unchanged. However, several features constructed at WAG 6 have impacted the overall surface water hydrology of the site:

- The 49 Trench French Drain, constructed in the central part of the site to intercept groundwater, discharges directly to surface water drainages within WAG 6 via two outfalls at the termination of the north and east limbs. Although discharge from the north limb of the French Drain is intermittent and low (< 1.0 gpm), the east limb has sustained discharges to drainage DA ranging from 0.3 to 20 gpm.

- In April and May of 1989, as part of the ICM, six large areas (covering approximately 15% of the site) were capped with HDPE to reduce infiltration. Around the capped areas, trapezoidal drainage channels or berms were constructed. Channels are 1 ft deep and 1 ft wide at the bottom and have 3:1 side slopes lined with an impermeable membrane and 6- to 8-in. riprap. To avoid erosion from accelerated runoff from capped areas, conveyance channels and attenuation channels were installed as energy dissipators (Eiffe et al. 1988). The conveyance channels lead to nearby streams; attenuation channels spread runoff over the land surface. Where these channels cross service roads, six old culverts were replaced with new culverts with increased hydraulic capacity. All culverts were designed to pass flows from a storm of 25-year frequency and 24-h duration. Fig. 3.53 shows the capped areas and their drainage features. The caps have increased the site's surface runoff volumes and the peak flow rates. Storm runoff volumes and rates have also been increased due to addition of other impervious areas such as Tumulus pads and several buildings.

WAG 6 is divided into 10 subareas that define drainage areas associated with surface streams. These subareas, shown in Fig. 3.54, are listed below and discussed in the following sections.

Subarea	Drainage Area (acres)
FA	12.2
FB	21.6
DA	9.6
DB	8.8
A	0.9
B	2.5
C	1.5
South Slopes	5.9
East Slopes	2.3
Southwest Slopes	2.7

Subarea FA. The western and èastern parts of Subarea FA are drained by separate streams (Streams FAA and FAB). The westernmost stream flows southeasterly, while the easternmost stream flows to the south. Both are about 500 ft long. They join in a low-lying marshy area and from there flow southeasterly as a single stream for about 230 ft; this stream then joins the stream draining Subarea FB. The joined stream passes through a culvert under the service road near the southern boundary of WAG 6 then runs about 500 ft before discharging into WOL.

The average stream channel slope is about 5%. In the upstream reaches, channels are not well-defined, but in the middle reaches the channels are about 8–10 ft wide—although flow is usually confined to a 1.5 ft-wide section. At the basin outlet, the stream channel is about 3 ft wide, and the bankfull depth is about 16 in. The overland slopes range from 2 to 12%, and the overland flow distances to the streams are about 150 ft.

Subarea FB. A single stream running north to south drains Subarea FB. The stream channel is 1900 ft long and its average slope is about 3%. In the upstream reaches, the channel is 6 to 18 in. wide and the bank-full depth is 1 ft. At the downstream end, the channel width is about 36 in., and the depth is about 16 in. Within this subbasin, the overland flow distances to stream FB range from about 150 to 300 ft.

The north leg of the 49 Trench area French Drain (226 ft long) is located in the northeast part of Subarea FB. The French Drain terminates in a 4 ft by 4 ft concrete settling tank close to the stream. However, records indicate discharge from the French Drain settling basin has been intermittent, (observed only five times from 1984–1985), and peak discharge has been less than 1 gpm (Davis and Marshall 1988).

Subarea DA. Subarea DA lies in the middle of WAG 6. The south end of the French Drain terminates in a 4-ft by 4-ft concrete setting tank approximately 200 ft east of Building 7842, which is located on the southwest ridge of Subarea DA. The tank has a 4-in. PVC outlet pipe and discharges directly overland to stream DA.

All of Subarea DA is drained by a natural easterly flowing stream. The stream is 550 ft long and has a channel slope of about 3.7%. The downstream channel is about 3 ft wide and 1 ft deep at bank-full capacity. The stream passes under the service road through a 30-in. culvert, crosses the WAG 6 boundary, and then joins the stream draining Subarea DB. The combined stream then runs into the floodplain of WOL.

Subarea DB. Subarea DB, located in the eastern part of WAG 6, is drained by a stream running north to south. The stream is about 750 ft long, and its channel has an average slope of about 4%. Its upstream reach is made up of various channels that are 3 to 6 in. wide and drain a flat floodplain. The stream's downstream reach is a riprap-lined, 2- to 3-ft wide channel. The stream passes through a culvert, crosses the WAG 6 boundary, and joins the stream from Subarea DA.

Subarea A. Subarea A is located in the northern part of WAG 6. Overland flow from the west and east slopes of Subarea A drains north into the stream leading to the EWB.

Subarea B. Subarea B is located in the northeastern part of WAG 6. A stream 350 ft long drains the area toward the northeast. The stream channel is about 16 in. wide and 6 in. deep. About 75 ft after crossing the WAG 6 boundary, the stream joins another stream flowing south, and together they join the unnamed tributary of WOC that separates WAG 6 and WAG 7 and discharges to the floodplain of WOL.

Subarea C. Subarea C is located in the easter part of WAG 6. A small stream runs east and empties into the WOL floodplain. The high activity solvent waste auger holes are located in Subarea C.

Slopes. The easternmost slopes of WAG 6 drain by overland flow into the unnamed tributary that flows east of the WAG 6 boundary. The southern slopes of WAG 6, south of the drainage divide of Subareas FB and DA, discharge directly into the floodplain of WOL.

There are no developed stream channels on these slopes. A small area west of the drainage divide of Subarea FA drains southeasterly toward stream FA draining into WOL. Some drainage also occurs toward the perimeter service road and into small channels running towards the WOL.

3.4.2 Stream Flow Data

Limited stream flow data are available from past ORNL research activities, and, more recently, from the WAG 6 RFI surface water sampling events. Available data are summarized below.

3.4.2.1 Continuous flow measurements

From June 1985 to June 198?, continuous flow measurements were made at three weirs located at road culverts near the southern boundary of WAG 6 (Davis et al. 1986). Stations 1 and 2 were located at the outlet of Subareas DB and DA. Station 3 was located at the outlet of the combined drainages of Subareas FA and FB (Fig. 3.55). At each site, a combination V-notch and rectangular weir was installed in the upstream end of the 15-in. culvert. Water surface elevation (stage height) was measured using a pressure transducer in a stilling well constructed in the pool upstream of the weir. The stage height was recorded every 15 minutes with a Stevens punch tape water level recorder. Stage height was converted to flow rate with a rating curve. Flows could be measured within the range of 0.09 to 1.07 cfs.

Because of equipment failures, flow measurements were considered unreliable for 7 days for Station 1, for 11 days for Station 2, and for 31 days for Station 3 during the 1985-1987 data period. Daily flow hydrographs for the same period are shown in Figs. 3.56a and 3.56b.

3.4.2.2 Storm runoff measurements

October 1980–March 1983 samplings. As part of the ETF site investigation activities initiated in 1980 (Davis et al. 1984), two Parshall flumes with 9-in. throats were constructed in two channels draining the ETF site (FAA and FAB streams in Subarea FA). Flumes I and II have drainage area of 1.6 acres and 2.2 acres, respectively. A PVC liner was placed about 13 ft upstream of each flume at 6.5 ft below the channel bottom so that the subsurface flow could also be passed through the flume. Sixty runoff events were recorded at Flume I and 121 at Flume II for the 30-month period from October 1980 to March 1983. The peak flows (in cfs) were:

	Flume I	Flume II
Maximum Discharge (cfs)	2.05	1.80
Mean Peak Discharge (cfs)	0.37	0.35
Standard Deviation of Peak Discharge (cfs)	0.42	0.38

Hydrographs recorded at the flumes for winter (November 1980) and summer (June 1981) storms are shown in Figs. 3.57a and 3.57b, respectively.

April-May 1990 storm runoff sampling. As part of the WAG 6 RFI activities, storm runoff measurements were made during April-May 1990. Automatic flow monitoring sites were established at four locations (Fig. 3.55) on the streams draining subareas FA, FB, DA, and DB. A trapezoidal flume with a 2-in. throat and 60° side slopes was installed in the stream channel draining Subarea FA. A Parshall Flume with a 6-in. throat was installed in the drainages of FB and DB. In drainage DA, a Parshall flume with a 18-in. throat was installed. The flume sizes were selected based on channel geometry at bankfull capacity. All of the flumes were prefabricated with fiberglass by Free Flow, Inc. and were equipped with two stilling wells, one upstream and the other downstream of the throat. The stilling wells were equipped with pressure transducers (2 to 5 psi sensitivity range) to measure the water stage. An Easy-Logger Model EL-834 was used to record the stage measurements (TM-06-05A, Surface Water and Sediment Investigation, Phase 1, Activity 2). The stage measurements were converted to flow rates using factory-supplied rating curves. The design characteristics of the flumes are shown in Table 3.16.

Figures 3.58 through 3.61 are storm hydrographs for April 28, May 17, May 20, and May 27, 1990 storms, respectively. A total of two storms were successfully monitored at each site. Table 3.17 shows the storm rainfall, runoff, and peak flows for each of the storms at each site.

3.4.2.3 Dry weather flows

During April and May of 1983, Davis et al. (1984) made several bucket-and-stopwatch measurements to quantify the dry weather flows at the ETF site. The average of the measured flows was about 0.0014 cfs. Streams were dry most of the time.

As part of surface water sampling for the WAG 6 RFI in 1989, dry-weather (base flow) flows were measured at various stream locations within WAG 6 during the sampling events as well as at seeps and the outfalls from the 49 Trench Area French Drain. Surface water sampling sites are shown in Fig. 3.55. The dates and prevailing weather conditions for the five surface water sampling events were as follows:

- February 8-9, 1989; high groundwater; pre-cap conditions; dry weather
- April 18-24, 1989; high groundwater; post-cap conditions, dry weather
- May 9, 1989; dry weather following a storm
- September 5-6, 1989; low groundwater; dry weather
- September 25-27, 1989; low groundwater; dry weather following a storm

Flows were measured using the velocity-area method. Flow velocity was measured at a stream depth of 0.6 ft using a Swoffer Model 2100-14 current meter. Water depth was measured using either a ruler or the depth gage on the current meter probe handle. Discharge was then calculated as flow velocity times the flow cross-section area, using the

USGS mid-section method. Flow from the seeps was measured using a beaker and a Huer stopwatch (BNI 1990a).

The results of the base flow measurements are shown in Table 3.18.

3.4.3 Precipitation and Runoff Relationships

3.4.3.1 Components of runoff

Precipitation reaches a stream channel through various paths, and stream flow hydrographs at any point in a stream can be visualized as a composite of runoff generated by different processes. Four runoff components are considered to contribute to stream flow in WAG 6. These are described below.

(1) Hortonian Overland Flow. Hortonian Overland Flow (overland flow) occurs when the rainfall intensity exceeds the infiltration rates of the land surface. The excess water travels over the surface, collecting in small rivulets and trenches, and flows into stream channels relatively quickly. Flow hydrographs dominated by overland flow exhibit fast rises to peak, high peaks, and sharp recessions. In small areas (less than 100 acres) that are bare or sparsely vegetated, overland flow hydrograph peaks may lag rainfall by 5 to 15 minutes.

(2) Subsurface Storm Flow. Also known as interflow, subsurface storm flow is the infiltrated water that travels subsurface to reach a stream channel. Subsurface storm flow occurs in areas where topsoil of high infiltration capacity is underlain by a low permeability strata. Such a mechanism can occur in humid, forested areas where all precipitation infiltrates the soil and essentially no overland flow occurs. Because vertical movement of the infiltrated water is impeded by the underlying low-permeability strata, water accumulates and flows laterally downgradient until discharging as a seep or to a stream channel. Subsurface storm flow hydrographs are less peakish and can lag rainfall by 1 to 30 hours. In areas with deep permeable soils, on steep hillslopes and in narrow valley bottoms, most of the volume of the storm runoff is from the subsurface storm flow.

(3) Saturated Overland Flow. Saturated overland flow results when precipitation falls on saturated slopes next to a stream channel; subsurface flow emerges to the surface on the lower parts of slopes. During the passage of the storm, as the groundwater table rises and falls, the degree of saturation of the slopes will also rise and fall. Saturated overland flow dominates the peak flow rates in humid forested areas.

(4) Base Flow. Base flow, also called dry-weather flow, is the discharge of groundwater into the stream when the hydraulically connected water table has a gradient toward the channel. Since groundwater flow is usually very slow, there is considerable lag between precipitation and groundwater flow into the streams. In humid areas during dry periods, groundwater flow accounts for most stream flow.

3.4.3.2 Areal variation of runoff processes

The relative amount of water contributed to stream flow by each of the runoff processes identified above is dependent on the physical characteristics of the individual drainage basins and precipitation. Two significant physical characteristics of the drainage basins are the soils and land cover.

Whereas precipitation can be assumed to be equal across WAG 6, areal variations in site soils and land vegetative cover are highly variable across the site. As described previously, 11 distinct soil types have been identified at WAG 6; several soil units (such as soil unit 5, underlain by a fragipan layer) present a high potential for storm flow. Soil infiltration rates presented in Sect. 3.3.2.4 are occasionally exceeded by rainfall intensities experienced at WAG 6. However, since the infiltration capacity of soils drops exponentially within 15 to 20 minutes after the onset of rainfall, minimum infiltration rates are expected to prevail as a storm progresses. Consequently, overland flow occurs during most storms in uncapped parts of WAG 6, where infiltration rates are limiting and where the land surface is bare or sparsely vegetated.

Because of these conditions, the relative amount of water contributed to stream flow by each of the four runoff processes cannot be determined with certainty and have, therefore, not been quantified.

3.4.3.3 Storm hydrographs

The storm hydrographs shown in Figs. 3.57a and 3.57b and Figs. 3.58a through 3.61 are representative of the responses of WAG 6 basins to storm rainfalls. While it is not possible to separate the storm hydrographs according to the four runoff components described above, it is possible to determine the surface runoff and base flow components. Overland flow, saturated overland flow, and some of the subsurface storm flow will contribute to surface runoff. By drawing a line between the flow rates at the beginning of the storm hydrograph and a point on the recession portion of the hydrograph, base flow can be isolated, and it can be seen that base flow represents a small portion of storm runoff volume.

A concept useful in defining overland flow hydrographs is the time of concentration, which is the time it takes for water to travel from the furthest point in the basin to the basin outlet. Using the site characterization summary (SCS) velocity charts for the DA, DB, FA, and FB drainage, the time of concentration was estimated to range from 10 to 75 minutes.

Lag time, which is the time between the centroid of rainfall excess and the hydrograph peak, was also computed for these basins. The computed lag times, 60% of the time of concentration, are 6 to 45 minutes. The observed storm hydrographs (Figs. 3.58 through 3.61) exhibit lag times of 25 to 75 minutes, similar to computed lag times. This indicates that overland flow concepts can explain the hyrdograph shapes.

The storm hydrographs for Flume I at the ETF site, shown in Figs. 3.57a and 3.57b, exhibit the very short lag times typical of an overland flow hydrograph. The small drainage basin at Flume I has shallow soils and sparse grass cover; therefore, overland flow dominates the peak of the hydrograph. Furthermore, because of saturated soil moisture conditions, the hydrograph peak during the winter storm was also dominated by overland flow, which equaled about 60% of the storm precipitation (Davis et al. 1984). The hydrographs for Flume II exhibited a more delayed response to rainfall, but as Davis et al. (1984) indicate, this was due to the impoundment of water upstream of the culvert where flows were measured.

3.4.3.4 Dry weather flows

Streams in WAG 6 are predominantly intermittent. Under high water table conditions during winter months, stream flow is comprised of discharge from the groundwater. During dry periods, when the water table elevation drops below the bottom of the stream channel or when the groundwater gradient toward the stream decreases, base flow ceases and streams become dry. Along their reaches, streams in WAG 6 are expected to behave as effluent (gaining) in the wet season or influent (losing) in the dry season. As the dry weather flow measurements in Table 3.18 show, no flow was observed in upstream reaches of the streams during dry weather.

The mean daily flows reported in Davis et al. (1984) for the period June 1985 to July 1986 at basins DA, DB, and F (FA and FB combined) were analyzed to determine the percentage of base flow (i.e., groundwater discharge). Flows during dry days and the portions of flows during wet days that were isolated by visual inspection of the daily flow recessions were summed for the entire period. Computed percentages were 43, 24, and 36 for the DA, DB, and F basins, respectively.

3.4.4 Effect of ICM Capping on Stream Flow

In a recent study by Eiffe et al. (1988), 25-year, 24-hour storm hydrographs were developed at various locations in WAG 6 to help in the design of ICM cap drainage culverts. The storm magnitude was estimated to be 5.48 in., based on the Weather Bureau Technical Paper No. 40 (Hershfield 1961). SCS Type II rainfall distribution was used to define the rainfall distribution (USDA 1985). The 5-minute peak rainfall amount was 0.72 in. Using these assumptions, stream flow hydrographs were generated using the HEC-1 (USACE 1981) model to simulate the effects of capping. The modeled peak flows and the percent increase in peak flow were:

Area	Pre-Cap Peak flow (cfs)	Post-Cap Peak flow (cfs)	Percent increase
DA	117	123	5
DB	29	33	14
F	33	42	27

3.4.5 Elements of Water Balance

The hydrologic water balance for the entire WAG 6 site or any basin within it can be expressed as a "lumped equation":

$$P = RO + ET + \Delta SM + \Delta GWS$$

where,

P = input to the system by precipitation
RO = losses from runoff processes (described in Sect. 3.4.3.1)
ET = losses from the system due to evapotranspiration
ΔSM = change in soil moisture
ΔGWS = change in groundwater storage

Assuming changes in both groundwater storage and soil moisture are negligible, the hydrologic water balance for the entire WAG 6 site can be simplistically described by:

$$P = RO + ET$$

There is considerable uncertainty as to the exact magnitude of the various components of the annual water balance for WAG 6, mainly because of the lack of adequate measurements of ET and the runoff components. However, using the estimated average annual precipitation (52.2 in.) and evapotranspiration (30 in.) suggested by Moore (1989a), the average annual runoff would be 22.2 inches. For comparison, the estimated mean annual runoff for the 1936-1960 period reported by McMaster (1967) for 19 small drainage basins in the Oak Ridge area ranged from 21.7 to 25.9 inches.

A water balance study was performed as part of the WAG 6 fate and transport modeling (see Sect. 5) using the CREAMS model (a field-scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems). CREAMS is a physically based rainfall runoff model that generates surface runoff, potential evapotranspiration, actual ET, and deep percolation from the input precipitation, monthly average temperature, and solar radiation. Daily precipitation data for the 1981-1990 period recorded at the ETF station was used to represent WAG 6 precipitation in the water balance study. Flow records available for the F, DA, and DB drainages for June 1986 through July 1987 were used in calibration of the model.

The modeled yearly water balance values for this period are shown in Table 3.19 (further details are presented in Sect. 5 of the RFI report). The surface runoff values given in Table 3.19 are assumed to include overland flow and saturated overland flow. Similarly, the deep percolation values are assumed to include both groundwater discharge and subsurface storm flow. Total runoff is the sum of the surface runoff and deep percolation components.

Disregarding the results for 1981 because initial conditions affect the first year of simulation, the total runoff and ET values for other years are reasonable. For 1982 and 1984, years in which precipitation was close to the computed long-term average for WAG 6, surface runoff and ET values are comparable to those presented by Moore (1989a) and McMaster (1967). However, during dry years surface runoff decreases roughly 7%, accompanied by an approximate 7% increase in deep percolation. For the 1981–1990 period as a whole, ET accounts for 61% of the annual precipitation while total runoff (surface runoff plus deep percolation) is 39% of the average annual precipitation, for this period. Surface runoff and deep percolation account for 23% and 16% of the annual water budget, respectively, or 59% and 41% of total runoff.

McMaster (1967) reported runoff (surface runoff and deep percolation components) varies seasonally, as follows:

October to December — 17%
January to March — 51%
April to June — 22%
July to September — 10%

Runoff is greatest in January through March, when ET is minimal, precipitation is high, and high soil moisture levels prevail. Runoff is lowest in July through September, when ET is high, precipitation is low, and soil moisture levels are low (thereby allowing for increased infiltration). Similar patterns are evident for wet versus dry years (Table 3.20).

Deep percolation into subsurface storm flow and groundwater discharge components cannot be separated accurately given the inherent uncertainties previously described. Likewise, the exact amount of groundwater discharge that occurs as baseflow to on-site streams or discharge to WOL could not be determined. Estimates of groundwater discharge reported in the literature show considerable variation. For example, Moore (1989a) assumes that in the Oak Ridge area, groundwater discharge totals 1.26 in. (roughly 2.4%) of annual precipitation; most of it is lost as deep evapotranspiration, with the remaining portion discharged at springs and streams. Conversely, Davis et al. (1986, 1987) in a water balance study for the ETF site (July 1986 to June 1987) observed that 24% of precipitation could be accounted for by overland flow, with the remaining 76% attributed to combined evapotranspiration and groundwater discharge. Assuming 52 in. of annual precipitation and 30 in. of annual evapotranspiration, groundwater discharge using the Davis et al. (1986, 1987) percentages would suggest groundwater discharge accounts for approximately 10 in. annually (or 20% of annual precipitation).

In the northern and eastern part of the site, groundwater discharges entirely to the streams as base flow. In the southwestern and southern parts of WAG 6, portions of the groundwater discharge to site streams as base flow, and the remaining portion discharges to WOL beyond the WAG 6 boundary.

3.4.6 Surface Water Quality

The natural quality of the surface waters in WAG 6 has been characterized based on the surface water samples collected at various times and locations within WAG 6. Earlier sampling events were limited to the ETF site (Davis et al. 1984). More recently, in 1989 and 1990, as part of the WAG 6 RFI, a more comprehensive surface water quality sampling has been done. The sampling activities and their results are described in TM 06-05 (BNI 1990b) and TM 06-05A, *Surface Water and Sediment Investigation, Phase 1, Activity 2.*

From evaluation of available data, the water in the streams is of the calcium-bicarbonate type, is moderately hard to very hard, and has low sodium, potassium, and chloride content. The pH of the water is between 6.6 and 7.6, indicating neutral to slightly acidic waters. Because surface water features on or adjacent to WAG 6 are receptors for contaminated water associated with runoff from WAG, the chemistry of the surface water varies from location to location based upon degree of contamination. The nature and extent of contamination of WAG 6 surface water is discussed in detail in Sect. 4 of the RFI report.

3.4.7 Summary of Findings Regarding Surface Water Hydrology

Key findings and conclusions regarding the surface water hydrology at WAG 6 are summarized below.

- The surface waters of WAG 6 include seven streams, all originating within WAG 6. Portions of the site drain into the EWB in the north, to the unnamed tributary on the east boundary, and to the WOL in the south.

- The waste management and research activities at the site since the 1970s have impacted the surface water hydrology of WAG 6. Flow paths have been altered due to construction of service roads, culverts, the French Drain, and the drainage features associated with the ICM caps over eight waste areas. This increase in impervious surfaces, plus clearing of some wooded areas, has increased overall flow rates and volumes; however, the increase is small.

- Streams in WAG 6 are intermittent. They are mostly dry during summer months except for some groundwater discharge.

- The stream density of the site is considered high; streams are short, the longest being about 1900 ft. Therefore, potential for dissolved contaminant migration from WAG 6 via surface waters is quite high.

- While steep slopes in WAG 6 promote fast response to rainfall events, high vegetative cover and variability in soil infiltration rates across the site moderate the storm response somewhat.

- The flow of the streams includes surface runoff (overland flow, saturated overland flow, subsurface storm flow) and base flow components. Adequate data do not exist to assess the relative percents of each of these flow components. However, the storm hydrographs at the stream outlets at the site boundary exhibit peak flow occurring within one hour of peak storm rainfall in most cases. Therefore, it can be stated that overland flow and saturated overland flow dominate the storm hydrograph shape and the storm volume.

- The long term (1948 to 1990) annual precipitation as measured at the Oak Ridge Station is 54 in. The average annual precipitation for WAG 6 (ETF site) has been estimated to be 52 in. The average annual evapotranspiration is 30 in. The balance, 22 in., is the average annual discharge from WAG 6. The average annual amount of groundwater discharged to on-site streams and into WOL cannot be accurately quantified. Estimated average annual recharge to groundwater ranges from 1.3 to 10 in. (3 to 20% of precipitation).

- Seasonal runoff distribution is proportional to variations in precipitation, evapotranspiration, and soil moisture levels. During the wet season, precipitation is highest and ET is minimal, but soil moisture content is quite high, such that runoff is high. Just the opposite occurs in dry periods; much of the precipitation infiltrates into the subsurface and runoff is low. In WAG 6, runoff ranges from 10% during dry periods (July through September) to 51% in wet months (January through March). Similar trends occur in wet versus dry years.

- The natural water in the streams is of the calcium-bicarbonate type, is moderately hard to very hard, and has low sodium, potassium, and chloride content. The pH of the water is neutral to slightly acidic (between 6.6 and 7.6).

3.5 ECOLOGY

This section summarizes the ecology of WAG 6 and describes the characteristics of the ecosystem components and critical habitats. This information will be used in later sections to determine potentially affected ecosystems.

This section is organized into three subsections. Sections 3.5.1 and 3.5.2 describe flora and fauna commonly found on the ORR; it is believed these same species are represented at WAG 6. Section 3.5.3 summarizes key findings regarding site ecology. Appendix 3B presents tables listing species found on the ORR.

3.5.1. Flora

The terrestrial ecology of the ORR has been summarized in several ORNL publications (e.g., Kitchings and Mann 1976; Boyle et al. 1982). Areas of WAG 6 that remain undisturbed are typical of habitat found throughout the ORR. However, most of the site has been altered because it is an active disposal area and an area for research and development of waste storage and disposal techniques. Much of WAG 6 has also been covered with temporary impermeable caps. Currently, the site consists primarily of fields planted in fescue and relatively young wooded areas along drainages, which have moderately steep terrain. The forested areas, shown in Fig. 3.62, are generally oak-hickory hardwood stands interspersed among the areas used for waste disposal.

Plant communities at WAG 6 are characteristic of those found in the intermountain regions of Appalachia from the Allegheny Mountains to the southern extension of the Cumberland Mountains. The predominant oak-hickory association often includes stands of mixed yellow pines as well as other hardwoods. Nearly pure stands of yellow poplar (*Liriodendron tulipifera*) are found on well-drained bottomlands and lower slopes, while willow (*Salix* spp.), sycamore (*Platanus occidentalis*), and boxelder (*Acer negundo*) occur adjacent to streams and on poorly drained floodplains. A floral association, which often occurs in coves and on sheltered slopes, is comprised of species such as beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), magnolia (*Magnolia* spp.), buckeye (*Aesculus sylvatica*), and basswood (*Tilia americana*).

A field survey for rare plant species was conducted in May 1990 on WAG 6. This included a walkover of all currently undisturbed areas, but no rare species were found (Cunningham 1990a). In addition, in July 1990 a wetlands survey was conducted of the stream drainages within the fenced area at SWSA 6 (Cunningham 1990b). Although a few wetland species were found, there was essentially no wetland community development.

3.5.2 Fauna

Approximately 60 species of reptiles and amphibians, 150 species of birds, and 40 species of mammals have been recorded on the ORR (see Appendix 3B). The great variety of wooded and open areas, as well as extensive edge communities, provide favorable habitats for a broad range of species. Individual habitat parameters or combinations of parameters can be used to predict the occurrence of species in different habitats. Small mammals may be confined to a single habitat type, while larger species or more mobile species may range over several types of habitats. Most of the animals found on the ORR are capable of adapting to a variety of habitats.

The fauna at WAG 6 are typical of those associated with maintained and forested areas. During a cursory survey of WAG 6 in June 1990, 33 bird species and 1 mammal species were observed (Kroodsma 1990). However, most of the bird, mammal, reptile, and amphibian species listed by Kitchings and Mann (1976) could be present at some time (even if only temporarily) on WAG 6.

No threatened or endangered bird or mammal species listed by the U.S. Fish and Wildlife Service and no critical habitats are known to be present on the ORR. Therefore, none should be present on WAG 6. Some species listed by the State of Tennessee as threatened or endangered, such as the Cooper's hawk (*Accipiter cooperii*) and sharp-shinned hawk (*Accipiter striatus*), may occasionally hunt for prey on the site. However, these species are not known to nest on WAG 6, nor would they be expected to do so. A lack of suitable habitat and the ongoing disturbances on SWSA 6 would be preventing factors (Kroodsma 1990).

Aquatic communities on the ORR are typical of lake and stream systems in East Tennessee. Within SWSA 6, three relatively small, intermittent streams comprise the principal aquatic communities. Distinct habitats within the streams consist of riffles, pools, and leaf packs. A habitat evaluation based upon comparisons with similarly sized streams on the ORR indicated that the east tributary did not contain sufficient quality habitat to maintain a fish population (Ryon 1990). The two branches of the west tributary had pools of sufficient depth, appropriate undercut banks, and established pool-riffle sequences to support some fish species; however, none were found during a fish survey in May 1990.

In September 1990, personnel from the ORNL Environmental Sciences Division surveyed the EWB by electrofishing and found five fish, all of which were bass (*Micropterus* spp.), and several frogs of undetermined species (Ryon 1990).

In May 1990, a survey was conducted of invertebrate species within the streams in SWSA 6 (Smith 1991). The three distinct habitat types (i.e. riffles, pools, and leaf packs), were sampled and the samples were examined for species listed by the State of Tennessee or the U.S. Fish and Wildlife Service as threatened or endangered. None of the listed freshwater invertebrates are known to exist on the ORR and none were found in the streams in SWSA 6 (Smith 1990).

3.5.3 Summary of Findings Regarding Ecology

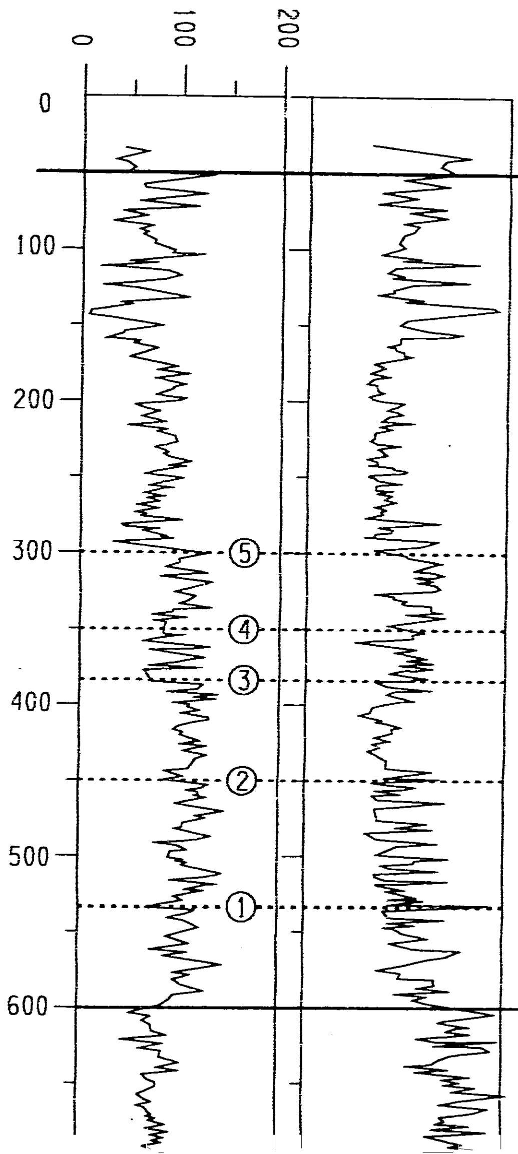
Key findings and conclusions regarding the ecology of WAG 6 are presented below.

- A field survey of flora indicated that no rare plant species are present in SWSA 6.
- A wetlands survey along stream drainages within SWSA 6 indicated essentially no wetland community development.
- No threatened or endangered bird or mammal species listed by the U.S. Fish and Wildlife Services are present at WAG 6.
- No invertebrate species listed as threatened or endangered by the State of Tennessee or the U.S. Fish and Wildlife Service have been found in the streams within SWSA 6.
- No fish were found in streams draining WAG 6.

Section 3 Tables

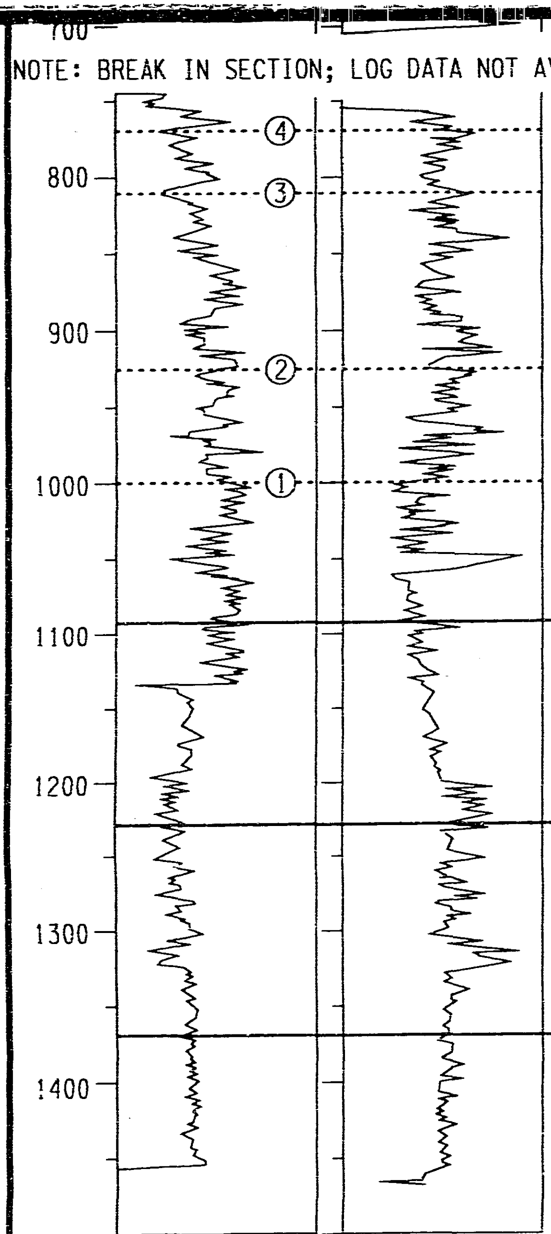
TABLE 3-1
GENERALIZED STRATIGRAPHY OF THE CONASAUGA GROUP

Composite Log*



Formation	Member	Approximate WAG 6 Member Thickness[a] (ft)	Lithologic Description
Maynardville Limestone (Cmy)	Chances Branch	Not Present	Medium to thin-bedded buff and light gray dolostones, ribbon-bedded dolomitic calcarenites, wackstones, and micrites, and medium gray oolitic packstones and grainstones.
Nolichucky Shale (Cnl)	Low Hollow	180	Wavy to evenly ribbon-bedded calcarenite and micrite alternating with oolitic packstones and grainstones.
	Upper Shale	62	Interstratified calcareous mudstones and limestones. The medium dark gray to grayish black, locally brownish black mudstones are wavy to evenly stratified and thickly laminated. The light gray limestones are wavy ribbon-bedded to laminated micrites, oolitic fossiliferous wackstones, and packstones.
	Bradley Creek	29	Predominantly lenticularly to irregularly stratified, light to dark gray algal wackstones and packstones.
	Lower Shale	459	Numerous repeated cycles of limestone, calcareous mudstone, and shale. The red-brown to maroon or red-gray mudstones are silty calcarenites, oolitic packstones, fossiliferous pelloidal wackstones, and intraclastic packstones and conglomerates. Bedding in the carbonates varies from parallel to wavy to lenticular.
	Upper[b]	246	Flat-pebble conglomerates interbedded with gray calcareous

Table 3.1. Generalized stratigraphy of the Conasauga Group



Formation	Member[b]	Thickness[a]	Description
			dolomitic wackstones, wavy to lenticularly bedded calcarenite, and fossiliferous pelloidal packstone.
Maryville Limestone (Cmr)	Lower	213	Calcareous mudstone interbedded with wackstones, packstones, calcarentites and calcareous siltstones. Carbonate lithologies tend to be critical. Mudstones are thickly to thinly bedded; packstones are massive to thinly bedded.
Rogersville Shale (Crg)		131	Massive to laminated calcareous and noncalcareous mudstones and evenly bedded to wavy current-rippled calcarenites and subarkosic siltstones. Mudstones range from red-brown to gray and gray-green. An upper member--Craig--is the limestone-rich interval in the upper portion of this formation.
Rutledge Limestone (Crt)		102	Upper and lower separated by a clastic-rich interval. Upper limestones consist of micrites, locally fossiliferous pelloidal wackstones and packstones, and silty calcarenites that are thinly bedded with highly variable stratification patterns. The middle interval consists of red-brown, red-gray, and grey mudstones and shales with interbedded laminae and lenses of subarkosic siltstone. The lowermost limestones are lenticularly bedded to mottled and bioturbated gray to gray-green wackstones and calcarenites interbedded with shales and mudstones.
Pumpkin Valley Shale (Cpv)	Upper	157	Red-brown, red-gray, and gray mudstones and shales interbedded with subarkosic siltstones. The mudstones are massive to thinly bedded and evenly to wavy parallel stratified. Siltstones exhibit complex stratification that range from thinly laminated to thinly bedded with wavy to evenly parallel to nonparallel stratification. Glauconite pellets are commonly interbedded or found within other beds.

*COMPOSITE LOG CONSTRUCTED USING, IN DESCENDING ORDER, HHMS-11, -6, -4, -7, -10, -9 LOGS.

(1)—MARYVILLE LIMESTONE AND NOLICHUCKY SHALE INTERNAL STRATIGRAPHIC MARKERS (DREIER AND TORAN 1989).

(a) Approximate on-site thickness derived from JOY-2 corehole.
(b) Informal, site-specific division into Upper and Lower Members.

Source: Haase, Walls, and Farmer 1985; Dreier and Toran 1989.

Table 3.2. Typical Maryville Limestone physical properties with depth[a]

Depth (ft)	pH	$CaCO_3$(%)	Sand[b] %	Silt[b] %	Clay[b] %	Bulk density (g/cc)
5	5.4	0.2	63	18	19	2.61
10	7.7	6.4	68	21	12	2.61
15	7.7	18.2	74	13	12	2.61
20	7.7	27.9	72	16	12	2.61
25	7.6	21.9	66	16	18	2.63
30	7.7	5.4	59	21	19	2.64
35	7.6	27.2	67	19	14	2.63
40	7.3	25.8	66	19	15	2.63
45	7.4	18.9	67	15	18	2.64
50	7.4	16.7	73	14	12	2.64
55	7.6	10.6	77	12	10	2.63
60	7.6	7.3	75	14	11	2.63
65	7.8	6.7	79	13	8	2.63
70	7.8	9.1	80	10	10	2.63
75	7.8	18.9	81	11	8	2.62
80	7.9	26.8	82	11	7	2.63
85	7.8	26.2	82	10	8	2.63
90	7.8	26.2	86	7	7	2.63
95	8.0	22.3	90	5	5	2.57
100	7.7	26.0	82	11	7	2.62
105	7.9	11.7	82	11	7	2.63
110	7.7	21.0	87	6	7	2.64
115	7.9	10.9	80	12	7	2.64
MEAN	7.6	17.1	76	13	11	2.63

[a]From analysis of cuttings from the 115 deep corehole #10 at SWSA 7 (Rothschild et al. 1984b; Davis et al. 1984).

[b]Based upon sieve analysis of < 2 mm fraction.

Table 3.3. Bedrock physical and chemical properties

		Units	Maryville Limestone[a]	Nolichucky Shale[b]
Kds	Am^{241}	L/kg	27600	28400
	Sr^{85}	L/kg	63.1	38
	Cs^{134}	L/kg	27400	26200
	Co^{58}	L/kg	2720	2197
	I^{125}	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
pH		-log[H⁺]	7.6	7.7
Bulk Density		g/cc	2.63	NA
Total Porosity[c]		%	1.8	NA

[a]Mean of 23 Maryville rock cutting samples (<2mm) from the 115-ft deep Well No. 10 in SWSA 7 (Davis et al. 1984)

[b]Mean of 3 Nolichucky rock cuttings samples from the 25-ft deep Well No. 13 at SWSA 7 (Rothschild et al. 1984b)

[c]Mean total porosity calculated, where: total porosity = ((1-(bulk density/2.68) x 100)

NA - Not Analyzed

Table 3.4. Saprolite physical and chemical properties

			WAG 6		SWSA 7
		Units	Maryville LS[a]	Nolichucky SH[b]	Maryville LS[c]
Kds	Am^{241}	L/kg	NA	NA	20398
	Sr^{85}	L/kg	NA	NA	202
	Cs^{134}	L/kg	NA	NA	49766
	Co^{58}	L/kg	NA	NA	2381
	I^{125}	L/kg	NA	NA	16.8
	Ca+Mg	L/kg	NA	NA	117
Exchangeable Ca		meq/kg	3.8	11.5	93.4
Exchangeable Mg		meq/kg	11.7	50	59.9
Exchangeable Na		meq/kg	2.9	1.2	2.5
Exchangeable Acidity		meq/kg	63.1	33.5	52.3
CEC		meq/kg	81.5	96.2	208
pH		$-\log[H^+]$	5.1	6.1	6.8
$CaCO_3$		%	NA	NA	2.97
Extractable Fe[d]		mg/kg	257.2	331	282
Extractable Mn[d]		mg/kg	1092	2842	623
Organic Matter		%	0.12	0.38	NA
Sand Fraction		%	31	32	366
Silt Fraction		%	32	28	22
Clay Fraction		%	37	40	42
Bulk Density		g/cc	1.59	NA	NA
Total Porosity[e]		%	40.7	NA	NA
Moisture[f]		%	3.9	<1	NA
Rock Fragment		%	70.2	82.1	NA
Liquid Limit			46.9	51.5	
Plastic Limit			33.4	28.4	
Plasticity Index			13.5	23.2	
Flow Index			15.2	9.7	
Shrinkage Limit			26.1	19.8	

[a]Mean of 16 C & Cr-horizon saprolite samples from three soil pits (I, III, and IV of Lietzke and Lee) in WAG 6 (Ammons et al. 1987).

[b]Mean of five C & Cr-horizon saprolite samples from test pit X in WAG 6, (Ammons et al. 1987).

[c]Mean of 12 Maryville saprolite samples from four 25-ft deep boreholes at SWSA 7 (Rothschild et al. 1984a).

[d]Sodium dithionite extractable (CBD).

[e]Total porosity calculated, where: total porosity = ((1-(bulk density/2.68) x 100)).

[f]Corrected for rock fragments.

NA - Not Analyzed.
LS - Limestone.
SH - Shale.

Table 3.5. Soil physical and chemical properties

		Units	WAG 6 Maryville Soils[a]	WAG 6 Maryville Soils[b]	WAG 6 Nolichucky Soils[c]	SWSA 7 Maryville Soils[d]	SWSA 7 Nolichucky Soils[e]
Kds	Am^{241}	L/kg	5670	NA	NA	1213	2500
	Sr^{85}	L/kg	494*	NA	NA	144	50.4
	Cs^{134}	L/kg	64100*	NA	NA	561	949
	Co^{58}	L/kg	782*	NA	NA	80.7	84.5
	I^{125}	L/kg	11.7	NA	NA	16.1	4.0
	Ca+Mg	L/kg	NA	NA	NA	112	35.4
Exchangeable Ca		meq/kg	20	59.7	14.7	42	17.5
Exchangeable Mg		meq/kg	31	5.2	7.4	19	5.2
Exchangeable Na		meq/kg	1	0.5	0	0.1	0
Exchangeable Acidity		meq/kg	154	37.6	37	116	92
CEC		meq/kg	210	103	86.5	177	115
Extractable Fe[f]		mg/kg	NA	2065	2414	NA	NA
Extractable Mn[f]		mg/kg	NA	434	412	NA	NA
pH		$-\log[H^+]$	4.4	5.6	4.9	4.9	5.3
Organic Matter		%	0.37	1.58	0.57	3.17	4.24
Sand Fraction		%	36	21	19	40	24
Silt Fraction		%	22	53	52	31	23
Clay Fraction		%	42	26	29	29	53
Bulk Density		g/cc	1.34	1.45	1.44	NA	NA
Total Porosity[g]		%	50	45.9	46.2	NA	NA
Moisture[h]		%	NA	12.5	2.8	NA	NA
Rock Fragments		%	NA	21.5	17.9	NA	NA
Liquid Limit			NA	33.6	39.5	NA	NA
Plastic Limit			NA	25.2	23.9	NA	NA
Plasticity Index			NA	8.4	15.6	NA	NA
Flow Index			NA	9.2	7.7	NA	NA
Shrinkage Limit			NA	23.0	18.7	NA	NA

[a]Mean of 24 [Maryville material] soil samples from three 6.7-ft deep trenches (334, 338, 342) in SWSA 6 (Davis et al. 1984).

[b]Mean of seven [Maryville material] A & B horizon soil samples from three soil pits (Pits I, III, and IV of Lietzke and Lee, 1986) in SWSA 6 (Ammons et al. 1987).

[c]Mean of 7 [Nolichucky and ancient alluvium material] A & B horizon soil samples from two soil pits (Pits IX and X of Leitzke and Lee, 1986) in SWSA 6 (Ammons et al. 1987).

[d]Mean of 12 B horizon soil samples reported from SWSA 7 (Rothschild et al. 1984a).

[e]Mean of 2 B horizon soil samples reported from SWSA 7 (Rothschild et al. 1984a).

[f]Sodium dithionite extractable (CBD).

[g]Mean total porosity calculated where Total Porosity = ((1-(bulk density/2.68) x 100)).

NA - Not Analyzed.

* - Davis et al. (1984) Kds reported for Cs-137, Co-60, and Sr-90.

Table 3.6. Summary of existing wells and piezometers identified at WAG 6

Date installed	No. of wells installed	Description	No. of wells still existing	Identification of wells still existing	Source
1954	28	6 5/8" perforated, corrugated steel pipe to depths of 20'; open from surface to TD.	4	284, 295, 305, 310	Webster 1981
1956	4	5 1/2" steel cased open hole completion wells to 126'; generally 80' open hole interval.	3	107, 108, 109	Webster 1981
1964-76	50	6 5/8" perforated, corrugated steel pipe to depths of 24'; open from surface to TD.	9	317, 318, 343, 345, 351, 356, 362, 363, 365	Lomenick & Wyrick 1965
1976	12	4" PVC Tracer test piezometers to depths up to 47'.	5	TR-03, -04, -05, -07, -09	Tamura 1980
1977-78	22	3" PVC to depths up to 69'.	17	367 through 71, 374 through 83, 385 through 86.	Webster 1981
1975-84?	30	2" and 3" PVC or SS installed by ORNL.	25	389–405, 403A, 404A, 405A, S-8, S-11, EXP-4, EXP-5	Solomon et al. 1988; Spalding 1990
1982-84	63	3" and 6" PVC piezometers to depths of 240' associated with ETF characterization.	26[a]	ETF-1 through -18, -20, -22, -27, -29, -36, -39, -40	Davis et al. 1984
1983	28	3" PVC French Drain piezometers.	20	0+54, 1+33, 1+53, 1+85, 2+02, 2+26, 2+51, 3+03, 3+52, 3+76, 4+01, 4+27, 4+58, 4+77, 5+04, 5+77, 5+50, 5+77, 6+16, 7+81	Davis and Stansfield 1984
1986	13	3" PVC piezometers associated with TARA characterization study.	13	TARA-1 through -13	Davis et al. 1987
1986	25	2" PVC (and two SS) RAP piezometers.	25	636 through 655, 739 through 741	Mortimore 1987

Table 3.6. (continued)

Date installed	No. of wells installed	Description	No. of wells still existing	Identification of wells still existing	Source
1987	30	2" and 4" SS RCRA Groundwater Quality Monitoring Wells.	30	745, 831 through 860	Mortimore and Ebers 1988
1987	6	3" PVC Tumulus I Pad monitoring wells.	5	1036 through 1040	Morrissey 1990
1988	10	2" PVC IWMF area piezometers, 5 to 15' deep.	10	T-1, -5, -7, -10, -17, -18, -20, -22, -27, -36	Morrissey 1990
1986-88	12	4" and 6" carbon steel casings with 20' open hole completions; installed as four 3-well clusters to depths of 400'.	12	HHMS-4A, -4B, -4C, -5A, -5B, -5C, -7A, -7B, -7C, -8A, -8B, -8C	Dreier and Toran 1989
1989-90	22	2" and 4" WAG 6 RFI RCRA-quality monitoring wells.	22	1225 through 1245, 1234A[b]	BNI 1990c; TM-06-08A
?	600?	Intra- and intertrench piezometers.	72	(see Appendix A)	various
	955		226		

[a]A high number of ETF wells still exist, but only 26 were identified in the field.
[b]Well 1234A has subsequently been redesignated # 1249 by ORNL.

SS - stainless steel screen and riser.
PVC - polyvinyl chloride screen and riser.

Table 3.7. Summary of vertical gradients for WAG 6 wells pairs

Well pair	Position	Head difference (ft)	Gradient direction	Vertical gradient (ft/ft)
745*/833	D	1.24[a]	UP[a]	0.044[a]
831/832*	R	0.87[a]	UP[a]	0.094[a]
838/839*	H/D	0.10[a]	DOWN[a]	0.003[a]
841*/842	H/D	3.78[a]	DOWN[a]	0.120[a]
843/844*	H	6.28[a]	DOWN[a]	0.230[a]
855/856*	R/H	0.49[a]	UP[a]	0.008[a]
857/858[a]	R	0.84[a]	DOWN[a]	0.023[a]
859/860[a]	H/R	0.91[a]	UP[a]	0.028[a]
840/1249*	H/D	2.8[b]	UP[b]	0.065[b]
1249/1234*	H/D	7.35[b]	UP[b]	0.098[b]
1237/1238*	R/H	4.44[b]	DOWN[b]	0.049[b]
ETF-14*/ETF-15	R	0.82[c]	DOWN[c]	0.017[c]
ETF-14/ETF-16*	R	1.14[c]	DOWN[c]	0.007[c]
HHMS-4B*/HHMS-4C	R	0.93[c]	DOWN[c]	0.005[c]
HHMS-5B*/HHMS-5C	D	4.57[c]	UP[c]	0.029[c]
HHMS-7B*/HHMS-7C	H	9.04[c]	DOWN[c]	0.005[c]
HHMS-7A*/HHMS-7B	H	2.34[c]	DOWN[c]	0.022[c]
HHMS-8B*/HHMS-8C	H	2.44[c]	DOWN[c]	0.020[c]

Indicates deep well of pair (e.g., 745)

[a]Based upon average of water level measurements recorded during quarterly sampling and other sampling performed from 6/88 through 6/90.

[b]Based upon average of water level measurements recorded during 5/90 and 6/90 sampling events.

[c]Based upon water level measurements collected 2/21/90.

R = Well pair located in apparent recharge zone relative to topographic and potentiometric setting.

D = Well pair located in apparent groundwater discharge zone.

H = Well pair situated in hillslope position reflecting transition between inferred groundwater recharge and discharge zone.

Table 3.8. Historical sources of WAG 6 groundwater geochemistry data

Wells	Data source
HHMS-4A, -4B, -4C, -5A, -5B, -5C, -6A, -6B, -6C, -7A	Dreier and Toran 1989, ORNL RAP data base
ETF -1, -2, -3, -4, -5, -6, -7, -8, -9, -10, -11, -12	Davis et al. 1987
T -1, -7, -10, -17, -18, -20, -36	Morrissey 1990
TARA -3, -4, -6, -8, -9, -10, -11, -12	Davis et al. 1989
367, 646	Davis et al. 1989
S-11	Soloman et al. 1988

Table 3.9. Summary of WAG 6 aquifer geochemistry

Well no.	Water type	Screen depth (ft)	Screen elevation (ft)	Monitored zone
All others[a]	Calcium-Bicarbonate	<100	>665	1,2,3,4,5,6
1234	Sodium-Carbonate/Bicarbonate	128-148	624-644	5
1236	Sodium-Carbonate/Bicarbonate	141-161	641-661	2
1239	Sodium-Carbonate/Bicarbonate	135-155	628-648	5
HHMS-4A	Sodium-Carbonate/Bicarbonate	380-400	390-410	5
HHMS-4B	Sodium-Carbonate/Bicarbonate	174-215	573-614	2
HHMS-5B	Sodium-Carbonate/Bicarbonate	196-219	547-570	2
HHMS-6B	Sodium-Carbonate/Bicarbonate	275-295	467-487	2
HHMS-6C	Sodium-Carbonate/Bicarbonate	158-178	584-604	2
HHMS-7A	Sodium-Carbonate/Bicarbonate	380-400	409-429	7
ETF-13	Sodium-Carbonate/Bicarbonate	241-251	559-569	5
HHMS-5A	Sodium-Chloride	380-400	367-387	2
HHMS-6A	Sodium-Chloride	380-400	364-384	2

Monitored Zone Key
1 Nolichucky Regolith
2 Nolichucky Bedrock
3 Nolichucky Regolith/Bedrock
4 Maryville Regolith
5 Maryville Bedrock
6 Maryville Regolith/Bedrock
7 Rogersville Bedrock

[a]This includes wells:
1225, 1227, 1228, 1229, 1231, 1233, 1237, 1238, 1240, 1241, 1242, 1243, 1244, 1245, 1249, 745, 831, 832, 833, 838, 839, 840, 841,, 842, 843, 844, 845, 848, 849, 850, 851, 852, 853, 854, 855, 856, 857, 859, 860, HHMS-4C, HHMS-5C, ETF-1 thru ETF-12, ETF-14, ETF-15, T-36, T-20, T-18, T-17, T-10, T-7, T-1, TARA-3, TARA-4, TARA-6, TARA-8, TARA-9, TARA-10, TARA-11, TARA-12, 367, 646, 5-11.

	Unit	Davis et al. 1984	Ammons et al. 1987	Tamura et al. 1980	Law 1983	Sledz and Huff 1981	Smith and Vaughn 1985 a, b	Davis et al. 1987	Moore 1988
I. SOILS									
Infiltration Rate (K)	cm/sec	3.5E-5 to 6.0E-6 b Geom. Mean = 1.56E-5	—	—	—	—	—	—	1.10E-2 to 2.31(
Total Porosity	—	.30 - .60[j]	.42 - .492[a]	—	—	—	—	—	—
Effective Porosity (ne)	—	0.5	—	—	—	—	—	—	
II. SAPROLITE									
Hydraulic Conductivity (K)	cm/sec	2.0E-5	—	—	—	—	—	3.53E-4 to 3.53E-6 5.3E-5 (for N/2 or WAG-6)[l] 2.1E-4 (for near W.O.L)[l]	4.76E-6
Total Porosity	—	.30 - .60	0.2 - 0.54[a]	—	—	—	—	—	—
Effective Porosity (ne)	—	<.05	—	0.02 - 0.03[h]	—	—	—	—	—
Average Linear Velocity	m/day	—	—	0.4 - 0.6[h]	—	—	—	—	—
Transmissivity (T)	m^2/Day	—	—	—	—	—	—	—	—
III. BEDROCK									
Hydraulic Conductivity (K)	cm/sec	2.08E-4 c 6.31E-5 d	—	—	—	—	—	—	4.74E-5 to 5.1E
Transmissivity (T)	m^2/Day	1.8 to 6.28[e] Mean = 3.65 0.46 to 2.02 (Matrix Only)	—	—	0.32[p]	—	1.35 Omr Geom Mean[j] 3.0 Omr (along Strike)[j] 0.6 Omr (to Strike)[j] 3.11 Onl (along Strike)[k] 1.03 Onl (to Strike)[k]	—	—
Storativity (S)	—	3.34E-4 to 3.0E-2[e] (Mean = 1.0E-2)	—	—	.003[p]	—	5.0E-3 (Geom. Mean)[j] 1.0E-2 to 1.0E-3 1.1E-3 (Genm. Mean)[k]	—	1E-2 to 1E-6 .0025[o]
Effective Porosity (ne)	—	0.007 Fractures[c] 0.10 Bulk Matrix[c] 0.03[f]	—	—	.002[p]	.0007[f]	—	—	.0005 to .0000 .0025[o]
Anisotropy	Kx:Ky	—	—	—	—	—	5:1[j] 3:1[k]	—	2.3:1
Dispersivity	meters	—	—	—	10[p]	—	—	—	—
Average Linear Velocity	m/day	—	—	—	—	—	—	—	—
Intrinsic Permeability	m^2	1.4E-12 to 2.8E-12 (Fractures) 1.0E-14 to 2E-14 (Bulk Matrix)	—	—	—	—	—	—	—
Aquifer Thickness	m	67[e]	—	—	—	—	24.76[g]	—	—
	ft	220[e]	—	—	—	—	81[g]	—	—

a Based on water retention data from seven A&B horizon soil samples from test pits within SWSA-6.
b From undisturbed soil samples at the ETF site.
c Derived from tracer test in Maryville bedrock at the ETF site within WAG 6.
d Mean K from slug tests performed in Maryville bedrock in ETF site wells, WAG 6.
e From two pump tests performed in shallow Maryville bedrock at ETF site using Theis solution.
f Determined using ETF site tracer test velocities (0.17 m/d) and mean slug test K (6.31E-5 cm/sec) and gradient = 0.094.
g Determined from pump test data at ETF site using Winterspoon-Gringarted solution.
h Determined from tracer test performed in southern portion of WAG 6.
i Based on water retention data from seven C-horizon soil analyses from seven test pits in WAG 6.
j From ETF pump test data using non-radial solution for Nolichucky bedrock.
k From Y-12 Nolichucky pump test data using non-radial solution.
l K values used in modelling as original K = 2.1E-4 did not work (dewatered the shallow aquifer).
m Maryville bedrock pump test data from Webster & Bradley for SWSA-5 at depths of 150-200' and 44-100' (
n Derived using ne=.03, K=1.58E-4 cm/sec, gradient=0.555.

