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ENVIRONMENTAL SCIENCES DIVISION

SUMMARY OF ENVIRONMENTAL CHARACTERIZATION ACTIVITIES AT THE OAK RIDGE NATIONAL LABORATORY SOLID WASTE STORAGE AREA SIX FY 1986 THROUGH 1987

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NUCLEAR AND CHEMICAL WASTE PROGRAMS
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ABSTRACT

The Oak Ridge National Laboratory (ORNL) Remedial Action Program (RAP), has supported characterization activities in Solid Waste Storage Area 6 (SWSA 6) to acquire information necessary for identification and planning of remedial actions that may be warranted, and to facilitate eventual closure of the site. In FY 1986 investigations began in the areas of site hydrology, geochemistry, soils, geology, and geohydrologic model application. This report summarizes work carried out in each of these areas during FY's 1986 and 1987 and serves as a status report pulling together the large volume of data that has resulted. Characterization efforts are by no means completed; however, a sufficient data base has been generated to begin data interpretation and analysis of site contaminants.

1. INTRODUCTION

(E. C. Davis)

1.1 Background Information on SWSA 6

Solid low-level radioactive wastes (LLW) have traditionally been disposed of at the Oak Ridge National Laboratory (ORNL) using shallow land burial techniques. Disposal sites have ranged in size from less than one hectare (1-2 acres) to the presently operating Solid Waste Storage Area 6 (SWSA 6), which is 27.5 ha (68 acres) and consists of over 1000 individual waste trenches and circular auger holes. SWSA 6 is the only ORNL disposal site currently being used for the burial of LLW. The previous five sites are in a monitoring and routine maintenance phase and none have been officially closed from a regulatory standpoint.

In 1985 ORNL began formal site-wide characterization activities at SWSA 6 using guidance applied to new burial sites by Department of Energy (DOE) Order 5820.2 and Nuclear Regulatory Commission (NRC) 10 CFR Part 61 (Boegly et al., 1985). Prior to this time, most of the characterization work was aimed at understanding the geology and hydrology of small areas encompassing particular experimental sites (Davis et al., 1984; Davis and Stansfield, 1984; Cerling and Spalding, 1982). The purpose of this initial site-wide characterization activity was to collect the necessary geologic and hydrologic data required to better understand the physical and geochemical processes taking place in and around the buried waste. Burial operations began in SWSA 6 in 1969, before guidance was available from either DOE or NRC; therefore, the focus of this characterization activity was to "catch up" and begin to collect the environmental data that would be required of a new LLW disposal site seeking to obtain a permit for disposal.

At the midway point of the characterization studies (May 1986), SWSA 6 was closed to further burial operations by DOE pending investigation of the disposal of hazardous wastes (Resource Conservation and Recovery Act or RCRA regulated wastes) in certain trenches. It was determined that approximately 25 percent of the landfilling acreage had been used for disposal of RCRA regulated wastes, principally lead, xylene, and toluene. In April 1986 ORNL revised its Part A application on file with the Environmental Protection Agency (EPA) to reflect the hazardous waste deposited since 1980. At this time, SWSA 6 became a RCRA regulated disposal site.

SWSA 6 was reopened for disposal in July 1986 after several changes in operating procedures were made. Specifically: (1) ORNL established a waste disposal training course to be taken by all employees requiring low level waste disposal services, (2) ORNL established a waste inspection system to assure that no further RCRA regulated hazardous wastes would be buried in SWSA 6, and (3) ORNL adopted the policy that no further burial would take place in unlined trenches or unlined auger holes. Since reopening of the site in July 1986, all burials have been in concrete lined silos.

The change in SWSA 6 regulatory status, i.e. from a DOE regulated LLW site to a RCRA regulated mixed waste site, has had a significant effect on environmental characterization activities. In September 1986, a closure plan for SWSA 6 was drafted (ORNL, 1986a) and submitted to the EPA and the Tennessee Department of Health and Environment (TDHE) satisfying EPA and TDHE regulations 40 CFR 265 Subpart G, and Rule 1200-1-11-.05(7), Rules Governing Hazardous Waste Management in Tennessee. As part of the closure plan, preparation and implementation of a Remedial Investigation (RI) Plan was recommended in order to determine the need for, and extent of, remedial measures at the site. In December 1986, the RI Plan was drafted (ORNL, 1986b) and submitted to the EPA and the TDHE for review and approval. The RI Plan extended the scope of the 1985 characterization activities to include additional RCRA monitoring requirements in order to provide a single, comprehensive characterization program for SWSA 6. To date, no response has been received pertaining to either of the two documents mentioned above, and activities, as outlined in the RI Plan, have been initiated.

1.2 Purpose

The purpose of this report is to summarize SWSA 6 characterization activities that have been carried out during FY's 1986 and 1987. In this regard it is a status report on field activities which have been initiated as outlined in the Draft RI Plan. Several of the characterization activities, such as the site soil survey and trench leachate sampling, have been completed and results are reported elsewhere (Lietzke and Lee, 1986; Solomon et al., 1987). However, other activities, such as surface water gauging, water table elevation monitoring, trench water dynamics studies, and mathematical modeling of hydrologic processes, represent ongoing data collection activities that are likely to continue throughout the entire SWSA 6 RI phase. Where possible, attempts have been made to interpret data that have been collected; however, as additional experiments are carried out and more information becomes available, final interpretation of data and assessment of the need for site remedial measures can be made.

Data collection activities have been integrated into a variety of other research and demonstration projects being carried out by the ORNL Remedial Action Program (RAP) as well as other programs. For example, siting of an above ground waste storage tumulus in SWSA 6 relied heavily on soils and water table data collected to date. The Test Area for Remedial Actions (TARA) site located in the northeastern corner of SWSA 6 is in the process of demonstrating trench closure techniques that will have application throughout SWSA 6 and the entire ORNL reservation. Waste inventory and site hydrologic data collected as a part of the site-wide characterization have been extensively used at the TARA site. Finally, ORNL Operations Division has relied heavily on environmental data in order to determine where to site additional concrete-lined waste silos and to assess the remaining usable space in SWSA 6.

1.3 Approach to SWSA 6 Characterization Activities

The approach being taken to characterize the disposal environment at SWSA 6 has been to carry out studies under five subtasks covering the major information need areas identified by Boegly et al. (1985). These subtasks include: (1) hydrology, (2) geochemistry, (3) geology, (4) soils, and (5) site hydrologic modeling. Each of the first four subtasks involves a significant field data collection component as well as a review and analysis of past data collection activities. The fifth subtask (hydrologic modeling) attempts to integrate all data collection by constructing a mathematical model of water flow at SWSA 6. This modeling activity is not a complete site pathways analysis (in the regulatory sense), but rather a first step in understanding water movement and important contaminant transport routes at SWSA 6. Progress made in FY's 1986 and 1987 in each of the above mentioned subtasks, as well as a brief operational history of SWSA 6, is covered in the following sections of this report.

2. SITE DESCRIPTION AND WASTE INVENTORY

(E. C. Davis and D. K. Solomon)

2.1 Site Description

SWSA 6 is located within DOE's Oak Ridge Reservation (ORR), which is located in a broad valley between the Cumberland Mountains, lying to the northwest, and the Great Smoky Mountains, lying to the southeast. The reservation is about 40 km west of Knoxville, Tennessee and about 241 km east of Nashville, Tennessee. The ORR is bounded on the south and west by the Clinch River, on the east by state highway 62, and on the north by the City of Oak Ridge and privately-owned land. ORNL is located near the center of the ORR in Roane and Anderson Counties in East Tennessee and is one of the three major operating facilities on the ORR; the other two are the Oak Ridge Gaseous Diffusion Plant (ORGDP) and the Y-12 Plant.

SWSA 6 is in Roane County just northeast of White Oak Dam and is approximately 2.9 km southwest of the main plant area. Approximate coordinates for the site center are N17,000 by E24,500 (ORNL grid system). Although limited burial operations began at the site in 1969, the site was opened for routine disposal in January 1972 (as SWSA 5 was becoming filled) with the excavation of the first LLW disposal trench. Since that time, 487 unlined trenches, 21 concrete-lined disposal casks, and 582 auger holes have been constructed to dispose of solid LLW generated at ORNL as well as a number of off-site facilities. The general locations of burial trenches and auger holes, as well as important site features, are summarized in Figure 1.1.

2.2 Past Disposal Techniques

Radioactive wastes have been disposed in SWSA 6 using two basic techniques: (1) shallow trenches, and (2) shallow auger holes. Trenches, generally 15 m long by 5 m wide by 5 m deep, were used for the disposal of large objects including shipping containers, steel drums, laboratory equipment, waste bales containing compacted waste, construction debris, contaminated vegetation and soil, and animals used for experimental purposes. For a detailed photographic record of trenches constructed in SWSA 6 between July 1984 and September 1985 consult Davis et al. (1986).

Circular auger holes, generally 1 m in diameter and 4 to 5 m deep, have been used to dispose of smaller waste packages that required immediate shielding with several meters of soil cover backfilled over the waste. Until June 1986, all trenches and the majority of the auger holes were unlined and, if contacted by groundwater, would rely on the natural radiochemical adsorption properties of the surrounding soil to prevent radionuclides from migrating from the disposal units. Beginning in June 1986, all new disposal units (both trenches and auger holes) have been lined with 15 to 20 cm concrete walls, floors, and covers to isolate the waste from the hydrologic environment and thus inhibit waste leachate formation.

Trenches used in SWSA 6 are assigned to one of the following types depending on the waste placed in them: (1) high level, (2) low level, (3) biological, (4) asbestos, (5) low level baled, (6) fissile, (7) high level concrete lined, and (8) low level concrete lined. Regardless of the type, each trench has been assigned a number beginning with 1 and continuing through 523 (as of August 1987). Two trenches (54 and 79) are included in the inventory but are reported to have never been used. They do; however, show up on the SWSA 6 trench map (Engineering Drawing C3E 20004 A055). Table 2.1 summarizes the number of trenches of each type constructed in SWSA 6 on an annual basis through December 1986.

Auger holes have been classified as one of three types depending on their waste content: (1) high level, (2) solvent, or (3) fissile. High level and solvent auger holes have been assigned consecutive numbers beginning with 1 and ending with 482. Fissile auger holes were separated from the high level and solvent holes and were numbered consecutively from 1 to 100. Table 2.1 summarizes the number of each type auger hole constructed on an annual basis.

2.3 Estimated Waste Inventory

An extremely important subtask of the field characterization program has been assembling existing information concerning waste inventory and disposal locations into a usable form for contaminant transport modeling and other characterization activities. Key questions that need to be addressed include: (1) where and when did disposal operations take place in SWSA 6, (2) what amount (Curies) of radioactivity is estimated to have been placed in each disposal unit, and (3) to what extent has radioactive decay decreased the estimated radionuclide inventory? To answer these and other questions, information relative to burials at SWSA 6 has been extracted from the ORNL Operations Division Solid Waste Disposal Log (a computer data base containing information about trenches and auger holes), the ORNL Engineering Division (trench and auger hole locations), and the ORNL SWSA 6 operator's log (dates of disposal and types of trenches and auger holes used). Three LOTUS spreadsheets have been constructed containing this information (Davis and Solomon, 1987).

Examination of the waste inventory data indicates that a total of 219,557 Ci of radioactivity are estimated to have been placed in SWSA 6 trenches and auger holes as of May 1986. Of this total, 92% is contained in auger holes and the remainder (8%) is contained in trenches (see Table 2.2). A second search of the Solid Waste Disposal Log was performed which contains information through January 1987 (last column of Table 2.2). With the additional trenches and auger holes opened between May 1986 and January 1987, the total activity reported in SWSA 6 jumps to 236,913 Ci with 89% in auger holes and 11% in trenches. If it is assumed that the activity reported in the ORNL Operations Division Waste Disposal Log was correct for the date of trench or auger hole closure, then 152,008 Ci remain on January 1, 1987 after radioactive decay of individual radionuclides is considered (Table 2.2). This is a 31% decrease in activity from the 219,557 Ci originally present and is primarily due to the decay of Europium that has taken place in auger holes 155, 197, 235, 236, and 272.

A total of 19 auger holes (272, 236, 275, 235, 490, 197, 449, 292, 480, 246, 423, 427, 155, 482, 313, 174, 166, 296, and 326) and 7 trenches (460, 436, 444, 391, 283, 482, and 410) contain a total of 213,123 Ci or 90% of the reported activity in SWSA 6. The three spreadsheets compiled as a part of this waste inventory evaluation make it possible to rapidly identify these high activity disposal units which should be the focus of SWSA 6 groundwater monitoring activities.

It is important to note that the bulk of each spreadsheet is made up of estimates of isotope inventories that were made by the waste generator at the time of disposal. They may only be within an order of magnitude of the actual Curie content of the waste. Any scenarios of contaminant transport or remedial action should take into account the possible error associated with these estimates.

In addition to the fact that the waste inventory numbers are best estimates, there are numerous errors contained in the Solid Waste Disposal Log that was reviewed in the preparation of this waste inventory. For example, a simple error in entering a trench or auger hole number would assign that waste, and associated isotope inventory, to the wrong trench or auger hole. This type of error was noted on numerous occasions throughout the data search and points to the need for better quality control on entries into the Waste Disposal Log. The SWSA 6 waste inventory search conducted as a part of this characterization study is a first attempt at making the isotope inventories available to a greater number of investigators than currently have access to the information. There are numerous pieces of missing information, such as locations of certain trenches or auger holes, that need to be added as the information is obtained.

3. SITE HYDROLOGY

(E. C. Davis and D. K. Solomon)

3.1 Site Precipitation Records

SWSA 6 precipitation has been measured at the Engineered Test Facility (ETF) located in the northwest corner of the site since August 1980. The rain gauge is a Belfort Instrument Company Model 9432 weighing bucket gauge which records precipitation events on a 7-d paper chart. Two additional rain gauges have been installed at the site; one weighing bucket type (identical to that located at the ETF) in the 49-trench section of SWSA 6, and a second tipping bucket type gauge located near the ETF site at the EPICOR-II resin leaching experiment. The gauge in the 49-trench section has been operational since March 1986, and the tipping bucket gauge at the EPICOR-II site has been in operation since June 1985. Table 3.1 summarizes the precipitation data collected at the ETF and 49-trench site compared to the average monthly precipitation measured at the Oak Ridge site.

Every year since the ETF gauge was installed in 1980 the SWSA 6 annual precipitation has been below the Oak Ridge mean precipitation of 1388 mm. The largest deficit occurred in 1986 when site precipitation was 417 mm below normal. Through June of 1987, the site is approximately 150 mm below normal indicating that another deficit year is likely to occur. Though the precipitation data summarized in Table 3.1 are monthly totals, individual daily totals have been collected in SWSA 6 and are part of an ORNL precipitation data set (Appendix A).

3.2 Surface Runoff

Surface runoff measurements began in SWSA 6 in June 1985 following the construction of three temporary gauging stations located at road culverts where the three major drainage creeks exit the site (Fig. 1.1). Each station consists of a 38 cm diameter combination V-notch and rectangular weir inserted in the upstream end of the drainage culvert. The V-notch portion of the weir is capable of measuring low flows between 0.002 and 0.06 L/s, while the rectangular portion is capable of measuring flows from 0.06 to 30.5 L/s. Flows above 30.5 L/s are beyond the measuring capability of the gauging stations and have been reported as out of range. A shallow pool was constructed immediately upstream of the weir and the banks of the pool were lined with filter fabric and crushed limestone to prevent erosion. A vertical stilling well was constructed in the center of the pool (anchored to a concrete base) and was fitted with a Stevens punch tape water level recorder that was programmed to record the elevation of the water surface in the pool (stage height) every 15 minutes. Table 3.2 summarizes important parameters of each of the three gauging stations.

As can be seen from examining the contributing drainage areas in Table 3.2, the three gauging stations account for runoff from 77.5% of the SWSA 6 site. The remaining 22.5% consists of the extreme eastern portion of the site that drains into the creek immediately to the east of SWSA 6. Because this creek also receives drainage from the liquid waste pits and trench area it would be difficult to separate out the portion of flow originating in SWSA 6. Another small portion of SWSA 6 located in the extreme southern end of the site drains directly to White Oak Lake through undefined channels and is thus impossible to gauge.

Stage height was related to discharge through bucket gauging of the streams under a variety of flow conditions making in order to construct rating curves. Figures 3.1 through 3.3 show the rating curve developed for each station. Included in Figures 3.1 through 3.3 are the curves showing the stage-discharge relationship printed on each weir by the manufacturer (plus symbol on figure) as well as the stage-discharge relationship based on the solution to Equations 3.1 and 3.2 which are the theoretical discharge equations for the V-notch portion of the weir (head less than 2.41 cm 0.95 in) and combination V-notch rectangular weir (head greater than 2.41 cm 0.95 in), respectively (diamond symbol on figure).

For $h \leq 2.41$ cm (0.95 in) when flow is in the V-notch only:

$$Q = 2.5\ (h/12)^{2.5} \qquad \text{Eq. 3.1}$$

For $h > 2.41$ cm (0.95 in) when flow is in the V-notch and rectangular weir:

$$Q = 2.5\ (h_1/12)^{2.5} + 3.33L\ [(h-h_1)/12]^{1.5} \qquad \text{Eq. 3.2}$$

where;

Q = flow in cfs,
h = height of water above the bottom of the V-notch (in),
h_1 = 0.95 in, and
L = width of rectangular weir (ft).

Surface runoff from Stations 1, 2, and 3 has been measured from June 1985 to present with only minor down time due primarily to battery failure associated with the water level recorder. During this two year period of record, flow at Station 1 has been out of range on 7 occasions, Station 2 on 11 occasions, and Station 3 on 31 occasions. This is not surprising, given that the weirs are all the same size and Station 3 has the largest contributing area (13.46 ha, see Table 3.2). Each of the time periods when flows were out of range (> 30.5 L/s) were preceded by either large precipitation events such as the 101 mm event that occurred on August 16, 1985, or by several consecutive days when precipitation was greater than 20 - 25 mm. Table 3.3 is included as an example of daily stream flows for Station 3 for the month of May 1987. Additional daily flow summary tables for each station, by month, are available, but are not included in this report. Instead, monthly summaries are presented in Tables 3.4 through 3.6. These summaries present the average monthly flow along with observed minimum and maximum flow at each Station.

3.3 Water Table Elevation Data

Water table elevation measurements have been made in SWSA 6 on a regular basis by the U.S. Geological Survey (USGS) since April 1975 (Webster et al., 1980). As a part of the SWSA 6 characterization activities, 47 of these same wells used by the USGS, as well as 17 newly installed piezometers, have continued to be monitored on a monthly basis for water elevation. Figure 3.4 illustrates the location of the water table monitoring wells and Table 3.7 summarizes the construction characteristics of each well included in the program. Table 3.8 summarizes the water table elevation data set that has been constructed from December 1986 to August 1987. From the data contained in Table 3.8, two water level contour maps have been constructed (Figs. 3.5 and 3.6). The data for September 1986 represents the water contours during a relatively dry season of the year, while the data for February 1987 represent contours during the wet winter months. The contours presented in Figures 3.5 and 3.6 were computer generated using a Cokriging technique to estimate water table elevations. Cokriging is a modification of the simpler technique of Kriging in which measurements at discrete points in space are used to calculate the parameter at an unsampled point. The topography of land surface was used as a covariate to improve the estimate of the water table. The procedure assumes that a relationship, albeit a complicated one, exists between land surface and the water table. The computer program CONTMAP was used to perform the calculations (Hoeksema, 1987). Cokriging was performed using a linear as well as an exponential model for the spatial dependence of the water table. A variety of correlation lengths were tried with the exponential model; however, the linear model was superior in all cases. Only wells in which the measured water level was within 2 m of the top of the screened interval were used in the Cokriging procedure. A topographic grid containing 625 equally spaced points was used as input for CONTMAP which returned an estimate of the water table at each of these points.

In addition to the 64 piezometers being monitored in SWSA 6, 30 new RCRA water quality monitoring wells have been installed (Fig. 3.7). The locations of the new water quality monitoring wells were based on: (1) siting wells upgradient of the site to monitor background water quality, (2) siting wells downgradient from the site to monitor the quality of water being discharged to White Oak Lake, and (3) siting wells downgradient of individual trench and auger hole areas. Figure 3.7 summarizes the location of the new SWSA 6 water quality wells. To date, the wells are being developed following installation and no samples have been collected for chemical analyses.

3.4 Site Water Balance

The term water balance was used in 1944 by C. W. Thornthwaite to refer to the balance between the inflow of water from precipitation and snowmelt and the outflow of water by evapotranspiration, groundwater recharge, and streamflow (Dunne and Leopold, 1978). The budget can be computed for a soil profile or, as in the case of SWSA 6, for an entire watershed. The balance for a small watershed underlain by impervious rock is often defined as:

$$P = I + AET + OF + SM + GWS + GWR \qquad \text{Eq. 3.3}$$

where;

P = precipitation
I = interception
AET = actual evapotranspiration
OF = overland flow
SM = change in soil moisture
GWS = change in groundwater storage, and
GWR = groundwater runoff.

If time and funds are available, each of the terms in Equation 3.3 can be evaluated; however, the approach that is often taken is to make calculations on an annual basis and assume that there is no net change of soil moisture or groundwater storage over the year. If this assumption is made, the right side of Equation 3.3 reduces to the sum of interception, evapotranspiration, and streamflow.

In the SWSA 6 characterization activities, precipitation (P) and streamflow (OF + GWR) are the two terms in Equation 3.3 that have been measured since June 1985. Expressing streamflow as a percentage of precipitation on a monthly basis leads to the seasonal relationship shown in Figure 3.8. This figure demonstrates that SWSA 6 runoff is highly seasonal and can be characterized by four distinct periods: (1) low runoff (0 - 10%) during the summer months, (2) increasing runoff (10 - 50%) during the late fall, (3) maximum runoff (30 - 50%) during the winter months, and (4) decreasing runoff (50 - 10%) during the spring months as the growing season begins. As can be seen in Figure 3.8, all three of the SWSA 6 watersheds exhibited the same seasonal pattern over the two year observation period with watershed 3 (area contributing to Station 3) exhibiting somewhat higher runoff percentages during the fall and winter months than either watersheds 1 or 2. Other than the fact that watershed 3 is larger than watersheds 1 and 2 (see Table 3.2), the only other major differences are that watershed 3 contains a higher percentage of forested and steeper sloped areas than 1 or 2 which may account for the increased percentage of runoff during the fall and winter.

In addition to examining the monthly water balance, the period July 1986 to June 1987 was selected as a 12-month period over which to perform an annual water balance. Figure 3.9, which displays the monthly hydrograph for piezometer 655, demonstrates that there is a considerable change in groundwater storage during this 12-month period (approximately 1.5 m difference between summer low and winter high); however, between July 1986 and June 1987 there is negligible change in storage. With this assumption of no change in soil moisture or groundwater storage, the annual water balance was performed and is summarized in Table 3.9. During this annual cycle, 24% of the precipitation was accounted for as surface runoff and the remaining 76% is attributed to interception, evapotranspiration, and perhaps direct recharge to deeper groundwater or White Oak Lake.

4. GEOCHEMISTRY

(D. K. Solomon and A. D. Kelmers)

4.1 Trench Leachate and Groundwater Well Sampling Activities

This section summarizes the results of the groundwater and trench leachate sampling and analysis activities conducted in SWSA 6 during FY 1986 and FY 1987. A complete description of the methods and results is given in Solomon et al. (1987), Solomon et al. (1986a), and Solomon et al. (1986b). The purpose of this work is to obtain contaminant and groundwater quality information that can be applied to the development of contaminant source terms. Water samples were analyzed both for the concentration of contaminants [radionuclides, EPA priority pollutant organic compounds, inorganic and organic compounds listed in the State of Tennessee guidance for Superfund Sites, inorganic elements in the EPA National Interim Primary Drinking Waste Standards (NIPDWS), and other chemicals] and for water quality parameters and components.

Only limited information on the identity or quantity of radionuclides emplaced is available from the SWSA 6 historic operational log. In addition to radionuclides, organic and metal contaminants are known to be present in SWSA 6, but no information on these materials was included in the SWSA 6 operational log. Waste containers varied from none to concrete boxes, glass bottles, or steel containers; again, historic documentation is not available. The limited information available makes prediction of contaminant release rates problematic, if not impossible, from the existing inventory (Davis and Solomon, 1987).

Therefore, we have undertaken an experimental approach to developing source term information by sampling and analyzing water from groundwater quality wells outside trenches and trench leachates from monitor wells within selected trenches. We have also explored contaminant releases from wastes in auger holes by obtaining groundwater from wells near auger hole areas because monitoring wells do not exist for individual auger holes.

Water was withdrawn from the wells using either positive displacement, 100% Teflon bladder pumps, or peristaltic pumps fitted with Teflon tubing down the well and Tygon tubing around the pump head. A number of field parameters were measured either as the sample was withdrawn or promptly after collection in the field. Field parameters are those which might be expected to change if the water was allowed to stand or was exposed to air. The field parameters measured were: temperature, pH, dissolved oxygen (DO), redox potential (Eh), and conductivity. Alkalinity titrations were initially done in the field but were subsequently done in the laboratory within 24-h after the sample was obtained. Several sample splits were obtained and appropriately stabilized and/or bottled for transport to the Analytical Chemistry Division (ACD) for subsequent analyses. The ACD performed analyses for: (1) alpha-, beta-, and gamma-emitting radionuclides by appropriate radiochemical counting techniques, including chemical separation steps where necessary, (2) cations, including elements on the NIPDWS list, by inductively coupled plasma spectrometry (ICP) or atomic adsorption (AA) techniques, (3) anions by ion chromatography, (4) EPA priority pollutants and other organics by gas chromatography - mass spectroscopy (GC-MS) methods, and (5) several miscellaneous chemical analyses for inorganic and organic carbon, ammonia, cyanide, etc. Completion of all these analyses for each water sample represented an appreciable effort and cost.

Because transport of contaminants in the unsaturated zone of SWSA 6 could be a significant source term component, commercially available apparatus for sampling groundwater under unsaturated conditions was obtained and tested. Although operational, the time required to obtain the minimum 2 L sample volume needed for the analyses would be prohibitive and no unsaturated zone samples were collected during FY 1986 or FY 1987. An unsaturated lysimeter sampler has been designed and is being fabricated. It will be tested in the future.

The field analyses of groundwater and trench leachate samples showed similar compositions. Sample pH ranged from pH 5.7 to 8.0, temperature from 10.5 to 25.5 °C, and alkalinity from 2.5 to 14.4 mM HCO^{3-}. The dissolved oxygen and Eh measurements showed generally oxidizing conditions. Higher dissolved oxygen values correlated with higher Eh values. Conductivity values were low, with the exception of one trench that had been used previously in a salt injection test. In general, all field analytical results were typical of values for shallow groundwaters in east Tennessee. As might be expected, the more extreme (highest or lowest) values were measured for samples from trenches where waste components could be contributing to or altering the groundwater composition.

The cation and anion analyses of trench leachate and groundwater samples also showed results typical of shallow groundwaters in east Tennessee. Calcium, magnesium, and sodium were the major cations, and bicarbonate, sulfate, and chloride were the major anions. Trench leachates were generally enriched in chloride, relative to groundwater samples.

Only a few elements on the NIPDWS list were identified in groundwater or trench leachate samples. Nickel was detected in several samples in concentrations as high as 0.27 mg/L, and mercury was detected in one groundwater sample (but not in any of the trench leachate samples) at a low concentration of 0.0007 mg/L.

As would be expected, because SWSA 6 is a radioactive waste disposal site, a number of radionuclides were present in both trench leachates and groundwater samples. Tritium (^{3}H) was ubiquitous in SWSA 6 samples. Concentrations as high as 340,000 ± 10,000 Bq/L were measured in one trench leachate. Tritium concentrations exceeded 1,000 Bq/L in 11 of the 16 trench leachate samples and in 2 of the 5 groundwater samples. Strontium-90 (^{90}Sr) and carbon-14 (^{14}C) were present at appreciable concentrations in a number of trench leachate samples, but were lower or absent in groundwater samples. The highest ^{90}Sr value observed was 3,600 ± 100 Bq/L and the highest ^{14}C value was 2,900 ± 100 Bq/L. Low levels of ^{137}Cs were detected in a few trench leachate samples. Cobalt-60 and total radium values were at or near the analytical detection limit in all samples. Uranium or thorium radionuclides were not identified in any samples.

The ^{3}H, ^{60}Co, and ^{90}Sr concentrations in each trench leachate and groundwater sample were compared. No correlations were observed; i.e., one trench leachate might be high in ^{3}H and low in ^{90}Sr, while another leachate might have the reverse relationship. This result might be expected, considering the heterogeneous nature of the contaminants, wastes, and waste containerization in the trenches. This finding; however, suggests that future monitoring of SWSA 6 groundwater contamination may have to include a complete radiochemical analysis rather than attempting to rely on monitoring of indicator radionuclides.

A total of 21 EPA priority pollutant organic compounds were identified in groundwater or trench leachate samples. Because most of the samples were collected from stainless-steel-cased wells, few, if any, of the organics detected are believed to have been present due to well installation operations. While caution should be used in considering the significance of ppb-level values for priority pollutant compounds which are near the analytical detection limit, several organics were present at high concentrations of up to about 1 mg/L - values which are 100 to 500 times the analytical detection limit. There would seem to be little question about the presence of these organics. The priority pollutants present at relatively high concentrations were: benzene, naphthalene, tetrachloroethene, toluene, and trichloroethene. Naphthalene, tetrachloroethene, and toluene were detected at high concentrations in more than one well and, therefore, these contaminants may be relatively widespread in the SWSA 6 site. High concentrations of priority pollutants were found both in trench leachate and groundwater samples. Several organics were present at concentrations which exceeded the State of Tennessee Superfund site guidelines; these were: chloroform, methylene chloride, xylenes, and naphthalene. While additional analyses for priority pollutant organics should be obtained in the future, the information developed to date suggests that mobile organic compounds could be a significant environmental concern at SWSA 6.

The presence of organic contaminants in SWSA 6 has several implications for groundwater monitoring plans. Based on the historic operational log, organic compounds have apparently been placed in both trenches and auger holes. Beta spectroscopy scintillation fluids and de-greasing compounds may represent the principle sources of organics present in trenches. Xylene, toluene, and benzene are typical components of scintillation fluids, and all of these have been observed in various water samples. Chlorohydrocarbons are frequently used in metal cleaning steps and such compounds have also been observed in various samples. No information is available in the historic operational log concerning the identity of the organics discharged to the 37 auger holes marked as "solvent auger holes" (Davis and Solomon, 1987). Future SWSA 6 monitoring plans should include adequate procedures to detect mobile organic compounds in the vicinity of the "solvent" auger holes. None of the organics identified in this study were at concentration near-to or above saturation in water. Thus, the present work does not indicate a need for special wells capable of sampling floating or sinking water-immiscible contaminants.

In order to explore the variation in contaminant concentration with time, four trenches were sampled on three separate dates over a 15-month period (during both high and low precipitation periods). Large variations (factors 10- to 100-fold) were observed in the concentrations of ^{3}H, ^{90}Sr, and ^{137}Cs. Although the radionuclide concentrations showed a weak correlation with trench hydrology (wet vs dry conditions), it may be difficult to predict the contaminant response to changes in infiltration, etc., because discordant changes were measured. For example, ^{90}Sr and ^{137}Cs concentrations were observed to increase in some cases while ^{3}H concentrations decreased, or vice versa. A better understanding of trench hydrology and waste leaching or dissolution processes may be necessary to rationalize such observations.

The saturation state of trench leachates and groundwaters with respect to a variety of common mineral phases was modeled with the geochemical code WATEQF (Plummer et al., 1983). Most of the trench leachate samples were computed to be supersaturated with respect to the iron-bearing minerals goethite, hematite, maghemite, and magnetite. Iron concentrations were much lower in groundwater samples. This observation suggests that iron in the trench leachates could be resulting from the corrosion and dissolution of waste components such as iron or steel parts, cans, etc. If so, the appearance of high concentrations of dissolved iron in site groundwaters might be useful as an indication of rapid movement of water from a trench to a near-by monitoring well.

The total radionuclide activity in four trench leachate samples was compared with the existing radionuclide inventory data (Davis and Solomon, 1987) for those trenches. A direct relationship might be expected, i.e., the trenches with the higher inventories might be expected to have the leachates with the higher activities. Such a relationship was not observed in the cases of the four trenches examined. In fact, an inverse relationship was seen; the trenches with the highest inventory had the lowest leachate activities, and vice versa. The inverse relationship may be an artifact of the small number of trenches sampled and a larger sample population might have shown simply a random relationship. The inverse relationship also could result from the use of higher integrity containers for the higher activity shipments. The limited data obtained to date suggests that the SWSA 6 radionuclide inventory information may be of little utility in attempting to estimate trench leachate radionuclide concentrations or release source terms. Such a conclusion may not be inconsistent with the known heterogeneity of waste materials and containers. This observation helps underscore the need for experimental measurement of contaminant concentrations and illuminates the difficulties which may be encountered in attempting to predict future site contaminant release rates.

For purposes of comparison with current regulatory philosophy, the trench leachate and groundwater contaminant data were compared with the State of Tennessee Guidelines for Superfund Sites (STGSS) and with the EPA NIPDWS. Although the SWSA 6 site will fall under the regulatory limits of the RCRA, the RCRA currently invokes limits established by the NIPDWS. Four organic compounds were present at concentrations near or substantially above the STGSS limit; these were: chloroform, methylene chloride, xylenes, and naphthalene. No elements were identified which exceeded the NIPDWS limits. As might be expected, because SWSA 6 is a radioactive waste disposal site, a number of alpha- and beta-emitting radionuclides exceeded the gross alpha- or beta-activity limits in the NIPDWS. Of these, tritium (^{3}H) was the worst offender.

Recommended future activities in SWSA 6 include: (1) development of methodology for sampling in the unsaturated zone and estimation of the fraction of contaminant source terms which may be represented by transport in the unsaturated zone, (2) analysis for organic chelating agents to explore the potential for mobilization of radionuclides or metal elements as soluble complexes, (3) a long term (3 to 5 year) study of selected trenches with repeated sampling during wet and dry seasons to help define the influence of trench hydrology on the source terms, (4) a soil-gas survey to help define the areal extent of organic contamination, and (5) additional groundwater sampling to quantify the amount and distribution of priority pollutant organic compounds in SWSA 6.

4.2 Radionuclide Sorption Information for SWSA 6 Soils

This section summarizes the results of some preliminary laboratory experiments to measure the sorption of radionuclides in various soil/groundwater systems typical of those in SWSA 6. A complete description of the methods and results can be found in Friedman and Kelmers (1987). This work was undertaken to support modeling of the mobility of radionuclides at the SWSA 6 site. Simplified mobility modeling frequently employs the use of a retardation factor (the rate of groundwater flow divided by the rate of transport of the contaminant). The retardation factor, R_f (dimensionless) can be derived from the expression

$$R_f = 1 + K_d(d/p) \qquad \text{Eq. 4.1}$$

where K_d is the experimentally measured sorption distribution coefficient (units of L/kg), d is the formation bulk density (units of kg/L), and p is the porosity (dimensionless). Although application of this simplified modeling approach to predict contaminant mobility is subject to a number of constraints (Kelmers et al., 1987), this method is widely used in characterizing disposal sites (for example, Lutton et al., 1982). Therefore, we experimentally measured K_d values for a number of radionuclides of interest to the SWSA 6 site.

Batch contact methodology was employed. For the soil/water contact, 2.0 g of the respective soil and 10.0 mL of the spiked and traced groundwater were placed in a 15 mL glass centrifuge tube. The tube was clamped on a wrist-action shaker which produced continuous mixing of the soil and water. After contact, the groundwater was recovered by centrifugation and counted. The distribution coefficient was calculated by dividing the element concentration on the soil (measured by difference in solution) by the concentration in the solution after contact. All contacts were run in triplicate and the K_d values were calculated as a mean $\pm$ 1 standard deviation. Many tests involved a contact time of 168 h, while in other tests, the effect of varying contact time was explored. All tests were carried out at room temperature. The compounds used to spike the groundwater were $CsNO_3$, $CoCl_2$, $Eu(NO_3)_3$, $SrCl_2$, and $UO_2(NO_3)_2$. The samples were traced by the addition of approximately 15,000 cpm of the respective radioactive compound: $^{137}CsCl$, $^{60}CoCl_2$, $^{155}EuCl_3$, $^{85}SrCl_2$, or $^{233}UO_2(NO_3)_2$. Many tests were run at a spike concentration of 10^{-3} mol/L, but in other tests the spike concentration was varied to construct sorption isotherms. Tests were always run with a single tracer present, but were frequently run in pairs, one with the single parallel tracer added and one with all tracers added, to explore the effect of sorption competition. In a few tests, the pH was deliberately varied to explore the sensitivity of the K_d values to possible changes in this site parameter.

Most of the experiments were carried out with an approximate 18 kg sample of soil provided by D. K. Solomon (Environmental Sciences Division, Oak Ridge National Laboratory) from the bottom (below the leached unsaturated zone) of a freshly-opened SWSA 6 trench located at N17,500, E24,650 (ORNL grid system). Approximately 2 kg of the as-received soil was passed through a 20 mesh screen. The -20 mesh soil fraction was homogenized in a V-blender and used in the sorption tests. A few tests were carried out with samples of well characterized unsaturated zone soils received from S. Y. Lee (Environmental Sciences Division, Oak Ridge National Laboratory). These soils are further described in Lietzke and Lee (1986). The groundwater used in the tests was obtained from well S-8. As received, the groundwater has a pH of 8.1. To stabilize the CO_2 content of the groundwater, a portion of the +20 mesh fraction of the soil sample was mixed with the groundwater. The stabilized groundwater had a pH of approximately 7.0-7.2. Sorption isotherms were constructed for cesium, cobalt, europium, strontium and uranium. General conclusions derived from the isotherm tests were:

(1) Sorption Rate - In the initial tests designed to select the minimum contact time which appeared to yield steady-state values, cesium, cobalt, europium, and strontium K_d values remained stable after 24 h or less. Uranium sorption continued to increase slightly over a 1 week period.

(2) Distribution Coefficient - In the linear portion of the sorption isotherms run at near neutral pH's typical of the SWSA 6 saturated zone,

cesium, cobalt, and europium K_d values were near the analytical detection limit of 3,000 L/kg. Strontium and uranium values were lower and ranged from 50 to 75 L/kg. Sorption ratios as high as 3,000 L/kg may result in retardation (reduced mobility) of solubilized radionuclides within the SWSA 6 site for environmentally favorable lengths of time.

(3) Sorption Capacity - The K_d value at the highest concentrations used in these tests (10^{-3} mol/L) was lower than those at lower concentrations (10^{-8} to 10^{-10} mol/L) in the cases of cobalt, strontium, and uranium. This decreased sorption capability presumably was due to saturation of the sorption sites; sorption isotherms typically "turn over" (the distribution coefficient decreases) at higher concentrations. Cesium and europium K_d values were near the analytical detection limit of 3,000 L/kg at all concentrations tested (up to 10^{-3} mol/L). Absence of sorption site loading effects at concentrations as high as 10^{-8} to 10^{-3} mol/L may represent unusually high sorption capacity in the SWSA 6 soil and, thus, favorable capability of the site to retain appreciable quantities of these radionuclides.

(4) Sorption Competition - In the isotherm tests where the other four elements were added to the radionuclide-traced element, little evidence of competition for sorption sites was observed in the cases of cesium, cobalt, and europium. Only the strontium and uranium isotherms suggested competition for sorption sites, as evidenced by decreased K_d values in the linear portion of the isotherm. This finding suggests that the sorption capacity of SWSA 6 soil for these elements may not be easily compromised by the presence of other solution species.

After completion of the sorption isotherm tests under steady-state conditions and relevant site saturated zone parameters, a few scouting tests were carried out to explore the effects of several parameters on the sorption behavior of selected elements. Significant observations from these tests were:

(1) Unsaturated Zone Soils - Sorption tests were run with three different well-characterized soils (claystone, sandstone with manganese coatings, and sandstone plus shale partings and clay films). Major differences, as compared to tests with the large soil sample from the trench bottom, were observed for some elements. For example, cesium K_d values ranged from 150 to 5,000 L/kg, cobalt from 200 to 650 L/kg, strontium from 40 to 130 L/kg, and uranium from 2 to 20 L/kg. Most of these soils changed the pH of the groundwater after contact to between 5 and 6. Apparently, these samples from above the saturated zone are mineralogically different from the trench bottom soil and more acidic. These results suggest that modeling the mobility of radionuclides in the unsaturated zone could be complex due to the variability of soils and groundwater parameters.

(2) Effect of pH - The effect of the test pH was explored only for europium and uranium. The K_d values for both elements were sensitive to the pH. Europium K_d's decreased from 3,000 L/kg at neutral pH to 100 L/kg at pH 4.3. Uranium K_D's displayed a maximum value of 3,000 L/kg at pH 5.5 and the values were lower at higher or lower pH's (300 L/kg at pH 4.2 and 55 L/kg at pH 7.4). For these elements at least, mobility modeling may require knowledge of the pH along the release pathway.

Distribution coefficient values are suggested in Table 4.1 for application in preliminary modeling of radionuclide mobility or retardation in the saturated zone (pH 7.0-7.5) at the SWSA 6 site. It should be clearly understood that the very limited work conducted to date has yielded information of only a preliminary nature. The batch contact methodology employed does not permit evaluation of important sorption aspects such as sorption/desorption disequilibrium (hysteresis), multiple species of radionuclides, multiple forms of radionuclides (colloidal as well as dissolved), or heterogeneity of the soil. Thus, the distribution coefficient recommended could be either conservative or nonconservative under some situations. With this proviso, the values presented in Table 4.1 are suggested.

5. SOILS OF SWSA 6

(S. Y. Lee and D. A. Lietzke)

5.1 Introduction

An understanding of SWSA 6 soils, their role in the chemical environment of the solum and saprolite zone, and in surface and subsurface water movement is crucial in remedial action and closure of this and other burial grounds located on Conasauga Group residuum. Nearly all radioactive wastes, with the exception of hydrofracture disposal, are buried in soil. Soil is defined as extending downward from the surface to an irregular lower depth that coincides with the beginning of rock. Rock is defined as unoxidized and unleached consolidated geologic material. Rock characteristics, including composition along with joints and fracture spacing, affect hydrologic properties and degree and rate of weathering. As the soil thickens with time, it influences the rate of rock weathering and the pathways and composition of water that eventually percolates downward and enters rock joints and fractures. This section includes descriptions of the surficial geology, geomorphology, and soils of SWSA 6, along with important physical, chemical and mineralogical properties that are related to radionuclide retardation.

SWSA 6 is located in the upper Maryville Limestone and lower Nolichucky Shale members of the Conasauga Group. The landforms on the site have been formed from episodic erosional processes. Drainageways tend to initially form in areas that either had a closer joint spacing or were more fractured, or in areas where the drainage network was inherited from and earlier erosion cycle. Overland water flow over time concentrates in these areas and carries away soil particles. Drainageways were gradually cut downward and extended upslope over time. Today, the drainageways in SWSA 6 have reached a geomorphic configuration where parallel slope retreat is gradually widening the drainageway and sediments are accumulating on the floodplain. Because soil in the past has been removed by overland flow, depth to rock is shallower in drainageway bottoms than on interfluves where more rainfall infiltrated and percolated downward, resulting in greater chemical weathering of rock and thicker soils. Figure 5.1 illustrates differences in depth to unleached, but oxidized saprolite. Core HHMS-4B is located on the summit of a Nolichucky hill in the south central part of the site. Depth to free calcium carbonate (CCE) is about 7 m (23 ft), while core HHMS-5A, located on the lower sideslope, is about 5 m (17 ft) to free carbonates. Soil pit No. 11, located on a low drainageway terrace landform had rock at a depth of about 1 m (3 ft). The status report on SWSA 6 geophysical studies by Dreier et al., (1987) includes two figures showing average depth to rock. The data include depth of penetration by split spoon and large auger. The data presented in Dreier et al., seems to coincide more with depth to unleached and unoxidized rock while the limited data presented in Table 5.1, (Ammons and Phillips, 1987) seem to coincide with depth to unleached but oxidized saprolite.

In summary, geology and geomorphology have had a great influence on the properties of the soil and underlying saprolite. It is important to realize that the soil-saprolite-rock system is a chromatigraphic column. Trends in pH, clay mineralogy, clay content and distribution, iron and manganese oxide content and distribution, cation exchange capacity, and physical properties change with depth below the surface. The ability and capacity of the soil-saprolite-rock system to retain radionuclides changes with depth, a very important consideration in determining trench depth, or the locations where downward or laterally migrating radioactive compounds are apt to be found.

5.2 Soil Survey

The soil survey of SWSA 6, Figure 5.2, shows the location and extent of each major kind of soil (Lietzke and Lee, 1986).

5.2.1 Maryville Soils

The following No. 40, 42, 431 and 43 sequence represents a weathering group from most to least weathered.

The No. 40 soils occur on geomorphically stable broad spur ridges. They formed in highly oxidized and leached saprolite. These soils have well defined genetic horizons that comprise the soil solum. Within the soil solum there is a clay enriched subsoil. Clay particles from this subsoil horizon are being translocated downward along with iron and manganese compounds into the oxidized and leached saprolite beneath where they coat saprolite fragments and plug voids where calcite has been removed from joints and fractures. Depth to unleached saprolite is usually deepest in areas of these soils, on the order of 3 or more meters.

The No. 42 soils occur on steeper, narrower spur ridges with more convexity than the No. 40 soils. Past erosion of soil particles from the surface has kept these soils in a more youthful stage of development. These soils have intermittent clay enriched subsoil horizons, and unleached saprolite comes closer to the surface. Clay particles along with iron and manganese compounds are being translocated downward into the oxidized saprolite beneath, coating most fragment surfaces. Depth to unleached saprolite is variable in areas of these soils where it usually occurs within a depth of 1.5 m below the surface.

The No. 431 soils occur outside the fence on a very steep drainageway sideslope where parallel slope retreat has been active. Overland runoff tends to carry away soil particles faster than the time it takes for a clay enriched subsoil horizon to form. These soils have indistinct soil horizons. However, depth to unleached saprolite is very deep beneath these soils, probably a result of closer fracture and joint spacing, or smaller fragments which allowed for deeper percolation of water. Iron and manganese compounds and some clay particles are being translocated downward to coat fragment surfaces in the leached saprolite beneath. Depth to unleached saprolite occurs at a depth of 6.1 to 7.5 m beneath these soils (Dreier et al., 1987).

The No. 43 soils occur on steep sideslopes of spur ridges. The constant but slow removal of surface soil particles tends to keep these soils in a steady state of youthfulness, where soil horizons are thin and indistinct, and depth to unleached saprolite is shallow. Manganese compounds are being translocated downward coating fragments below. Translocation of iron compounds and clay particles into deeper saprolite zones is not as evident in these soils as in the No. 40 and 42 soils. Depth to unleached saprolite is minimum in areas of these soils, varying from 0.5 to 1.5 m (Dreier et al., 1987).

5.2.2 Nolichucky Soils

Nolichucky soils are represented by two soils in SWSA 6. The No. 51 soils occur on hilltops and sideslopes. Because of surface removal of soil particles by erosion processes, these soils have thin and weakly expressed soil horizons. They have an intermittent clay enriched subsoil horizon similar to the Maryville No. 42 soils. Clay particles along with iron and manganese compounds are being translocated downward in these soils coating fragment surfaces and plugging voids. Depth to unleached saprolite varies from about 3 m to more than 6 m.

The No. 50 soils occur on landforms with low relief. In SWSA 6 the landforms in which these soils occur appear to be footslope landforms to the higher Maryville soils. However, most Nolichucky landforms are more subdued that Maryville landforms. Because of lower permeability in the Nolichucky shale, there is more surface runoff and less downward percolation of water. In addition, runoff water from higher areas flows across these soils keeping them wetter. These soils have an intermittent clay enriched subsoil horizon. Clay particles along with iron and manganese compounds are being translocated downward coating fragment surfaces and filling voids. Depth to unleached saprolite is usually less than 1.5 m.

The following two soils formed in colluvium that was transported downslope under the influence of gravity as a water saturated mass. These soils occupy footslope and toeslope landforms, and drainage divide saddles. Most of the colluvium is derived from highly weathered surficial Maryville and Nolichucky soils. Some colluvium, in lower areas of SWSA 6 has a component of colluvium derived from the area of old alluvium that is located in the northwest corner of the site.

The No. 47 soils formed in 50 cm to more than 2 m of colluvium. They have a clay enriched subsoil horizon. At some depth there is a discontinuity between the colluvium and the underlying saprolite residuum. Water tends to perch at this discontinuity, which results in a zone where there is fluctuation in redox potential, a zone where iron and manganese compounds are either oxidized (immobilized) or reduced (made more soluble) depending on seasonal wet periods. These soils have a high capacity to retain rainfall and transmit it laterally downslope. Small areas of No. 47 soils occur as narrow linear gully fills throughout larger areas of Maryville and Nolichucky soils. If these soils are not recognized when locating trenches, and if the trench intercepts an old colluvium filled gully, then shallow subsurface laterally flowing water is directed into the trench. On-site evaluation should be made before trenches are dug to ensure that no colluvium will be encountered.

The No. 48 soils are similar to the No. 47 soils in many respects, but they occur on lower toeslope landforms and have more than one discontinuity where water can perch and then move laterally. The No. 48 soils have a dense subsoil horizon termed a fragipan or otherwise commonly known as a hardpan. This pan has very low permeability and perches water for long periods. Pans can be recognized by their grayish appearance and brittleness. At some depth between one and three meters the colluvium lays on residuum. The No. 48 soils should not be used for waste disposal either by trench or tumuli methods because of wetness and less than desirable bearing capacity. Some areas of No. 48 soils have been covered by fill materials that were dug from trenches on adjacent hills.

5.2.3 Alluvial Soils

Alluvium consists of soil particles that were transported by running water and deposited from flowing water. Initially, they are highly stratified, but biologic activity eventually destroys the stratification in the upper part of the soil where there is maximum biologic activity.

Old alluvium is located in the northwest corner of SWSA 6. This old alluvium consists of the loess covered uneroded remnants of a terrace produced by the Clinch River one to several million years ago when the river was flowing at a much higher level than it does today. The No. 92

soils show the present extent of this old alluvium. The presence of chert gravels along with sandstone and highly rounded quartzite gravels and cobbles elsewhere on the site indicates its larger extent in the past.

The No. 92 soils are the oldest and most weathered soils on the site. They have a surficial capping of loess that has a very high silt content. The clay enriched subsoil is red, high in iron oxide and clay. Because of a past history when these soils were wet and deoxidized, manganese and iron were translocated elsewhere. As the Clinch River downcut, the alluvium gradually was reoxidized. Iron and manganese in the upper solum were replenished by lateral flow from higher areas and from dust deposition. Manganese content is still low in both the upper alluvium and residuum beneath compared to other residual soils on the site. Because these soils are old, highly weathered and leached, and have a thick alluvial mantle, depth to unleached saprolite and rock is the greatest on the site.

The No. 98 soils occur in drainageways. These soils are very youthful in the upper part and become older with increasing depth. The uppermost soil was washed from surrounding hillsides when the land was first cleared. Deeper soil layers were washed in from older geomorphic events that destabilized the uplands. These soils are generally well drained, but fill with water for periods of time whenever storm intensity exceeds the infiltration rate of upland soils which produces overland flow. These soils comprise an important link in the natural filtration and purification system. They should not be covered by fill materials. These soils and the No. 99 soils described below have the highest organic matter content of any soils on the site. Water that leaks from trenches or that flows laterally through colluvium upwells through these soils or flows through them to a defined stream channel.

The No. 99 soils are wet and poorly drained. Springs and seepy areas keeps the soil wet most of the year. Reducing conditions dominate. Upwelling water brings manganese to the surface where it oxidizes in the uppermost soil layers. In some areas where surface runoff keeps the soils wet, downward moving water carries manganese downward in advance of iron. These soils are forming in surface sediments that were washed from upland slopes when the land was cleared and farmed. They have the capacity to retain much water and to transmit it downward and laterally. Because of their importance in filtration and retention of ions, they should not be filled or disturbed, but left in a natural vegetated state. However, redox potentials can be increased or made to fluctuate by engineering modifications of the stream channel.

The No. 101 soils occur on low terraces where a thin mantle of loess and alluvium between 50 and 100 cm thick has buried an older very wet soil that has a clayey subsoil layer. These soils occur on slightly higher terrace landforms than the adjacent No. 99 floodplain soils which lack a buried soil within a depth of 1 m. The No. 101 soils have a relatively high pH and organic matter content in contrast to the very acid upland soils, and have the capacity to retain some ions that cannot be retained in the upland soils.

5.3 PHYSICAL PROPERTIES

As sedimentary rocks weather at depth, oxidation and hydrolysis occurs. Water leaches soluble ions, which gradually reduces the bulk density and transforms rock into saprolite. The transition from rock to oxidized and unleached saprolite, and from oxidized and unleached saprolite to oxidized and leached saprolite is diffuse and highly irregular, due to differential water flow in the saprolite and rock. Table 5.2 (Ammons and

Phillips, 1987) lists some saprolite bulk densities. Soil No. 43 is the least weathered of the soils and has the highest bulk density in C horizons (leached and oxidized saprolite), while soils No. 42 and 40, which are older and more deeply weathered, have lower bulk density. Oxidation reactions produce changes in minerals, either creating new or altered minerals that tend to be more stable than their predecessors. Cementing agents of calcium carbonate, iron oxide and silica are removed and the sedimentary rock fragment size is gradually reduced to individual particles of sand, silt and clay. In the soil solum, the most intensely weathered part of the soil, shale and siltstone fragments have been mostly reduced to individual clay and silt sized particles (Table 5.2). However, fragment content increases with depth to approach 100 percent in deeper saprolite zones. Silt content is highest in the surface soil horizons and decreases with depth (Table 5.2). Not all of the silt is derived from residuum. Soils No. 40 and 92 have a high silt content capping partially derived from wind blown loess. However, even the less weathered No. 43 and 50 soils show a maximum silt content in the surface and a decrease with depth.

Clay content reaches a maximum in the subsoil B horizon. Clay has been translocated from upper A and E soil horizons into B horizons. Some clay from the B horizon is translocated downward into leached saprolite where it coats fragments. Clay content in the saprolite is variable depending on the original clay content of particular strata. As calcium carbonate is gradually removed from Maryville and Nolichucky limestone strata, it is replaced by clay minerals plus translocated iron and manganese compounds. The shrink-swell activity of the clay produces cracks, enhancing the permeability. Clay migration and expansion also forces an increase in volume of the original strata volume which gradually disrupts the geologic rock structure and produces pedogenic soil structure.

Tree roots differentially migrate into and downward through these particular zones. Organic matter and biologic activity can occur at considerable depth. Water flow is differentially channelized in these clay filled strata from the soil solum above.

Most of the sand fraction and nearly all coarse fragments (larger than 2 mm), are composed of sedimentary rock fragments in soils No. 43, 42, 40 and 50. In contrast, most sand-sized particles and coarser fragments in soil No. 92 are composed of quartz, chert, sandstone and quartzite grains, pebbles, gravels and a few cobbles.

The ability of a soil to infiltrate water depends on particle size distribution and stable soil aggregates. Soils high in silt and clay have lower infiltration than soils with higher sand and gravel contents. Stable aggregates enhance infiltration by the clumping of silt and clay sized particles into sand and gravel sized aggregates. Saprolite removed from trenches does not have stable aggregates. Initial infiltration is high because of the high fragment and void content. However, the fine earth "melts" and forms an impermeable crust as raindrops impact the soil surface. The crust having low porosity prevents infiltration, which generates surface runoff and a sediment load.

The ability of soil to retain water depends upon both particle size distribution and quantity and sizes of pores, along with thickness of permeable soil. Moisture content at one-third bar (Table 5.2), is equivalent to a state where pore water is under slight tension, and large pores have drained free of water by gravity. Moisture content at fifteen bars represents a moisture content where most pores are free of water, and plants experience severe moisture stress. The difference between the two values is a measure of the soils ability to retain water. Soils with slow permeability or shallow depth to an impermeable layer and that have little ability to retain water tend to generate more surface runoff. Soils No. 43 and 50 are examples. As coarse fragment content increases water retention decreases.

The engineering properties listed in Table 5.3 are from disturbed and manipulated solum and saprolite materials and can be used to evaluate properties of on-site fill and trench cover materials. Engineering properties of the soil solum, e.g., all soil layers designated as A, and B horizons, likely will not change over time. However, when saprolite from several cm below the surface is first brought to the surface, it has a very high coarse fragment content, usually less than 12% fines and behaves as a gravelly clay or gravelly silt as shown in Table 5.3 (Data from Ammons and Phillips, 1987). With time the surface fragments slake and the physical saprolite properties approach those of the soil solum, within engineering groups MH, ML, CL-ML, and CL.

A very important fact must be noted in evaluating physical properties of disturbed saprolites. The in-place properties of saprolite are much different than their disturbed properties, and are very difficult to evaluate. Properties of disturbed saprolites listed in Tables 5.2 and 5.3 can be directly related to physical properties of saprolite spoil removed from trenches and used for cover materials, but not directly to properties of undisturbed in-place saprolites.

Saturated waterflow in saprolites occurs in defined but highly irregular pathways. These pathways are observable by color patterns produced by the variable redox conditions that result in migration of iron and manganese compounds. The flow zone center is identified by the grayish-white appearance, from the loss of iron and manganese compounds that normally coat mineral grains. Adjacent to the reduced zone there is an iron enriched zone of goethite. From saturated zones, water spreads out by unsaturated flow into the smaller and finer planar joint and fracture voids carrying manganese which is deposited in these tight places.

Raw on-site saprolite in SWSA 6 has several problems for burial fill or final cover. Initially, it has very low moisture retention and very high permeability. Rainfall passes right on through into the refuse and ponds on the trench floor. After a period of 5 to 8 y, shale and siltstone fragments disintegrate to silt and clay sized particles in the upper 15 to 30 cm of the cover. At this point in time, the surface tends to seal, and the infiltration rate decreases markedly and less water percolates down into the refuse. However, overland runoff increases the rate of erosion. There are droughty periods and also periods when water is perched on the surface. These conditions are deleterious for maintenance of plant cover. As plant cover decreases, the erosion rate increases and small rill and gullies tend to form on sloping ground. During this period of time, scheduled maintenance is required to cover rills and gullies, and to till, lime and fertilize, and replant cover vegetation. After several more years, with soil formation processes, and the addition of organic matter from vegetation and bacteria, natural stable soil aggregates are formed and the system approaches a steady state where the soil-plant-climate is self adjusting and a stable plant covered soil surface is maintained with minimal periodic maintenance. This scenario assumes that compacted wastes are placed in trenches and there is only a short period of fill settlement that requires regrading of depressions and liming, fertilization and reseeding of trench surfaces. However, the very high fragment content of the disturbed saprolite used as fill makes initial compaction very difficult. Slow settlement of the fill will take place over a number of years as fragments slowly disintegrate and voids become filled with fine earth.

5.4 Chemical Properties

Soils have many properties of and behave as a chromatigraphic column. Distribution of organic carbon and iron related soil colors in the solum are visual evidence of differential movement of different kinds of chemical compounds. Table 5.4 lists chemical properties of some SWSA 6 soils. Within the Maryville soils, the No. 43 soil is the least weathered even though it is forming in very acid saprolite that has been leached free of calcium carbonate. Soils No. 42 and 40 are more weathered with the most weathered and altered No. 40 soils located on the most stable landforms. Depth to unleached saprolite is minimum under the No. 43 soils. These soils have fairly high calcium levels in the soil solum, which was probably cycled upwards by trees, although effects of past liming cannot be ruled out. The data used to characterize the No. 42 soils came from beneath a large white oak. From sqil survey activities elsewhere on the Reservation, white oak, along with flowering dogwood are very common tree species growing on Maryville soils. Both of these species are calciophiles. White oak roots tap into the unleached saprolite and cycle calcium to the surface. Dogwood, a shallow rooted species requires fairly high calcium levels for its growth, calcium supplied by the white oak.

Depth to partially leached saprolite occurs at a depth of about 120 cm in the Nolichucky soil. Present vegetation on the Nolichucky soil is shallow rooted pine, the Cr horizon at a depth of 84 cm preventing deep penetration and proliferation of roots except along dip planes and joints. From observations elsewhere on the Reservation, white oak and flowering dogwood are scarce on Nolichucky soils, even though depth to unleached saprolite is quite close to the surface.

Strontium, which has a similar mobile behavior as calcium, in a soil system with an active biologic component tends to move downward or laterally along waterflow pathways or is cycled back to the surface by vegetation where it accumulates. Sorption of Sr is quite variable (Table 5.5). Sorption values (Rs) in the Maryville leached saprolite range from 160 to 1217. Based on the values of 525 and 1111 from Nolichucky leached saprolite, it may have similar ability to retain limited Sr as the Maryville saprolite.

Exchangeable cations (Table 5.2) are low in the leached saprolite, that part of the soil-saprolite-rock system where wastes have been buried. High acidity in the upper soil solum gradually destroys silicate minerals releasing silica and aluminum. Aluminum, being a cation tends to remain and becomes fixed by vermiculite, in the process transforming vermiculite into a very stable hydroxy interlayered vermiculite (HIV). Some aluminum combines with silica and forms kaolinite. Silica, in monomeric anionic form migrates readily downward in the soil. Technetium, also in anionic form in the soil environment, behaves in a similar manner as shown by the low sorption values in Table 5.5. With the exception of soil organic compounds which possess anion exchange capacity, the mineral components of oxidized soil possess very little anion exchange capacity.

Cation exchange capacity and percent base saturation provide information on the ability of the soil and saprolite to retain cations. Cation exchange capacity tends to be high in the soil solum where organic matter contributes both cation and anion exchange. With increasing depth, clay minerals provide most cation exchange capacity and there is minimal anion exchange capacity. This is verified by the sorption data in Table 5.5. Cobalt-60 is retained in the soil solum where base saturation is higher, or where there is organic matter and higher clay contents.

Iron and manganese compounds coat and largely control chemical properties of the oxidized and leached saprolite zone beneath the soil solum, the zone where most low level wastes have been buried in SWSA 6. Values of iron and manganese extractable by the citrate-dithionite-bicarbonate procedure are shown in Table 5.4. This procedure removes all amorphous and most crystalline coatings of iron and manganese compounds. Manganese has been differentially translocated downward into the leached saprolite zone relative to the iron. Acidified hydroxylamine hydrochloride selectively removes some Mn compounds with minimal disturbance of Fe compounds. These values are listed in Table 5.4 and are much less than CDB extractable Mn values. The hydroxylamine Mn may be a measure of pure manganese compounds while the CDB Mn may be a measure of manganese compounds plus complexed iron-manganese compounds. Values of hydroxylamine reducible Mn from cores HHMS-4B and HHMS-5A are listed in Table 5.6. This data also illustrates the differential movement and accumulation of manganese in the leached saprolite zone. The Mn values in the lower unleached saprolite zone are probably from Mn compounds in the disturbed sample. Manganese and iron compounds are important in complexing heavy metals. The retention of uranium is related to the presence and distribution of these two compounds in the soil and saprolite. However, there is no statistical relationship between either CDB Mn or Hydroxylamine Mn and sorption values for U, Sr, or Co. A complex combination of oxyhydroxides and clay minerals that coat saprolite fragment surfaces is evidently responsible for the retention of these nuclides in leached saprolite. Technetium (Tc) sorption in the soil solum and leached saprolite was minimal given the lack on anion exchange capacity. Cesium sorption was very high in both the solum and leached saprolite containing illite and its weathering products

Wherever there is downward moving water, manganese always moves ahead of iron. This is shown in Table 5.4 in the No. 43, 42, and 40 soils weathering sequence. Iron is more evenly distributed and less mobile. Manganese is also more easily reduced and oxidized, and in its reduced Mn^{+2} form, is quite mobile. Radioactive nuclides and heavy metals complexed and carried by manganese will be transported to drainageway soils where the manganese precipitates near the soil surface as it upwells or as lateral flow brings it into a higher redox environment. Manganese tends to form concentrations which, with age, form hard nodules in low drainageway soils where the water table fluctuates. Environments can be created or modified in drainageway soils to insure that most dissolved manganese and the heavy metals it carries are precipitated.

5.5 Mineralogy

Most of the soil minerals in SWSA 6 are inherited from the parent rock. The minerals in the rock were modified from either primary minerals in a previous geomorphic cycle or further modified from older sedimentary rock in the erosion-sedimentation cycles of the Middle Cambrian. The mineralogy of sand and silt sized particles is dominated by quartz and feldspars, most likely an albite, with illite, (hydrated mica) and some glauconite pellets (Ammons and Phillips, 1987). Weatherable minerals in the oxidized and leached saprolite zone are undergoing further alteration and transformation in this acidic environment. Weatherable minerals in the oxidized but unleached saprolite below will show some alteration, but the presence of free calcium carbonate effectively "pickles" the alteration of many minerals that require and acidic environment for alteration or destruction.

The mineralogy of clay fractions for selected SWSA 6 soils is detailed in Table 5.7 (Data from Ammons and Phillips, 1987). In the oxidized but unleached saprolite the dominant mineral in the clay fraction is illite, a hydrous mica that has lost part of its interlayer potassium (K). Some pre-weathered chlorite and glauconite may also be present in lower leached saprolite layers in the sand and silt-sized fractions. However, in the oxidized and leached saprolite zone, most of the chlorite and glauconite minerals have been altered to vermiculite or destroyed in the acid environment.

Illite is undergoing further hydrolysis, with additional loss of K and is gradually being converted to vermicu'ite. Illite content decreases in the upper part of the leached saprolite as it is being converted to vermiculite. In the extremely acid upper saprolite and soil solum where silicate minerals are being destroyed with the release of aluminum, hydroxy interlayered vermiculite (HIV) is formed.

The formation of HIV involves the movement of monomeric or polymeric aluminum into the interlayer position that K once occupied. The movement of aluminum into the interlayer position greatly reduces the effective surface area of the mineral and greatly reduces the cation exchange capacity compared to vermiculite. In old and stable soils, there is a gradual conversion of HIV to pedogenic chlorite.

Pedogenic chlorite, formed in near surface soil horizons under very acidic conditions, has a somewhat similar X-ray diffraction pattern as chlorite, a primary silicate mineral. However, pedogenic chlorite, a secondary clay mineral, is extremely stable in an oxidized acidic soil environment while chlorite is rapidly destroyed or rapidly altered in a similar environment. Pedogenic chlorite has a lower cation exchange capacity than HIV. Pedogenic chlorite occurred in the soil solum of both the No. 40 and No. 92 soils, the two oldest and most weathered soils on the site. Vermiculite content was least in the old alluvium soil, as most was transformed to HIV and pedogenic chlorite. Gibbsite was identified only in the subsoil of the old alluvium soil, No.92. Gibbsite does not normally form in a soil environment as long as vermiculite is available for the uptake of aluminum released by mineral destruction. Only when the uptake capacity of vermiculite and HIV is satisfied will gibbsite form, an indication of a very highly weathered and fairly old soil. The stratigraphic position of the No. 92 soils and the highly weathered nature indicates that they are the oldest soils in the site. The No. 40 soils are the next oldest and the No. 42 soils next. The No. 42 and No. 50 soils are the least weathered. The No. 42 soils are forming in acidic leached saprolite high on a hillslope while the No. 50 soils are forming in a lower landform where there has been less leaching of the underlying saprolite. Even though the solum of the No. 50 soils is very acid, depth to unleached saprolite occurs within a depth of 1.5 m. The presence of calcium slows the conversion of vermiculite to HIV in the No. 50 soils where only trace amounts are observed.

The presence of smectite, an expanding clay mineral with high cation exchange capacity is suspected in the Nolichucky soil, further evidence of the youthfulness and lessor leaching of these particular soils. The No. 51 Nolichucky soils which occur on hillsides underlain by several cm of leached saprolite would be expected to have similar chemical and mineralogical properties as the No. 42 Maryville soils, and have no trace of smectite.

The chemistry and mineralogy of the No. 98, 99 and 101 drainageway soils should be quite similar to the solum properties of the upland soils, as they are forming in sediments that were washed from the surrounding uplands after the land was cleared and farmed. Manganese and iron compounds and quantities will be different in the drainageway soils than the upland soils. Drainageway soils should receive additional attention for their chemical properties as they are part of nature's natural filtration and purification system.

5.6 Summary

The soil map of SWSA 6 shows the location and extent of each major kind of soil. Within each geologic formation, soils were identified according to morphologic characteristics. Weathering groups of soils were related to past geomorphic processes that shaped the present day landforms. Depth to unleached saprolite or to rock may not coincide with the formation of the soil solum, since weathering can be active, while geomorphic processes are differentially stripping off surface horizons. During the past history of the site, the Clinch river flowed over part of the site. Evidence for this is the presence of exotic well rounded quartzites from the Unakas as well as local subrounded chert from the Knox Group. As the Clinch continued to down cut, erosion processes stripped off most of the alluvium, leaving a small uneroded and loess covered remnant in the northwest corner. When the soil survey was made in 1985, most of the site was thought to be underlain by the upper Maryville Limestone. Further investigations have shown that the lower Nolichucky Shale and the broad transition zone between the two members occupies the southern third of the site.

Average soil solum thickness on the site, except for the No. 40 and 92 soils, is thin less than 1 meter. Soil solums have a relatively high silt and clay content, and contain organic carbon. They have good sorption properties for radioactive nuclides, but their thinness makes them relatively unimportant for remedial action and closure. In fact, during clearing activities, most of the soil solum in areas that have been heavily trenched was pushed off into drainageways or buried by raw leached and unleached saprolite removed from trenches.

Of importance for remedial action and future development of burial grounds in the Conasauga Group are the properties of the oxidized and leached saprolite. It is in this material that most low level wastes have been buried. In-place properties of saprolites are much different from disturbed properties. In-place saprolite has fairly low permeability on a soil scale, but high permeability on a geologic scale. The deep depth of leaching is evidence for the rather high geologic permeability, caused by differential movement resulting in closely spaced fracture network. When this saprolite is removed, it readily parts into individual fragments bounded by joints and fractures. The chemical properties of in-place saprolite are largely controlled by the iron-manganese-clay complex that coats most fracture and joint surfaces, with minimal effects of clay minerals within fragments. The data contained in Tables 5.1 through 5.7 were obtained from disturbed crushed and otherwise manipulated samples, and is more applicable to properties of disturbed saprolite. Important physical, chemical and sorption properties of undisturbed saprolite must be obtained from in-place observations with minimal disturbance. The methodology to accomplish this is either not available, not fully developed, or extremely expensive.

Leached saprolite varies greatly in physical, chemical and physical properties depending on how weathered it is. The saprolite beneath the No. 43 soils is not highly weathered. Coarse fragment content is high and there is relatively low clay content. The leached saprolite beneath Soils

42 and 40 is more highly weathered. Fragment content is lower and the clay content is higher. The leached saprolite beneath the No. 51 soils should have similar properties as that beneath the No. 40 and 42 soils.

Engineering properties of the soil solum are not too important because of the shallow depth. However, solum engineering properties are an indication of what saprolite fill properties will become as it weathers. Freshly removed saprolite has an unified soil classification of GC, GM or GP, which indicated very high gravel content with very few fines. Over time the gravel content will decrease and the fines will increase, with a resulting shift to the ML, CL, ML-CL classifications and a plastic index of 15 or higher.

Sorption properties of the soil solum probably reflect both the inplace and disturbed properties. Sorption values for the leached saprolite were obtained from samples ground to pass a 2 mm sieve. This soil material has a much higher surface area and a much greater contribution from clay minerals than the in-place saprolite would. Even so, cesium retention is high. Uranium retention will be good considering the presence of widespread manganese and iron coating in the leached saprolite. Uranium retention in uncoated or only partially coated oxidized and unleached saprolite will probably be lower. Strontium retention is highly variable and probably over estimated for the in-place leached saprolite. Cobalt retention of in-place leached saprolite is associated to the iron-manganese-clay coating complex. Cobalt retention seems to be quite variable but quite high in leached saprolite, but retention in unleached saprolite is not known.

Water flow pathways in both leached saprolite and unleached saprolite are highly variable and irregular. Water that infiltrates the soil solum starts to become channelized in the lower solum. Tree stem flow directs water beneath the tree directly into tree roots and tree root voids. The influence of trees and tree roots on subsurface water flow pathways remains for long periods after tree removal. Water flow zones in leached, unleached saprolite and into the rock beneath have different chemical properties than the bulk chemical properties listed in Table 5.4. Saturated water flow in these flow zones can carry radioactive nuclides for long distances with minimal interaction with sidewalls. Most contaminated water flow from trench bottoms and lower sidewalls probably occurs in established flow zones although some water will be transmitted for short distances as saturated flow through smaller fracture and joint planar pores before it assumes a condition of unsaturated flow. Unsaturated flow is slower and allows for more time for contaminates to come into contact with pore sidewalls. Keeping water from ponding in trench bottoms is crucial to preventing or slowing movement of nuclides. Chemical and clay doping of trench bottoms can be utilized to retain certain very mobile nuclides. The study of the chemical environment of existing filled trench bottoms is needed to determine the redox potential and how far nuclides have already moved under fluctuating perched water tables, not an easy job.

Remedial action for the closure of SWSA 6 will require a plan to provide for periodic maintenance for a considerable time. Irregular settlement of trench fill as decay of organic fill occurs and soil collapses into voids will necessitate the addition of fill to depressions and regrading the surface to a convex shape. Fill will have to be obtained either on-site or from suitable off-site soil. Liming, fertilization and seeding will have to be done with each reshaping. Vegetation will have to be selected for its shallow rooting characteristics. As the fill stabilizes and with less regrading disturbances, woody plants will begin to invade the site, some will have deep rooting character.

6. GEOLOGY AND TRACER TESTS

(R. B. Dreier)

The purpose of this section is to present a progress report on geologic investigations directed toward completing activities described in the Draft Remedial Investigation Plan for Solid Waste Storage Area 6 (ORNL 1986b). Geologic activities can be divided into four subgroups: (1) surface structural mapping, (2) borehole data interpretation, (3) shallow constant head tracer tests, and (4) surface geophysical investigations. A summary of FY 1986 - 1987 activities under each of these subgroups follows.

6.1 Surface Structural Mapping

Surface mapping of all observed structural fabrics was conducted in 10 investigatory trenches, I-K (Fig. 6.1). Primarily, orientation measurements were taken of bedding planes and extension fractures, and less commonly of shear fractures. In addition, geologic structures were interpreted from photographs taken of waste trenches in the south-central region of SWSA 6. Preliminary results of this work were presented in Dreier and Beaudoin (1986). During FY 1987, additional photographs from the French drain area (Davis and Stansfield, 1984) were interpreted and final structure maps were constructed of the central (Fig. 6.2) and south-central (Fig. 6.3) portions of the waste facility. There is a distinct change in structural strike between these two regions, from NE in the south to E in the north. A NE strike corresponds to the regional strike of the ORR and of this portion of eastern Tennessee. At present the cause of the strike deviation in the vicinity of Trenches G, H and J and the French drain trench has not been determined. These variations in structural trends are also shown by stereograms of bedding surfaces from each investigatory trench (Fig. 6.4).

Additional orientation data, collected by V. M. Mares (ORAU summer intern) from a newly constructed cuttings containment pit at the HHMS-8 site (the starred site north of trench J - Fig. 6.1), shows trends that do not match those of either the south-central or central structure maps (Fig. 6.5). At this location, trends approximate NNE as opposed to the E trends of trenches G, H and J or the NE trends of trenches D, I and F. At present the cause of this apparent rotation in structural trend is unknown; however, the pit neighbors a north-trending drainage (Fig. 6.1) that may represent the surface expression of a cross-strike tear fault. Fabric rotations may be a result of movement along this fault. The data from the containment pit is minimal because only 33 measurements were taken (Fig. 6.5) and more information in required to corroborate these findings. In any event, additional orientation data from the vicinity of drainage regions should be acquired to investigate the amount of deformation related to tear faults.

Fracture densities were measured from several of the investigation trenches and were reported in Dreier and Beaudoin (1986). To informally evaluate measuring consistency, densities in Trench J were measured by two separate investigators. Results of this study are shown in Figure 6.6 together with a schematic cross-section of the trench. Fracture densities approximate 20 fractures/dm and appear to be independent of fracture type (bedding plane, extension or shear).

6.2 Borehole Data Interpretation

At the end of FY 1986, drilling was initiated on WOL-1 (Fig. 6.1), a corehole south of White Oak Lake. The well was drilled to sample lithologies of units that immediately underlie SWSA 6 and for Hydrofracture geologic and hydrologic investigations. FY 1986 drilling activities for this well are summarized in Dreier (1986). Briefly, well construction activities can be divided into three phases: (1) retrieval of core from the Nolichucky, Maryville, Rogersville, and Rutledge members of the Conasauga Group. Where possible, core retrieved from the Nolichucky Shale and the Maryville Limestone was oriented by using a Christensen core barrel and an Eastman Whipstock multishot instrument; (2) reaming, collecting geophysical logs, casing and grouting the portion of the well drilled in Phase 1. Geophysical logs were acquired by Gearhart and include electric logs (SP, long and short normal, and dual induction laterolog); nuclear logs (gamma and compensated density side wall neutron), acoustic logs (acoustic velocity and variable density), plus a sibilation, temperature, caliper and dipmeter log. Phase 2 was necessary in order to isolate the Hydrofracture Injection Zone (Pumpkin Valley Shale) from the overlying strata; (3) core retrieval of the Pumpkin Valley Shale. WOL-1 is finished in the top 1.5 m of the Rome Formation immediately below the Pumpkin Valley Shale/Rome contact. Data collected from Phase 3 as well as any future well tests conducted in the hole will be used for Hydrofracture characterization studies.

Lithologic units in WOL-1 core were logged in reconnaissance by C. M. Beaudoin and P. M. Baxter. Logging techniques follow those developed by C. S. Haase and standard symbols used are shown in Figure 6.7. This method gives summaries at a minimum of 0.61 m increment of the rock type, color, stratification sequence, bedding type and other appropriate miscellaneous descriptors (such as solutional features, brecciation etc.).

In addition to lithologic logging, WOL-1 core was logged by G. E. Harlow to record structural fabrics. This consisted of descriptions of various fractures, stylolites, faults, and minor folds. Fractures were differentiated on the basis of: (1) relative orientation (oblique to bedding or in bedding plane), (2) shape (en-echelon or planar), (3) aperture, and (4) whether or not they were filled with vein minerals. When observed, cross-cutting relationships between structural elements were recorded.

Fracture densities, for each fracture type, were measured in approximately 76 cm (30 in) increments. Densities were measured by recording the number of fractures that intersected a line drawn perpendicular to the predominate fracture trace of each type. Line length varied from 76 to 190.5 cm (30 to 75 in) depending on fracture orientation and core integrity.

Figure (6.8) shows the results of the lithologic and fracture density measurements Two major fracture types are observed in WOL-1 core. These consist of oblique-to-bedding fractures containing vein minerals, and planar plain fractures orientnd within the plane of bedding. A comparison of the lithologic and structural logs reveals the following preliminary generalities. The highest fracture densities were recorded in predominately silty shales interbedded with limestones. The majority of the fractures present in these lithologies were of the plain, bedding parallel type, and had small apertures. Coarse, limestone breccia contained the lowest density of fractures, with the few present being the oblique-to-bedding, vein-filled type.

During a second examination of the core, a mechanical goniometer was used to reorient the core to its downhole position, and facilitate the measurement of structural fabric orientation. Measurements were made approximately every 1.5 meters (5 ft) as dictated by the 1.5 meters (5 ft) core orientation log increments. Figure 6.9 shows orientation of fabrics measured from core.

The dip meter log obtained from the WOL-1 borehole shows computed dip angle and dip direction of strata as a function of well depth. These data points are plotted as either solid arrows or open arrows as a function of data reliability. Those plotted as solid arrows reflect a correlation coefficient above 0.60. Open arrows reflect a correlation coefficient between 0.60 and 0.30. Correlations are ignored if the coefficient is below 0.30.

Statistical analysis of dip angles measured via a mechanical goniometer compared to computed dipmeter results reveals a mean difference of 9.45 degrees and a standard deviation of 10.72 degrees (using the entire measured dip angle population, n = 59). Using measured dip angles that are bracketed by at least one solid arrow from the computed dipmeter reveals a mean difference of 6.82 degrees and a standard deviation of 6.54 degrees (n = 35). Using measured dip angles that are bracketed by two solid arrows from the computed dipmeter log shows a mean difference of 6.42 degrees and a standard deviation of 5.49 degrees (n = 26).

It appears, in general terms, that the largest differences between measured dip angles and computed dip angles occurs in areas of the core that have been deformed by faults. Fault locations are marked with a star in Figure 6.8. These larger differences are generally confined to the fault zones, with measured and computed values approaching agreement above and below the zone. Furthermore, these fault zones observed in the core, are commonly marked by open arrows (correlation coefficient between 0.60 and 0.30) on the computed dipmeter log.

In addition to WOL-1 borehole data, other data from boreholes in or near SWSA 6 were used to construct a grid-north/south geologic cross-section (Fig. 6.10). This work was part of a larger effort to summarize available geological information from Melton Valley, and further discussion of the cross-sections are contained in Dreier et al. (1987a). At present, new HHMS wells are being drilled (starred locations in Fig. 6.1) and geophysical log data derived from these wells will further constrain the geologic interpretation shown in Figure 6.10. In addition to geologic cross-sections, Dreier et al. (1987a) also presents the most recent geologic map of Melton Valley, including the SWSA 6 area.

6.3 Shallow Constant Head Tracer Tests

In order to assess the influence of fractures on groundwater flow directions and rates, several constant head tracer tests were conducted. Two sites were picked based on the results of the fracture orientation measurements discussed in section 6.1. Site TTGH is located by investigation trenches G and H (Fig. 6.1) where bedding strikes trend EW (Fig. 6.11). Similarly, site TTDI is located by investigation trenches D and I where bedding strikes trend NE (Fig. 6.12). The first test was run at site TTGH during the fall of 1986. Methods and results of this test are presented in Dreier et al. (In Press). To summarize, the test at TTGH showed a strongly asymmetric plume with a preferred lateral flow direction opposite to the groundwater gradient at the water table. Comparison of lateral flow directions with fracture orientations suggest that flow is strongly influenced by the intersection of bedding-strike-parallel extension fractures with other fracture sets. The second test at site TTDI was stopped when the site was inadvertently contaminated with sodium chloride.

During the summer of 1987, tracer tests were again conducted at these sites by W. R. Sadler (graduate student intern). At both sites, the same injection and monitoring holes were used for the summer 1987 tests as for the earlier tests. Site preparation began by excavating fallen, weathered material from the injection hole and by removing the more weathered material from the sides to obtain a relatively fresh surface for study. The diameter of the injection hole is approximately 1.5 m at the top tapering to 1.1 m at the bottom and the center depth is approximately 1.1 m. The six boreholes, which are spread symmetrically around the injection hole (Figs. 6.11 and 6.12), were then cleaned out. Because of differences in the equipment and methods used, the holes were over-bored from 5.1-cm diameter to 10.2-cm diameter and reached to an average depth of 95 cm below the land surface.

Two piezometers were constructed in each borehole using 2.5-cm diameter slotted PVC well casing and alternating layers of sand and bentonite. The well casing joints were securely "water proofed" with duct tape except for the bottom 12.7 cm of slotted pipe. The deep piezometers were all at the same elevation with an average bottom depth from land surface of 95 cm. The piezometers consisted of 15.2 cm of sand surrounding the untaped portion of slotted casing, topped with 25.4 cm of bentonite pellets. Directly above the bentonite was another 15.2 cm of sand and the shallow slotted well casing. All of the shallow wells were also at the same elevation with an average bottom depth from land surface of 21.3 cm. Another 25.4 cm of bentonite pellets followed and the remainder of the hole was backfilled with excavated material. The actual distance between the side of the injection hole to the center of the piezometer was then measured. The deep piezometers averaged 23.7 cm from the injection hole, whereas the shallow piezometers averaged 19.3 cm.

The sides of the injection hole were structurally mapped by recording strike and dip of bedding planes, two sets of extension fractures, and shear fractures where present (or seen) (Figs. 6.11 and 6.12). These measurements corresponded to those measured in trenches G and H and in trenches D and I (Fig. 6.4).

After site preparation was completed, water was introduced into the injection hole from a hose attached to a 5700 L water tank. The water level in the injection hole was brought to a constant level and maintained by monitoring the flow rate from the hose. Water levels in the monitoring wells were measured using a pressure transducer that converts pressure into ft of water above the point measured. Levels were intermittently monitored until flow reached steady state flow, shown by constant pressure reading in the monitor wells (Fig. 6.13).

The tracer used in the second series of tests was potassium bromide. It was chosen because sodium chloride had been used for the previous test and therefore had contaminated the site. In addition, there was concern about sorption of Na^+ by clay minerals. Br^- is very easy to measure in the field because it can be detected by a selective ion electrode, which needs only a pH meter that reads millivolts. Millivolt measurements can then be later converted into Br^- concentrations. This method was also attractive because it did not require permanent removal of water from the local hydrologic system.

After steady state flow had been reached, the tracer was introduced into the water in the injection hole and the input water from the supply tank. A concentration of about 300 ppm was maintained. Samples of 10 ml from each well were taken through a permanent tube using a syringe. The sample was then placed in a beaker, the millivolts read, and the sample replaced in the well within about two minutes. Each well had its own tube, syringe, and beaker to prevent cross contamination.

Results of the most recent tracer tests (TTGH and TTDI) are shown in Figures 6.13 through 6.17. To date, this information has not been plotted on site maps (Figs. 6.11 and 6.12) and flow directions have not been interpreted with respect to fracture orientations. It is anticipated that such interpretations will be completed in future reports.

For site TTGH, the flow rate required to maintain a constant head was approximately 8-9 ml/s (Fig. 6.13). This value decreased during the test because of intense rainstorms on the 2nd through the 4th day of the test. The highest water levels in the monitoring wells were observed in the shallow wells, particularly 1s (shallow) and 2s (Fig. 6.14).

The highest Br^- concentrations at TTGH were observed in 3s and 4s (Fig. 6.15). For comparison, during the earlier test at this site, the highest concentrations were observed at monitoring wells 1 and 2. This difference may be a seasonal effect. During the first test (run in November), steady state was achieved within 9-10 h and water levels were measured in deep monitoring wells. During the second test (run in June/July), steady state was achieved after 5 d and water levels were only measurable in the shallow monitoring wells. Hence, for the second test, water flow was possibly through both fractured saprolite and more mature soil horizons. During the second test, the highest Br^- concentrations did not reach those of the injection hole water (approximately 300 ppm) and water in the monitoring wells was probably diluted by residual water from the storm events.

For site TTDI, the flow rate required to maintain a relatively constant head was much higher than that observed at TTGH, approximately 50 ml/s (Fig. 6.13). The highest water levels were observed in the deep monitoring wells, particularly for wells 6d, 5d and 1d, all north of the injection hole. The head distribution was very asymmetrical, with little to no observable water in wells 3s and 3d. The highest Br^- concentration was observed in well 6d (Fig. 6.17). Concentrations in this well approached those of the injection hole and were significantly higher than those observed in any of the other monitoring wells. This direction is parallel to the trend of the extension fractures perpendicular to strike (Fig. 6.12).

After the test was finished, the monitoring wells at TTDI were dug out so that the soil and saprolite between the injection hole and the monitoring wells could be examined. At well 6, apparently a tree root had grown along and enlarged a weathered strike perpendicular extension fracture. Hence, results of this test, and probably test TTGH, were strongly influenced by heterogeneities associated with the mature soil horizons (A and B) and by the B/C soil interface.

6.4 Surface Geophysical Investigations

A status report on surface geophysical investigations (Dreier et al., 1987b) was issued at the end of third quarter FY 1987. This report described activities in progress to conduct a shallow seismic refraction survey of SWSA 6. Included in the report are: (1) the project design, (2) results of a feasibility study conducted to assess the suitability of seismic refraction techniques to investigate soil thickness, and (3) a synthesis of existing well construction data that will aid in interpreting results of the geophysical investigations. Since that time, in-house planning documents for the seismic survey (Environmental ALARA Memorandum EAM, waste-management plan and project plan) have been completed. At present, the survey is being conducted and completion date for data acquisition is scheduled for late September. It is anticipated that data interpretation will be presented in future reports.

7. CHARACTERIZATION OF SOURCE TERM

(D. K. Solomon)

Although waste was originally placed in the unsaturated zone in SWSA 6, standing water has been observed in waste trenches resulting in the mobilization and release of contaminants. In order to assess the short- and long-term performance of SWSA 6 it is necessary to establish a contaminant source term. A source term is a mathematical expression which describes the quantity of contaminants released as a function of time. Since the flux of water moving through a trench is an essential part of the source term a study of trench dynamics was initiated. The specific objectives of this study are: (1) define the extent and general occurrence of groundwater within SWSA 6 waste trenches, (2) develop a conceptual model for trench-water dynamics, and (3) quantify the groundwater discharge from specific waste trenches in direct support of source term development.

Water may enter a trench by infiltration directly through the trench cap, by lateral discharge of subsurface storm flow along saturated macropores, and by direct inflow as a result of a high water table intersecting the bottom of a trench. It is also possible that micropore water moving through the unsaturated zone might enter a trench; however, it is likely that the physical nature of the waste placed within trenches (uncompacted steel drums etc.) will result in the presence of many large pores which are not capable of transmitting water under unsaturated conditions. Thus unsaturated flow, except directly through the trench cap, is considered to be of limited importance.

7.1 Occurrence of Groundwater in Trenches

A total of 20 intra-trench monitoring wells and 6 water-table monitoring wells were utilized to evaluate the hydrologic condition of trenches in SWSA 6. Nineteen of the trench monitoring wells and 3 of the water-table monitoring wells were installed specifically for this project. Two separate methods were used to install the new monitoring wells. Ten of the wells were drilled by augering with 15.2 cm continuous flight augers. The wells were cased with 5.1 cm or 7.6 cm flush-thread polyvinyl chloride (PVC) monitoring screen (slot aperture of 2.5 mm) and riser pipe. The wells were completed using 99% pure quartz sand extending from the bottom of the bore hole to approximately 60 cm above the screened interval, followed by a 30 cm bentonite plug, and finished with cement grout to the surface. Twelve of the wells were constructed of type 314 stainless steel monitoring screen (slot aperture of 2.5 mm) and flush thread riser pipe equipped with a stainless steel drive point. These wells were hydraulically pushed and hammered into place. Construction details of each monitoring well along with ORNL coordinates, and measuring point elevation are located in Table 7.1.

The location of each monitoring well is shown in Figure 7.1. Since waste trenches in SWSA 6 have been grouped geographically an attempt was made to include at least one trench monitoring well in each group.

Water-level recording equipment was used to obtain nearly continuous measurements from 7 of the trench monitoring wells and 3 of the water-table monitoring wells. Manual water-level measurements were made at time intervals ranging from 1 to about 4 weeks on the remaining wells. Water-level measurements using the recording equipment began in February and March of 1986 and were processed quarterly. A breakpointing method was used to eliminate repetitious measurements and all data has been stored in monthly files using ASCII format. A list of monitoring wells and the type of data collected is shown in Table 7.2.

Monthly hydrographs from each well equipped with a water-level recording device, including daily precipitation, were prepared for data analysis. Hydrographs extending over the entire period of study were prepared for each well on which manual measurements were made. Figures 7.3 and 7.4 are examples of hydrographs for the recording and hand-monitored wells, respectively.

Examination of the water-level data shows that trenches can be hydrologically classified according to one of five criteria:

(1) inundated (the water-level elevation observed in the trench monitoring well is approximately equal to the water-level elevation observed in the adjacent water-table monitoring well),

(2) unsaturated (the water table outside the trench was consistently below the trench bottom and standing water was not observed in the monitoring well),

(3) bathtubbing (the water table elevation adjacent to the trench was consistently less than the water level elevation inside the trench but measurable standing water was observed in the trench monitoring well),

(4) intermittently inundated (combination of 1 and 2), and

(5) intermittently bathtubbing (combination of 2 and 3).

The hydrologic condition of each group of trenches in which at least 1 monitoring well is present is shown in Figure 7.4. Specific examples of these conditions are described below.

Trench 260 was inundated during the entire period of study from March 1986 to March 1987. The difference between the trench water level and the surrounding water table (measured in well S6) was indistinguishable during the winter and spring when the trench water level was less than 2 m below land surface. During the summer and fall when the trench water level was greater that 2 m below land surface the difference between the trench and water-table elevation was generally about 0.2 m; however, it was as great as 1 m during the middle of August, 1986. These differences are most likely related to a transition in the heterogeneous nature of the waste and surrounding geology that apparently occurs at about 2 m below land surface. A hydrograph showing water levels for both trench 260 and well S6 extending over the entire period of study is shown in Figure 7.5.

Standing water was observed in trench 80 from February 1986 to April 30, 1986, for a 15-d period from August 29 to September 13, 1986, and from October 15, 1986 to the end of the study period in April 1987. An adjacent water-table monitoring well does not exist; however, data from well S8 (30 m to the west) indicates that the trench water level is higher than the surrounding water table and thus a bathtubbing condition exists during part of the year. During periods of bathtubbing the difference between the trench water-level and the surrounding water table (extrapolated from well S8) varied from about 0.2 to 1.2 m with the largest differences occurring in the fall when standing water first began to appear in the trench monitoring well. The smallest differences were observed in the spring when the water table was near its seasonal high. The water level in trench 80 responded rapidly to storm events during the winter and spring when the trench was bathtubbing. For example, a water-level rise of 0.4 m was observed in early December 1986 in response to about 80 mm of precipitation which occurred over a 48-h period.

Water-level data from trench 123 and an adjacent water table well (392) indicate that a bathtubbing condition existed for much of the period of study. Water-level recording equipment was not operating from April

1987 to November 1987; however, manual measurements made during October indicate that trench 123 was dry during this time. The difference between the trench water-level and the surrounding water table varied from 1 to 2 meters. Very little response to storm events was observed in either the trench water levels or the water table measured in well 392. A French drain protects this area from lateral subsurface storm flow and it appears that rapid changes in water levels associated with storm events are effectively controlled by the drain.

Continuous water level measurements were made on trench 46 and manual water level measurements of the water table were made at approximately monthly intervals on well 382. A bathtubbing condition was observed in February 1986 when measurements were first made and lasted until about March 27, 1986. The surrounding water table was about 0.5 m below the trench water level during this time. The trench remained unsaturated until December 9, 1986 when bathtubbing was again observed in response to about 80 mm of precipitation which occurred over a period of 48 h. The water level recorder failed on December 10 and measurements were not resumed until January 5, 1987 at which time the trench was once again unsaturated. A longer bathtubbing period was then observed from January 20, 1987 to February 10, 1987. A final bathtubbing period began February 21, 1987 and lasted until the end of the study period.

Continuous water level measurements were made on trench 381 from March 1986 to July 1986 and from December 1986 to March 1987. Manual measurements were made from April 1987 to December 1987. The monitoring well remained unsaturated during the entire period of study.

Continuous water level measurements were made on trench 319 from March 1986 to July 1986. The trench remained unsaturated during this entire period. The surrounding water table varied from about 2.5 m in October

1986 to 1 m in February 1987 below the bottom of the trench.

Continuous water level measurements were made on trench 92 and the surrounding water table from well S10. Standing water water was observed in trench 92 during the entire period of study with the exception of July and August 1986 when the monitoring well was dry. Hydrographs from trench 92 and well S10 are virtually identical during fall, winter, and spring; however, the water table (measured in well S10) was consistently 0.2 m lower than the trench water level. Although this indicates a slight bathtubbing condition the similarities in the hydrographs and the relatively small difference in water levels indicates that a condition of inundation may be more appropriate.

Only a partial record of water level data for trench 257 is available from June 1986 to August 1986. Standing water was observed throughout this period. Since this period represents the seasonal low of the water table it is assumed that standing water exists in this trench throughout the entire year. The existence of a bathtubbing condition cannot be determined due to the lack of an adjacent water table monitoring well.

Three monitoring wells are located in trench 219; however, only a partial water level record is available from June 1986 to August 1986. Standing water was observed throughout this period and it is assumed that this trench contains standing water the entire year. The existence of a bathtubbing condition cannot be evaluated conclusively due to the lack of an adjacent water table monitoring well; however, water level data from well 382 (35 m to the south) suggest that a bathtubbing condition does exist.

Manual measurements were made on trench 417 and indicate that the trench was unsaturated for the period of study. The water table is 4 to 5 m below the bottom of the trench.

Manual measurements made on trench 444 indicate that the trench was unsaturated during the entire period of study. The water table is approximately 5 m below the trench bottom.

Trench 8 remained essentially unsaturated during the period of study. Occasionally a small puddle of water (perhaps 2 or 3 cm deep) was observed on the bottom of the monitoring well during manual measurements. It is felt that this is due to either leakage around the well casing or possibly condensation of water vapor within the well casing.

Trench 405 was generally dry; however, a slight indication of standing water was observed during the winter and spring especially after large storm events. Standing water approximately 10 cm deep was observed on several occasions; however, a conclusive statement concerning possible periods of bathtubbing can not be made.

Manual water level measurements indicate that trench 315 was generally dry; however, measurable standing water was observed after significant storm events during the winter and early spring. Lack of an adjacent water table well precludes a conclusive evaluation of the bathtubbing condition; however, water level data from wells 371 and 345 installed by the U. S. Geological survey (Webster et al., 1980) indicate that the standing water may result from inundation due to a high water table rather than a bathtubbing condition.

Only a partial record from April 1986 to August 1986 is available for trench 288. This trench was inundated during this period and appears to be hydrologically similar to trench 260.

Manual water level measurements on trench 391 indicate that an unsaturated condition existed throughout the period of study.

7.2 Response of Trench Monitoring Wells to Storm Events

The response of trench monitoring wells to individual storm events is shown in Figure 7.6 in which the total rise of a trench hydrograph normalized by the total precipitation is plotted against the difference between the water level in the trench and the surrounding water table prior to the onset of the storm. With the exception of trench 80 only the trenches that had a water level which was within about 0.5 m of the surrounding water showed a significant response to individual storm events. A water table well adjacent to trench 80 does not exist and the elevation of the water table was extrapolated using data from wells S10 and S8. This extrapolation suggest that the water level in trench 80 is perched above the surrounding water table by as much as 2 m; however, the response of trench 80 to storm events may not be significantly different from the rest of the monitored trenches if this extrapolation is in error.