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Table 3.10. Summary of aquifer hydraulic properties.

	Poreda, Cerling, and Solomon 1988	Clapp 1990	Luxmoore, Spalding, and Munro 1981	Tucci 1984	Webster and Bradley 1988	Connell and Chapman-Bailey 1989	WAG 6 Draft Perform. Assess Modeling 1990	Rothschild et al. 1984a	All Compiled WAG 6 Slug Tests
3	—	1.8E-3 to 5.1E-4y 9.4E-4 (Geom. Mean)	1.97E-4 to 3.47E-4	—	—	—	3.49E-3 to 5.65E-5 (M)u 3.49E-3 to 2.29E-7 (U)v	1.67E-3 to 3.5E-5t	—
	—	—	—	—	—	—	0.39 to 0.476	—	—
	—	—	—	—	—	—	0.7 (CALC)w	—	—
	—	—	—	3.53E-6 to 3.53E-4	1.02E-6 to 2.36E-3 1.58E-4 (Geom. Mean)	8.47E-5 to 2.3E-3(Cnl) 1.69E-3 to 2.29E-7(Cmr)	—	2.57E-5s	2.01E-4 (Overall Geom.Mean) 7.62E-5 to 9.61E-6 (Cmr) 3.05E-5 (Geom. Mean Cmr) 3.71E-3 to 3.88E-5 (Cnl) 3.22E-4 (Geom. Mean Cnl)
	—	—	—	—	—	—	—	—	—
	—	—	—	—	0.03	—	—	—	—
	—	—	—	—	2.5E-1n	—	—	—	—
	—	—	—	2.43 to 4.87 (8-16 ft²/day)	1.18E-1 to 6.33	—	—	—	—
	3.33E-4 to 5.3E-4 (5 wells)x 1.8E-3 to 9.7E-3 (Well 388)x	—	—	3.62E-6 to 2.3E-3	—	5.65E-5 to 3.06E-4 (Cnl) 8.01E-5 to 5.3E-8 (Cmr)	1.24E-4	—	3.01E-5 (Overall Geom.Mean) 1.85E-3 to 1.70E-8 (Cmr) 4.97E-5 (Overall Geom.Mean) 5.01E-4 to 4.20E-6 (Cnl) 8.13E-5 (Cnl Geom. Mean)
	—	—	—	1.8E-2 to 1.39E-1	5.3E-8 to 6.7E-5	—	4.8E-1 m²/day	—	—
	—	—	—	—	—	—	0.001	—	—
	—	—	—	—	—	—	.02	—	—
	—	—	—	3:1 to 20:1	—	—	3:1	—	—
	—	—	—	—	—	—	3	—	—
	—	—	—	—	—	—	<9.16E-2	—	—
	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—

o Assumes at depth, ne = 5.
p From tracer tests performed in Conasauga Rocks in Bear Creek Valley.
q From pump tests performed in Conasauga Rocks in Bear Creek Valley.
r From outcrop measurements.
s Based on slug test data from SWSA-7 wells in similar geologic materials.
ctively. t Based on soils developed on similar parent materials at SWSA-7; results of four pump-in tests in shallow augured holes <.21' deep.

u Range of K values initially tried based upon measured values for WAG 6.
v Range of K values altered than utilized in modelling to agree with Moore stormflow concept.
w Model results.
x Based on He³/H³ age dating data.
y Based on infiltration tests in three 402 ft² plots within WAG 6.

Other: (M) Range of field measure values; (U) Range of values used in modelling; Cmr Maryville Fm; Cnl Nolichucky Fm

Table 3.11. WAG 6 regolith hydraulic conductivity distribution

	K (cm/sec)				
	Maximum	Minimum	Mean	Geometric mean	Number of analyses
Overall Regolith	3.7E-3	9.6E-6	7.5E-4	2.0E-4	25
Maryville Regolith	7.6E-5	9.6E-6	3.9E-5	3.1E-5	5
Nolichucky Regolith	3.7E-3	3.7E-5	9.3E-4	3.2E-4	20

Hydraulic conductivities used for each well in Appendix 3A.

Note: 1 cm/sec = 2835 ft/d.Table 3.11 and 12

Table 3.12. WAG 6 bedrock hydraulic conductivity distribution[a]

Unit	Depth	K (cm/sec) Maximum	Minimum	Mean	Geometric mean	Number of analyses
All Bedrock[b]		1.9E-3	1.9E-9	1.0E-4	3.1E-5	68
Maryville LS	(Overall)	1.9E-3	1.7E-8	1.5E-4	4.9E-5	45
	Upper 50'	1.9E-3	1.5E-6	1.8E-3	4.8E-5	35
	51-100'	2.2E-4	1.5E-6	6.1E-5	2.9E-5	14
	101-200'	4.9E-5	1.7E-3	2.1E-5	2.1E-6	4
	≥ 200'	2.9E-5	7.6E-7	1.6E-5	7.3E-6	3
Nolichucky Shale	(Overall)	5.0E-4	4.2E-6	1.5E-4	8.1E-5	19
	Upper 50'	5.0E-4	2.4E-5	1.8E-4	1.3E-4	15
	51-100'	2.1E-4	2.4E-5	1.8E-4	9.7E-5	4
	101-200'	6.6E-5	4.7E-6	3.5E-5	2.2E-6	3
	≥ 200'	4.7E-(	4.2E-6	4.5E-6	4.4E-6	2
Rogersville Shale[b]	Overall	2.3E-8	1.9E-9	1.3E-8	6.6E-9	2

[a]From WAG 6 slug test data only except where noted; does not include well screens straddling regolith and bedrock.
[b]Includes HHMS well cluster slow recovery data.

Note: 1 cm/sec = 2935 ft/d

REGOLITH

FLOW LINE[b]	WELLS USED TO DETERMINE GEOMETRIC MEAN CONDUCTIVITY	GEOM. MEAN HYDRAULIC CONDUCTIVITY (cm/sec)	HYDRAULIC GRADIENT[c]	EFFECTIVE POROSITY[d]	AVG. LINEAR VELOCITY (m/day)	AVG LINEA VELOC (m/d
A	740,741,857,859; T-10, -22, -27, -36	1.36E-4	0.0535	.03	0.21	0.2
B_1	854; ETF-17, -20, -22, -25, -36, -39, -40	5.3E-5	0.0714	.03	0.10	
B_2	851, 852, 853, 854	1.8E-4	0.0464	.03	0.24	0.2
B_3	853, 854	1.9E-4	0.0625	.03	0.34	
C_1	849, 853	1.1E-4	0.0482	.03	0.16	
C_2	849,1036, 1037, 1038, 1039, 1040	2.0E-3	0.0397	.03	2.28	0.8
C_3	849, 1036,1037	1.4E-3	0.0403	.03	1.62	
D	(f)	—	—	—	—	(f)
E_1	(f)	—	—	—	—	
E_2	(f)	—	—	—	—	(f)
E_3	(f)	—	—	—	—	
F	(f)	—	—	—	—	(f)
G	(f)	—	—	—	—	(f)
H_1	(f)	—	—	—	—	(f)
H_2	(f)	—	—	—	—	
I_1	382, 385, 836	1.6E-4	0.0360	.03	0.16	0.2
1_2	382, 835, 836	1.6E-4	0.0676	.03	0.31	
1_3	382, 835, 838	1.4E-4	0.0714	.03	0.29	
J_1	838,845, 849	2.0E-4	0.0541	.03	0.31	0.3
J_2	(f)					
	MEAN	2.19E-4	0.0537	.03	0.33	-
		OVERALL GEOMETRIC MEAN	MEAN GRADIENT	MEAN EFFECT. POROSITY	OVERALL GEOM. MEAN LINEAR VELOC. (m/d)	

[a] *Upper 50 ft of saturated bedrock only.*
[b] *Labels correspond to flow lines shown on Figure 3.49.*
[c] *Average hydraulic gradient along the length of flow line shown.*
[d] *Effective porosity based upon aquifer testing results (Tamura et al. 1980).*
[e] *Effective porosity based upon aquifer testing results at ETF area (Davis et al. 1984).*
[f] *Groundwater flow only occurs in bedrock in the area.*

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Table 3.13. WAG 6 average linear velocities by flow line.

BEDROCK[a]

WELLS USED TO DETERMINE GEOMETRIC MEAN CONDUCTIVITY	GEOM. MEAN HYDRAULIC CONDUCTIVITY (cm/sec)	HYDRAULIC GRADIENT[c]	EFFECTIVE POROSITY[e]	AVG. LINEAR VELOCITY (m/day)	AVG. LINEAR VELOCITY (m/day)	FLOW LINE[b]
379, 380, 739, 858, 860	8.6E-5	0.0535	.03	0.13	0.13	A
855, 856, ETF-1 through -9, -11, -12, -15	1.2E-4	0.0714	.03	0.25		B_1
642, 745, 833, 654, 851, 852, 854	1.6E-4	0.0464	.035	0.22	0.26	B_2
65, 54, 853, 8545	1.9E-4	0.0625	.03	0.34		B_3
642, 849, 851, 853, 854	9.4E-5	0.0482	.03	0.10		C_1
642, 654, 381, 849	9.0E-5	0.0397	.03	0.10	0.10	C_2
381, 642, 654, 849	9.0E-5	0.0403	.03	0.10		C_3
637, 638, 639, 832	2.3E-5	0.1000	.03	0.07	0.07	D
385, 640	4.1E-5	0.0811	.03	0.10		E_1
640, 655	5.3E-5	0.0769	.03	0.12	0.10	E_2
637, 638, 639, 832, 846	2.1E-5	0.1429	.03	.09		E_3
843, 844, 374	1.2E-5	0.1096	.03	0.34	0.04	F
368, 840, 841, 842	1.4E-4	0.1045	.03	0.42	0.42	G
371, 644, 839, 840, 845	1.6E-4	0.0769	.03	0.34	0.20	H_1
644, 845	8.2E-5	0.0513	.03	0.12		H_2
384, 382, 653	9.5E-5	0.0360	.03	0.10		I_1
653, HHMS-4C, HHMS-5C	1.6E-4	0.0676	.03	0.31	0.18	I_2
381, 383, 652, 839	8.7E-5	0.0714	.03	0.18		I_3
371, 381, 644, 839, HHMS-4C	1.0E-4	0.0541	.03	0.16	0.28	J_1
381, 381, 644, 839, HHMS-4C	1.0E-4	0.1707	.03	0.49		J_2
MEAN	7.81E-5	0.07953	.03	0.15		
	OVERALL GEOMETRIC MEAN	MEAN GRADIENT	MEAN EFFECT. POROSITY	OVERALL GEOM. MEAN LINEAR VELOC. (m/d)		

Table 3.14. Statistics of flows at the USGS gaging stations in WOC basin through 1981

USGS gaging station number[a]	Station number	Drainage area (ft^2)	Tape of gage	Periods(s) of record	Discharge (cfs)		
					Mean	Max.	Min.
035650	2	2.08	Water stage recorder	1950-55	3.9	616	0.7
035370	3	3.62	Water stage recorder and Cipolletti weir	1950-53 1955-64 1978-81	9.6	642	.9
035375	4	1.48	Water stage recorder and v-notch sharp-crested weir	1955-64 1977-80	2.5	242	0
035380	5	6.01	Water stage recorder	1953-55 1960-64 1977-79	13.5	669	0

Source: Webster and Bradley. 1988. *Hydrology of the Melton Valley Radioactive Waste Burial Grounds at Oak Ridge National Laboratory*, USGS Open-File Report 87-686, Knoxville, Tennessee.

Mean discharge for stations 3, 4, and 5 includes 3.5 cfs imported water.

[a]Locations shown on Fig. 3.5.1.

Table 3.15. Monthly flow statistics of Clinch River at Melton Hill Dam (Tailwater), Water Year 1988-1989

Month	Mean (cfs)	Maximum (cfs)	Minimum (cfs)
October 1988	1,922	5,140	400
November 1988	1,363	5,120	0
December 1988	1,874	4,740	400
January 1989	6,727	11,600	2,070
February 1989	7,371	14,200	433
March 1989	3,299	10,500	0
April 1989	1,571	5,650	400
May 1989	5,678	13,000	833
June 1989	9,728	19,100	317
July 1989	6,606	10,900	1,250
August 1989	6,099	8,380	1,270
September 1989	6,736	10,500	0
Annual	4,895	19,100	0

Source: USGS. 1990. *Water Resources Data, Tennessee Water Year 1989*, U.S. Geological Survey, Water-Data Report TN-89-1, 1990.

Table 3.16. Design characteristics of flumes

Drainage	Flume type	Throat size, in.	Channel bank-full capacity, cfs	Operational flow range of flume, cfs
DA	Parshall	18	23.0	0.15-21.0
DB	Parshall	6	288.0	0.05-3.9
FA	Trapezoidal	2	1.3	0.022-0.95
FB	Parshall	6	13.0	0.05-3.5

Table 3.17. Storm rainfall, runoff, and peak flow rates

Date	Storm rainfall (in.)	Storm runoff (in.)				Peak flow (cfs)			
		DA	DB	FA	FB	DA	DB	FA	FB
4/28/90	0.69			0.04				0.11	
5/17/90	0.82	0.26	0.23	0.10	0.17	4.21	2.19	0.42	2.0
5/20/90	0.33				0.04				0.19
5/27/90	0.58	0.17	0.53			2.74	1.9		

Table 3.18. Base flow measurements, RFI surface water sampling[a]

Location	Feb 8-9	April 18-24	May 9	Sept 5-6	Sept 25-27
Subarea A					
WEWB	--	--	--	--	--
SWA1	--	--	--	--	--
Subarea B					
SWB 1	--	0.02	10.7	--	--
Subarea C					
SWC 1	--	--	--	--	--
Subarea DA					
W49TS[b]	0.24	0.11	0.14	0.060	--
WDA1	--	13.2	68.2	--	--
Subarea DB					
WDB1	--	--	10.1	--	--
Subarea FA					
WBAB2	--	--	--	--	3.23
WBAB1	--	--	0.5	--	--
WBAA1	--	--	--	--	--
WFBA1	--	--	--	--	--
Subarea FB					
WFBB3	--	--	--	--	--
WFBB2	--	--	1.3	--	--
W49TN	--	--	--	--	--
WSP1	--	--	25.3	--	1.32
WFBB1	--	--	2.9	--	--

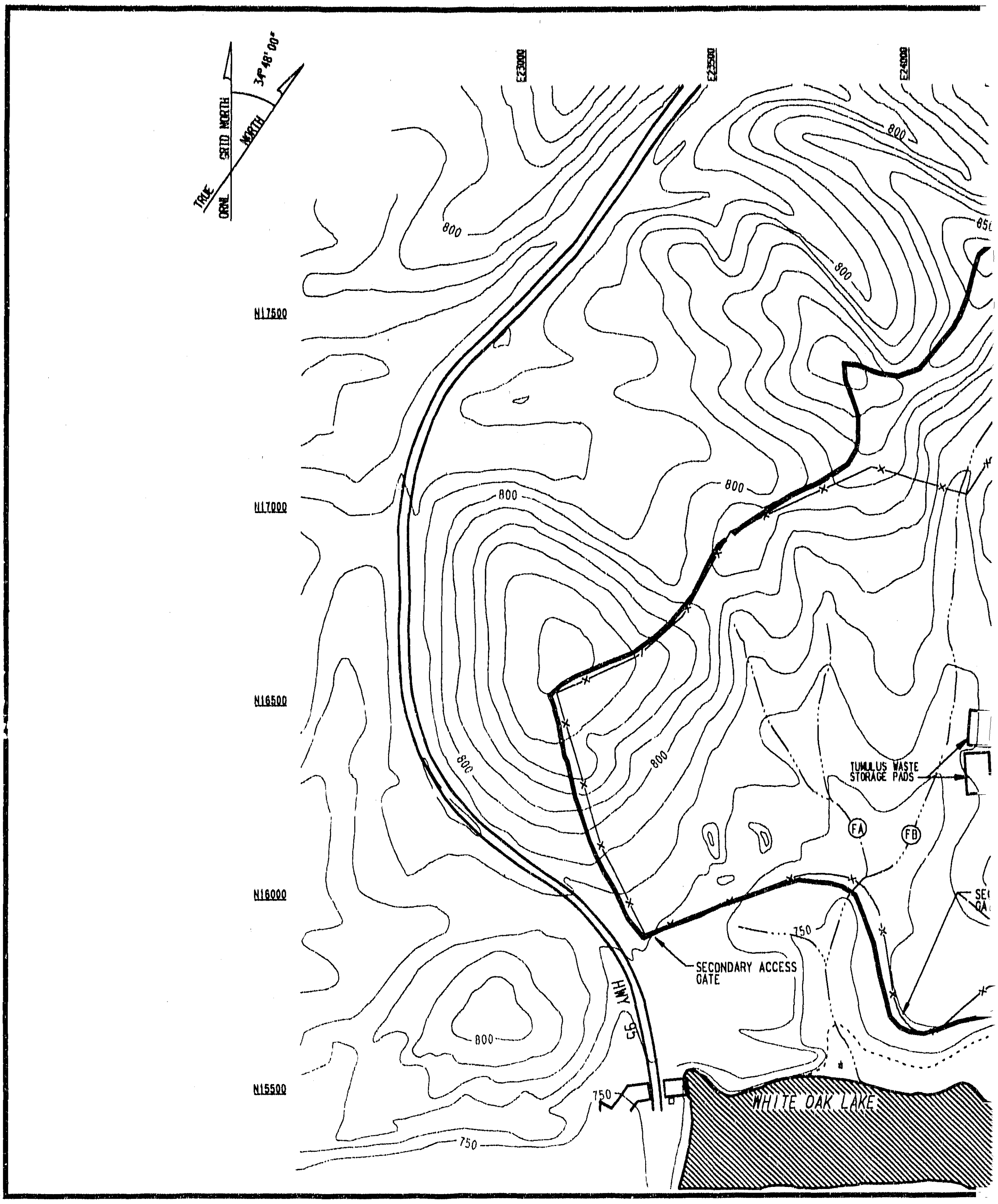
[a]Flow rates are given in liter/second due to low flow rates; 1L/sec = 3.53E-2 cfs.
[b]French Drain outfall.

-- Not measured.

Table 3.19. Modeled yearly water balance values

Year	Precipitation (in.)	Surface runoff (in.)	ET (in.)	Deep percolation (in.)	Surface runoff plus deep percolation (in.)
1981	40.7	5.4	30.0	4.2	6.9
1982	52.6	11.7	30.3	10.9	22.7
1983	41.6	8.8	26.3	6.4	15.2
1984	50.9	14.3	29.3	7.5	21.8
1985	39.8	6.6	29.5	3.4	10.0
1986	38.5	7.2	26.7	5.1	12.3
1987	45.3	9.9	28.3	7.1	17.0
1988	45.1	10.8	28.5	4.8	15.6
1989	64.5	17.3	32.7	14.6	31.9
1990	63.5	19.2	32.4	11.6	30.8

Section 3 Figures



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9-3

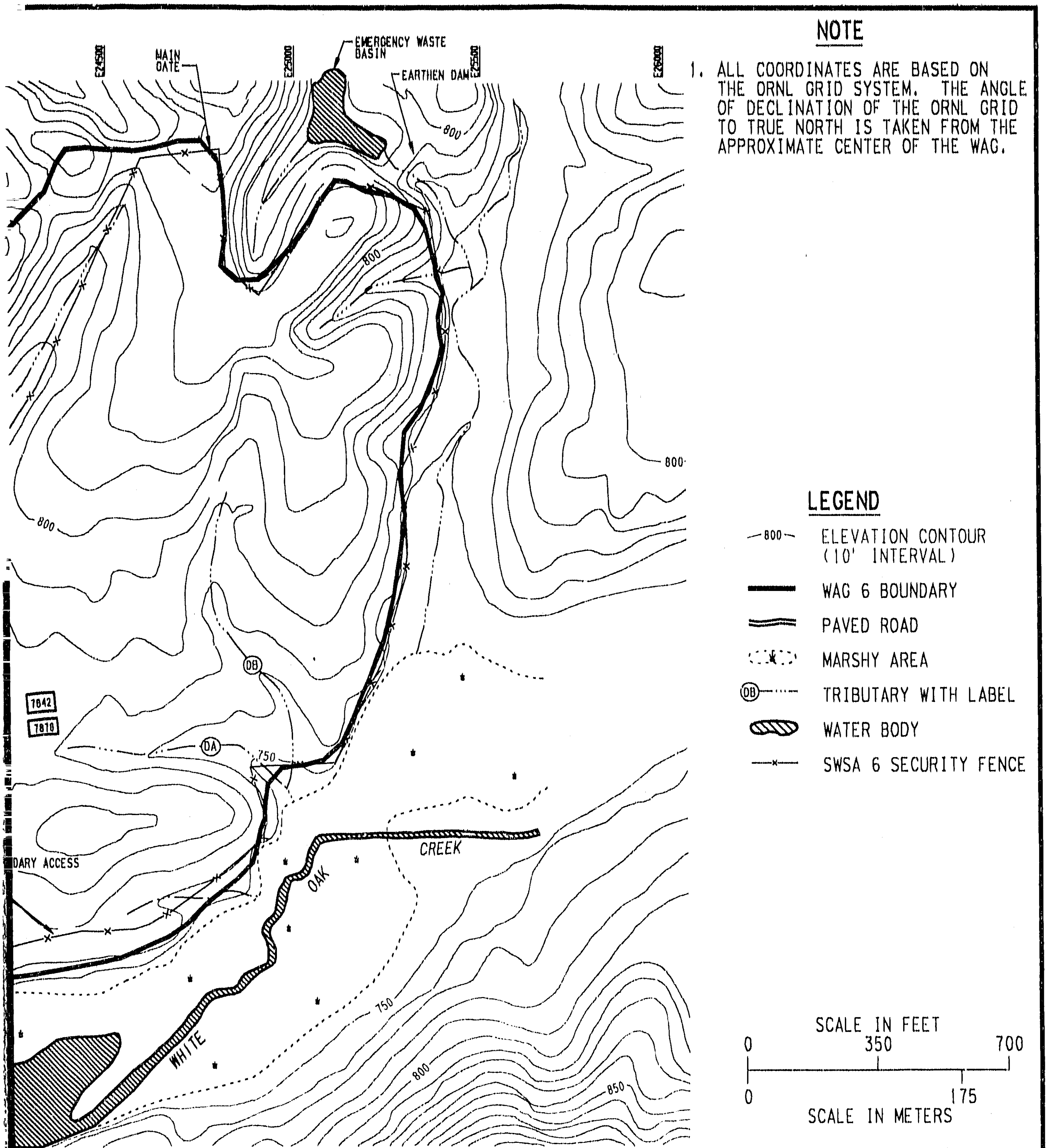


Fig. 3.1. WAG 6 topography.

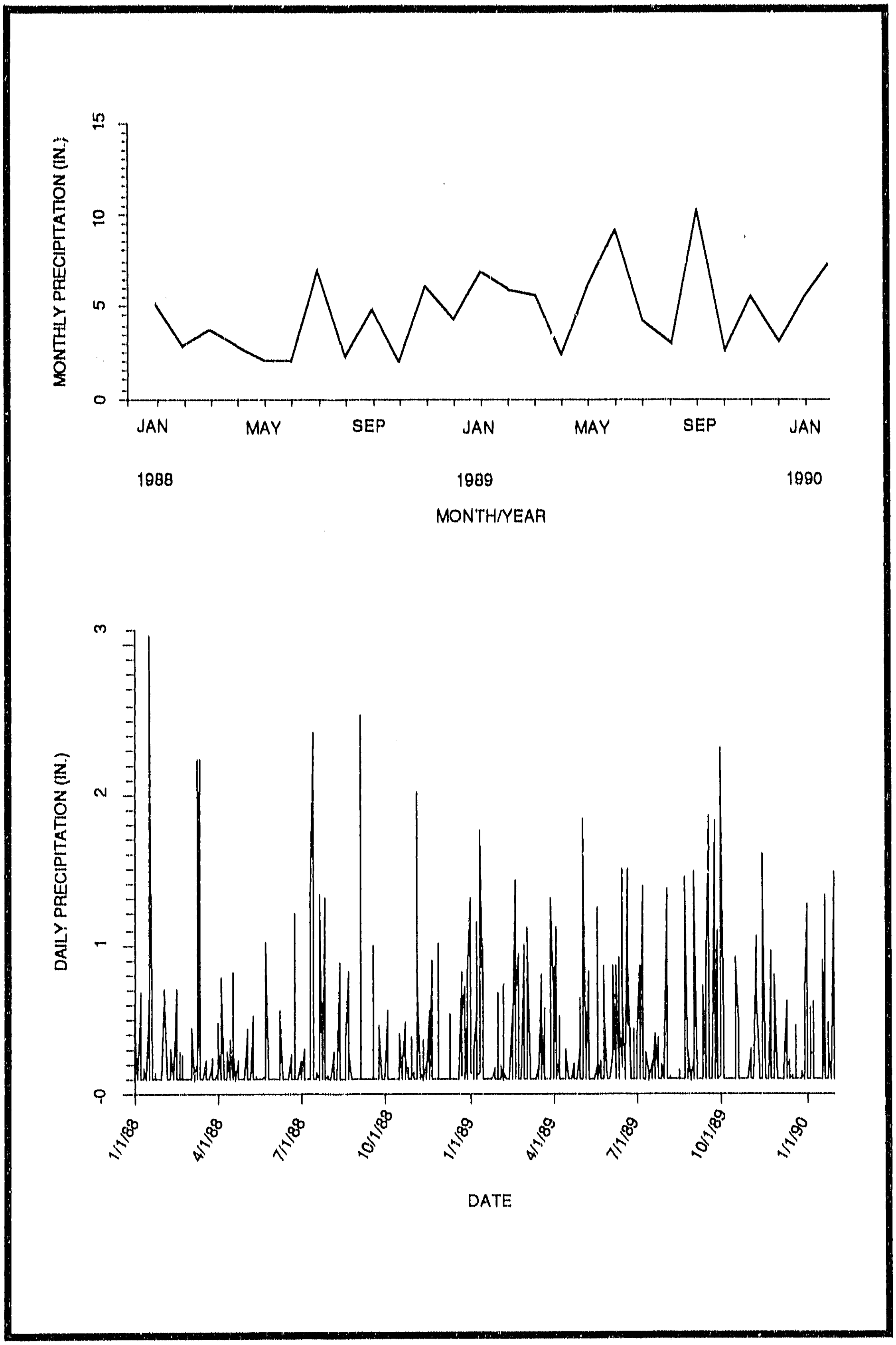


Fig. 3.2. WAG 6 daily and monthly precipitation for period 1/88 - 1/89 (as measured at the ETF station). *Source:* Gregory, S. K. 1990. Personal communication with T. F. Zondlo, CH2M Hill, Oak Ridge, Tennessee.

5.18F4104.172
Adapted from WAG 6 06F141.DGN

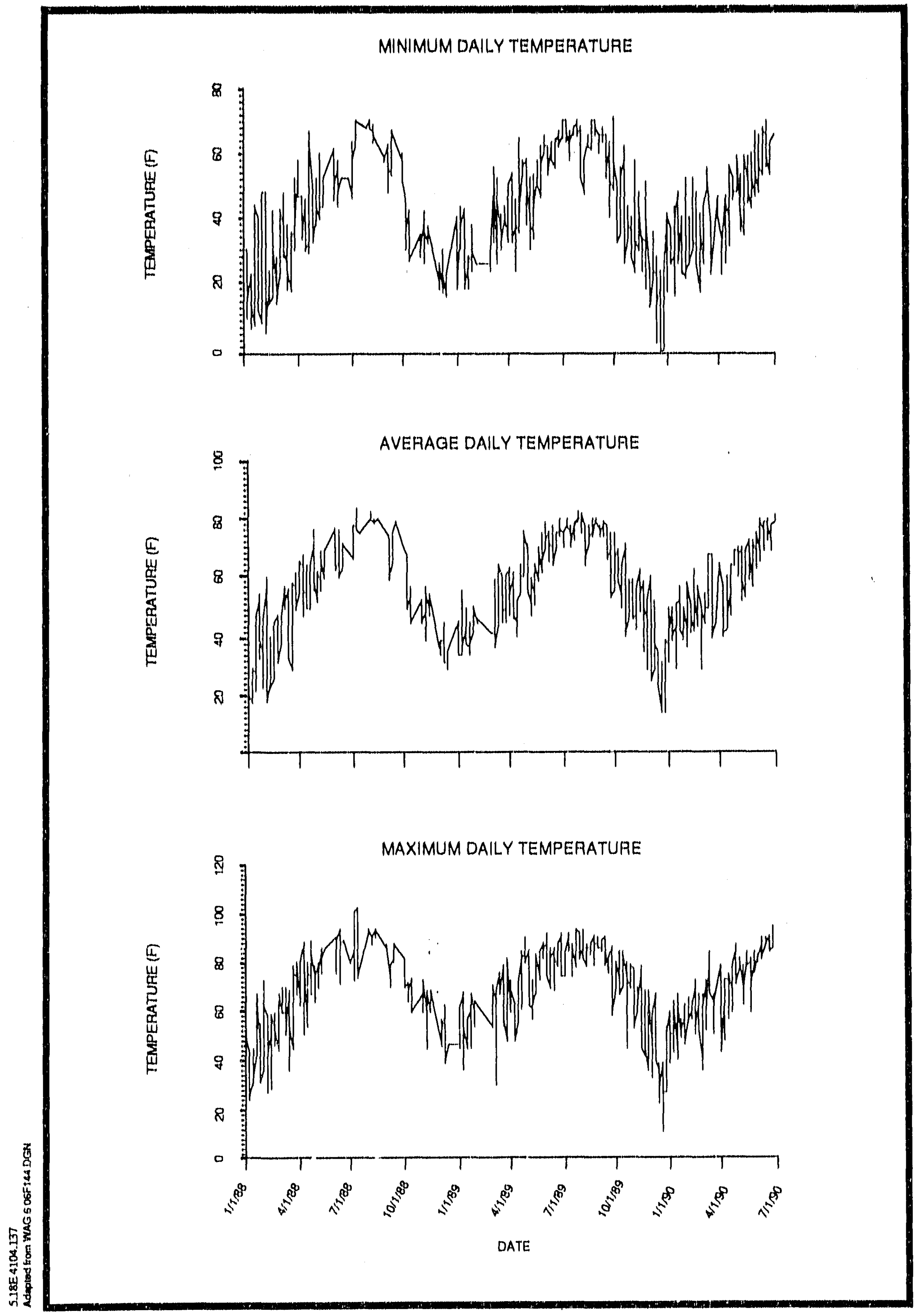


Fig. 3.3 WAG 6 minimum, maximum, and average daily temperature for period 1/88-1/90 (as measured at the ATDD station). *Source:* ATDD (Atmospheric Turbulence and Disturbance Testing) Laboratory. 1990. Personal communication with T. F. Zondlo, CH2M Hill, Oak Ridge, Tennessee.

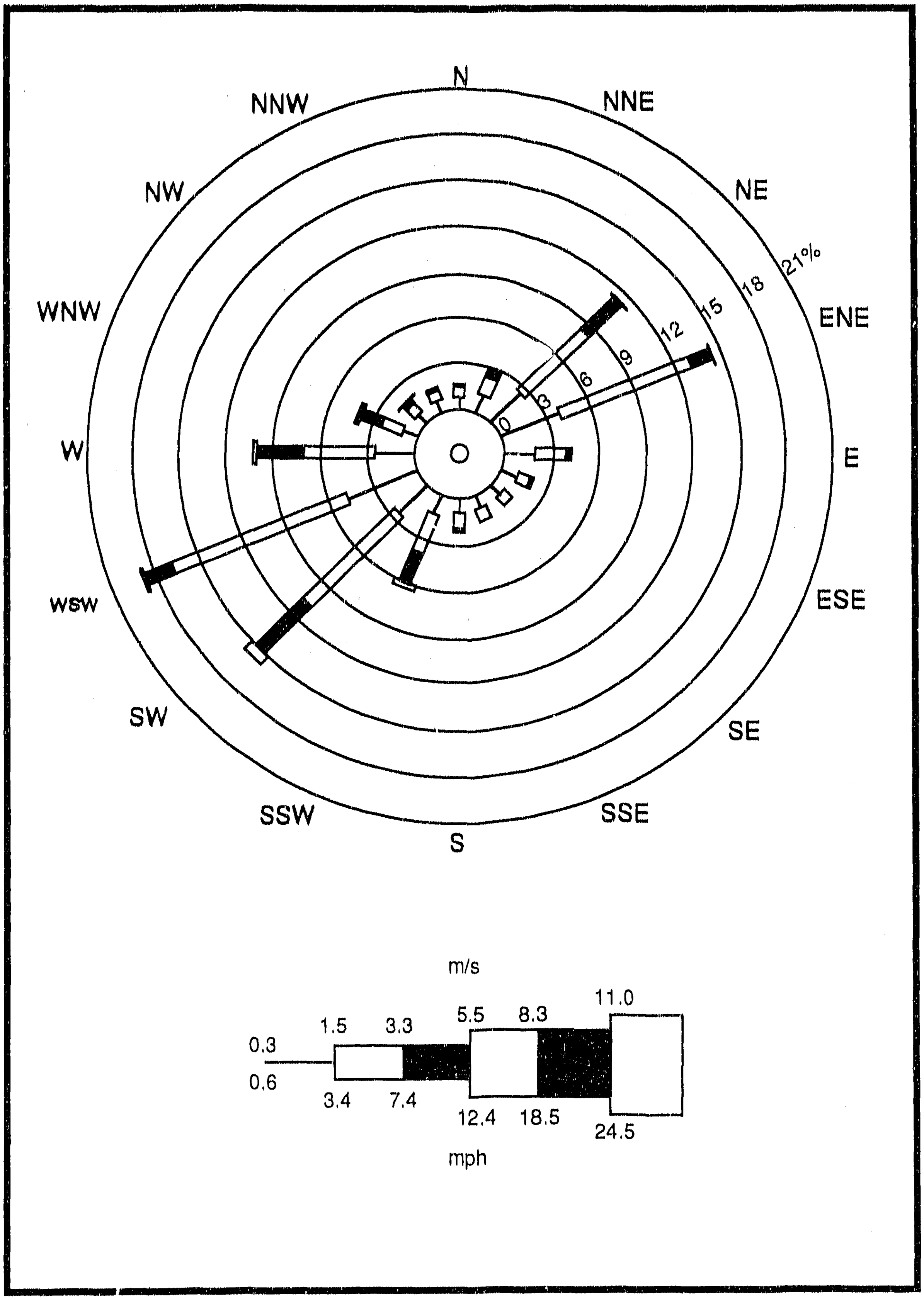


Fig. 3.4. Wind rose for period January 1988 through June 1990, measured at meteorological tower A (at 300-ft level) in Melton Valley. *Source*: ATDD (Atmospheric Turbulence and Disturbance Testing) Laboratory, 1990. Personal communication with T. F. Zondlo, CH2M Hill, Oak Ridge, Tennessee.

5.18 4104.3

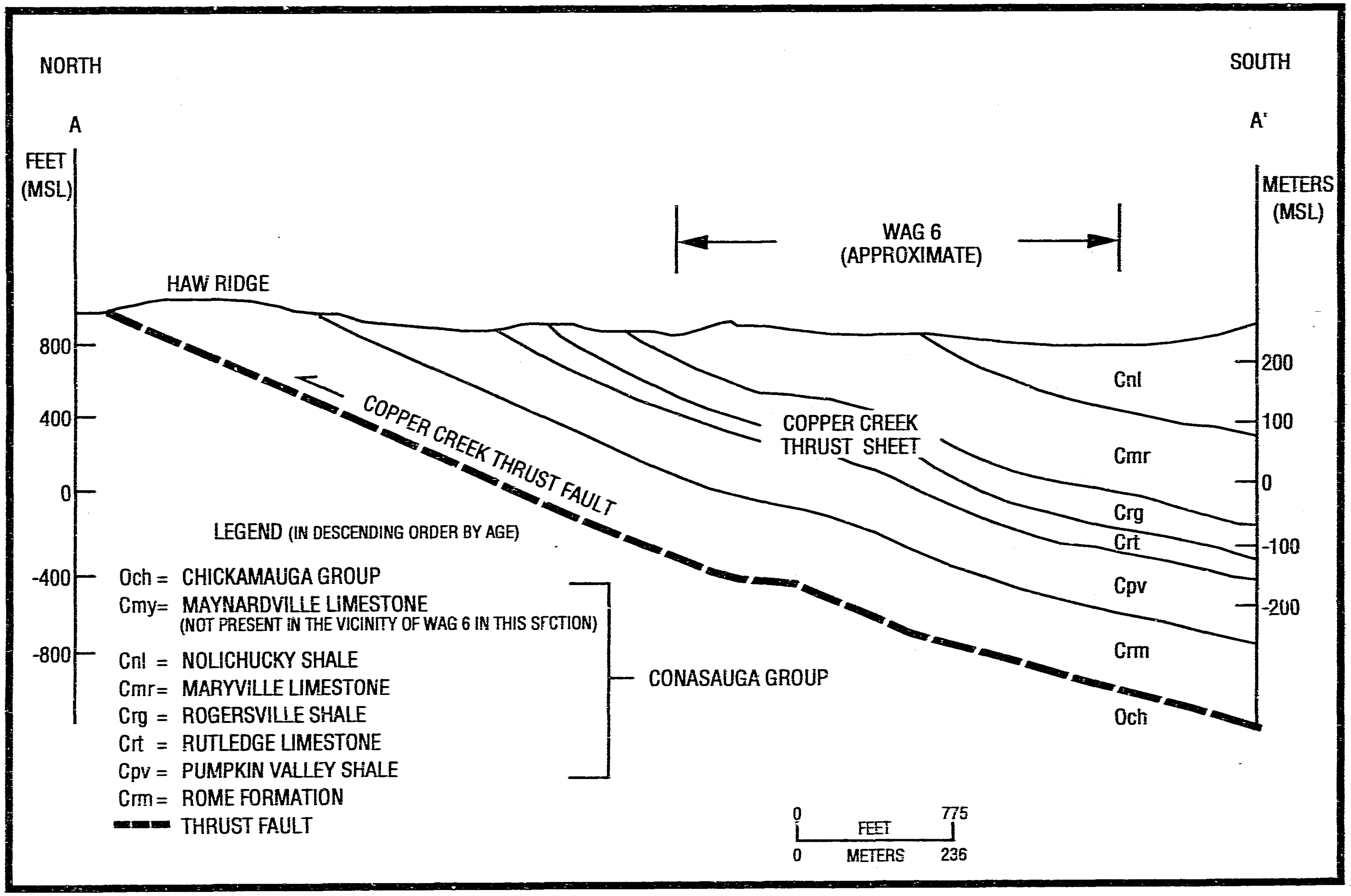
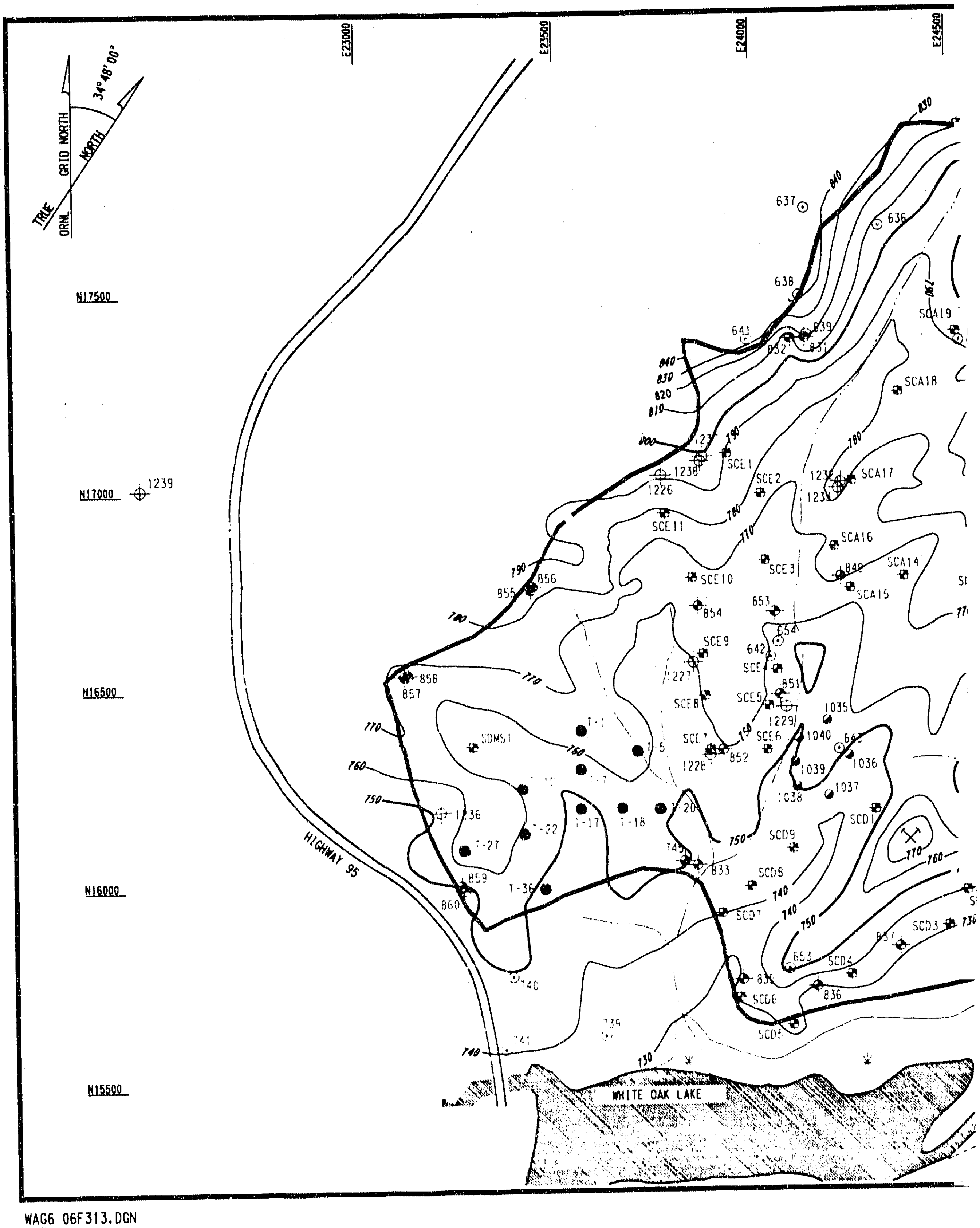


Fig. 3.5. WAG 6 regional structural setting. *Source:* Dreir, R. B., et al. 1987. *Fracture Characterization in the Unsaturated Zone of a Shallow Land Burial Facility*, pp. 51-59 in American Geophysical Union monograph, *Flow and Transport Through Fractured Rock.*

5.18 4104.4



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9-3

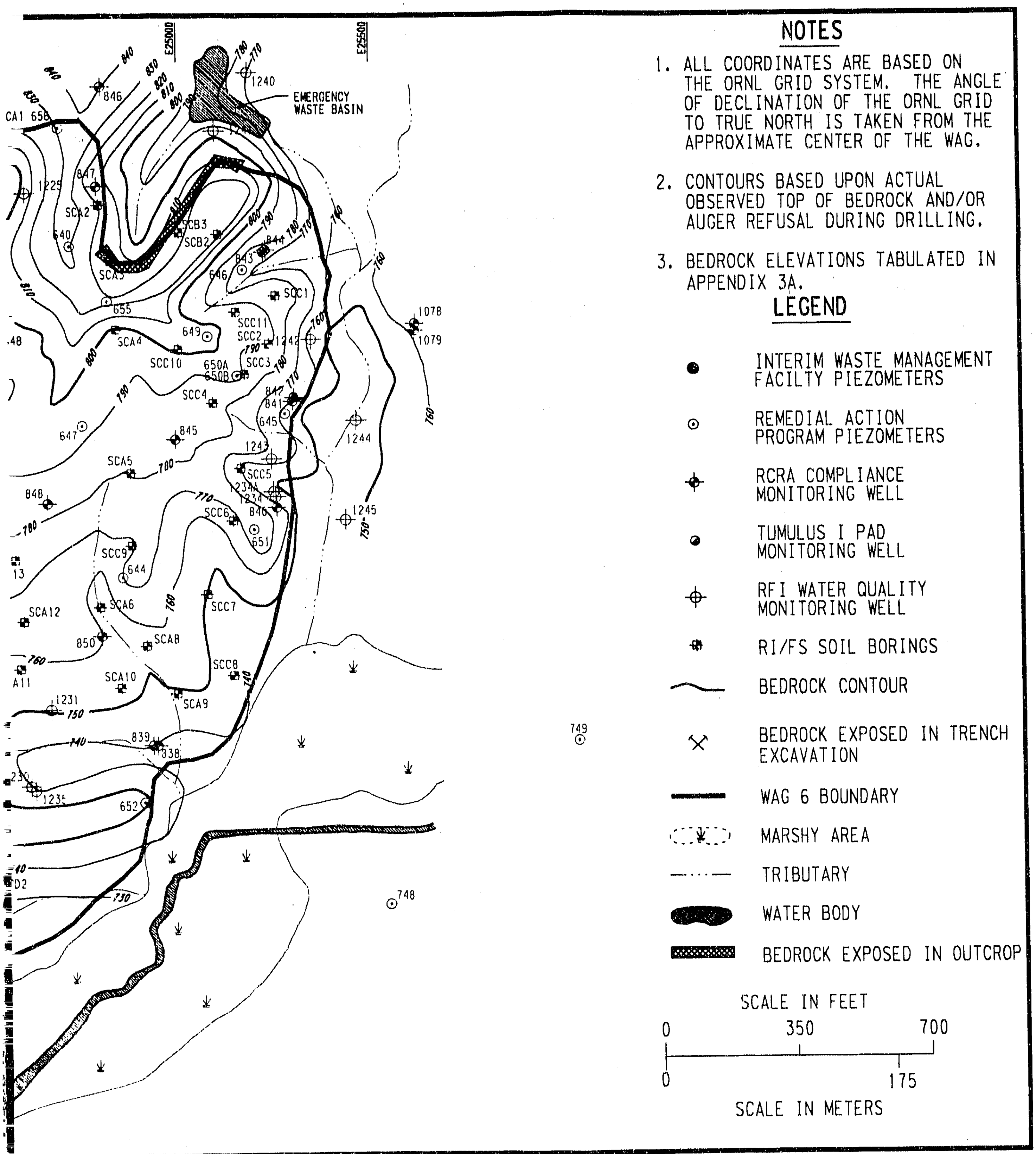
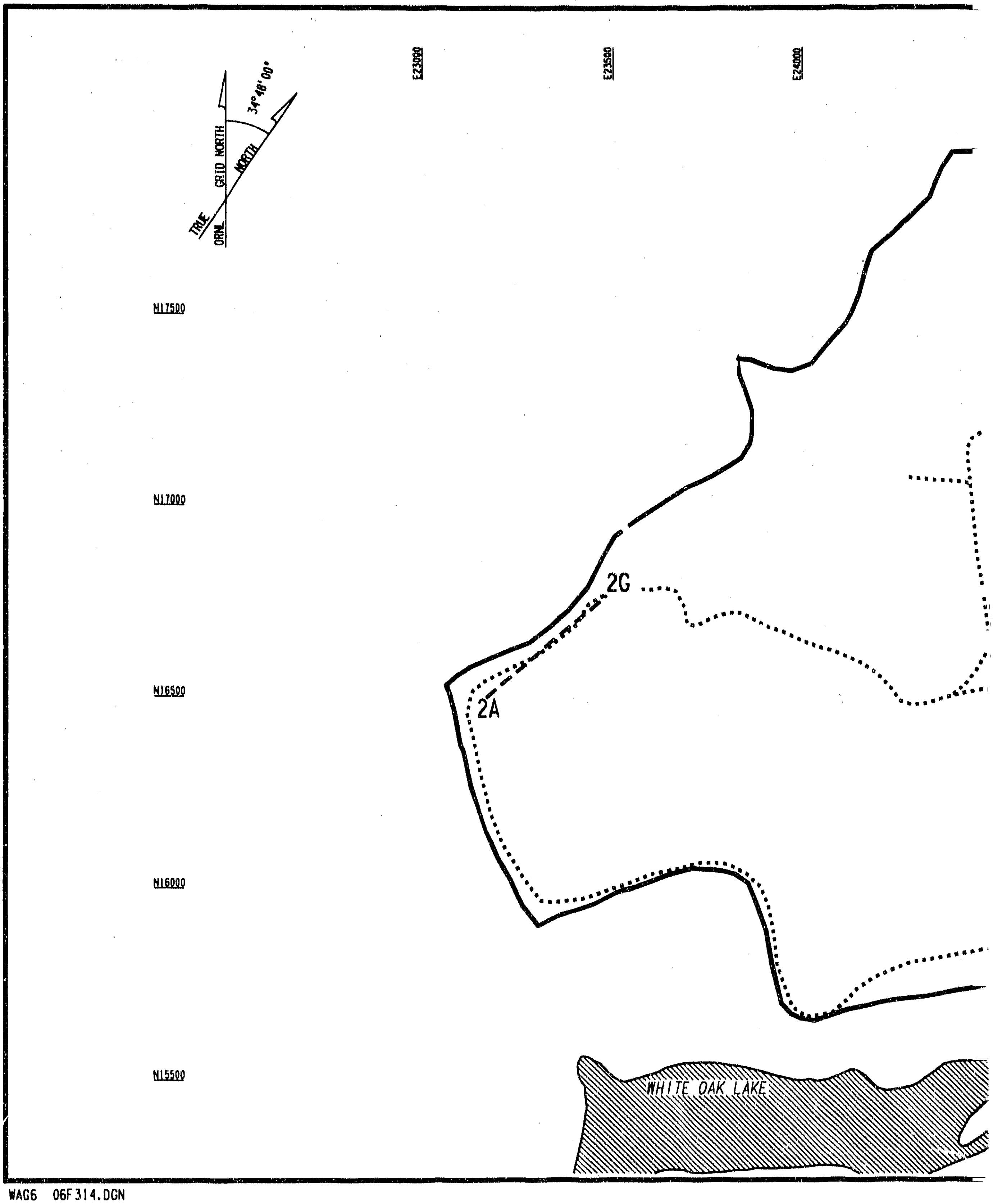


Fig. 3.6. WAG 6 bedrock elevation contour map.



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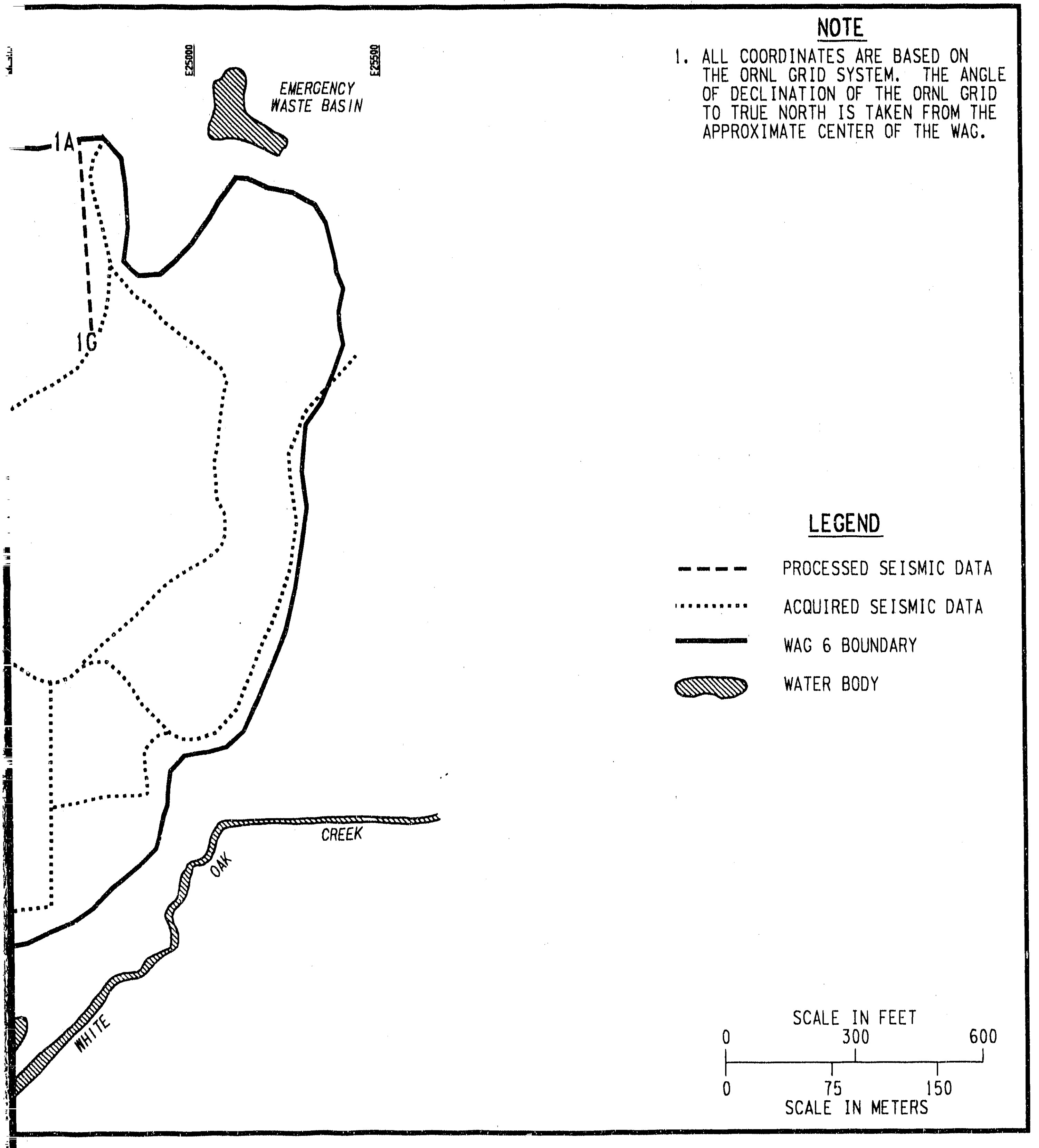
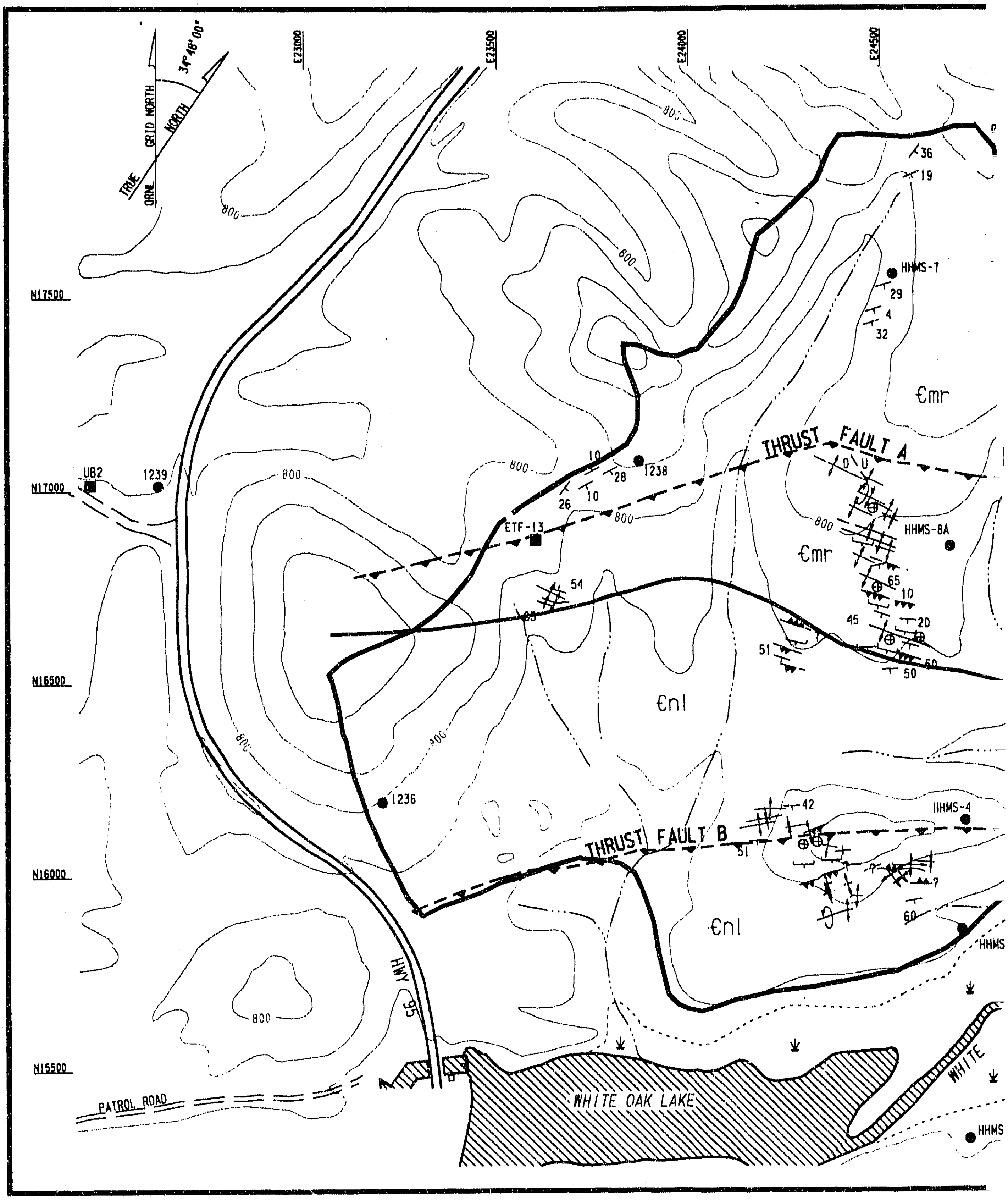


Fig. 3.7. ORNL refraction seismic transects at WAG 6. *Source:* Dreier, R. B., R. J. Selfridge, and C. M. Beaudoin. 1987. *Status Report on SWSA 6 Geophysical Studies*, ORNL/RAP/LTR-87/31, Oak Ridge National Laboratory, Oak Ridge, Tennessee.



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9-3

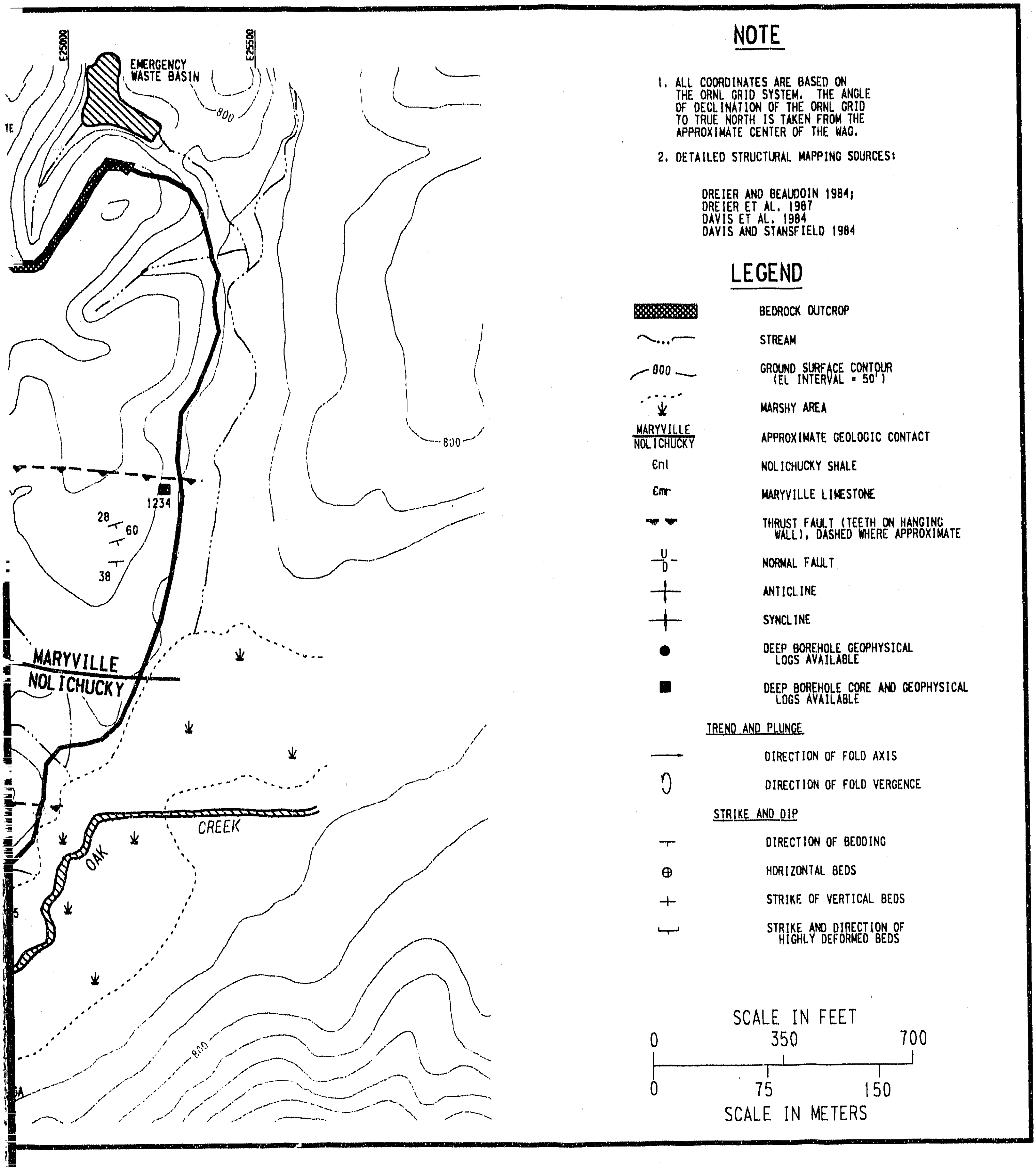
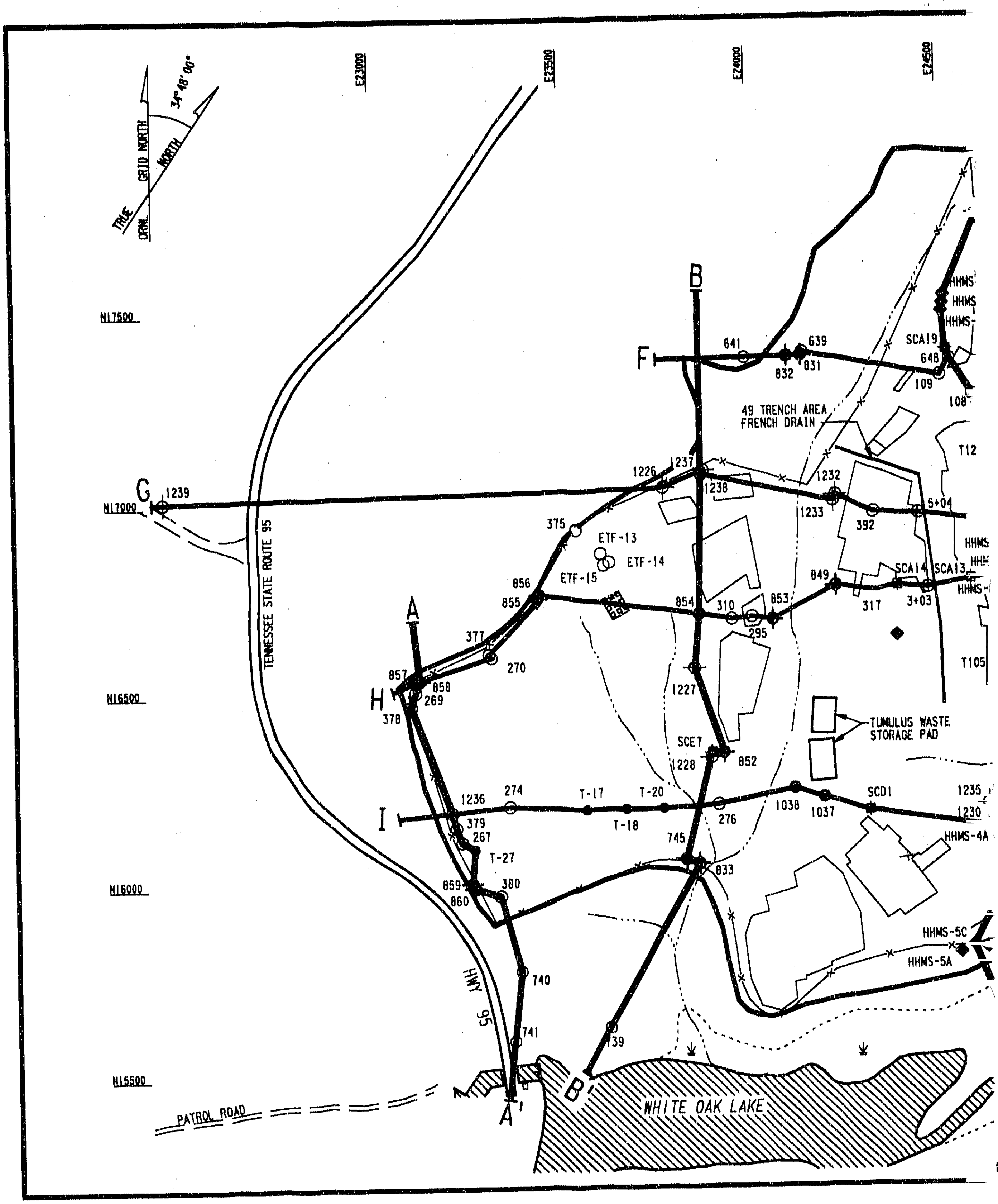


Fig. 3.8. Geologic map of WAG 6.



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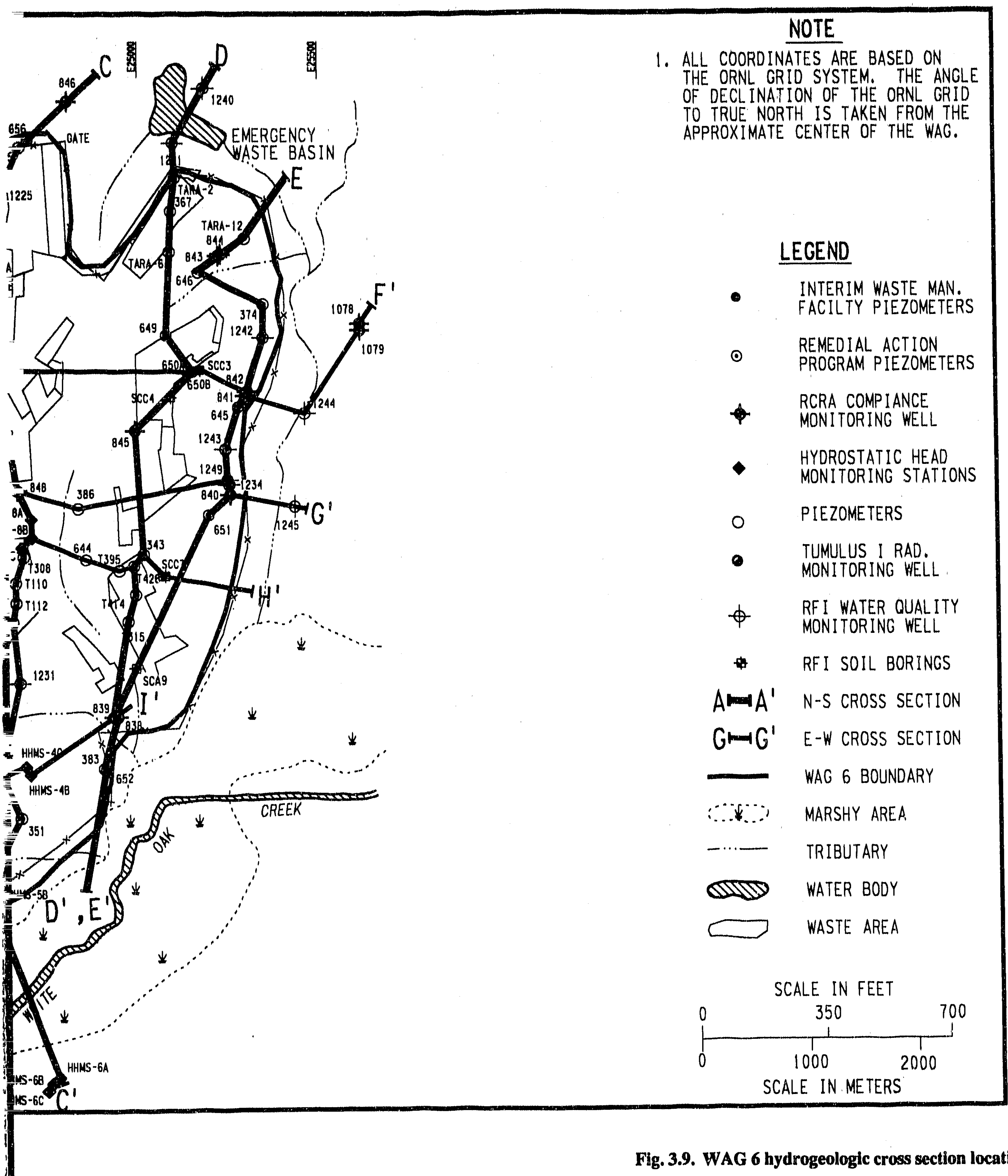


Fig. 3.9. WAG 6 hydrogeologic cross section location map.

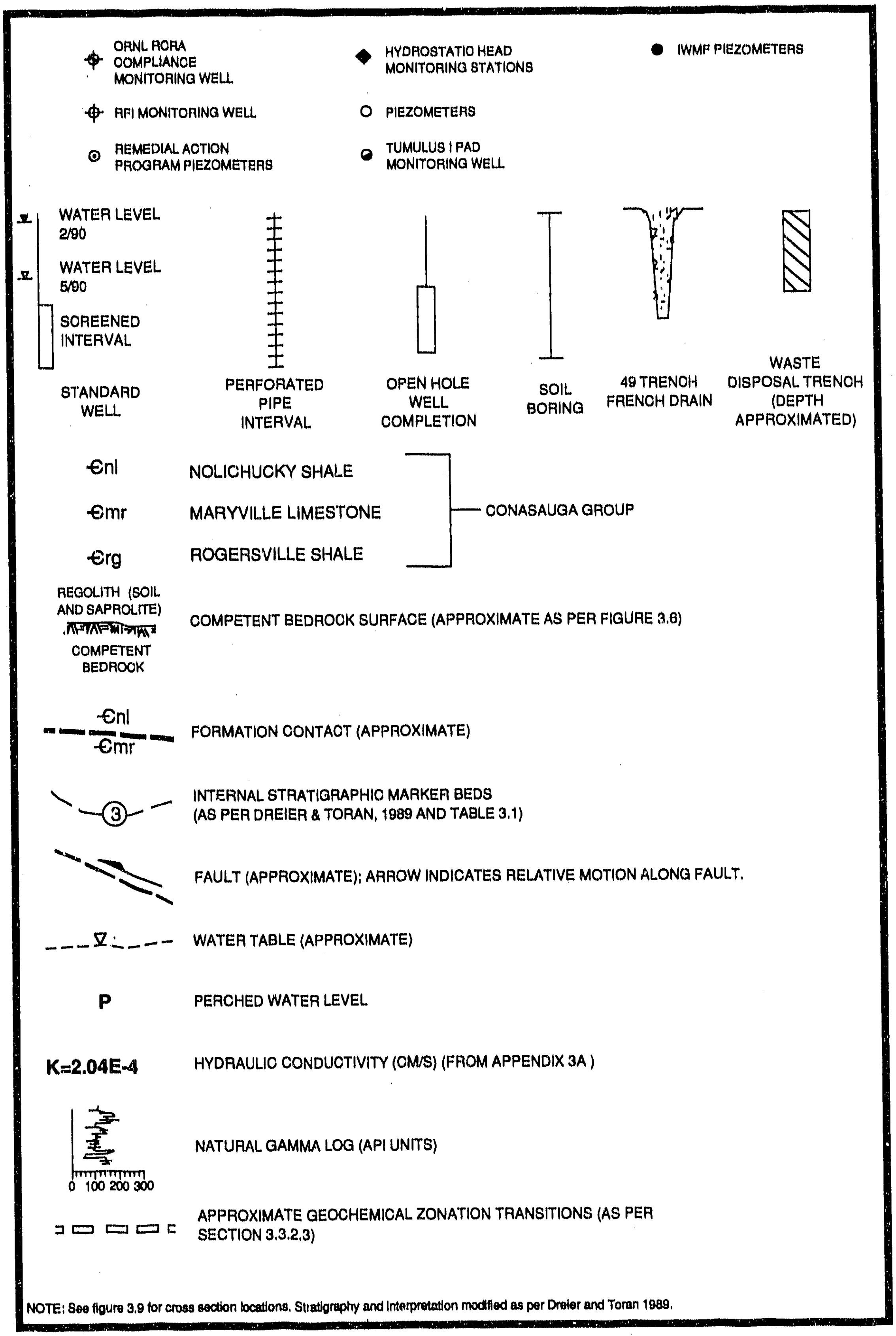
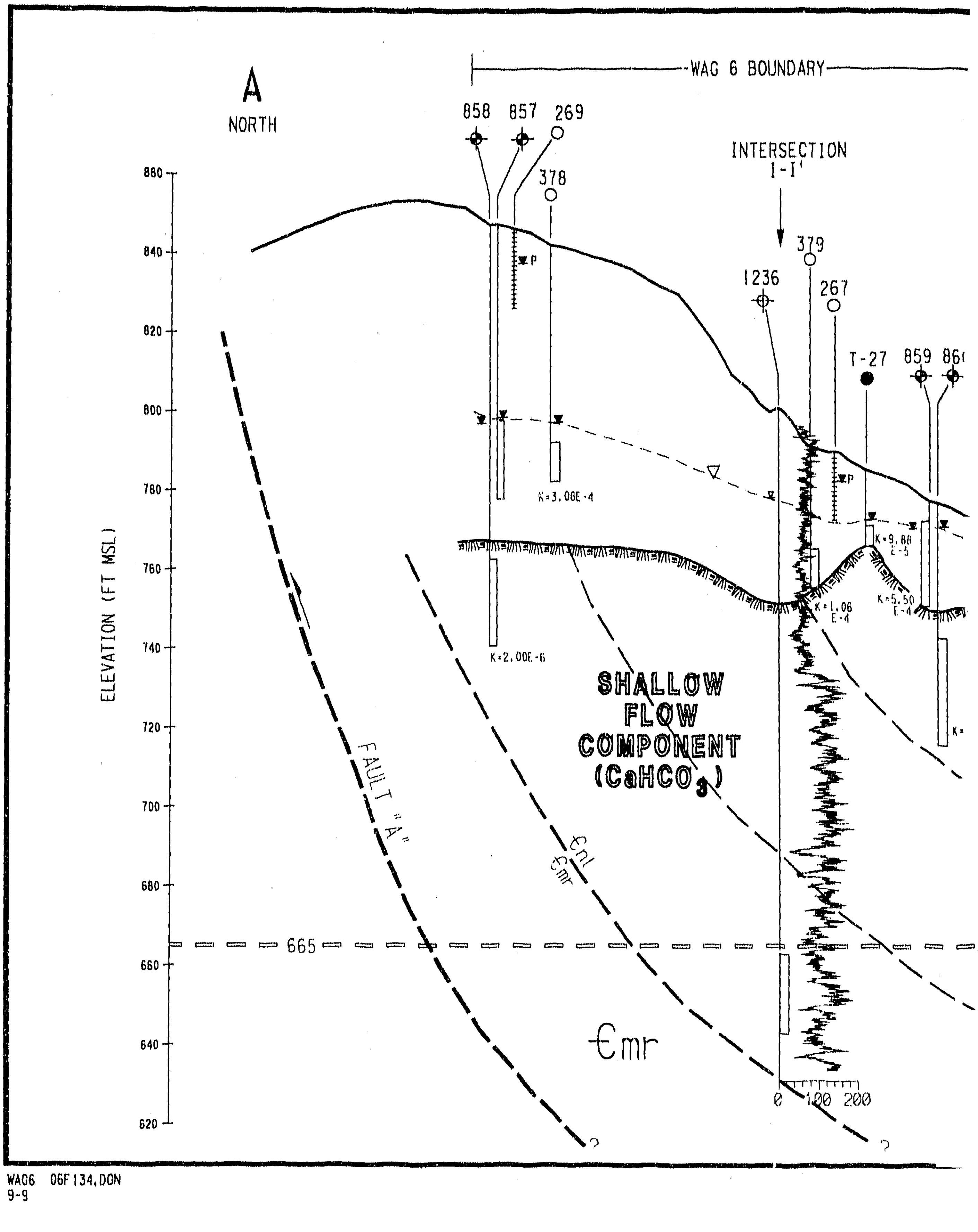


Fig. 3.10. Index sheet for hydrogeologic sections. *Source:* Dreier, R. B., and L. E.Toran. 1989. *Hydrogeology of Melton Valley Determined from Hydraulic Head Measuring Station Data*, ORNL/TM-11216, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

5.18F 4104.146
Adapted from WAG6 LEGENDS.DGN



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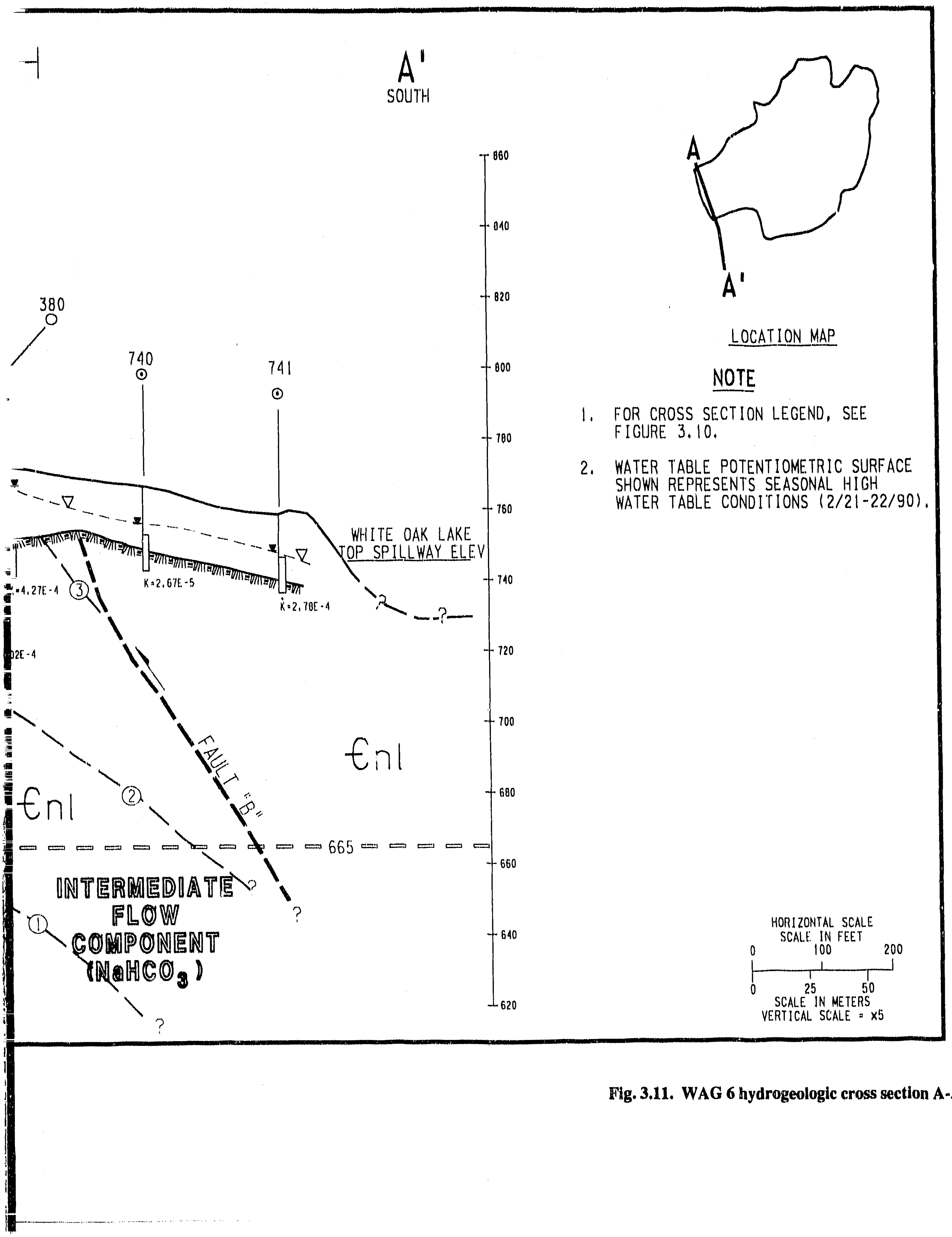
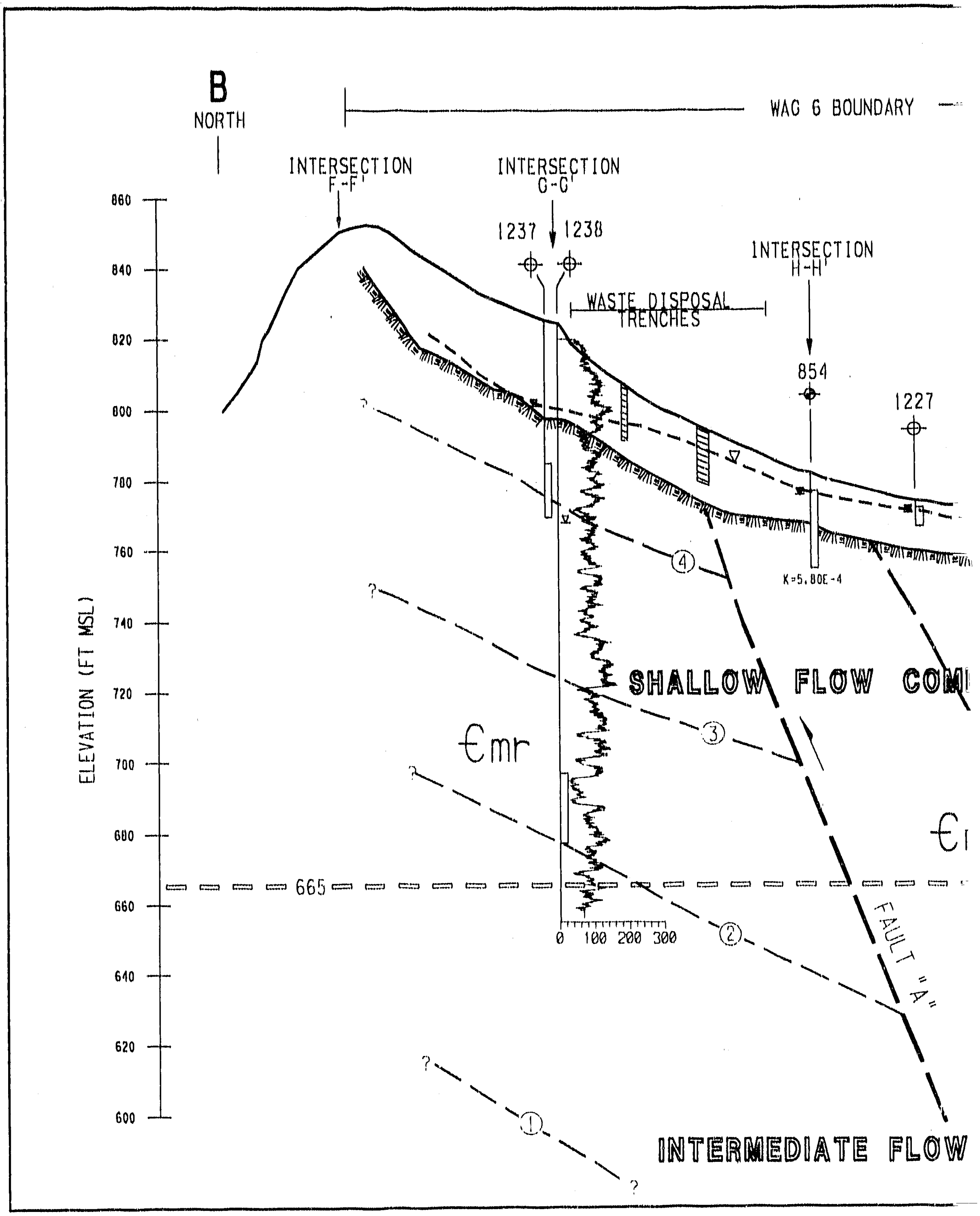


Fig. 3.11. WAG 6 hydrogeologic cross section A-A'.



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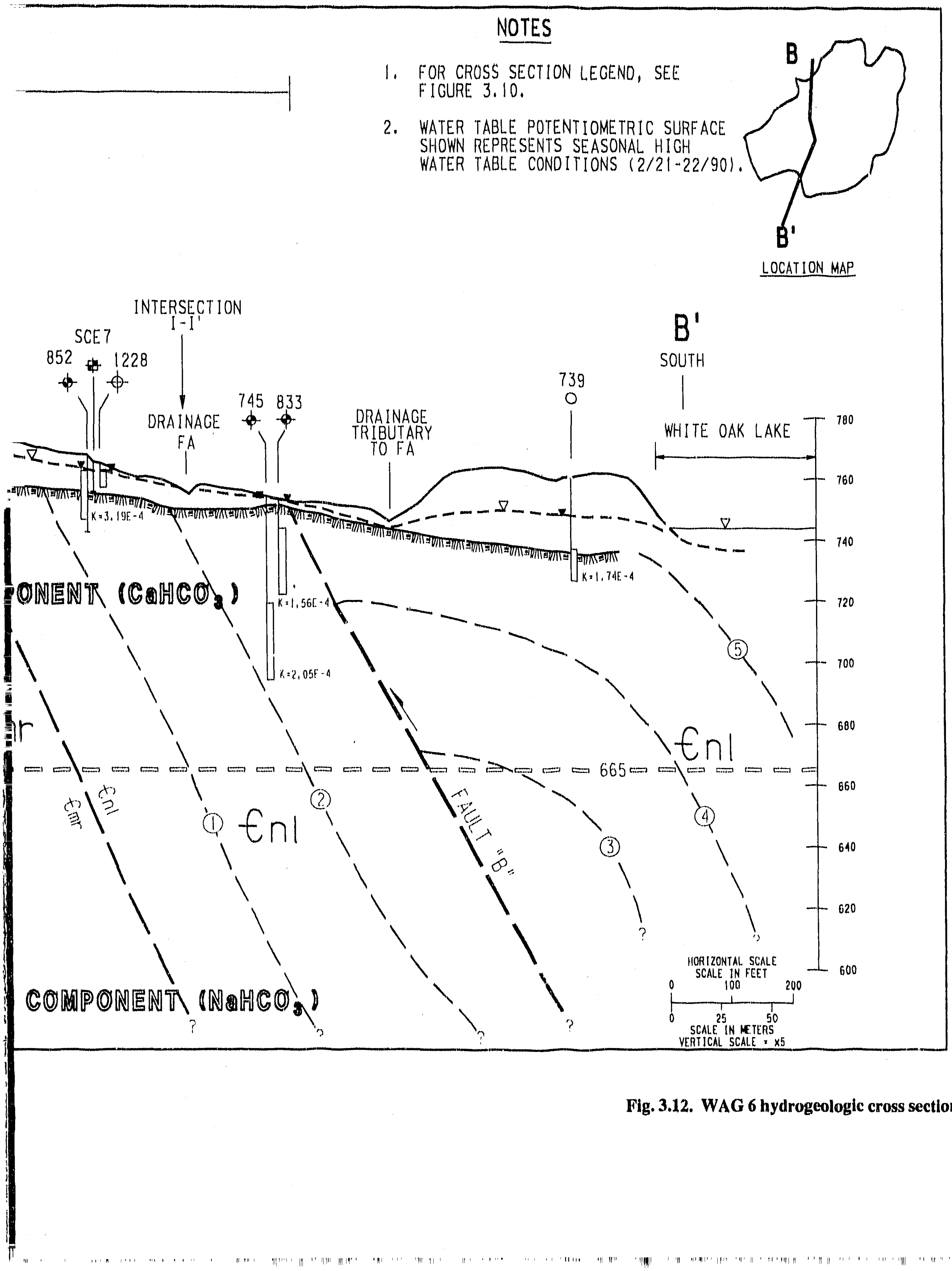
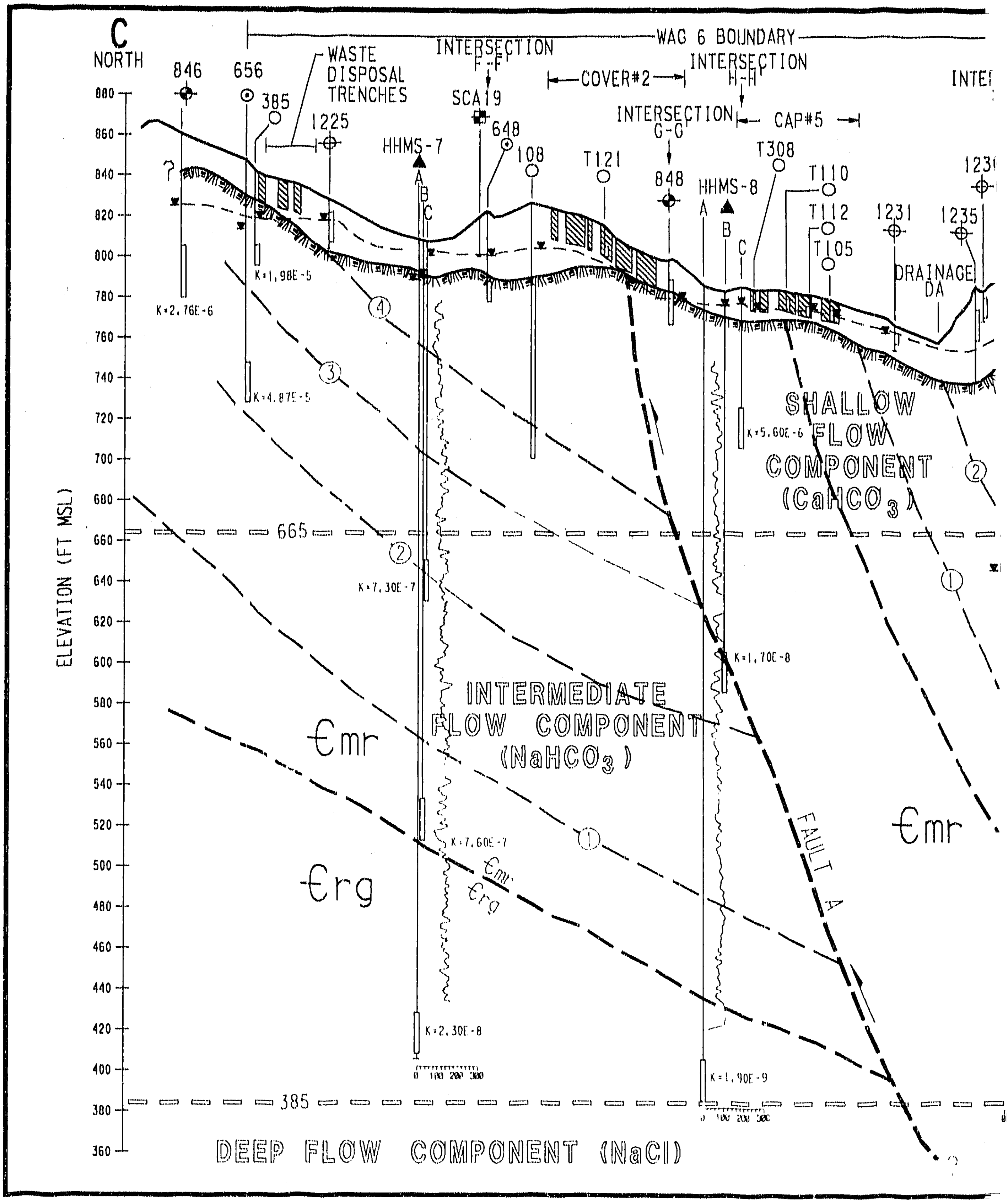


Fig. 3.12. WAG 6 hydrogeologic cross section B-B'.



WAG6 06F139.DGN
9-9

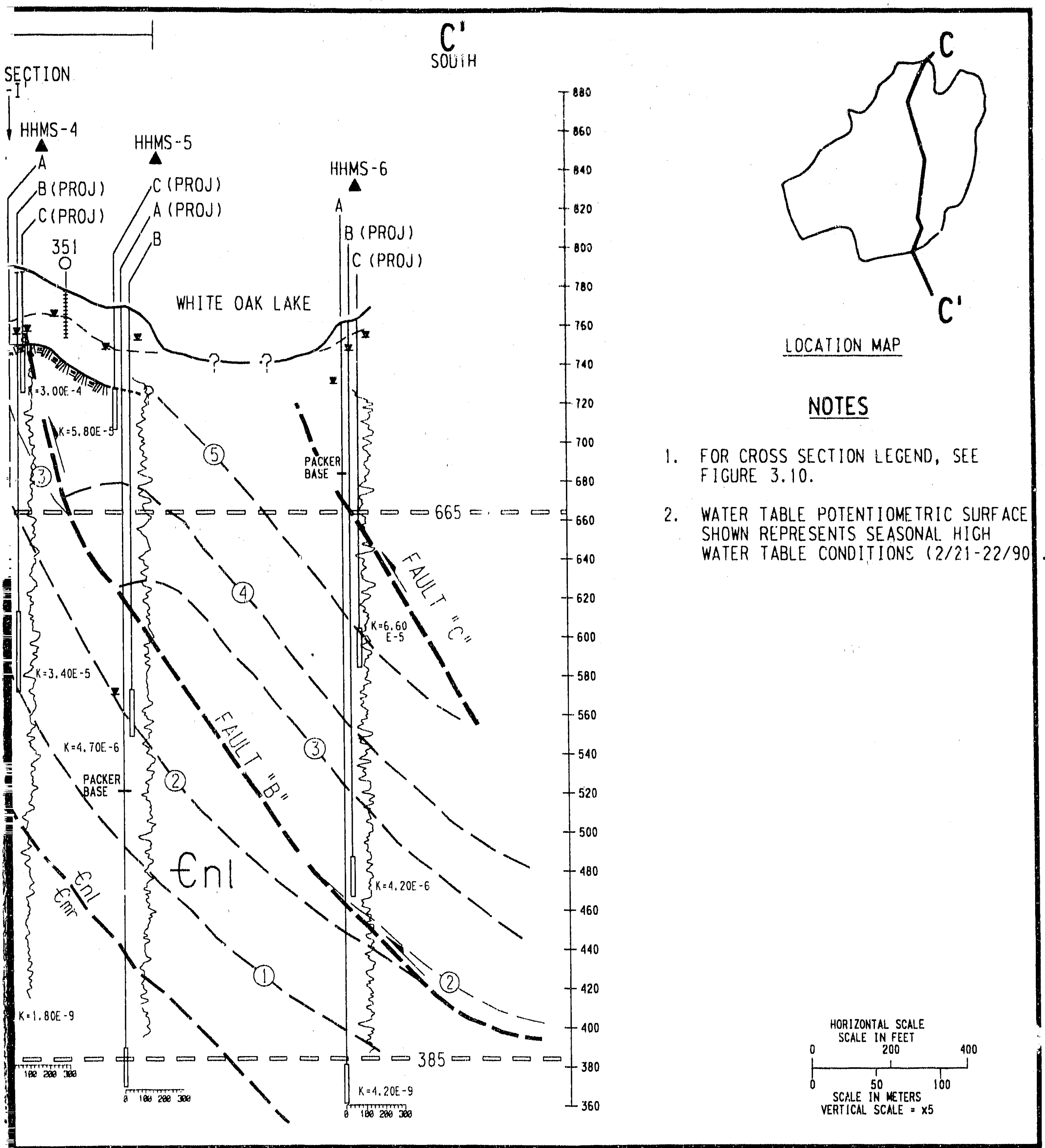
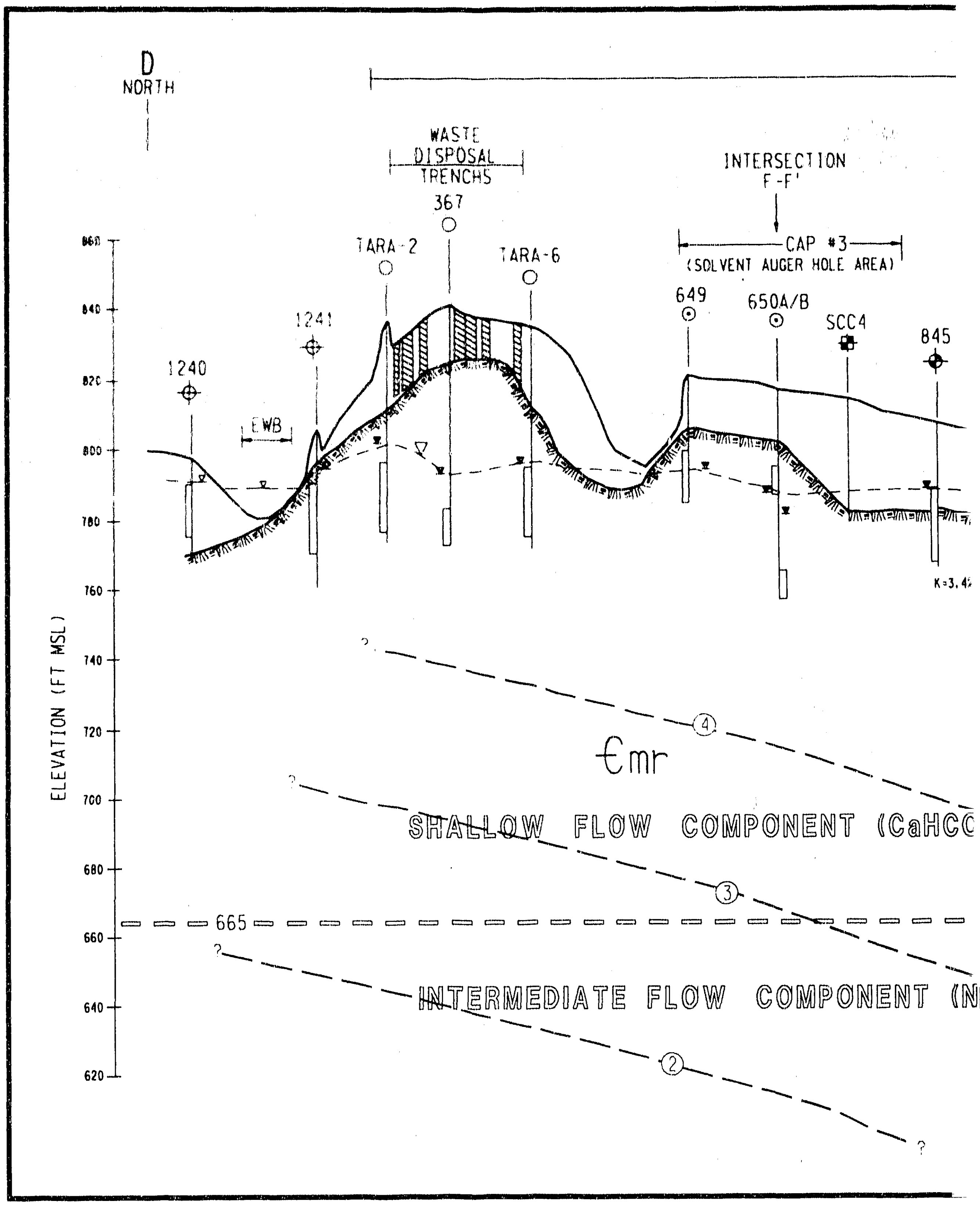


Fig. 3.13. WAG 6 hydrogeologic cross section C-C'.



WAG6 06F316.DGN
9-9

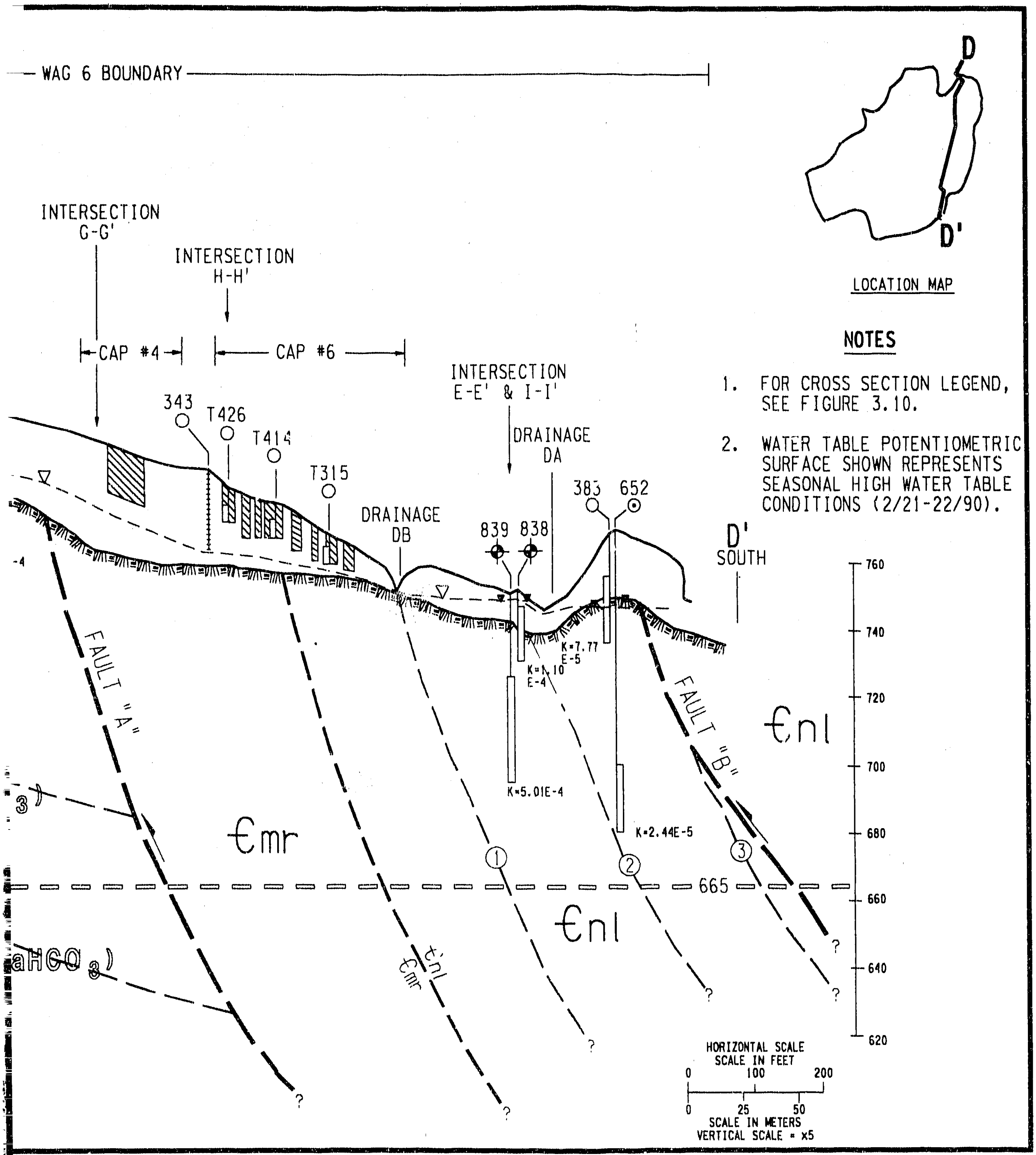
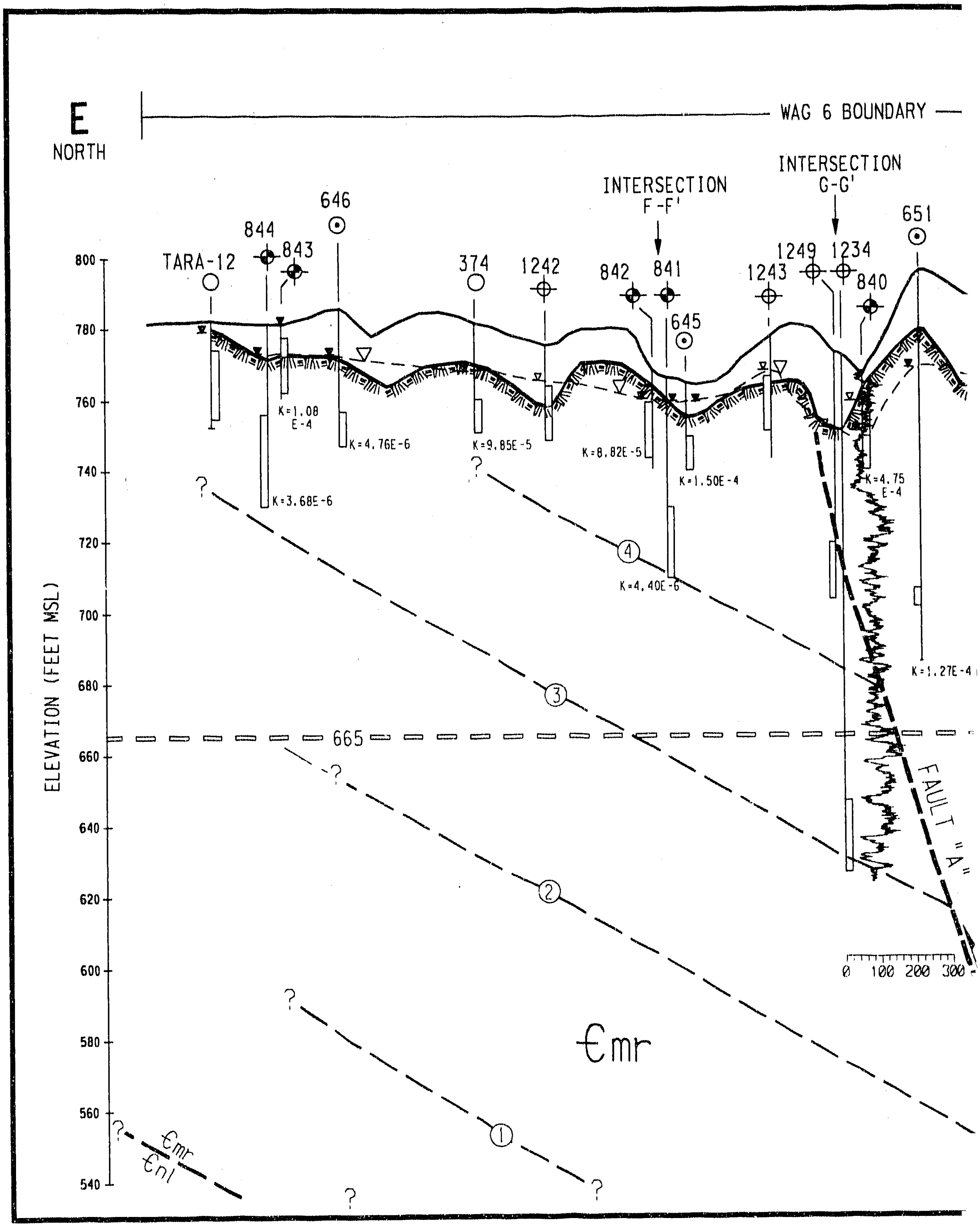


Fig. 3.14. WAG 6 hydrogeologic cross section D-D'.



WAG6 06F132.DGN
9-9

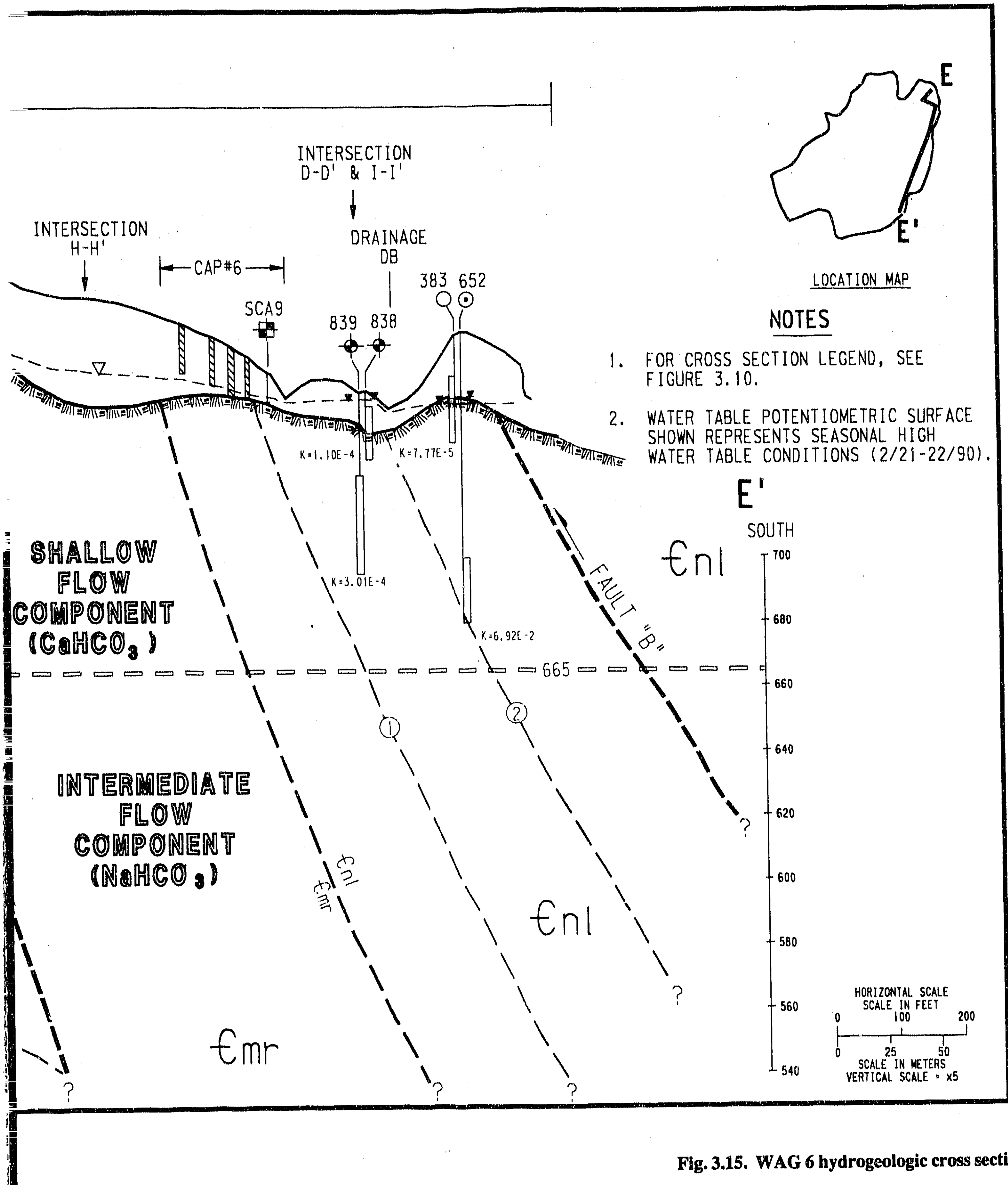
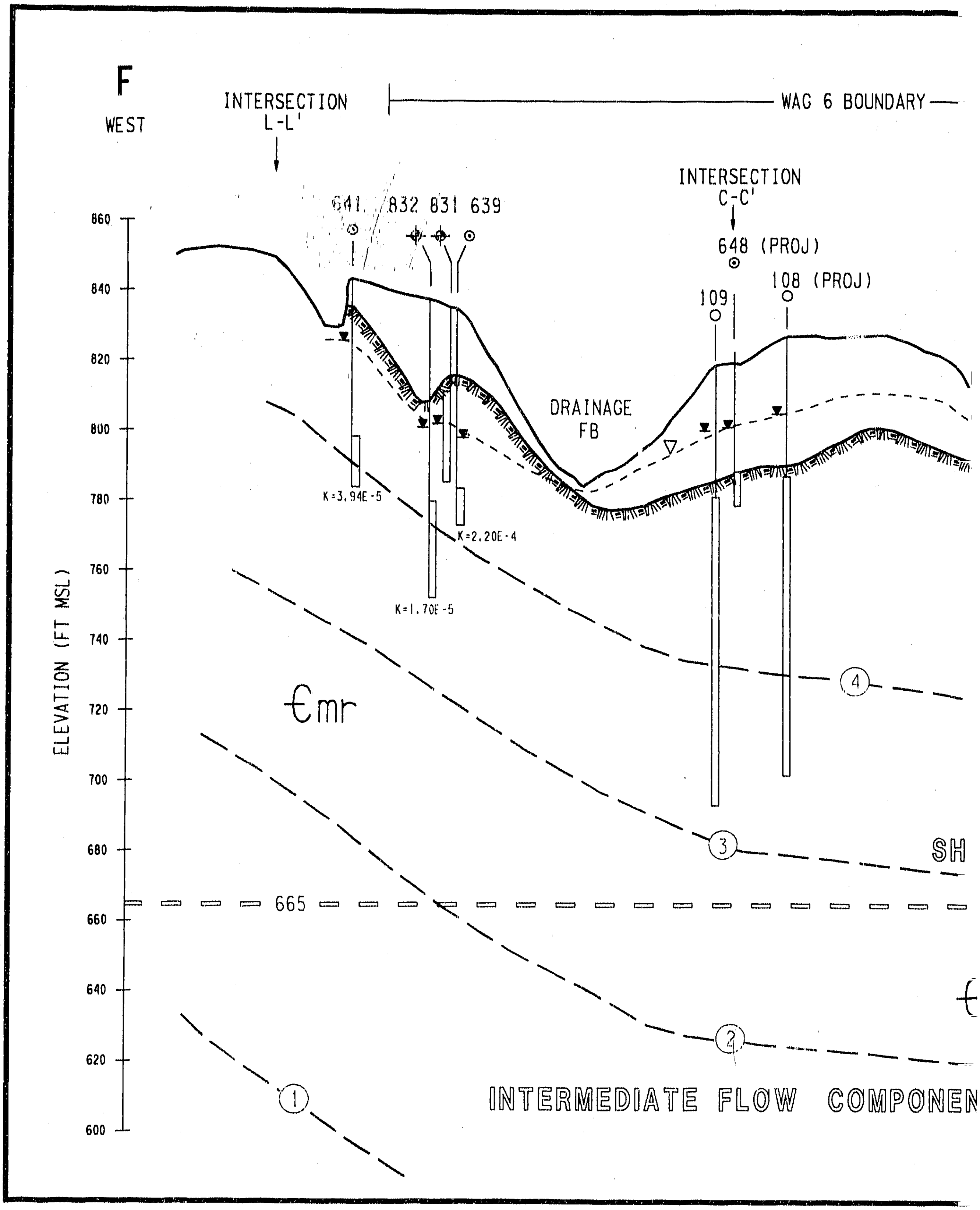


Fig. 3.15. WAG 6 hydrogeologic cross section E-E'.