Figure 7.6 shows that the ratio of the total rise in trench water levels to the total precipitation from a single storm event varied from 0 to about 26. For a trench with a horizontal bottom and a uniform input of water through the trench cap the relationship between the infiltrating input, seepage out, and change in trench water level is:

$$ppt - Q/A = Hn \qquad \text{Eq. 7.1}$$

where;

H = change in water level,
ppt = total precipitation,
n = drainable porosity of the trench waste,
Q = total seepage out of the trench (for the same time interval in which H is measured), and
A = horizontal area of the trench.

If the total seepage is considered to be small during the short time in which the change in water level occurs this equation reduces to:

$$H/ppt = 1/n \qquad \text{Eq. 7.2}$$

Measurements of the drainable porosity of trench waste have been made on several trenches (see Section 7.3.1) and range from about 0.17 to 0.39. Thus a value of about 3 for the ratio of the total rise in the trench water level to the total precipitation would suggest that the entire influx of water to a trench is occurring by direct infiltration through the trench cap. A value greater than 3 would suggest that either: (1) lateral subsurface input is occurring or (2) overland flow is being channeled towards the trench.

Figure 7.6 (with the possible exception of trench 80) suggest that when the trench water level is more than about 0.5 m above the surrounding water table the majority of water moving into the trench can be accounted for by direct infiltration through the trench cap. However, when the water level difference is less than about 0.5 m as much as 90% of the total trench influx may occur through pathways other than direct infiltration through the cap. If the affect of seepage out of the trench during the rising of the hydrograph is included the fraction of trench influx accounted for by direct infiltration through the cap would decrease in all cases. See section 7.3 for a discussion on trench seepage.

The previous analysis of the response of trench water levels to individual storm events has implications for remedial actions in SWSA 6. An individual trench cap may be an effective remedial action for trenches located in topographically high areas where the surrounding water table at its seasonal high is at least 1 m below the bottom of the trench. However, trench caps are not likely to significantly reduce the amount of water passing through the waste in low lying areas where significant lateral subsurface storm flow and inundation by a high water table is occurring.

7.3 Trench Seepage

Although the pathway used by water flowing into the trench is important in terms of remedial action, only the flux of water seeping out of the trench is important for defining the source term. Several different methods are being used to compute the discharge of water seeping from a trench and include: (1) hydraulic modeling, and (2) the dilution method. The following describes each of these methods along with the results obtained to date.

7.3.1 Hydraulic Modeling

The discharge of groundwater from a trench can be estimated by solving the equations for groundwater flow in a saturated-unsaturated porous media over a region of interest. Although analytic solutions exist for simple geometries and homogeneous material properties the complexities present in SWSA 6 are more amenable to numerical models such as FEMWATER-2D (Yeh, 1987). The principle parameters required for numerical saturated-unsaturated flow models are the saturated hydraulic conductivity, porosity, and the saturated hydraulic conductivity-moisture content relationship for the geologic formation, trench bottom, and bulk waste.

Although the saturated hydraulic conductivity and porosity of the saprolite in SWSA 6 can be estimated from previous studies based on aquifer pump tests, these parameters are unknown for the trench bottom and bulk waste. In order to estimate these hydraulic parameters trenches 92 and 123 were injected with water at a constant rate while water level measurements were made both inside and outside the trench.

The drainable porosity was calculated using a method developed by Spalding (1986). If water is pumped into a trench at a constant rate, the drainable porosity is equal to the total volume pumped into the trench minus the total seepage that occurred while filling divided by the total volume of the filled portion of the trench. Mathematically this is:

$$(V_{in}-V_{seep})/\ H_{rise}A = n \qquad \text{Eq. 7.3}$$

where;

V_{in} = total volume pumped into the trench to produce a water level rise of H,
V_{seep} = total seepage that occurred during a water level rise of H,
A = horizontal area of the trench, and
n = porosity.

If the seepage rate at any given water level is the same when the trench is draining as filling and the water content of the trench waste is the same immediately prior to filling as after draining an additional mathematical statement concerning the porosity can be made:

$$V_{seep}/\ H_{fall}\ A = n \qquad \text{Eq. 7.4}$$

Thus 2 equations (7.3 and 7.4) and 2 unknowns (V_{seep} and n) exist and can be solved simultaneously to provide an estimate of the porosity (n).

The requirement that the seepage rate at any given water level during filling of the trench be equal to the seepage rate at that same water level during draining assumes that the hydraulic gradient along the bottom and sides of the trench be the same during filling and draining. Although the hydraulic gradient along the bottom and side of a trench will largely be controlled by the water level in the trench, a change in the pressure head in the area surrounding the trench, such as a rise in the water table, will also affect the gradient. Since water is being added to the hydrologic system surrounding the trench, the actual hydraulic gradient will be less during the draining portion of the test. This will result in an underestimate of the seepage rate during filling and thus an over estimation of the porosity. This problem can be lessened by filling the trench as quickly as possible thereby reducing the total seepage that can occurs during filling. The assumption that the water content of the waste be the same before filling as after draining is another source of error. Since many large voids are likely to be present due to the nature of the waste this is not considered to be a large source of error. Furthermore, any water that was held by the matrix of the waste would result in an underestimate of the porosity and would tend to compensate for the overestimate caused by the seepage assumption.

In addition to porosity, trench pump in tests can be used to estimate the saturated hydraulic conductivity of the trench sides and bottom. A constant head permeability test can be performed by holding the water level in the trench at a constant level until a steady state flow field is established. As a trench is filled with water the ratio of seepage that occurs out the trench sides to the seepage out the bottom is continually increasing. Therefore, if the water level in a trench is held constant at a level that is significantly above the bottom, the total seepage rate will be largely affected by the permeability of the trench sides. If an additional constant level test is conducted near the bottom of the trench, a much larger fraction of the total seepage will be controlled by the vertical permeability of the trench bottom. The saturated hydraulic conductivity of the sides and bottom can then be found by numerical modeling. Since numerical flow models require the saturated hydraulic conductivity as input, and yield temporal and spatial estimates of the total hydraulic head, a trial and error method will be used; the model FEMWATER2D will be run successively while adjusting the hydraulic conductivity until a match between observed and computed total heads is obtained.

A pump in test on trench 92 was conducted from May 20 to 22, 1987. Water was injected into the trench via a 5.1 cm stainless steel drive point with a 1.22-m screen. Water level measurements were made in 3 intra-trench monitoring wells along with well S10 which is a water table monitoring well adjacent to the trench. Water level data was recorded at 5 minute intervals using pressure transducers and an automatic data logging system. The flow rate was measured using a BadgerMeter model 40 flow meter and a stop watch. The flow meter had previously been calibrated and the metered volume was within 1% of the measured volume. The average flow rate during the filling portion of the trench was 1.80 L/s and was quite constant, having a standard deviation of 0.02 L/s. A constant head was maintained at an elevation of 238.60 m for approximately 1 h. The flow rate required to maintain this head was 55 L/min. It is doubtful that a steady state flow system was established in this short time period; however, the test could not be continued due to an insufficient supply of injection water. Hydrographs for all of the trenches monitored are shown in Figure 7.7 The hydraulic modeling is not yet complete; however, the large constant head flow rate suggest a relatively large value for the saturated hydraulic conductivity of the trench sides. The very similar response of each of the intra-trench monitoring wells suggest that the permeability of the trench waste is extremely high. Since the injection well was located ? m from monitoring well T92 it appears that the trench itself behaves more like an open hole than a porous media.

Porosity was calculated for 2 arbitrarily chosen sections of the trench (Fig. 7.7). Region 1 extends from 237.30 m to 237.68 m above mean sea level (MSL). Region 2 extends from 237.68 m to 238.62 m above MSL. The calculated porosities for regions 1 and 2 are 0.19 and 0.39, respectively. A decreasing porosity with depth is reasonable since compaction of waste near the bottom is expected due to the weight of the overlying waste.

A pump in test on trench 123 was also conducted and began on June 4, 1987. Problems with the data logging system forced an interruption in the test. A rerun of the test began on June 12, 1987 after the water from the initial test had drained from the trench. Water was injected via a 5.1 cm stainless steel drive point with a 1.22 m screen. Water levels were monitored in 3 intra-trench wells and 1 water table monitoring well. The average flow rate of the injection water was 1.82 L/s with a standard deviation of 0.02 L/s. A constant head was maintained on three separate occasions. Constant head was maintained near 243.94 m above MSL for about 2.5 h. The flow rate during this time was determined by turning the pump on and off in such a way to maintain the water level within about 0.03 m of the desired level. This procedure was continued for sufficient time to allow a minimum volume of about 300 L to be injected into the trench. Estimates of the constant head flow rate were not made during the first 1.5 h of the constant head condition. A flow rate of 5.53 L/min was measured during the final 1 h of this constant head condition.

A second constant head was maintained near 243.04 m above MSL beginning on June 25, 1987 for a total of about 28 h. The initial flow rate during the first 1.5 h of the constant head condition was 2.88 L/min. This rate declined to 1.06 L/min during the 3rd through 5th h of the test. Since the seepage was very slow, the trench was allowed to drain overnight and the water level was returned to the prescribed value the following day. The seepage flow rate was then computed as the total volume pumped into the trench to restore the water level divided by the elapsed time giving a value of 0.53 L/min.

A final constant head test was begun on June 29, 1987 at a level near 243.01 m above MSL. A constant head flow rate of 0.53 L/min was measured. Hydrographs for each monitoring well are shown in Figure 7.8. Although the hydraulic modeling is not yet complete the constant head flow rates measured in trench 123 are about 10 times less than trench 92 indicating a much lower hydraulic conductivity.

Porosity was calculated for two arbitrarily chosen regions of the trench (Fig. 7.8). Region 1 extends from 242.6 to 243.2 m above MSL while region 2 extends from 243.2 to 243.9 m above MSL. The average porosity for regions 1 and 2 are 0.25 and 0.17, respectively. Since the porosity was thought to decline with depth these results are unexpected but not impossible due to the nature of the trench waste.

7.3.2 Trench Dilution

Conservation of mass for a tracer injected into a trench can be used to provide an estimate of the groundwater discharge. This approach is similar to the point-dilution method used for measuring groundwater velocity in which a conservative tracer is instantaneously injected into a well. As groundwater flows into a bore hole (or trench which behaves hydrologically as an open hole) the concentration of an injected tracer will decline in a manner that is proportional to the flux of water coming into the hole. Following the development of Drost et al. (1968) the concentration C will decrease at the following rate:

$$dC/dt = QC/V \qquad \text{Eq. 7.5}$$

where;

C = concentration,
Q = discharge from borehole/trench, and
V = volume of borehole/trench.

This analysis assumes that: (1) the volume of water in the borehole/trench is constant, (2) the tracer is conservative, and (3) that the borehole/trench is well mixed. In addition to these assumptions a solution to Equation 7.5 requires that Q either be a constant or a known function of time. Although Q is certainly not constant over a long time period, a reasonable approach is to assume that Q is constant over some short time period which in practice corresponds to the frequency at which C is measured. If samples are always collected at the same trench water level, the discharge computed by solving Equation 7.5 will represent an average over the period between sample collections. Under these assumptions the solution to Equation 7.5 is:

$$\mathrm{Ln}(C_2/C_1) = Q(t_2-t_1)/V \qquad \text{Eq. 7.6}$$

Thus a value for Q can be computed using measurements of C and V which are closely spaced in time.

Optimally, a dilution test would be performed by pumping water from a waste trench, mixing in a tracer and injecting this water back into the trench. Since it was first necessary to perform a pump in test to determine the drainable porosity of the waste, it was decided to add tracer to the injection water during the test in order to provide a preliminary assessment of the dilution method as well as providing order of magnitude results. Sodium Chloride was used as a tracer in trench 92 while fluorescein dye was used in trench 123. Calculation of trench discharge based on the tracer concentration in the trench were initiated once the water level inside the trench had returned to the pre-injection level. Specific conductance, rather than actual concentration, was measured in trench 92 by lowering a conductivity cell directly into the monitoring well. Since only differences in the tracer concentration are important for the discharge calculation, any residual electrolytes present in the trench water prior to the injection would not affect the results. Fluorescein was measured in 25 ml samples from trench 123 by the Analytical Chemistry Division (ACD) using a spectrofluorimeter.

The results for the test on trench 92 are summarized in Table 7.3. The tracer was first injected on April 20, 1987 and regular conductivity measurements began on April 28, 1987 at which time the trench water level had returned to the pre-injection level. The injection water had a conductivity of 0.72 mS/cm while the initial conductivity of the trench water was 0.36 mS/cm. Conductivity measurements were made until July 29, 1987. The volume of water in the trench required to compute the discharge was estimated by multiplying the water level above the bottom of the well (assumed to be the trench bottom) by the horizontal area of the trench and by a drainable porosity of 0.19. Table 7.3 shows that the calculated discharge during late April and early May was about 80 L/d and dropped to about 15 L/d shortly thereafter. Since very little rainfall occurred during late April and early May it appears that some of the water injected during the test was still draining. The total discharge computed for the entire test period of 93 d was 1800 L or an average of 20 L/d. By comparison the total rainfall over the area of the trench during this period was 4900 L or an average of about 53 L/d.

The water level in trench 92 during most of the test period is shown by Figures 7.9, 7.10, and 7.11. The rainfall occurring in late June resulted in a 0.55-m rise of the trench water level and was the only rapid water level response observed during the test period. A water level rise of 0.55 m over the entire trench corresponds to a total volume of about 2300 L (using a porosity of 0.19). Thus, all of the discharge computed by the dilution method for the test period can be accounted for by the late June storm event. Although no water level response to storm events was observed during May, the trench water level did decline by 0.58 m from the beginning to the end of the month. This decline corresponds to a total volume of about 2400 L. At steady state it is possible for water to move into a trench and then out without the water level changing and thus the total discharge computed using only the change in water level is an absolute minimum. The total discharge computed using only the change in trench water level over the period of the dilution test is about 4,700 L. Thus, the dilution method appears to significantly underestimate the discharge from trench 92.

Several possibilities exist for these discordant results. The value used for drainable porosity is critical for relating the volume of water in the trench to the observed water level. The porosity measured by the test described in Section 7.3.1 represents an average over the section of the trench tested, which was from 1.5 to 1.9 m above the bottom. The water level during the dilution test was always less than 1.1 m above the trench bottom, and thus a porosity of 0.19 may not be appropriate. A smaller value would in fact be expected towards the bottom of the trench where fine-grained sediments accumulate. A smaller porosity would reduce the computed discharge based on the change in trench water level.

An additional problem in computing the volume of water in the trench from water level data is the possibility that the bottom of the trench is not horizontal, resulting in a nonlinear relationship between volume and water level. Although this affect is probably small when the water level is significantly greater than the trench bottom, it could result in bad volume estimates when the water level is near the trench bottom.

A final problem with interpreting the results from this test is that the sodium chloride tracer may not be geochemically conservative. Any addition or subtraction of electrolytes from the trench waste would alter the test results. This potential problem can be overcome by using a more exotic tracer that, although it may be more difficult to measure, would be geochemically conservative.

Thus, the results of this test are not definitive. Dilution testing does appear to be promising for measuring discharge from trenches; however, additional tests, conducted under the following conditions are needed: (1) tests need to be conducted at higher water levels where problems with the geometry of the trench bottom are lessened, and (2) a more exotic, geochemically conservative tracer should be used.

A dilution test was conducted during FY 1986 on trench 260 and was described by Solomon and Switek (1986). The average discharge from June 16 to August 1 was computed to be 310 L/day. An estimate of porosity was not available for this trench and a value of 0.3 was assumed for the discharge calculations. The average rainfall over the trench during this period was about 37 L/day. The water level in trench 260 did not respond to storm events during this test period.

A dilution test was also conducted on trench 123. Water tagged with fluorescein dye at a concentration of 13 mg/L was first injected on June 4, 1987. Several subsequent injections were made to calculate hydraulic parameters. Regular sampling began on July 10, 1987 and will be continued as long as a measurable concentration exists in the trench. Initial results indicate that an average of about 90 L/day is discharging from this trench. The complete results from this test will be reported at a later time.

7.4 Hydrochemical Separation of Stream Flow

Traditionally waste trenches have been viewed as a contaminant source to the saturated groundwater system. The significant amount of subsurface storm flow (also referred to as interflow or quickflow) apparent in many trenches suggest that rapid transport of contaminants may occur along a pathway that bypasses the groundwater system. In theory, this water would be included in discharge estimates made using either the dilution or the hydraulic modeling method; however, it should not be included as a contaminant source to the saturated groundwater system.

In order to assess and quantify this process a time series of samples were collected from the 4 principle surface water drainage systems in SWSA 6. Sample collection, analysis, and data reduction were done by S. M. Gregory (Univ. of North Carolina). Samples were collected near monitoring stations 1, 2, 3, and 4. Three separate storms were sampled. The first storm began on February 26, 1987 with a total of 62 mm falling over a period of 60 h. The second storm began on March 24, 1987 and produced 8 mm of precipitation over a 12-h period. The third storm was actually a set of three events that were closely spaced in time. The first precipitation occurred just after midnight on April 15, 1987 and produced 21 mm in 4 h. An additional 5 mm fell over a 2-h period beginning about 4:00 AM on April 16, 1987. A final event producing 5 mm in 10 h began at 3:00 PM on the same day.

Samples were collected by Manning automatic samplers at a frequency of one sample per h, and in the case of one storm that lasted over a period of days, one sample per two hours for the latter part of the storm. The samplers were started at the onset of rainfall and operated until it appeared that the streams had returned to base flow. Although a number of sampler malfunctions occurred, in most cases there was adequate coverage of each storm. All samples were stored in polyethylene bottles with polyseal caps.

A total of 96 samples were analyzed for tritium and 17 of these samples were also analyzed for dissolved silica (Si). Tritium is the most wide spread contaminant in SWSA 6 and is thought to be present as tritiated water (HTO). Thus, an analysis of ^3H transport will provide an upper (conservative) limit on the release of contaminants during storm events. Silica was chosen as an analyte because its is not a major constituent of the trench waste and because its concentration in trench leachate samples was the most constant of all analytes in a recent study on trench leachate chemistry (Solomon et al., 1987).

Tritium activities were measured using a Packard Tri-Carb 4640 liquid scintillation counter. All samples were treated with potassium permanganate to oxidize trace organic compounds and distilled to separate the ^3H from other radionuclides. Each sample was counted for 30 minutes. The detection limit of 1 pCi/ml was far below the stream samples which ranged from 130 to 7310 pCi/ml. Silica was measured on filtered (0.45 micron) samples by Inductively Coupled Plasma (ICP) Spectrometry. The detection limit for the silica analysis is about 0.1 mg/L.

7.4.1 Results of Storm Sampling

Tritium concentrations during periods of high stream discharge decreased in all the streams due to dilution of base flow by overland flow, subsurface storm flow and increased uncontaminated groundwater discharge. Figure 7.12 is a plot of ^3H concentration vs discharge at monitoring station 3 during all of the storms sampled. A well defined relationship exists between concentration and discharge at low discharge values; however, more scatter is present at higher discharges. This scatter is thought to occur due to a washout effect in which ^3H, present above the water table, is rapidly transported to streams during storm events.

Although dilution of base flow does occur during storms the concentration of ^3H does not decrease by the same factor that discharge increases. The instantaneous flux of ^3H passing a monitoring station can be computed by multiplying discharge by concentration. Instantaneous fluxes along with stream discharge and tritium concentrations for each of the monitoring stations are shown in Table 7.4. Figures 7.13 and 7.14 show the ^3H flux as a function of time at monitoring station 3 superimposed on the stream hydrographs for the February and April storms, respectively. The variation in ^3H flux mimics the stream hydrograph, indicating that significant ^3H releases occur when the streams are in flood.

Table 7.4 shows that the flux of ^3H in SWSA 6 streams can increase by as much as a factor of 200 from base flow to peak discharge. If the saturated groundwater flow system were the only source of contaminants to the streams, groundwater discharge would also have to increase by as much as 200 times during storms. Traditional studies of stream flow generation suggest that base flow does increase during and after storm events; however, the magnitude of the change as well as the rapid rise and fall of both stream discharge and the ^3H flux would be virtually impossible to produce by only an increase in groundwater discharge. Thus the rapid and large change in the ^3H flux during storm events suggests that an additional source of ^3H, such as contaminated interflow, is present.

7.4.2 Three Component Mixing Model

Figure 7.15 shows a conceptual model for stream flow generation in SWSA 6. Five sources of water (overland flow, stream interception, bypassing-trench interflow, through-trench interflow, and base flow) and two sources of contaminants (base flow and through-trench interflow) are considered. Although a continuum between each of these sources probably exists, it is useful to discuss each source as a discrete reservoir having concentrations and discharges which are averaged over the reservoir. If stream interception, overland flow, and bypassing-trench interflow are lumped together, a 3 component mixing model can be formulated for the concentration of ^3H in streams. Mass balance of ^3H leads to the following equation:

$$Q_s \, {}^TC_s = Q_g \, {}^TC_g + Q_{bi} \, {}^TC_{bi} + Q_{ti} \, {}^TC_{ti} \qquad \text{Eq. 7.7}$$

where;

Q_s = total stream discharge,
Q_g = discharge of groundwater (base flow),
Q_{bi} = discharge of bypassing-trench interflow,
Q_{ti} = discharge of through-trench interflow,
${}^TC_s$ = tritium concentration in the stream,
${}^TC_g$ = tritium concentration in groundwater,
${}^TC_{bi}$ = tritium concentration in bypassing-trench interflow, and
${}^TC_{ti}$ = tritium concentration in through-trench interflow.

Since the total stream discharge is derived from three sources, the following mass balance for water exists:

$$Q_s = Q_g + Q_{bi} + Q_{ti} \qquad \text{Eq. 7.8}$$

A total of 8 variables are present in equations 7.7 and 7.8 and only three of these (Q_s , $^{T}C_{ti}$, and $^{T}C_s$) are accurately known at all points in time. The number of unknowns can be reduced if we assume that: (1) the concentration of ^3H in groundwater is constant in time and equal to the ^3H concentration measured in base flow prior to a storm, and (2) groundwater discharge during storms can be described using classical methods of hydrograph separation. Even though the number of unknowns has now been reduced to 3, a unique solution is still not possible since only 2 equations exist. Chemical mass balance of another species (besides ^3H), having a different distribution among the 3 reservoirs, can provide an additional equation and thus lead to a unique 3 component mixing model. Dissolved silica was chosen since its presence in SWSA 6 is controlled by natural geochemical processes and not by the bulk waste, as is the case with ^3H. The following equation can be written for the mass balance of silica:

$$Q_s \, ^{si}C_s = Q_g \, ^{si}C_g + Q_{bi} \, ^{si}C_{bi} + Q_{ti} \, ^{si}C_{ti} \qquad \text{Eq. 7.9}$$

By measuring the concentration of silica in the stream and by assuming that: (1) the concentration of silica in groundwater is constant in time and equal to the silica concentration of base flow, (2) the silica concentration in through-trench interflow is constant in time and equal to the mean silica concentration measured in trench leachate (Solomon et al. 1987), and (3) the silica concentration of bypassing interflow is constant in time and equal the concentration of silica measured in interflow using special subsurface collectors in Walker Branch Watershed. Thus, equations 7.7, 7.8, and 7.9 represent a system of 3 equations with 3 unknowns ($^{T}C_{ti}$,

Q_{ti}, and Q_{bi}) which can be solved simultaneously to define a unique 3 component mixing model.

Silica measurements were made on samples collected from monitoring station 3 during the storm that occurred in April. The concentrations of silica in bypassing interflow, groundwater, and through-trench interflow were set at 1.0, 3.7, and 3.2 mg/L, respectively. The results of the mixing model are shown in Table 7.5. During the first large peak of the storm hydrograph when the total stream discharge was 79.1 L/s the model predicts that the discharge of bypassing interflow and through-trench interflow are 16.1 and 62.0 L/s, respectively. The model continued to predict that a large fraction of the total stream discharge was from through-trench interflow until the stream discharge had reduced to about 3 L/s. The computed concentration of ^3H in through-trench interflow varied from 850 to 1,360 pCi/ml with one low extreme of 110 pCi/ml during this time. Two subsequent peaks in stream discharge occurred in which the mixing model was not successful. Negative ^3H concentrations were computed indicating a breakdown in the assumptions used to formulated the model.

Several possibilities exist for the failure of the mixing model during the later part of the storm. During the early part of the storm when the total stream discharge went from 1 to 79 L/s, the base flow component of the total flow was small and thus the model was not sensitive to small errors in the actual value of base flow obtained by estimate from classical hydrograph separation. During the later part of the storm the estimated base flow was between 30 and 100% of the total and thus the model was much more sensitive to the value of base flow.

The sensitivity of the model to the assumed concentrations of silica in both bypassing interflow and through-trench interflow were also examined. A difference of only about 10% in the distribution of the total stream discharge was computed when the concentration of silica in bypassing interflow was varied from 0 to 1 mg/L. The model was considerably more sensitive to the concentration of silica in through-trench interflow. Although dissolved silica was the most uniform of all analytes in a recent study of trench leachate chemistry the mean concentration of 3.2 mg/L had a standard deviation of 1.6 mg/L. The distribution of total stream discharge varied by as much as 50% when plus and minus 1 standard deviation was used.

Although several problems exist with the 3 component mixing model, it is clear that a significant washout of contaminants occurs via rapidly moving interflow. The large increase in the ^{3}H flux that occurs during storm events cannot be explained by considering the saturated groundwater system as the only direct source of contaminants to streams.

The change in ^{3}H flux with respect to discharge was not the same at all of the monitoring stations. For example, during the April storm station 3 discharge changed by a factor of about 80 from base to peak flow while the ^{3}H flux changed by only a factor of about 23. During this same storm, the discharge at monitoring station 4 changed by a factor of 2.7 while the ^{3}H flux changed by a factor of 2.0. Thus, a 1.0 unit change in discharge at monitoring station 3 produced a 0.28 unit change in ^{3}H flux while a 1.0 unit change in discharge at monitoring station 4 produced a 0.75 unit change in ^{3}H flux. Monitoring station 4 is the French drain which was designed to lower the water table and intercept interflow during storms. These differences (0.28 compared to 0.75) suggest that less dilution of contaminated discharge is occurring in the French drain.

7.4.3 Annual Tritium Release

The relationship between ^{3}H concentration and stream discharge developed from the 3 storms sampled and shown in Figure 7.12 can be used to estimate the total annual release of ^3H from station 3 during the 1986 calendar year. A logarithmic regression equation was fit to the data shown in Figure 7.12 and used to compute the ^3H flux for each of the 15 minute-interval discharge measurements. The resulting curve of ^3H flux vs time was then integrated over the entire year to give the total ^3H discharge for 1986. A total release of 65.8 Ci was computed.

During CY 1986 station 3 was in flood approximately 27.5 % of the time, which accounted for 85.6 % of the total water discharge. The ^3H discharge followed a similar trend with 64.7% of the total release occurring during storm event. One storm in February, in which the stream was in flood for about 7 days, accounted for a release of 7.9 Ci, which is about 12% of the annual total. Although not all of the ^3H released during storm events will result from through-trench interflow, these results suggest that perhaps 50% of the total ^3H source term should be partitioned into an interflow transport pathway and should not be included as a source to the saturated groundwater system.

7.5 Strategy for Source Term Characterization

The work presented in this report outlines the specific procedures being used to help define the source term in SWSA 6. Ultimately it will be necessary to multiply estimated instantaneous discharges by estimated instantaneous concentrations over an entire average water year to obtain a source term; however, several major obstacles must first be overcome. As pointed out in Chapter 4, the actual concentrations of contaminants in trench leachates is not constant and appears to be a function of the water flux and the kinetics of the leaching process. Although additional sampling may help provide an empirical relationship between concentration and discharge for a given trench, it may be difficult to generalize such a relationship over the entire site. The most practical solution at this point may be to formulate a conservative estimate by setting the concentration to the maximum observed value. The following strategy is recommended for establishing a generalized through-trench water flux over the site:

1. Two additional trench pump tests should be performed and interpreted using a 3-dimensional flow model,

2. Hydraulic parameters established during pump test modeling should be combined with the observed water levels in a 3-D flow model to yield monthly estimates of the discharging water flux,

3. The variability in estimated discharges should be considered to decide whether or not a generalization of these discharges to all of the trenches is justified,

4. At least 2 dilution tests should occur over the same period and on the same trenches as the hydraulic modeling. These tests should be conducted in such a way that only tracer, and not additional water, is added to the trench, and

5. The total contaminant flux should be partitioned between the saturated groundwater system and interflow. Additional hydrochemical separation of stream flow would aid in this endeavor.

The majority of the data needed to make a first approximation to the source term has already been collected. Since the source term is fundamental to nearly all phases of the remedial investigation, it is critical that this work be continued.

8. HYDROGEOLOGIC MODELING

(P. M. Craig)

The results presented below summarize the first phase of a pathways analysis for SWSA 6, which will be useful in ORNL's Remedial Action Program. The work consisted of a two-dimensional groundwater flow study coupled with a preliminary contaminant transport analysis. Webster (1976) reported that a principle mechanism for transporting radionuclides from waste disposal areas is by dissolution in groundwater. Thus, in order to estimate the rate and direction of contaminant migration into the environment from waste disposal sites, it is necessary to first characterize the hydraulic, hydrologic and geologic parameters that influence the movement of groundwater within the unconsolidated and bedrock aquifer systems.

The primary purpose of this study was to analyze and model the steady state movement of groundwater within SWSA 6's hydrologic boundary. A secondary investigation involved analysis and modeling the transport of radioactive contaminants via the groundwater system. Another purpose for conducting groundwater modeling of SWSA 6 was to better understand and characterize the hydrogeology and its influence on the transport of radionuclides. Although additional hydrogeologic data is needed to better characterize the subsurface and contaminant transport flow systems (some of which is currently scheduled or now being collected), this modeling effort can provide a basis for future refined groundwater flow and contaminant transport modeling and help define future data collection activities.

8.1 Hydrogeologic Description of SWSA 6

SWSA 6, which lies in Melton Valley, is underlain by the Nolichucky shale and Maryville limestone formations of the Conasauga Group. The formations strike northeasterly at about 56 degrees and dip is to the southeast at angles generally between 30 and 40 degrees (Tucci, 1986). The Conasauga is a heavily fractured formation providing microscale fluid conduits which control flow locally and cause the regional aquifer system to be anisotropic. Although the original bedrock material was impermeable, post depositional folding and weathering has created a secondary fracture system which allows water movement through the bedrock and weathered unconsolidated zone (weathered bedrock). The unconsolidated zone ranges in depths from about 1.2 m (4 ft) in topographic low areas to as much as 12 m (40 ft) in topographic high regions. The fracture system extends below the unconsolidated zone, though it may decrease with depth. Tests suggest that the water table aquifer may extend to depths of 61 m or more below the ground surface (Davis et al., 1984). More recent data from the hydraulic head monitoring wells (HHMS) further suggest that the uppermost aquifer extends well into bedrock (Toran and Solomon, 1987). However, modeling analysis (Tucci, 1986) indicate that the deeper system, though hydrologically connected, may be essentially decoupled from the shallow system. Tucci estimated that nearly all groundwater flow is within the regolith with less than 3% of the flow occurring between the regolith and bedrock, and less than 1% of the total groundwater flow discharging to the Clinch River through bedrock. Thus, the hydrologic role of bedrock is uncertain at this point. The modeling effort described in this report represents one limiting case in which deep recharge is assumed to be minimal.

Hydraulic conductivities for SWSA 6's unconsolidated zone, based on slug tests, vary from less than 0.1 ft/day (3.5×10^{-5} cm/s) to 1.0 ft/day (3.5×10^{-4} cm/s). The anisotropy is thought to range between 1:1 to 0.333:1 (strike normal/strike parallel). As mentioned previously, the anisotropy is primarily a result of a preferred fracture orientation. It is thought that the anisotropy may vary with depth due to the changes in the fracture system; however, no data has been obtained to determine any vertical variation. The bedrock hydraulic conductivities are approximately an order of magnitude less than the unconsolidated zone. Currently a series of well nests are being tested which will provide better information on the vertical variation of hydraulic conductivities.

A manually interpreted water table map of SWSA 6 is shown in Figure 8.1 for data obtained in October 1986 (Moore, 1987). The configuration of the water table is a subdued image of the topography of SWSA 6. The topographic lows act as groundwater discharge points for the unconsolidated aquifer system. This negative flux (groundwater exiting the aquifer) results in lower water table elevations than would exist if no drains were present.

When analyzing the groundwater and surface water contaminant pathways these surface drains should play a major role in the transport of contaminants out of SWSA 6. Other factors which affect contaminant transport are: (1) adsorption, absorption, and ion exchange (characteristics of the aquifer material), (2) amount and areal variation of recharge, (3) the conductance between the groundwater system and the surface creeks, and (4) the hydraulic properties of the groundwater system.

The effect of the adsorption, absorption, and ion exchange processes is to decrease the linear velocities of the individual contaminant to less than that of the groundwater flow. Once these contaminants are discharged to a creek via groundwater flow, they may become sorbed to stream sediments or remain dissolved in the water and transported at a much higher rate than found within the aquifer. Thus, the containment of contaminant constituents within the hydrologic boundaries of the waste disposal areas is complicated due to the potential of rapid transport via the surface water system.

8.2 Groundwater Flow Modeling

Shallow groundwater flow in SWSA 6 is from areas of high hydraulic energy to areas of low hydraulic energy discharging to small creeks or White Oak Lake/White Oak Creek. Groundwater flow is controlled by a combination of the hydraulic gradient and the primary (aquifer material) and secondary (resulting from the fracturing) hydraulic conductivity of the aquifer material. Local variations in flow directions may deviate in the direction of fractures, but the overall trend of groundwater flow is approximately the same as the areal hydraulic gradient as illustrated by water table contour maps.

8.2.1 Model Selection

A U. S. Geological Survey code developed by McDonald and Harbaugh (1984) entitled "A Modular Three-Dimension Finite Difference Groundwater Flow Model" was chosen to model the shallow, water table aquifer system within SWSA 6. This code is capable of modeling the hydrogeologic system described in sections 8.1 and 8.2. In addition, MODFLOW (a PC version of the code) is validated, well documented, and readily available to the public. Sources reviewed during the model selection process included models available from the International Groundwater Modeling Center (IGWMC, 1986), a report by Science Applications, Inc. (SAI, 1981), and a monograph by Bachmat, et al. (1984).

MODFLOW is a three-dimensional, finite-difference, block-centered model adopted for use in both confined or unconfined aquifers, or a combination of both. Flow from external stresses, such as flow to wells, areal recharge, evapotranspiration, flow to creeks, and flow through riverbeds, can also be simulated. The model is applicable to steady or nonsteady flow in an anisotropic, heterogeneous medium. The finite-difference groundwater flow equations can be solved using either the strongly implicit procedure (SIP) or slice-successive overrelaxation.

8.2.2 Model Parameters

At this time, mainly due to the lack of data, only the unconsolidated zone has been modeled. This is a justifiable approach for a two dimensional model. Work currently being conducted on the characterization of the deep bedrock aquifer in the Melton/Bethel Valleys will provide information for future modeling efforts.

The MODFLOW model requires several data sets in order to simulate groundwater flow in SWSA 6. For steady state simulations the data required are: (1) hydraulic conductivities, (2) anisotropy, (3) areal recharge, (4) aquifer bottom, (5) drain locations, elevations, and conductance, and (6) initial and boundary conditions. These parameters will be discussed below.

8.2.2.1 Hydraulic Conductivities. The hydraulic conductivities (K_c) used in the initial model set up came from geometric means of slug test data from wells completed in the unconsolidated zone. The K_c over the entire active area was set to 2.1 x 10^{-4} cm/s (0.6 ft/d).

During calibration this K_c resulted in excessive drainage of the aquifer. Final calibration values of 5.3 x 10^{-5} cm/s 0.15 ft/d) in the upper portion of SWSA 6 and 2.1 x 10^{-4} cm/s (0.6 ft/d) closer to White Oak Creek (Fig. 8.2) were used.

Transmissivities are calculated by the MODFLOW model based on the K_c and the aquifer thickness. For unconsolidated simulations, transmissivities are allowed to vary based on computed thicknesses until the heads converge.

8.2.2.2 Anisotropy. As mentioned in Section 8.1, SWSA 6 exhibits an anisotropy along strike in a range of 1:1 to 3:1 (K_x/K_y), with the major axis strike parallel. Initially a value of 3:1 (K_x/K_y) was used in the model.

The anisotropy was adjusted in the model calibration to a value of 2:1. This allowed more water to exit the aquifer through the constant head boundary and reduced the flow to the drains.

8.2.2.3 Areal Recharge. Average annual rainfall for ORNL is approximately 1372 mm (54 in). Total precipitation measured at the ETF within SWSA 6, for 1986 was 978 mm (38.5 in). An initial groundwater recharge value of 81 mm/yr (3.2 in/yr) (8.3% of the 1986 and 5.9% of the annual average precipitation) was used in the model. The recharge was assumed to be homogeneous over the area modeled.

This estimate comes from a preliminary modeling study of Melton Valley (Tucci, 1986). While this estimate is at the low end for estimates of recharge (from 5% to 30% of the average annual precipitation) the modeling results and the fact that 1986 was in a drought period lends it credibility. Additional analysis of detailed water budgets during periods of more normal amounts of percipitation will help define this parameter. Loss of water to the bedrock system, which was not included in the model, would increase the total recharge.

8.2.2.4 Aquifer Bottom. The elevation of the bottom of the unconsolidated aquifer is needed to obtain the aquifer thickness, which is used in the computation of transmissivities. At the beginning of the modeling effort, an attempt was made to set the bottom of aquifer equal to auger refusal depths obtained during the installation of the new SWSA 6 monitoring wells. Several problems became evident with this method. First, there were several locations where the water table was below auger refusal. Secondly, the thickness of the aquifer in other places was felt to be too small based on previous work (Webster and Bradley, 1986; Davis et. al, 1984). From these observations, and lack of other information, a flat bottom of the aquifer was set to an elevation 6.1 m below the constant head boundary at White Oak Lake. This resulted in a bottom elevation of 221 m above MSL.

8.2.2.5 Drain Information. The surface streams in SWSA 6 primarily act as groundwater discharge points and therefore act as drains (Fig. 8.3). MODFLOW requires the drain elevation, the drain location, and the drain conductance (which controls the rate of water movement into the drain).

The drain conductance parameter is a lumped term which includes stream length and width (in the cell), hydraulic conductivity of the stream bed, stream bed thickness, and any losses associated with converging flows. A first guess of this parameter may be calculated by the following:

$$CD = \frac{K_s \times A}{T_b} \qquad \text{Eq. 8.1}$$

Where;

CD = Drain conductance,
A = Area of stream in the cell,
T_b = Stream bed thickness, and
K_s = Stream bed hydraulic conductivity.

This value may then need adjustment to account for other losses. MODFLOW calculates the discharge to the drain as a function of the head above the drain elevation times the drain conductance. A value of 2.55 cm^3/s (9.0×10^{-4} ft^3/s) was used.

8.2.2.6 Initial and Boundary Conditions. The hydrologic boundary conditions for the shallow water table aquifer within SWSA 6 consist of a combination of fixed-head and zero-flux boundaries (Fig. 8.3). The fixed-head boundary is located south of SWSA 6 along White Oak Lake and the marshy areas north of White Oak Creek. The fixed-head boundary was set to an elevation of 227 m above MSL. The zero-flux boundary was used where the groundwater flow, as observed in Figure 8.1, is parallel to the east and west boundaries and where a presumed groundwater divide occurs along the northern boundary. Following the topographic high regions, the zero-flux boundary extends north from White Oak dam, bends in a northeastern direction, then due east and finally southward until it converges again with the fixed-head boundary.

8.2.3 Calibration Results

The first phase of modeling has been completed using the available data. The objective was to calibrate a steady state flow model to match the heads and surface water flow rates at SWSA 6. October 1986 data (based on Moore's study) was used as a comparison to the computed heads (see Fig.

8.1). A rough estimate of base flow from the streams flowing out of SWSA 6 (0.5 L/s or 0.018 ft^3/s) was used to compare computed flow from drains. The base flow estimate was taken from a period of record that is significantly influenced by the local drought (1980 to 1986), therefore the actual average base flow may be up to 3 times that estimated.

Figure 8.4 shows the water level results of the model calibration. In order to obtain a quick comparison of the computed vs actual (estimated) heads a Root Mean Square (RMS) error was calculated. This squares the sum of the differences, divided by the number of nodes, and then takes the square root. An attempt was made to optimize the RMS while keeping the drain flow between 0.5 and 1.0 L/s (0.018 and 0.036 ft^3/s). The final calibrated model resulted in a base flow of 0.54 L/s (0.019 ft^3/s) and an RMS of 2.14 m (7.03 ft). Figure 8.5 shows the spacial variation in the differences in the computed and hand estimated water tables.

8.2.4 Sensitivity Analysis.

Five parameters were chosen to be varied in order to determine their effect on the calibrated results. The parameters are: (1) hydraulic conductivities, (2) recharge, (3) aquifer base, (4) drain conductance, and (5) anisotropy. The values were adjusted and the resulting RMS error was determined. Figure 8.6 (a)-(e) show how each parameter was varied and its effect on the RMS error. For several cases the RMS error was lower than the calibrated model; however, the RMS error does not take into account the drain flows as does the calibration procedure.

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APPENDIX A

SWSA 6 RAINFALL RECORDS

ETF RAINFALL (mm) 1980

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1									0.0	0.0	0.0	0.0
2									3.4	0.9	0.0	0.0
3									0.0	0.0	0.0	0.0
4									0.0	0.0	1.8	0.0
5									0.0	0.0	0.0	0.0
6									0.0	0.0	0.0	0.0
7									0.0	0.0	0.0	0.0
8									0.0	0.0	0.0	0.0
9									0.0	0.0	0.0	28.7
10									22.9	0.0	0.0	0.5
11								1.8	0.0	0.0	0.0	0.0
12								5.8	0.0	0.0	0.0	0.0
13								0.0	0.0	0.0	0.0	0.0
14								0.0	0.0	0.0	0.5	0.0
15								8.9	0.0	0.0	20.4	0.0
16								0.0	0.0	0.0	0.0	0.0
17								6.4	1.4	0.0	18.8	0.0
18								0.2	0.0	26.1	4.3	0.0
19								0.0	0.0	0.0	0.0	0.0
20								1.8	5.7	0.0	0.0	0.0
21								0.0	0.0	0.0	0.0	0.0
22								0.0	0.0	0.0	0.0	0.0
23								0.0	0.0	0.0	18.7	0.0
24								0.0	5.4	7.4	19.7	12.9
25								0.0	7.5	2.7	0.0	0.0
26								0.0	0.0	0.0	2.6	0.0
27								0.0	0.0	8.5	14.8	0.0
28								0.0	9.7	0.7	0.0	0.0
29								0.0	2.6	0.0	0.0	0.0
30								0.0	10.1	0.0	0.0	1.4
31								7.6		0.0		0.0
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TOTAL								32.5	68.7	46.3	101.6	43.5

GRAND TOTAL 292.6 mm

ETF RAINFALL (mm) 1981

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.0	21.8	2.3	1.5	0.6	1.6	8.0	0.0	10.1	7.4	0.0	13.8
2	0.0	22.5	0.0	0.0	0.0	6.1	0.0	3.7	0.0	0.0	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	3.7	0.0	0.0	4.1	0.0	0.0	0.0
4	0.0	0.0	13.3	0.0	0.0	14.1	0.0	0.0	11.4	0.0	0.0	0.0
5	0.0	0.0	5.8	27.5	0.0	0.9	33.7	0.0	0.0	2.2	5.3	0.0
6	2.9	0.0	0.1	0.1	0.0	40.5	0.0	12.7	0.0	0.0	0.0	0.0
7	0.8	0.0	0.0	0.0	0.0	0.0	3.4	15.6	0.0	0.6	0.0	0.0
8	0.0	3.2	0.0	0.0	0.0	0.0	0.0	4.6	0.0	0.0	0.0	0.0
9	0.0	0.1	0.0	12.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	0.0	33.2	0.0	0.0	1.0	17.2	1.8	0.0	0.0	0.0	0.0	0.0
11	0.0	5.2	0.0	0.0	0.2	0.5	0.0	1.1	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.9	0.0	3.8	0.0	0.0	0.0	0.0
13	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.0	0.0	2.0	5.5	0.0	0.0	0.0	19.6	0.0	0.0	18.3
15	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	25.7	0.0	0.0	3.6
16	0.0	0.0	1.2	0.6	0.0	0.0	0.0	9.6	0.1	0.0	21.9	0.3
17	0.0	14.8	0.0	10.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
18	0.0	10.1	0.0	2.9	1.3	0.0	0.0	3.1	0.0	16.7	0.5	0.0
19	0.0	2.8	0.0	7.0	16.1	0.0	0.0	0.7	0.0	0.0	1.5	0.0
20	5.8	0.2	0.0	20.3	3.4	0.0	1.3	8.7	0.0	0.0	0.5	0.0
21	1.4	0.0	0.0	0.0	0.4	0.0	0.0	9.7	0.0	0.0	0.0	16.0
22	0.0	2.8	16.2	0.0	0.0	16.4	0.0	0.0	0.0	0.5	0.0	11.4
23	0.0	2.6	1.1	5.5	0.0	0.0	0.0	0.0	0.0	21.4	7.2	4.0
24	0.0	0.0	0.0	0.0	0.0	0.0	23.1	2.2	0.0	0.0	4.6	0.7
25	0.0	0.0	0.0	0.0	15.2	20.4	0.0	0.0	0.0	19.4	0.0	6.0
26	0.0	0.0	0.0	0.0	8.5	0.0	0.0	0.0	0.0	24.9	0.0	0.0
27	4.3	0.0	0.0	0.0	17.7	0.0	0.0	0.0	0.0	0.4	21.3	1.0
28	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0
29	0.0		0.0	3.5	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
30	6.9		31.8	0.0	30.6	0.0	0.0	0.0	0.0	0.0	16.4	0.0
31	0.0		0.0		8.0		0.0	0.0		0.0		22.2
TOTAL	22.1	119.3	73.4	93.7	108.5	122.3	74.0	75.5	71.0	93.5	79.2	102.4

GRAND TOTAL 1034.9 mm

ETF RAINFALL (mm) 1982

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	1.0	0.0	0.8	0.0	0.0	6.5	0.0	0.0	25.1	0.0	0.0	62.1
2	8.1	17.6	0.0	0.0	0.0	0.0	0.0	0.0	20.6	0.0	0.0	0.0
3	33.9	7.3	0.0	3.7	0.0	0.0	3.8	0.0	0.0	0.0	49.2	0.0
4	16.9	0.0	0.0	0.0	0.0	11.4	9.5	0.0	0.0	0.0	5.9	0.0
5	0.0	0.0	5.2	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.7
6	0.1	3.4	18.3	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0
7	5.2	0.0	21.4	0.0	11.7	0.0	0.0	0.0	0.0	10.8	0.5	0.0
8	0.0	0.0	0.0	12.4	3.6	0.0	24.4	6.0	0.0	7.4	0.0	0.0
9	0.0	30.6	0.1	0.3	0.0	0.0	0.6	35.3	0.0	0.4	0.1	0.0
10	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.8	0.0	0.0	0.0	2.4
11	0.0	0.0	0.0	0.0	0.0	0.0	36.4	6.1	0.0	0.0	0.0	25.5
12	0.0	6.0	0.0	0.0	0.0	11.5	0.0	0.0	0.5	25.1	17.7	5.2
13	0.4	2.9	5.7	0.0	0.0	1.6	0.0	0.0	2.9	15.1	0.0	0.0
14	0.2	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	11.2	5.7	32.4	1.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	22.0
16	1.3	27.8	3.7	0.0	0.0	9.8	0.0	2.7	0.0	0.0	0.0	0.0
17	0.0	3.4	8.0	17.6	0.0	0.0	0.0	17.9	0.0	0.0	0.0	0.0
18	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19	10.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2
20	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	2.6	0.0	0.0
21	26.3	0.0	25.2	2.2	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	7.5	0.0	0.0	0.0	2.6	7.0	13.0	0.0	0.0	0.0	0.0	0.0
23	20.2	0.0	0.0	0.0	0.0	0.0	0.0	15.3	0.0	0.0	46.2	5.2
24	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
25	0.0	0.0	7.4	13.5	0.0	0.0	0.0	0.0	9.9	0.0	0.0	1.3
26	0.0	5.2	0.0	4.1	5.0	1.5	0.0	0.0	1.8	0.0	0.0	9.8
27	0.0	17.7	0.0	4.5	5.3	1.7	0.0	2.3	0.0	0.0	7.2	0.0
28	0.0	0.0	0.0	0.4	26.8	0.0	2.3	0.0	0.0	0.0	21.0	15.9
29	0.0		0.0	0.0	0.0	4.8	0.9	0.0	0.0	0.0	0.0	0.0
30	0.0		0.0	0.0	0.0	2.2	8.1	0.0	0.0	0.0	3.0	0.0
31	16.0		32.4		0.8		39.0	5.1		0.0		0.0
TOTAL	162.8	130.9	162.6	64.4	60.7	70.4	138.0	92.4	63.6	61.4	150.8	177.3

GRAND TOTAL 1335.3 mm

ETF RAINFALL (mm) 1983

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.0	23.7	0.0	0.0	0.0	0.0	1.9	1.1	0.0	0.0	0.0	0.0
2	8.5	14.9	0.0	8.7	0.0	0.0	0.0	0.0	1.4	0.0	0.0	23.0
3	0.1	0.9	0.0	1.2	2.7	0.0	0.0	0.0	1.1	0.0	2.8	37.0
4	0.0	0.0	0.0	0.0	0.0	20.6	4.4	0.0	6.4	0.0	12.3	2.8
5	0.0	0.0	7.7	42.8	0.0	0.0	2.9	0.0	0.0	30.8	0.0	1.5
6	0.0	15.4	5.9	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	14.9
7	0.0	1.8	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	4.5	20.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9	9.7	0.5	0.0	23.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	3.3	24.5	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0
11	2.8	4.3	0.0	0.0	0.0	0.0	0.0	12.1	0.0	2.3	0.6	21.4
12	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	1.1	0.0	8.7
13	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	13.0	44.6	0.0	0.3
14	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	4.9	5.2
15	0.0	0.0	0.0	0.7	7.4	0.0	0.0	0.0	0.0	0.0	15.3	0.0
16	0.0	0.0	0.0	0.0	7.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	9.7	0.0	0.0	0.0	0.0	0.0	0.0
18	0.0	0.0	1.6	9.0	0.0	5.3	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	27.1	1.1	8.8	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	21.4	0.0	21.4	0.0	8.7	0.0	7.6	0.0	19.7	0.0
21	9.6	0.0	0.8	0.0	16.3	0.0	0.0	0.0	15.3	1.4	0.0	15.4
22	0.1	11.7	0.0	2.7	17.7	11.7	0.0	0.0	0.0	8.1	0.0	17.2
23	0.0	0.0	0.0	17.3	5.0	0.0	0.0	6.6	0.0	28.1	20.8	0.0
24	0.0	5.6	0.0	1.2	0.2	0.0	3.0	2.8	0.0	0.0	10.7	0.0
25	0.1	0.0	0.0	0.0	0.0	0.0	9.9	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	13.5	0.0	0.0	5.0	0.0	4.3	0.0	0.0	27.2	0.0
28	0.0	0.0	0.0	0.0	0.0	0.5	0.0	2.3	0.0	0.0	19.2	36.9
29	2.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
30	3.1		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0		1.6		0.0		8.4	0.0		0.0		0.0
TOTAL	39.3	103.3	54.1	114.3	132.1	53.9	48.0	29.2	44.8	116.4	137.3	184.8

GRAND TOTAL 1057.5 mm

ETF RAINFALL (mm) 1984

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	0.0	1.9	0.0
2	0.0	0.0	0.0	0.0	38.4	0.0	3.3	0.0	0.0	0.0	7.6	1.3
3	0.0	1.9	0.0	5.8	28.4	0.0	0.0	5.1	14.0	0.0	0.0	0.0
4	1.7	0.0	0.0	28.3	6.4	0.0	15.2	0.0	0.0	0.0	6.4	0.0
5	0.0	0.0	5.2	0.5	0.0	0.0	14.7	0.0	0.0	0.0	0.0	7.6
6	0.0	4.5	5.0	0.0	36.8	0.0	3.8	0.0	0.0	0.0	0.0	0.0
7	0.0	2.2	0.0	0.0	81.7	0.0	27.9	2.5	0.0	0.0	0.0	0.0
8	0.0	0.0	0.0	0.0	16.9	0.0	0.0	0.0	0.0	22.2	0.0	0.0
9	0.0	0.0	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	11.6	6.2	0.0	0.0	0.0	0.0	0.0	30.5	0.0	0.0	43.2	1.3
11	2.7	3.0	0.0	0.0	0.0	0.0	16.5	0.0	0.0	0.0	0.0	0.0
12	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
13	0.0	28.4	5.1	0.0	13.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
14	0.0	0.1	0.0	0.0	0.0	16.2	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.0	0.0
16	4.0	0.0	9.3	2.8	0.0	0.0	9.5	0.0	0.0	0.0	0.0	0.0
17	0.2	0.0	2.5	0.5	0.0	0.0	21.0	0.0	0.0	6.4	0.0	2.5
18	21.4	0.0	2.5	0.0	0.0	0.0	17.8	0.0	0.0	0.0	9.5	2.5
19	0.0	2.7	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	1.3	12.7
20	0.0	0.0	32.1	1.9	0.0	0.0	0.0	0.0	0.0	27.3	0.0	7.6
21	0.0	0.0	4.6	0.0	0.0	7.6	0.0	0.0	0.0	0.0	0.0	0.0
22	0.0	0.0	0.0	16.7	0.0	2.4	3.8	0.0	0.0	58.4	0.0	0.0
23	5.8	9.5	0.0	0.0	7.3	0.0	0.0	2.5	0.0	39.4	0.0	6.4
24	13.9	2.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.1
25	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.9	0.0	10.8	0.0	0.0	0.0	0.0	0.0
27	0.0	29.5	0.0	14.0	0.0	0.0	30.5	0.0	0.0	0.0	0.0	0.0
28	0.0	1.5	45.2	5.3	42.3	0.0	0.0	0.0	0.0	2.5	22.9	0.0
29	0.0	0.7	0.0	7.8	0.0	40.3	0.0	0.0	0.0	0.0	0.0	0.0
30	0.0		0.0	3.1	0.0	25.3	3.2	0.0	6.4	0.0	6.4	4.4
31	0.0		0.0		0.0		1.9	0.0		0.0		1.3
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TOTAL	61.3	92.2	113.3	95.4	272.1	91.8	180.6	43.2	20.3	156.2	113.0	52.7

GRAND TOTAL 1292.1 mm

ETF RAINFALL (mm) 1985

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	12.7	34.3	0.0	0.0	1.3	0.0	4.4	5.7	0.0	31.8	15.9	8.9
2	0.0	6.4	0.0	0.0	29.8	2.5	0.0	0.0	0.0	5.1	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	3.8	0.0
4	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.1	0.0
5	0.0	11.4	1.9	22.9	0.0	0.0	0.0	0.0	1.9	0.0	0.0	2.5
6	0.0	0.0	0.0	0.0	0.0	1.3	1.3	15.9	12.7	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	1.3	33.0	0.0	2.5	0.0	0.0	1.3	0.0
8	10.8	0.0	0.6	0.0	3.8	0.0	14.6	0.0	0.0	0.0	0.0	0.0
9	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11	0.0	13.3	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	10.2
12	0.0	0.0	0.0	0.0	0.0	14.0	0.0	0.0	0.0	0.0	0.0	7.0
13	0.0	10.2	0.0	0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	3.2
14	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	0.0	0.0	0.0	20.3	0.0	0.0	0.0	1.3	0.0	1.3	0.0	0.0
16	0.0	0.0	0.0	0.0	0.6	0.0	0.0	101.0	0.0	0.0	7.6	0.0
17	5.1	1.3	0.0	0.0	5.7	19.7	2.5	38.1	0.0	0.0	0.0	0.0
18	0.0	0.0	0.0	0.0	0.0	10.8	0.0	0.0	0.0	0.0	0.0	0.0
19	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
21	0.0	0.0	3.2	0.0	7.6	0.0	0.0	0.0	0.0	15.9	10.8	0.0
22	0.0	0.0	8.9	0.0	0.0	0.0	0.6	0.0	0.0	0.0	3.8	0.0
23	0.0	0.0	8.3	0.0	1.3	0.0	29.2	0.6	11.4	17.8	0.0	0.0
24	0.0	0.0	0.0	0.0	1.9	0.0	0.0	25.4	11.4	0.0	0.0	0.0
25	0.0	1.3	1.3	0.0	0.0	0.0	0.0	9.5	0.0	0.0	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	10.2	15.2	12.7	5.1	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	19.7	1.9
28	2.5	0.0	0.0	0.0	6.4	0.0	22.9	0.0	0.0	0.6	24.1	0.0
29	2.5		0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	2.5	0.0
30	1.3		0.0	0.0	0.0	40.0	6.4	15.9	0.0	0.0	0.0	0.0
31	19.1		9.5		0.0		0.0	0.0		0.0		17.8
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TOTAL	56.5	79.4	36.8	43.2	59.7	132.7	100.9	230.5	42.5	75.6	101.6	52.7

GRAND TOTAL 1012.0 mm

ETF RAINFALL (mm) 1986

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	0.0	0.0	0.0	0.0	0.0	1.9	5.1	0.0	8.9	0.0	0.8	5.9
2	0.0	0.0	0.0	0.0	0.0	0.0	26.0	0.0	25.4	0.0	0.0	7.1
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	2.5	0.0	2.5	0.0
5	0.0	0.0	0.0	0.0	0.0	12.7	0.0	0.0	0.0	0.0	2.6	0.0
6	0.0	0.0	0.0	10.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	0.0	0.0	14.6	0.0
8	0.0	0.0	0.0	17.8	0.0	0.0	0.0	0.0	0.0	2.5	1.3	28.0
9	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.0	0.0	3.8	9.2	50.0
10	0.0	8.9	0.0	0.0	0.0	0.0	8.3	17.8	0.0	16.5	0.0	3.9
11	0.0	1.3	3.8	0.0	0.0	0.0	1.3	7.6	0.0	1.3	18.3	13.2
12	0.0	0.0	13.3	0.0	0.0	2.5	0.0	0.0	10.8	22.2	0.0	0.0
13	0.0	0.0	13.3	0.0	0.0	0.0	12.1	0.0	0.0	19.4	0.0	0.0
14	0.0	22.2	3.8	0.0	0.0	0.0	6.4	0.0	0.0	5.7	3.8	0.0
15	0.0	0.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.0
16	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.5	8.9	0.0	0.0	0.0
17	0.0	47.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.9
18	7.0	7.6	0.0	0.0	7.6	0.0	0.0	0.0	0.0	0.0	0.0	2.9
19	9.5	0.0	37.5	0.0	0.6	0.0	0.0	0.0	3.8	0.0	0.0	0.0
20	0.0	0.0	0.0	6.4	1.3	0.0	0.0	25.4	0.0	0.0	12.4	0.0
21	0.0	0.0	0.0	4.4	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0
22	0.0	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23	0.0	0.0	0.0	0.0	19.7	0.0	0.0	0.0	3.2	0.0	10.9	7.6
24	0.0	5.1	0.0	0.0	20.3	0.0	0.0	0.0	0.0	7.9	13.0	1.3
25	14.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	43.2	5.6	0.0
26	0.6	0.0	0.0	0.0	8.9	0.0	0.0	43.2	0.0	0.0	10.9	0.0
27	0.0	2.5	0.0	0.0	1.3	3.2	1.3	20.3	0.0	0.0	0.0	0.0
28	0.0	0.0	0.0	11.4	14.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29	0.0		0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0
30	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
31	0.0		0.0		0.0		7.6	1.3		0.0		0.0
TOTAL	31.1	103.5	71.7	51.4	76.8	26.0	68.0	124.5	64.8	122.6	108.6	129.7

GRAND TOTAL 978.7 mm

ETF RAINFALL (mm) 1987

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	2.8	0.0	0.8	0.0	0.0	0.0						
2	0.0	9.9	0.0	6.5	0.0	0.0						
3	0.0	0.0	0.0	15.1	18.4	1.3						
4	0.0	0.0	0.0	0.0	4.2	0.0						
5	0.0	0.0	0.0	0.0	0.0	0.0						
6	0.0	0.0	0.0	0.0	0.0	0.0						
7	0.0	0.0	0.0	0.0	0.0	0.0						
8	0.0	0.0	2.6	0.0	0.0	0.0						
9	3.1	0.0	9.7	0.0	0.0	0.0						
10	2.0	0.0	0.0	0.0	0.0	0.0						
11	0.0	0.0	4.8	5.3	0.0	0.0						
12	0.0	0.0	0.6	3.1	0.8	8.9						
13	0.0	0.0	0.0	0.0	0.0	1.3						
14	4.3	4.8	0.0	8.0	0.0	0.0						
15	2.5	3.2	0.0	21.1	0.0	0.6						
16	0.0	20.1	2.8	9.4	2.8	0.0						
17	3.6	3.8	0.0	0.9	23.1	3.2						
18	52.2	1.3	17.6	0.0	0.0	5.1						
19	17.2	0.0	9.9	0.0	0.0	3.2						
20	0.0	3.1	0.0	0.0	3.3	2.5						
21	0.0	0.8	0.0	0.0	9.5	13.3						
22	11.2	20.6	0.0	0.0	0.0	40.6						
23	0.0	0.0	0.0	0.0	0.0	0.6						
24	0.5	0.0	7.4	3.6	1.3	0.0						
25	22.5	0.0	0.8	0.0	3.3	0.0						
26	0.0	12.0	0.0	0.0	0.0	0.6						
27	2.3	27.9	2.8	0.8	0.0	0.0						
28	0.0	21.1	0.0	0.0	0.0	0.0						
29	0.0		0.0	0.0	19.7	0.0						
30	0.0		15.8	1.5	14.7	0.0						
31	0.8		0.0		0.0							
TOTAL	124.9	128.4	75.4	75.2	101.1	81.2						

GRAND TOTAL 586.1 mm

49 TRENCH RAINFALL (mm) 1986

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1				0.0	0.0	2.5	5.1	0.0	8.9	0.0	0.0	4.6
2				0.0	0.0	0.0	26.7	0.0	25.4	0.0	0.0	8.1
3				0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4			0.0	0.0	0.0	0.0	0.0	0.0	1.9	0.0	4.1	0.0
5			0.0	0.0	0.0	12.7	0.0	0.0	0.0	0.0	0.8	0.1
6			1.3	8.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7			0.0	0.0	0.0	0.0	0.0	3.5	0.0	0.0	14.2	0.0
8			0.0	16.9	0.0	0.0	0.0	0.0	0.0	0.0	1.0	28.6
9			0.0	0.0	0.0	7.6	0.0	0.0	0.0	3.2	9.2	43.2
10			0.0	0.0	0.0	0.0	8.9	7.3	0.0	19.4	0.0	4.0
11			2.9	0.0	0.0	0.6	1.9	13.3	0.0	0.0	19.8	11.4
12			14.0	0.0	0.0	1.3	0.0	1.9	10.8	22.5	0.0	0.5
13			12.7	0.0	0.0	0.0	13.3	0.0	0.0	18.7	0.0	0.0
14			3.2	0.0	0.0	0.0	7.6	0.0	0.0	6.4	3.8	0.0
15			0.6	1.3	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0
16			0.0	0.0	0.0	0.0	0.0	1.3	7.6	0.0	0.0	0.0
17			0.0	0.0	0.0	0.0	0.0	0.4	0.0	0.0	0.0	10.0
18			0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	0.0	1.4
19			34.3	0.0	0.6	0.0	0.0	0.0	2.9	0.0	0.0	0.0
20			0.0	6.4	1.6	0.0	0.0	26.7	0.0	0.0	12.0	0.0
21			0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22			0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0
23			0.0	0.0	19.1	0.0	0.0	0.0		0.0	11.2	7.9
24			0.0	0.0	17.2	0.0	0.0	0.0	0.0	8.9	12.9	0.5
25			0.0	0.0	3.8	0.0	0.0	0.0	0.0	42.9	5.3	0.0
26			0.0	0.0	8.3	0.0	0.0	40.6	0.0	0.0	10.9	0.0
27			0.0	0.0	1.9	1.9	1.3	19.1	0.0	0.0	0.0	0.0
28			0.0	11.3	12.6	0.6	0.0	11.4	0.0	0.0	0.0	0.0
29			0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0
30			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
31			0.0		0.0		6.4	2.5		0.0		0.0
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TOTAL			68.9	49.5	73.2	27.3	71.1	128.1	58.8	121.9	108.7	120.4

GRAND TOTAL 827.9 mm

49 TRENCH RAINFALL (mm) 1987

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	3.0	0.0	0.3	0.0	0.0	0.0						
2	0.0	9.9	0.0	6.1	0.0	0.0						
3	0.0	0.0	0.0	13.2	17.0	0.6						
4	0.0	0.0	0.0	0.0	5.1	0.0						
5	0.0	0.0	0.0	0.0	0.0	0.0						
6	0.0	0.0	0.0	0.0	0.0	0.0						
7	0.0	0.0	0.0	0.0	0.0	0.0						
8	0.0	0.0	2.2	0.0	0.0	0.0						
9	3.1	0.0	9.2	0.0	0.0	0.0						
10	1.9	0.0	0.0	0.0	0.0	0.0						
11	0.0	0.0	4.1	5.1	0.0	0.0						
12	0.0	0.0	1.0	3.0	0.4	8.9						
13	0.0	0.0	0.0	0.0	0.0	1.3						
14	4.6	4.6	0.0	7.6	0.0	0.0						
15	1.7	3.2	0.0	19.7	0.0	0.6						
16	0.0	21.2	3.4	8.6	1.8	0.6						
17	3.7	2.5	0.0	0.5	23.6	2.5						
18	51.8	2.6	16.3	0.0	0.0	5.7						
19	15.6	0.0	12.2	0.0	0.0	3.8						
20	0.0	3.1	0.0	0.0	3.1	2.5						
21	0.0	0.9	0.0	0.0	9.7	12.9						
22	10.9	20.9	0.0	0.0	0.0	41.3						
23	0.0	0.0	0.0	0.0	0.0	0.6						
24	0.5	0.0	7.4	3.3	1.5	0.0						
25	21.8	0.0	0.8	0.0	5.6	0.0						
26	0.0	13.4	0.0	0.0	0.0	1.3						
27	2.0	25.2	2.8	0.6	0.0	0.0						
28	0.0	21.3	0.0	0.0	0.0	0.0						
29	0.0		0.0	0.0	21.6	0.0						
30	0.0		15.8	1.3	14.0	0.0						
31	0.0		0.0		0.0							
TOTAL	120.7	128.8	75.2	69.1	103.2	82.6						

GRAND TOTAL 579.6 mm

Table 2.1 Annual Summary of Trench and Auger Hole Construction by Type

	Trench Type						Auger Hole Type		
Year	High Level	Low Level	Biol.	Asbestos	Baled Waste	Fissile	High Level	Solvent	Fissile
1972	1	3	2	0	0	0	0	0	19
1973	5	7	9	0	0	1	12	2	9
1974	4	18	16	0	0	2	37	4	3
1975	7	18	16	0	0	1	29	7	12
1976	8	17	16	1	0	0	28	8	3
1977	1	14	19	0	0	0	24	7	16
1978	4	15	21	1	0	0	14	5	5
1979	4	18	20	4	0	0	26	0	6
1980	2	11	17	4	0	0	42	3	4
1981	2	7	13	2	0	0	33	0	2
1982	2	7	13	3	12[1]	0	34	0	9
1983	2	15	10	7	1	0	42	1	5
1984	1	18	13	7	1	0	49	0	7
1985	3	11	8	5	1	0	44	0	0
1986	12	19	4	1	1	0	31	0	0
TOTALS	58	198	197	35	16	4	445	37	100
	TOTAL TRENCHES = 508						TOTAL AUGER HOLES = 582		

[1] Total includes 9 small (approximate 3 m by 3 m by 3 m) baled waste trenches located at the SWSA 6 Engineered Test Facility.

Table 2.2 Summary of Estimated Total Activities in SWSA 6 by Disposal Unit

Disposal Unit	Total Activity from May 1986 Data Search (Ci)	Total Activity from May 1986 Data Search Decayed to 1-1-87 (Ci)	Total Activity from Jan. 1987 Data Search (Ci)
Trenches	17,404	13,426	25,537
High Level and Solvent Auger Holes	202,148	138,577	210,588
Fissile Auger Holes	5.5	5.2	788
Totals	219,557.5	152,008.2	236,913

Table 3.1 Monthly Precipitation Totals from the ETF and 49 Trench Area Rain Gauges in SWSA 6 Compared to the Oak Ridge Area Mean Precipitation

MONTH	ETF GAUGE (mm)	49 TRENCH GAUGE (mm)	AVERAGE (mm)	OAK RIDGE MEAN (mm)	DIFFERENCE (mm)
1980					
AUG	32.5		32.5	96.3	-63.8
SEP	68.7		68.7	92.2	-23.5
OCT	46.3		46.3	74.9	-28.6
NOV	101.6		101.6	116.1	-14.5
DEC	43.5		43.5	141.0	-97.5
	----		----	----	----
TOTAL	292.6		292.6	520.5	-227.9
1981					
JAN	22.1		22.1	137.4	-115.3
FEB	119.3		119.3	120.6	-1.3
MAR	73.4		73.4	153.9	-80.5
APR	93.7		93.7	109.0	-15.3
MAY	108.5		108.5	106.4	2.1
JUN	122.3		122.3	105.2	17.1
JUL	74.0		74.0	135.1	-61.1
AUG	75.5		75.5	96.3	-20.8
SEP	71.0		71.0	92.2	-21.2
OCT	93.5		93.5	74.9	18.6
NOV	79.2		79.2	116.1	-36.9
DEC	102.4		102.4	141.0	-38.6
	----		----	----	----
TOTAL	1034.9		1034.9	1388.1	-353.2
1982					
JAN	162.8		162.8	137.4	25.4
FEB	130.9		130.9	120.6	10.3
MAR	162.6		162.6	153.9	8.7
APR	64.4		64.4	109.0	-44.6
MAY	60.7		60.7	106.4	-45.7
JUN	70.4		70.4	105.2	-34.8
JUL	138.0		138.0	135.1	2.9
AUG	92.4		92.4	96.3	-3.9
SEP	63.6		63.6	92.2	-28.6
OCT	61.4		61.4	74.9	-13.5
NOV	150.8		150.8	116.1	34.7
DEC	177.3		177.3	141.0	36.3
	----		----	----	----
TOTAL	1335.3		1335.3	1388.1	-52.8

Table 3.1 Continued

MONTH	ETF GAUGE (mm)	49 TRENCH GAUGE (mm)	AVERAGE (mm)	OAK RIDGE MEAN (mm)	DIFFERENCE (mm)
1983					
JAN	39.3		39.3	137.4	-98.1
FEB	103.3		103.3	120.6	-17.3
MAR	54.1		54.1	153.9	-99.8
APR	114.3		114.3	109.0	5.3
MAY	132.1		132.1	106.4	25.7
JUN	53.9		53.9	105.2	-51.3
JUL	48.0		48.0	135.1	-87.1
AUG	29.2		29.2	96.3	-67.1
SEP	44.8		44.8	92.2	-47.4
OCT	116.4		116.4	74.9	41.5
NOV	137.3		137.3	116.1	21.2
DEC	184.8		184.8	141.0	43.8
	----		----	----	----
TOTAL	1057.5		1057.5	1388.1	-330.6
1984					
JAN	61.3		61.3	137.4	-76.1
FEB	92.2		92.2	120.6	-28.4
MAR	113.3		113.3	153.9	-40.6
APR	95.4		95.4	109.0	-13.6
MAY	272.1		272.1	106.4	165.7
JUN	91.8		91.8	105.2	-13.4
JUL	180.6		180.6	135.1	45.5
AUG	43.2		43.2	96.3	-53.1
SEP	20.3		20.3	92.2	-71.9
OCT	156.2		156.2	74.9	81.3
NOV	113.0		113.0	116.1	-3.1
DEC	52.7		52.7	141.0	-88.3
	----		----	----	----
TOTAL	1292.1		1292.1	1388.1	-96.0
1985					
JAN	56.5		56.5	137.4	-80.9
FEB	79.4		79.4	120.6	-41.2
MAR	36.8		36.8	153.9	-117.1
APR	43.2		43.2	109.0	-65.8
MAY	59.7		59.7	106.4	-46.7
JUN	132.7		132.7	105.2	27.5
JUL	100.9		100.9	135.1	-34.2
AUG	230.5		230.5	96.3	134.2
SEP	42.5		42.5	92.2	-49.7
OCT	75.6		75.6	74.9	0.7
NOV	101.6		101.6	116.1	-14.5
DEC	52.7		52.7	141.0	-88.3
	----		----	----	----
TOTAL	1012.0		1012.0	1388.1	-376.1

Table 3.1 Continued

MONTH	ETF GAUGE (mm)	49 TRENCH GAUGE (mm)	AVERAGE (mm)	OAK RIDGE MEAN (mm)	DIFFERENCE (mm)
1986					
JAN	31.1		31.1	137.4	-106.3
FEB	103.5		103.5	120.6	-17.1
MAR	71.7	68.9	70.3	153.9	-83.6
APR	51.4	49.5	50.5	109.0	-58.6
MAY	76.8	73.2	75.0	106.4	-31.4
JUN	26.0	27.3	26.7	105.2	-78.6
JUL	68.0	71.1	69.6	135.1	-65.6
AUG	124.5	128.1	126.3	96.3	30.0
SEP	64.8	58.8	61.8	92.2	-30.4
OCT	122.6	121.9	122.3	74.9	47.3
NOV	108.6	108.7	108.7	116.1	-7.4
DEC	129.7	120.4	125.1	141.0	-16.0
	----	----	----	----	----
TOTAL	978.7	827.9	970.6	1388.1	-417.5
1987					
JAN	124.9	120.7	122.8	137.4	-14.6
FEB	128.4	128.8	128.6	120.6	8.0
MAR	75.4	75.2	75.3	153.9	-78.6
APR	75.2	69.1	72.2	109.0	-36.8
MAY	101.1	103.2	102.2	106.4	-4.3
JUN	81.3	82.8	82.0	105.2	-23.2
	----	----	----	----	----
TOTAL	586.3	579.8	583.0	732.5	-149.5

Table 3.2 Construction Parameters for SWSA 6 Gauging Stations

Parameter	Station 1	Station 2	Station 3
Location	N16315 E25000	N16315 E24874	N16055 E23870
Construction Date	November 1984	November 1984	November 1984
Weir Type	Combination[a]	Combination	Combination
Flow Range (L/s)	0.002 - 30.5	0.002 - 30.5	0.002 - 30.5
Top of Stilling Well Elevation (M MSL)	230.07	229.65	229.31
Measuring Point Elevation (M MSL)	229.49	229.22	229.08
Contributing Area (ha)	3.66	4.14	13.46
Percentage of SWSA 6	13.3	15.1	49.1

[a] Combination V-notch and rectangular weir.

Table 3.3 Daily Stream Flows for the Month of May 1987, for SWSA 6 Station 3

Day of the Month	Total Volume (m^3)	Daily Average (L/s)	Maximum Flow (L/s)	Minimum Flow (L/s)	Daily Rainfall (mm)
1	17.4	0.201	0.201	0.201	0
2	14.5	0.168	0.201	0.124	0
3	63.9	0.740	23.046	0.124	18
4	209.7	2.427	17.086	0.529	5
5	32.6	0.377	0.529	0.201	0
6	20.7	0.240	0.344	0.201	0
7	15.9	0.184	0.201	0.124	0
8	10.7	0.124	0.124	0.124	0
9	9.7	0.113	0.124	0.089	0
10	8.8	0.102	0.124	0.060	0
11	8.0	0.093	0.124	0.038	0
12	7.8	0.090	0.344	0.038	1
13	6.2	0.072	0.124	0.038	0
14	5.6	0.065	0.089	0.021	0
15	5.6	0.065	0.124	0.021	0
16	10.7	0.124	0.124	0.124	2
17[1]	150.1	1.737	19.991	0.124	23
18	49.6	0.574	1.274	0.201	0
19	15.0	0.174	0.201	0.089	0
20	13.4	0.155	0.201	0.124	3
21	42.3	0.490	1.897	0.124	10
22	39.2	0.454	0.998	0.201	0
23	14.1	0.163	0.201	0.124	0
24	10.4	0.120	0.344	0.089	1
25	10.7	0.124	0.529	0.060	4
26	8.5	0.098	0.201	0.060	0
27	6.9	0.080	0.749	0.038	0
28	27.4	0.317	2.603	0.021	0
29	124.6	1.442	25.431	0.021	21
30[1]	256.9	2.973	28.731	0.201	14
31	124.8	1.444	4.681	0.749	0
	1,342.0				102

[1] Flows were out of range on 5/17/87 from 17:00 to 17:15 and on 5/30/87 from 19:45 to 20:00.

Notes:

1. The drainage area for this station is 13.46 hectares.
2. The total volume of precipitation which fell this month on the watershed was 13729 cubic meters.
3. The average monthly flow is 0.501 L/s.

Table 3.4 Average Monthly Stream Flows for SWSA 6 Station 1

Month	Year	Average Monthly (L/s)	Maximum Flow (L/s)	Minimum Flow (L/s)
June	85[1]	0.134	29.068	0.000
July	85[1]	0.060	17.369	0.000
August[2]	85[1]	0.307	26.571	0.000
September	85	0.028	0.102	0.000
October	85	0.094	4.410	0.006
November	85	0.297	25.755	0.000
December	85	0.125	2.753	0.046
January	86	0.152	1.391	0.102
February	86[1]	1.720	29.917	0.071
March	86	0.324	16.663	0.071
April	86	0.121	3.142	0.014
May	86	0.045	2.383	0.000
June	86	0.009	0.102	0.000
July	86	0.000	0.000	0.000
August	86	0.012	3.971	0.000
September	86	0.044	5.335	0.000
October	86	0.135	9.585	0.000
November	86	0.285	10.173	0.046
December	86	0.514	27.395	0.046
January	87[1]	0.524	28.227	0.027
February	87	0.523	13.284	0.046
March	87	0.153	12.640	0.046
April	87[1]	0.146	29.068	0.027
May	87	0.037	9.585	0.000
June	87	0.052	17.369	0.000

[1] There were measured heads during the month that were out of range.

[2] Stage height recorder was down during this month due to mechanical failure.

Table 3.5 Average Monthly Stream Flows for SWSA 6 Station 2

Month	Year	Average Monthly (L/s)	Maximum Flow (L/s)	Minimum Flow (L/s)
June	85	0.232	29.492	0.020
July	85[1]	0.215	23.753	0.000
August[2]	85[1]	0.411	26.162	0.000
September	85	0.094	1.543	0.009
October	85	0.146	7.091	0.020
November	85[1]	0.413	29.492	0.000
December	85	0.246	3.343	0.085
January	86	0.148	0.972	0.085
February	86[1]	3.291	30.345	0.085
March	86[1]	0.382	26.162	0.057
April	86	0.225	12.322	0.020
May[2]	86	0.038	0.085	0.003
June[2]	86	0.005	0.328	0.000
July	86	0.001	0.120	0.000
August	86[1]	0.041	18.447	0.000
September	86	0.059	10.472	0.000
October	86	0.195	11.694	0.000
November	36	0.361	19.177	0.036
December	86[1]	0.780	29.492	0.120
January[2]	87	0.079	0.120	0.057
February[2]	87[1]	0.897	30.345	0.085
March	87[1]	0.708	19.177	0.190
April	87[1]	1.039	23.753	0.120
May	87	0.088	14.271	0.009
June[2]	87[1]	0.103	15.623	0.003

[1] There were measured heads during the month that were out of range.

[2] Stage height recorder was down during this month due to mechanical failure.

Table 3.6 Average Monthly Stream Flows for SWSA 6 Station 3

Month	Year	Average Monthly (L/s)	Maximum Flow (L/s)	Minimum Flow (L/s)
June	85[1]	0.489	29.577	0.010
July	85[1]	0.394	29.577	0.000
August[2]	85[1]	2.303	29.577	0.010
September	85	0.182	7.144	0.000
October	85	0.733	17.798	0.089
November	85[1]	1.446	29.577	0.201
December	85	0.964	10.532	0.201
January	86	0.866	9.937	0.201
February	86[1]	2.774	30.430	0.529
March	86[1]	1.740	29.577	0.344
April	86[1]	0.850	28.731	0.124
May	86	0.343	23.046	0.000
June	86	0.050	4.233	0.000
July	86	0.002	0.201	0.000
August	86[1]	0.174	26.243	0.000
September	86	0.356	25.431	0.001
October	86[1]	1.148	30.430	0.000
November	86[1]	2.071	30.430	0.201
December	86[1]	3.164	30.430	0.529
January	87[1]	2.646	30.430	0.344
February	87[1]	3.466	30.430	0.529
March	87[1]	1.948	29.577	0.529
April	87[1]	1.665	30.430	0.201
May	87[1]	0.501	28.731	0.021
June	87[1]	0.277	30.430	0.004

[1] There were measured heads during the month that were out of range.

[2] Stage height recorder was down during this month due to mechanical failure.

Table 3.7 Summary of SWSA 6 Piezometer Well Construction Characteristics

WELL NUMBER	ORNLN	ORNLE	TOP OF CASING ELEVATION (M)	WELL DEPTH (M)	GROUND ELEVATION (M)
ETF-13	16872	23596	247.57	77.36	246.63
ETF-14	16849	23618	245.99	29.46	245.36
ETF-15	16841	23603	246.05	14.76	245.54
TR-2	15872	24541	233.47	5.96	233.05
107	17041	24402	247.23	37.18	247.23
108	17279	24584	252.33	38.40	252.33
109	17330	24499	249.82	38.40	249.82
110	17204	24684	251.55	38.10	251.55
272	16221	23520	234.90	2.94	234.54
274	16210	23347	240.12	5.93	239.87
276	16211	23895	231.43	1.95	231.19
277	16207	24182	236.00	6.61	235.74
278	16552	24223	236.83	4.48	236.28
279	16696	24205	238.14	3.72	237.52
284	16750	23983	240.26	5.92	239.46
295	16703	23992	239.16	5.18	238.62
317	16766	24328	242.23	4.20	241.49
318	17225	24323	243.85	3.61	243.63
343	16763	25010	240.72	6.07	240.45
345	16361	24881	230.80	3.50	230.60
351	16028	24661	237.37	6.90	237.01
356	16481	24451	235.52	5.11	235.30
358	16090	24448	242.42	5.93	242.02
362	16588	23718	237.21	3.20	236.37
363	16420	23748	233.64	1.47	232.85
365	16454	23681	234.64	2.27	233.99
367	17723	25091	257.30	21.25	248.31
369	17476	24805	256.32	13.98	255.48
370	17154	24981	247.09	11.43	245.95
371	16393	25090	234.11	9.85	233.28
373	16945	25208	239.41	10.75	238.97
374	17462	25346	238.80	10.12	238.12
375	16935	23531	248.77	8.74	247.98
376	16584	23497	246.72	11.47	245.80
377	16610	23297	255.96	17.93	255.05
378	16474	23092	257.57	19.26	256.67
379	16156	23206	241.66	11.24	241.43
380	15977	23320	236.15	10.19	235.46
381	16248	24266	237.76	11.47	237.00
382	15815	24025	233.37	7.22	232.65
383	16165	24895	235.14	10.49	234.50
385	17903	24669	257.18	15.24	256.41
386	16892	24828	238.35	3.24	237.49
388	17111	24886	241.48	4.49	240.36
389	16798	24203	240.34	4.55	239.68
390	16842	24200	240.86	4.60	239.89
391	16900	24192	240.98	2.99	240.98

Table 3.7 Continued

WELL NUMBER	ORNLN	ORNLE	TOP OF CASING ELEVATION (m)	WELL DEPTH (m)	GROUND ELEVATION (m)
636	17668.03	24326.18	254.41	16.95	253.90
637	17715.14	24135.97	262.60	21.21	261.94
638	17495.05	24119.35	259.03	22.23	258.57
639	17395.38	24138.11	255.26	20.11	254.77
640	17614.70	24719.55	254.74	18.47	254.75
641	17383.49	23985.24	257.78	18.73	257.17
642	16580.96	24035.55	236.81	8.71	236.83
644	16748.86	24848.36	236.58	4.54	236.60
645	17173.65	25274.60	233.56	6.55	233.09
646	17550.78	25167.05	239.84	12.45	239.31
649	17375.49	25075.50	250.35	10.82	250.37
651	16870.85	25190.67	243.38	34.41	242.71
652	16159.68	24900.00	234.61	26.86	234.73
653	15792.51	24070.40	233.66	18.95	232.72
654	16618.16	24054.76	236.23	28.02	236.25
655	17469.72	24815.30	255.91	32.84	255.50
656	17923.92	24692.96	258.39	36.94	258.33

Table 3.8 Water Table Elevation Data for SWSA 6 Piezometers

WELL NUMBER	ELEV. 12-3-85 METERS	ELEV. 3-10-86 METERS	ELEV. 5-27-86 METERS	ELEV. 7-8-86 METERS	ELEV. 8-21-86 METERS	ELEV. 9-22-86 METERS
ETF-13	239.53	239.67	239.57	239.32	238.97	239.07
ETF-14	241.15	241.26	241.11	240.91	240.60	240.74
ETF-15	241.04	240.13		240.78	240.62	240.60
TR-2	228.33	227.51	233.47	233.47	227.51	227.51
107	239.66	239.82	240.31	240.26	239.27	239.27
108	242.74	242.72	242.56	242.35	242.18	242.30
109	242.48	242.36	242.24	242.00	241.77	249.82
110	242.48	242.36	242.24	242.00	241.77	249.82
272	233.32	232.98	232.91	231.98	231.96	232.05
274	234.34	234.39	234.19	234.19	234.19	234.19
276	230.95	229.12	229.21	231.43	230.09	230.33
277	231.61	230.42	236.00	236.00	236.00	236.00
278	234.65	233.91	233.95	233.16	233.08	233.51
279	236.44	235.55	235.43	235.14	234.32	235.21
284	236.48	235.84	235.54	235.22	235.05	235.35
295	236.38	235.76	235.65	235.21	235.04	235.31
317	239.09	238.22	238.03	238.03	238.03	238.03
318	240.48	240.24	240.24	240.24	240.24	240.24
343	235.49	234.65	240.72	240.72	240.72	240.72
345	229.58	229.42	229.36	228.95	228.77	229.04
351	231.32	230.47	230.47	230.47	230.47	230.47
356	232.63	231.62	231.99	231.38	231.72	231.59
358	236.49	236.49	236.49	236.49	236.49	236.49
362	234.75	234.77	234.01	234.01	234.63	234.68
363	232.63	232.58	232.67	232.17	232.17	232.30
365	233.45	233.29	233.51	232.37	232.83	233.05
367	240.93	241.32	240.87	240.66	240.55	240.30
369	245.53	245.57	245.20	244.92	244.95	244.82
370	239.58	239.72	239.76	239.04	238.97	239.04
371	227.81	227.51	227.36	227.25	228.99	227.31
373	231.34	232.61	231.53	231.01	230.79	230.53
374	232.93	232.77	232.12	231.86	231.79	231.77
375	241.69	241.84	241.55	241.42	241.23	241.22
376	238.84	238.85	239.00	238.84	238.66	238.69
377	241.26	241.11	241.27	241.16	240.98	240.96
378	238.46	238.67	239.14	238.78	238.39	238.31
379	233.06	234.05	233.40	232.91	232.41	232.21
380	231.60	231.88	230.88	230.31	229.95	229.94
381	231.95	230.84	230.76	229.76	229.88	230.12
382	228.05	228.38	227.37	227.28	227.24	227.26
383	227.55	227.24	227.22	227.04	227.79	227.14
385	248.22	248.74	247.24	246.95	246.69	247.19
386	236.88	236.73	236.43	235.90	235.66	236.04
388	240.01	239.79	239.77	239.28	238.74	239.37
389	236.90	235.79	235.79	235.79	236.49	235.79
390	238.28	237.37	237.69	236.88	237.53	236.46
391	238.89	237.99	238.26	237.99	238.14	237.99

Table 3.8 Continued

WELL NUMBER	ELEV. 12-3-85 METERS	ELEV. 3-10-86 METERS	ELEV. 5-27-86 METERS	ELEV. 7-8-86 METERS	ELEV. 8-21-86 METERS	ELEV. 9-22-86 METERS
636			243.94	243.63	243.54	243.92
637			245.40	245.13	244.97	244.93
638			244.41	244.10	243.59	243.94
639						
640						244.29
641			249.36	252.06	245.02	248.96
642						234.15
644						234.14
645						230.97
646						234.72
649						241.87
651						235.21
652						228.09
653						227.41
654						234.82
655						242.99
656						245.50

Table 3.8 Continued

WELL NUMBER	ELEV. 11-3-86 METERS	ELEV. 12-3-86 METERS	ELEV. 1-8-87 METERS	ELEV. 2-4-87 METERS	ELEV. 3-4-87 METERS	ELEV. 4-6-87 METERS
ETF-13	238.93	239.06	239.24	239.48	239.65	239.80
ETF-14	240.64	240.86	241.00	241.22	241.44	241.59
ETF-15	240.54	240.75	240.94	241.07	241.22	241.34
TR-2	233.47	233.47	233.47	233.47	233.47	233.47
107	239.39	239.76	239.97	240.08	240.10	240.01
108	242.32	242.64	242.69	242.98	243.21	243.20
109	242.01	242.36	242.37	242.65	242.85	242.89
110	242.01	242.36	242.37	242.65	242.85	242.89
272	232.60	233.37	232.85	233.33	233.47	233.56
274	234.19	234.30	234.19	234.45	235.08	235.63
276	230.74	231.23	230.83	231.18	231.09	231.23
277	236.00	236.00	236.00	236.00	236.00	236.00
278	234.07	234.98	234.08	234.86	235.22	234.80
279	235.40	236.06	235.44	236.20	236.08	236.60
284	235.54	236.08	235.71	236.15	236.54	236.74
295	235.58	236.13	235.66	236.08	236.33	236.35
317	238.03	238.65	238.05	238.82	239.15	238.98
318	240.24	240.31	240.24	240.29	240.44	240.40
343	240.72	240.72	240.72	240.72	240.72	240.72
345	229.46	229.61	229.44	229.47	229.46	229.55
351	230.47	231.15	230.47	230.92	232.18	231.05
356	232.04	232.69	231.78	232.44	232.48	232.54
358	236.49	236.49	236.49	236.49	236.49	236.49
362	234.69	234.77	234.67	234.72	234.68	234.71
363	232.49	232.54	232.49	232.51	232.54	232.62
365	233.19	233.48	233.29	233.39	233.39	233.51
367	240.35	241.12	241.08	241.65	242.05	241.52
369	245.10	245.48	242.34	245.86	246.25	245.90
370	239.06	239.47	239.75	240.02	240.21	240.09
371	227.48	227.64	227.45	227.62	227.62	227.74
373	230.61	231.31	232.98	233.33	233.60	233.44
374	231.81	232.15	232.45	233.23	233.84	233.39
375	241.17	241.45	241.59	241.81	242.06	242.22
376	238.47	238.46	238.70	238.92	239.18	239.48
377	240.77	240.71	240.72	240.81	241.06	241.34
378	238.31	238.31	238.31	238.31	238.53	239.52
379	232.12	232.54	233.16	233.92	234.56	234.90
380	229.95	230.84	231.09	232.43	233.14	232.76
381	230.57	231.57	230.75	231.66	231.98	231.74
382	227.45	228.04	228.10	228.53	228.82	228.33
383	227.30	227.56	228.10	227.70	227.76	227.90
385	247.64	248.58	248.77	249.09	249.28	248.87
386	236.51	236.98	236.86	236.98	237.02	237.02
388	239.70	240.13	239.85	240.07	239.99	240.17
389	235.79	236.55	236.05	236.40	236.74	236.81
390	236.92	237.72	237.18	238.25	238.20	238.53
391	237.99	238.60	237.99	238.65	239.09	238.76

Table 3.8 Continued

WELL NUMBER	ELEV. 12-3-85 METERS	ELEV. 3-10-86 METERS	ELEV. 5-27-86 METERS	ELEV. 7-8-86 METERS	ELEV. 8-21-86 METERS	ELEV. 9-22-86 METERS
636	244.04	244.65	244.29	244.87	245.26	245.17
637	244.82	245.68	245.88	246.50	247.34	246.81
638	243.81	244.23	244.89	245.18	245.55	245.59
639						
640	244.29	244.99	245.38	245.58	245.80	245.47
641	248.74	249.29	249.74	250.40	251.02	250.92
642	234.53	235.13	235.09	235.28	235.41	235.16
644	234.65	235.25	234.99	235.23	235.38	235.19
645	230.96	231.12	231.20	231.33	231.40	231.41
646	234.94	235.60	235.71	236.03	236.08	236.04
649	241.99	242.24	242.03			
651	233.35	233.51	233.51	233.71	233.74	233.88
652	228.33	228.48	228.36	228.50	228.46	228.39
653	227.52	227.99	228.08	228.46	228.71	228.30
654	235.21	235.54	235.47	235.68	235.85	235.76
655	243.11	243.56	243.82	244.16	244.45	244.09
656	245.54	246.29	246.76	247.48	247.95	247.52

Table 3.8 Continued

WELL NUMBER	ELEV. 5-6-87 METERS	ELEV. 6-1-87 METERS	ELEV. 7-9-87 METERS	ELEV. 8-5-87 METERS
ETF-13	239.87	239.82	239.68	239.49
ETF-14	241.56	241.46	241.28	241.09
ETF-15	241.36	241.27	241.15	240.97
TR-2	233.47	233.47	233.47	233.47
107	239.98	239.91	239.83	239.75
108	242.93	242.80	242.66	242.48
109	242.54	242.45	242.31	242.09
110	242.54	242.45	242.31	242.09
272	233.06	232.94	232.90	232.01
274	235.12	234.64	234.19	234.19
276	230.76	230.65	230.58	230.06
277	236.00	236.00	236.00	236.00
278	233.90	233.98	234.16	233.14
279	235.46	235.46	235.43	235.07
284	235.77	235.63	235.51	235.17
295	235.69	235.62	235.52	235.13
317	238.03	238.23	238.03	238.03
318	240.24	240.24	240.24	240.24
343	240.72	240.72	240.72	240.72
345	229.40	229.32	229.17	228.78
351	230.47	230.47	230.47	230.47
356	231.65	231.74	232.02	231.38
358	236.49	236.49	236.49	236.49
362	234.71	234.75	234.71	234.55
363	232.52	232.52	232.47	232.17
365	233.31	233.32	233.26	232.72
367	240.55	240.12	239.59	242.81
369	245.63	245.48	245.27	245.06
370	239.95	239.70	239.47	239.27
371	227.58	227.40	227.35	227.24
373	233.22	232.75	231.96	231.51
374	232.70	232.25	232.09	231.91
375	242.21	242.06	241.83	241.63
376	239.57	239.45	239.22	239.06
377	241.57	241.71	241.72	241.63
378	240.06	240.17	239.88	239.52
379	234.81	234.19	233.57	233.17
380	231.87	231.20	230.79	230.39
381	230.66	230.43	230.45	229.80
382	227.92	227.56	227.37	227.21
383	227.48	227.27	227.25	227.12
385	248.46	247.75	247.27	247.04
386	236.80	236.63	236.57	235.96
388	239.82	239.72	239.72	239.05
389	235.79	235.94	235.79	235.79
390	237.71	237.94	237.35	236.42
391	238.38	238.73	237.99	237.99

Table 3.8 Continued

WELL NUMBER	ELEV. 5-6-87 METERS	ELEV. 6-1-87 METERS	ELEV. 7-9-87 METERS	ELEV. 8-5-87 METERS
636	244.64	244.61	244.49	243.93
637	247.33	245.83	246.15	245.32
638	245.62	244.97	244.57	244.35
639				
640	245.60	244.72	244.39	244.14
641	250.68	249.92	249.58	249.33
642	235.21	234.66	234.37	233.93
644	235.07	234.68	234.49	234.04
645	231.35	231.20	231.13	230.98
646	235.83	235.59	235.48	235.20
649	242.27	250.35	250.35	250.35
651	233.81	233.67	233.62	233.33
652	228.41	228.13	228.08	227.83
653	228.10	227.67	227.51	227.35
654	235.64	235.40	235.32	234.98
655	243.95	243.41	243.11	242.85
656	247.46	246.71	246.20	245.90

Table 3.9 Summary of SWSA 6 Water Balance for July 1986 to June 1987.

MONTH	YEAR	RAINFALL (mm)	RAINFALL (M^3)	STA 1 VOLUME (M^3)	STA 2 VOLUME (M^3)	STA 3 VOLUME (M^3)	TOTAL VOLUME (M^3)
JULY	1986	69.6	14796.96	0.0	1.7	4.5	6.2
AUGUST	1986	126.3	26851.38	31.9	108.8	465.8	606.5
SEPTEMBER	1986	61.8	13138.68	114.5	152.5	921.8	1188.8
OCTOBER	1986	122.3	26000.98	362.9	523.3	3074.9	3961.1
NOVEMBER	1986	108.7	23109.62	738.2	936.0	5367.0	7041.2
DECEMBER	1986	125.1	26596.26	1376.6	2089.2	8474.3	11940.1
JANUARY	1987	122.8	26107.28	1403.7	2130.0[1]	7088.1	10621.8
FEBRUARY	1987	128.6	27340.36	1264.8	1782.2	8384.7	11431.7
MARCH	1987	75.3	16008.78	409.0	576.0[1]	5217.4	6202.4
APRIL	1987	72.2	15349.72	379.5	534.0[1]	4315.3	5228.8
MAY	1987	102.2	21727.72	100.0	235.4	1342.0	1677.4
JUNE	1987	82.0	17433.20	135.9	267.8	718.4	1122.1
	TOTALS	1196.9	254460.90	6317.0	9336.9	45374.2	61028.1

TOTAL RAINFALL AS RUNOFF = 24%

[1] Estimate of total volume due to flow recorder failure during this month.