WAG6 06F129.DGN
9-9

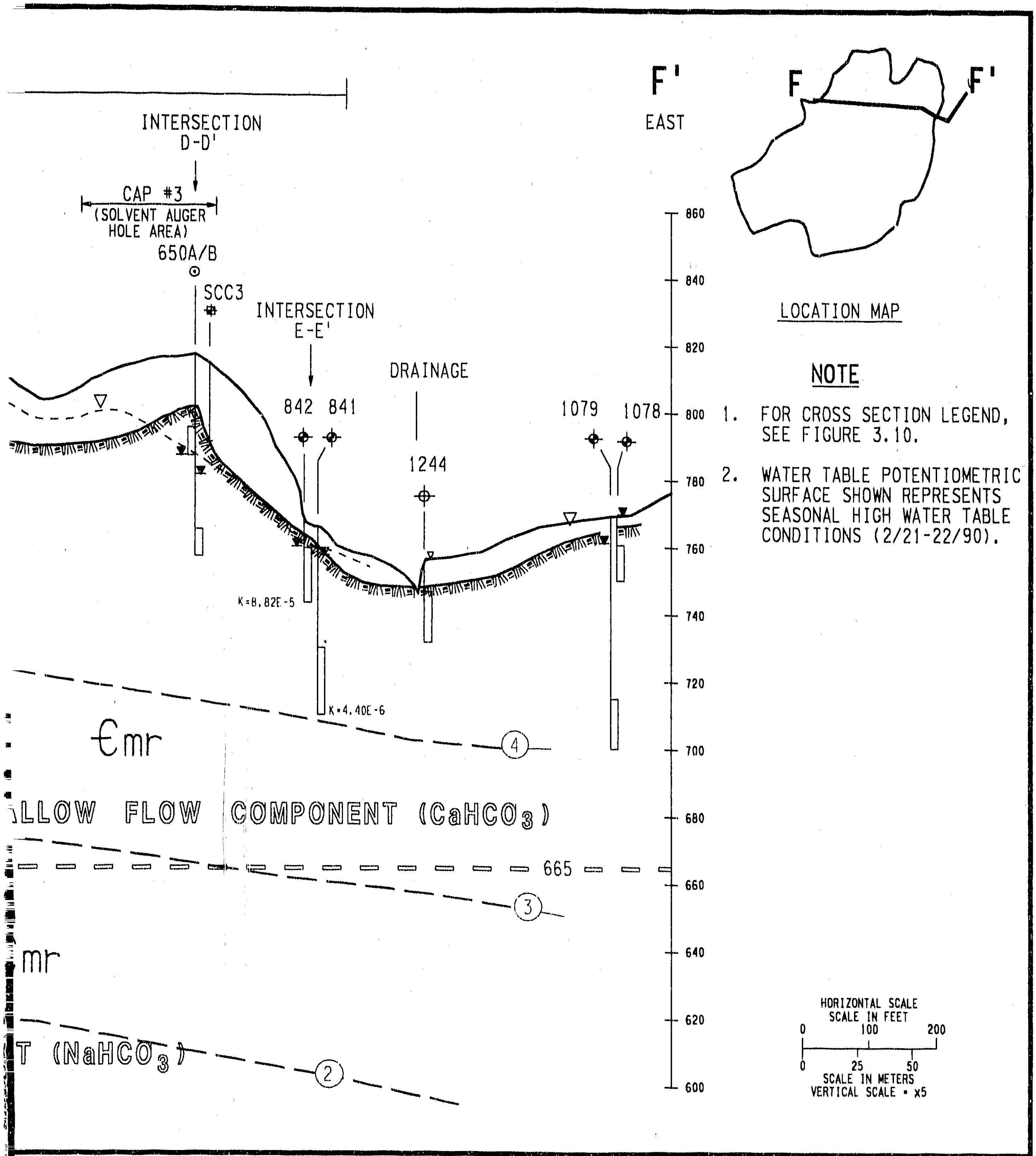
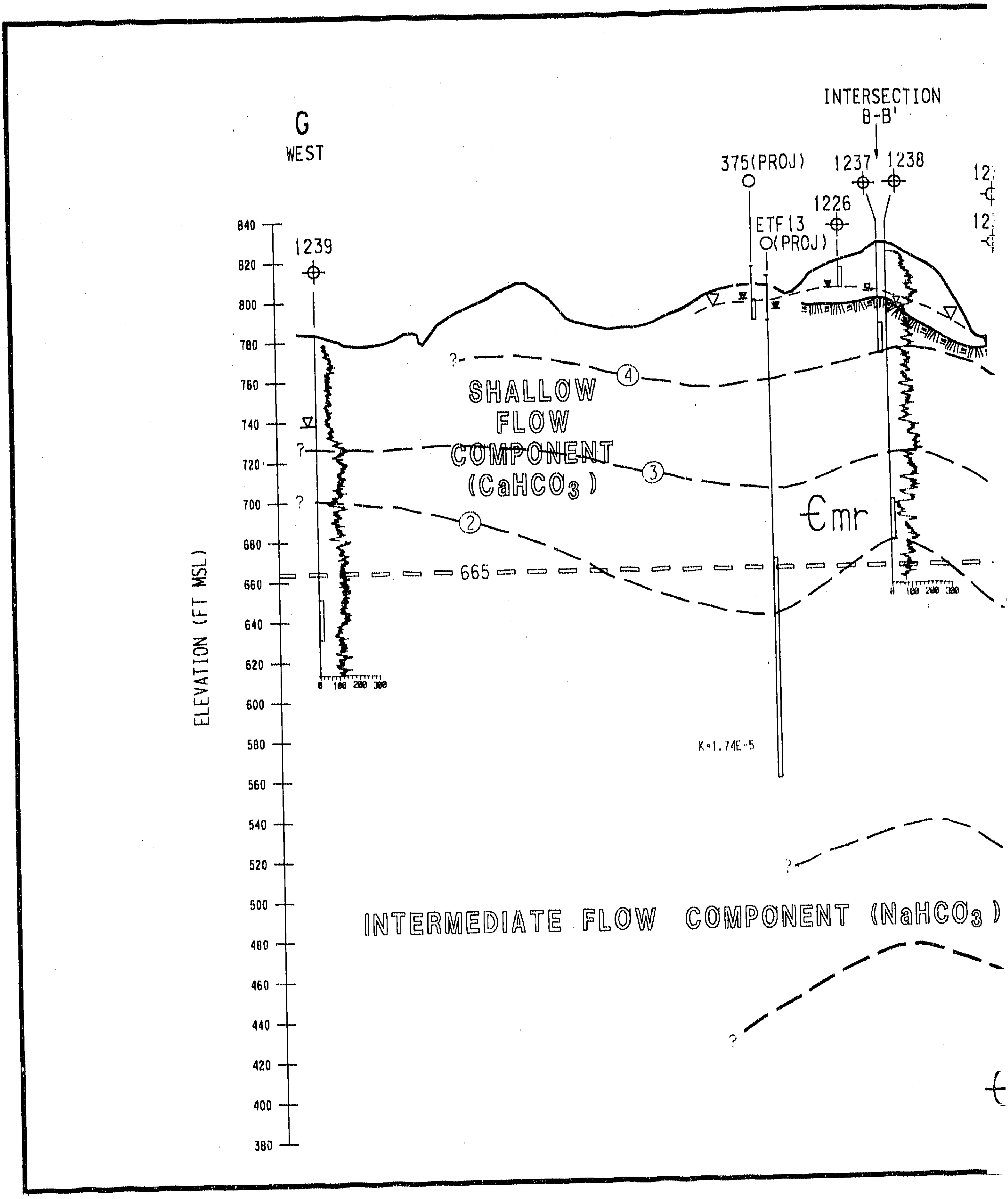


Fig. 3.16. WAG 6 hydrogeologic cross section F-F'.



WAG6 06F136.DGN
9-9

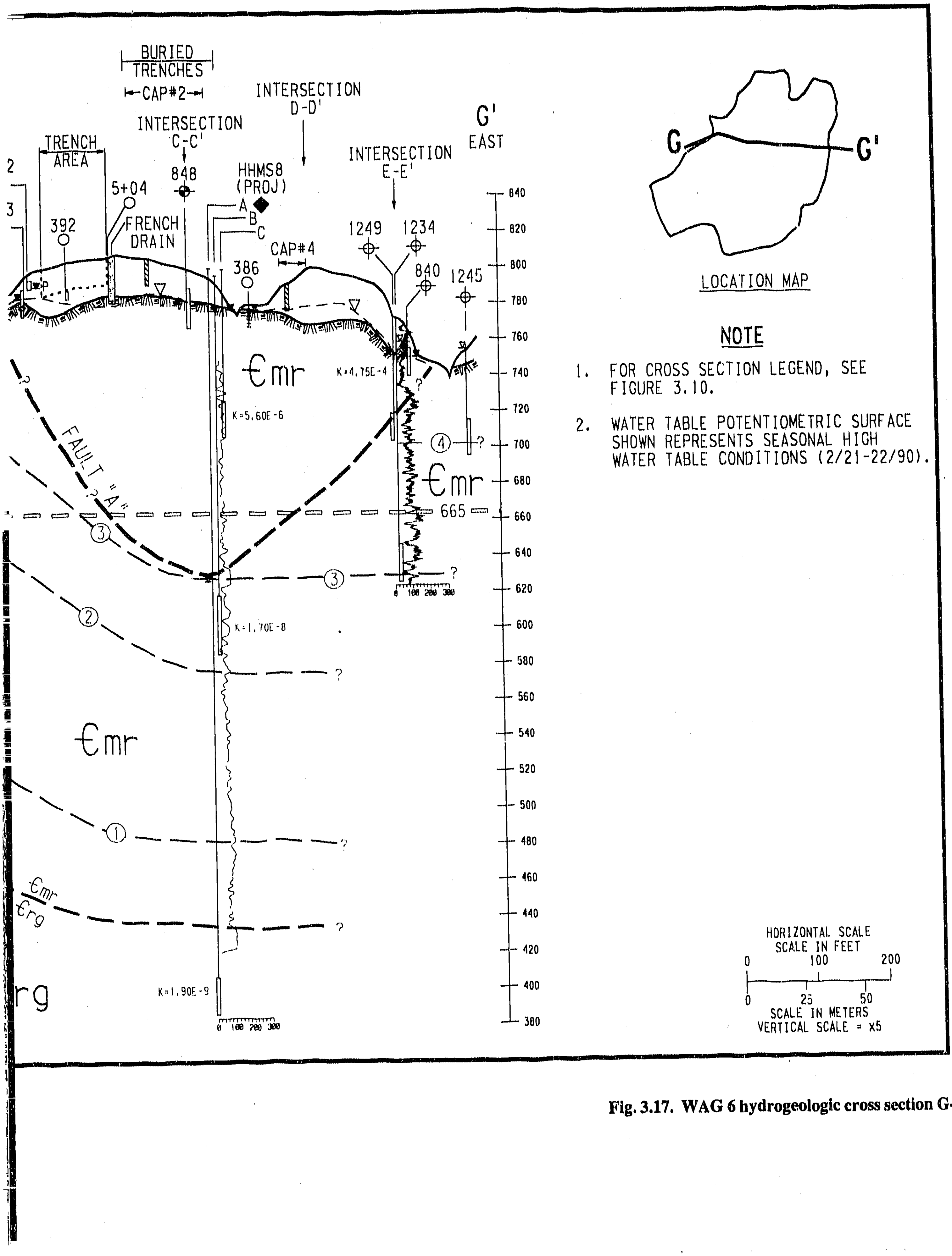
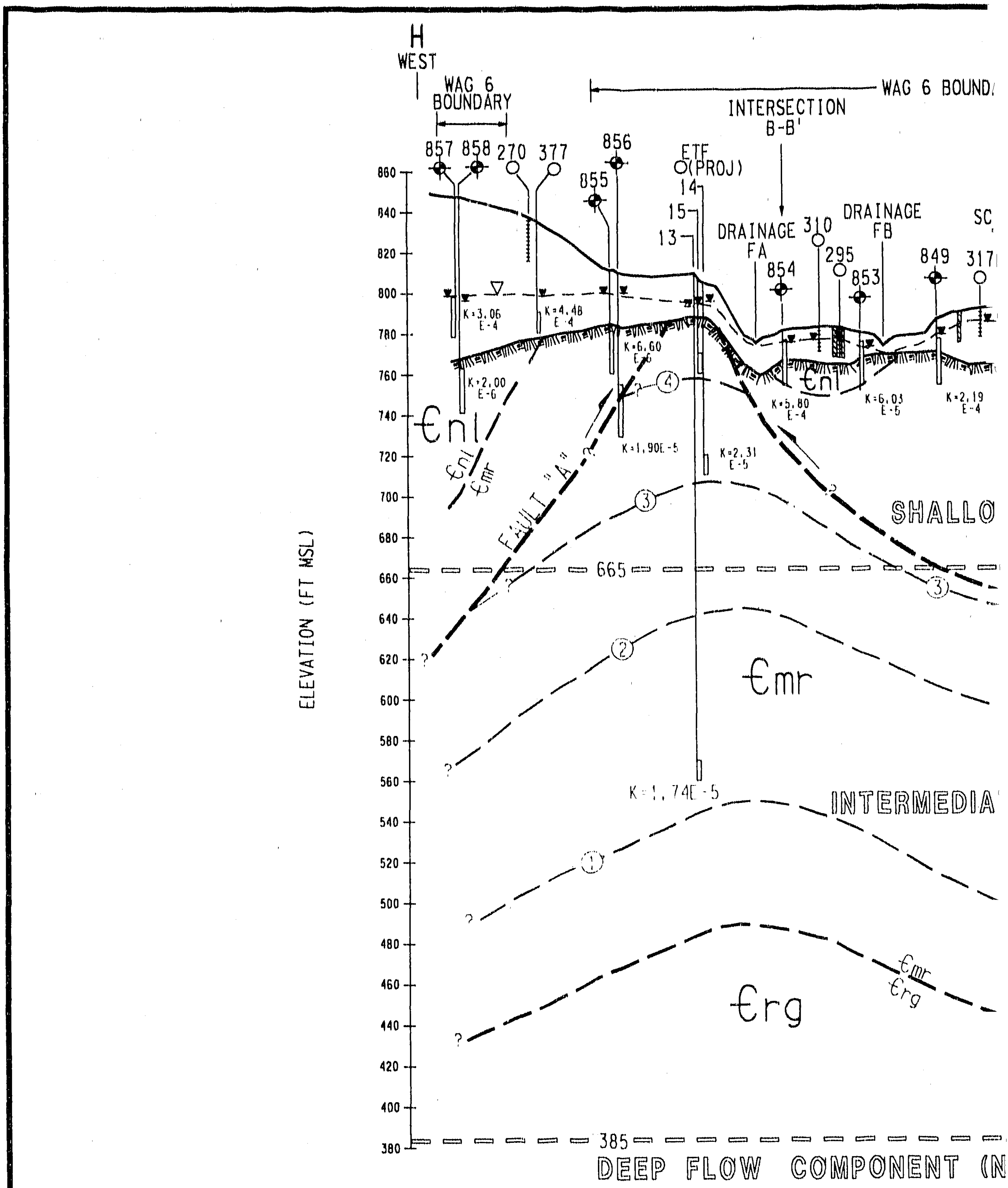


Fig. 3.17. WAG 6 hydrogeologic cross section G-G'.



WAG6 06F135.DGN
9-9

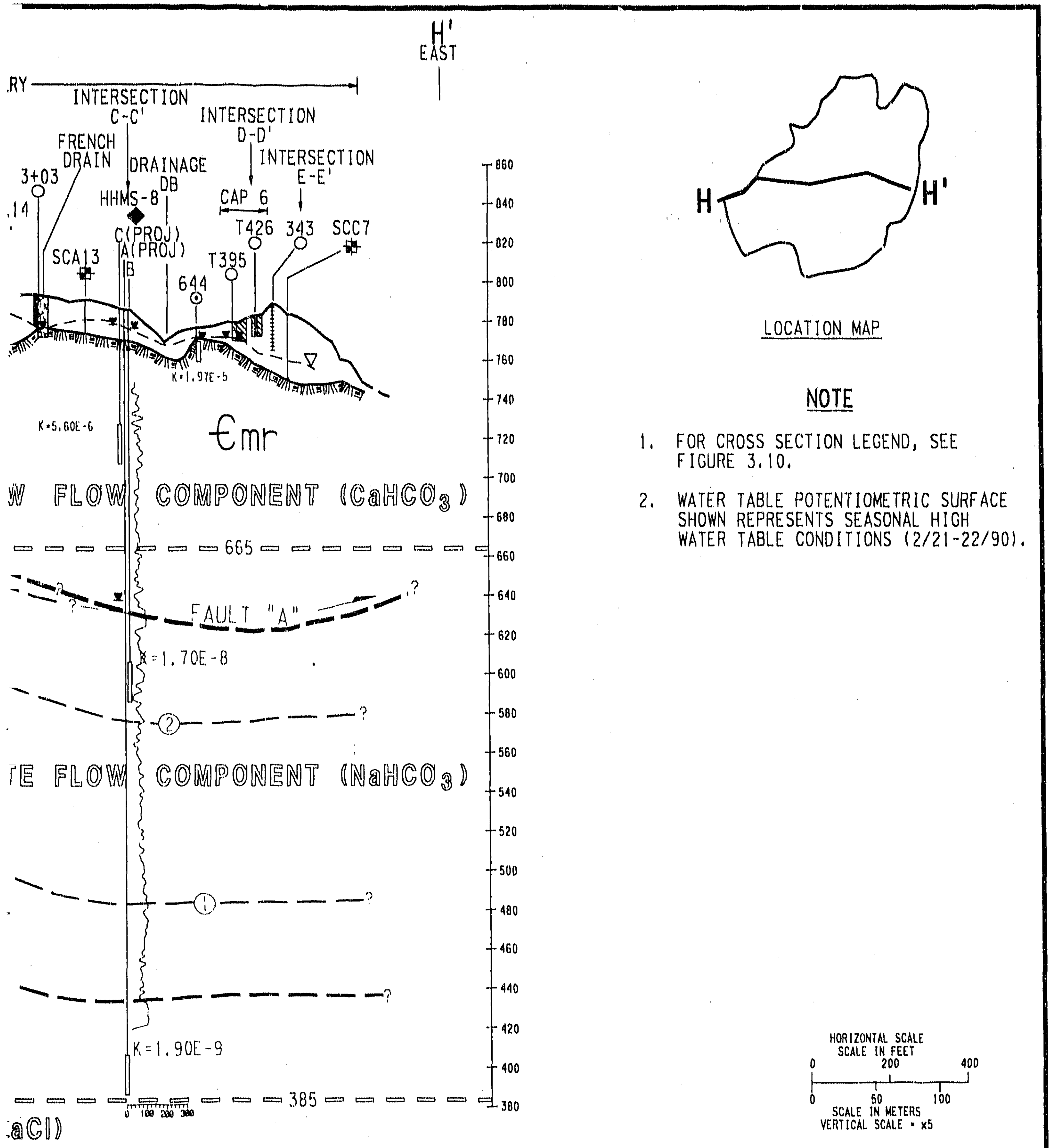
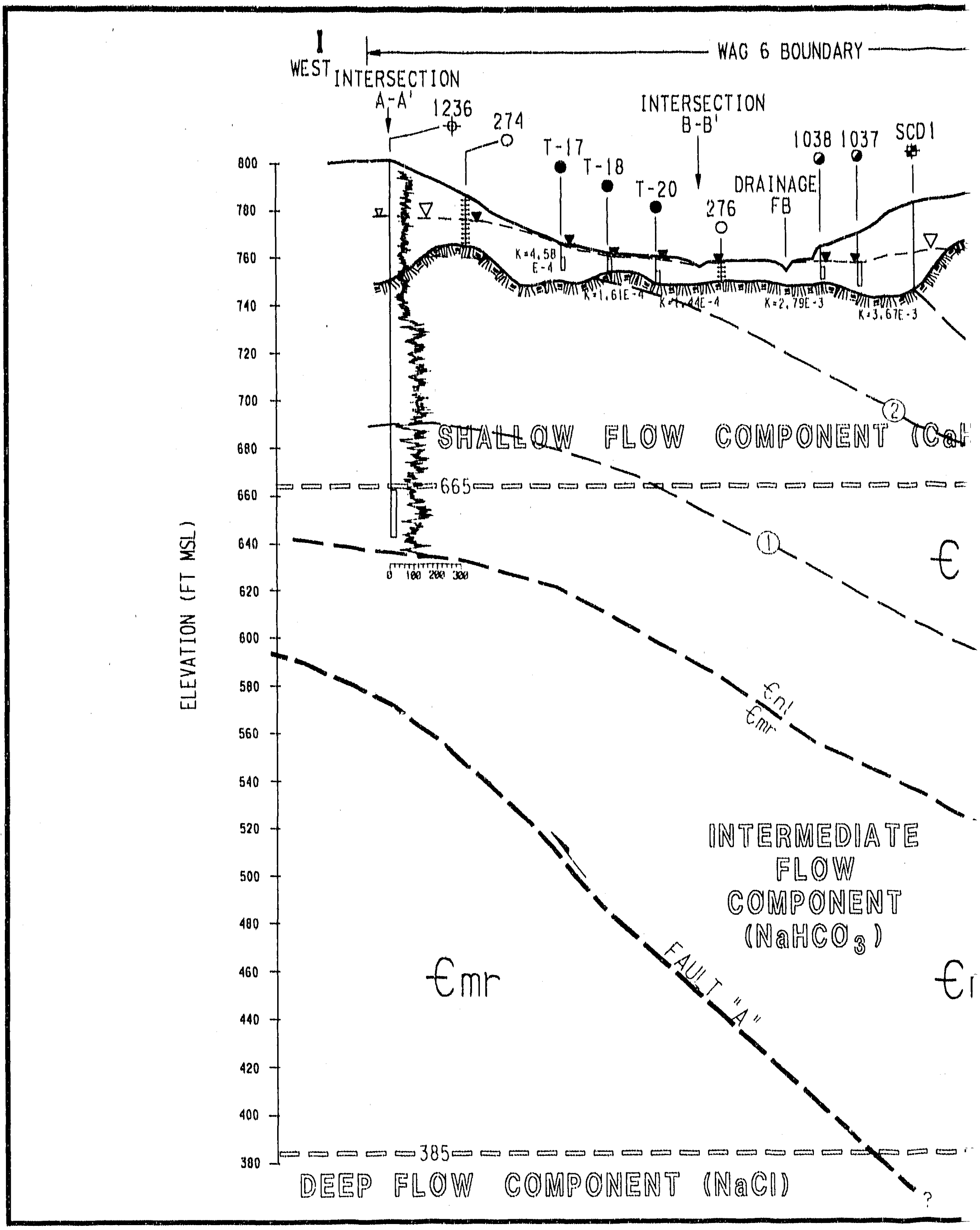
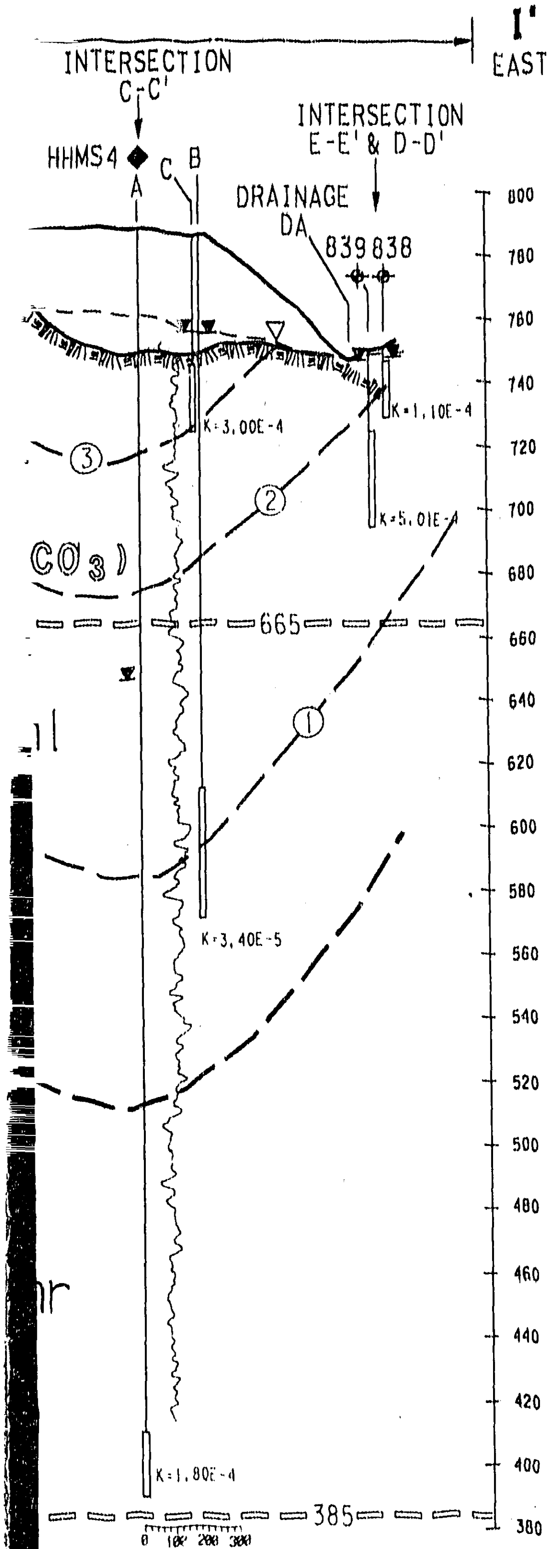
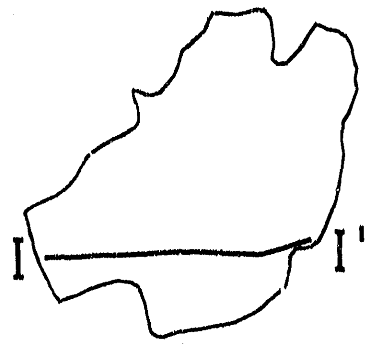


Fig. 3.18. WAG 6 hydrogeologic cross section H-H'.



WAG6 06F130.DGN
9-9





LOCATION MAP

NOTE

1. FOR CROSS SECTION LEGEND, SEE FIGURE 3.10.
2. WATER TABLE POTENTIOMETRIC SURFACE SHOWN REPRESENTS SEASONAL HIGH WATER TABLE CONDITIONS (2/21-22/90).

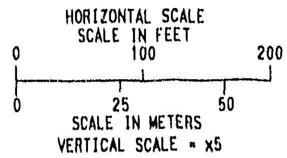
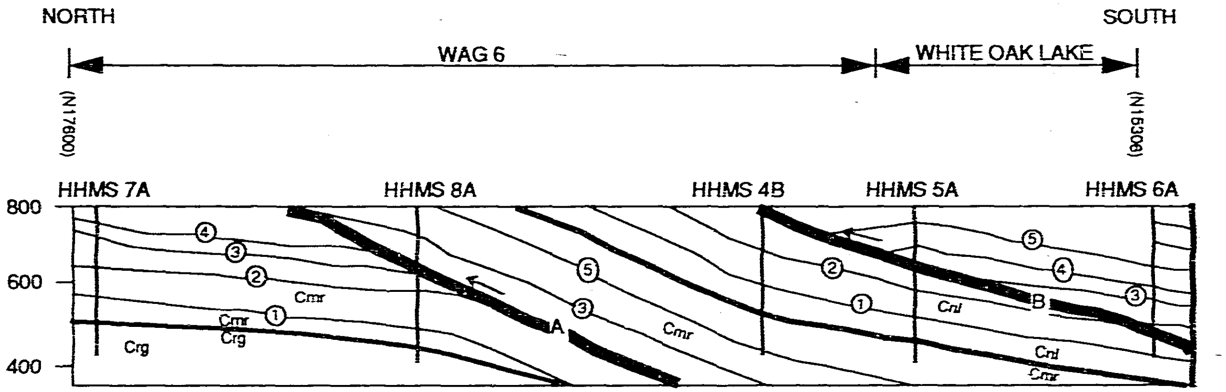


Fig. 3.19. WAG 6 hydrogeologic cross section I-I'.



NOTES

1. STRIKE-PERPENDICULAR GEOLOGIC CROSS SECTION THROUGH SWSA 6 AND WHITE OAK LAKE.

2. STRATIGRAPHIC AND STRUCTURAL DATA FROM HHMS A BOREHOLES FROM SITE 4 THROUGH 8, WOL-1, ARE PROJECTED ALONG A GRID-EAST DIRECTION TO THE LINE OF SECTION.

LEGEND

Cnl	NOLICHUCKEY SHALE
Cmr	MARYVILLE LIMESTONE
Crg	ROGERSVILLE SHALE
—①—	INTERNAL MARYVILLE AND NOLICHUCKEY STRATIGRAPHIC MARKER HORIZONS
▬	THRUST FAULTS
Cmr / Crg	FORMATION CONTACT

Fig. 3.20. WAG 6 north-south deep well structural cross section. *Source:* Dreier, R. B., and L. E. Toran. 1989. *Hydrogeology of Melton Valley Determined from Hydraulic Head Measuring Station Data*, ORNL/TM-11216, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

5.18E 4104.141
Adapted from WAG 6 06F137.DGN

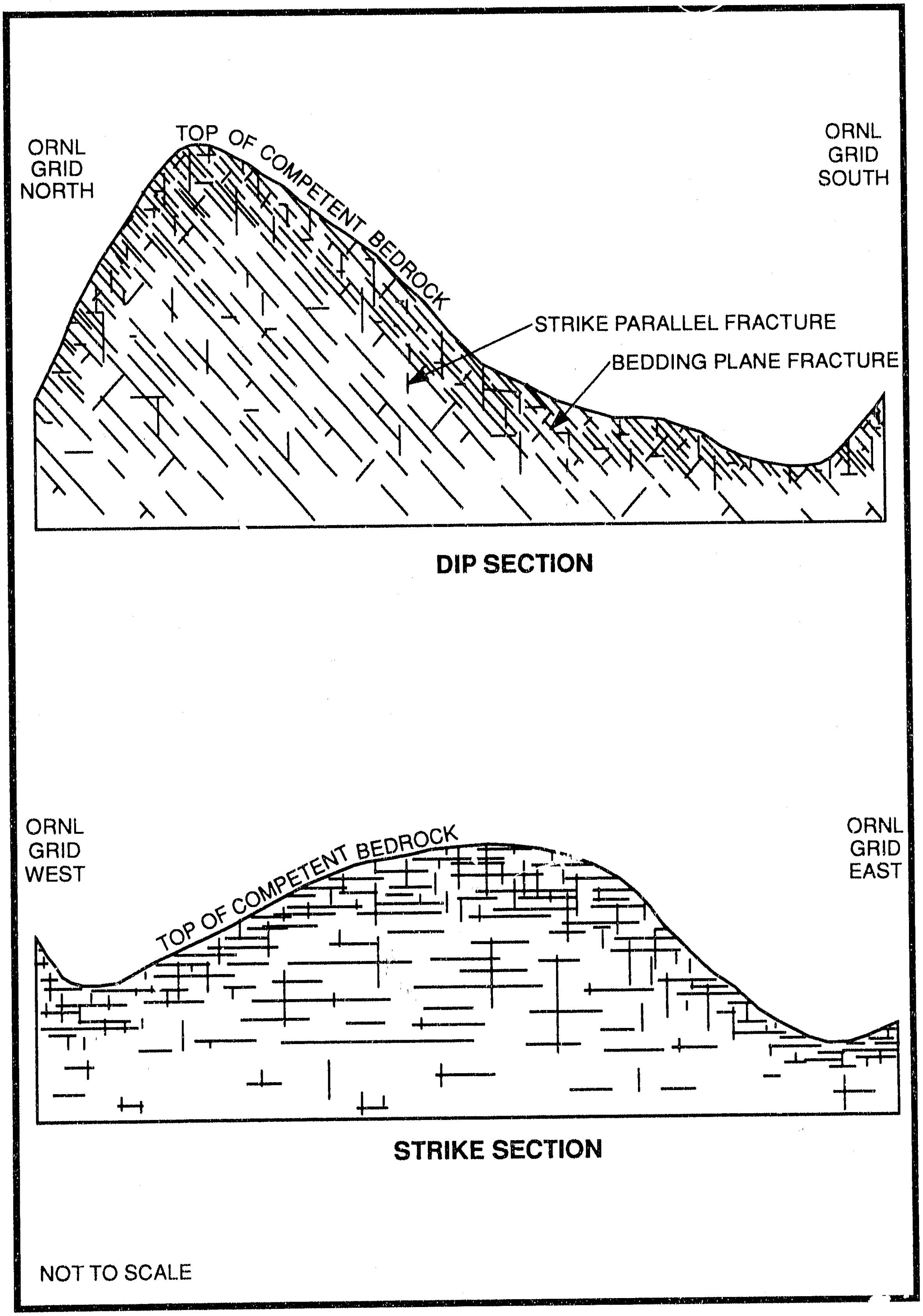


Fig. 3.21. Conceptual diagram of bedrock fracturing (Modified after Moore 1991).

5.18 4104.2

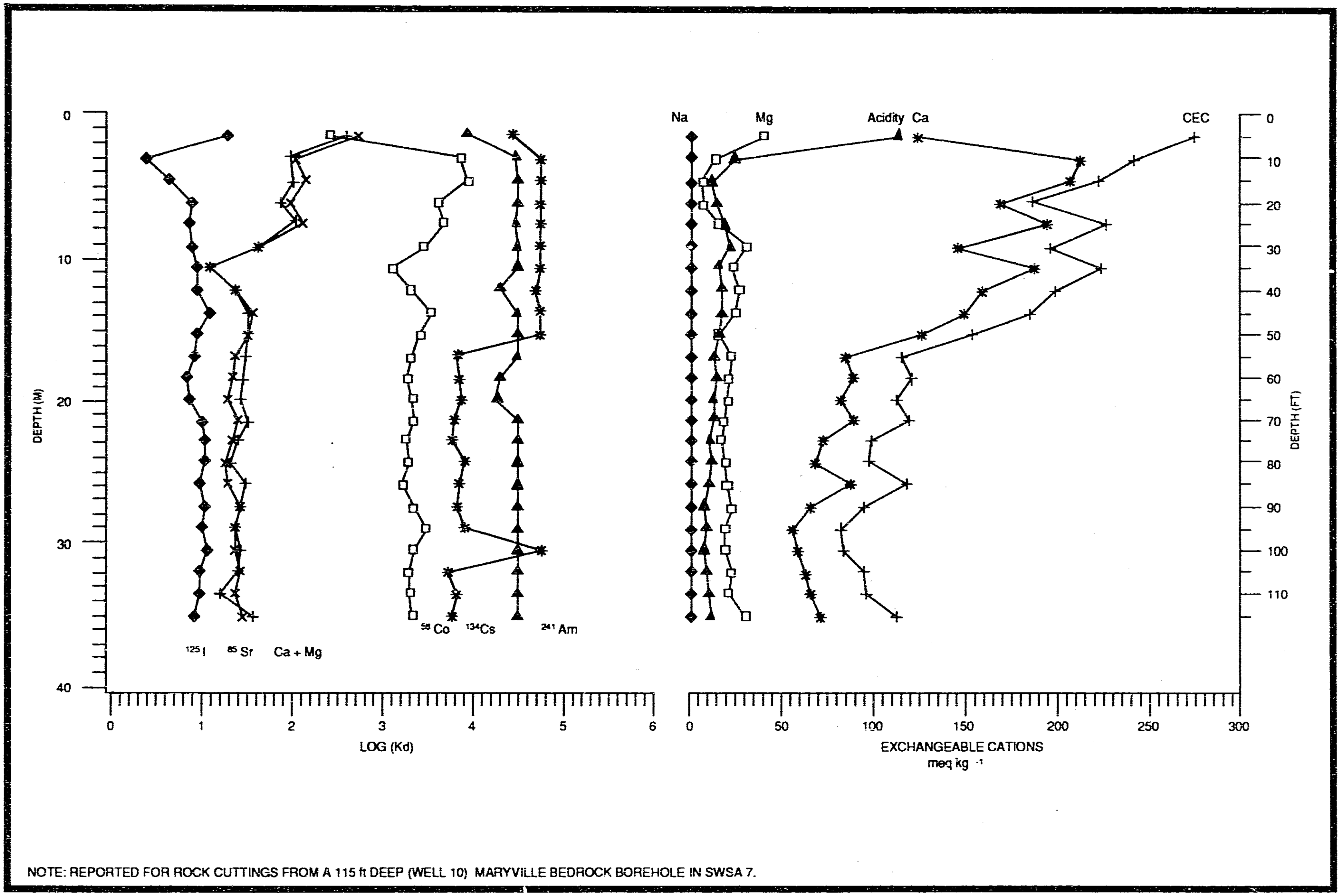
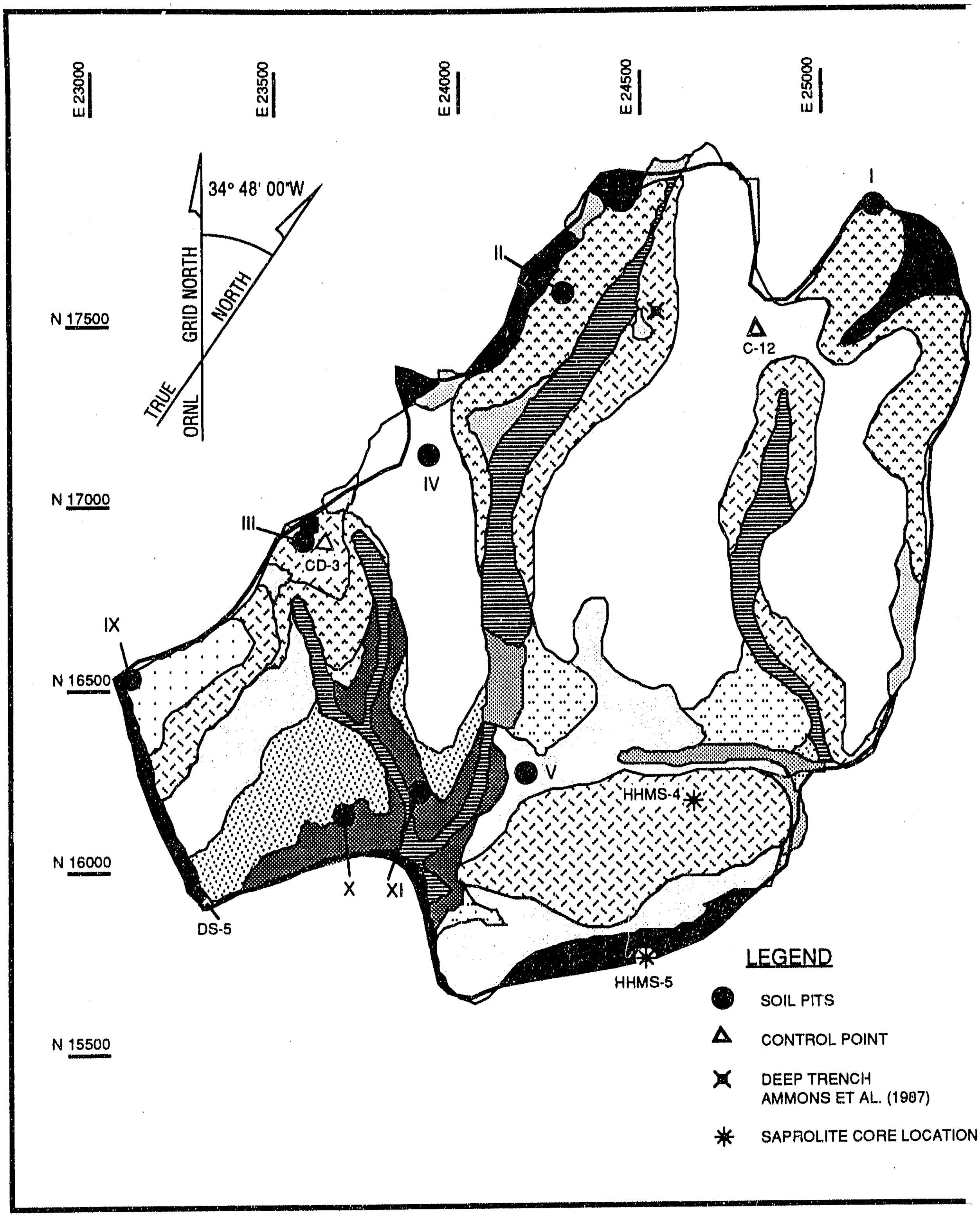


Fig. 3.22. Chemical properties of Maryville Limestone w/depth. Source: Rothschild, E. R., et al. 1984b. *Geohydrologic Characterization of Proposed SWSA 7*, ORNL/TM-9314, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

5.18E 4104.136
Adapted from WAG 6 06f169.DGN

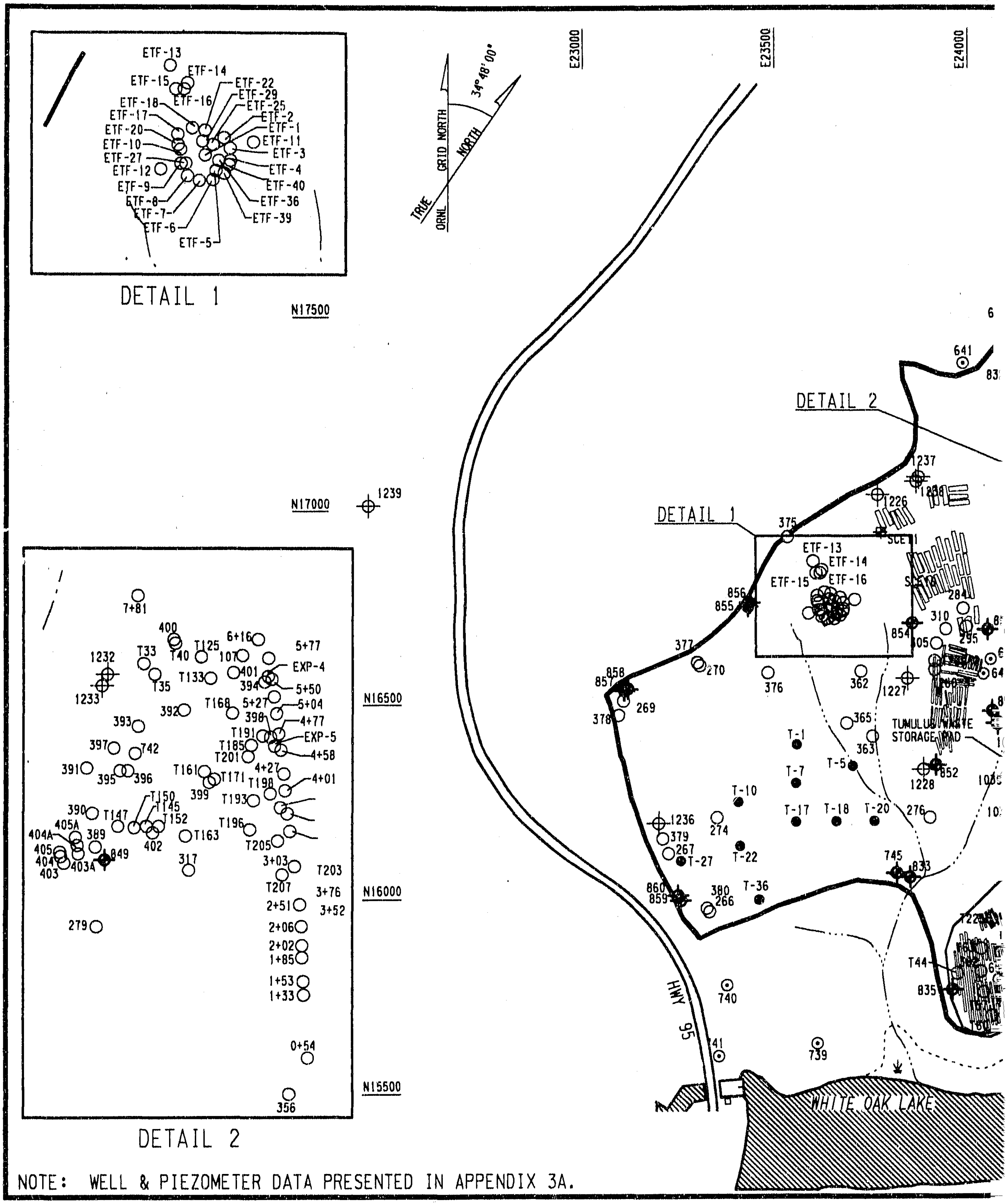


5.18F 4104.173
Adapted from WAG6 06F168.DGN

E 25500

MAP UNIT	SOIL TAXONOMY
1	TYPIC DYSTROCHREPTS; LOAMY-SKELETAL, MIXED, THERMIC, SHALLOW.
2	STEEP AND VERY STEEP SIDE SLOPES WITH DOUBLY CONVEX SLOPES. SOILS ARE MOSTLY TYPIC DYSTROCHREPTS; LOAMY-SKELETAL, MIXED, THERMIC. (BERKS-VARIANT SERIES).
3	LONG NARROW SIDE SLOPES WITH SLOPE GRADIENTS MORE THAN 12% AND NARROW DOUBLY CONVEX UPLAND SUMMITS. SOILS ARE MOSTLY RUPTIC-ULTIC DYSTROCHREPTS; LOAMY-SKELETAL, MIXED THERMIC (MUSE SERIES).
4	BROAD UPLAND SUMMITS AND BROAD SIDE SLOPES WITH SLOPE GRADIENTS BETWEEN 6 AND 12%, AND DOUBLY CONVEX SLOPE CONFIGURATION. SOILS ARE MOSTLY TYPIC HAPLUDULTS; CLAYEY, MIXED, THERMIC (MUSE SERIES).
5	FOOT-SLOPES WITH MOSTLY DOUBLY CONCAVE SLOPE CONFIGURATION. SLOPES RANGE FROM 6 TO 20%. SOILS ARE TYPIC FRAGIDULTS; FINE-SILTY, MIXED, THERMIC (LEADVALE SERIES) AND TYPIC HAPLUDULTS; FINE-SILTY, MIXED, THERMIC (SHELOCTA SERIES).
6	DRAINAGEWAYS WITH MOSTLY WET ALLUVIAL SOILS THAT CLASSIFY AS TYPIC OR AERIC FLUVAQUENTS; FINE-SILTY, MIXED, THERMIC (SERIES NOT DESIGNATED).
7	DRAINAGEWAYS THAT HAVE BEEN FILLED WITH DEBRIS FROM LAND CLEARING ACTIVITIES OR WITH EARTH MATERIALS FROM TRENCHING OPERATIONS (UDORTHENTS).
8	FOOT-SLOPE LANDFORMS THAT HAVE BEEN FILLED WITH DEBRIS FROM LAND CLEARING ACTIVITIES OR WITH EARTH MATERIALS FROM TRENCHING OPERATIONS (UDORTHENTS).
9	BROAD, NEARLY LEVEL UPLAND SUMMIT, PLUS SHOULDER AND SIDE SLOPES WITH GRADIENTS OF 6 TO 20%. THE SUMMIT SOILS FORMED IN LOESS/ALLUVIUM/SHALE RESIDUUM, WHEREAS THE SIDE-SLOPE SOILS FORMED IN ALLUVIUM/SHALE. SOILS ARE TYPIC PALEUDULTS; FINE-SILTY AND CLAYEY, SILICEOUS AND MIXED, THERMIC (TURBEVILLE SERIES).
10	LOW UPLAND WITH SLOPE GRADIENTS BETWEEN 6 AND 12% AND MOSTLY DOUBLY CONVEX SLOPE CONFIGURATION. SOILS ARE MOSTLY RUPTIC-AQUULTIC DYSTROCHERPTS; LOAMY-SKELETAL AND CLAYEY, MIXED THERMIC (SERIES NOT DESIGNATED).
11	TOE-SLOPES WITH SLOPE GRADIENTS OF 2 TO 6% AND DOUBLY CONCAVE SLOPE CONFIGURATION. SOILS ARE MOSTLY AQUIC HAPLUDULTS; CLAYEY, MIXED, THERMIC. (TUPELO SERIES)

Fig. 3.23. WAG 6 soil map. *Sources:* Lietzke, D. A., and S. Y. Lee. 1986. *Soil Survey of Solid Waste Storage Area Six*, ORNL/TM-10013, Oak Ridge National Laboratory, Oak Ridge Tennessee. Ammons, J. T., et al. 1987. *Characteristics of Soils and Saprolite in SWSA 6*, ORNL/RAP/LTR-87-84, Oak Ridge National Laboratory, Oak Ridge, Tennessee.



NOTE: WELL & PIEZOMETER DATA PRESENTED IN APPENDIX 3A.

WAG6 06F317.DGN
9-9

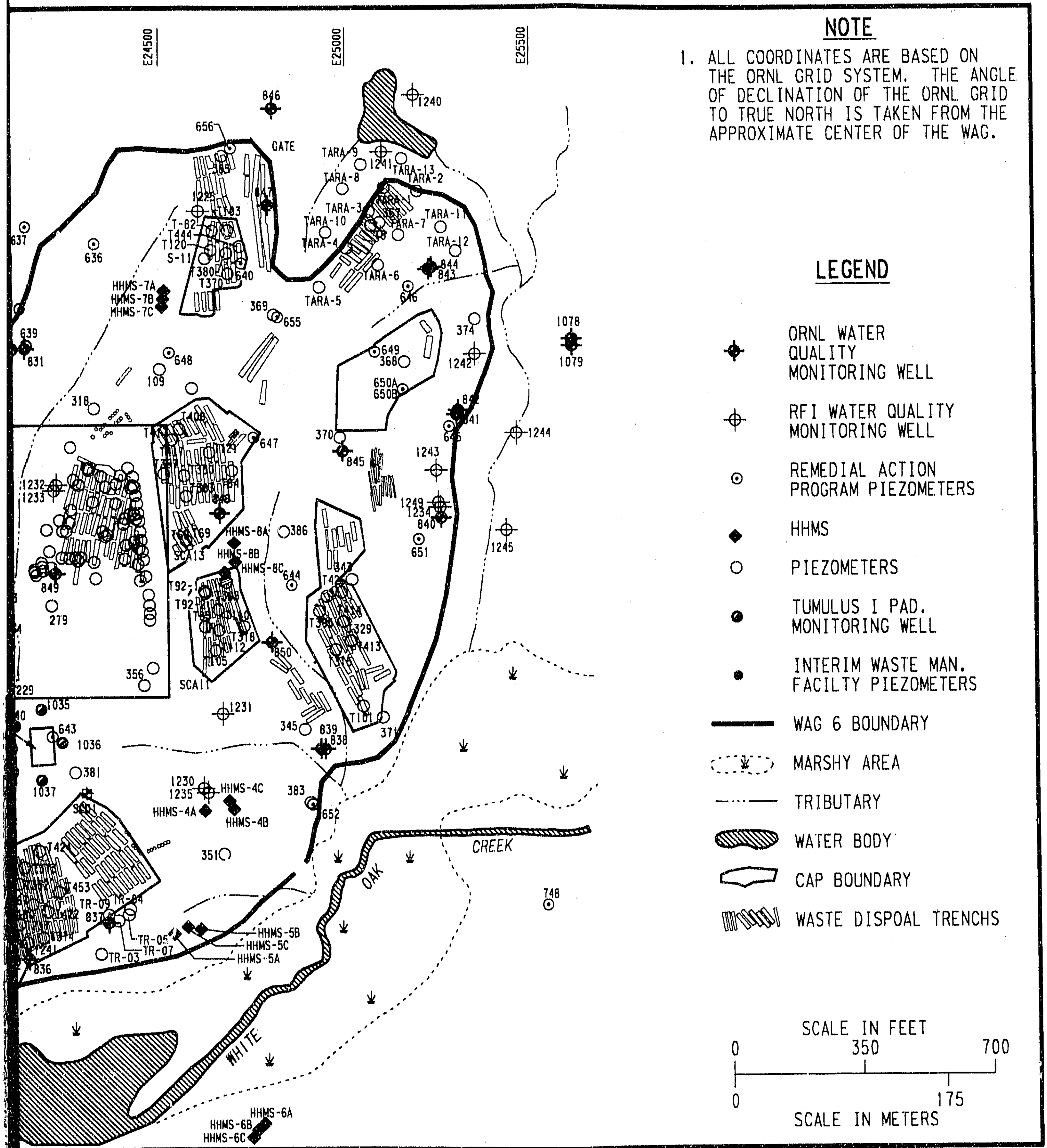
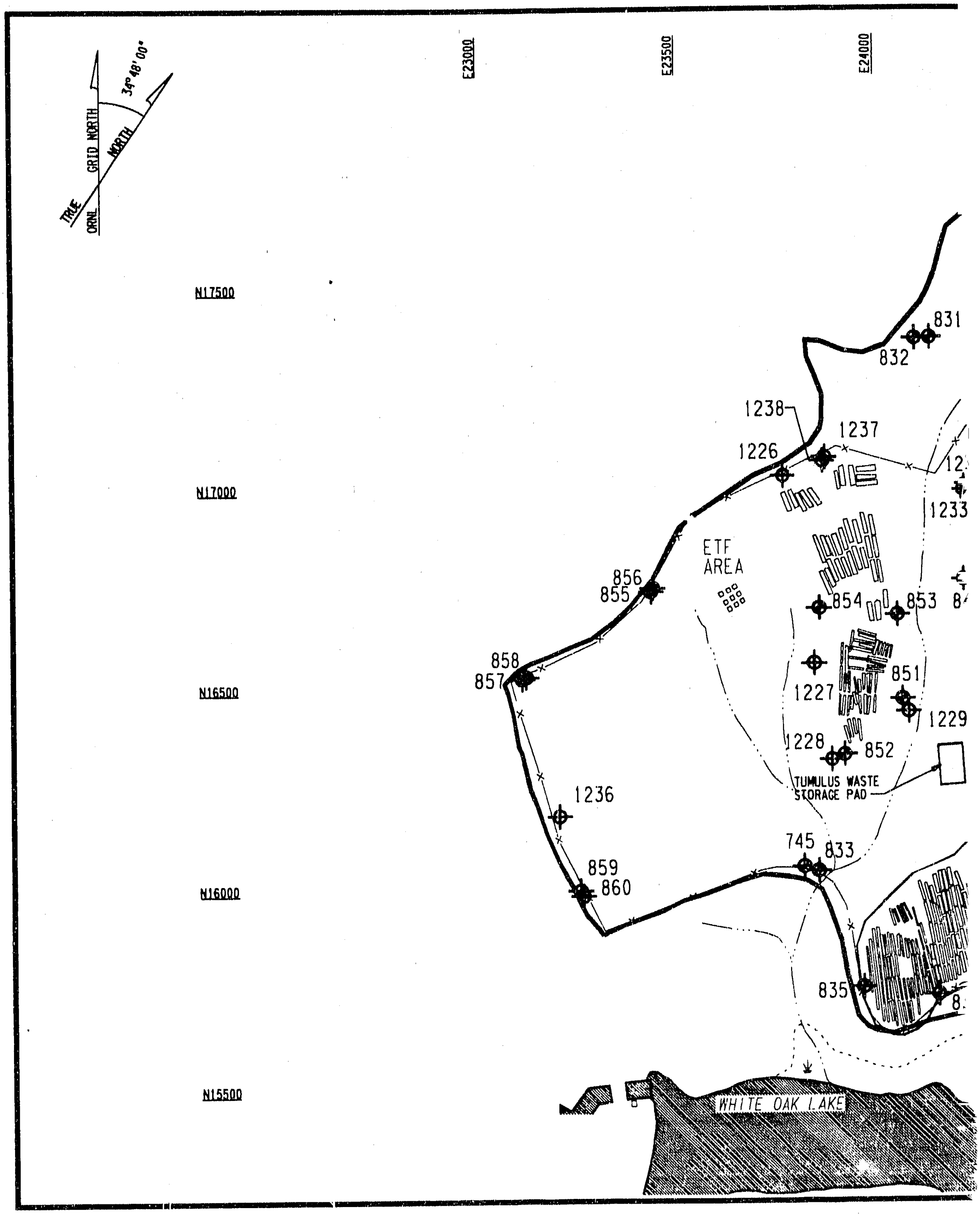


Fig. 3.24. Existing wells and piezometers at WAG 6 as of June 1990.