Table 4.1 Suggested Distribution Coefficients for SWSA 6 Modeling

Element	K_D (L/kg)	Comments
Cs	3,000	May be lower in unsaturated zone soils
Co	3,000	May be lower in unsaturated zone soils
Eu	3,000	May be lower at lower pH's
Sr	30	Value accommodates sorption site competition
U	40	Value accommodates sorption site competition; may be higher in unsaturated zone; may be higher at lower pH's

Table 5.1 Calcium Carbonate Equivalent (CCE) and pH for Two Nolichucky Cores in SWSA 6. HHMS-4B and HHMS-5A[1]

Core No.	Depth	pH	CCE	Soil Zones
HHMS-4B	0.6	5.1	0.1	soil solum
	1.2	4.8	0.6	
	1.8	5.1	0.1	
	2.4	5.3	0.07	
	3.0	5.1	0.0	oxidized and leached
	3.6	5.6	0.0	saprolite
	4.3	5.3	0.6	
	4.9	5.7	0.6	
	5.5	6.1	0.7	
	7.0	7.6	26.2	
	7.5	8.4	22.8	oxidized and unleached
	8.5	8.1	21.7	saprolite
	9.3	8.3	17.1	
	10.6	8.3	17.0	
	11.8	8.2	25.3	
	12.4	8.1	27.7	
	unoxidized and unleached rock			
HHMS-5A	0.6	4.9	0.1	soil solum
	1.2	4.8	0.0	
	1.8	5.1	0.1	
	2.4	5.3	0.1	oxidized and leached
	3.0	5.7	0.6	saprolite
	3.6	6.2	0.1	
	7.3	7.7	31.3	
	7.9	8.2	22.5	
	8.5	7.6	13.9	oxidized and unleached
	9.7	7.9	25.8	saprolite
	11.5	8.3	20.7	
	12.2	8.0	25.9	
	unoxidized and unleached rock			

[1] From Ammons and Phillips, (1987).

Table 5.2 Physical Properties of Selected SWSA 6 Soils

Soil	Horizon	Depth (cm)	Sand	Silt	Clay	Rock Frag	USDA[1] Text	Moist. 1/3 (Bars)	Moist. 15 (Bars)	Moist. Reten.[2]	Bulk Den. (g/cc)	Total Por. (%)
			--Fine Earth--									
			--------%-------					-------%------				
MARYVILLE SOILS												
43	Ap	0-10	19	70	11	24	Sh. Sil	37	14	24	-	-
	Bw	10-55	33	40	27	71	Ex. Sh. L.	21	14	7	1.59	40
	Cr1	55-110	30	30	40	86	Ex. Sh. C.	19	15	4	1.91	28
	Cr2	110-145	59	20	21	78	Ex. Sh. SCl.	20	15	4	1.96	20
	Cr3	145-205	49	32	19	94	Ex. Sh. L.	18	12	6	-	-
42	Ap	0-10	26	71	3	9	Sil.	35	19	16	1.52	43
	Bw	18-25	25	51	24	9	Sil.	24	16	9	-	-
	C/Bt	84-105	21	20	59	57	V. Sh. C.	35	24	11	-	-
	C1	105-132	28	35	37	67	Ex. Sh. C.	43	24	19	1.45	45
	C2	132-150	24	30	46	67	Ex. Sh. C.	45	27	18	-	-
	Cr	175-260	44	28	28	79	Ex. Sh. CL.	30	16	14	1.34	50
	Fe Zone	201-213	32	32	36	59	V. Sh. CL.	38	22	16	-	-
40	Ap and E	0-27	8	85	7	10	Silt	24	12	12	1.42	45
	Bt1 and Bt2	27-70	10	47	43	15	Silty Clay	31	23	8	1.42	47
	Bt3 and CBT	70-110	34	27	39	25	Sh. CL.	33	23	10	-	-
	C1	110-170	5	36	59	47	V. Sh. C.	43	32	11	1.45	46
	C2	170-190	6	37	57	38	V. Sh. C.	48	33	15	-	-
	Cr1	190-230	29	36	35	86	Ex. Sh. C.	33	23	10	-	-
	Mn-Fe Zone	205-300	16	36	48	72	Ex. Sh. C.	55	32	23	-	-
	Cr2	230-310	43	29	28	94	Ex. Sh. C.	29	19	10	1.44	54
	Fe Zone	290-310	37	23	40	92	Ex. Sh. C.	34	20	14	-	-
	Cr3	310-366	19	42	39	44	V. Sh. C.	36	19	17	-	-
	Cr4	366-396	40	21	39	50	V. Sh. CL.	22	18	4	-	-
NOLICHUCKY SOILS												
50	Ap	0-14	11	56	33	13	Clay Loam	19	17	2	-	-
	Bt	14-23	18	37	45	16	Sh. Clay	21	19	4	-	-
	Btg	23-50	12	64	24	54	V. Sh. CL.	26	23	3	-	-
	Cr1	50-74	25	27	48	87	Ex. Sh. C.	24	21	3	-	-
	Cr2	74-84	20	30	50	76	Ex. Sh. C.	28	25	3	-	-
	Cr3	84-120	37	33	30	89	Ex. Sh. CL.	22	19	3	-	-
	Cr4	120-123	33	22	45	68	Ex. Sh. C.	37	27	10	-	-
	Cr5	123-150	46	27	27	91	Ex. Sh. SCL	24	17	7	-	-
OLD ALLUVIUM												
92	Ap and E	0-20	22	74	4	4	Silt Loam	19	13	6	1.35	49
	Bt1 and Bt2	20-53	23	49	28	2	Clay Loam	19	16	3	1.55	42
	2Bt3	53-80	23	47	30	17	Gr. CL.	19	11	8	1.36	49
	2Bt5	119-190	20	40	40	18	Gr. CL.	24	21	3	1.52	43
	Lower Alluvium		17	34	49	1	Clay	27	23	4	-	-
	Basal Gravel Zone		72	3	25	43	V. Gr. CL.	15	12	3	-	-
	Maryville Residuum		17	38	45	94	Ex. Sh. C.	24	21	3	-	-

[1] Ex. = Extremely >50% fragments. V. = Very 35 to 50% fragments. Sh. = Shaly

15 to 35% fragments. Gr. = Gravelly 15 to 35 % chert, sandstone and quartzite rounded and subrounded. SIL. = Silt Loam. L. = Loam. CL. = Clay Loam. SCL. = Sandy Clay Loam (An Artifact of the seiving process). C. = Clay.

[a] Retention between 1/3 and 15 bar tension of the fine earth fraction (< 2 mm).

Table 5.3 Engineering Properties of Selected SWSA 6 Soils

Soil	Horizon	Depth (cm)	Liquid Limit	Plastic Limit	Plasticity Index	Flow Index	Shrinkage Limit	% Coarser than 0.05mm	% Finer than 0.05mm	USC[1] Group
MARYVILLE SOILS										
43	Ap	0-10	50	32	28	14	24	39	61	MH
	BW	10-55	29	20	9	10	18	8	20	GC
	Cr1	55-110	-	-	-	-	-	90	10	GR-GC
	Cr2	110-145	-	-	-	-	-	91	9	Gp-GC
	Cr3	145-205	-	-	-	-	-	97	3	GP
42	Ap	0-10	43	30	13	7	23	34	66	ML
	Bw	18-25	27	20	7	10	18	32	68	CL
	C/Bt	84-105	49	25	24	14	17	66	34	GC
	C1	105-132	50	34	16	9	26	76	24	GP
	C2	132-150	-	-	-	-	-	75	25	GP
	Cr	175-260	-	-	-	-	-	88	12	GC
	Fe Zone	201-213	-	-	-	-	-	72	28	GC
40	Ap and E	0-27	22	16	6	1	15	18	82	CL-ML
	Bt1 and Bt2	27-70	-	-	-	-	-	23	77	CL-ML
	Bt3 and CBT	70-110	43	29	14	8	22	50	50	ML
	C1	110-170	-	-	-	-	-	50	50	ML
	C2	170-190	62	46	16	27	35	43	57	MH
	Cr1	190-230	-	-	-	-	-	90	10	GP-GC
	Cr2	230-310	-	-	-	-	-	97	3	GP
	Cr3	310-366	-	-	-	-	-	54	46	GP
	Cr4	366-396	-	-	-	-	-	70	30	GP
NOLICHUCKY SOILS										
50	Ap	0-14	36	23	13	8	19	22	78	CL
	Bt	14-23	46	23	23	9	16	31	69	CL
	Btg	23-50	-	-	-	-	-	51	49	GC
	Cr1	50-74	-	-	-	-	-	90	10	GP-GC
	Cr2	74-84	51	28	23	10	20	81	19	GC
	Cr3	84-120	-	-	-	-	-	93	7	GP-GC
	Cr4	120-123	-	-	-	-	-	78	22	GC
	Cr5	123-150	-	-	-	-	-	95	5	GP-GC
OLD ALLUVIUM										
92	Ap and E	0-20	27	16	11	4	14	25	75	CL
	Bt1 and Bt2	20-53	31	18	13	5	15	22	78	CL
	2Bt3	53-80	47	29	18	3	22	36	64	ML
	2Bt5	119-190	49	33	16	17	25	34	66	ML
	Lower Alluvium		-	-	-	-	-	17	83	ML
	Basal Gravel Zone		-	-	-	-	-	84	16	GC
	Maryville Residuum		-	-	-	-	-	95	5	GC

[1] Unified Soil Classification.

Note: A number 200 seive was not used to measure the 0.74 mm fraction so the break was made at the 0.5 mm break.

Table 5.4 Chemical Properties of Selected SWSA 6 Soils

Soil	Horiz.	Depth (cm)	% Total Carbon	Exchangeable Bases Ca	Mg	K	KCl Ext. Al	Titr. Acid. (KCl)	CEC	% Base Sat.	pH 1:1 H_2O	pH KCl	CDB[1] Fe	Mn Ele.	HA[2] Red. Mn
MARYVILLE SOILS															
43	Ap	0-10	4.3	23.2	1.0	0.7	0	0	25	100	6.6	5.7	826	400	297
	Bw	10-55	0.6	1.1	0.7	0.5	0	0	2	100	6.7	4.9	1612	627	49
	Cr1	55-110	0.2	1.0	2.4	0.6	1	2	6	66	4.8	3.5	1928	229	7
	Cr2	110-145	0.1	1.2	2.2	0.3	2	3	6	57	4.9	3.3	1642	908	150
	Cr3	145-205	0.1	0.6	0.9	0.3	1	0	3	100	5.0	3.4	1305	1534	95
42	Ap	0-10	4.1	9.1	0.6	1.3	0	0	11	100	6.4	5.8	765	918	40
	Bw	18-25	0.6	1.7	0.3	0.9	0	0	3	100	6.1	5.2	1550	752	4
	C/Bt	84-105	0.6	2.5	0.6	1.1	0	0	4	100	5.4	4.3	3626	207	2
	C1	105-132	0.2	1.0	0.9	0.9	11	9	12	25	4.6	3.5	3326	100	12
	C2	132-150	0.1	0.2	1.8	0.6	10	9	13	24	4.9	3.5	3886	1368	167
	Cr	175-260	0.1	0.1	0.9	0.3	8	7	9	18	5.0	3.5	2173	874	156
	Fe Zone	201-213	0.1	0.2	1.1	0.3	7	6	9	34	5.2	3.6	2723	161	48
40	Ap-E	0-27	0.7	0.6	0.1	0.2	2	2	3	37	4.8	3.8	1254	620	39
	Bt1-Bt2	27-70	0.3	4.7	0.6	0.3	7	6	12	49	5.1	3.6	2855	35	56
	Bt3-CBT	70-110	0.4	0.1	0.3	0.2	10	9	10	7	5.3	3.6	3580	114	13
	C1	110-170	0.1	0.1	0.3	0.2	11	12	13	5	5.5	3.5	5467	118	17
	C2	170-190	0.1	0.1	0.8	0.2	12	10	11	10	5.1	3.5	2315	126	211
	Cr1	190-230	0.1	0.1	0.8	0.2	11	8	9	9	4.8	3.5	3480	988	125
	Mn-Fe	205-300	0.1	0.1	0.2	0.2	8	7	8	14	5.2	3.6	3264	2834	609
	Cr2	230-310	0	0.1	1.2	0.2	10	8	9	16	4.8	3.5	1876	1820	209
	Fe Zone	290-310	0	0.1	1.3	0.2	9	8	10	16	5.3	3.7	2850	1950	116
	Cr3	310-366	0	0.1	1.6	0.3	9	8	10	21	5.1	3.5	1871	1628	182
	Cr4	366-396	0	0.2	2.1	0.3	7	6	8	32	4.9	3.5	1443	2215	324
NOLICHUCKY SOILS															
50	Ap	0-14	0.7	1.0	1.6	0.4	7	6	9	34	4.7	3.5	2807	592	47
	Bt	14-23	0.5	3.7	1.4	0.4	8	6	12	43	4.8	3.1	2652	1552	164
	Btg	23-50	0.4	2.9	1.5	0.5	10	9	14	36	4.8	3.5	2641	520	45
	Cr1	50-74	0.1	0.7	2.3	0.4	9	8	11	27	4.8	3.4	2244	932	62
	Cr2	74-84	0.1	0.6	2.3	0.2	9	8	11	27	5.0	3.4	4279	259	22
	Cr3	84-120	0.4	2.2	6.2	0.3	0	0.4	9	96	6.5	5.1	2538	103	208
	Cr4	120-123	0.7	44.0	7.9	0.1	0	0.4	53	99	7.0	6.2	2855	200	25
	Cr5	123-150	0.5	31.0	6.3	0.2	0	0	37	100	7.3	6.2	2296	165	224
OLD ALLUVIUM															
92	Ap-E	0-20	1.8	8.2	0.4	0.3	0	0.4	9	96	5.9	5.5	2683	13	29
	Bt1-Bt2	20-53	0.5	1.2	0.1	0.4	3	2	4	44	4.5	3.8	1948	11	6
	2Bt3	53-80	0.1	0	0.1	0.2	3	7	7	5	5.0	3.7	2203	182	0
	2Bt5	119-190	0.1	0	0.1	0.2	8	7	7	5	4.9	3.5	2683	11	0
	Lower Alluvium		0.2	0.1	0.4	0.3	7	5	6	15	4.9	3.5	4029	52	1
	Basal Gravel Zone		0.1	0.2	0.2	0.4	5	5	5	13	4.7	3.5	2126	155	1
	Maryville Residuum		0	0.1	0.3	0.4	14	12	13	6	4.6	3.5	3723	81	1

Source: Ammons and Phillips (1987). Due to rounding, and exchangeable sodium values, totals might not agree.

[1] Citrate-Dithionite-Bicarbonate Extraction Method
[2] Hydroxylamine Reducible Manganese

Table 5.5 Sorption Ratio of Co, Sr, Cs, Tc, and U on Selected SWSA 6 Soils

Soil	Horizon	Depth	pH[1]	pH[2]	Co	Sr	Cs	Tc	U
Maryville Soils									
43	A	0-10	6.6	6.6	>10000	80	9340	0.20	5346
	Cr	145-205	5.0	5.5	3443	1217	>10000	0	798
42	A	0-10	6.4	5.9	>10000	95	>10000	0.58	4115
	C/Bt	84-105	5.4	4.7	4321	4106	>10000	0.15	2161
	C	132-150	4.9	5.1	1219	323	>10000	0.02	2723
	Cr	201-213	5.2	7.6	>10000	160	>10000	0.12	229
40	A and E	0-27	4.8	4.1	1202	1085	>10000	0.12	2850
	Bt	28-70	5.1	4.2	85	51	6257	0.33	1259
	Cr1	190-230	4.8	4.3	3678	267	>10000	0	2545
	Cr2	290-310	5.3	4.1	512	450	>10000	0.18	1656
Nolichucky Soil									
50	Ap	0-14	4.7	4.2	474	421	>10000	0	948
	Btg	22-50	4.8	6.5	>10000	41	3725	0.22	1265
	Cr1	50-74	4.8	4.4	954	525	>10000	0.07	948
	Cr2	123-150	7.3	4.2	1226	1111	>10000	0	1962
Old Alluvium									
92	Ap and E	0-20	5.9	4.0	112	96	>10000	0.17	1457
	Bt1	20-53	4.5	4.2	2703	2654	>10000	0.13	1725
	2Bt2	53-80	5.0	3.9	346	352	>10000	1.34	2149
	2Bt5	119-190	4.9	4.0	56	46	1978	0.18	1659
Lower Alluvium			4.9	4.0	355	321	>10000	0.47	3972
Basal Pebble Zone			4.7	4.1	219	149	>10000	0.19	3431
Maryville Residuum			4.6	3.9	781	772	>10000	0	1625

[1] 1:1 H_2O pH.

[2] Equilibrium pH.

Table 5.6 Hydroxylamine Reducible Manganese and pH for Two Nolichucky Cores in SWSA 6. HHMS-4B and HHMS-5A

Core No.	Depth (m)	pH 1:1 H20	Mn ppm	Soil and Saprolite Zones
HHMS-4B	0.6	5.1	36	soil solum
	1.2	4.8	184	
	1.8	5.1	323	
	2.4	5.3	308	
	3.0	5.1	462	oxidized and leached
	3.6	5.6	509	saprolite
	4.3	5.3	390	
	4.9	5.7	512	
	5.5	6.1	355	
	7.0	7.6	87	
	7.5	8.4	89	oxidized and unleached
	8.5	8.1	92	saprolite
	9.3	8.3	87	
	10.6	8.3	73	
	11.8	8.2	69	
	12.4	8.1	88	
HHMS-5A	0.6	4.9	13	soil solum
	1.2	4.8	47	
	1.8	5.1	261	
	2.4	5.3	723	oxidized and leached
	3.0	5.7	308	saprolite
	3.6	6.2	268	
	7.3	7.7	125	
	7.9	8.2	93	
	8.5	7.6	68	oxidized and unleached
	9.7	7.9	92	saprolite
	11.5	8.3	89	
	12.2	8.0	98	

Source: Ammons and Phillips, (1987).

Table 5.7 Clay Mineralogy of Selected SWSA 6 Soils

Soil	Horizon	Depth (cm)	Minerals Present in the < 0.002 mm Clay Fraction							
			Sm[1]	Verm[2]	HIV[3]	Ped[4]	KaO[5]	Ill[6]	Mn and Fe Oxides	Gibb[7]
MARYVILLE SOILS										
43	Ap	0-10	ND	M	Tr	ND	Tr	H	Tr	ND
	Cr3	145-205	ND	L	ND	ND	Tr	H	Tr	ND
42	Ap	0-10	ND	L	H	Tr	Tr	M	Tr	ND
	C/Bt	84-105	ND	L	H	Tr	Tr	M	Tr	ND
	C2	132-150	ND	H	M	Tr	Tr	M	Tr	ND
	Fe Zone	201-213	ND	M	M	Tr	Tr	H	Tr	ND
40	Ap and E	0-27	ND	Tr	H	Tr	Tr	L	Tr	ND
	Bt1 and Bt2	27-70	ND	L	H	Tr	Tr	L	Tr	ND
	Cr1	190-230	ND	M	M	ND	Tr	M	Tr	ND
	Fe Zone	290-310	ND	M	L	ND	Tr	H	Tr	ND
NOLICHUCKY SOILS										
50	Ap	0-14	Tr	M	Tr	ND	Tr	H	Tr	ND
	Btg	23-50	Tr	M	Tr	ND	Tr	H	Tr	ND
	Cr1	50-74	Tr	H	Tr	ND	Tr	H	Tr	ND
	Cr5	123-150	Tr	H	Tr	ND	Tr	H	Tr	ND
OLD ALLUVIUM										
92	Ap and E	0-20	ND	L	L	Tr	Tr	H	Tr	ND
	Bt1 and Bt2	20-53	ND	Tr	H	L	L	L	Tr	ND
	2Bt3	53-80	ND	Tr	h	L	L	L	Tr	ND
	2Bt5	119-190	ND	L	H	Tr	M	M	Tr	Tr
	Lower Alluvium		ND	L	H	ND	M	H	Tr	ND
	Basal Gravel Zone		ND	L	H	ND	M	M	Tr	ND
	Maryville Residuum		ND	M	L	ND	Tr	H	Tr	ND

Source: Ammons and Phillips (1987).

Notes: ND = None Detected. Tr = Trace < 10%. L = Low 10-20%. M = Medium 20-30%. H = High > 30%.

[1] Smectite
[2] Vermiculite
[3] Hydroxy Interlayered Vermiculite
[4] Pedogenic Chlorite
[5] Kaolinite
[6] Illite
[7] Gibbsite

Table 7.1 Construction Details of Wells Installed for Study of Trench Water Dynamics

Well Number	ORNLN	ORNLE	Measuring Point Elev. (ft)	Land Surface Elev. (ft)	Casing Diameter (cm)	Total Depth[1] (m)	Screened Interval[1] (m)
S6	16574.5	23947.2	781.18	780.41	7.6	5.79	2.74-5.79
S8	17024.7	24610.3	806.28	806.48	5.1	13.78	10.73-13.78
S10	16718.1	24607.5	787.29	786.42	7.6	8.78	5.73-8.78
S11	17627.7	24620.8	829.21	827.76	5.1	13.81	9.24-13.81
T8	17714.7	25067.7	843.03	841.22	5.1	4.85	3.32-4.85
T46	15803.3	23986	763.64	762.78	7.6	3.93	2.10-3.93
T80	16967.3	24686.6	803.44	802.63	7.6	4.42	2.9-4.42
T92	16715.8	24617.5	787.16	786.31	7.6	4.11	2.59-4.11
T219-1[2]	[3]	[3]	765.94	764.85	5.1	[4]	4
T219-2	[3]	[3]	766.41	765.27	5.1	2.5	1.52-2.50
T219-3[2]	[3]	[3]	766.35	765.43	5.1	[4]	[4]
T257	16837	23865.6	792.17	791.05	5.1	3.6	2.07-3.60
T260	16577	23908.3	780.44	779.79	7.6	3.84	2.32-3.84
T260-2	16614.8	23908.8	781.65	779.92	5.1	2.89	1.37-2.89
T260-3	16592.1	23908.7	782.18	779.77	5.1	2.12	0.60-2.12
T288	16533.7	23902.4	780.82	777.77	5.1	4.32	2.80-4.32
T315	[3]	[3]	781.89	781.89	5.1	2.59	1.07-2.59
T319	17030.7	24601.4	810.14	807	7.6	4.24	2.71-4.24
T381	17192.2	24618.9	826.99	823.94	7.6	4.94	3.41-4.94
T391[2]	17159.5	24617.8	821.82	821.21	5.1	4.42	2.90-4.42
T405[2]	[3]	[3]	804.12	803.44	5.1	3.2	1.68-3.20
T417	17140.9	24529.3	820.89	817.78	5.1	3.87	2.35-3.87
T444	17660.4	24714.9	837.53	835.19	5.1	4.05	2.53-4.05

[1] Below land surface.
[2] Well has been destroyed.
[3] Original coordinates found to be wrong. Wells are being resurveyed.
[4] Not known.

Table 7.2 Summary of Water Level Data Used in Study of Trench Water Dynamics

Well Number	Type of Record	Period of Record	Comments
S6	Breakpointed files	Feb. 86-present	
S8	Manual measurements	Feb. 86-present	
S10	Breakpointed files	Feb. 86-present	
S11	Manual measurements	Feb. 86-present	
T8	Manual measurements	Apr. 86-present	
T46	Breakpointed files	Feb. 86-present	
T80	Breakpointed files	Feb. 86-present	
T92	Breakpointed files	Feb. 86-present	
T123	Breakpointed files	Mar. 86-Jul. 86, Dec. 86-present	
T123	Manual measurements	Oct. 86-present	
T219-1	Manual measurements	Jun. 86-Aug. 86	Destroyed
T219-2	Manual measurements	Jun. 86-Aug. 86	
T219-3	Manual measurements	Jun. 86-Aug. 86	Destroyed
T257	Manual measurements	Jun. 86-Aug. 86	
T260	Breakpointed files	Feb. 86-present	
T260-2	Manual measurements	Jun. 86-present	
T260-3	Manual measurements	Jun. 86-present	
T288	Manual measurements	Apr. 86-Aug. 86	
T315	Manual measurements	Jun. 86-present	
T319	Breakpointed files	Mar. 86-Jul. 86, Dec. 86-present	
T381	Breakpointed files	Mar. 86-Jul. 86, Dec. 86-present	
T381	Manual measurements	Apr. 86-present	
T391	Manual measurements	Jun. 86-present	Destroyed
T405	Manual measurements	Jun. 86-Jun. 87	Destroyed
T417	Manual measurements	Jun. 86-present	
T444	Manual measurements	Apr. 86-present	
W392	Breakpointed files	Mar. 86-Jul. 86, Dec. 86-present	
382	Manual measurements	Mar. 86-present	
382	Manual measurements	Oct. 86-present	

Table 7.3 Results from Dilution Test on Trench 92

Date	Specific Conductance (mS/cm)	Volume of Water in Trench (L)	Discharge (L/day)
4/28/87	0.820	4160	
4/30/87	0.790	3760	76
5/8/87	0.630	2570	89
5/19/87	0.594	2170	13
5/26/87	0.558	1980	19
6/9/87	0.532	1380	5.9
6/29/87	0.404	1980	23
7/16/87	0.436	985	6.4[1]
7/29/87	0.405	588	4.5

[1] Discharge computed using change in concentration from 6/9/87.

TABLE 7.4 Result of Stream Sampling During Storms Events

MONITORING STATION	DATE OF SAMPLE	TIME OF SAMPLE (EST)	TRITIUM CONC. (pCi/ml)	DISCHARGE (L/s)	TRITIUM FLUX (Ci/ml)
MS 1	4/14/87	23:30	390	0.04	1
MS 1	4/15/87	00:30	130	29.07	227
MS 1	4/15/87	01:30	170	11.38	116
MS 1	4/15/87	02:30	220	4.41	58
MS 1	4/15/87	03:30	250	2.38	36
MS 1	4/15/87	04:30	290	1.70	30
MS 1	4/15/87	05:30	310	1.10	20
MS 1	4/16/87	11:20	370	0.22	5
MS 2	2/26/87	16:40	2070	0.20	25
MS 2	2/26/87	18:40	2090	0.20	25
MS 2	2/27/87	00:40	610	6.07	222
MS 2	2/27/87	01:40	420	8.92	225
MS 2	2/27/87	02:40	240	17.02	245
MS 2	2/27/87	05:40	390	8.35	195
MS 2	2/27/87	07:40	300	14.27	257
MS 2	2/27/87	14:40	1230	3.76	277
MS 2	2/28/87	04:40	1880	0.97	109
MS 2	2/28/87	10:40	850	19.06	972
MS 2	2/28/87	14:40	1410	2.32	196
MS 2	2/28/87	16:40	520	14.49	452
MS 2	2/28/87	18:40	800	9.31	447
MS 2	2/28/87	20:40	1110	3.90	260
MS 2	3/1/87	10:40	1620	1.24	121
MS 2	3/1/87	16:00	1200	0.72	52
MS 2	4/14/87	07:35	2520	2.09	316
MS 2	4/14/87	20:35	2300	1.24	171
MS 2	4/14/87	21:35	2310	1.34	186
MS 2	4/14/87	23:35	2310	1.54	213
MS 2	4/15/87	00:35	340	50.42	1029
MS 2	4/15/87	01:35	410	16.80	413
MS 2	4/15/87	02:35	740	8.92	396
MS 2	4/15/87	05:35	1440	3.76	325
MS 2	4/15/87	07:05	1690	2.56	260
MS 2	4/15/87	10:05	2010	1.86	224
MS 2	4/16/87	10:30	1930	1.86	215
MS 2	4/16/87	16:30	2070	1.24	154
MS 2	4/16/87	17:30	1650	8.17	809
MS 2	4/16/87	18:30	1400	5.10	428
MS 2	4/16/87	20:30	1670	3.34	335
MS 3	2/26/87	16:45	3520	1.86	393
MS 3	2/26/87	23:45	980	19.64	1155
MS 3	2/27/87	01:45	490	39.62	1165
MS 3	2/27/87	02:45	660	54.15	2144
MS 3	2/27/87	10:45	850	66.32	3382
MS 3	2/27/87	12:45	1000	50.67	3040
MS 3	2/27/87	14:50	790	32.12	1522
MS 3	2/27/87	16:50	1020	22.78	1394
MS 3	2/28/87	02:50	1540	9.19	849

TABLE 7.4 Continued

MONITORING STATION	DATE OF SAMPLE	TIME OF SAMPLE (EST)	TRITIUM CONC. (pCi/ml)	DISCHARGE (L/s)	TRITIUM FLUX (Ci/ml)
MS 3	2/28/87	08:50	1160	12.38	862
MS 3	2/28/87	10:50	260	54.15	845
MS 3	2/28/87	16:50	410	60.97	1500
MS 3	2/28/87	18:50	290	57.33	998
MS 3	2/28/87	20:50	460	30.17	833
MS 3	3/1/87	14:00	1690	7.31	741
MS 3	3/24/87	13:55	3220	0.92	178
MS 3	3/24/87	16:55	2030	1.27	155
MS 3	3/24/87	19:55	2780	1.57	262
MS 3	3/24/87	20:55	2240	2.12	285
MS 3	3/24/87	21:55	1890	2.60	295
MS 3	3/24/87	22:55	2060	2.24	277
MS 3	3/25/87	05:55	2430	1.90	277
MS 3	3/25/87	09:55	2310	1.57	218
MS 3	3/25/87	11:55	3000	1.27	229
MS 3	4/14/87	20:45	3330	1.00	200
MS 3	4/14/87	23:45	3410	1.00	205
MS 3	4/15/87	00:45	940	79.87	4505
MS 3	4/15/87	03:45	840	20.74	1045
MS 3	4/15/87	07:25	380	9.55	218
MS 3	4/15/87	13:25	1530	5.62	516
MS 3	4/15/87	21:25	1530	3.38	310
MS 3	4/16/87	05:25	1810	2.60	282
MS 3	4/16/87	06:25	860	6.48	334
MS 3	4/16/87	10:35	910	5.62	307
MS 3	4/16/87	15:35	1900	3.38	385
MS 3	4/16/87	16:35	930	4.84	270
MS 3	4/16/87	17:35	370	10.33	229
MS 3	4/16/87	19:35	670	7.50	302
MS 3	4/16/87	21:35	520	5.62	175
MS 3	4/16/87	23:35	820	4.68	230
MS 3	4/17/87	09:35	1770	3.38	359
MS 4	2/26/87	16:55	4510	0.06	16
MS 4	2/27/87	04:55	3850	0.17	39
MS 4	2/27/87	06:55	3530	0.30	64
MS 4	2/27/87	09:55	3040	0.47	86
MS 4	2/27/87	11:55	3100	0.68	126
MS 4	2/27/87	17:00	3750	0.47	106
MS 4	2/28/87	09:00	2782	0.17	28
MS 4	2/28/87	19:00	1620	0.47	46
MS 4	2/28/87	21:00	1760	0.47	50
MS 4	3/1/87	13:00	2460	0.17	25
MS 4	4/14/87	07:50	7310	0.03	13
MS 4	4/14/87	22:50	7080	0.03	13
MS 4	4/14/87	23:50	6950	0.03	13
MS 4	4/15/87	01:50	3300	0.08	16
MS 4	4/15/87	03:50	3150	0.08	15
MS 4	4/15/87	09:00	5360	0.08	26

TABLE 7.5 Results from Three Component Mixing Model

Date of Sample	Time of Sample (EST)	Stream Discharge (L/s)	Groundwater Discharge (L/s)	Q_{bi} (L/s)	Q_{ti} (L/s)	$^{T}C_{ti}$ (pCi/ml)
4/14/87	20:45	1.00	1.00	0.00	0.00	0.00
4/14/87	23:45	1.00	1.00	0.00	0.00	0.00
4/15/87	00:45	79.87	1.00	16.06	62.01	1160.14
4/15/87	03:45	20.74	1.02	2.32	17.18	847.85
4/15/87	07:25	9.55	1.04	0.26	8.15	108.09
4/15/87	13:25	5.62	1.08	-0.48	4.96	1267.90
4/15/87	21:25	3.38	1.13	-0.31	2.53	1357.75
4/16/87	05:25	2.60	1.18	-0.10	1.50	1715.20
4/16/87	06:25	6.48	2.67	1.58	2.21	331.75
4/16/87	10:35	5.62	2.98	0.23	2.38	-93.72
4/16/87	15:35	3.38	3.35	0.10	-0.07	-5725.29
4/16/87	16:35	4.84	3.42	0.36	1.04	-1570.68
4/16/87	17:35	10.33	3.50	1.38	5.38	-446.03
4/16/87	19:35	7.50	3.65	0.49	3.32	-450.10
4/16/87	21:35	5.62	3.79	0.20	1.60	-2386.45
4/16/87	23:35	4.68	3.94	0.46	0.27	-11853.07
4/17/87	09:35	3.38	4.68	0.46	-1.74	1323.45

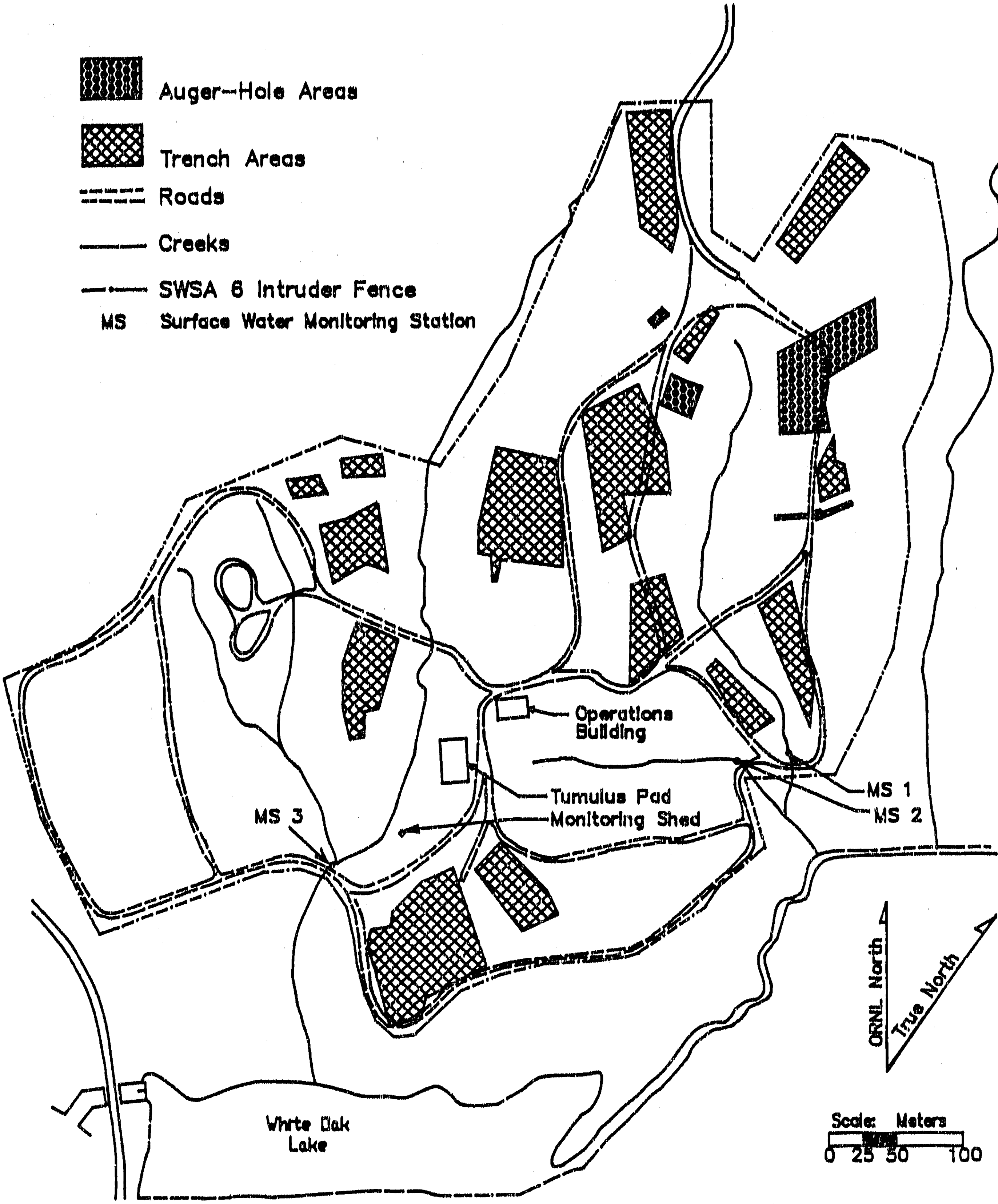


Figure 1.1 Plan view of the SWSA 6 site showing locations of groups of trenches and auger holes.

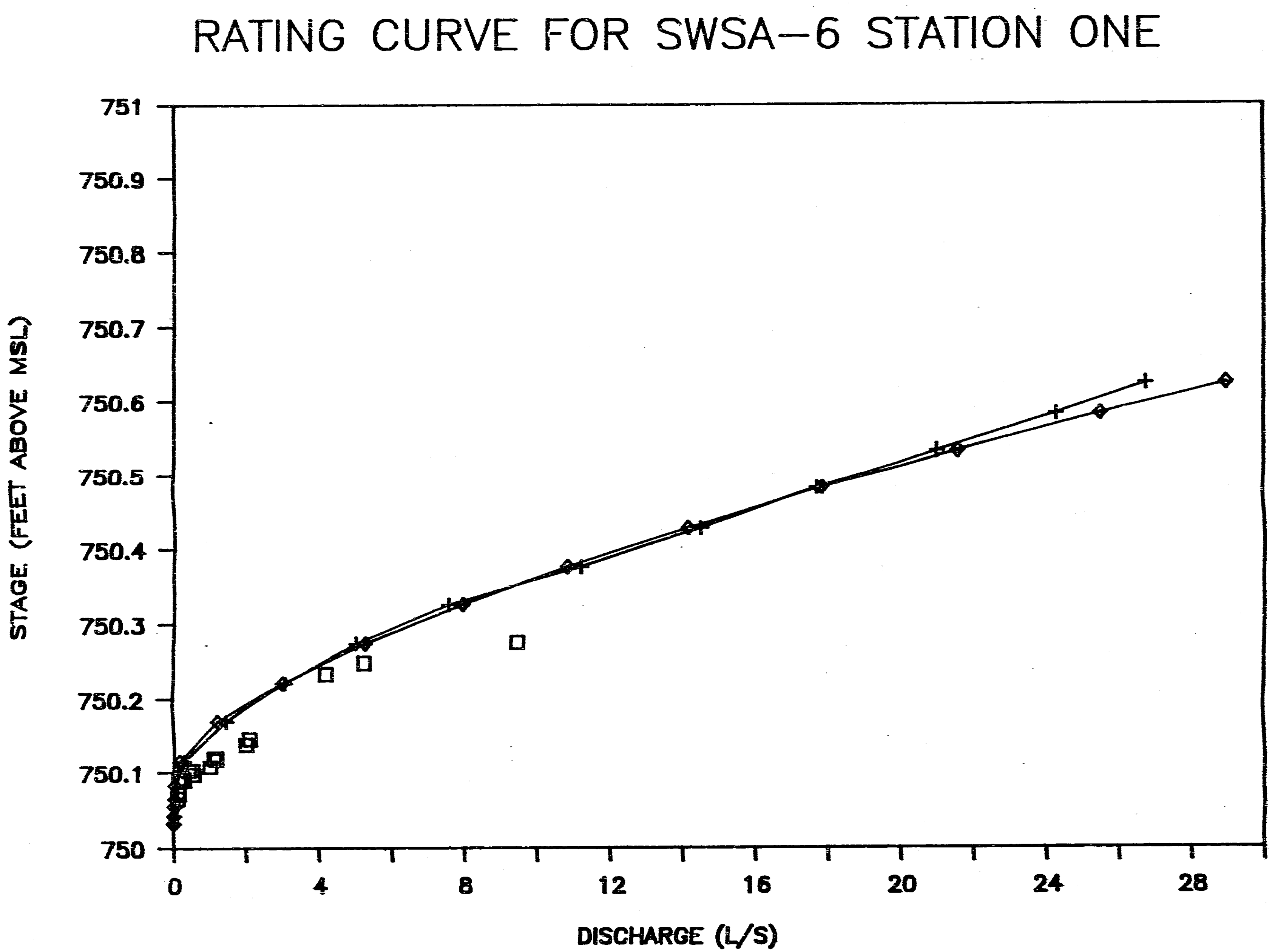


Figure 3.1 Rating curve for SWSA 6 station one.

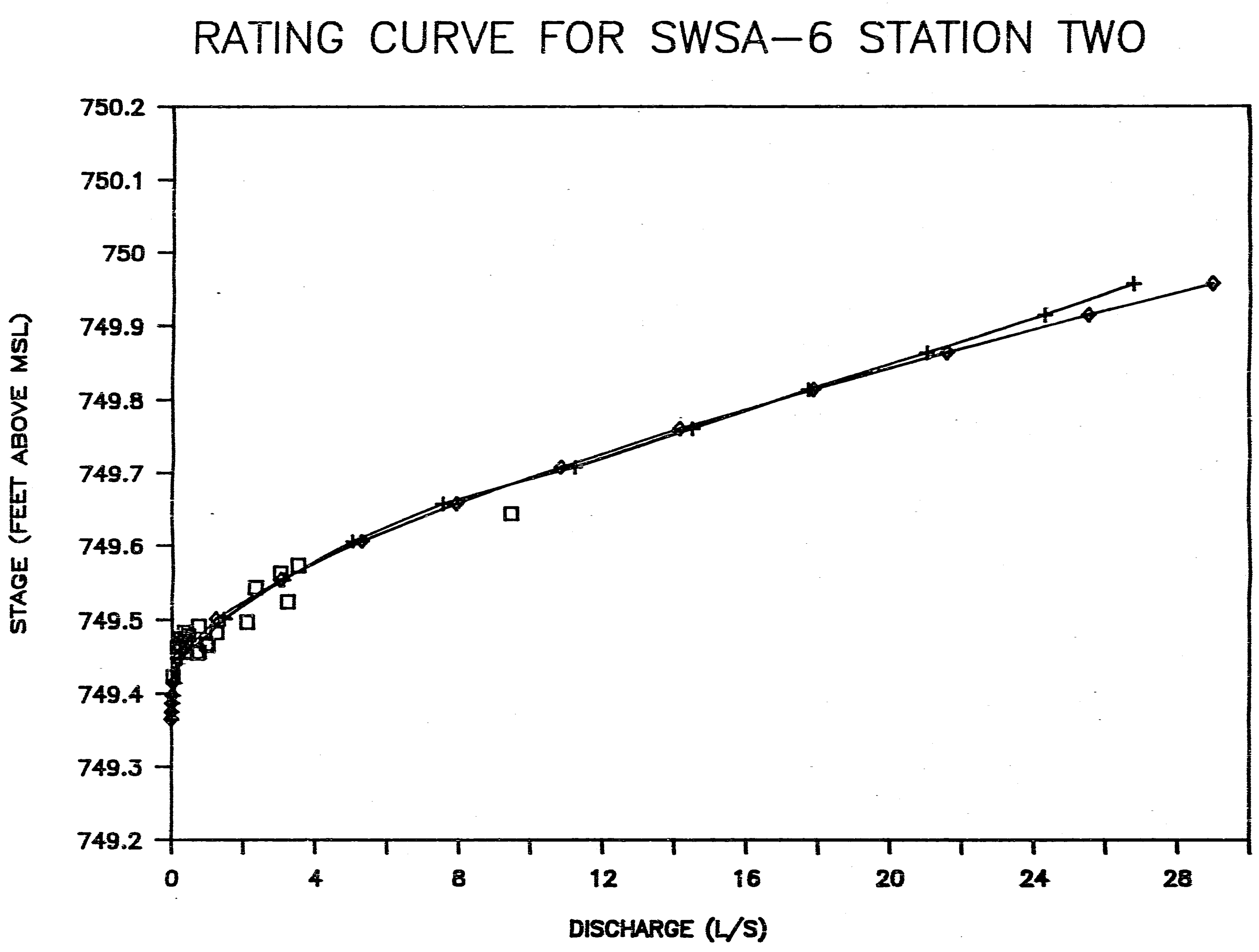


Figure 3.2 Rating curve for SWSA 6 station two.

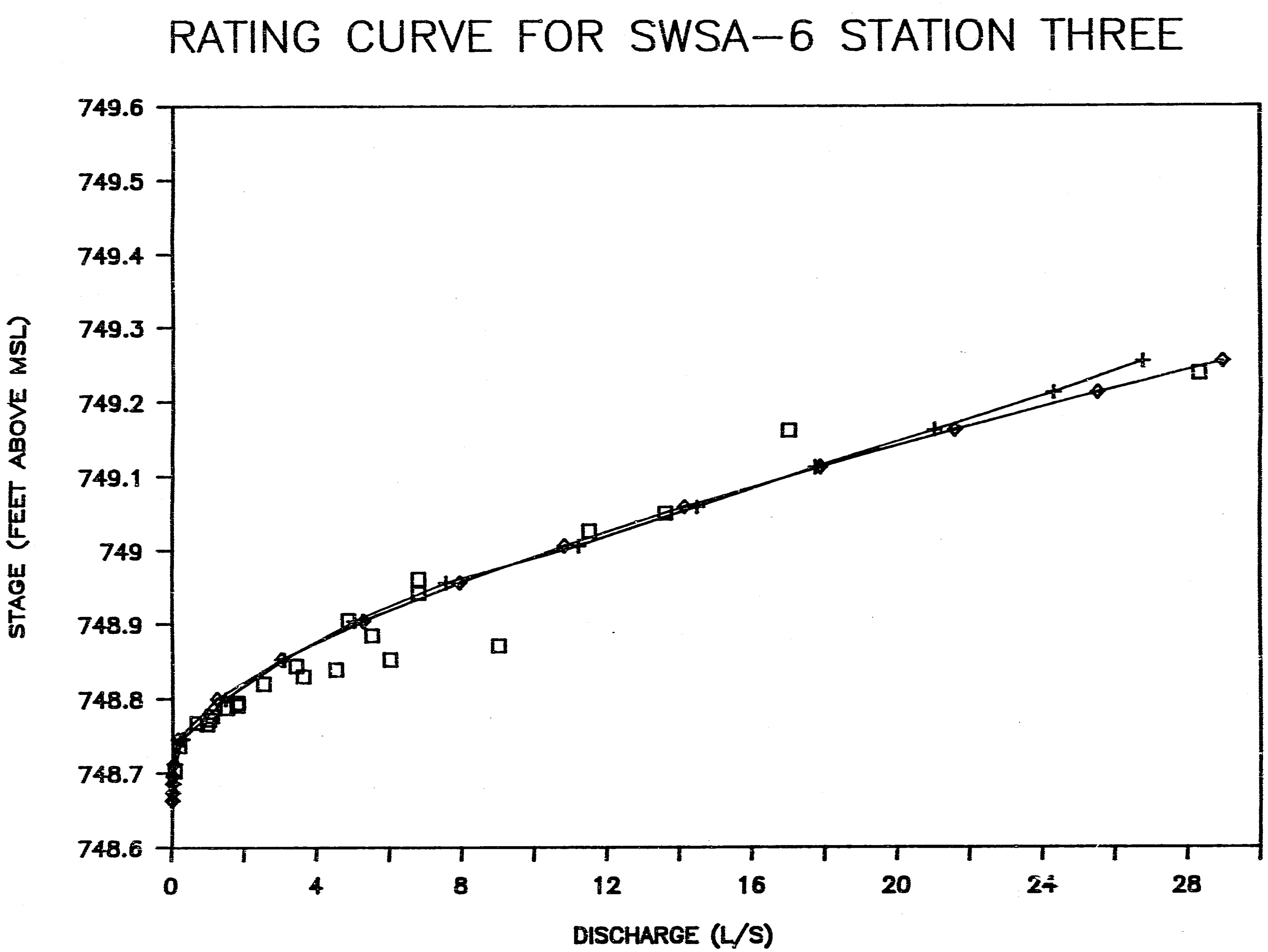


Figure 3.3 Rating curve for SWSA 6 station three.

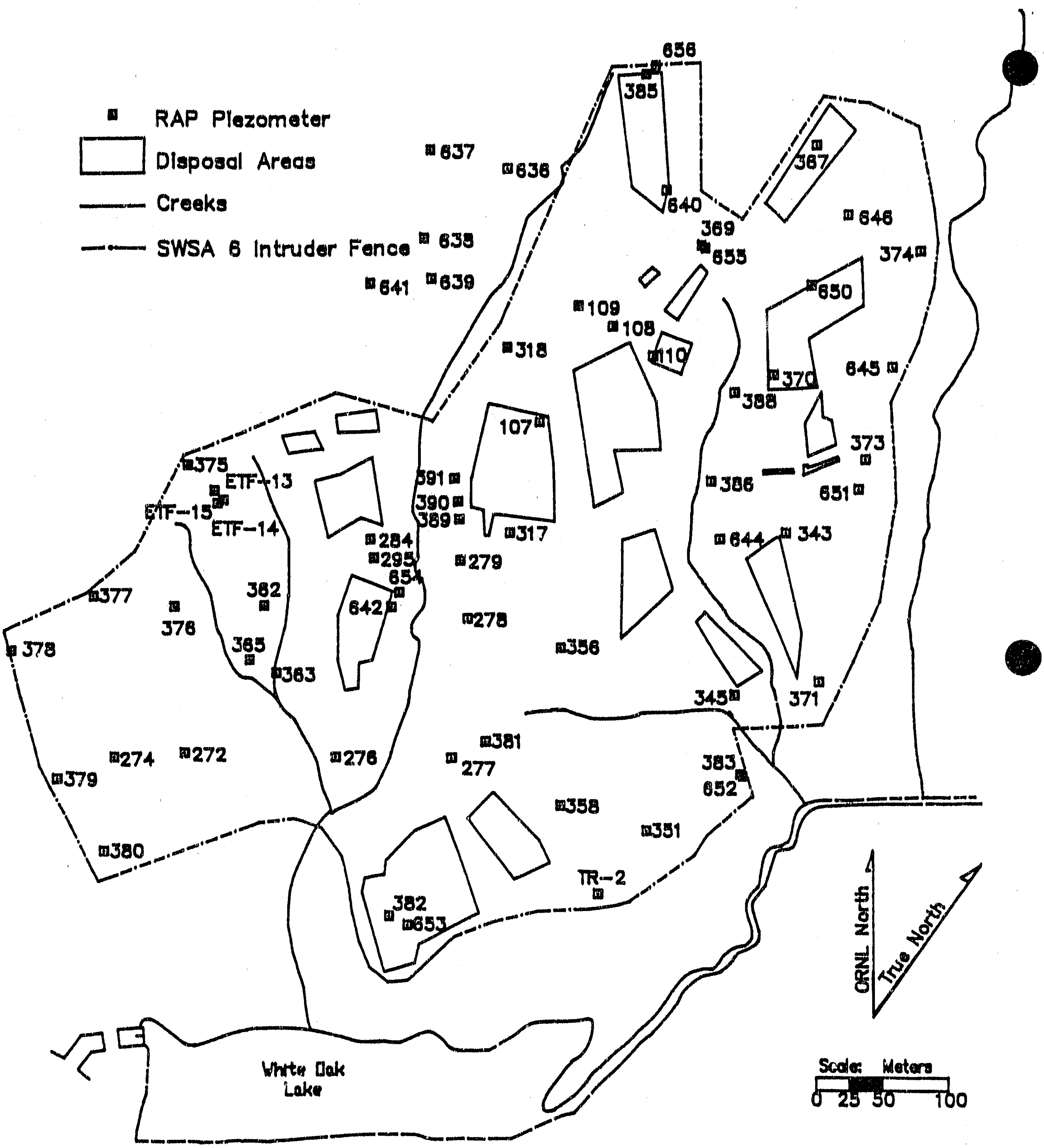


Figure 3.4 Location of SWSA 6 piezometers used for water table elevation monitoring.

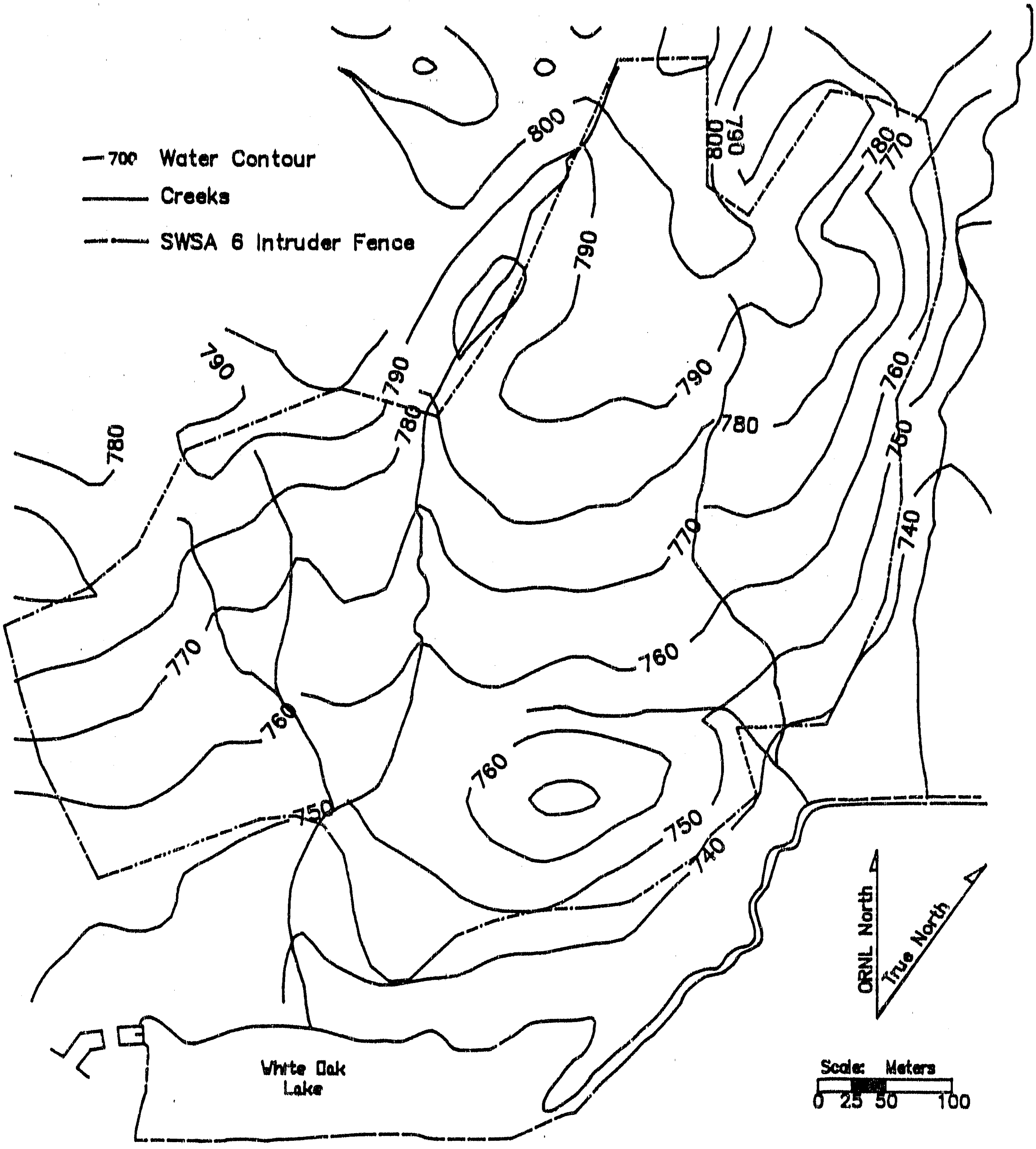


Figure 3.5 SWSA 6 water level contours for September 1986.

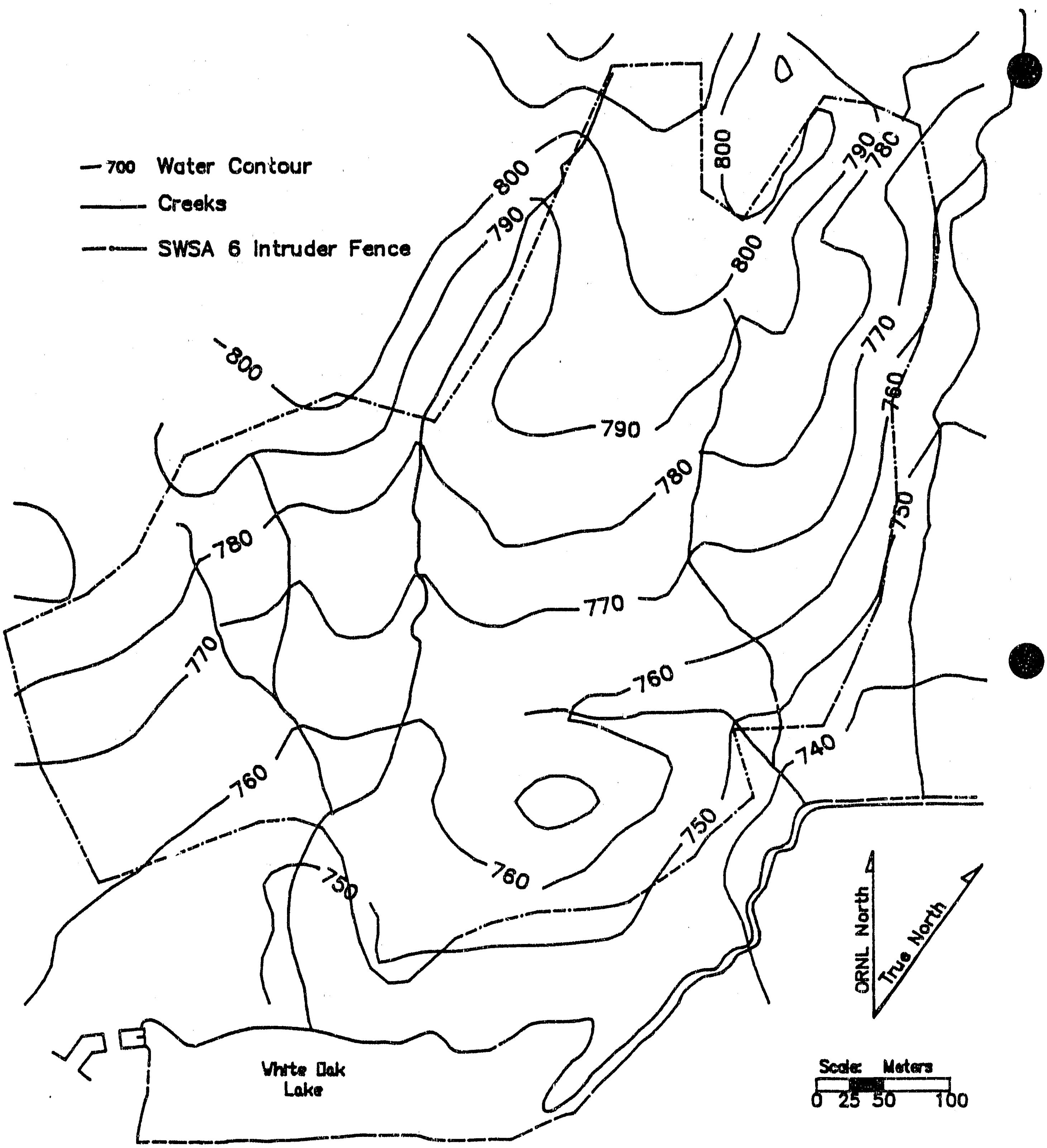


Figure 3.6 SWSA 6 water level contours for February 1987.

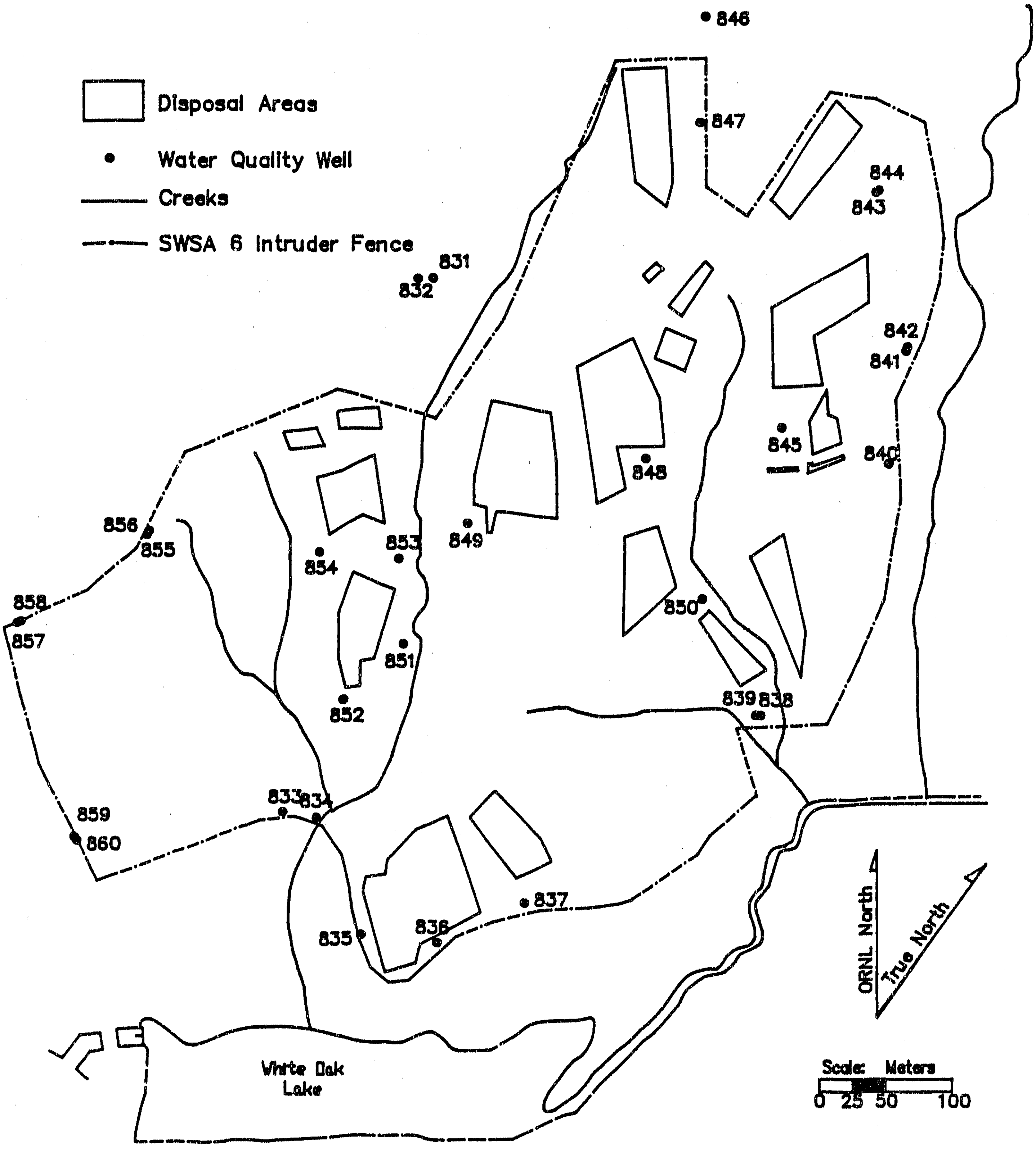


Figure 3.7 Location of SWSA 6 water quality wells.

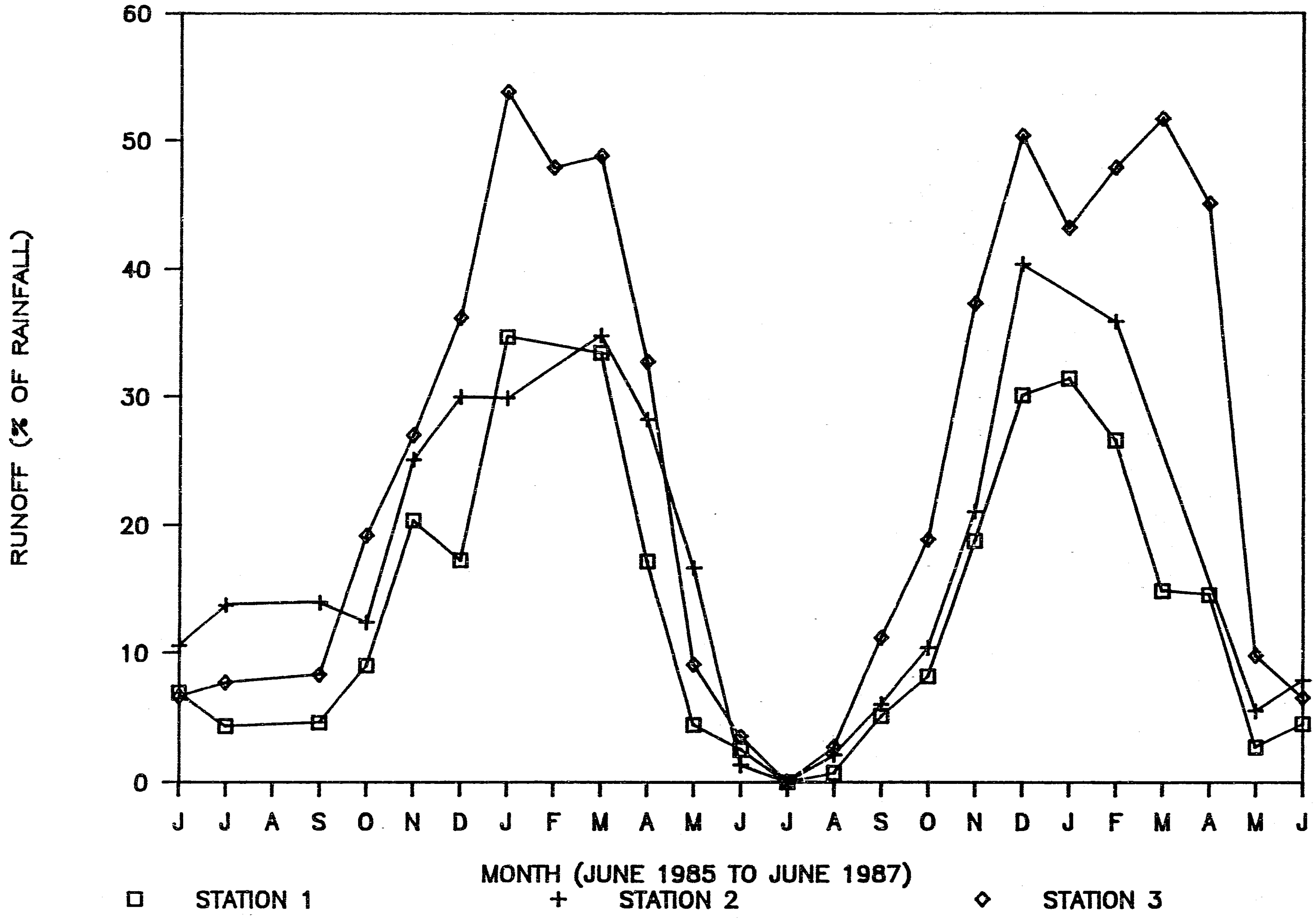


Figure 3.8 Relationship between monthly streamflow and precipitation in SWSA 6 for June 1985 to June 1987.

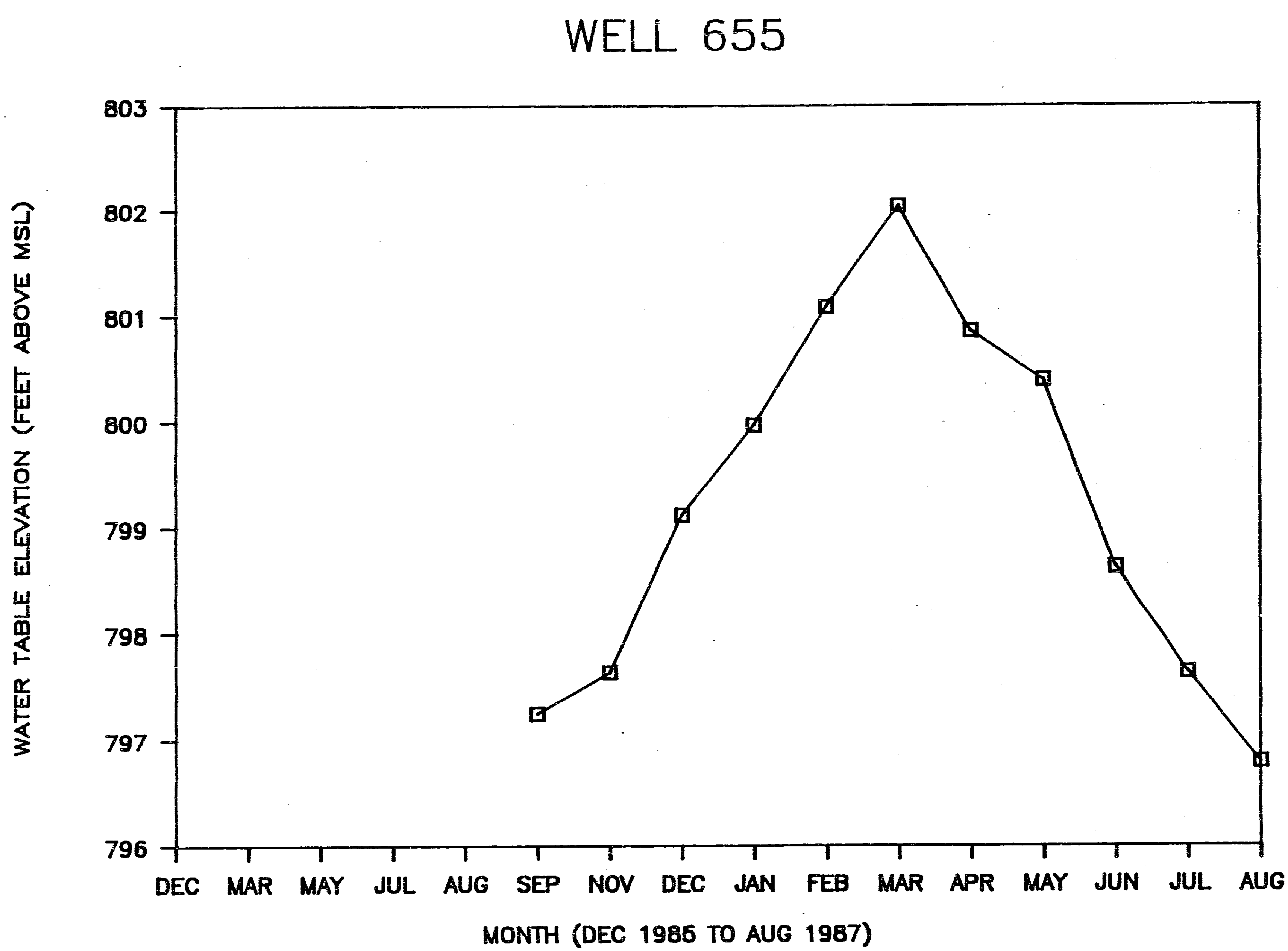


Figure 3.9 Monthly hydrograph for SWSA 6 piezometer 655.

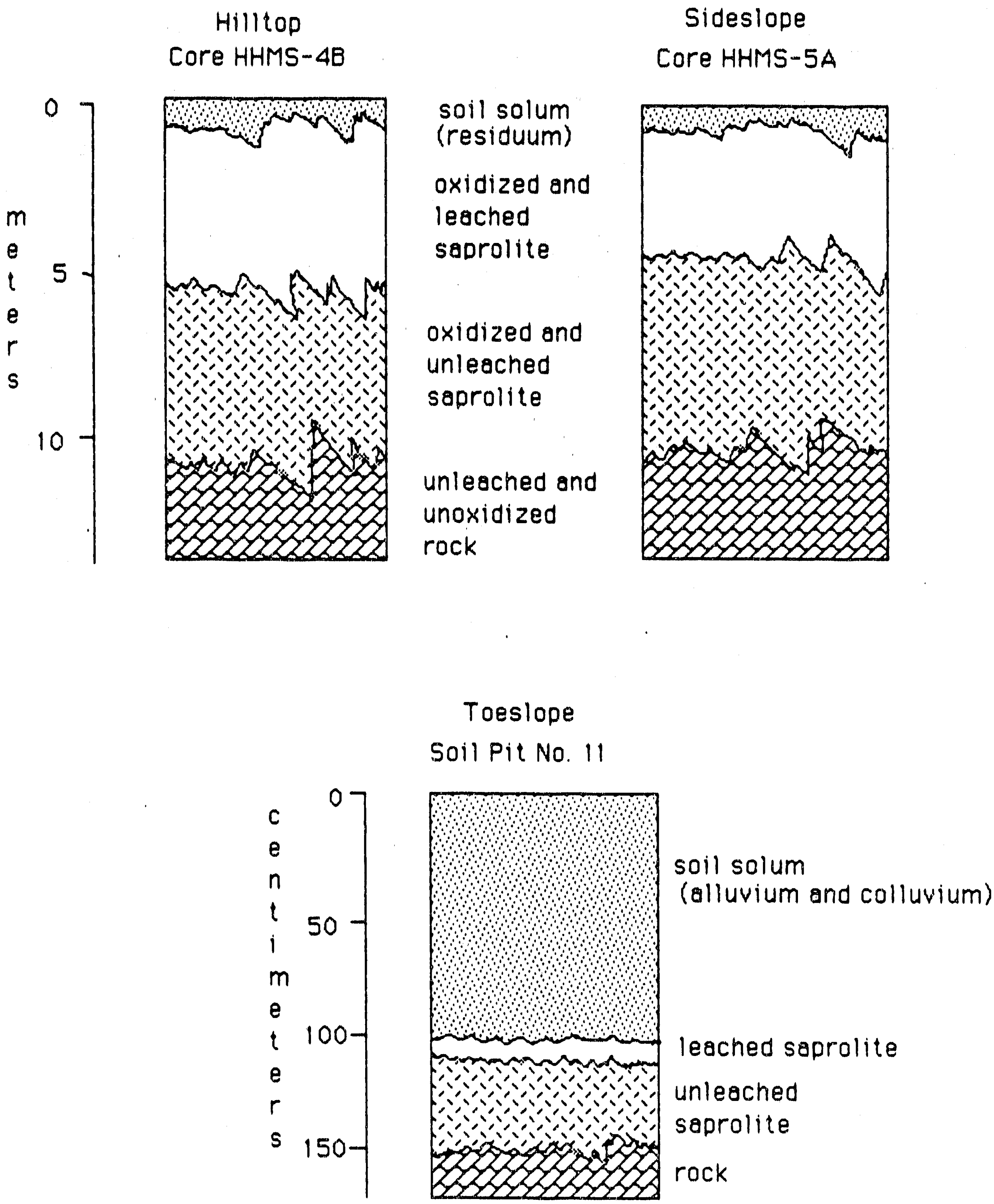


Figure 5.1 Comparison of landform and soil depth in SWSA 6.

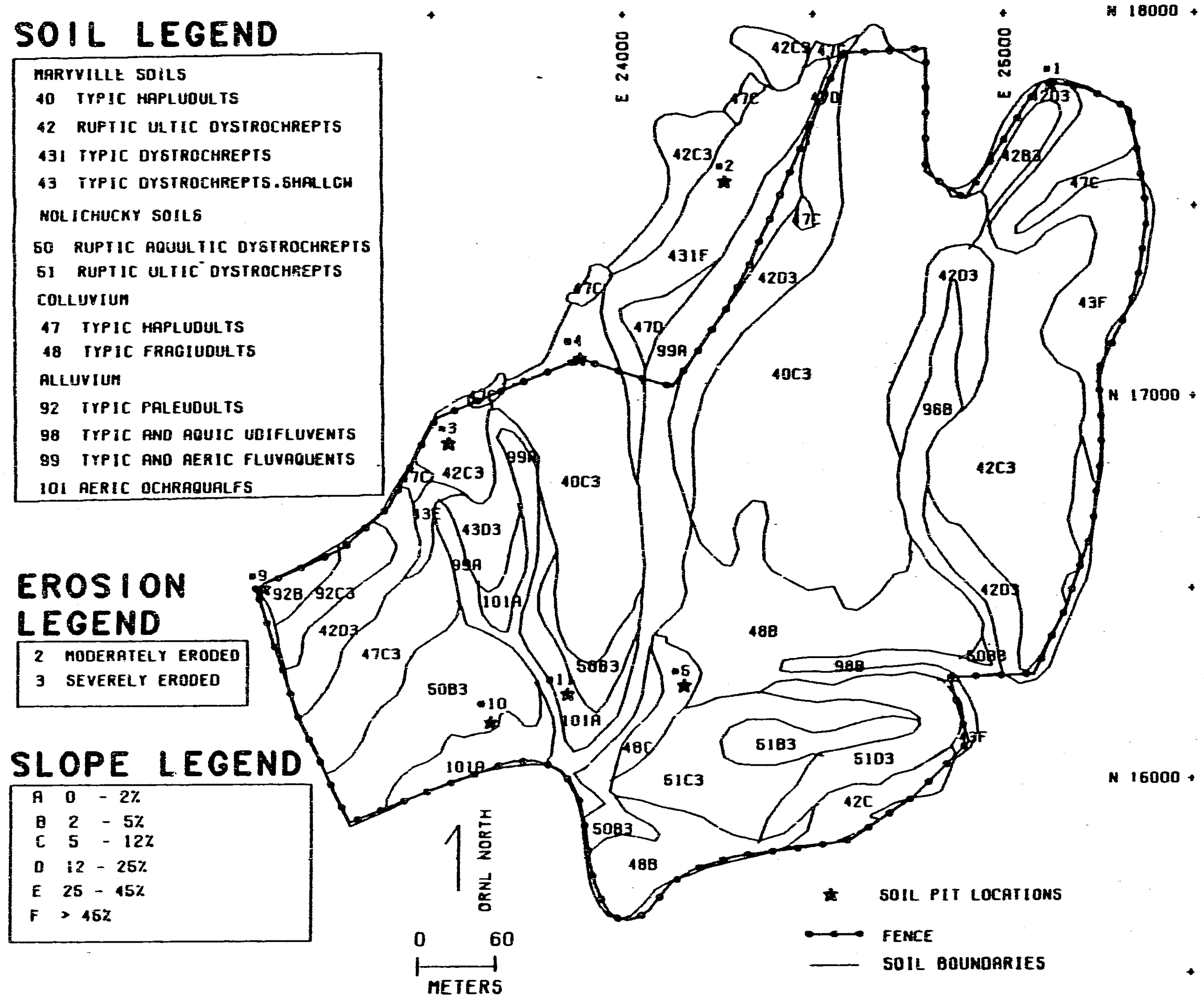


Figure 5.2 Soil map of SWSA 6.

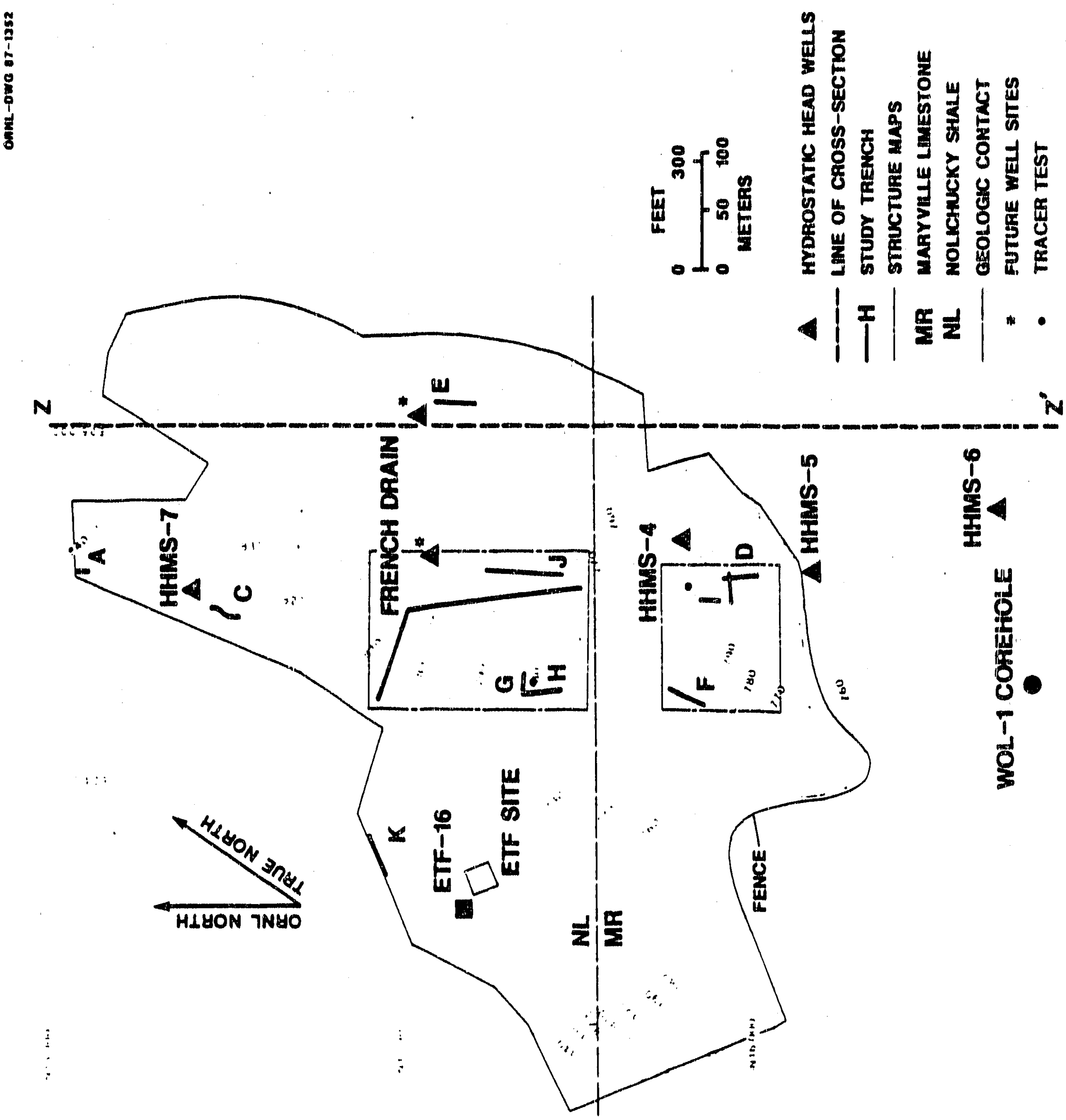


Figure 6.1 Location of geological investigations in SWSA 6.

ORNL-DWG 86-16645

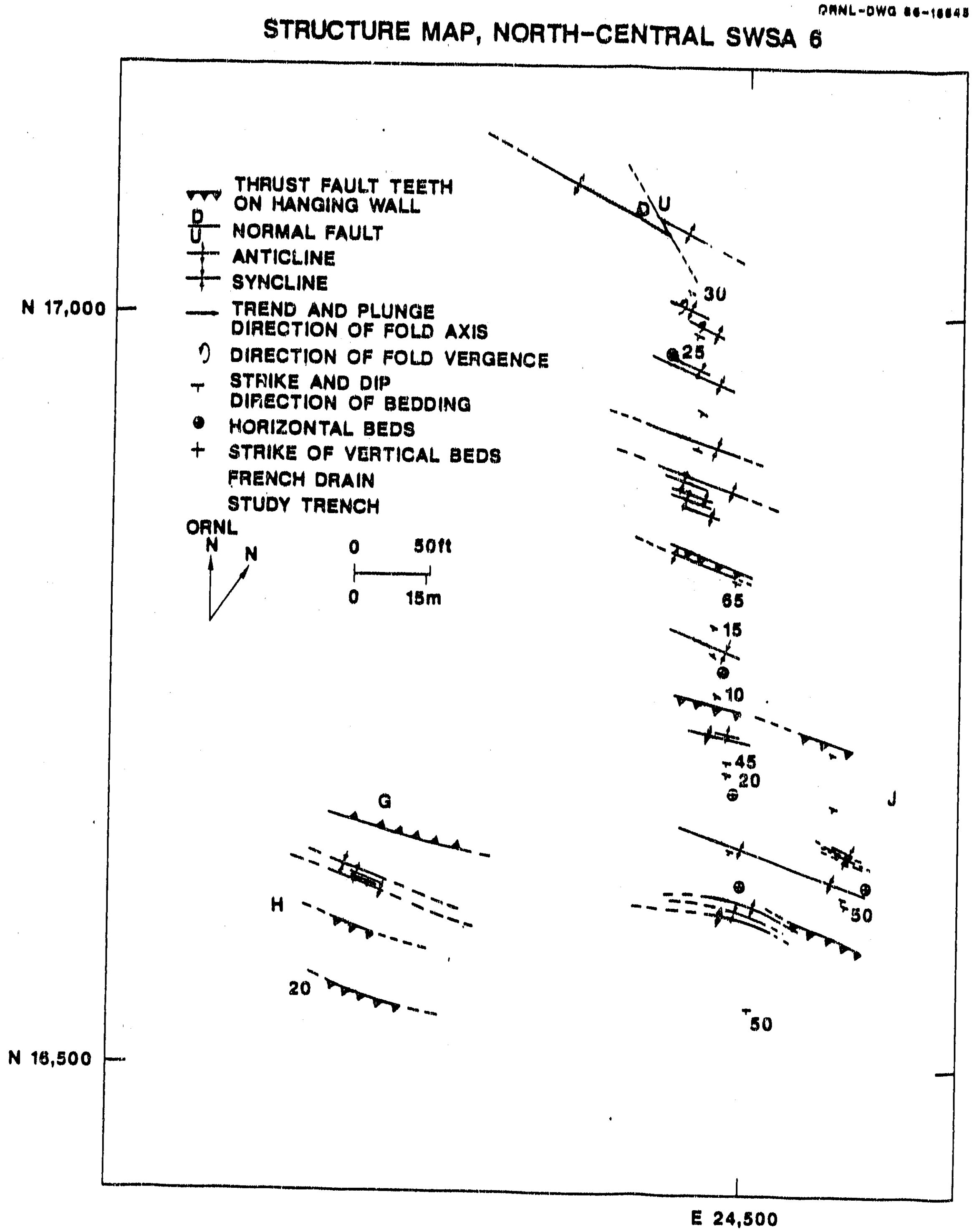


Figure 6.2 Structure map - central SWSA 6.

ORNL-DWG 86-18746

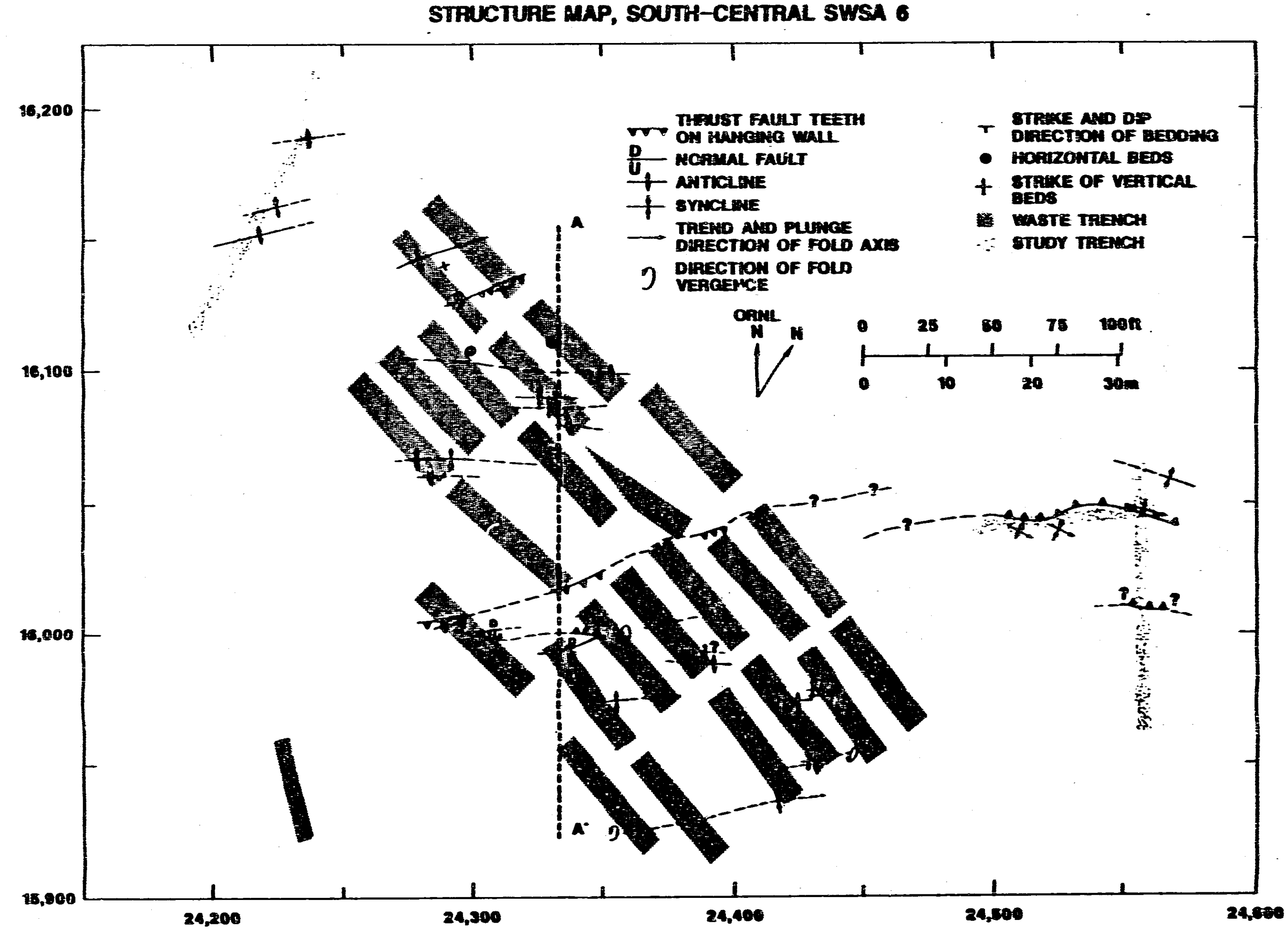


Figure 6.3 Structure map - south-central SWSA 6.

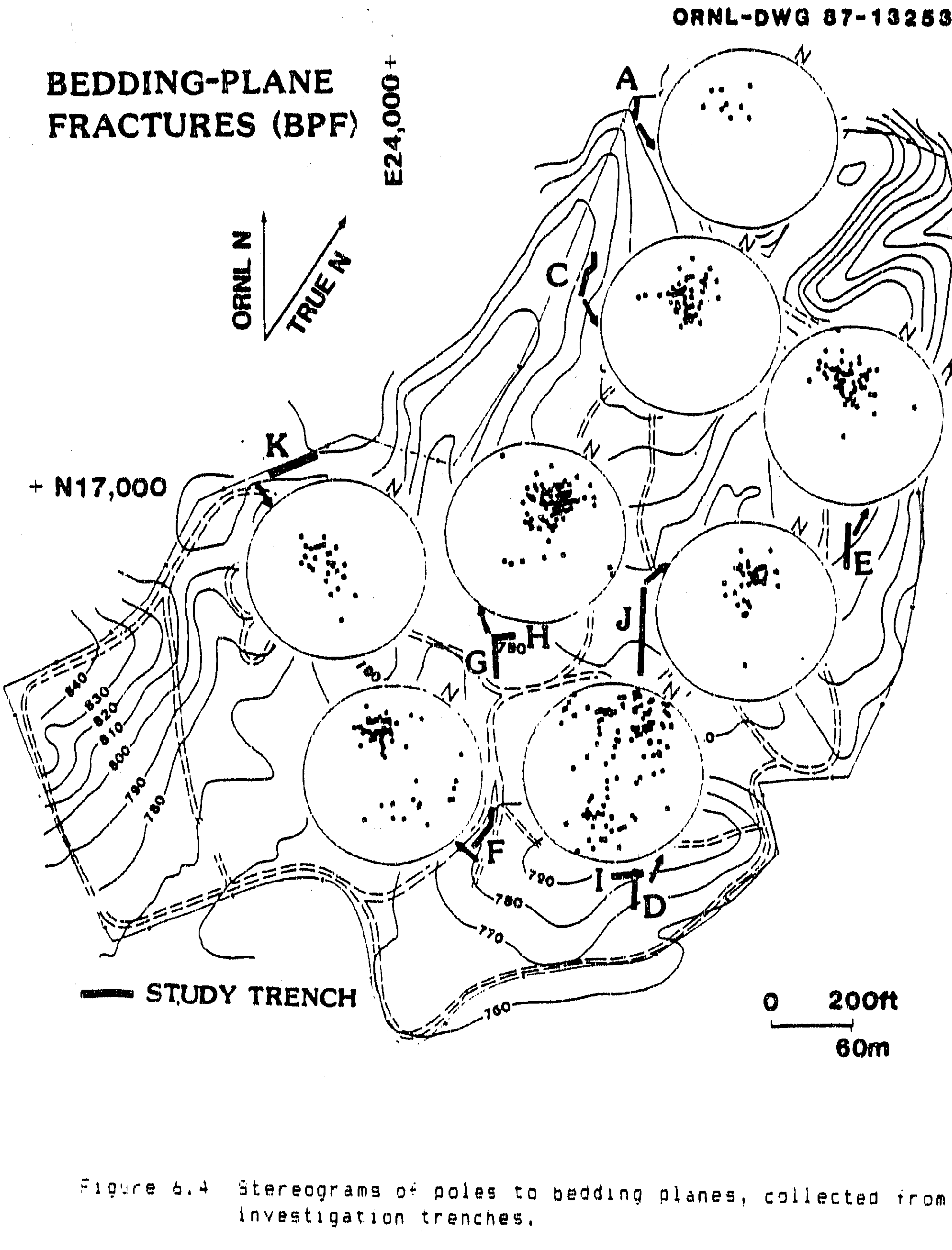


Figure 6.4 Stereograms of poles to bedding planes, collected from investigation trenches.

FRACTURES, CONTAINMENT PIT
SITE HHMS 8

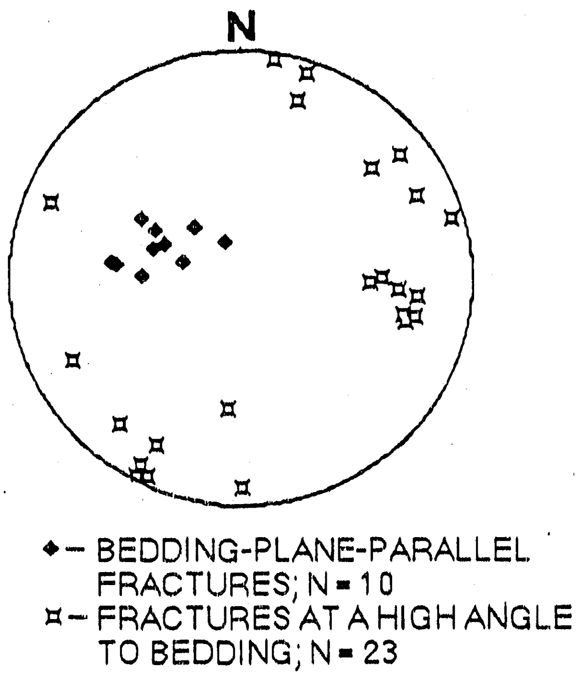


Figure 6.5 Stereogram of structural fabrics measured in containment pit at site HHMS 8.

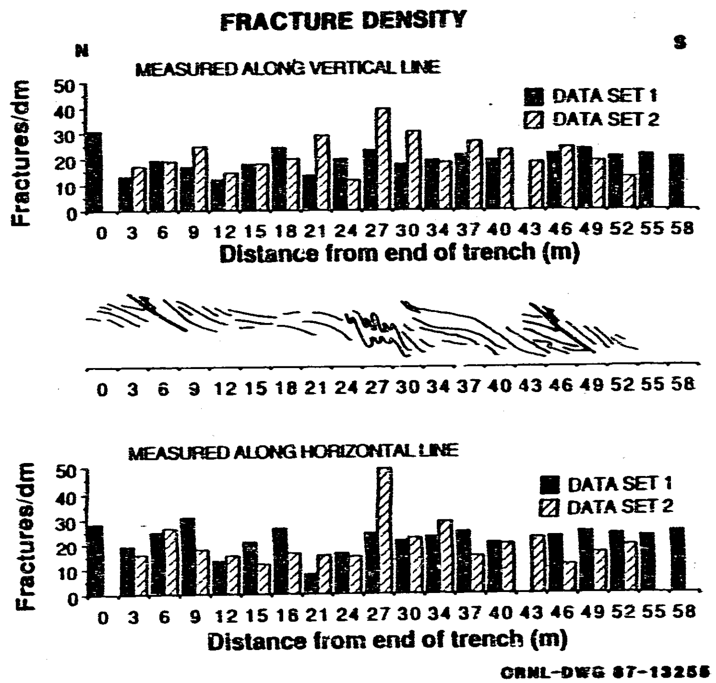


Figure 6.6 Fracture densities - Trench J.

Lithological Log Symbol Key

Color

white	light to medium gray	dark gray
black	maroon-brown	maroon
gray to gray-green	gray to maroon-brown	gray to brown
gray to tan		

Stratification Sequence

simple	composite	interbedded

Bedding Type

structureless	mottled to irregular	planar, continuous
planar, discontinuous	cross bedded	flaser, simple
flaser, wavy	wavy	lenticular, single
lenticular, connected		

Lithology Adjective

graded bedding	soft sediment def.	oolitic
bioturbation	trace fossils	fossiliferous
fractured/deformed	filled fractures	stylolites
solutional features	brecciated	glauconitic

Lithology

chert	dolostone	cherty dolostone
calcareous dolostone	silty dolostone	shaly dolostone
limestone	cherty limestone	silty limestone
shaly limestone	sandstone	dolomitic sandstone
calcareous sandstone	shaly sandstone	siltstone
dolomitic siltstone	salcareous siltstone	shaly siltstone
mudstone	calcareous mudstone	silty mudstone
shale	calcareous shale	silty shale
limestone conglomerate		

Figure 6.7 Key to lithologic logging symbols.