WAG6 06F318.DGN
9-4

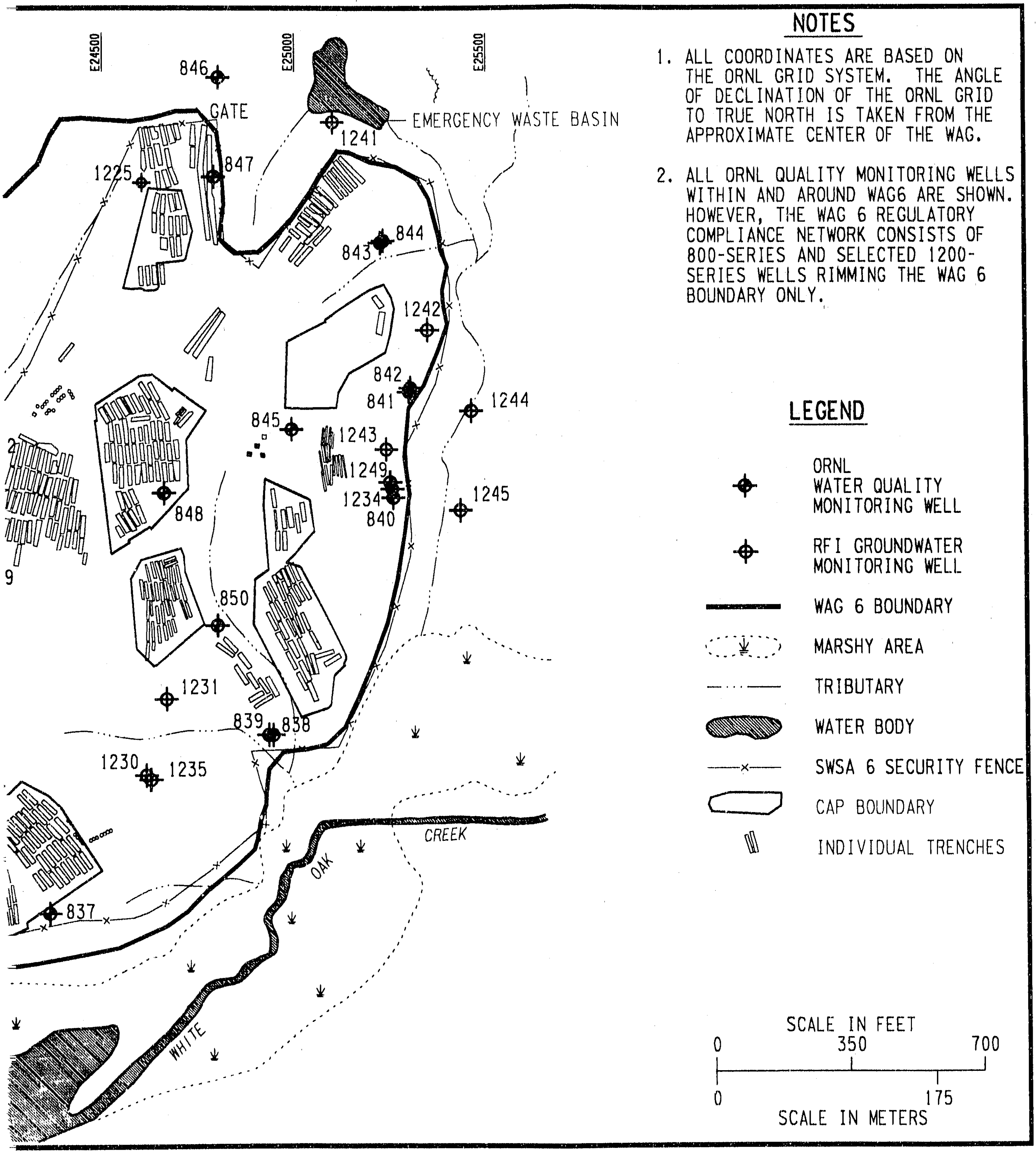


Fig. 3.25. WAG 6 groundwater quality monitoring wells.

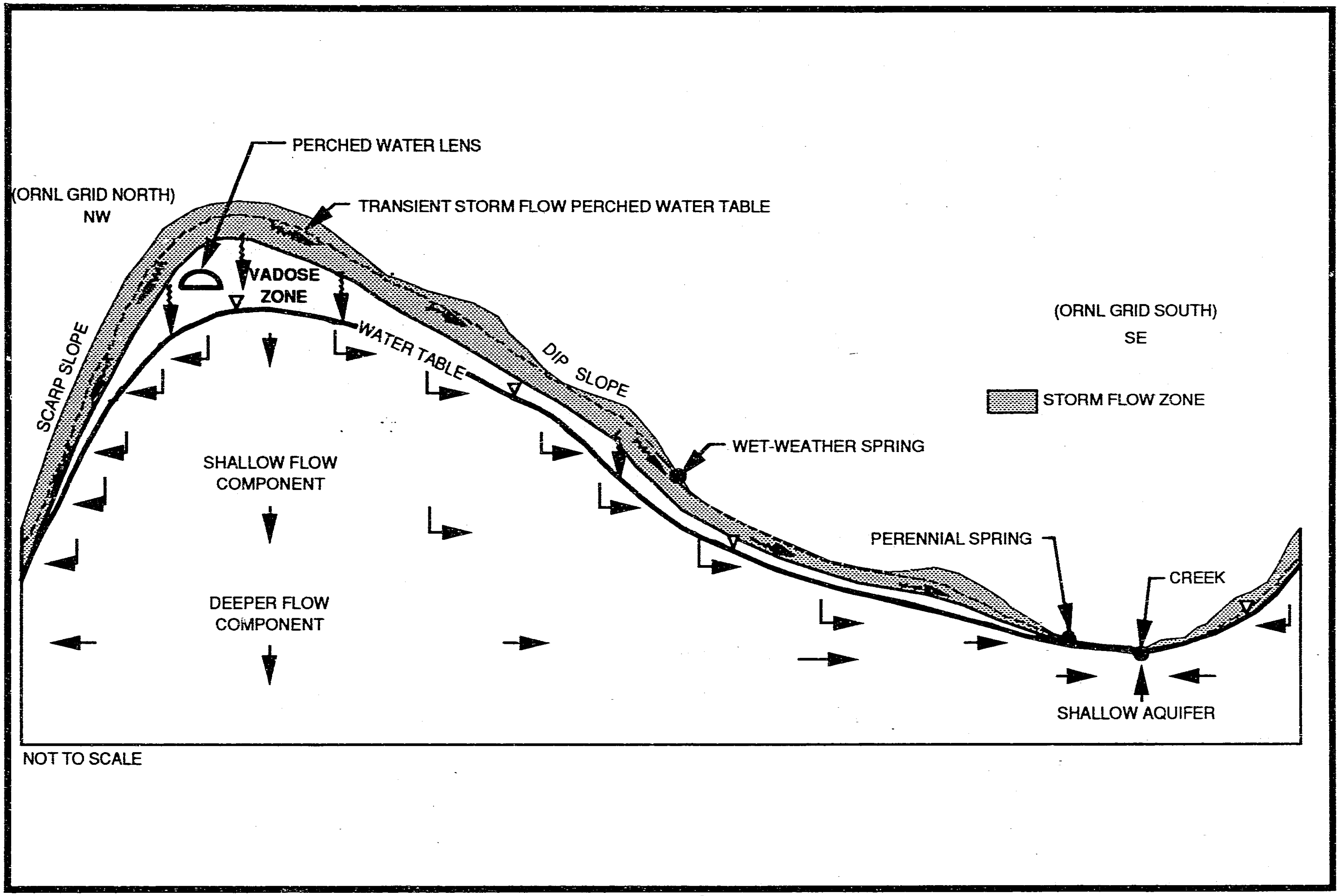
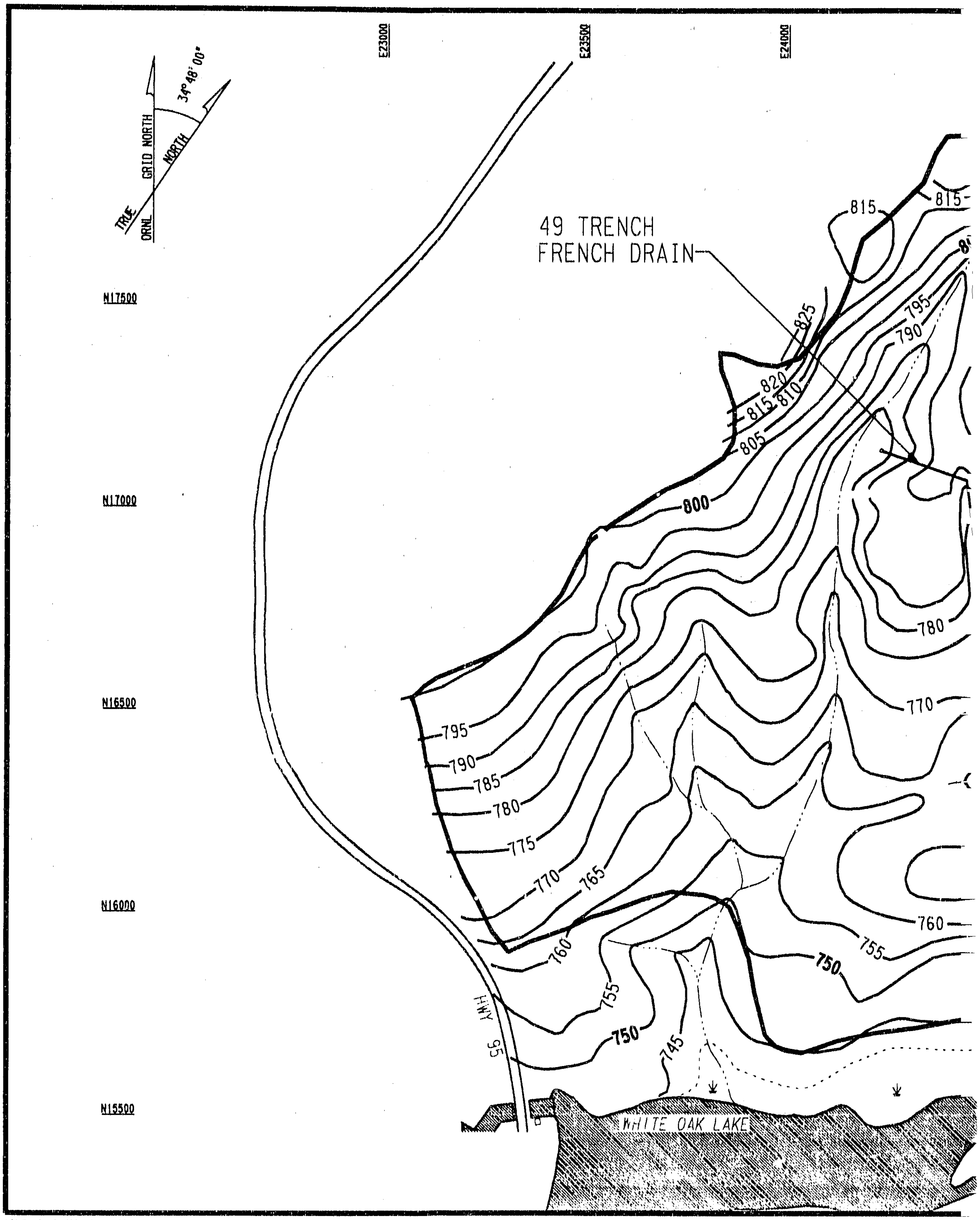


Fig. 3.26. Conceptual grour water occurrence at WAG 6. *Source:* After Moore, G. K. 1988. *Concepts of Groundwater Occurrence and Flow Near Oak Ridge National Laboratory, Tennessee,* ORNL/TM-10969, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

5.18E 4104.147
Adapted from WAG6 06F257.DGN



WAG 6 06F319.DGN
9-4

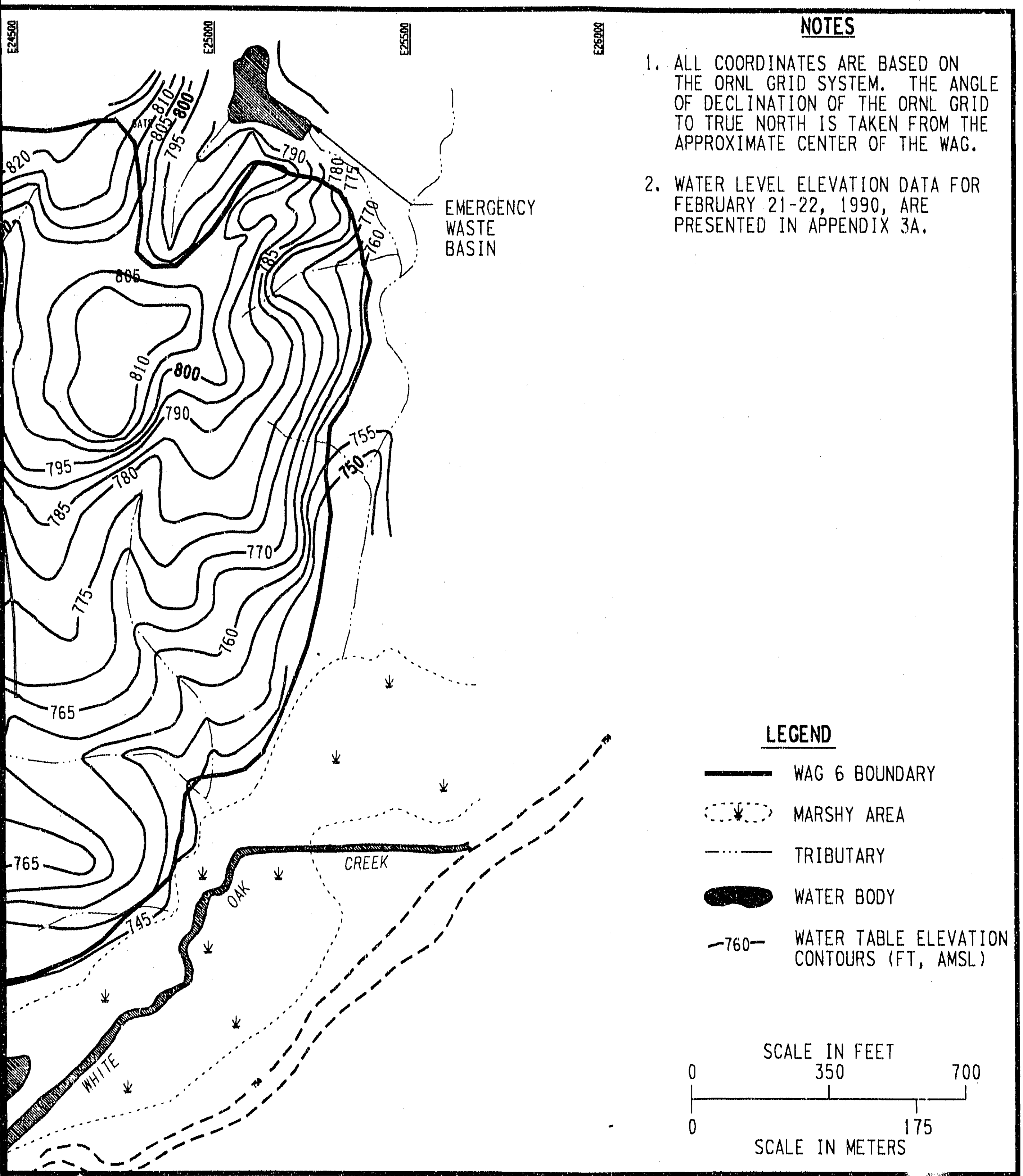
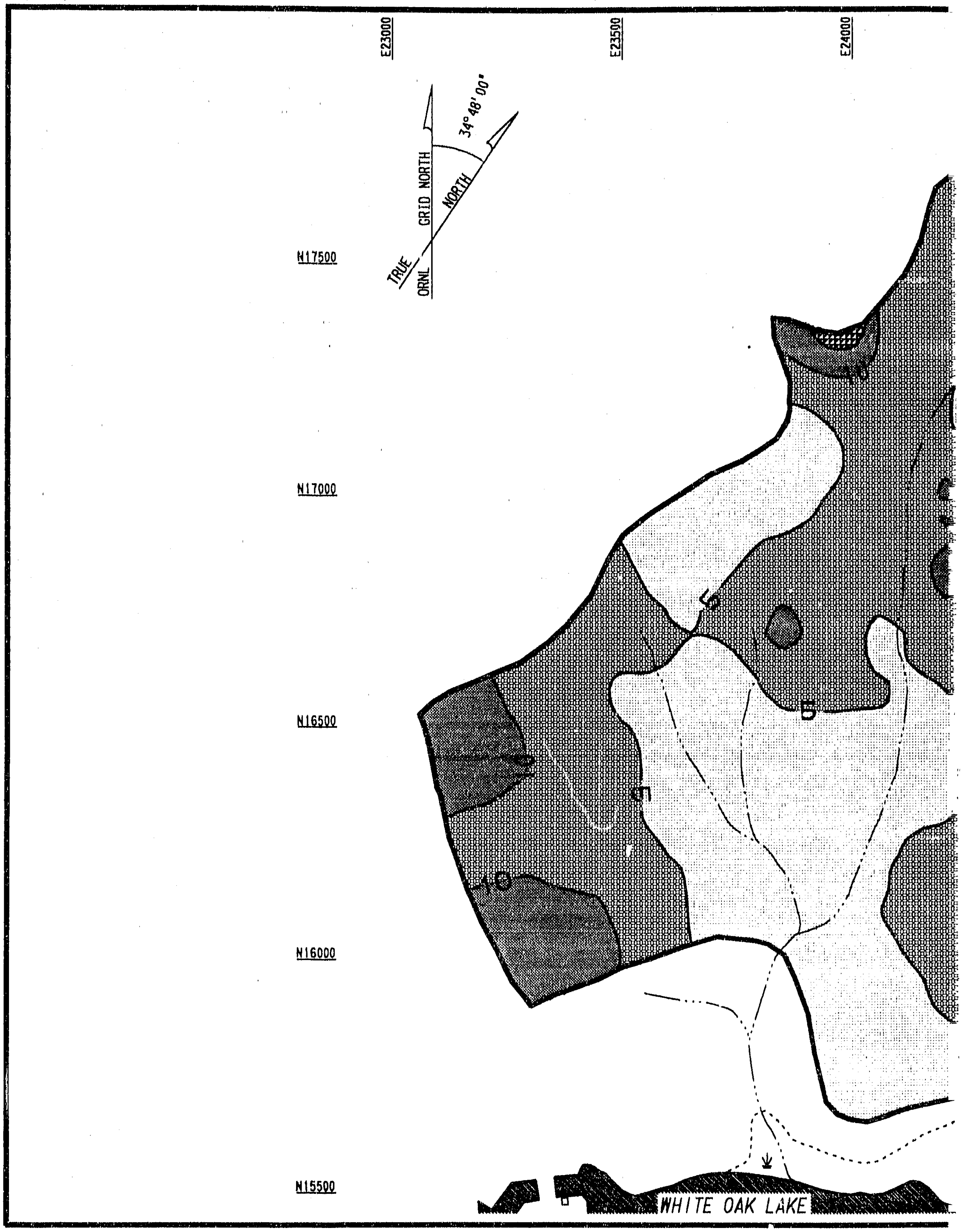


Fig. 3.27. WAG 6 potentiometric map for February 21-22, 1990.



WAG6 DELTFLUC.DGN
9-4

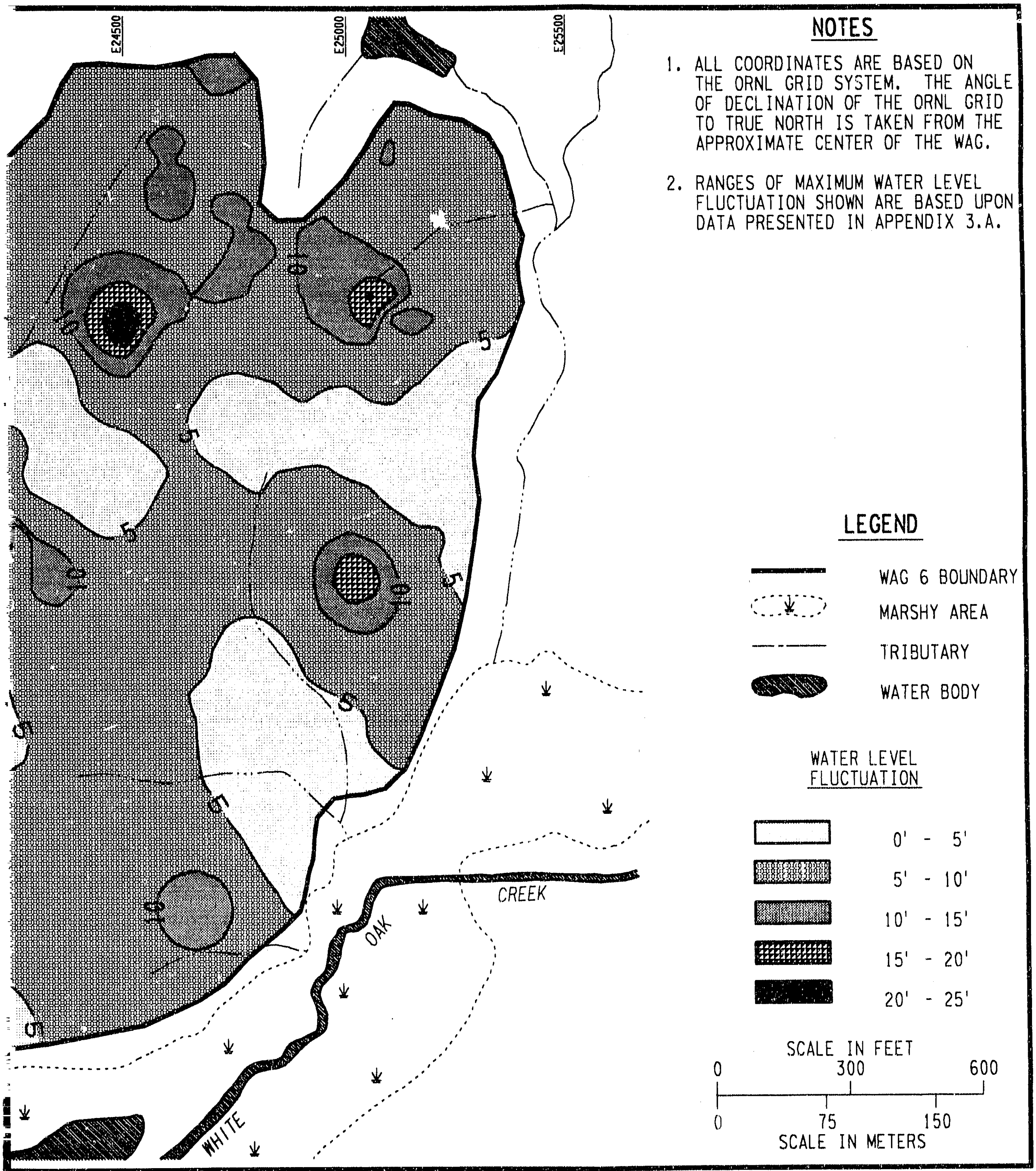


Fig. 3.28. WAG 6 maximum historic water level fluctuation.

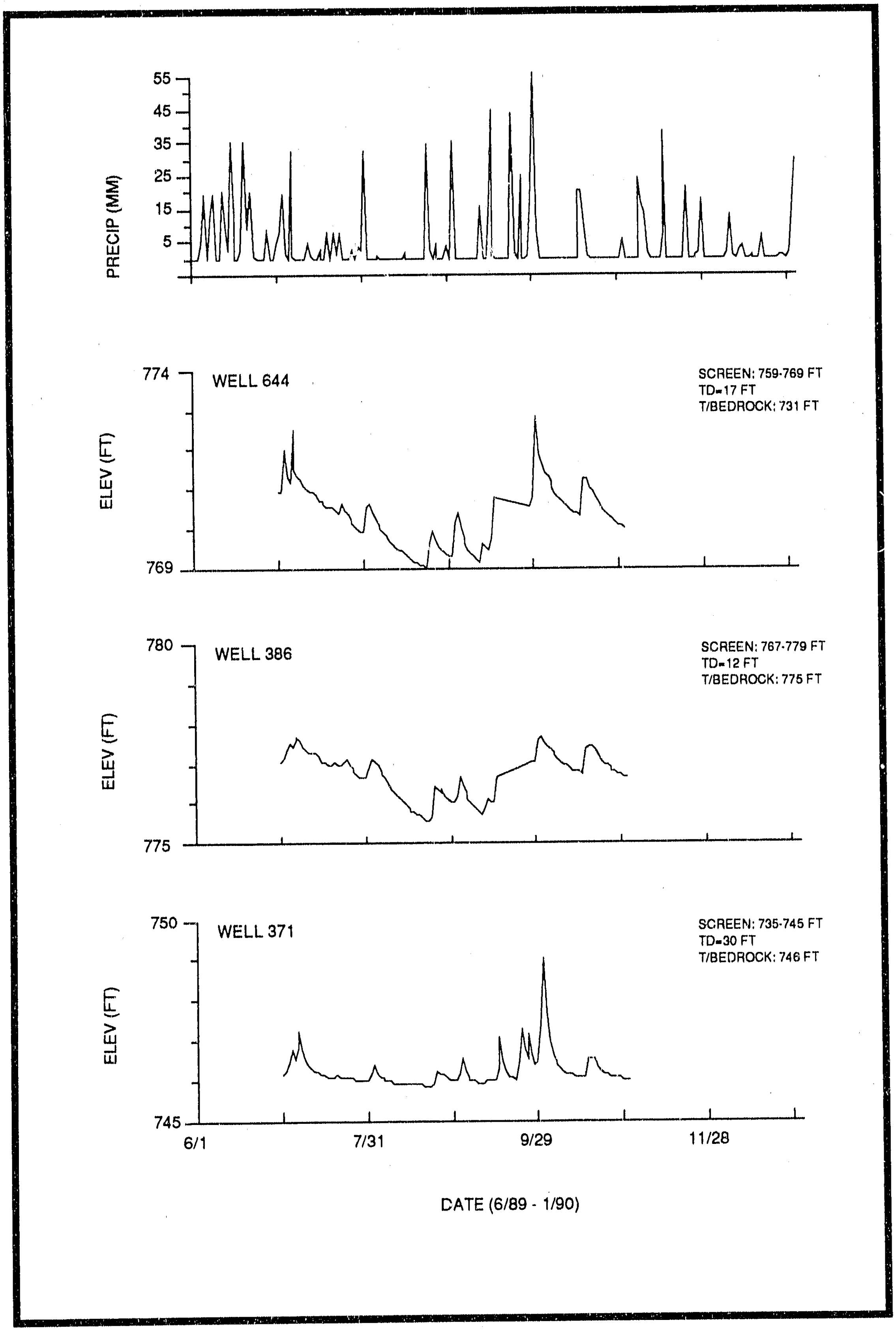


Fig. 3.29. WAG 6 shallow well response to precipitation.

5.18E 4104.140
Adapted from WAG 6 06F145.DGN

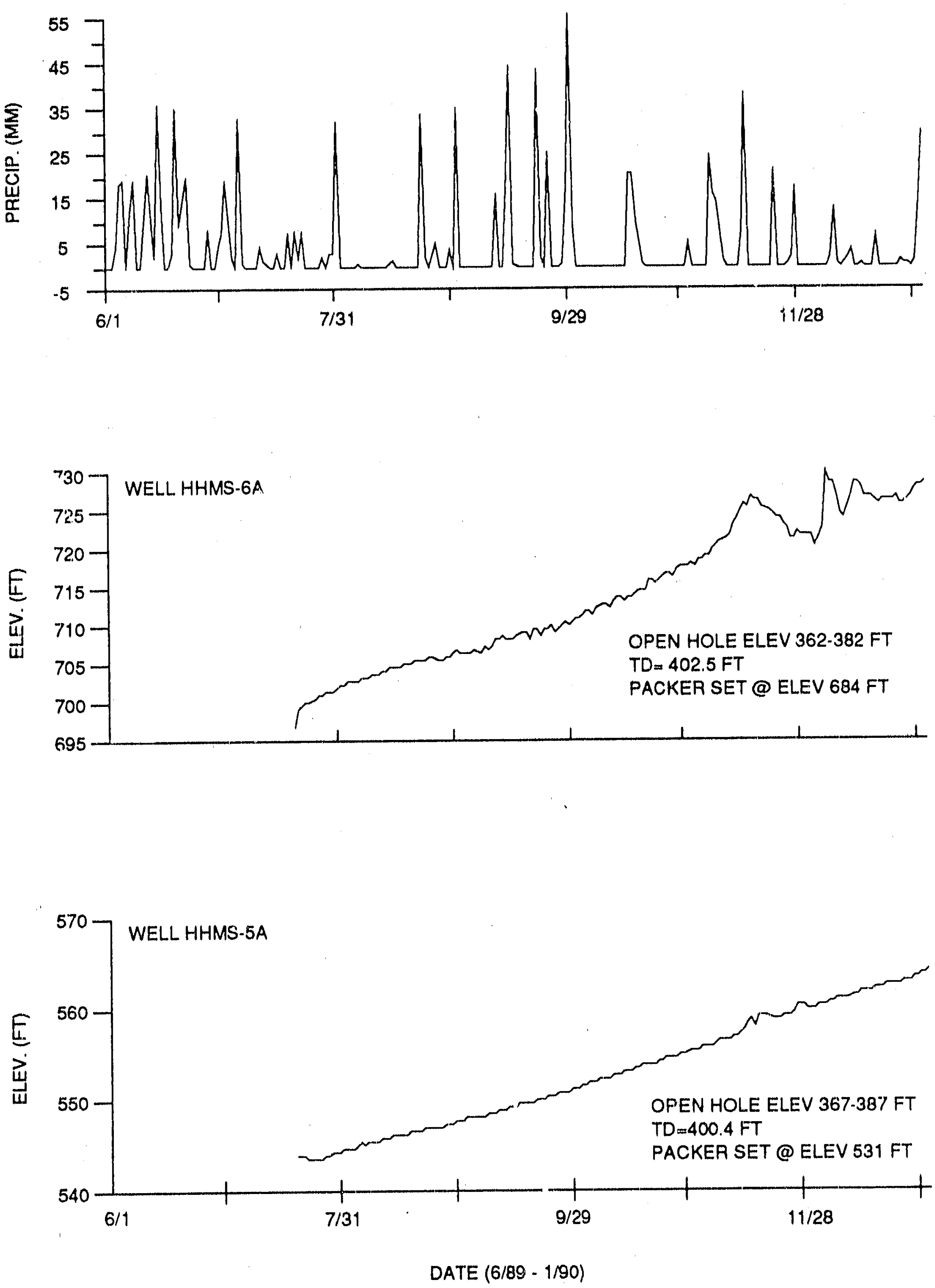
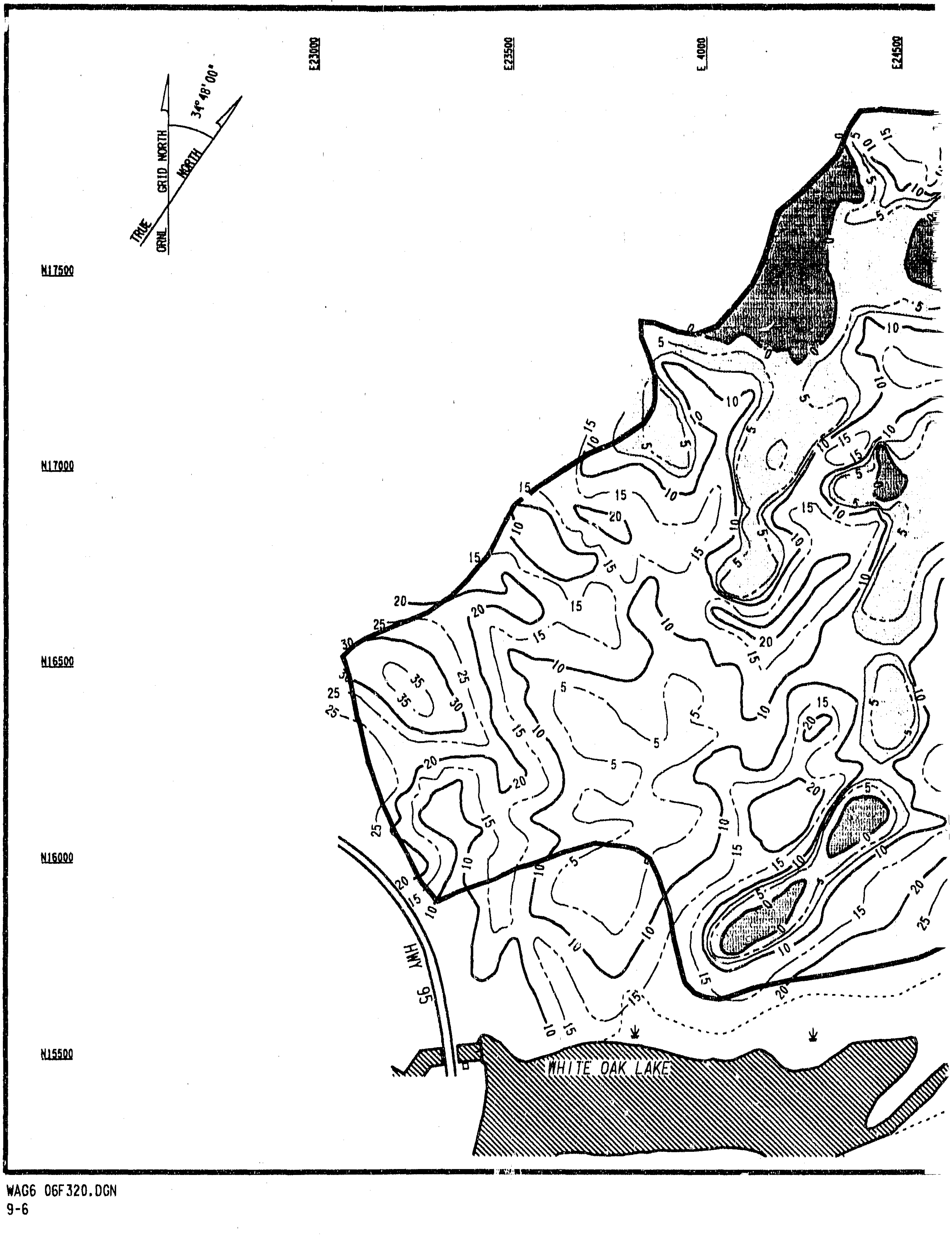


Fig. 3.30. WAG 6 deep well response to precipitation.

4.18E 4104.142
Adapted from WAG 6 06F146.DGN



WAG6 06F320.DGN
9-6

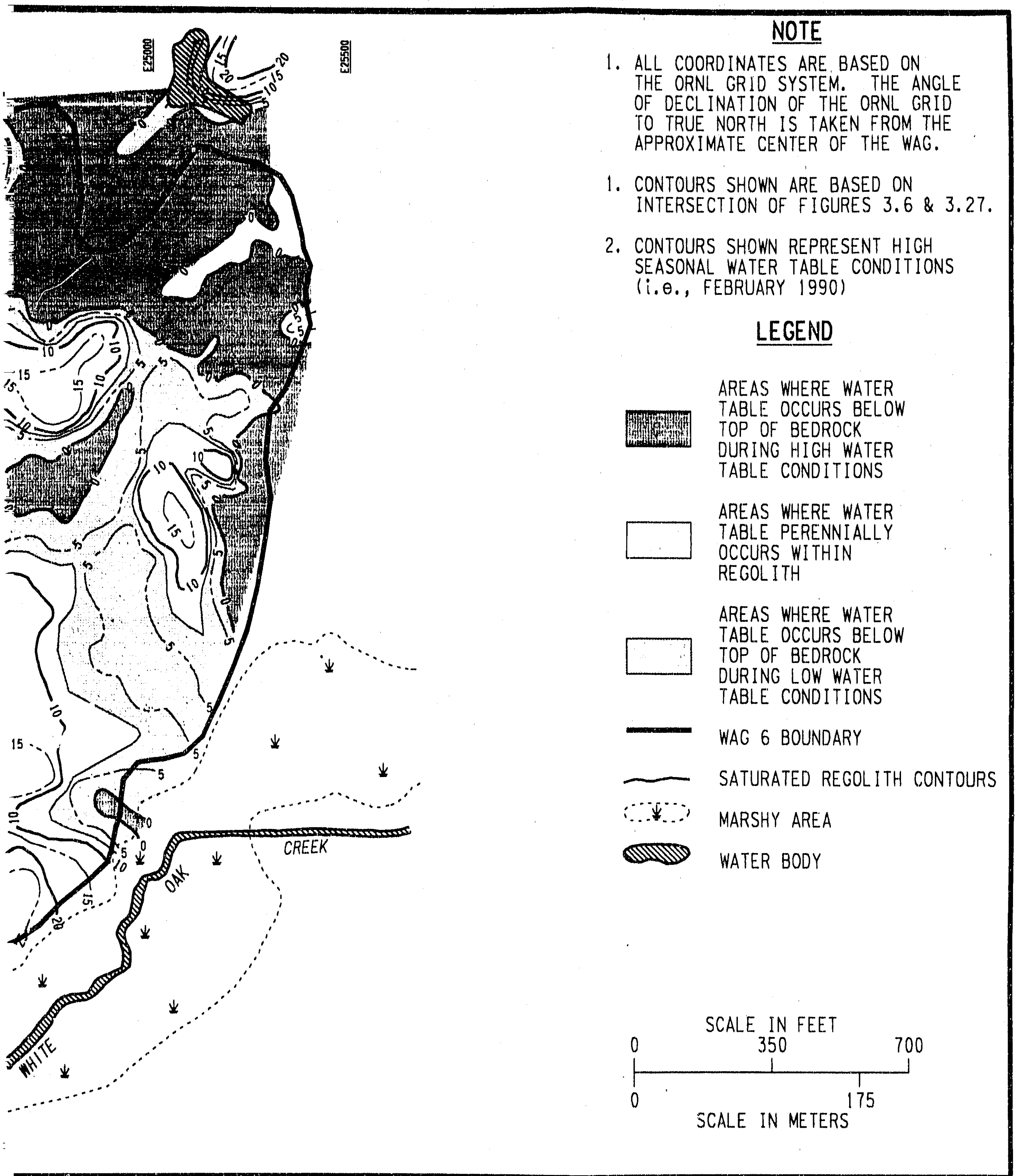
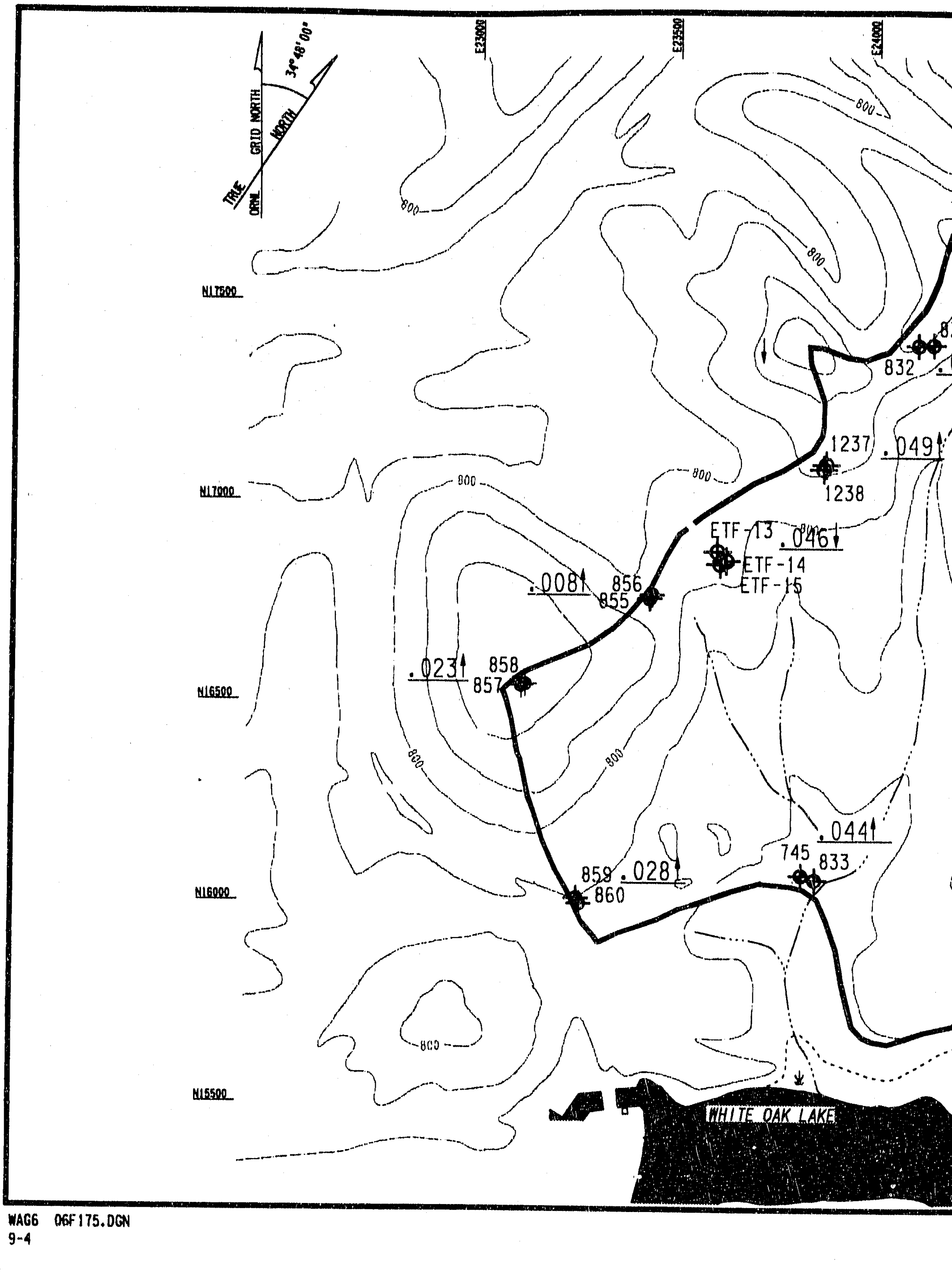


Fig. 3.31. WAG 6 saturated regolith thickness, February 21-22, 1990.



WAG6 06F175.DGN
9-4

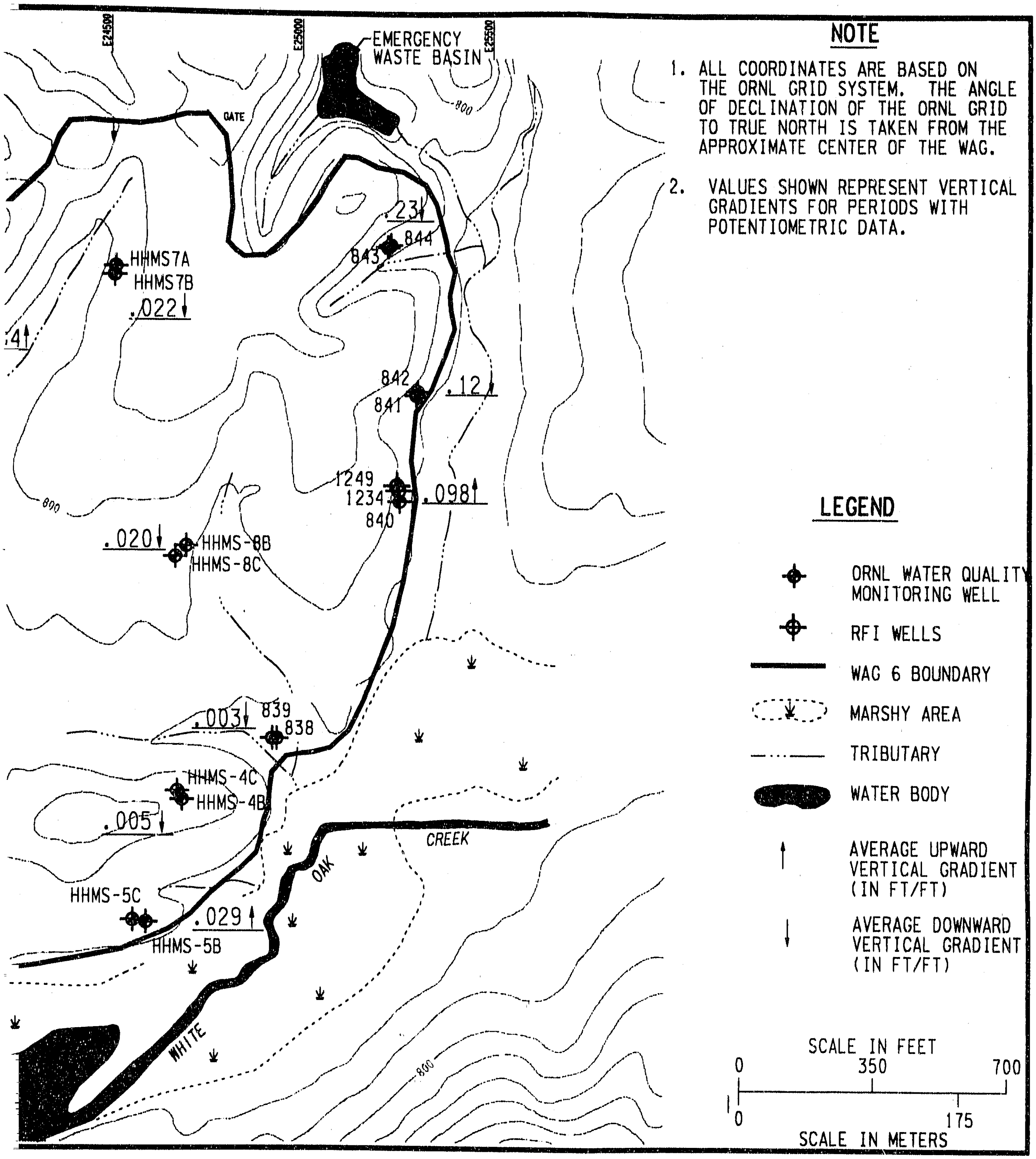
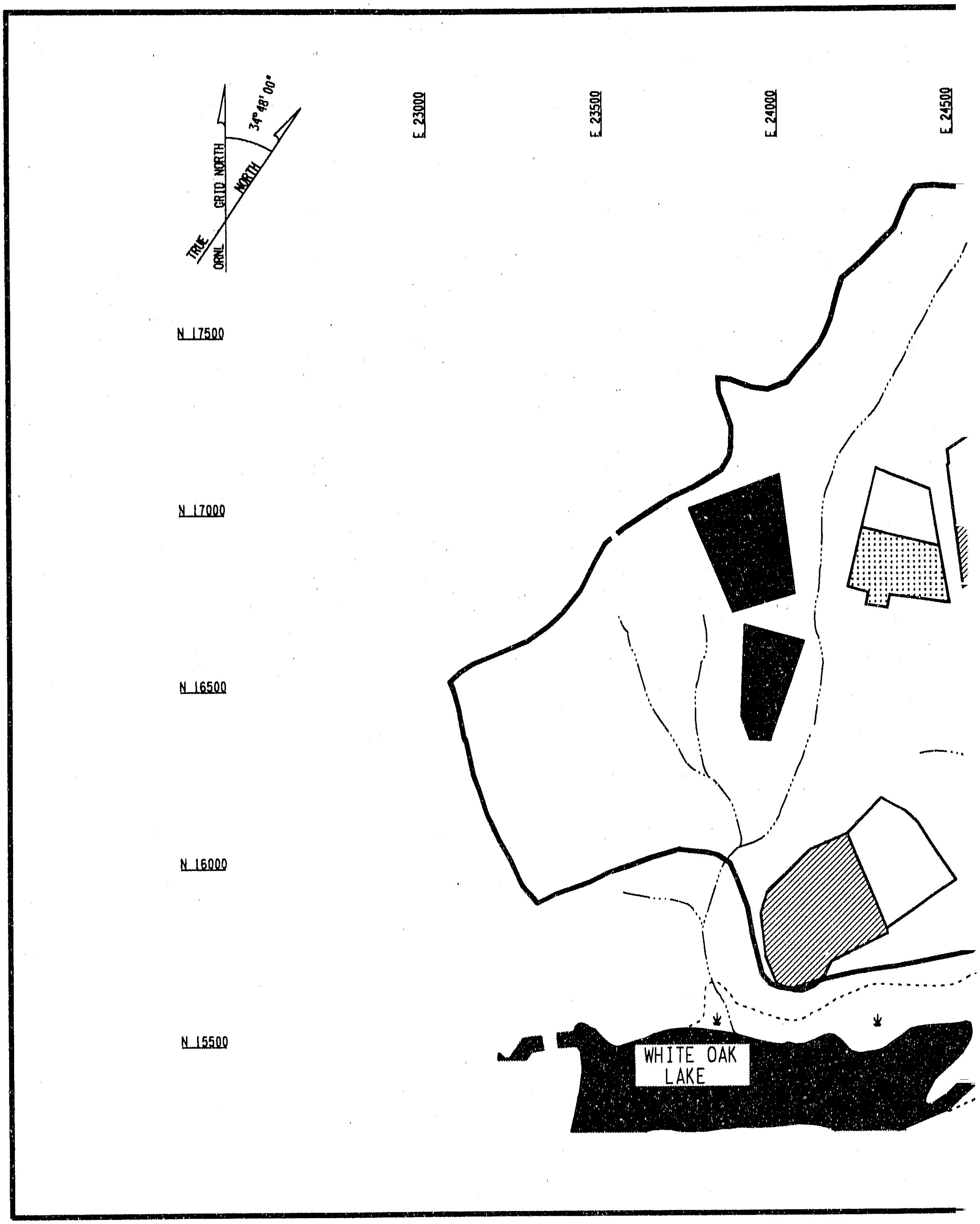


Fig. 3.32. WAG 6 vertical hydraulic gradient distribution.



WAG6 06F321.DGN
9-4

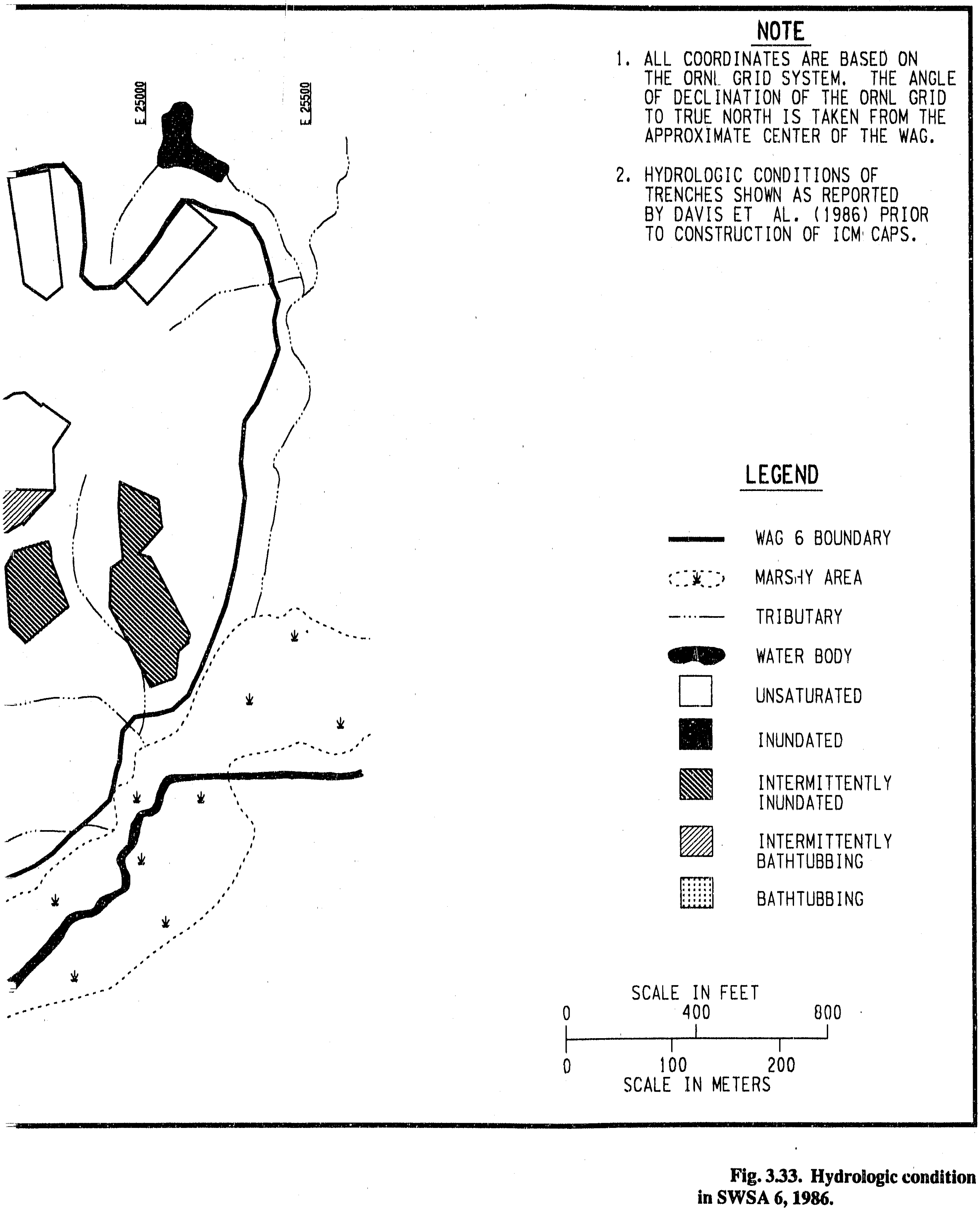
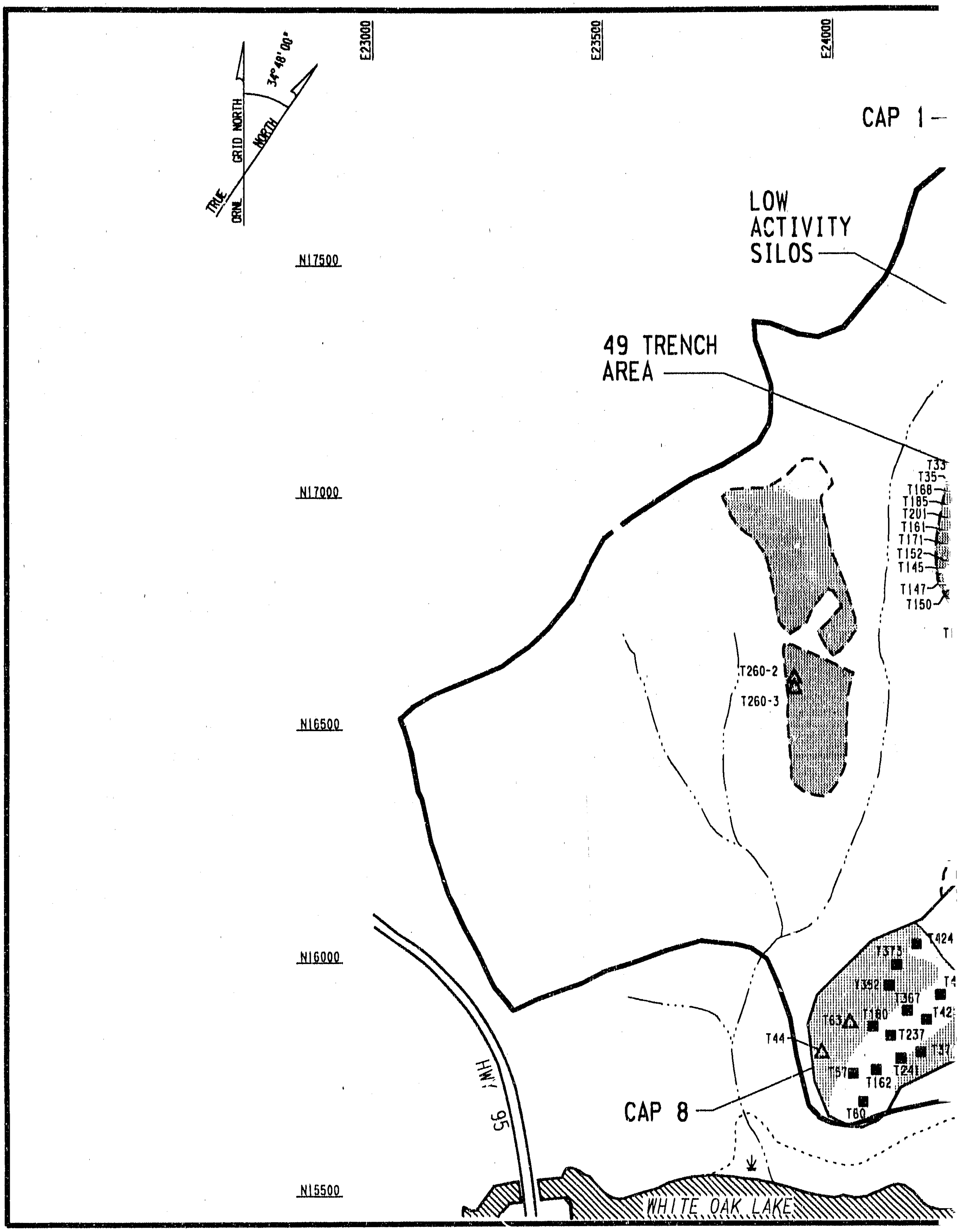


Fig. 3.33. Hydrologic condition of trenches in SWSA 6, 1986.



WAG6 06F322.DGN
9-5

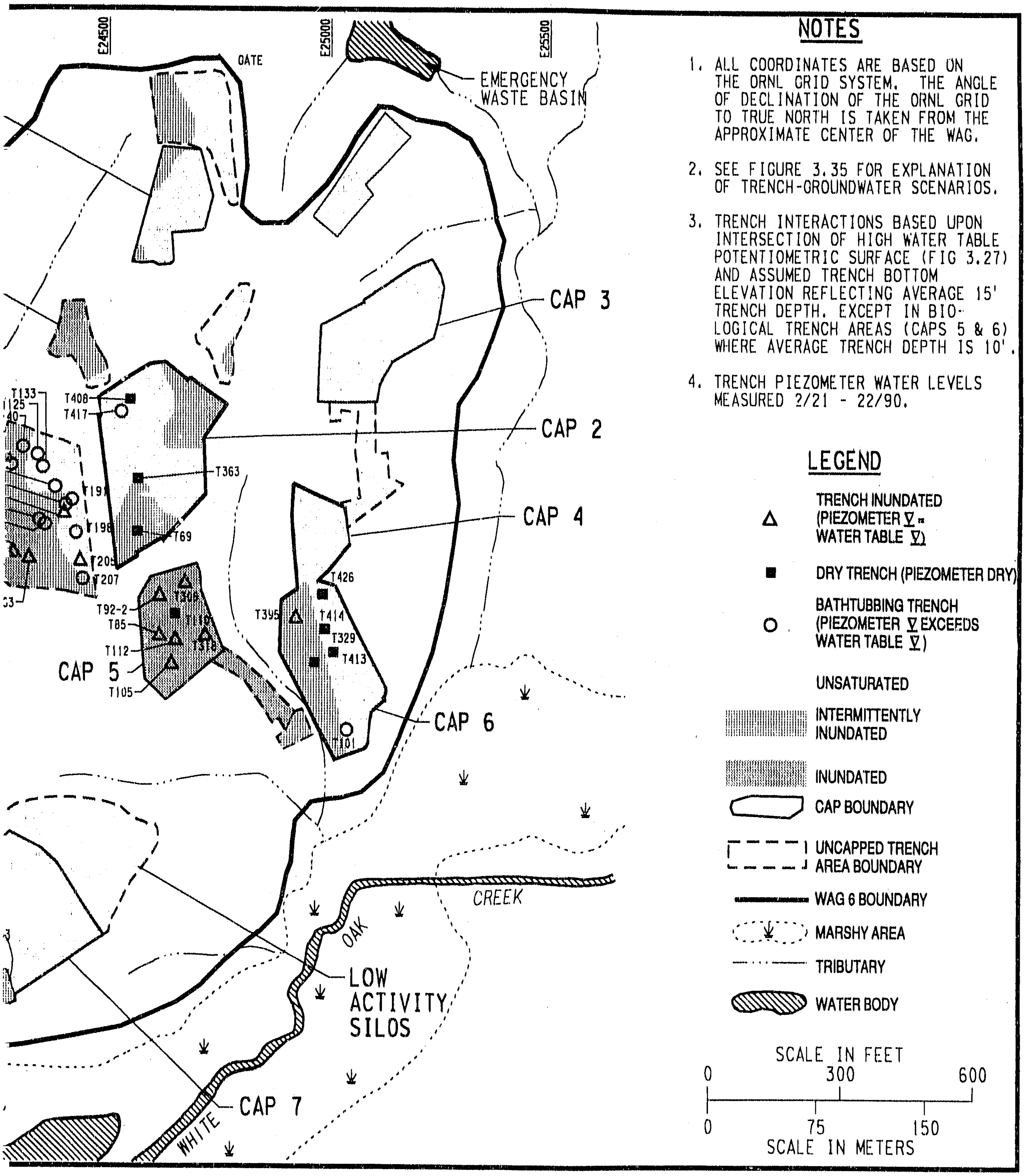
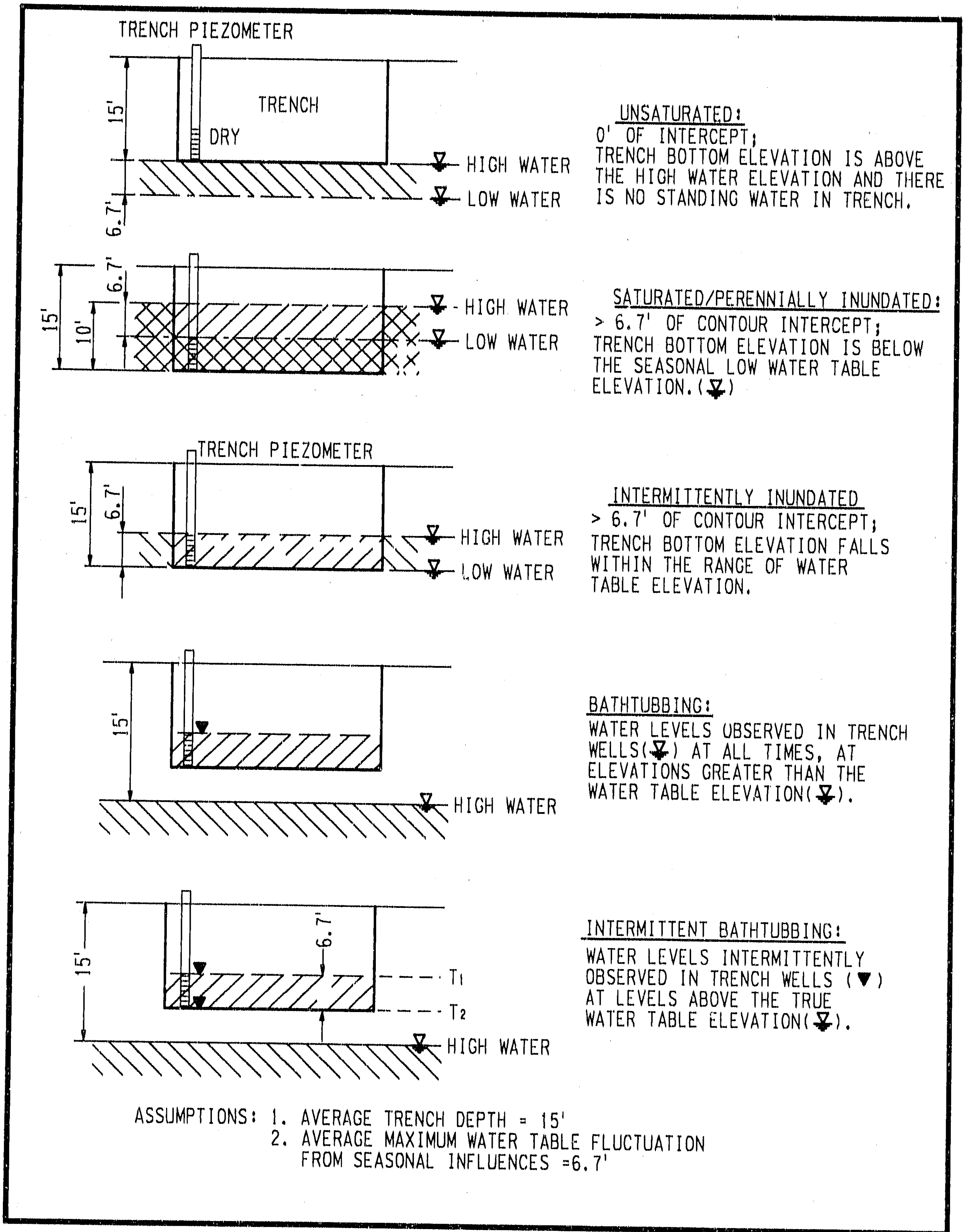


Fig. 3.34. WAG 6 trench groundwater interaction map, February 1990.



WAG6 06F323.DGN
9-4

Fig. 3.35. Typical WAG 6 trench groundwater interaction scenarios.

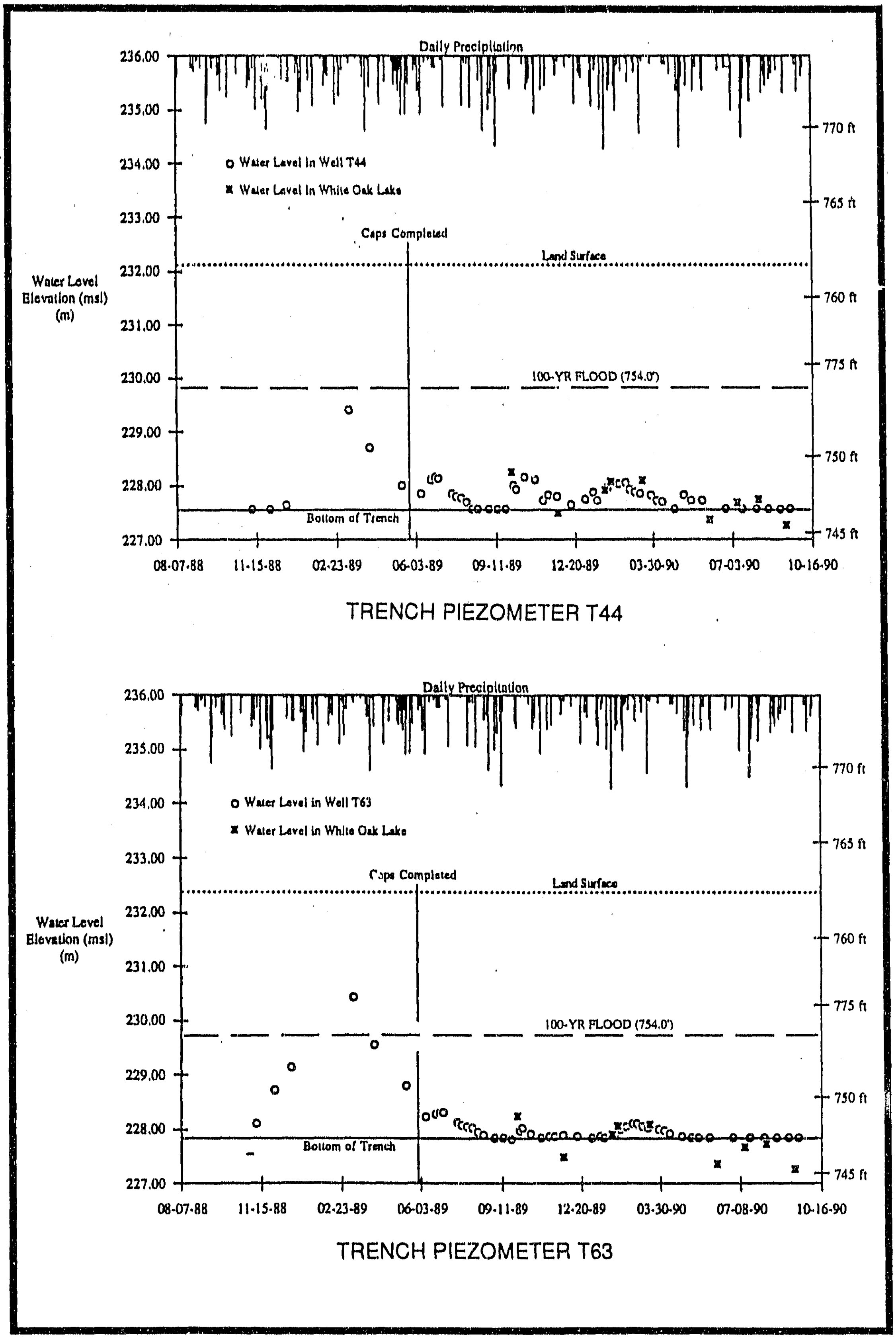
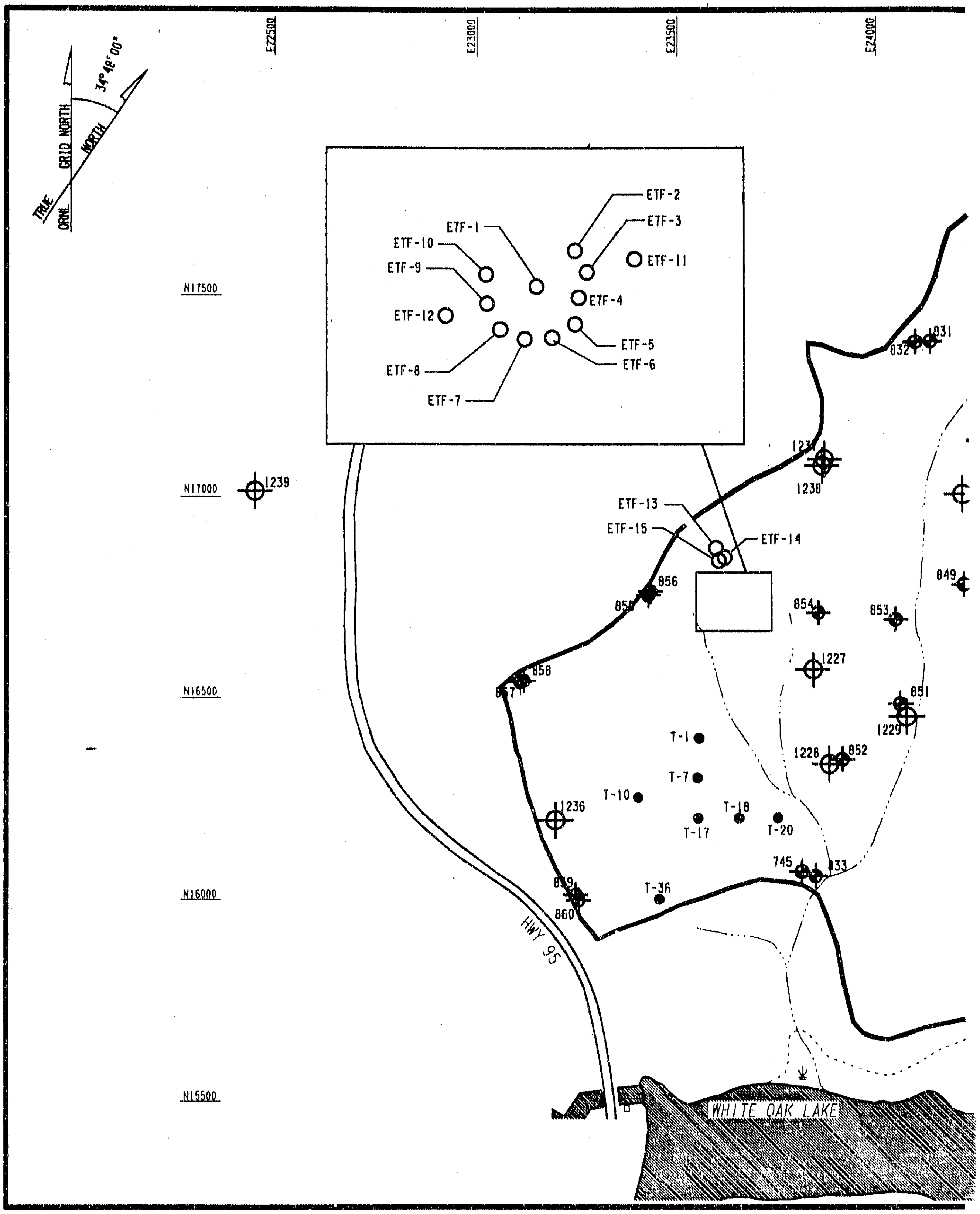


Fig. 3.36. Hydrograph and associated hyetograph for wells T44 and T63. *Source:* Ashwood, T. L., and B. P. Spalding. 1991. *SWSA 6 Interim Corrective Measures Environmental Monitoring: FY 1990 Results*, ORNL/ER-36, Oak Ridge National Laboratory, Oak Ridge, Tennessee.



WAG6 06F324.DGN
9-4

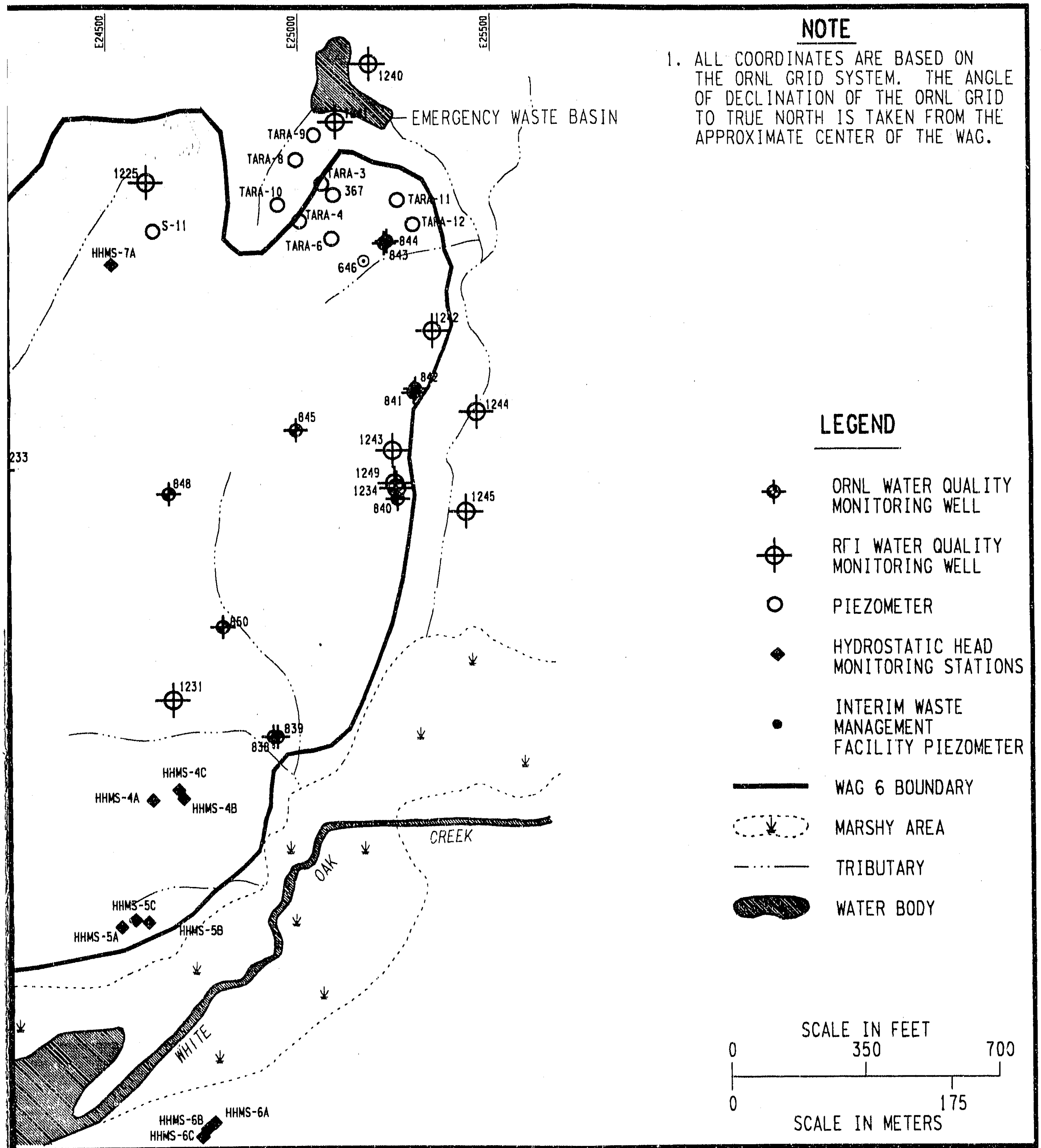
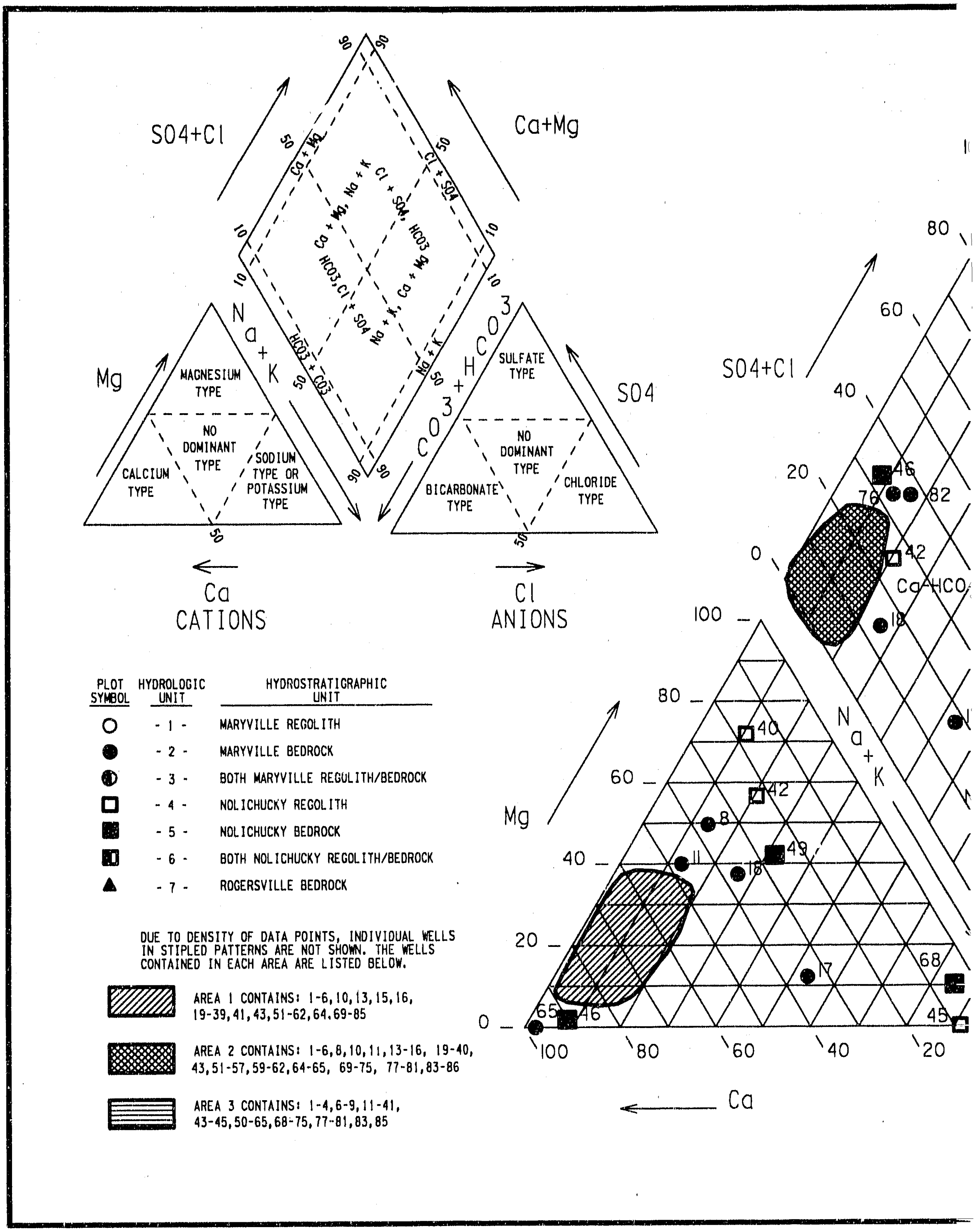
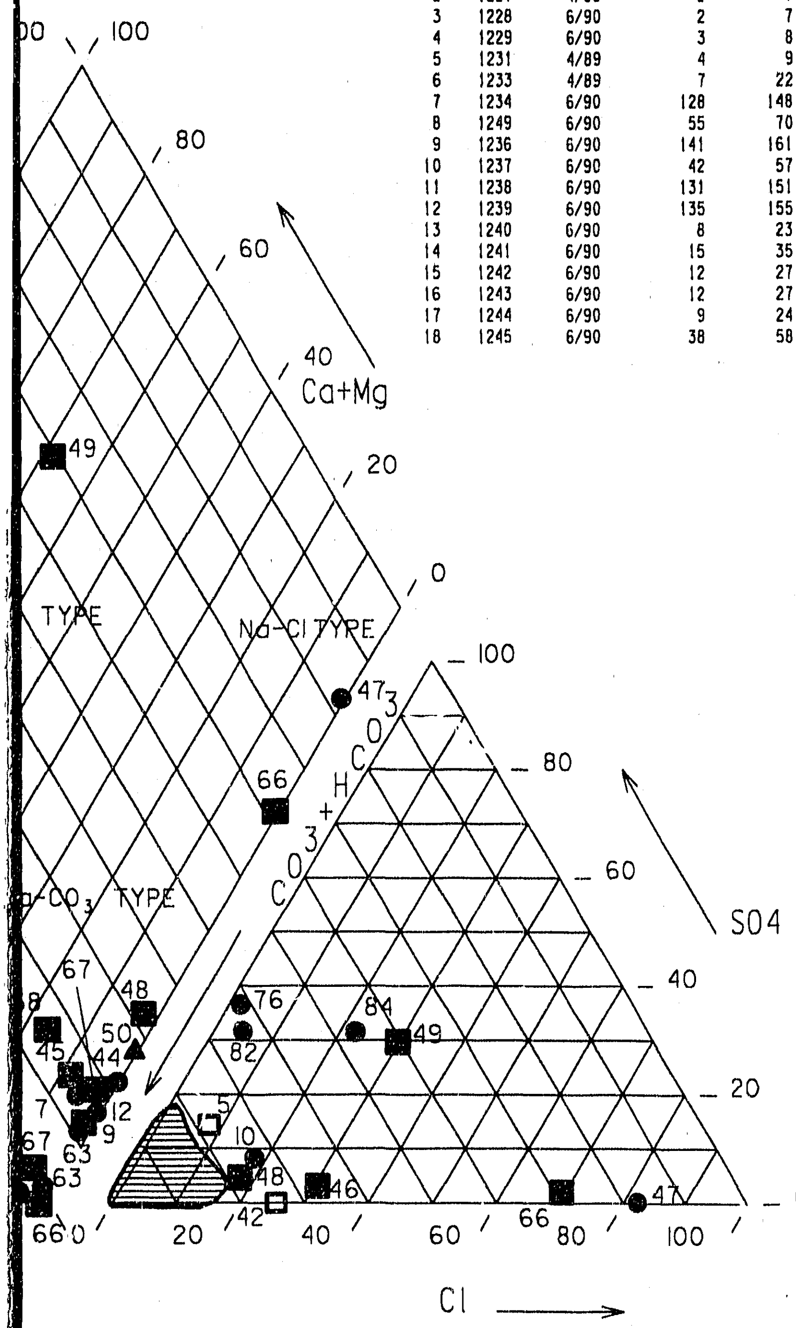


Fig. 3.37. WAG 6 aquifer geochemistry sampling locations.



WAG6/DATA PIPER2.DGN



PLOT #	WELL #	DATE SAMPLED	DEPTH (FT) T/SCREEN	DEPTH (FT) B/SCREEN	HYDROLOGIC UNIT
1	1225	4/89	7	22	1
2	1227	4/89	2	7	4
3	1228	6/90	2	7	4
4	1229	6/90	3	8	4
5	1231	4/89	4	9	4
6	1233	4/89	7	22	2
7	1234	6/90	128	148	2
8	1249	6/90	55	70	2
9	1236	6/90	141	161	5
10	1237	6/90	42	57	2
11	1238	6/90	131	151	2
12	1239	6/90	135	155	2
13	1240	6/90	8	23	1
14	1241	6/90	15	35	2
15	1242	6/90	12	27	2
16	1243	6/90	12	27	2
17	1244	6/90	9	24	2
18	1245	6/90	38	58	2
19	745	6/90	35	60	5
20	831	6/90	24	50	2
21	832	6/90	58	86	2
22	833	6/90	10	31	5
23	838	6/90	5	22	6
24	839	6/90	25	56	5
25	840	6/90	11	27	2
26	841	6/90	36	56	2
27	842	6/90	8	23	2
28	843	6/90	4	19	3
29	844	6/90	25	52	2
30	845	4/89	19	40	3
31	848	4/89	10	32	3
32	849	4/89	11	33	3
33	850	4/89	6	22	3
34	851	4/89	4	20	6
35	852	4/89	5	22	6
36	853	4/89	5	26	3
37	854	4/89	5	27	3
38	855	6/90	30	52	2
39	856	6/90	55	81	2
40	857	6/90	50	70	4
41	858	6/90	85	106	5
42	859	6/90	5	26	4
43	860	6/90	34	62	5
44	HHMS-4A	7/87	380	400	2
45	HHMS-4B	7/87	174	215	5
46	HHMS-4C	7/87	41	62	5
47	HHMS-5A	7/87	380	400	2
48	HHMS-5B	7/87	196	219	5
49	HHMS-5C	7/87	42	63	5
50	HHMS-7A	7/87	380	400	7
51	ETF-1	10/80	25	29	1
52	ETF-2	10/80	28	32	1
53	ETF-3	10/80	27	31	1
54	ETF-4	10/80	27	31	1
55	ETF-5	10/80	26	30	1
56	ETF-6	10/80	26	30	1
57	ETF-7	10/80	26	30	1
58	ETF-8	10/80	25	30	1
59	ETF-9	10/80	27	31	1
60	ETF-10	10/80	27	31	1
61	ETF-11	10/80	42	50	1
62	ETF-12	10/80	42	50	1
63	ETF-13	6/90	241	251	2
64	ETF-14	6/90	85	95	2
65	ETF-15	6/90	37	47	2
66	HHMS-6A	7/87	380	400	5
67	HHMS-6B	7/87	275	295	5
68	HHMS-6C	7/87	158	178	5
69	T-36	10/89	12	17	4
70	T-20	10/89	6	11	4
71	T-18	10/89	2	7	4
72	T-17	10/89	6	11	4
73	T-10	10/89	17	22	4
74	T-7	10/89	4	9	4
75	T-1	10/89	4	9	4
76	TARA-3	11/87	32	52	2
77	TARA-4	11/87	35	55	2
78	TARA-6	11/87	41	61	2
79	TARA-8	11/87	16	36	2
80	TARA-9	11/87	17	37	2
81	TARA-10	11/87	17	37	2
82	TARA-11	11/87	27	47	2
83	TARA-12	11/87	8	28	2
84	367	11/87	59	69	2
85	646	11/87	29	39	2
86	S-11	3/87	30	45	2

Fig. 3.38. WAG 6 aquifer geochemistry.

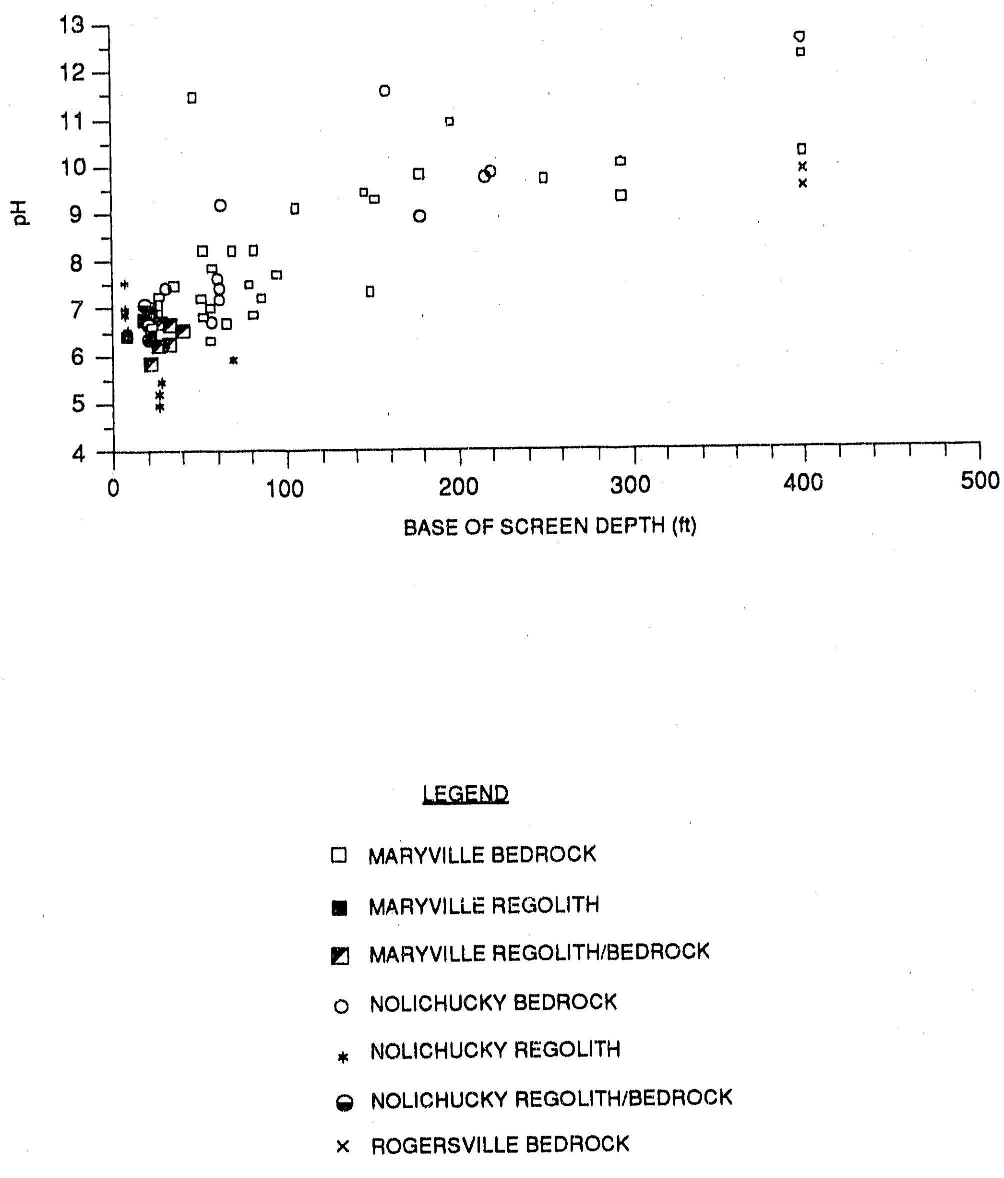


Fig. 3.39. WAG 6 groundwater pH versus depth.

5.18F 4104.178

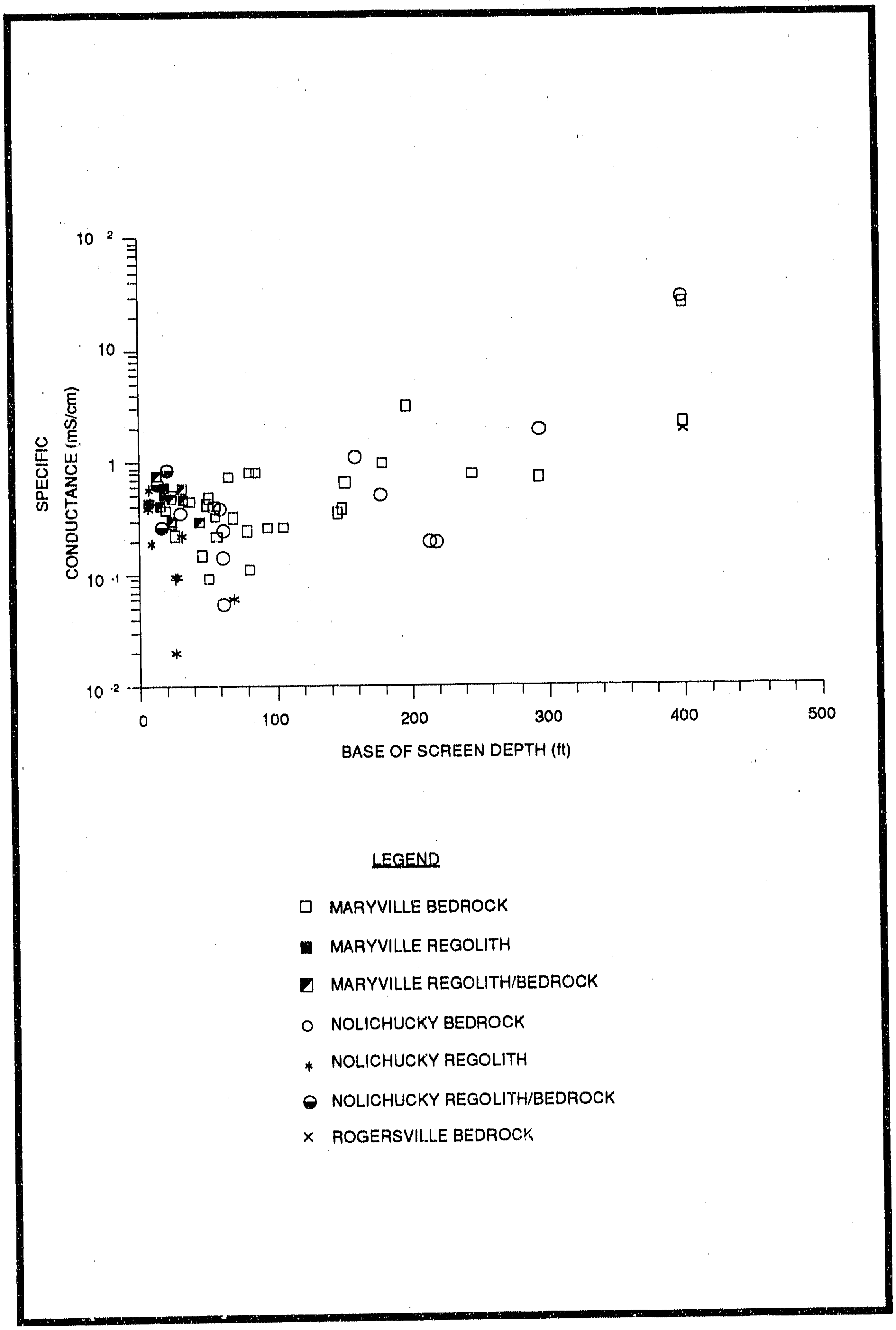
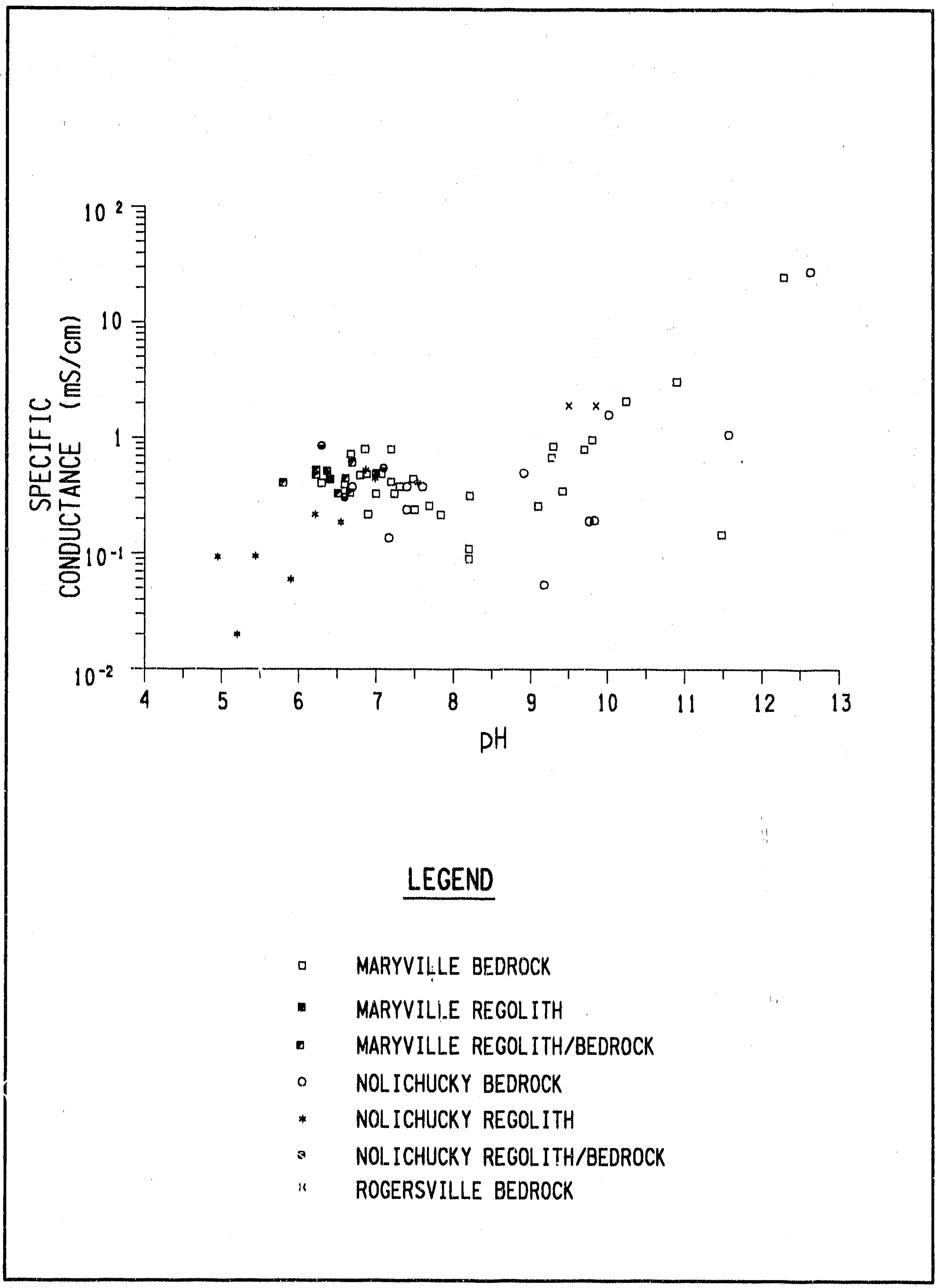


Fig. 3.40. WAG 6 groundwater specific conductance versus depth.

5.18F4104.178A



WAG6 06F325.DGN
9-4

Fig. 3.41. WAG 6 groundwater pH versus specific conductance.

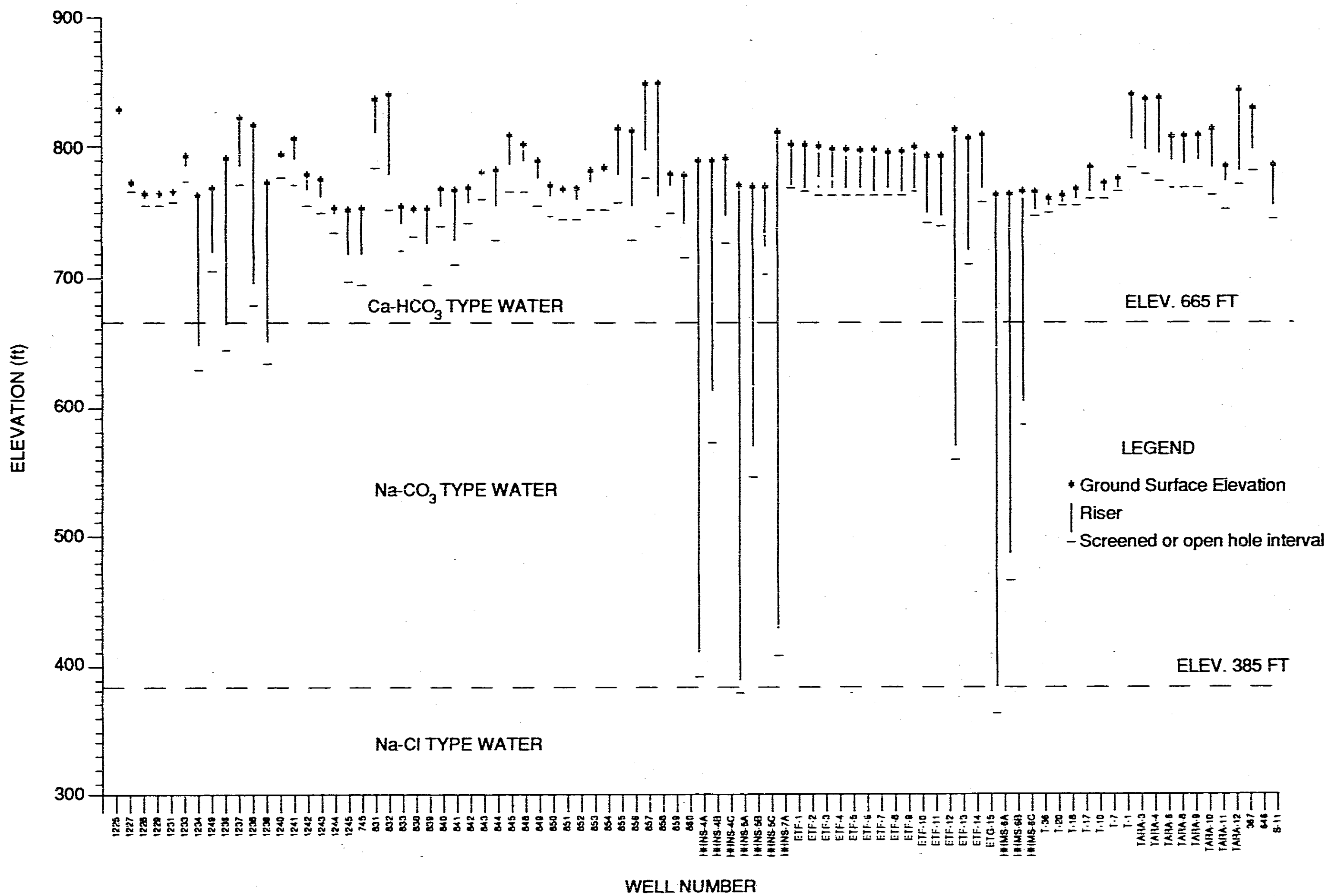
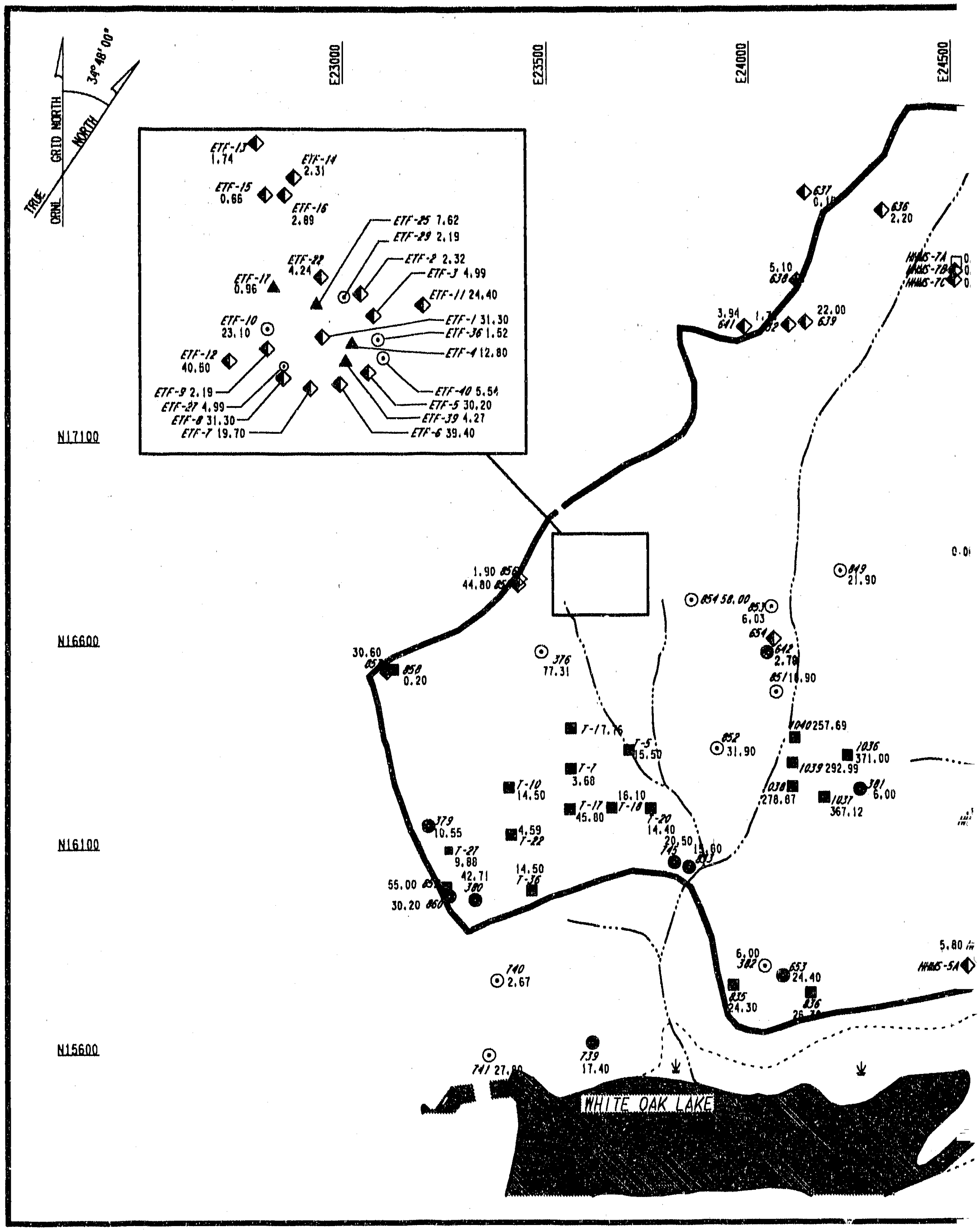


Fig. 3.42. Relation of screened interval to geochemical zone.