WOL-1 (0 to 100 ft)

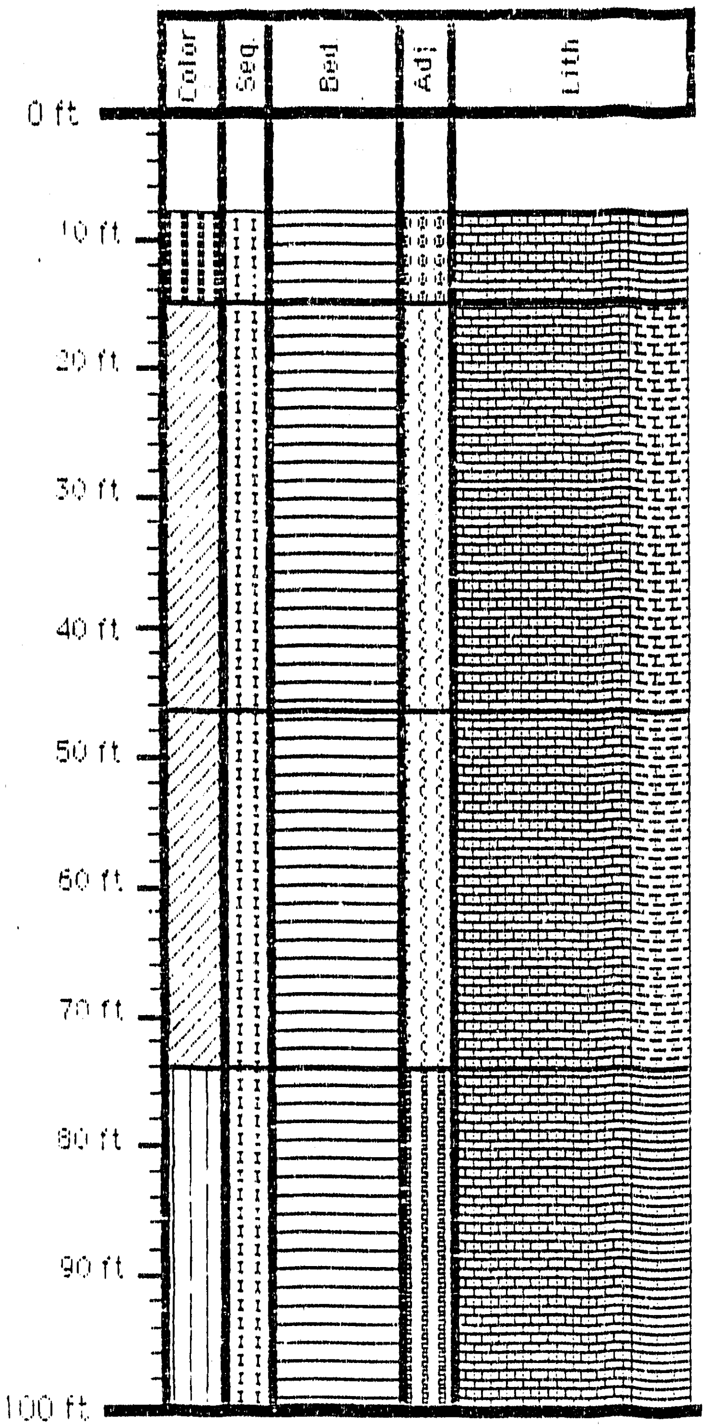
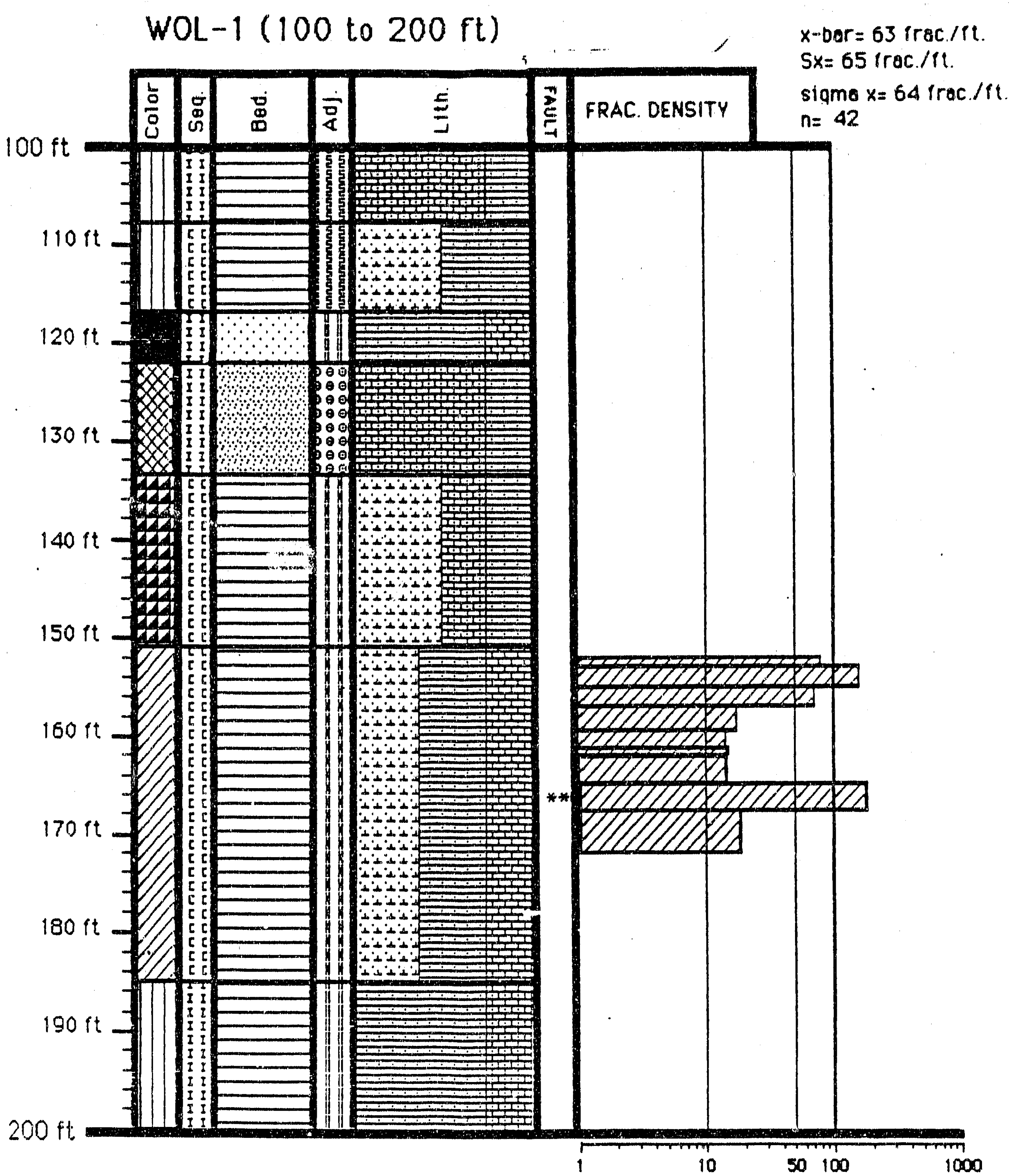
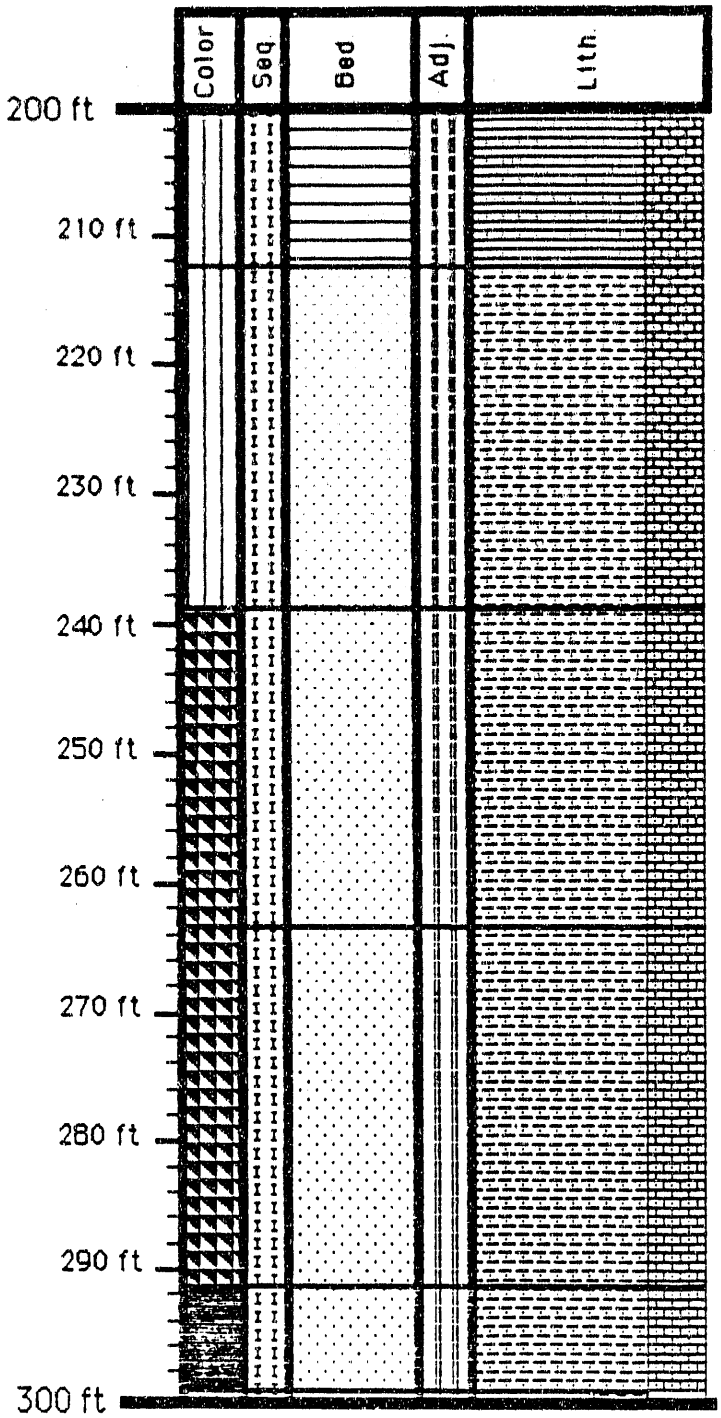


Figure 6.8 Lithology and fracture density log (15 pages).

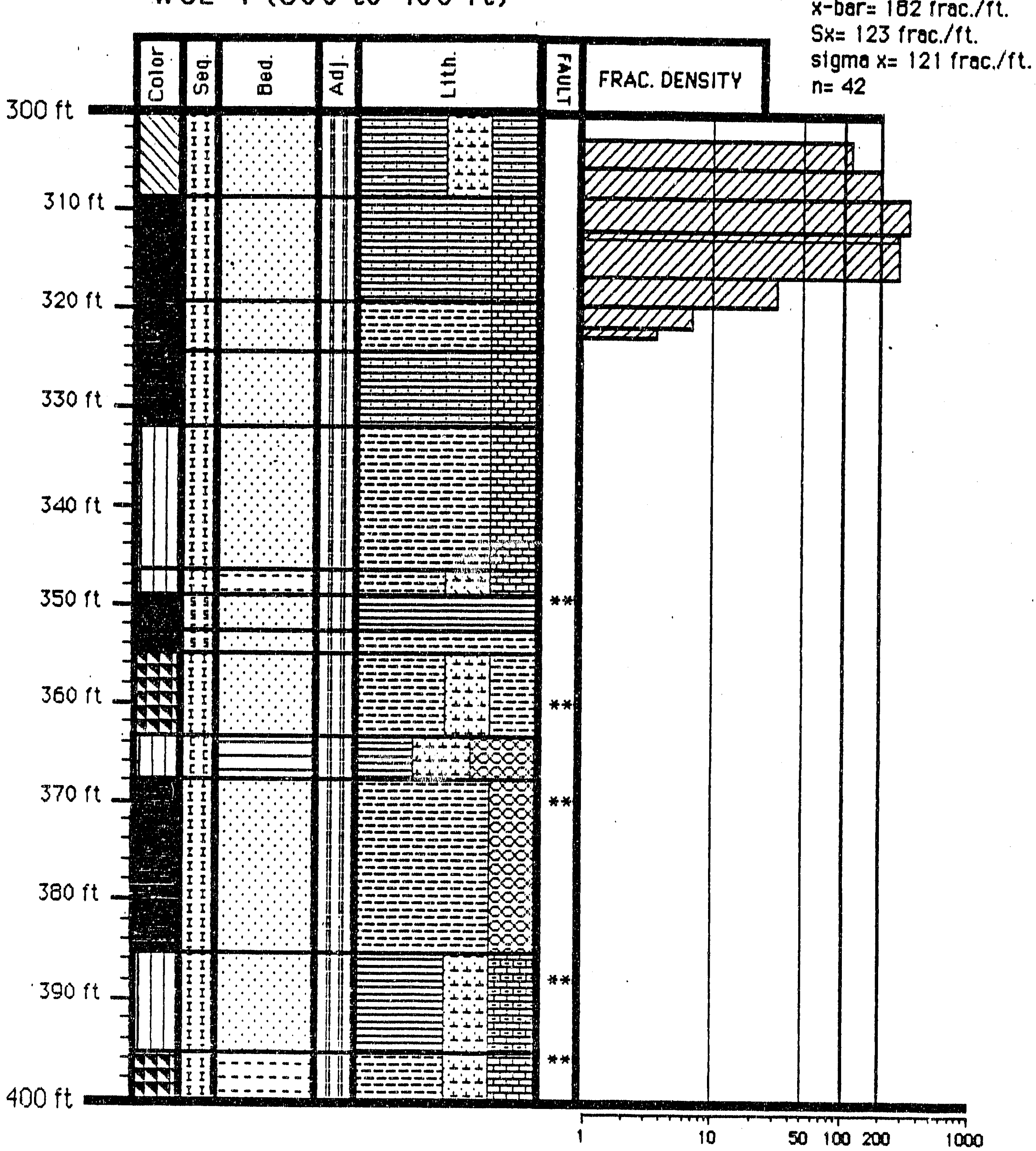


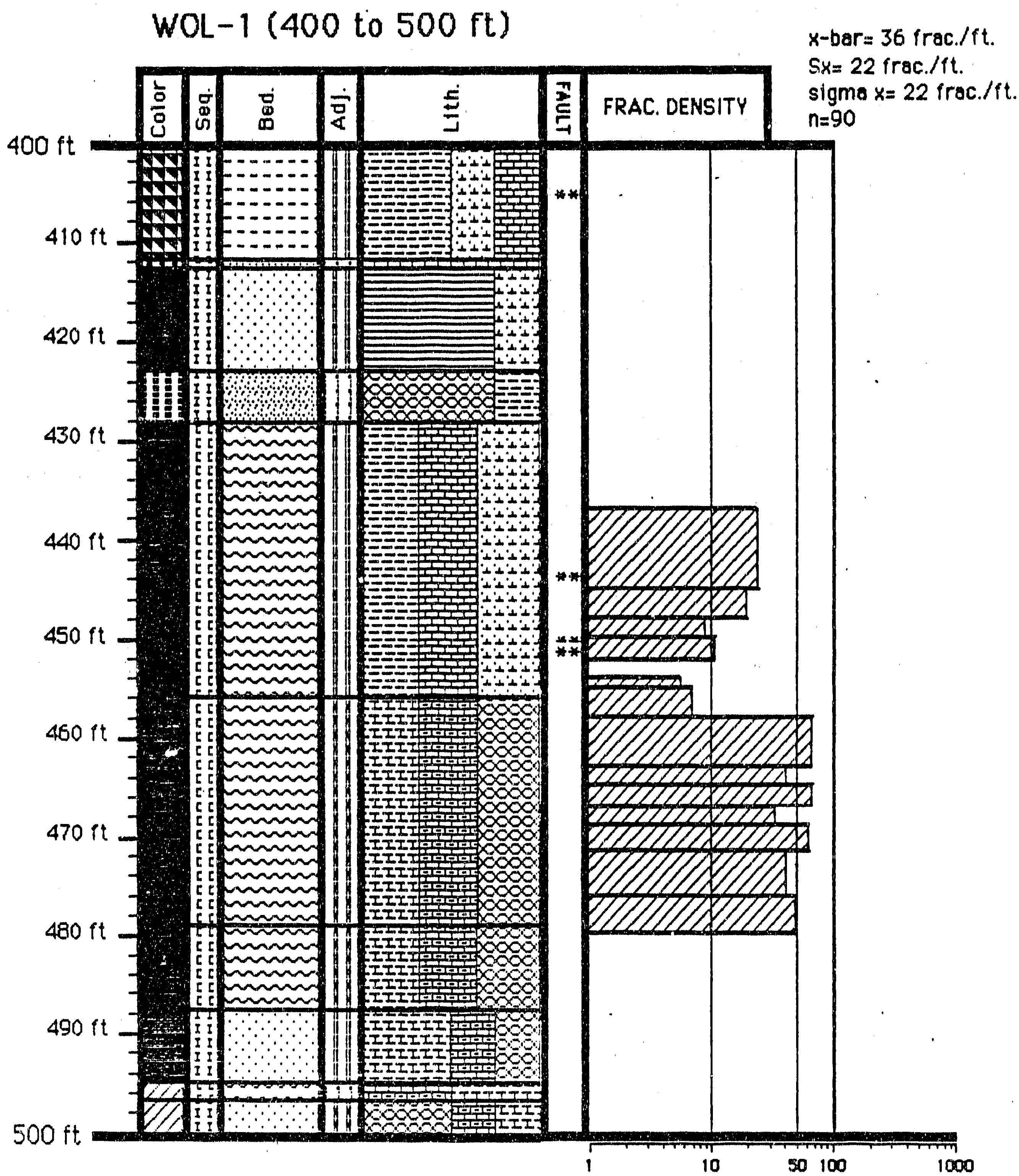
WOL-1 (100 to 200 ft)
x-bar= 63 frac./ft.
Sx= 65 frac./ft.
sigma x= 64 frac./ft.
n= 42
Color
Seq.
Bed.
Adj.
Lith.
FAULT
FRAC. DENSITY
100 ft
110 ft
120 ft
130 ft
140 ft
150 ft
160 ft
170 ft
180 ft
190 ft
200 ft
**
1
10
50
100
1000

WOL-1 (200 to 300 ft)

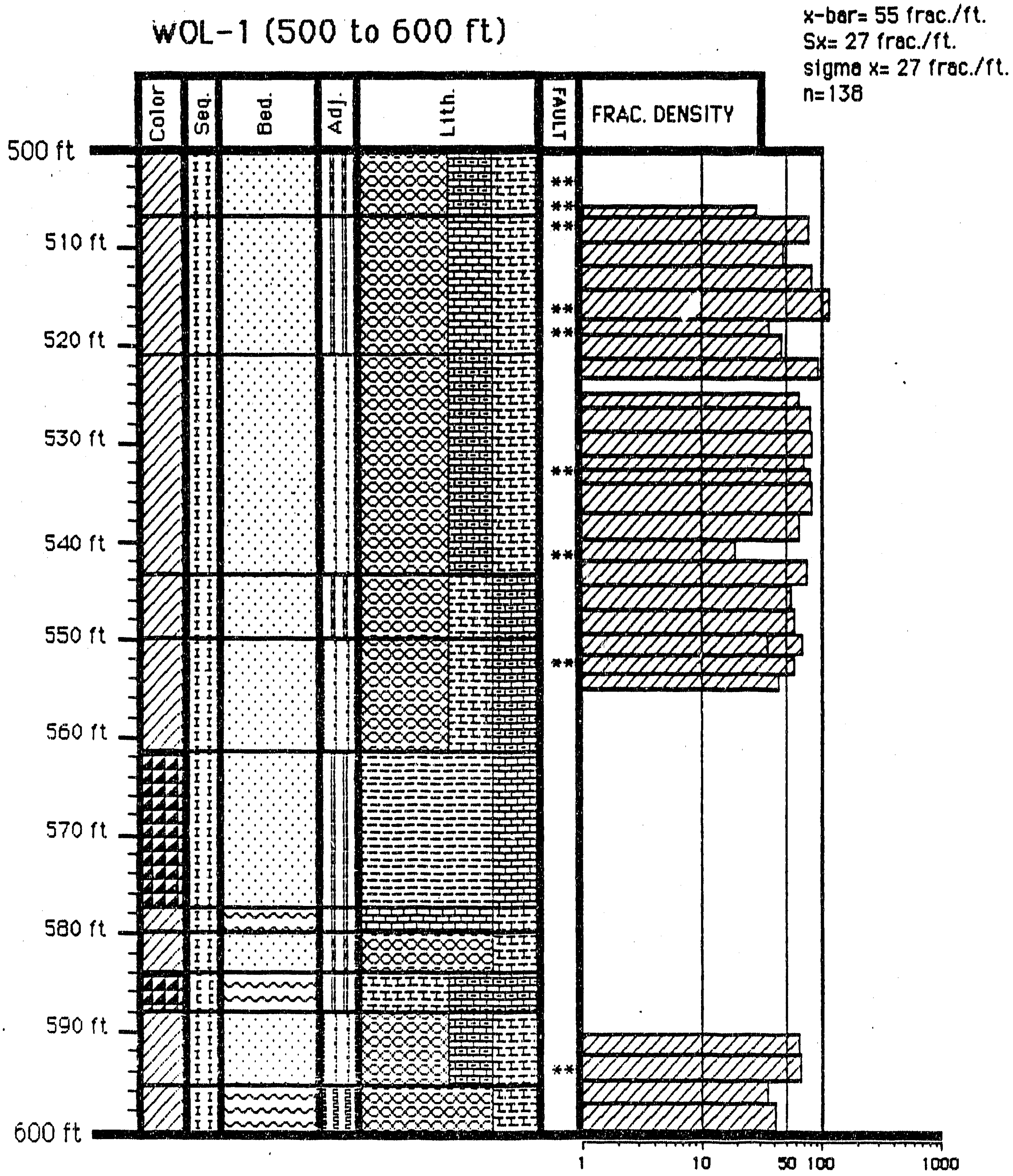


WOL-1 (300 to 400 ft)

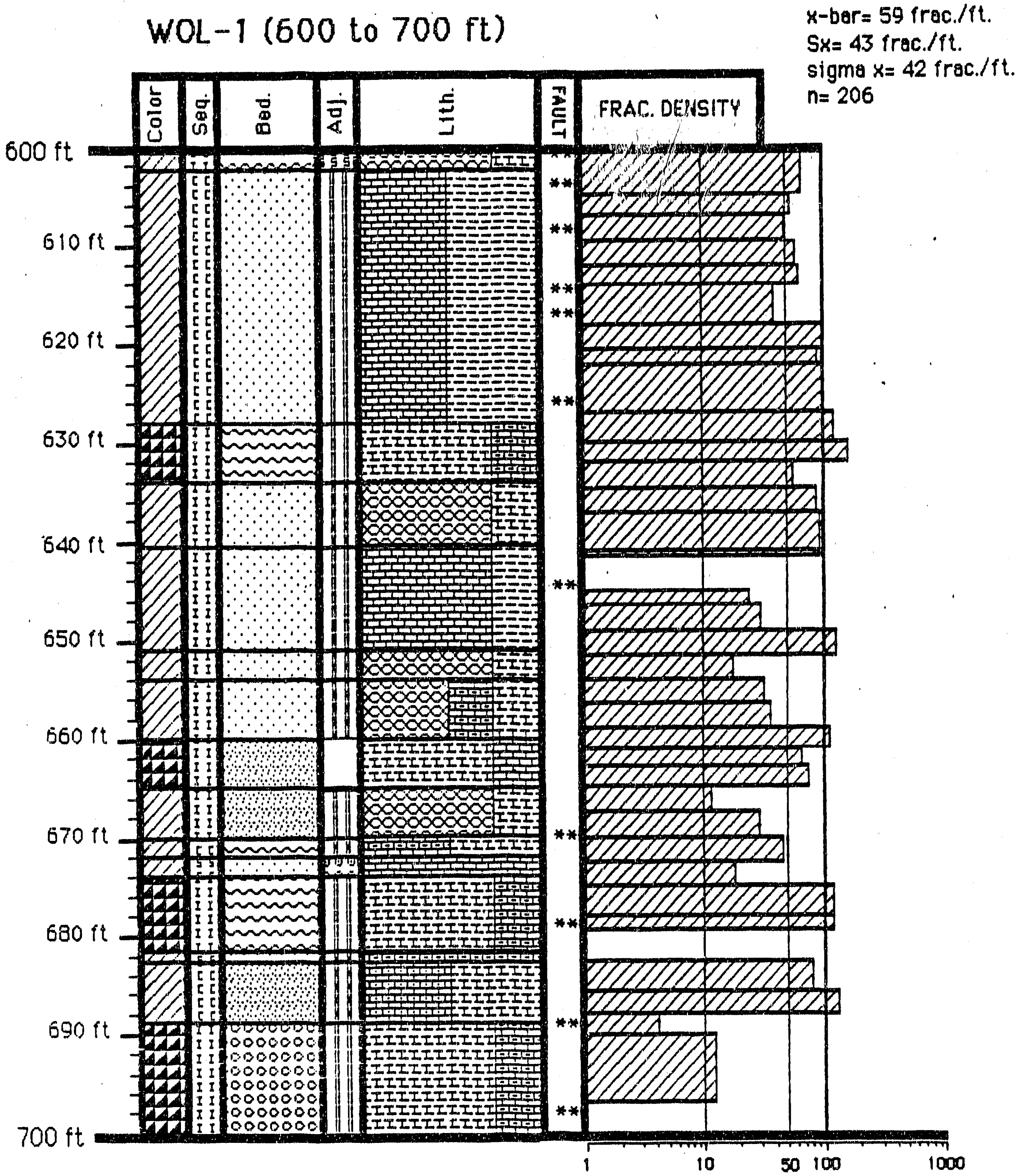




WOL-1 (400 to 500 ft)
x-bar= 36 frac./ft.
Sx= 22 frac./ft.
sigma x= 22 frac./ft.
n=90
Color
Seq.
Bed.
Adj.
Lith.
FAULT
FRAC. DENSITY
400 ft
410 ft
420 ft
430 ft
440 ft
450 ft
460 ft
470 ft
480 ft
490 ft
500 ft
1
10
50
100
1000

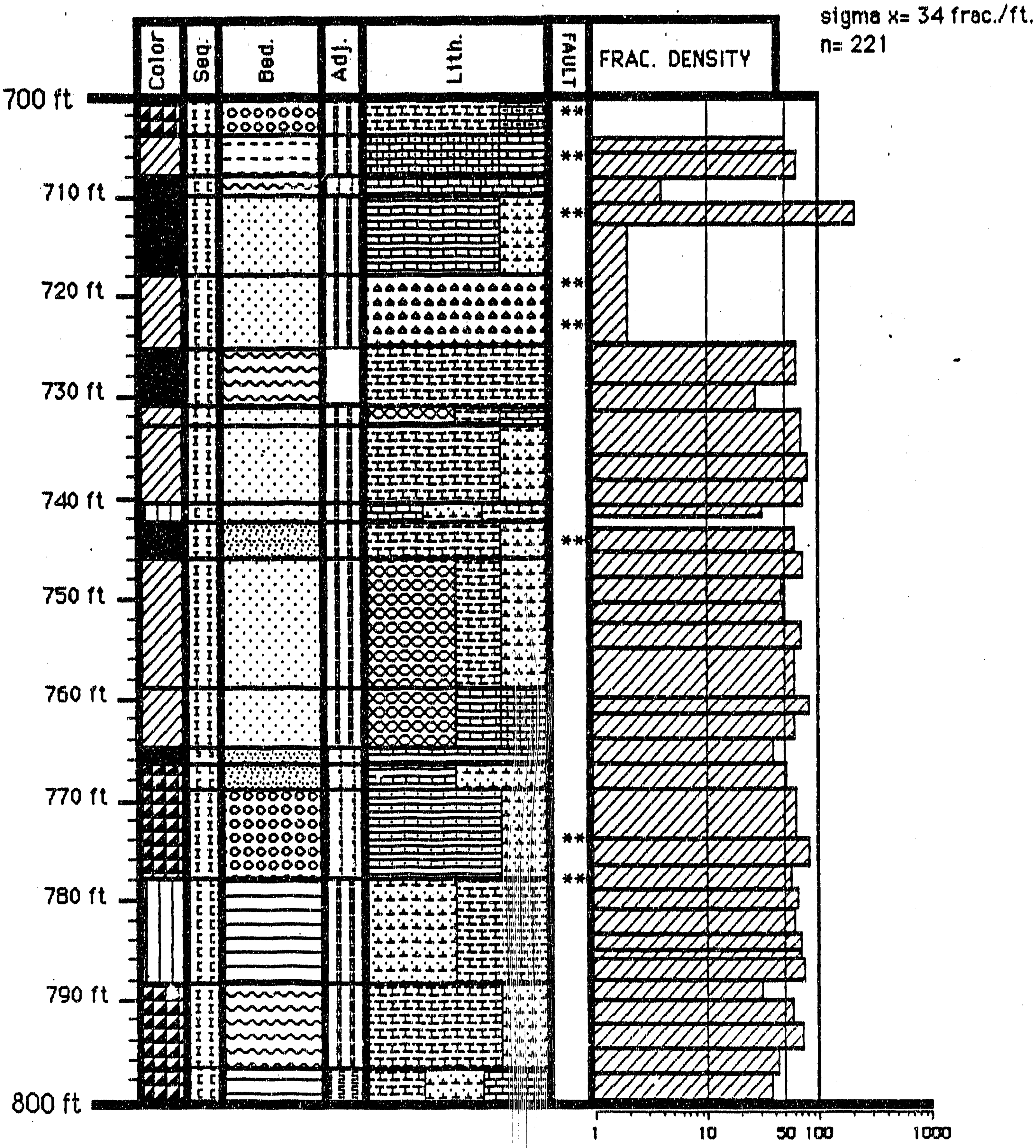


WOL-1 (500 to 600 ft)
x-bar= 55 frac./ft.
Sx= 27 frac./ft.
sigma x= 27 frac./ft.
n=138
Color
Seq.
Bed.
Adj.
Lith.
FAULT
FRAC. DENSITY
500 ft
510 ft
520 ft
530 ft
540 ft
550 ft
560 ft
570 ft
580 ft
590 ft
600 ft
1
10
50 100
1000



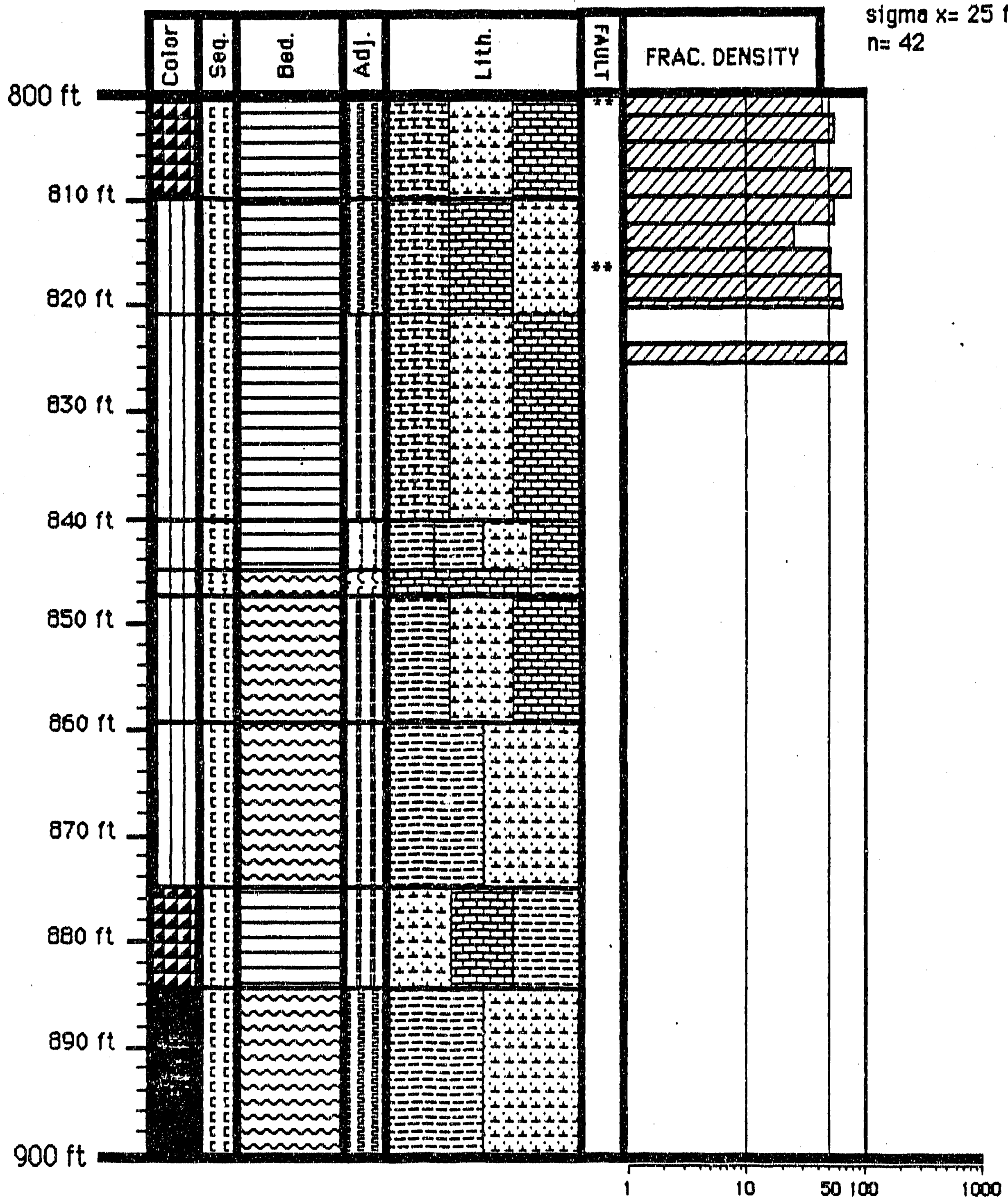
WOL-1 (600 to 700 ft)
x-bar= 59 frac./ft.
Sx= 43 frac./ft.
sigma x= 42 frac./ft.
n= 206
Color
Seq.
Bed.
Adj.
Lith.
FAULT
FRAC. DENSITY
600 ft
610 ft
620 ft
630 ft
640 ft
650 ft
660 ft
670 ft
680 ft
690 ft
700 ft
1
10
50
100
1000

WOL-1 (700 to 800 ft)

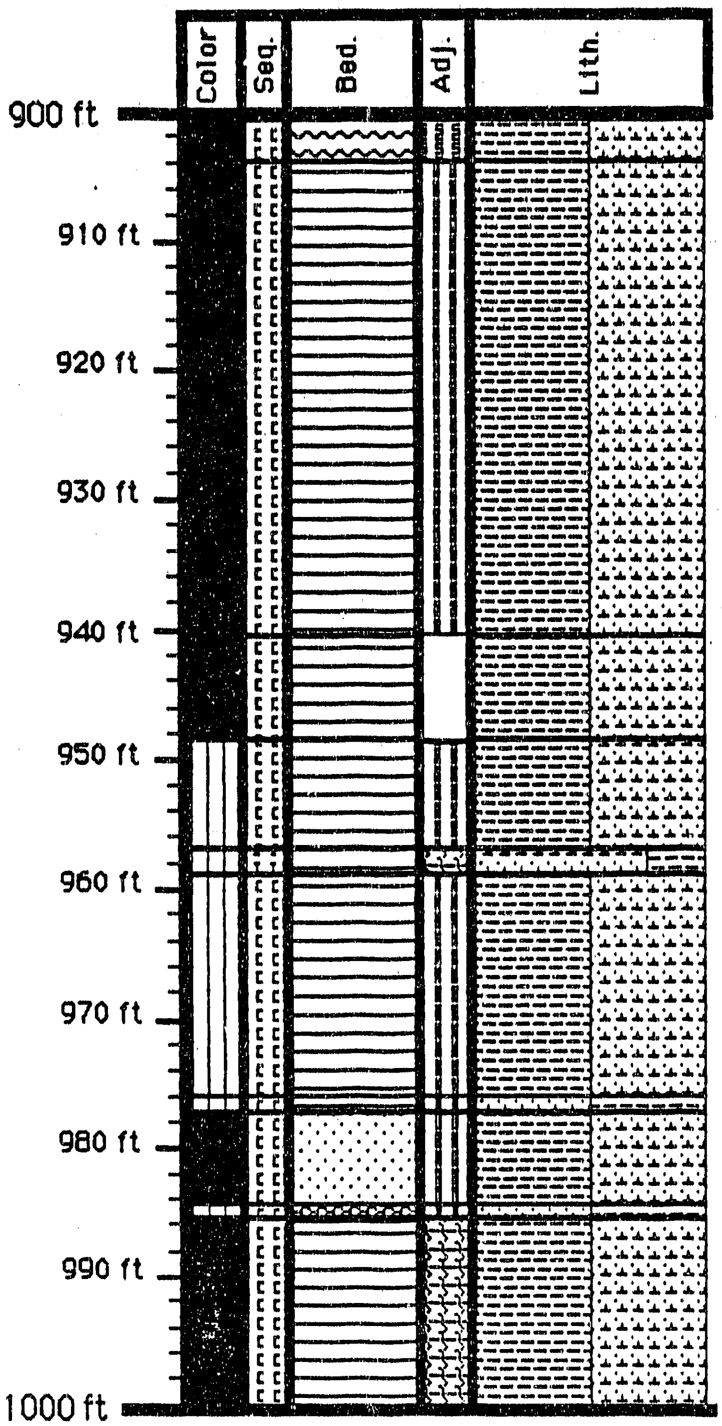


WOL-1 (800 to 900 ft)

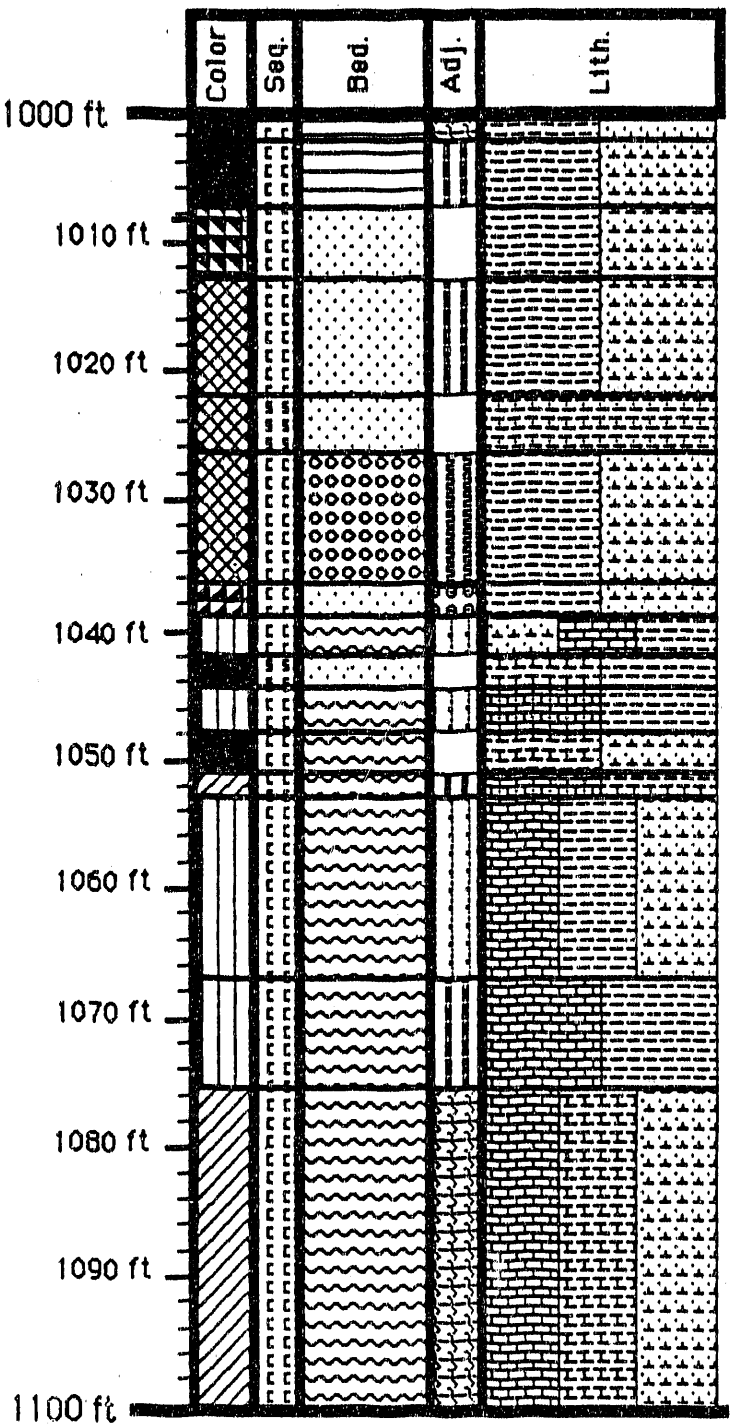
x-bar= 47 frac./ft.
Sx= 25 frac./ft.
sigma x= 25 frac./ft.
n= 42



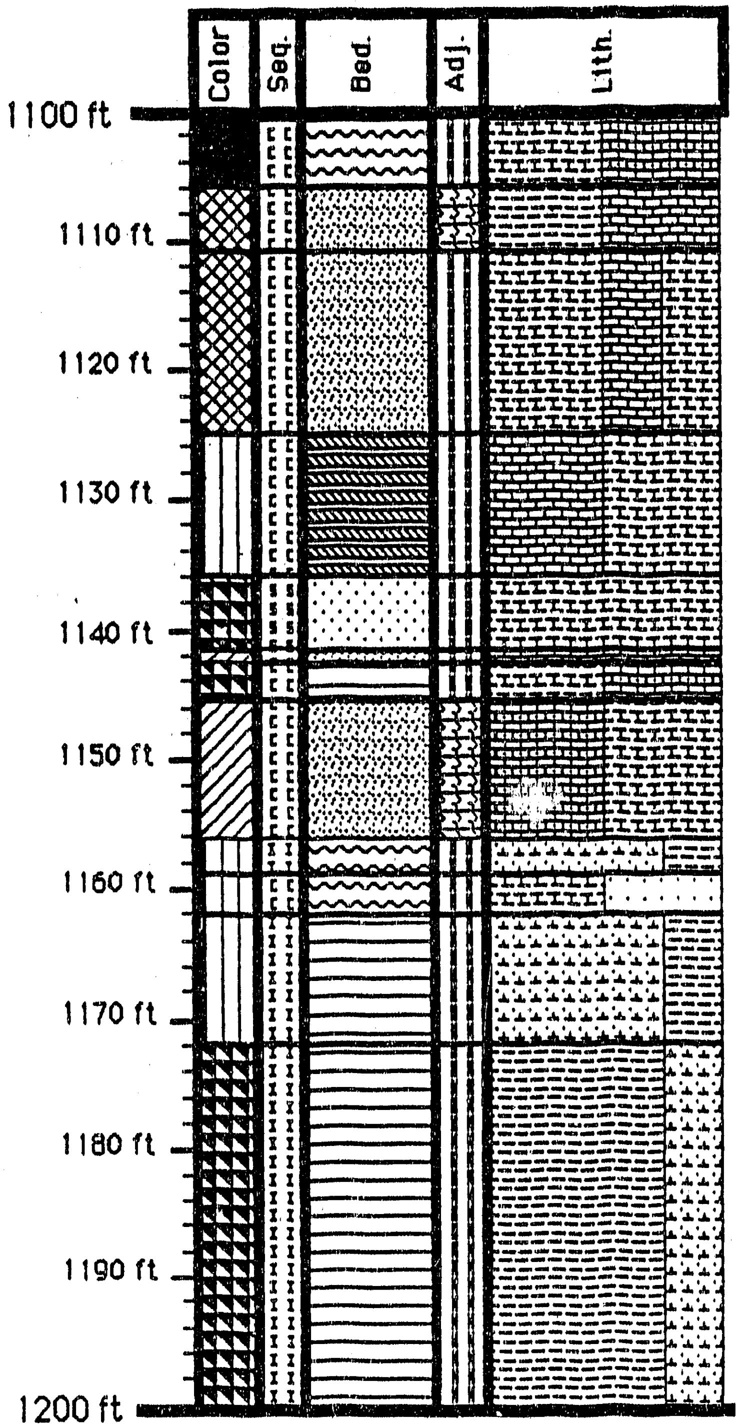
WOL-1 (900 to 1000 ft)



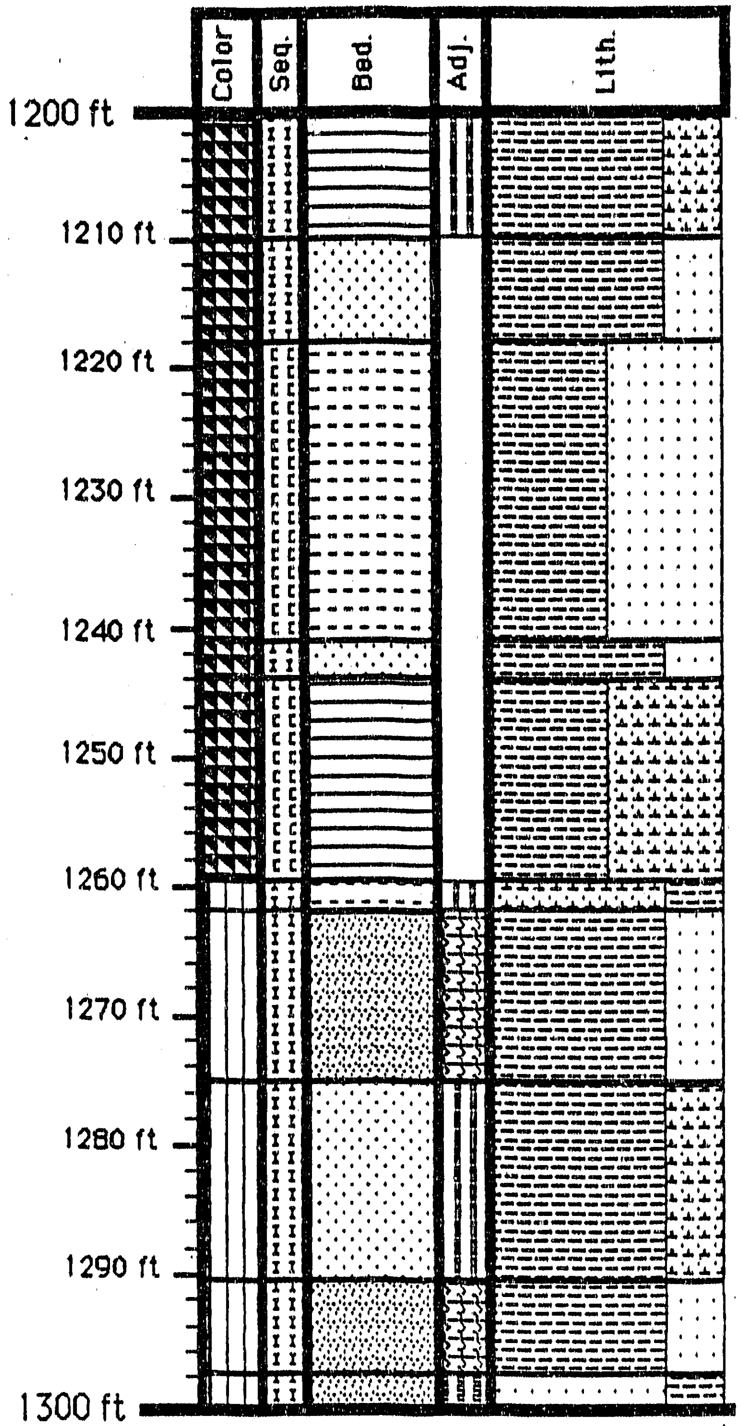
WOL-1 (1000 to 1100 ft)



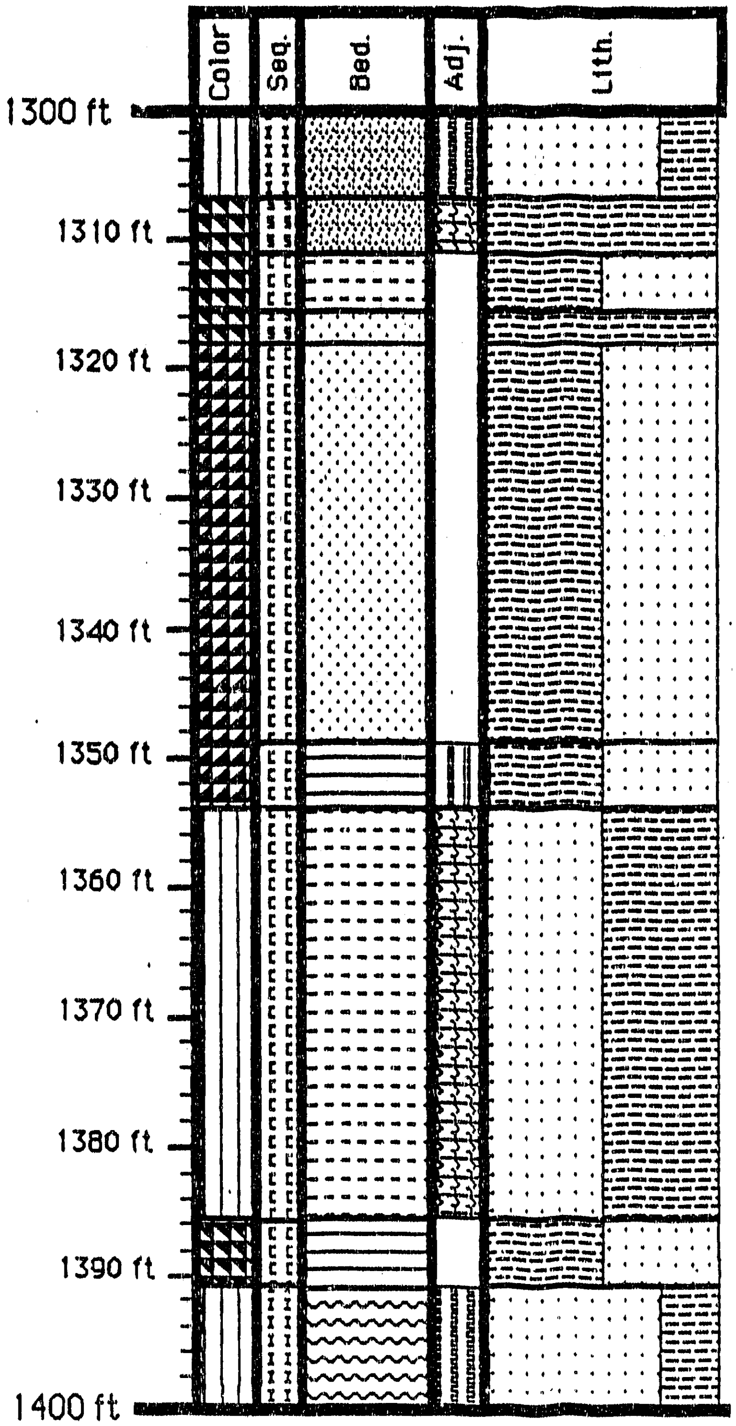
WOL-1 (1100 to 1200 ft)



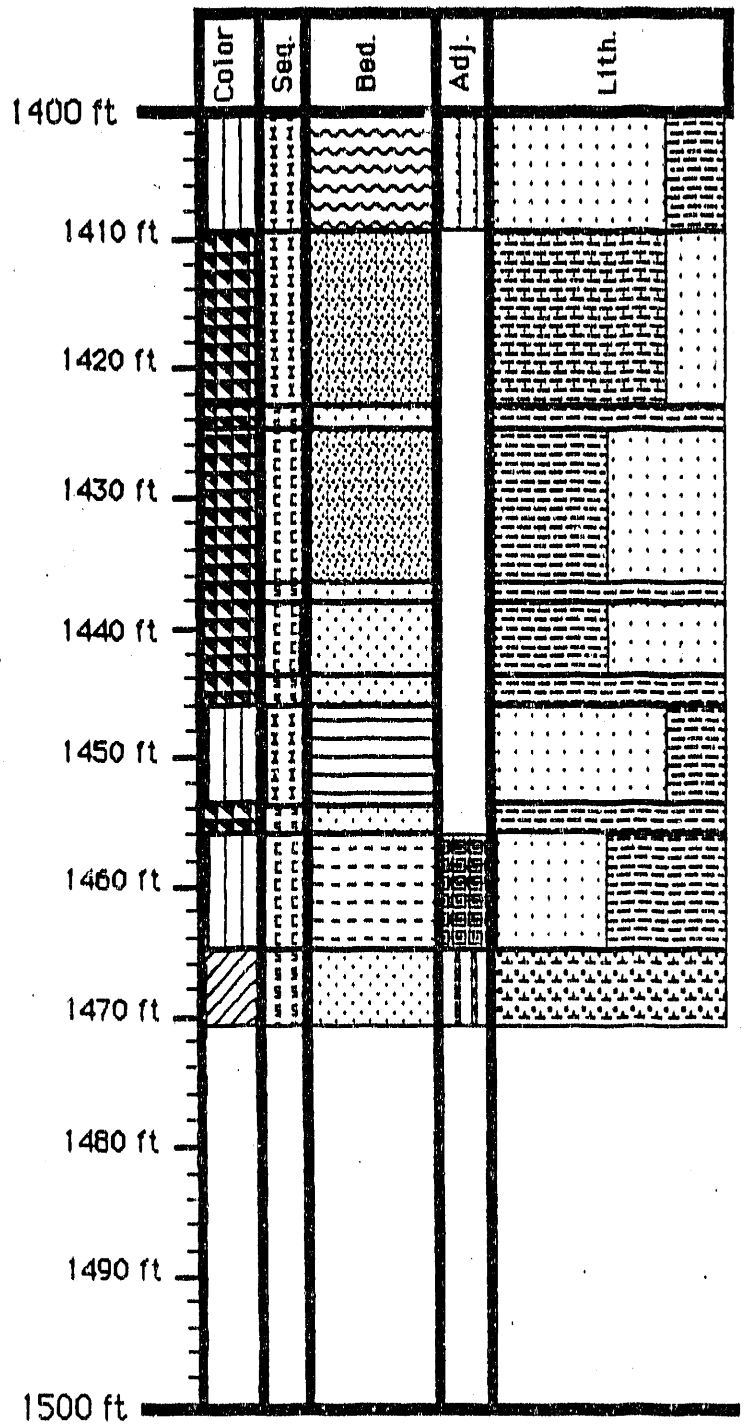
WOL-1 (1200 to 1300 ft)



WOL-1 (1300 to 1400 ft)



WOL-1 (1400 to 1500 ft)



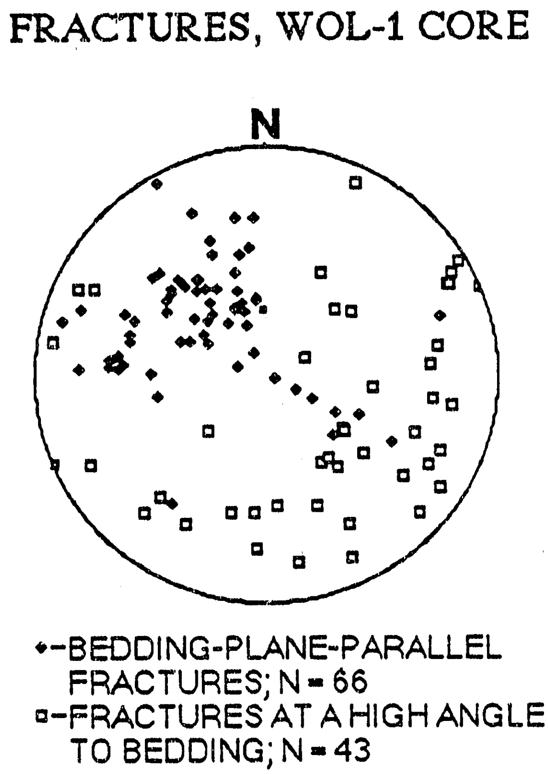


Figure 6.9 Stereogram of oriented core.