5.18E 4104.143
Adapted from WAG 6 06F171.DGN



TRUE
GRID NORTH
ORNL
NORTH
34°48'00"
E23000
E23500
E24000
E24500
N17100
N16600
N16100
N15600
ETF-13 1.74
ETF-14 2.31
ETF-15 0.66
ETF-16 2.89
ETF-25 7.62
ETF-29 2.19
ETF-2 2.32
ETF-3 4.99
ETF-22 4.24
ETF-17 0.96
ETF-11 24.40
ETF-10 23.10
ETF-1 31.30
ETF-36 1.52
ETF-4 12.80
ETF-12 40.60
ETF-40 5.54
ETF-9 2.19
ETF-5 30.20
ETF-27 4.99
ETF-39 4.27
ETF-8 31.30
ETF-6 39.40
ETF-7 19.70
637
636 2.20
5.10
638
3.94
641
22.00
639
1.90
44.80
30.60
858 0.20
376 77.31
854 58.00
6.03
849 21.90
85/10.90
T-1 7.76
T-5 15.50
T-7 3.68
852 31.90
1036 371.00
1039 292.99
1037 367.12
278.87
381 6.00
T-10 14.50
16.10
T-17 45.80
T-18
T-20 14.40
379 10.55
4.59 T-22
T-27 9.88
42.71
380
20.50
14.50 T-36
55.00
30.20
6.00 382
653 24.40
835 24.30
836
740 2.67
5.80
741 27.80
739 17.40
WHITE OAK LAKE

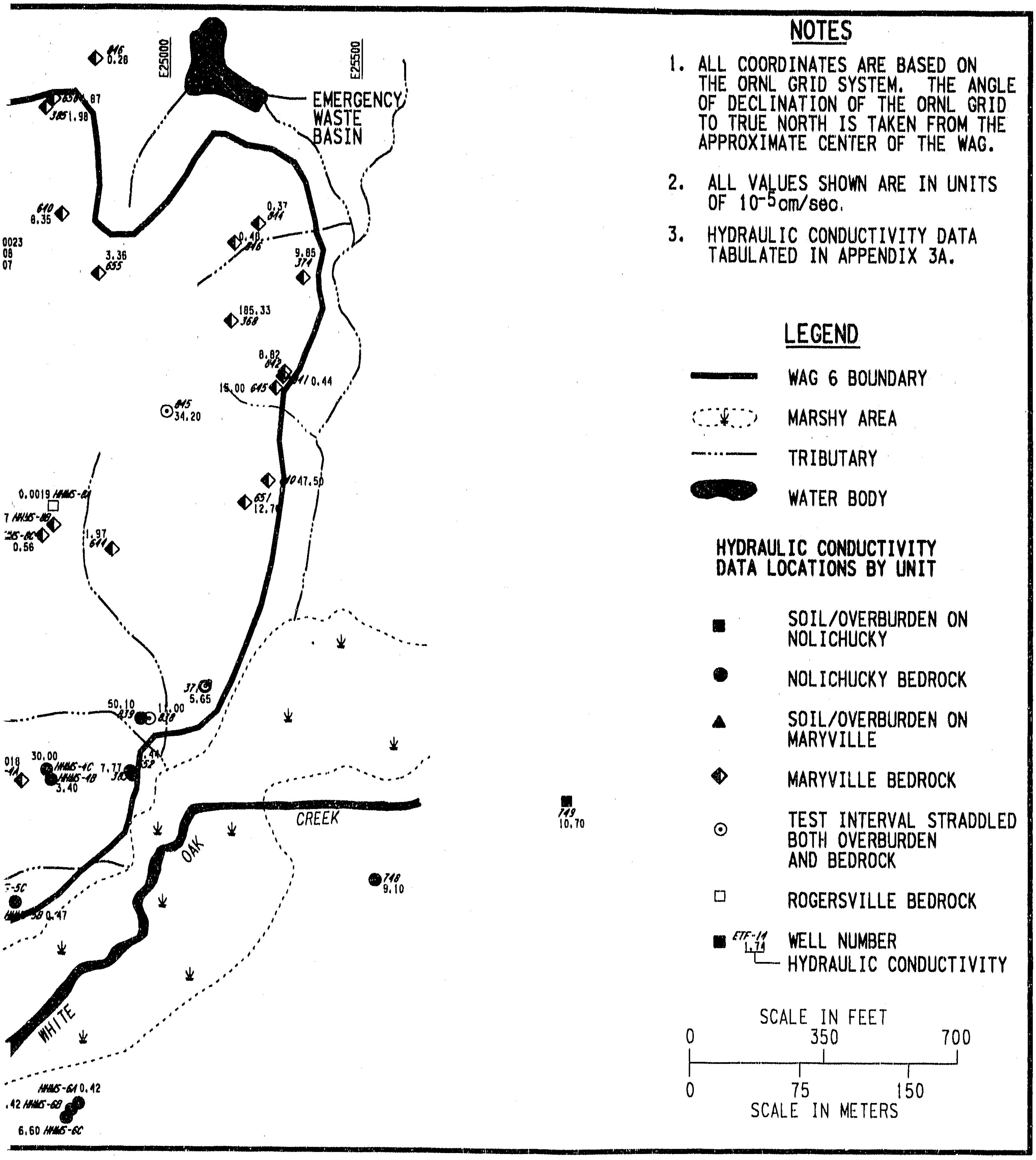


Fig. 3.43. WAG 6 hydraulic conductivity distribution ma

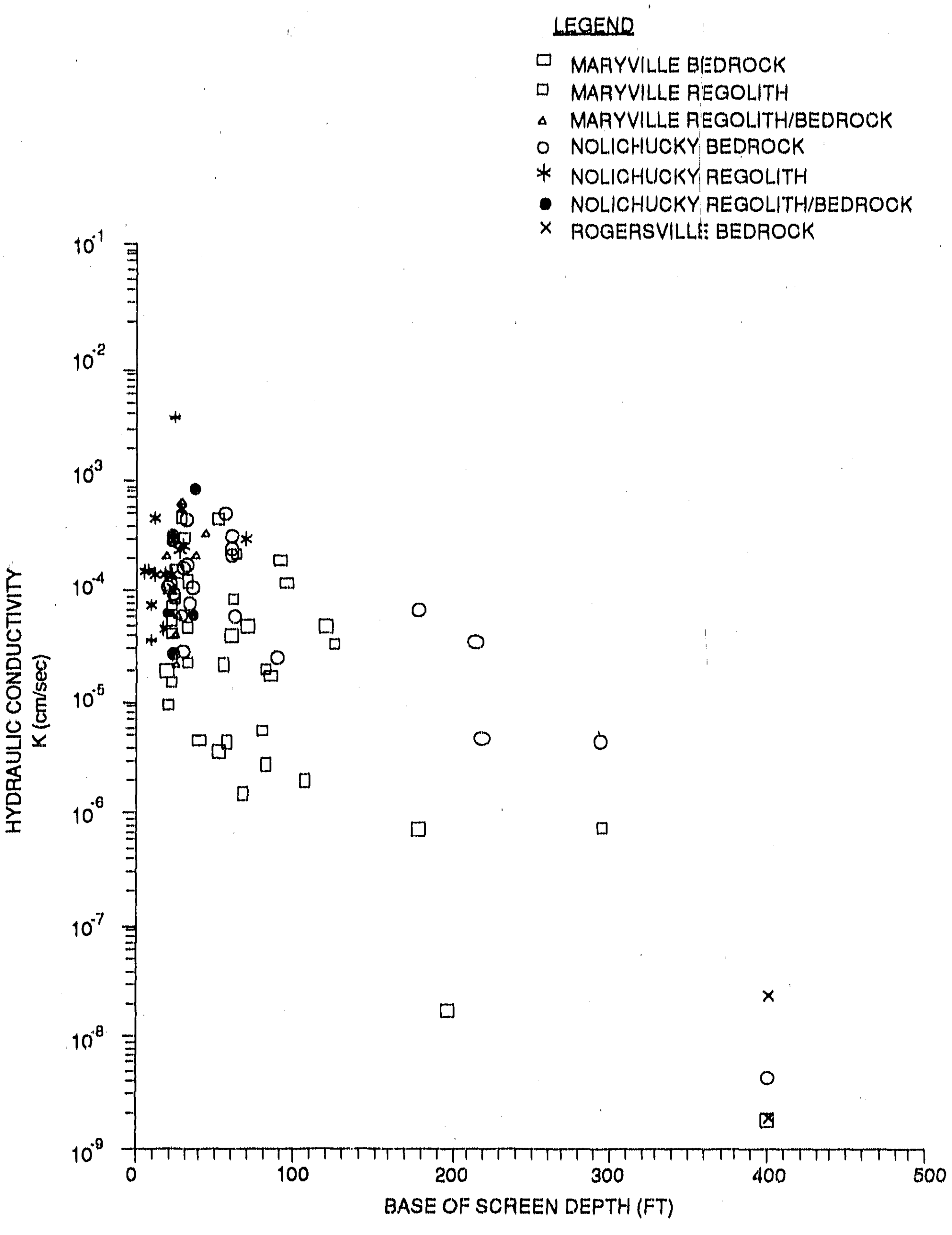


Fig. 3.44. WAG 6 hydraulic conductivity versus depth plot.

5.18F 4104.174
Adapted from WAG 6 06F172.DGN

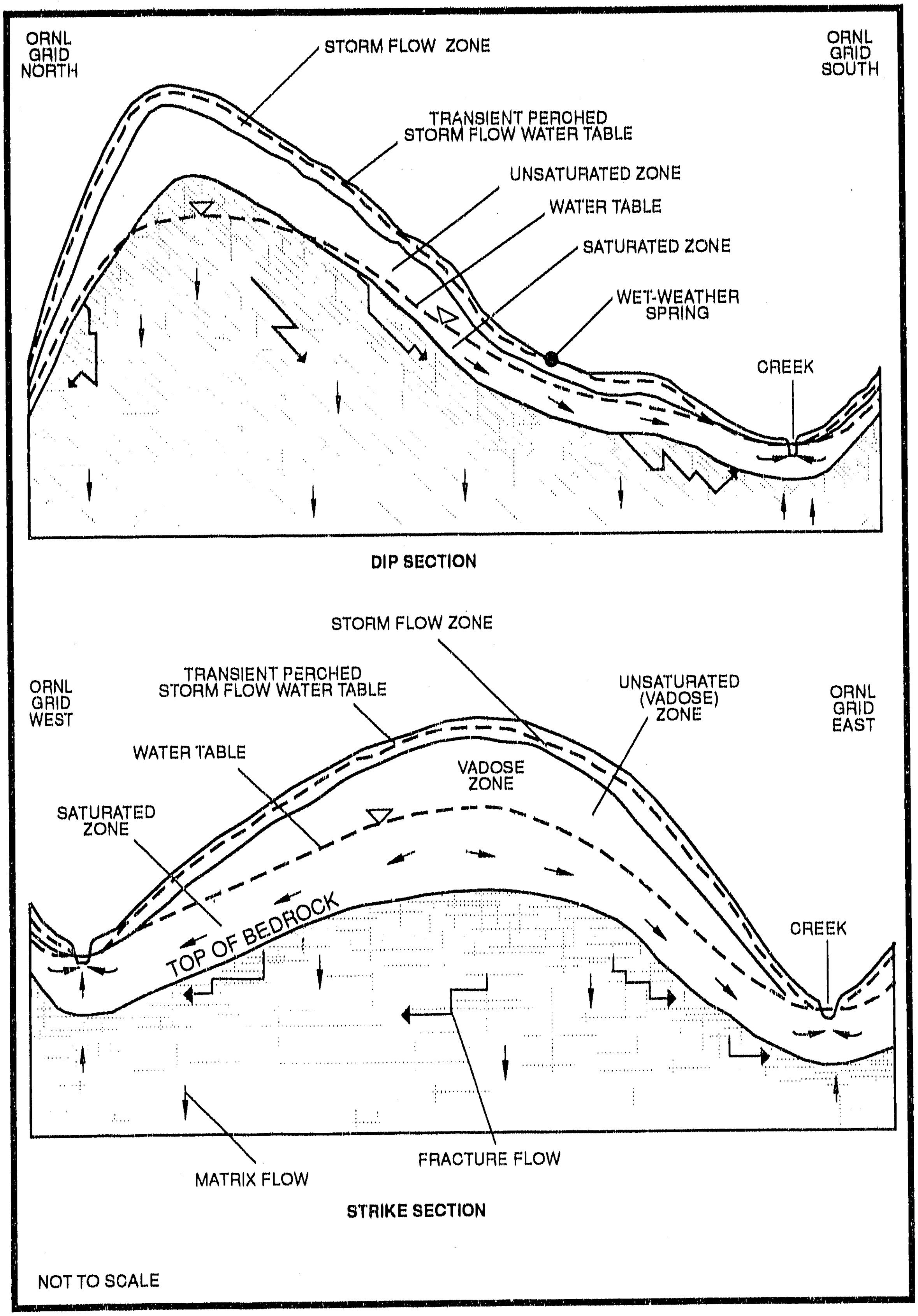
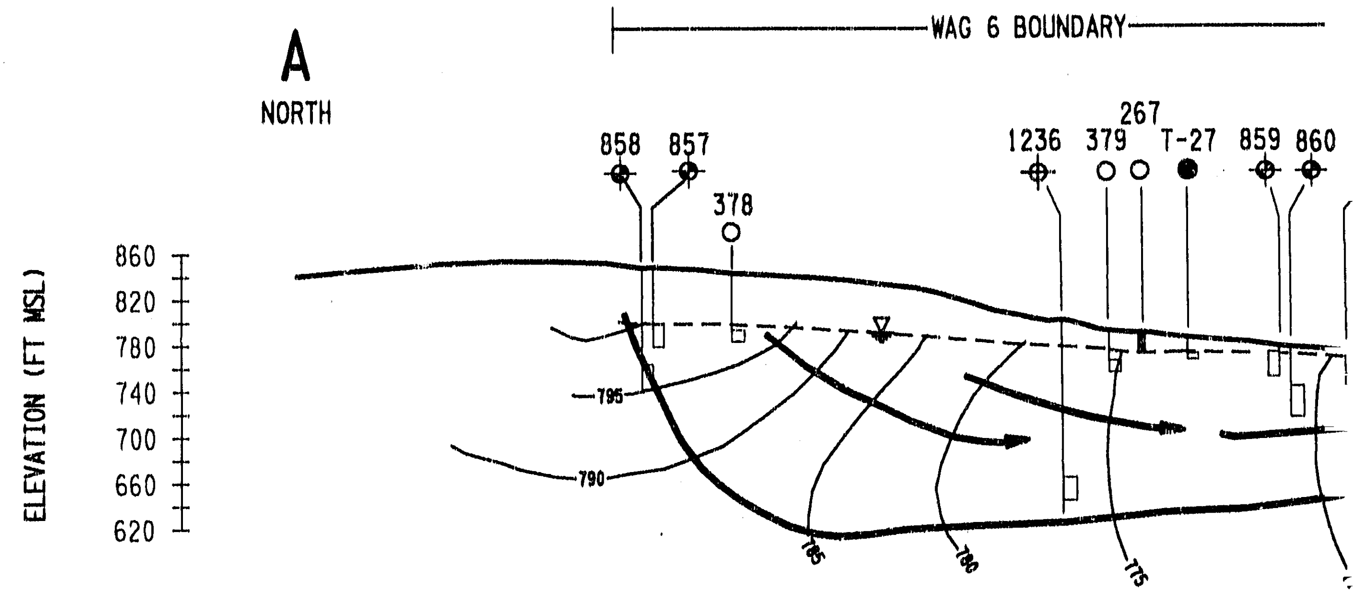


Fig. 3.45. Groundwater flow at WAG 6. *Source:* Modified after Moore, G. K. 1991. Personal communication, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

6.10 4104.9



WAG6 06F326.DGN
9-4

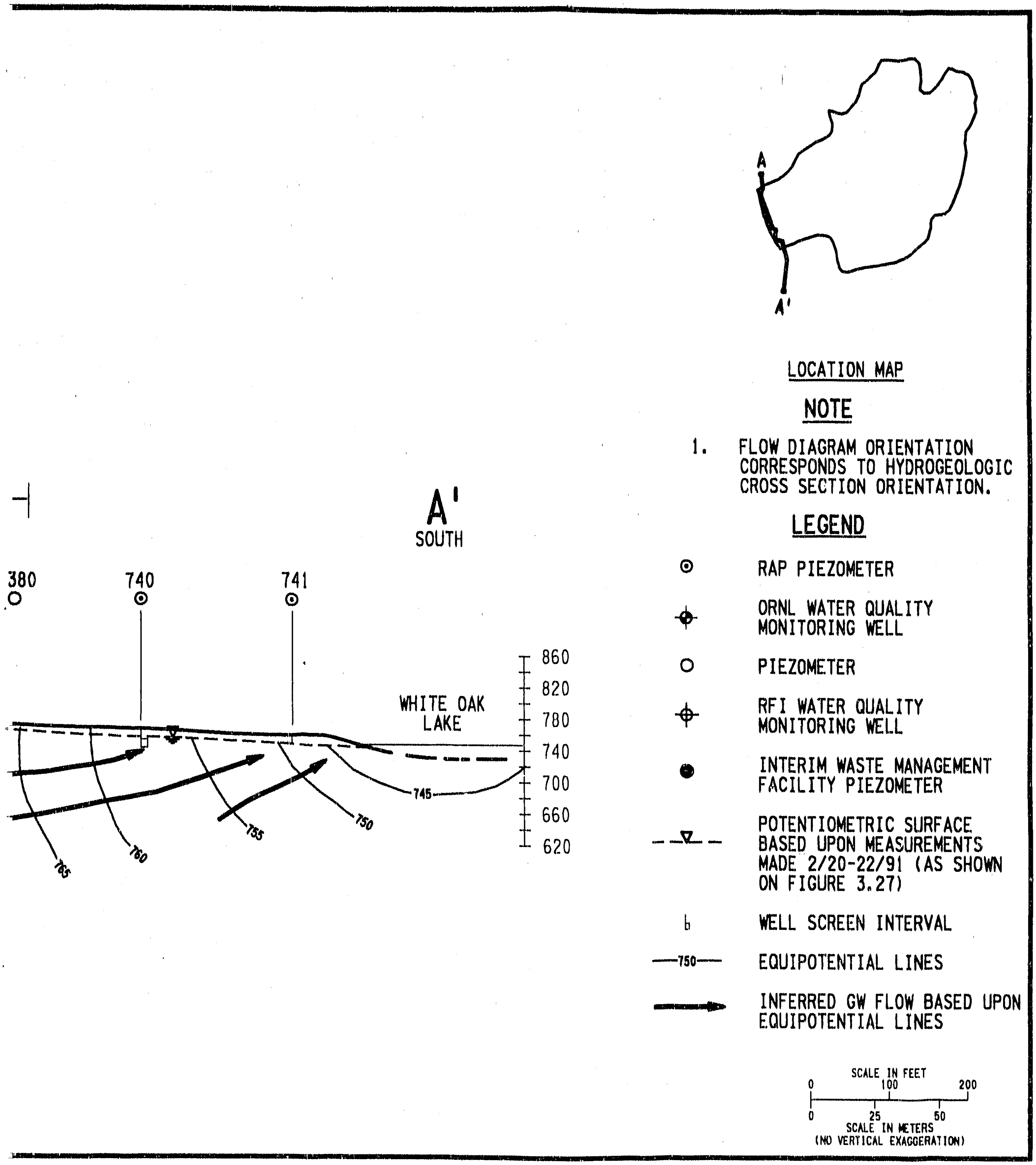
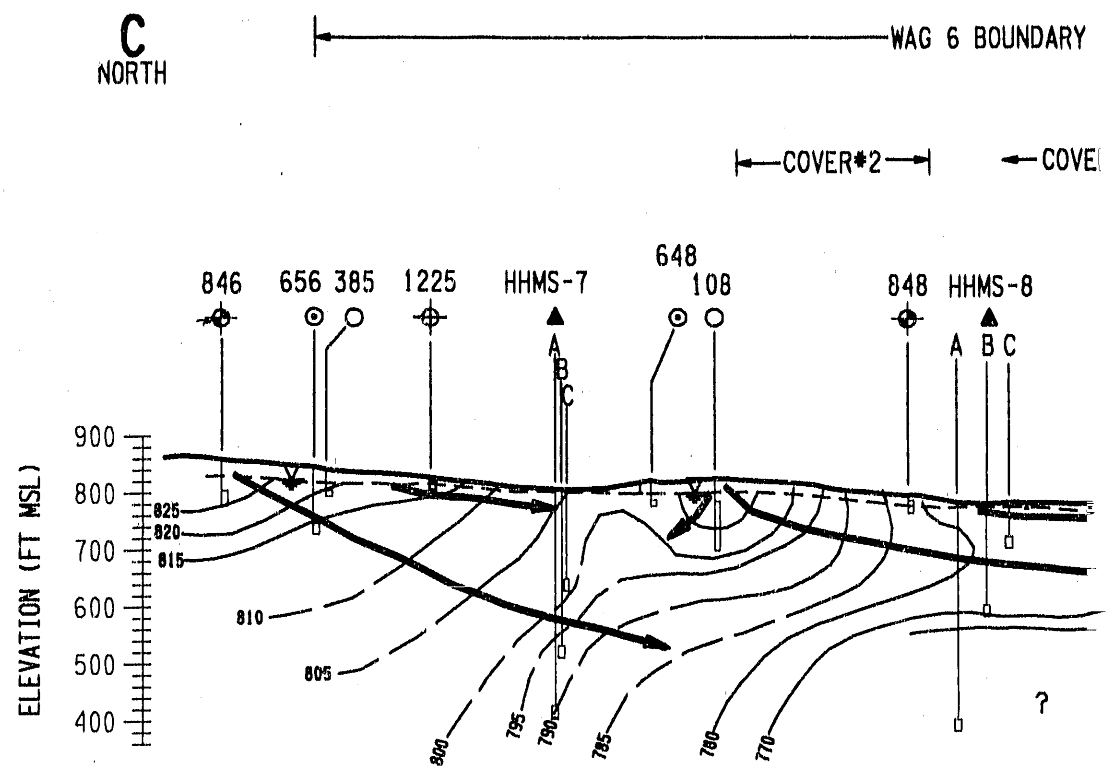


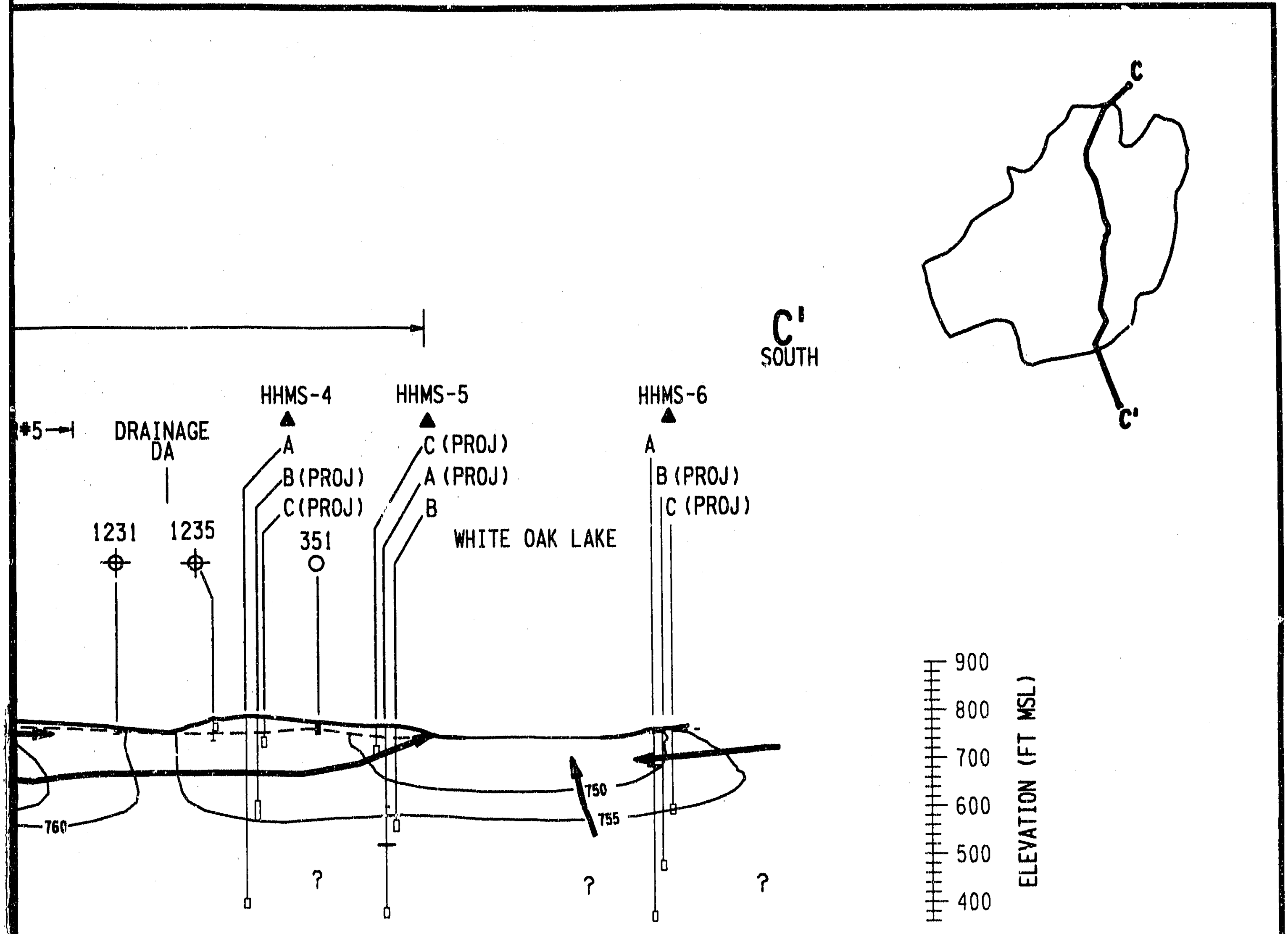
Fig. 3.46. WAG 6 north-south conceptualized groundwater flow diagram A-A'.



LEGEND

- POTENTIOMETRIC SURFACE BASED UPON MEASUREMENTS MADE 2/20-22/91 (AS SHOWN ON FIGURE 3.27)
- WELL SCREEN INTERVAL
- 750 EQUIPOTENTIAL LINES
- INFERRED GW FLOW BASED UPON EQUIPOTENTIAL LINES
- RAP PIEZOMETER
- ORNL WATER QUALITY MONITORING WELL
- PIEZOMETER
- RFI WATER QUALITY MONITORING WELL
- HHMS

WAG6 06F327.DGN
9-4



NOTES

1. HYDROGRAPHS FOR DEEP WELLS HHMS-8A, 8B, 4A, 5A, AND 6A INDICATE THESE WELLS ARE STILL RECOVERING FOLLOWING INSTALLATION (SEE FIG. 3.30) AND HAVE NOT YET EQUALIZED. CONSEQUENTLY INTERPRETATIONS OF FLOW AT DEPTH ARE UNKNOWN.

2. FLOW DIAGRAM ORIENTATION CORRESPONDS TO HYDROGEOLOGIC CROSS SECTION ORIENTATION.

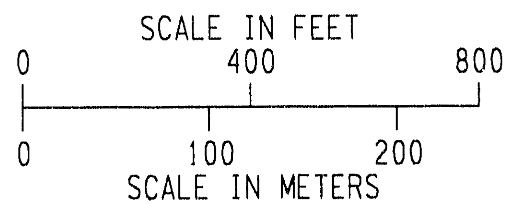
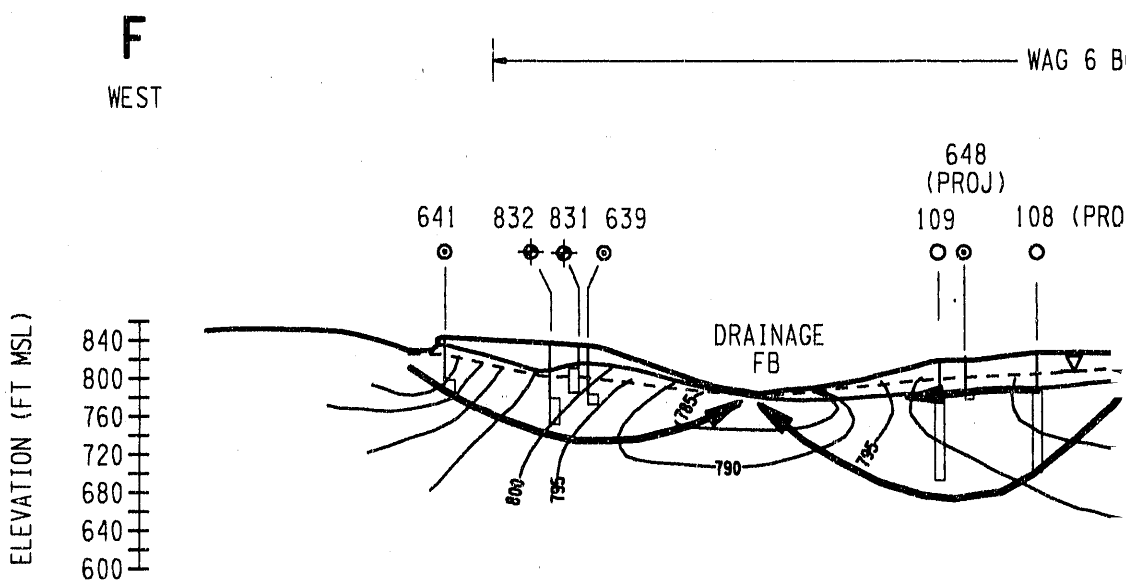


Fig. 3.47. WAG 6 north-south conceptualized groundwater flow diagram C-C'.



LEGEND

- POTENTIOMETRIC SURFACE BASED UPON MEASUREMENTS MADE 2/20-22/91 (AS SHOWN ON FIGURE 3.37)
- WELL SCREEN INTERVAL
- 750 EQUIPOTENTIAL LINES
- INFERRED GW FLOW BASED UPON EQUIPOTENTIAL LINES
- RAP PIEZOMETER
- ORNL WATER QUALITY MONITORING WELL
- PIEZOMETER
- RFI WATER QUALITY MONITORING WELL

1.

WAG6 06F328.DGN

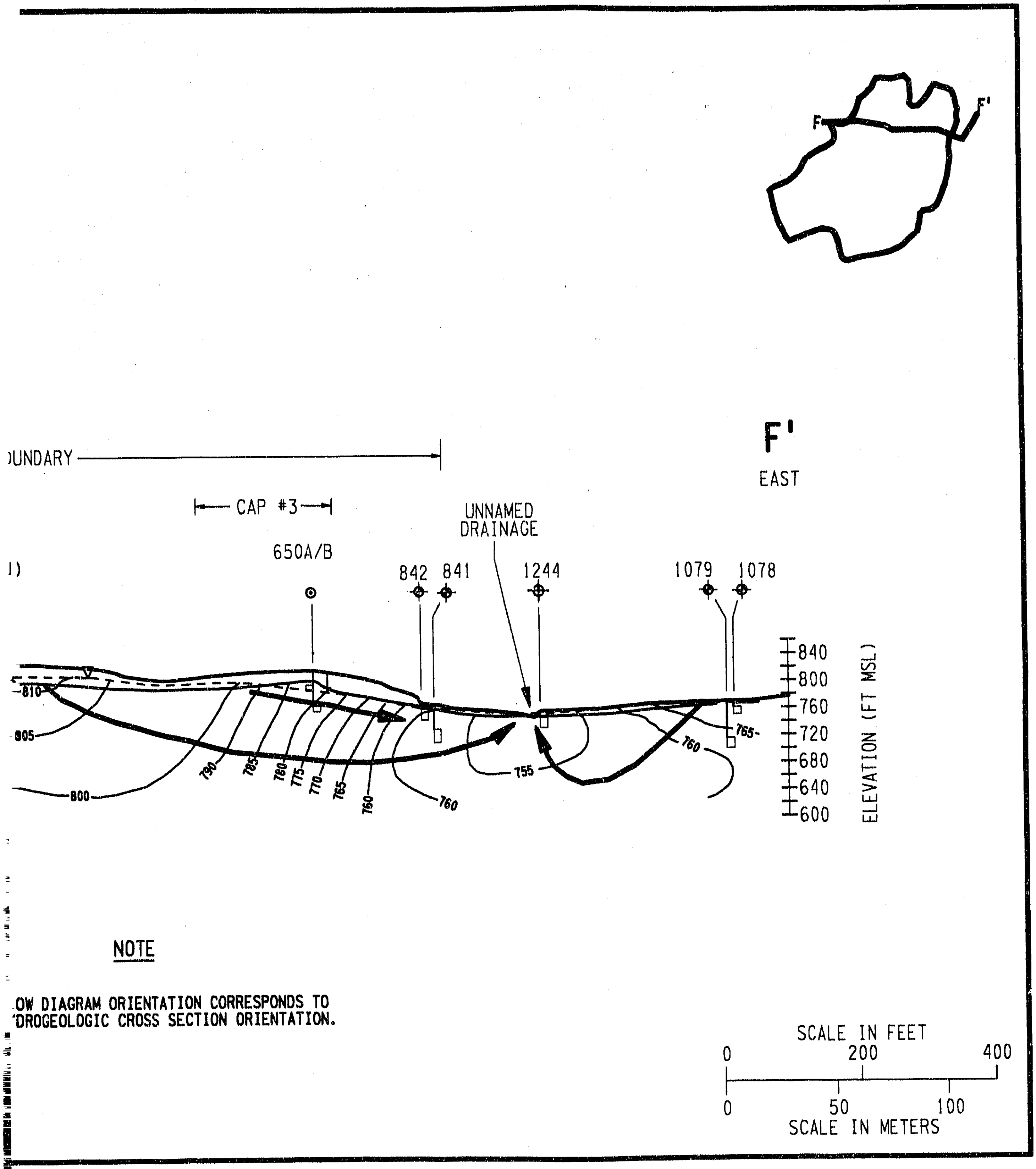
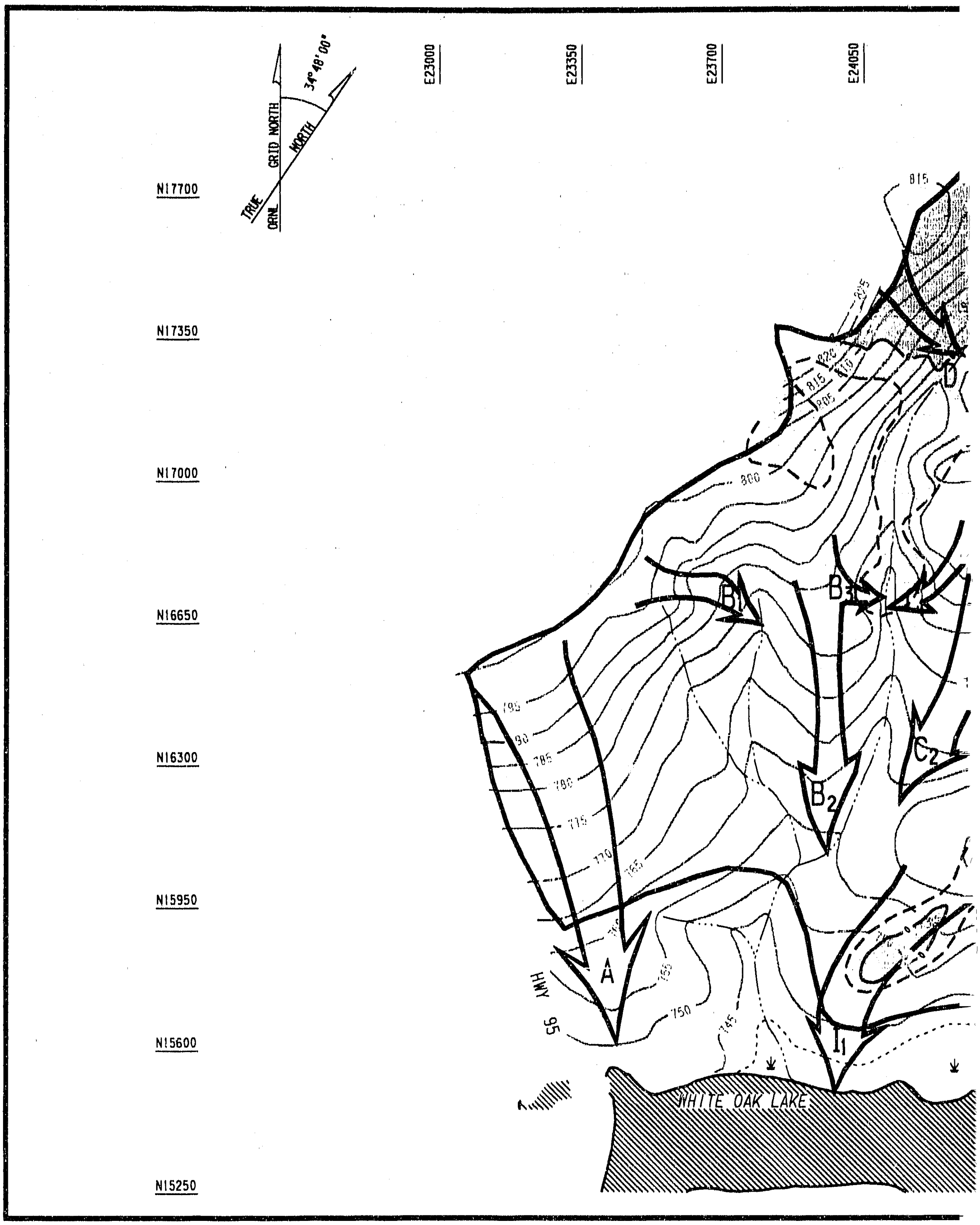


Fig. 3.48. WAG 6 north-south conceptualized groundwater flow diagram F-F'.



WAG6 06F329.DGN B
9-9

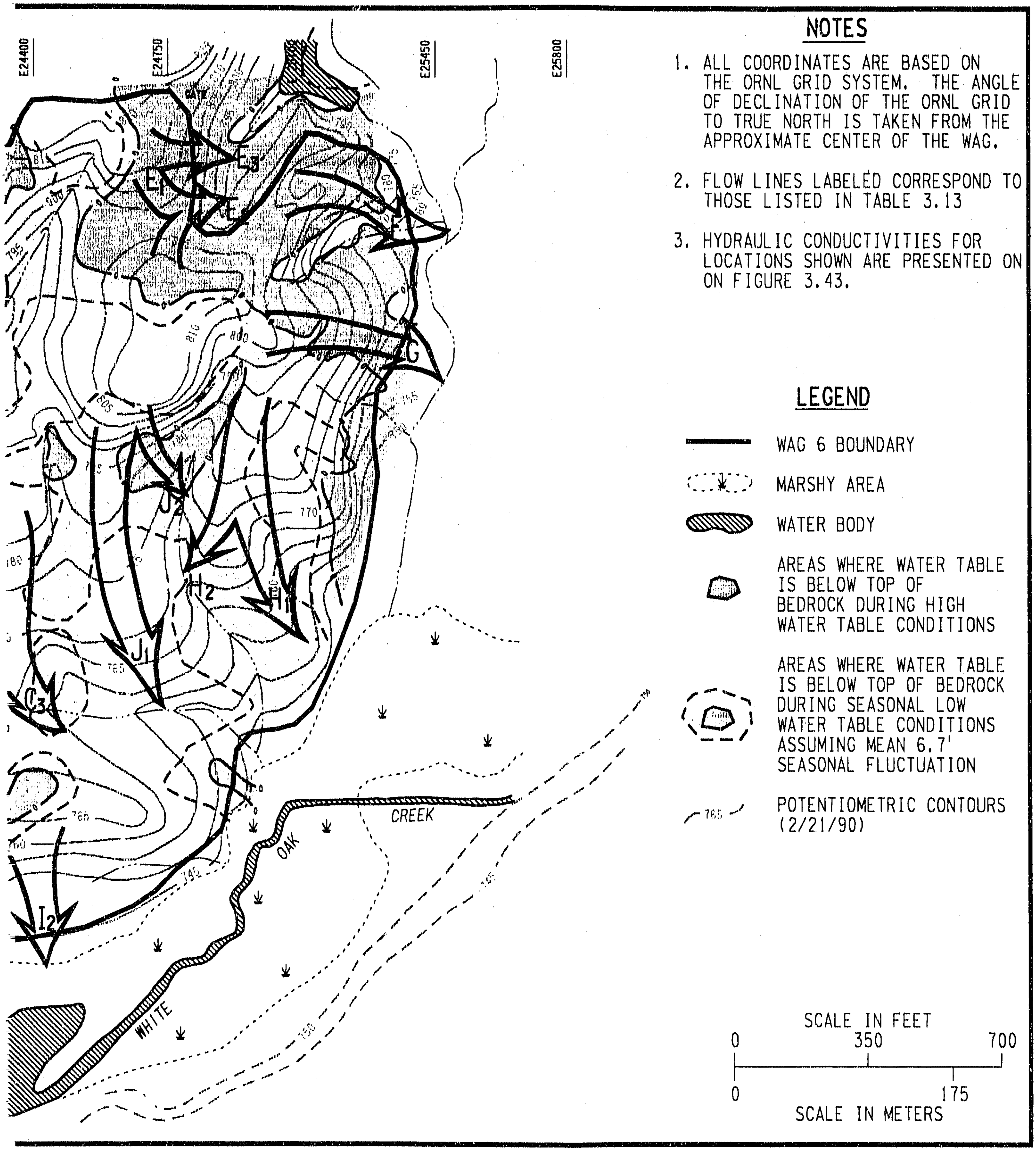
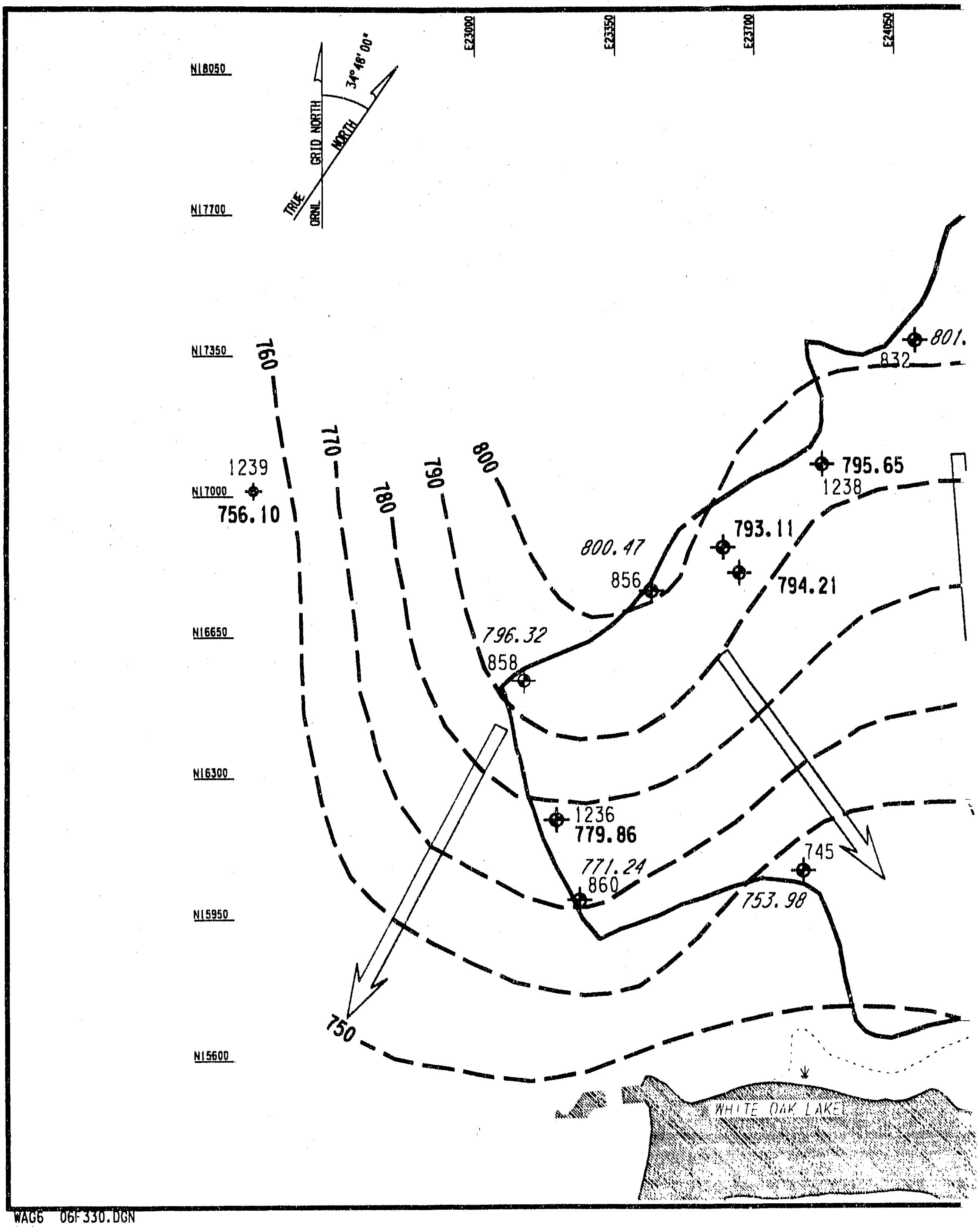


Fig. 3.49. WAG 6 shallow groundwater flow lines.



WAG6 06F330.DGN
9-1

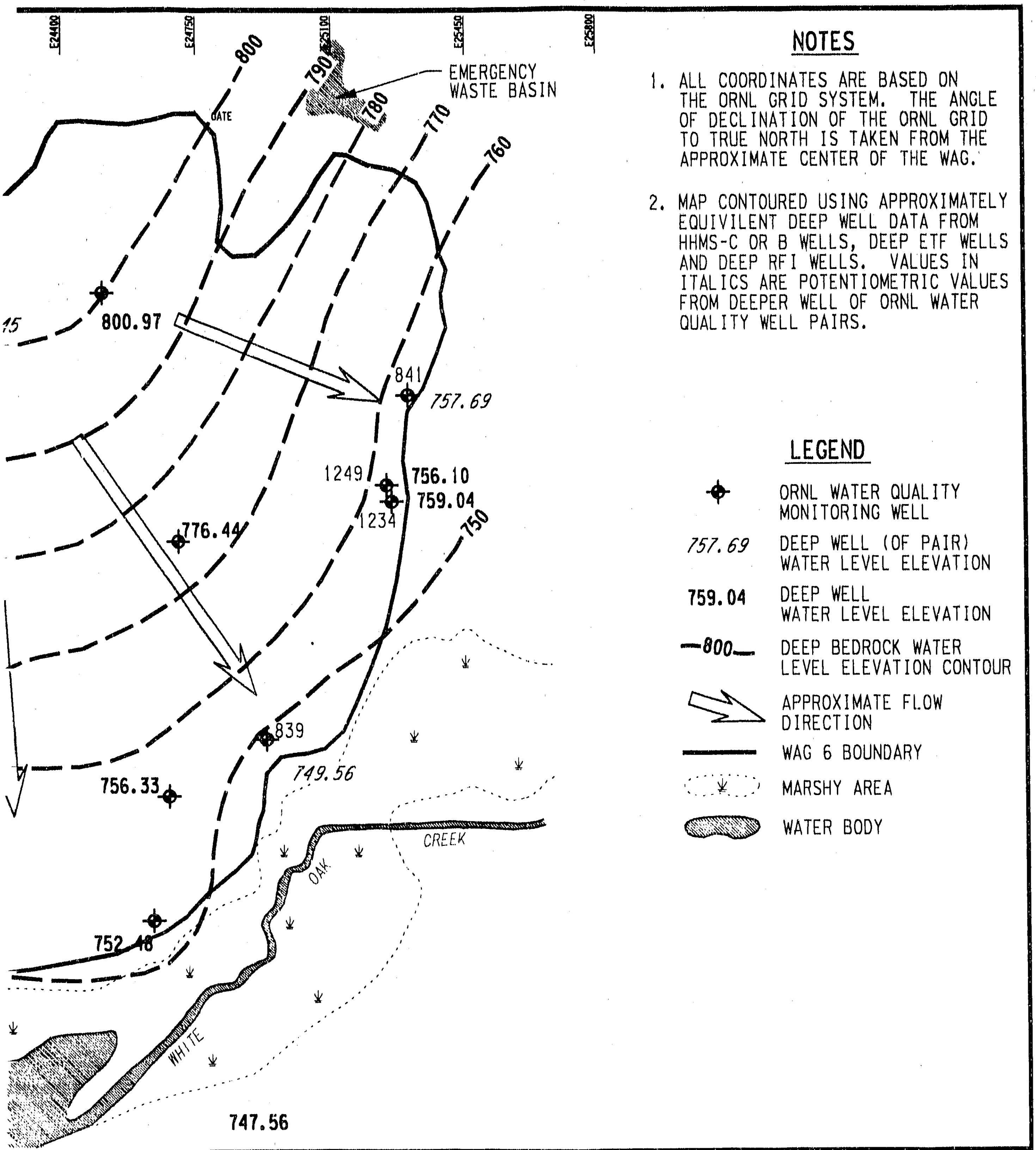


Fig. 3.50. WAG 6 approximate deep groundwater potentiometric map, February 20-21, 1990.

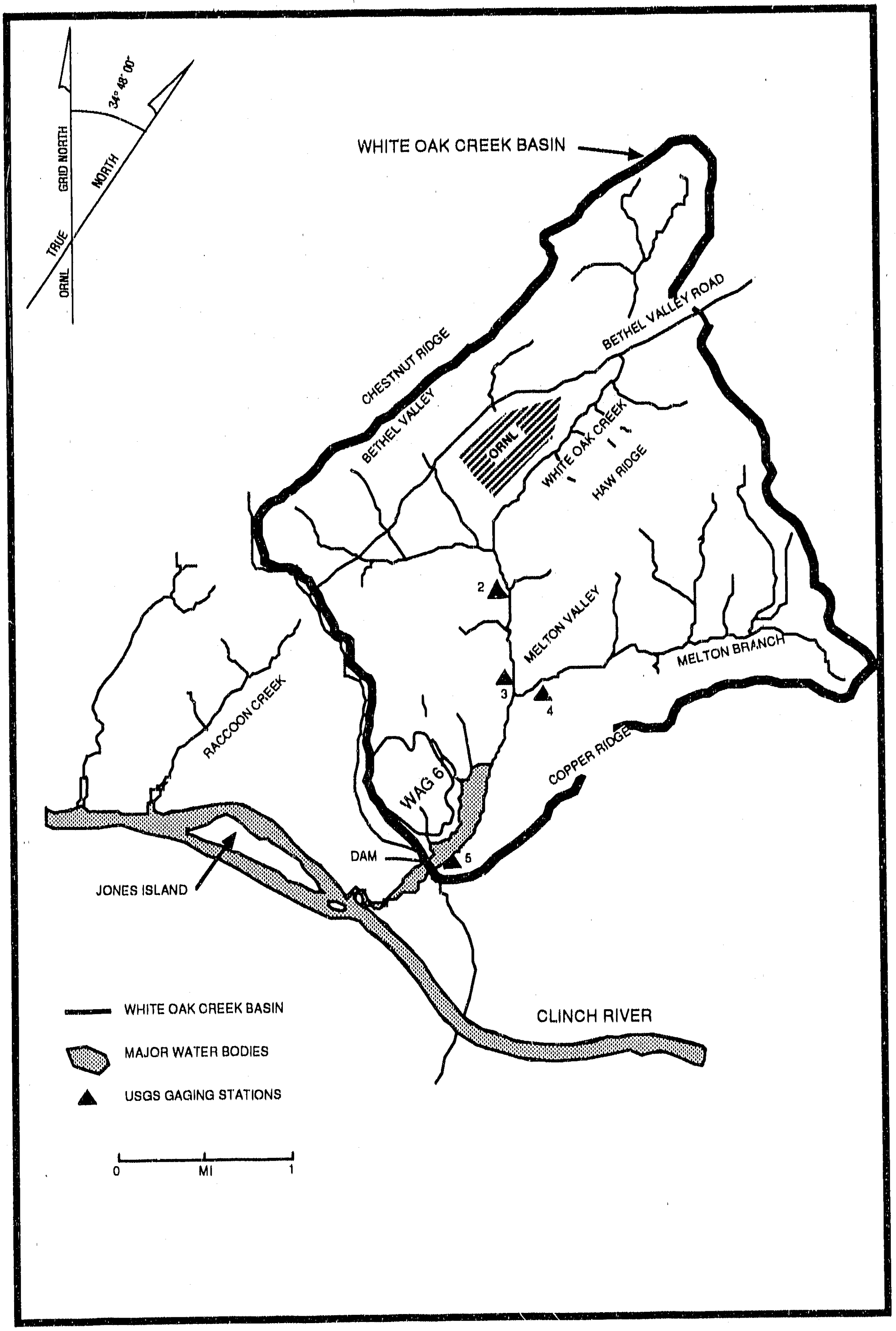


Fig. 3.51. White Oak Creek Basin (showing location of USGS gaging stations).

5.18E 4104.138A
Adapted from WAG6 06F188.DGN

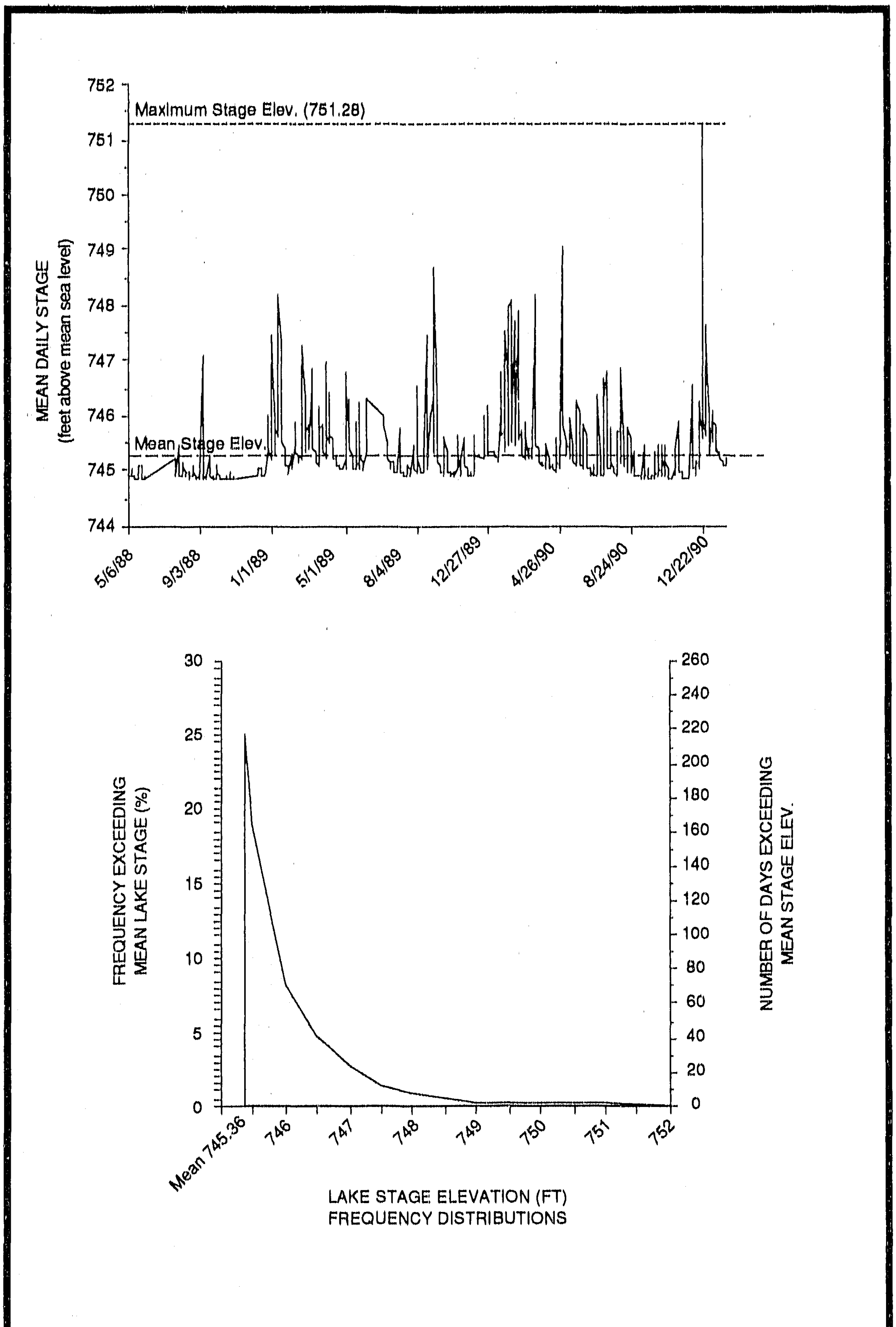
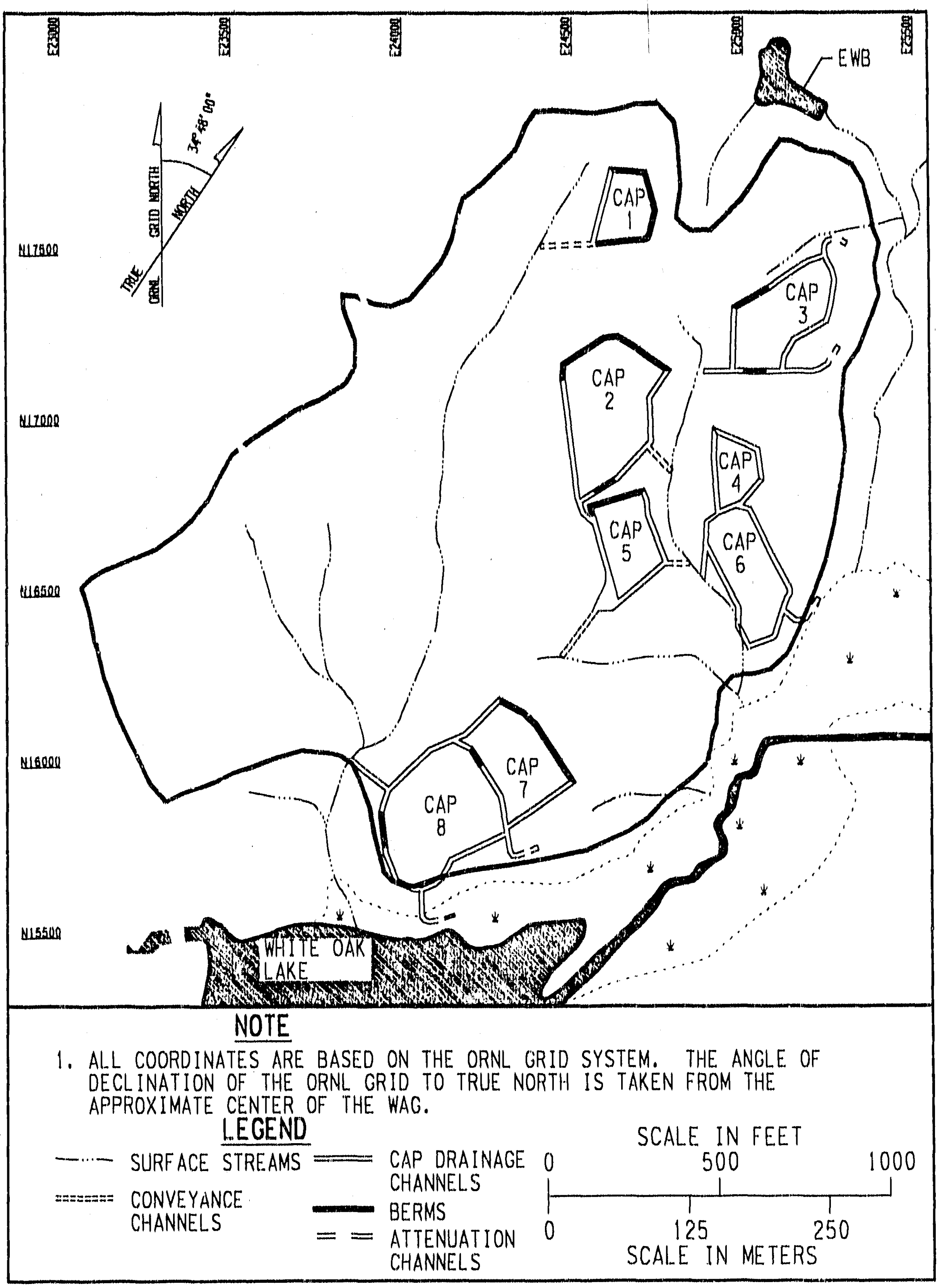


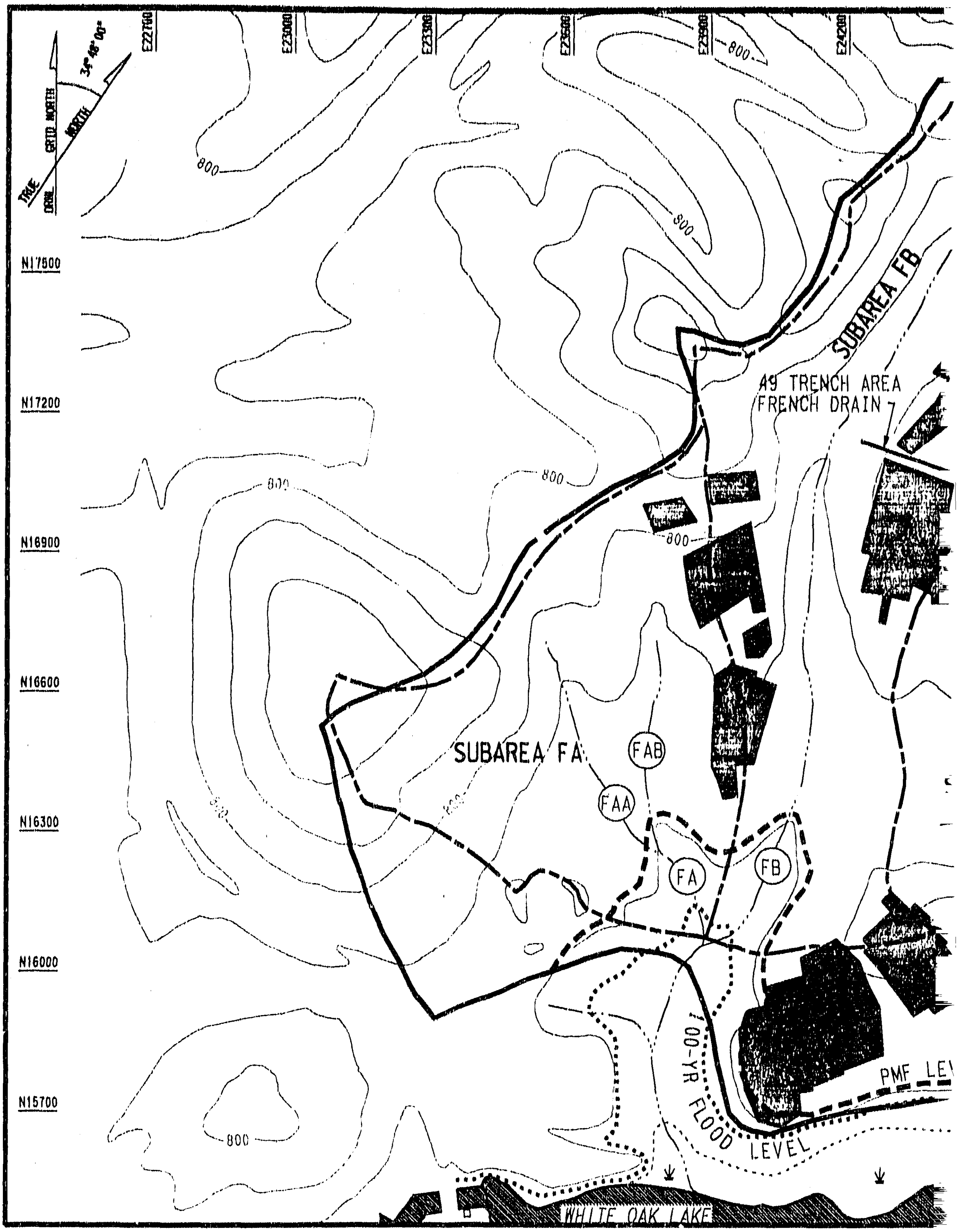
Fig. 3.52. Mean daily lake levels and frequency of distribution, White Oak Lake.

5.18F 4104.167
Adapted from WAG6 06F304.DGN



WAG6 06F109.DGN
9-1

Fig. 3.53. Temporary cap drainage features.



WA06 06F331.DGN
9-4

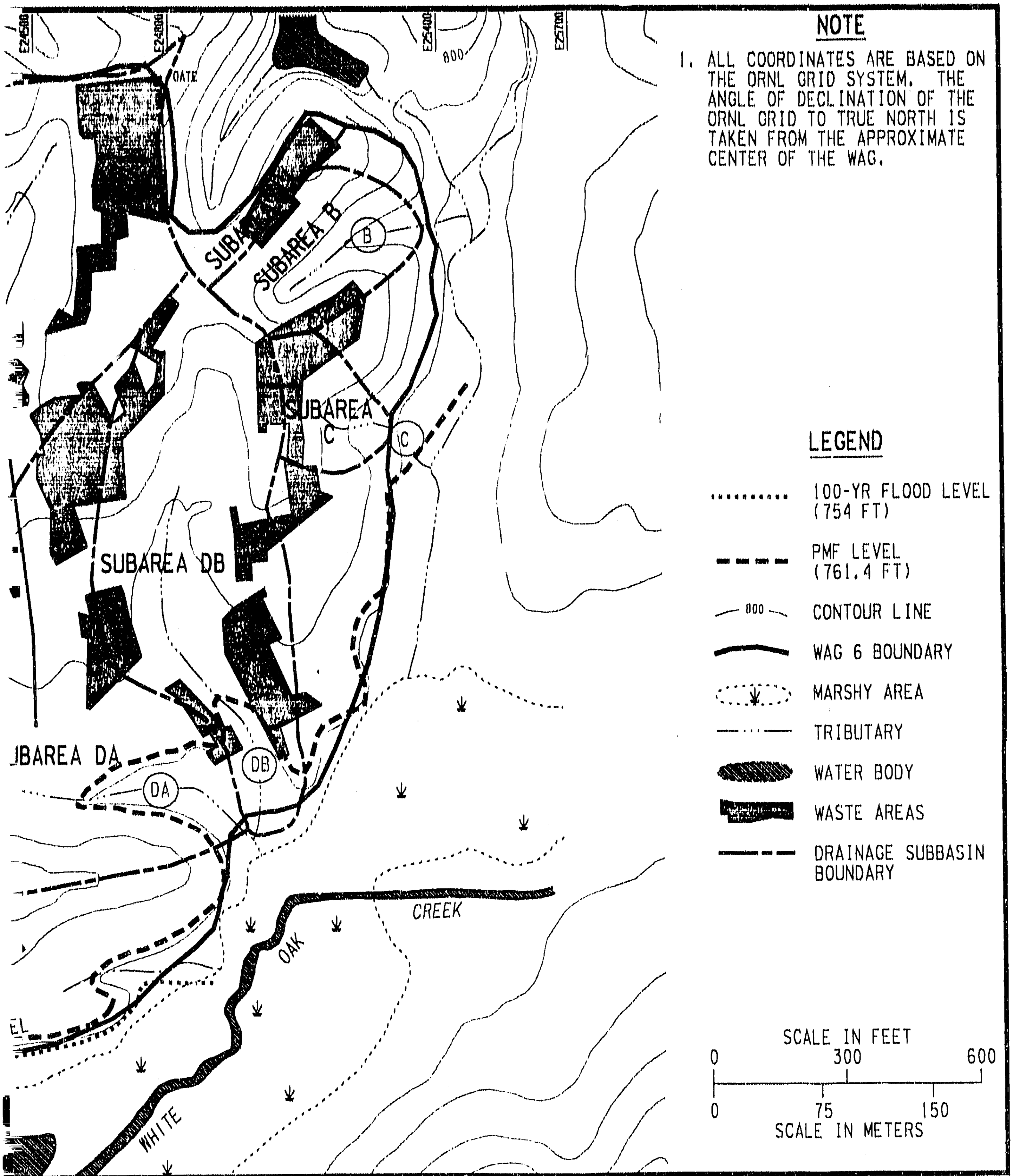
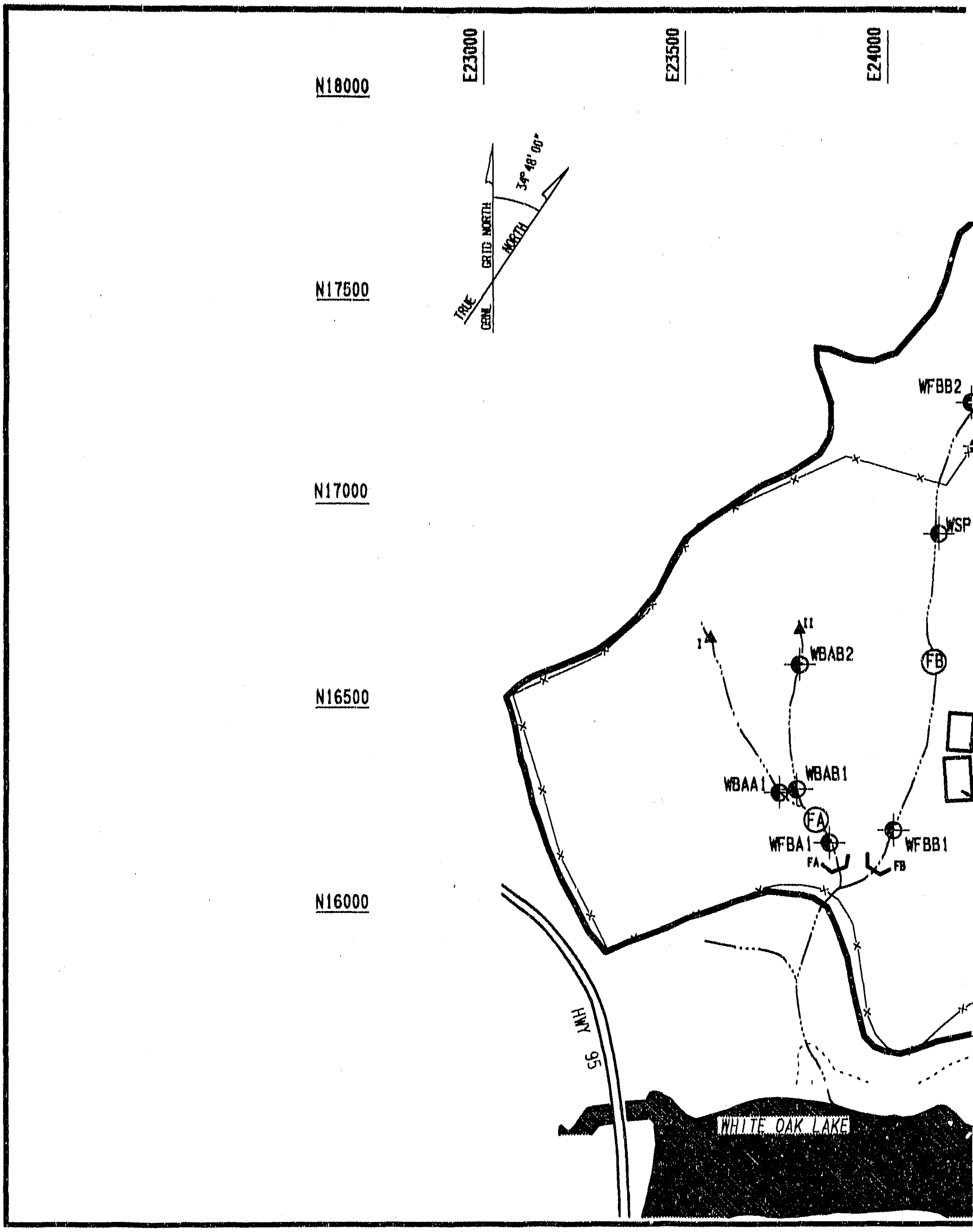


Fig. 3.54. WAG 6 site drainage areas.



WAOG 06F363.DGN
9-1

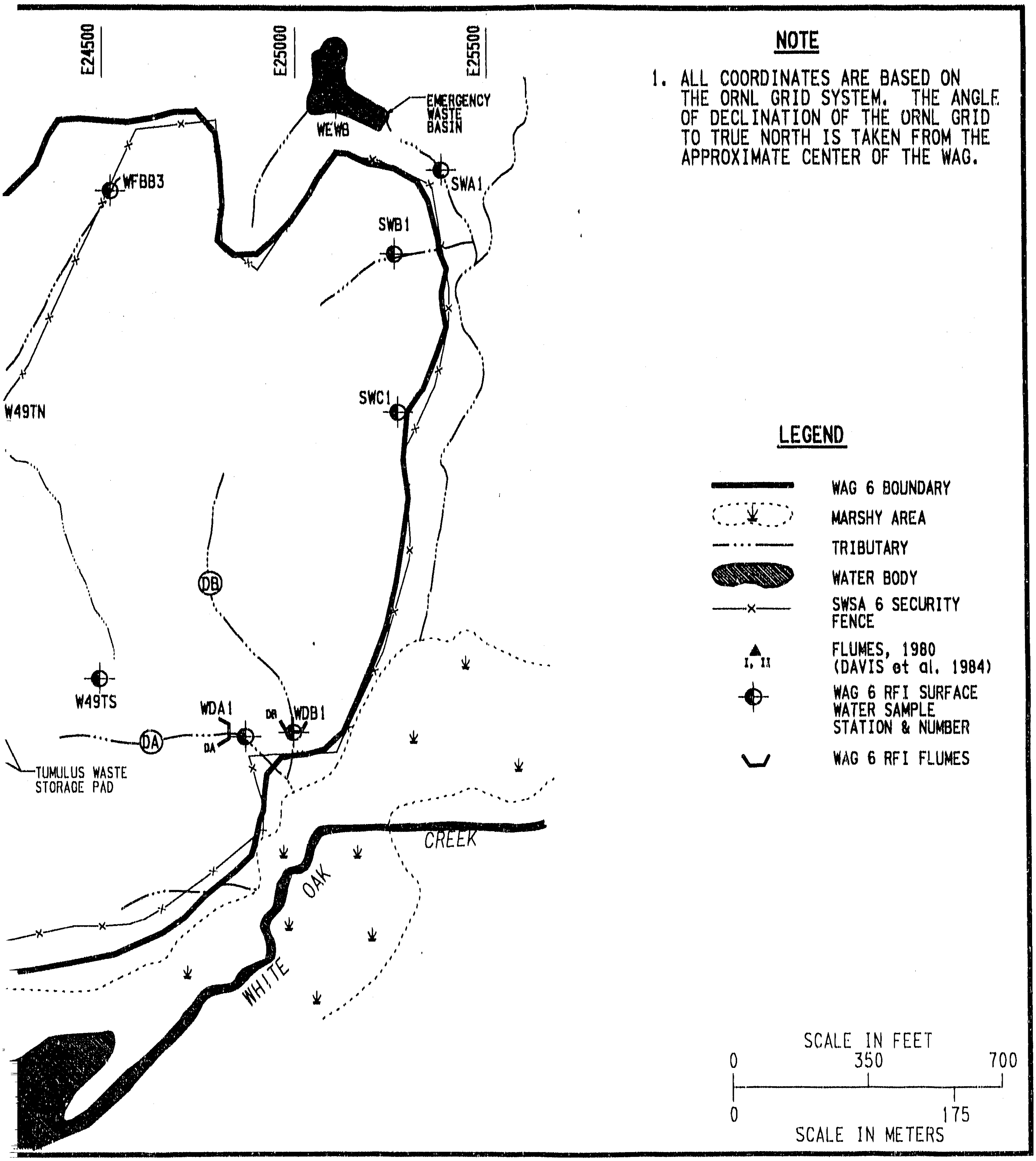


Fig. 3.55. WAG 6 surface water flow station and sampling sites.

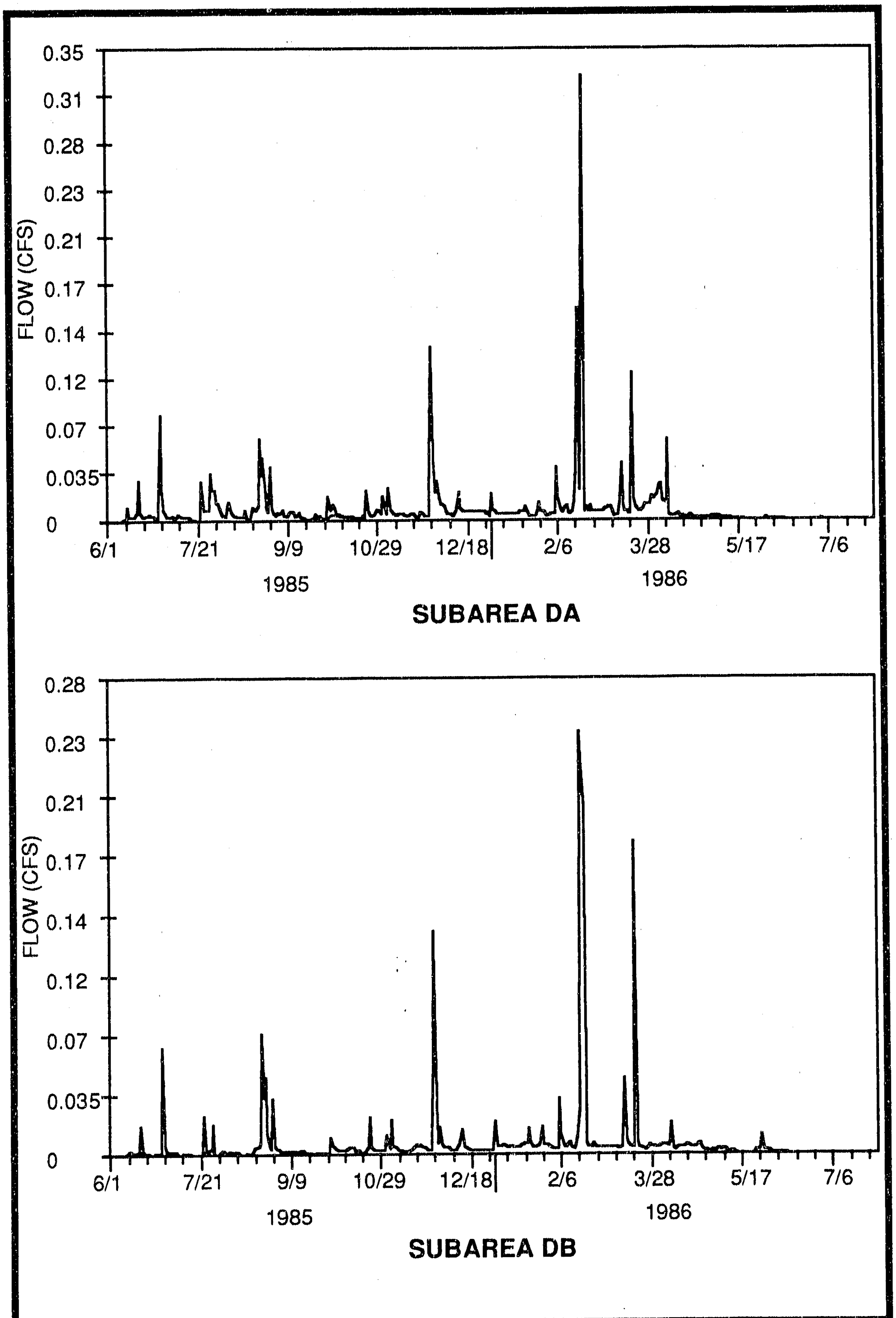


Fig. 3.56a. Mean daily flow hydrographs, June 1985-July 1986, Subareas DA and DB.

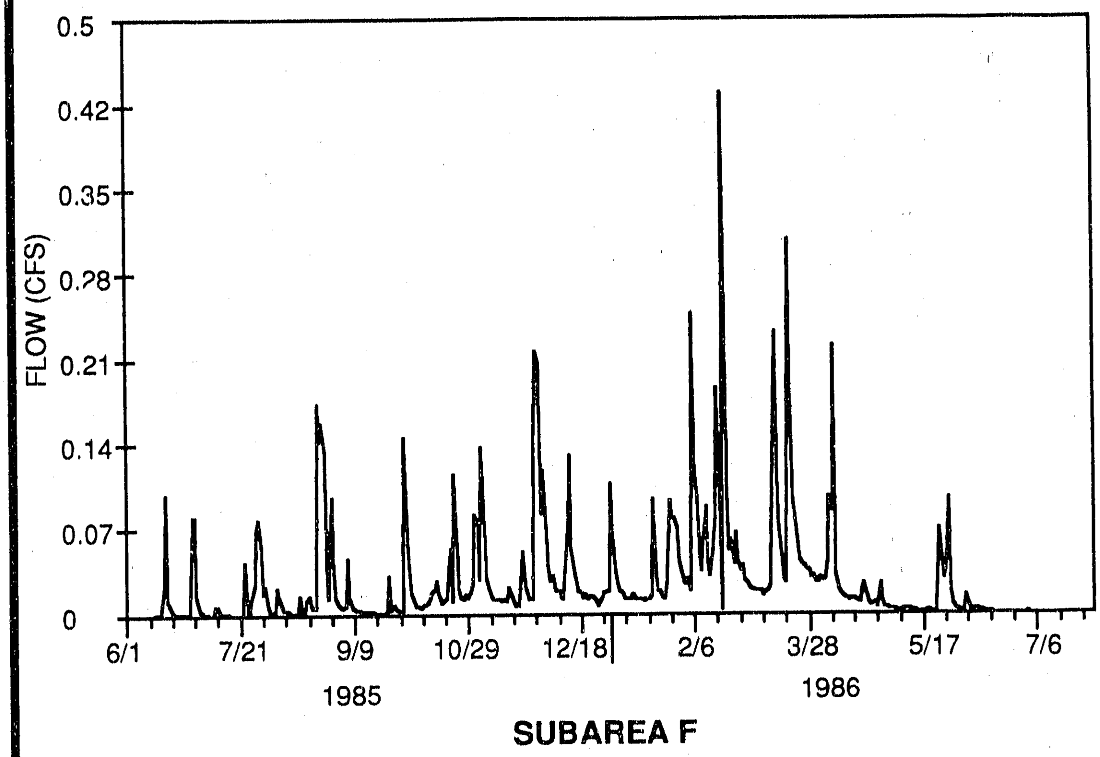
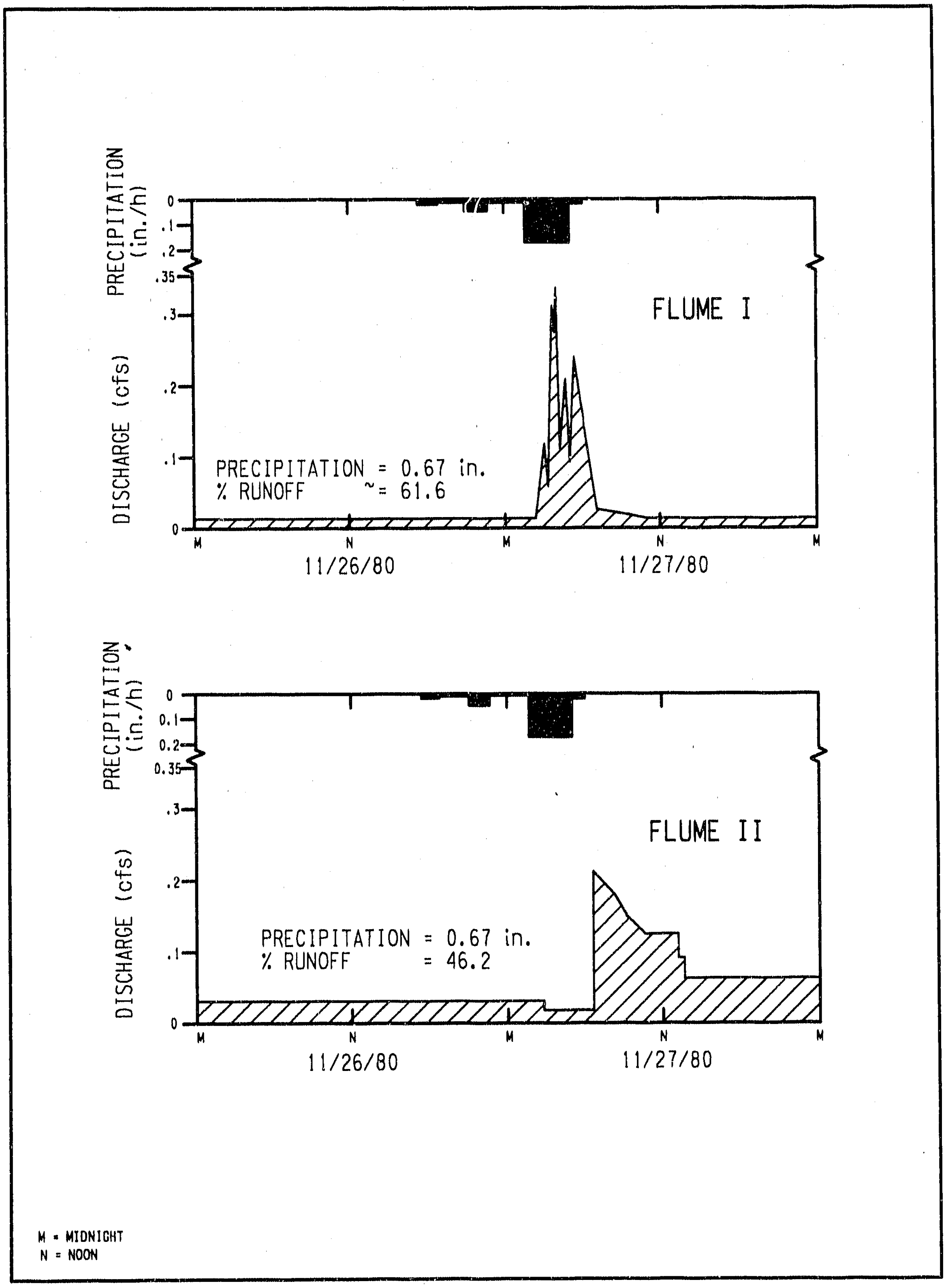
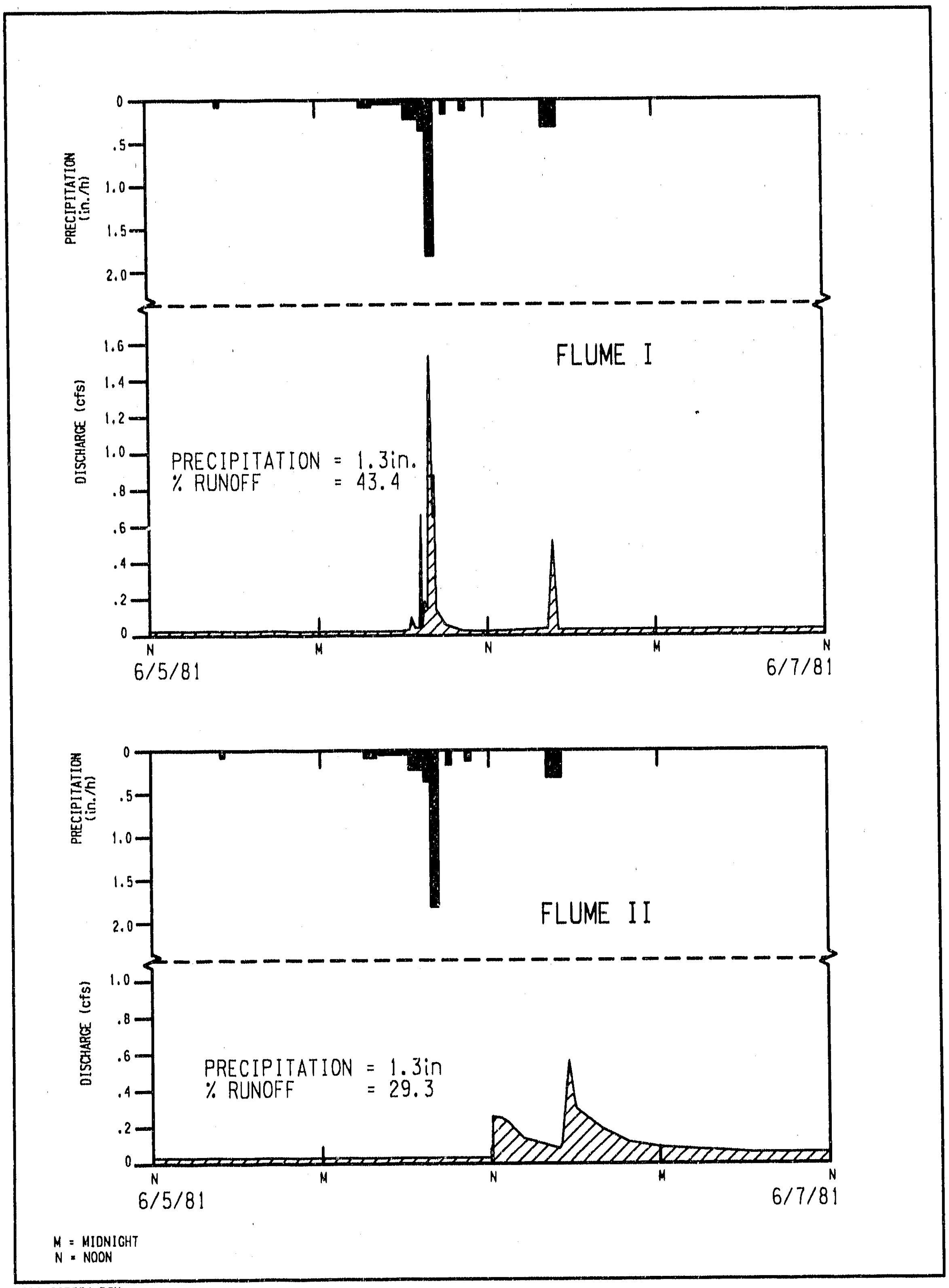


Fig. 3.56b. Mean daily flow hydrograph, June 1985-July 1986, Subarea F (combined FA and FB)



WAG6 06F333.DGN
9-1

Fig. 3.57a. Storm hydrograph, ETF site (November 1980).
Source: 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, Tennessee.



WAG6 06F334.DGN
9-1

Fig. 3.57b. Storm hydrograph, ETF site (June 1981). *Source*: 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, Tennessee.

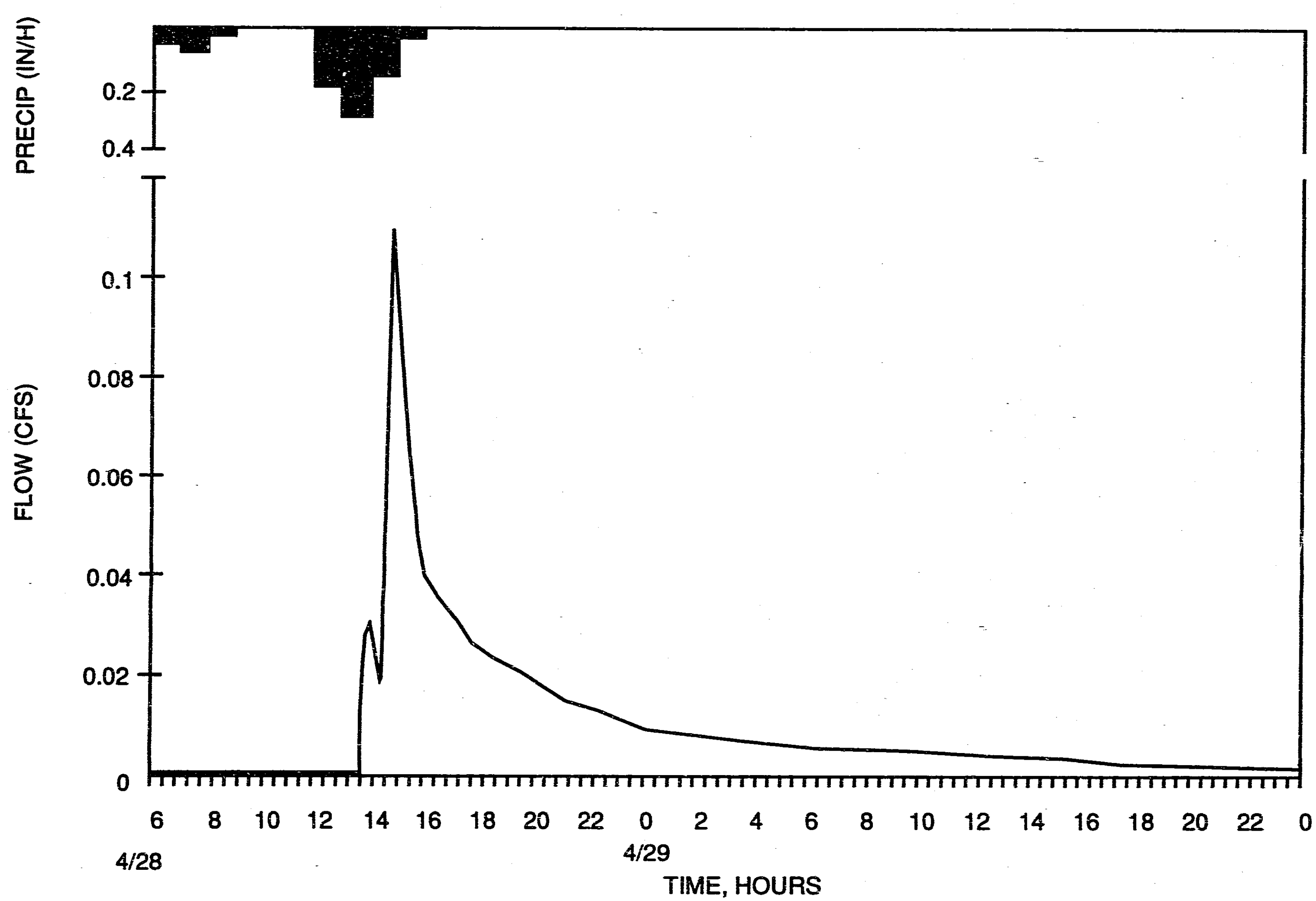


Fig. 3.58. Storm hydrograph, April 28, 1990 (Subarea FA).

5.14 3122.8

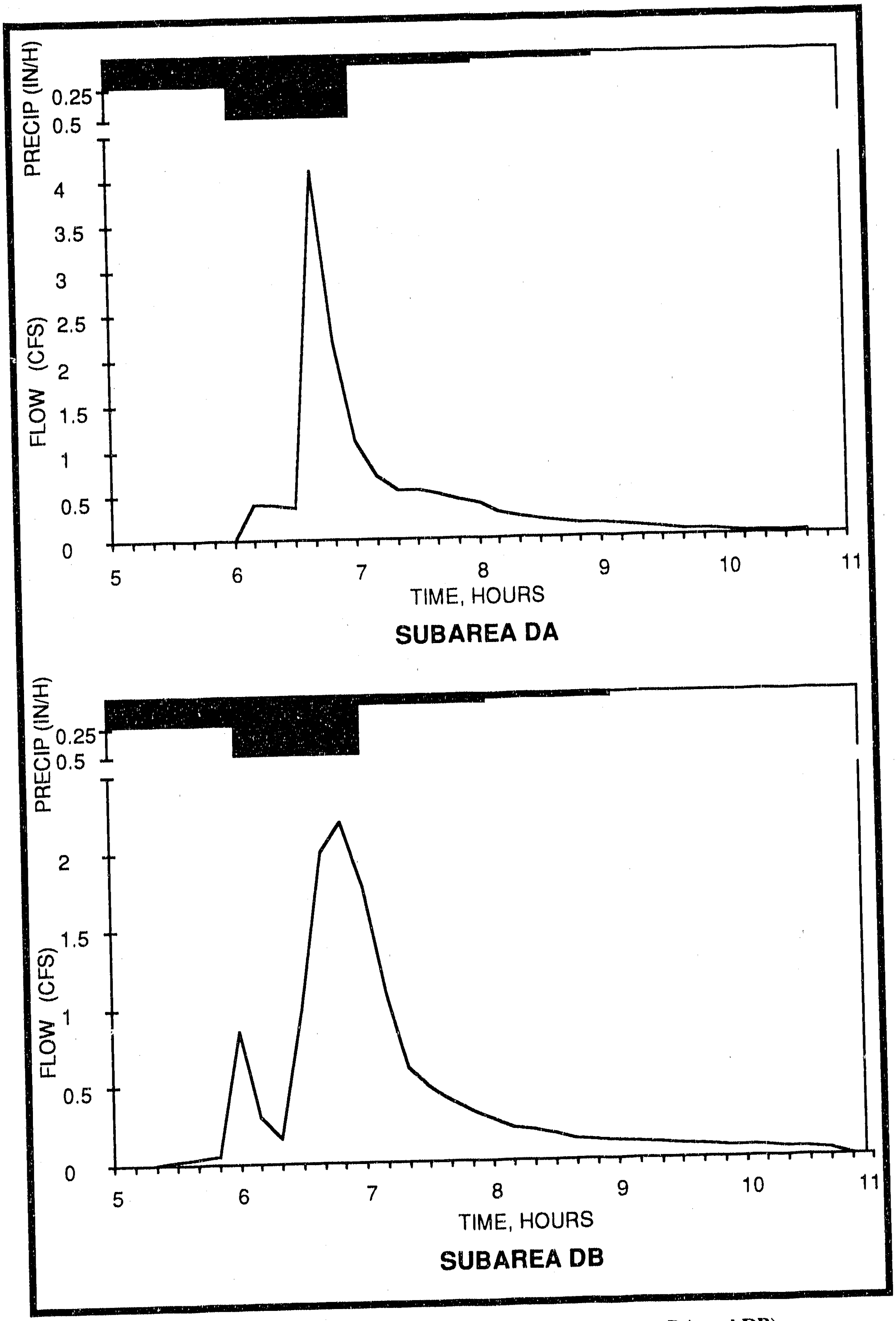


Fig. 3.59a. Storm hydrographs, May 17, 1990, (Subareas DA and DB).

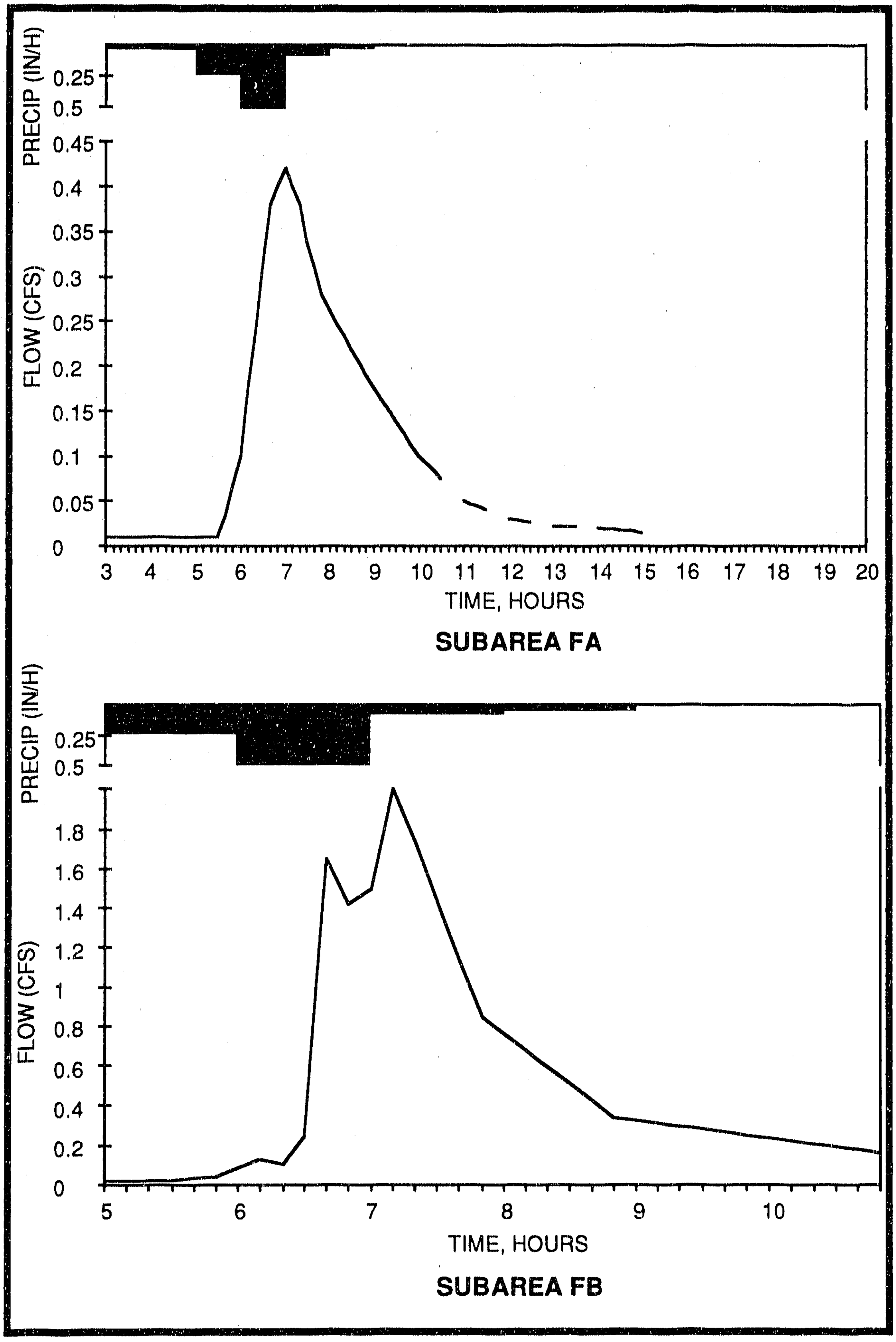


Fig. 3.59b. Storm hydrographs, May 17, 1990 (continued) (Subareas FA and FB).

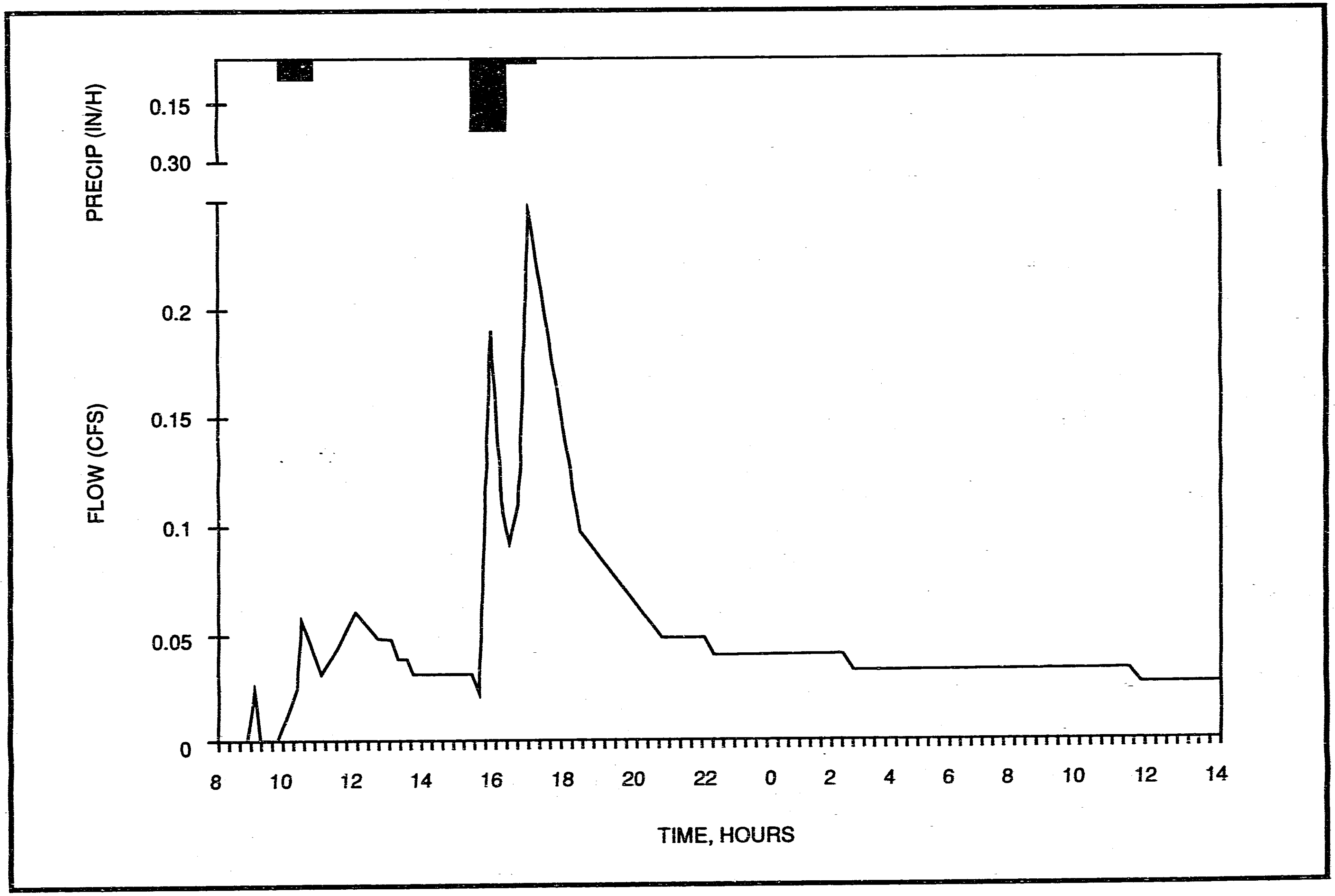


Fig. 3.60. Storm hydrograph, May 20, 1990 (Subarea FB).

5.14 3122.11

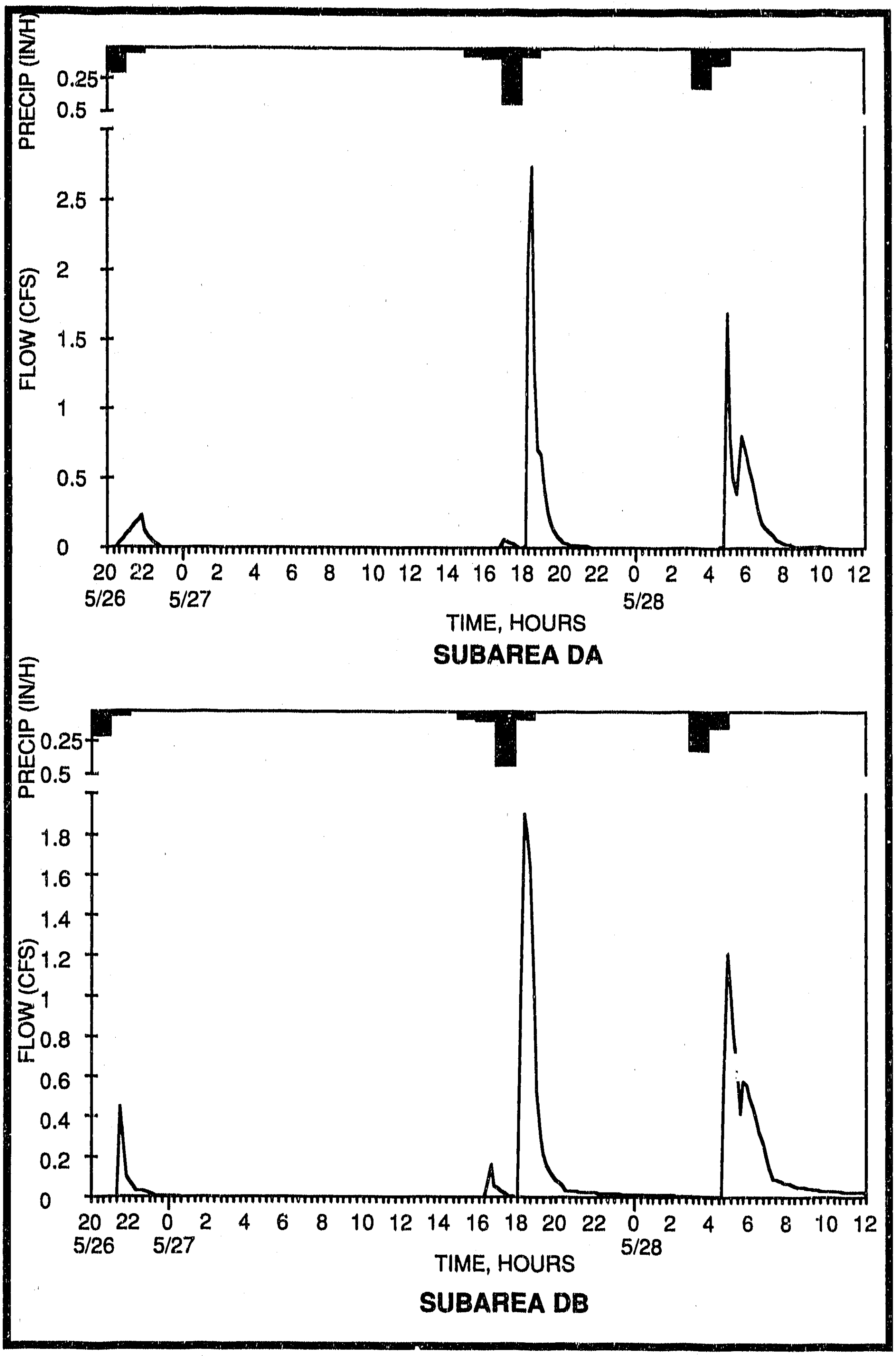
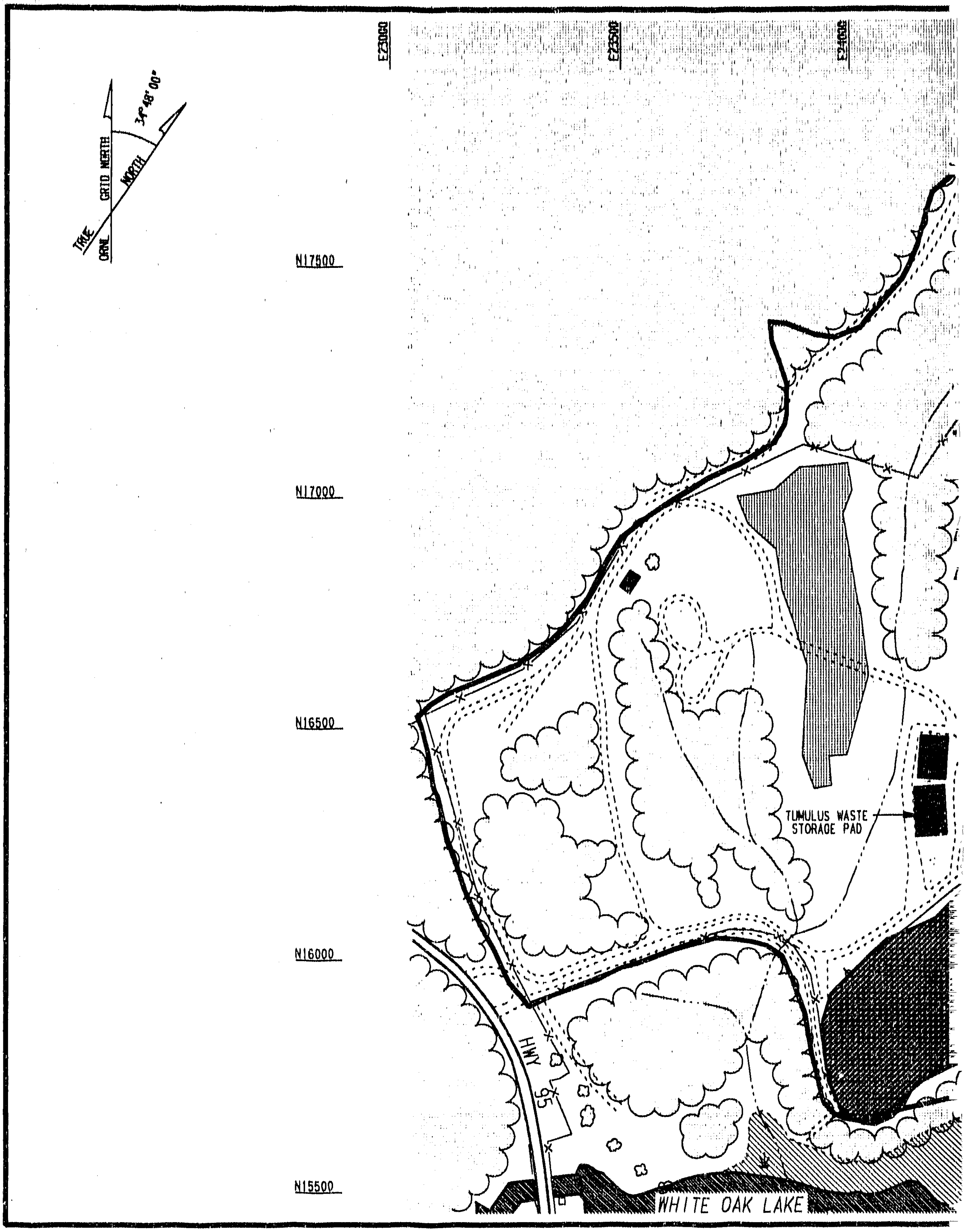


Fig. 3.61. Storm hydrographs, May 26-28, 1990 (Subareas DA and DB).



WAG6 DGF212.DGN
9-4

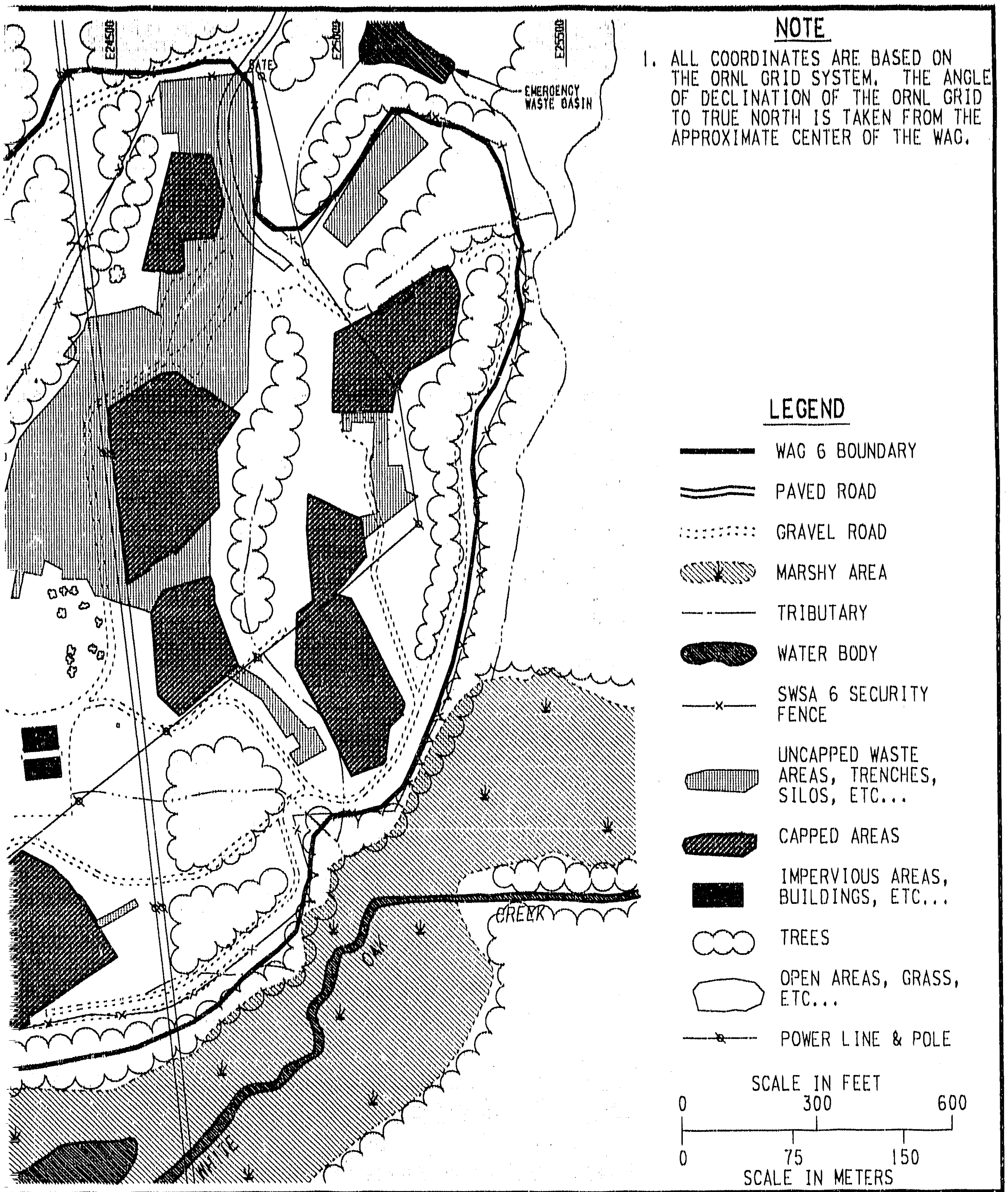


Fig. 3.62. WAG 6 land usage map.

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