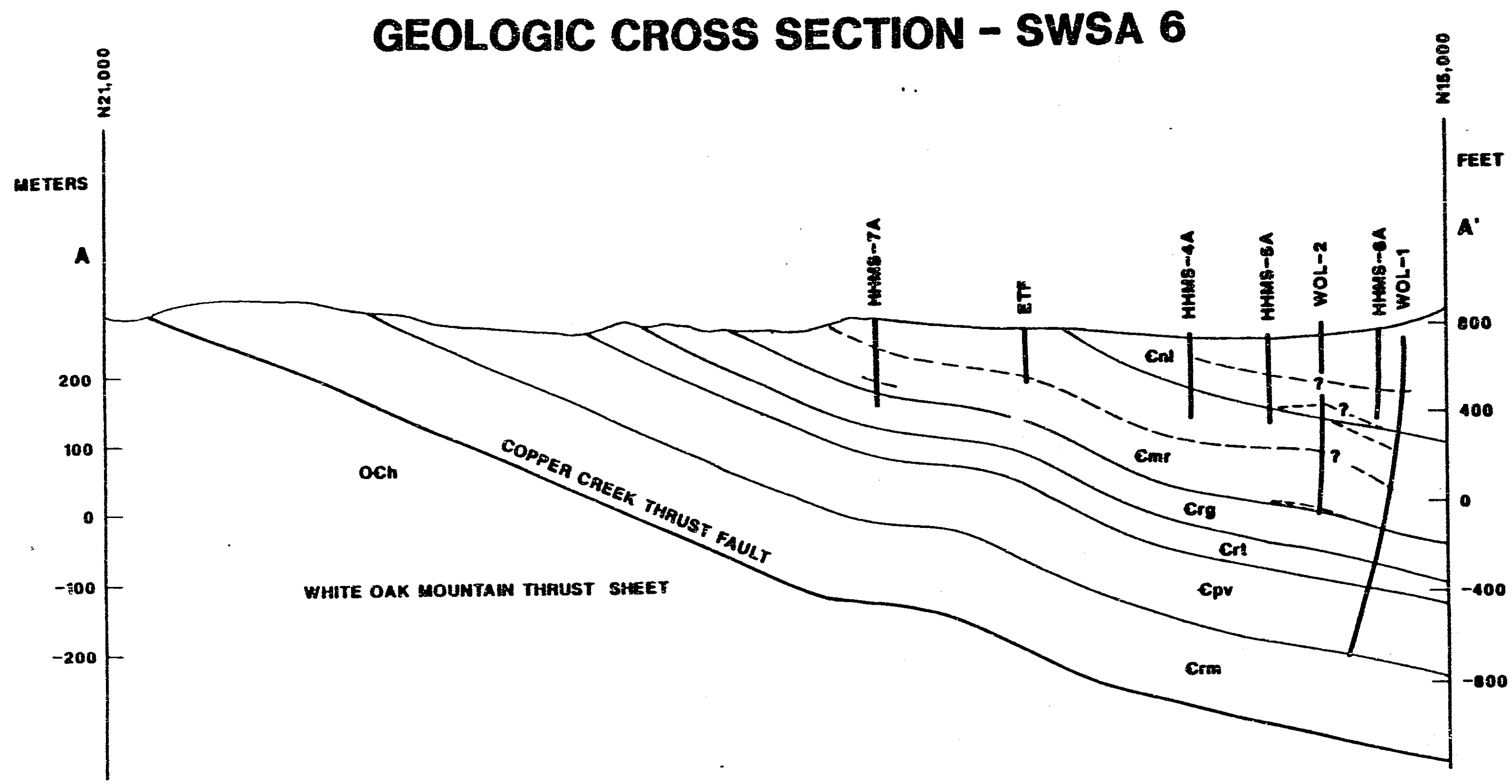
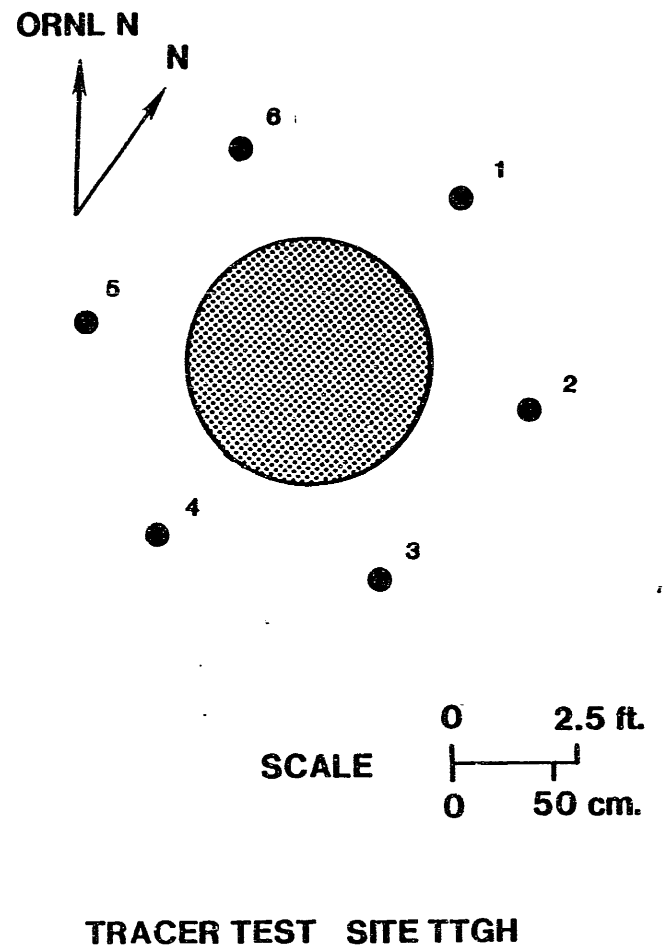


Figure 6.10 SWSA 6 cross-section.



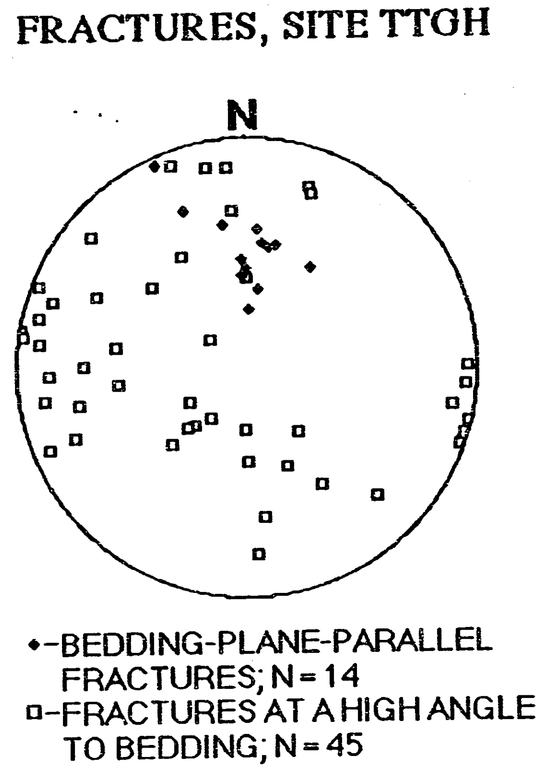


Figure 6.11 TTGH base map and fracture stereograms.

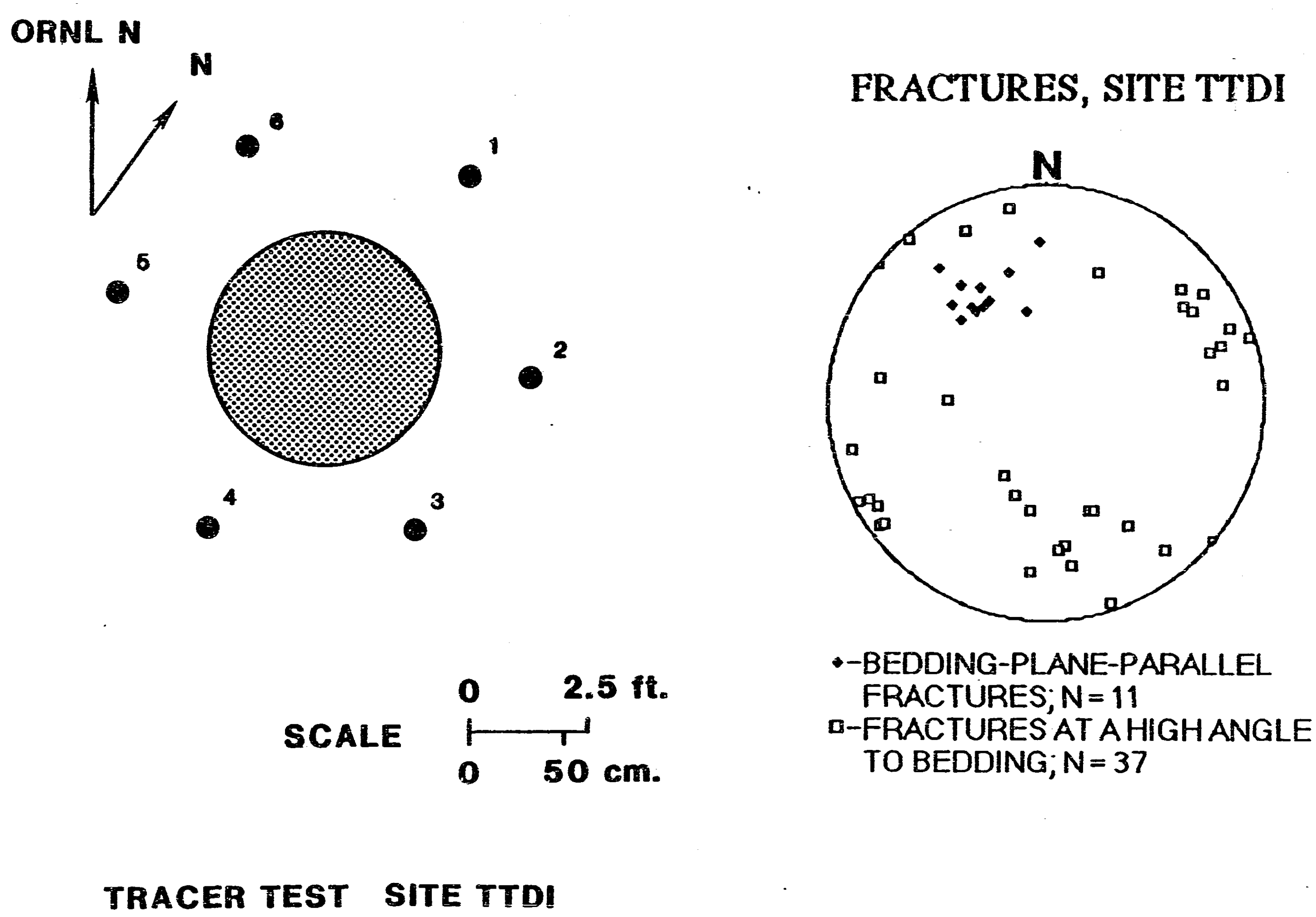
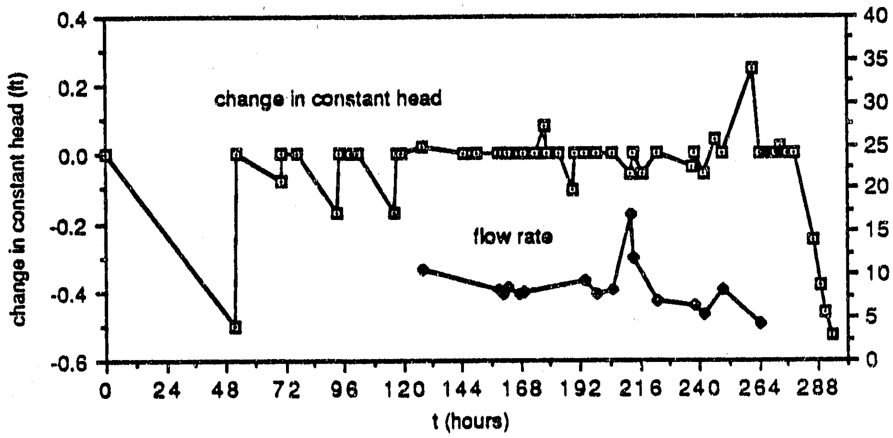


Figure 6.12 TTDI base map and fracture stereograms.

TTGH injection hole data



TTDI injection hole data

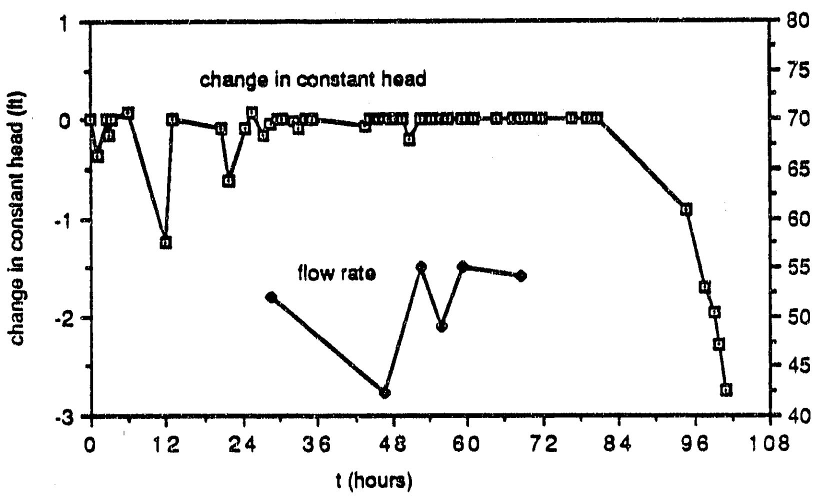


Figure 6.13 TTGH and TTDI injection hole data.

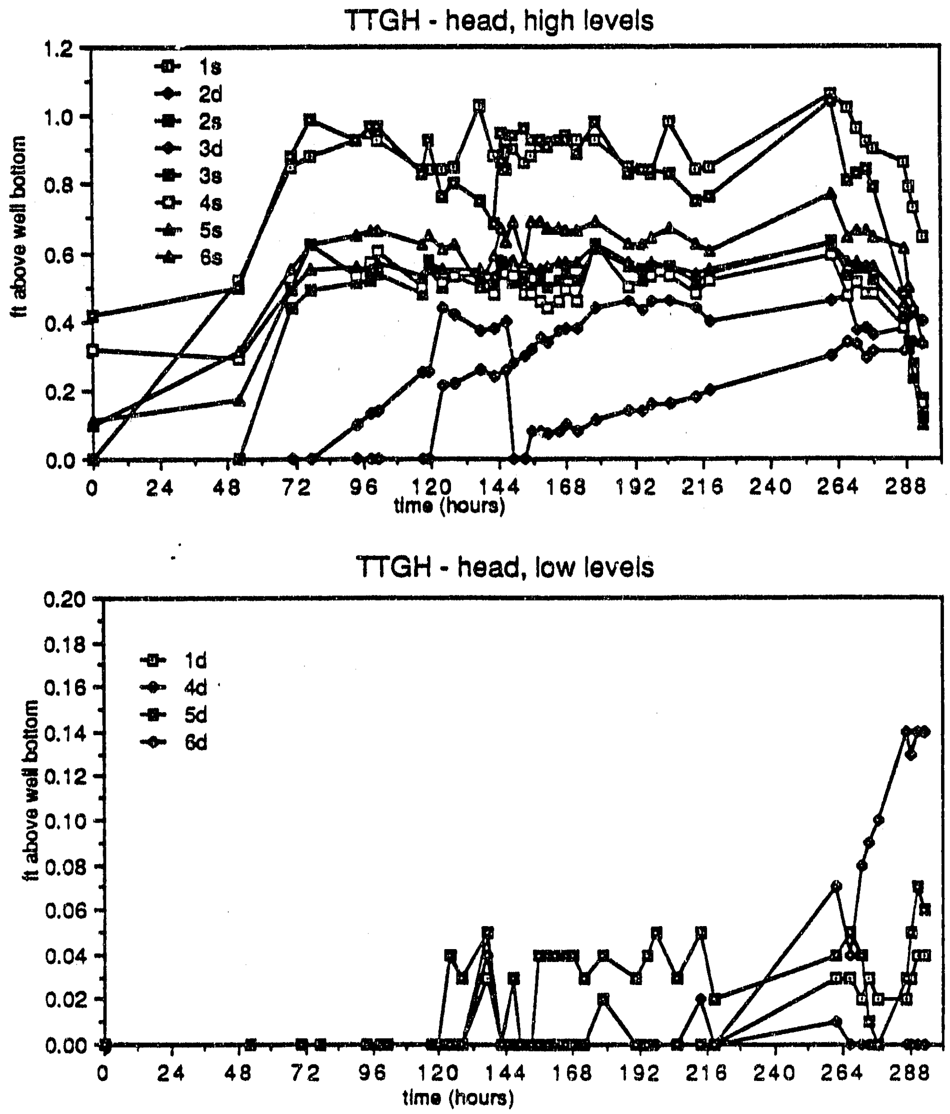


Figure 6.14 TTGH head data.

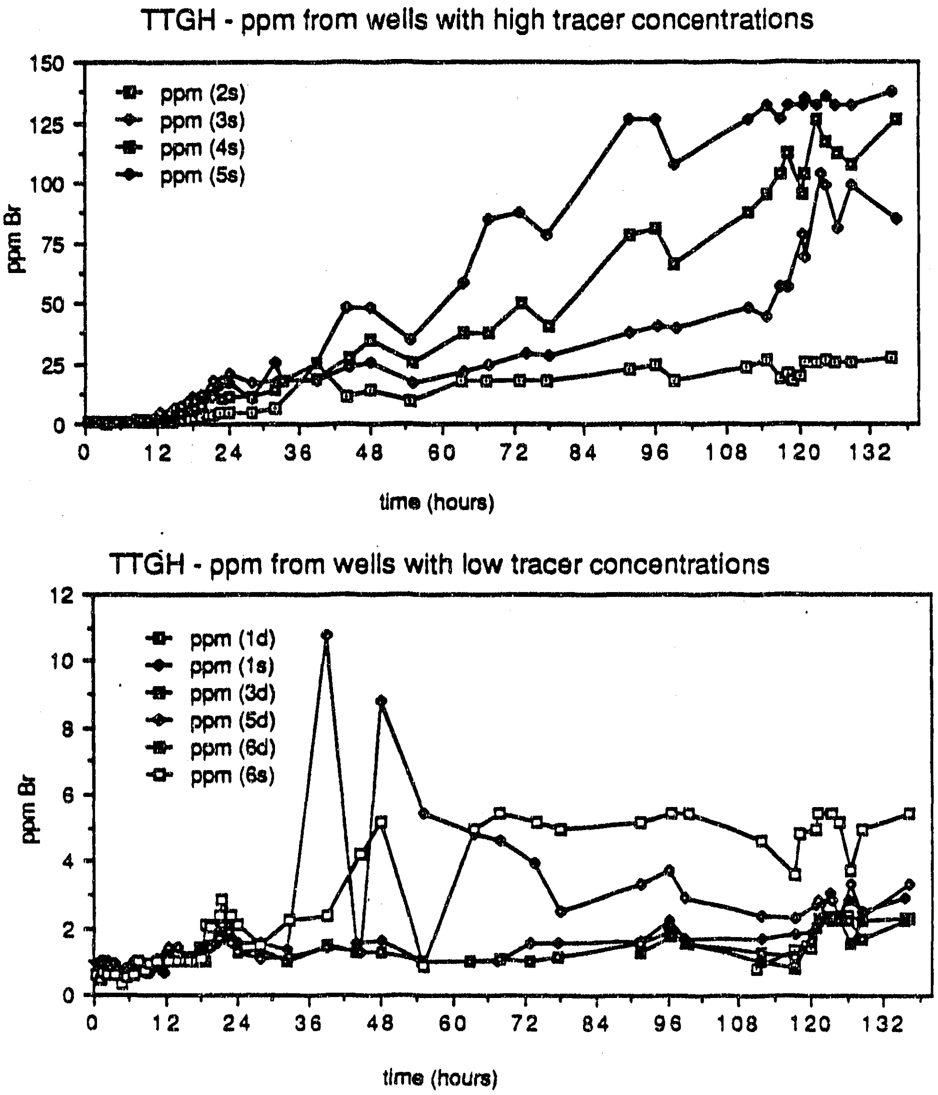


Figure 6.15 TTGH concentration curves.

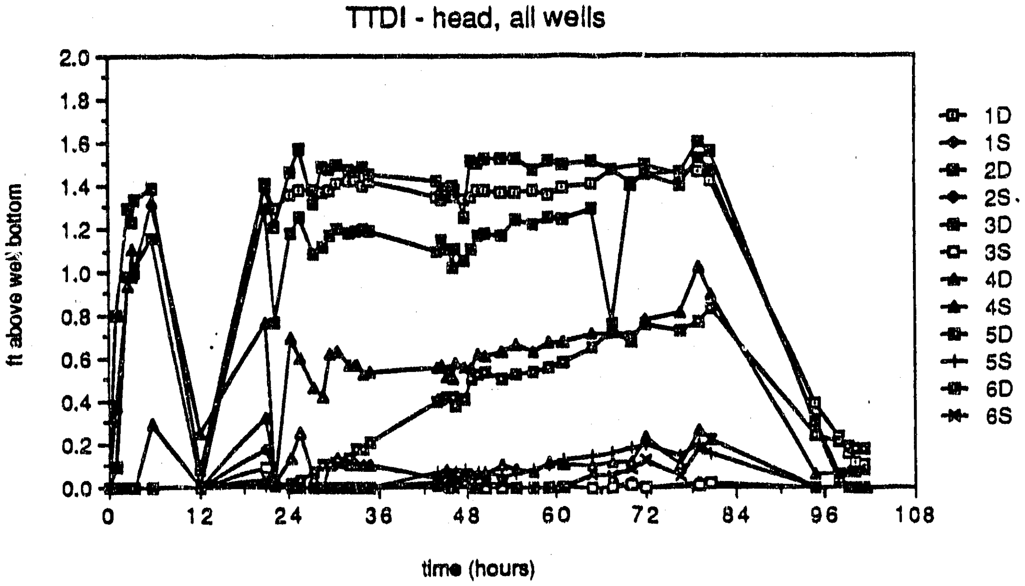
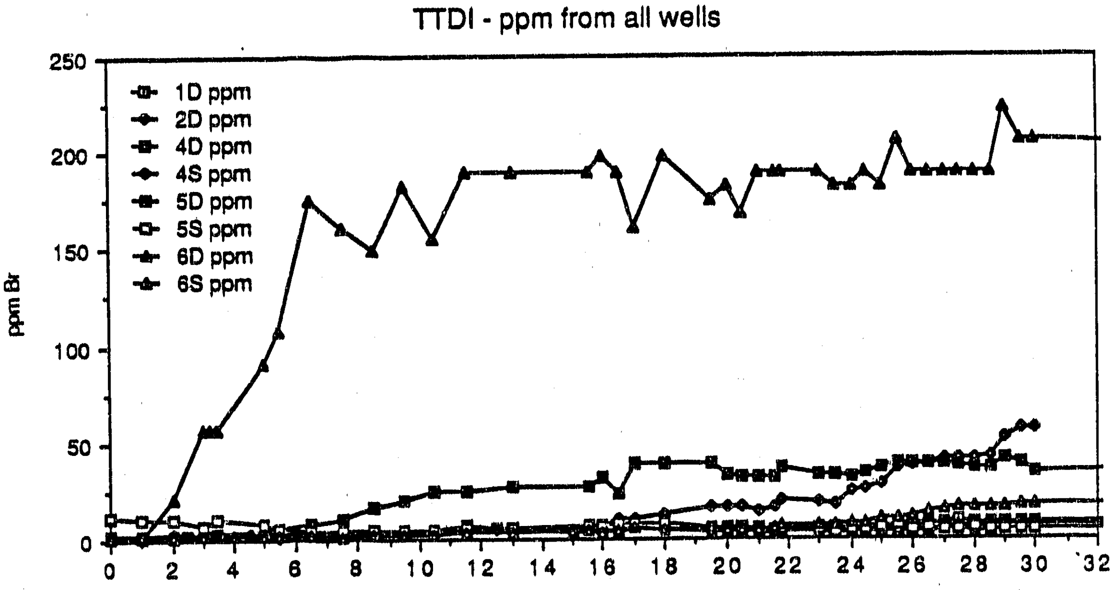
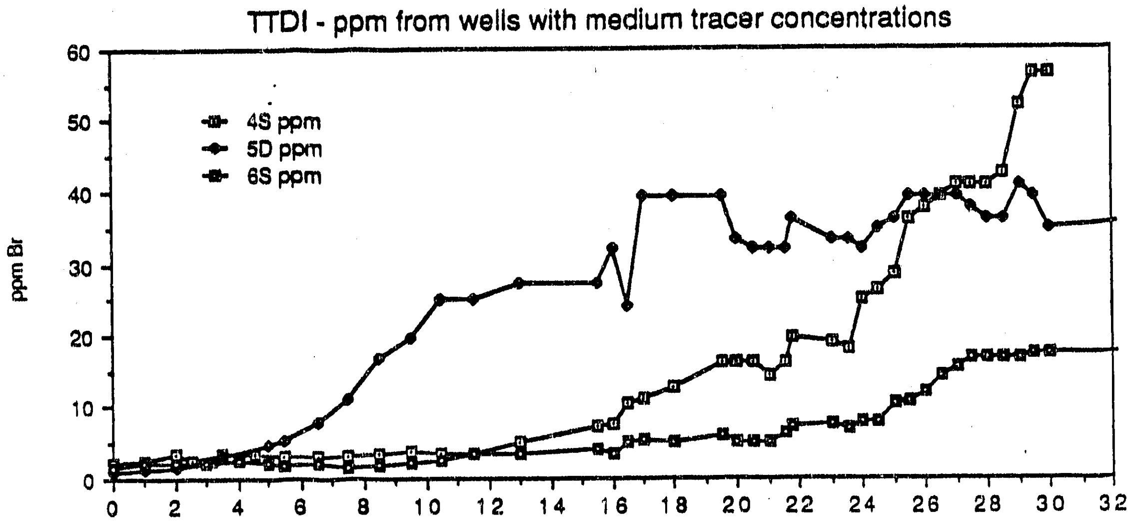


Figure 6.16 TTDI head data.





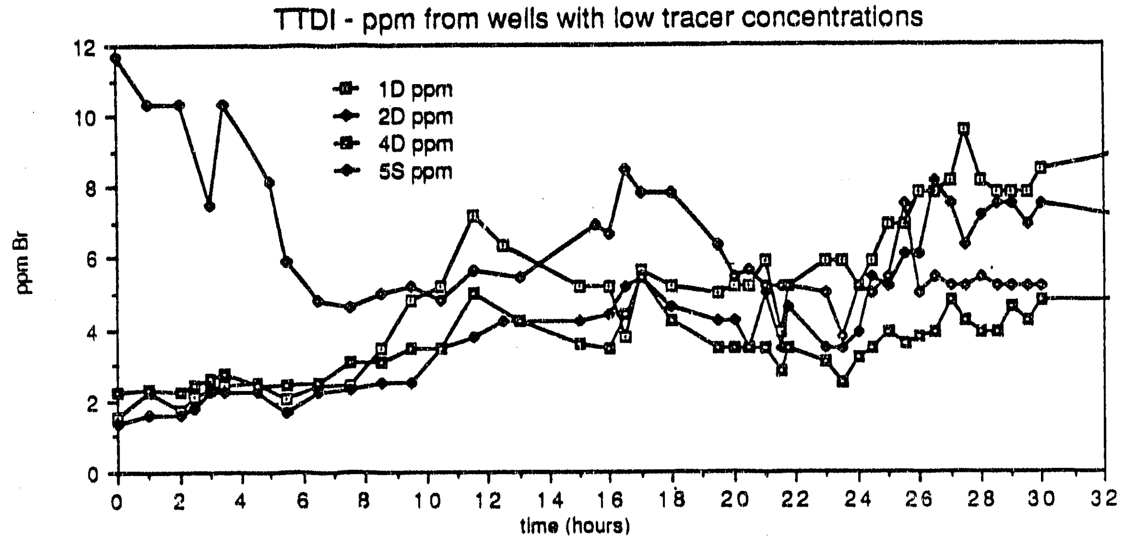


Figure 6.17 TTDI concentration curves.

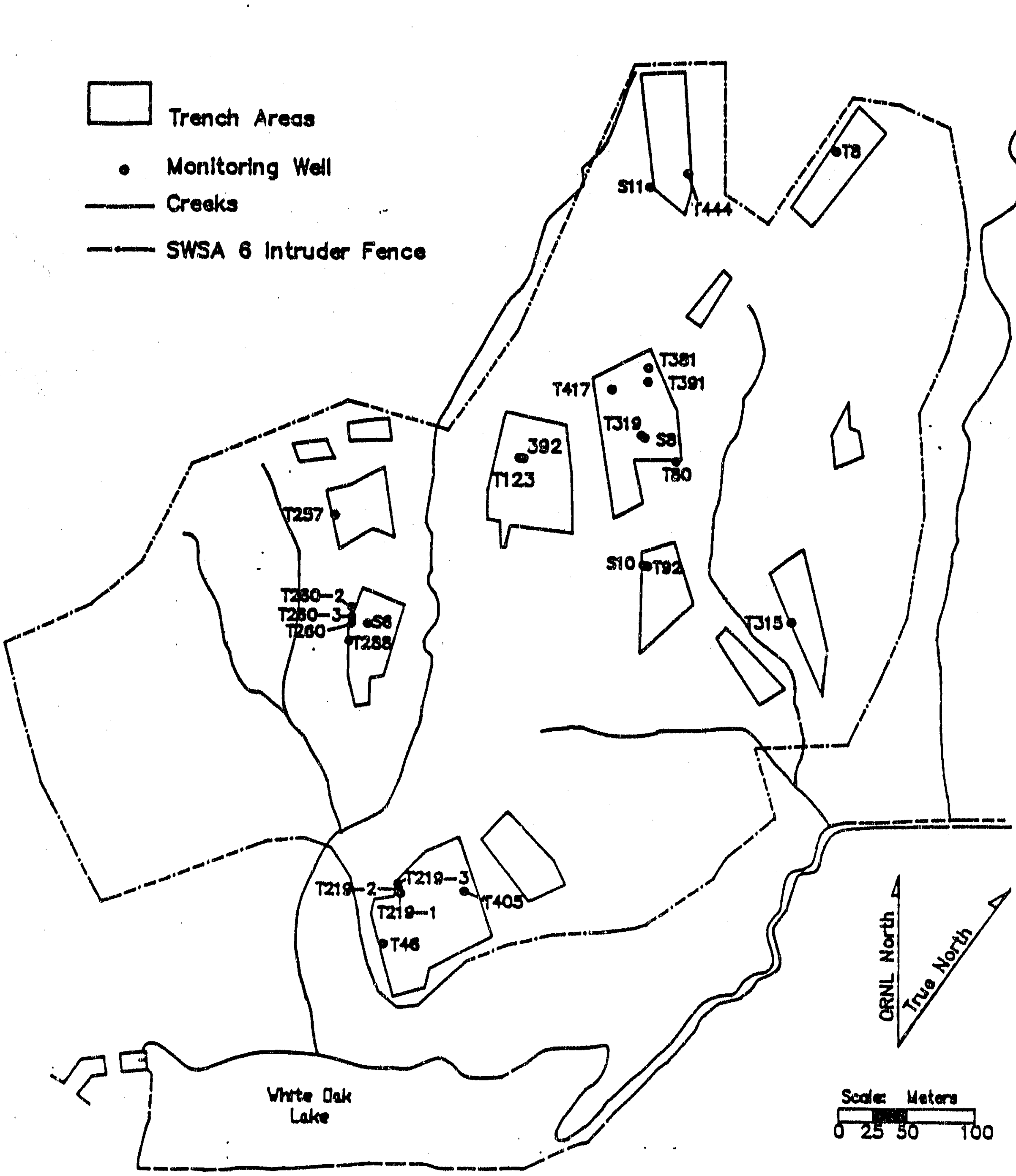


Figure 7.1 Location of monitoring wells used in study of trench-water dynamics in SWSA 6.

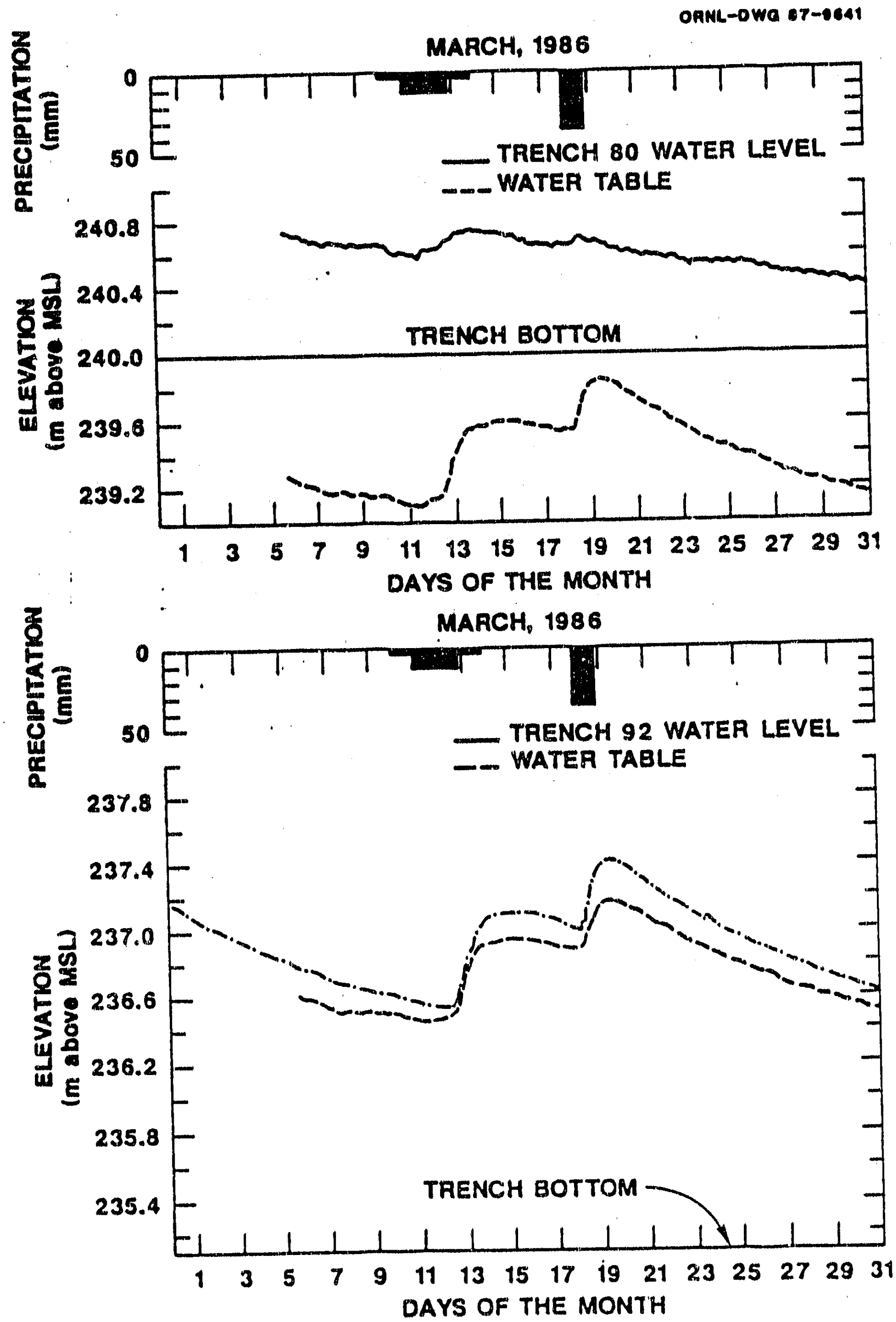


Figure 7.2 Hydrographs of typical trench monitoring wells in which data was collected using automatic recording equipment.

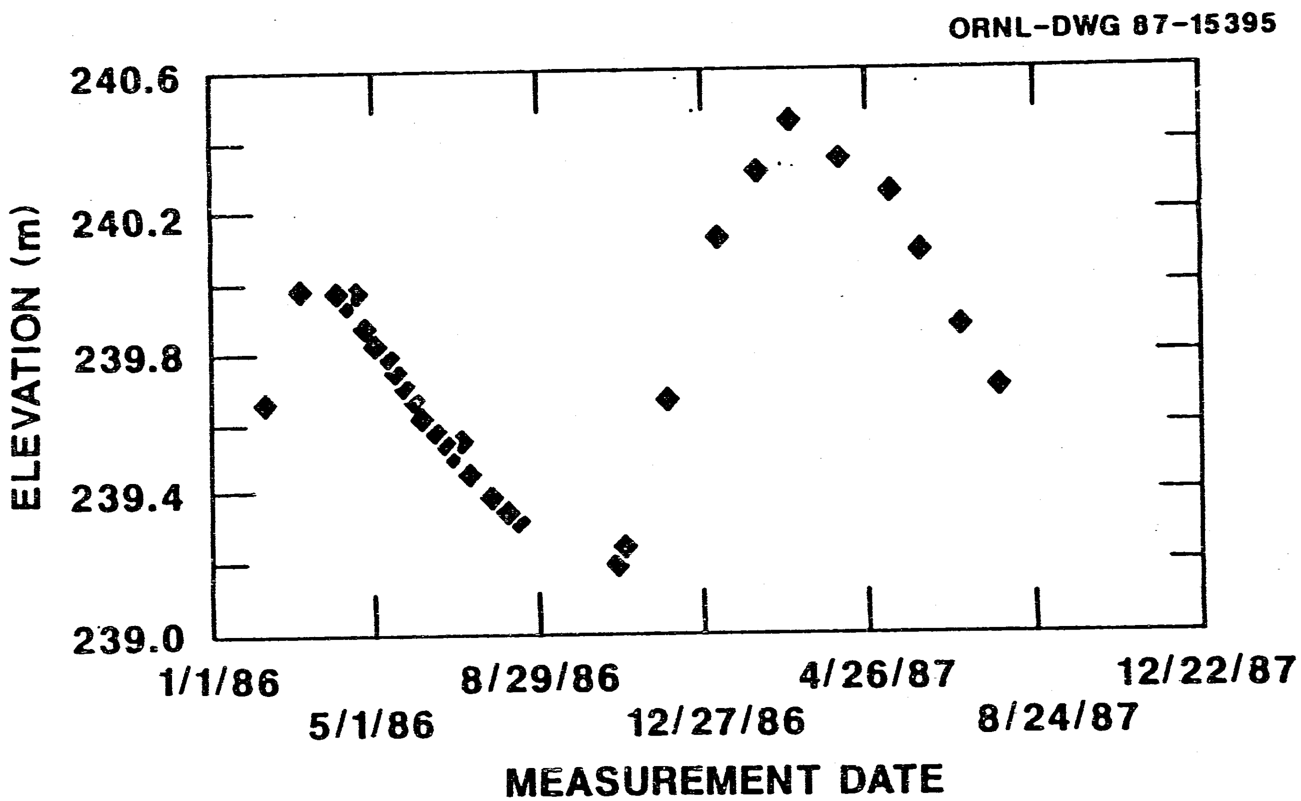


Figure 7.3 Hydrograph of typical monitori:g well in which data was collected manually.

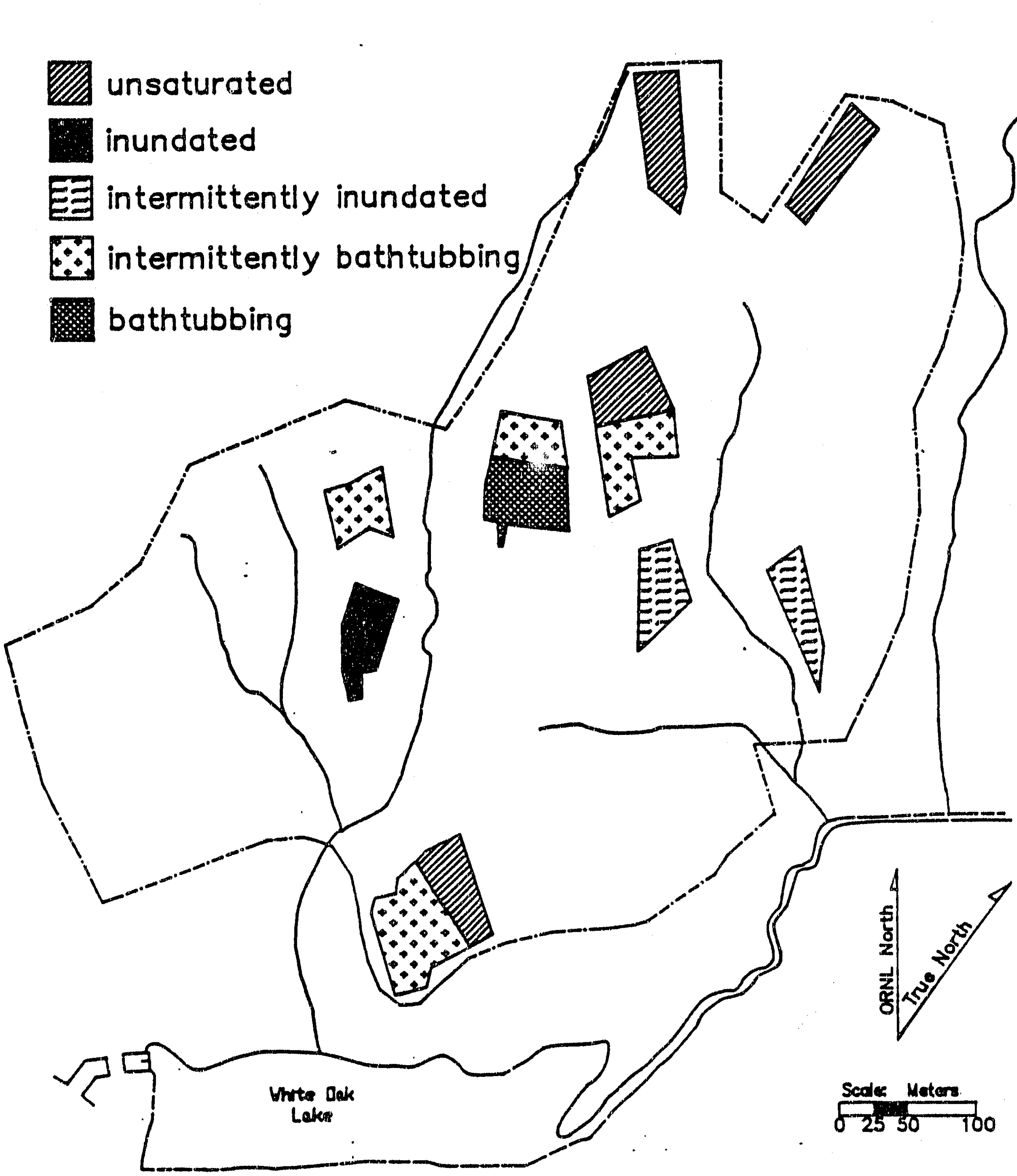


Figure 7.4 Hydrologic condition of trench groups in SWSA 6.

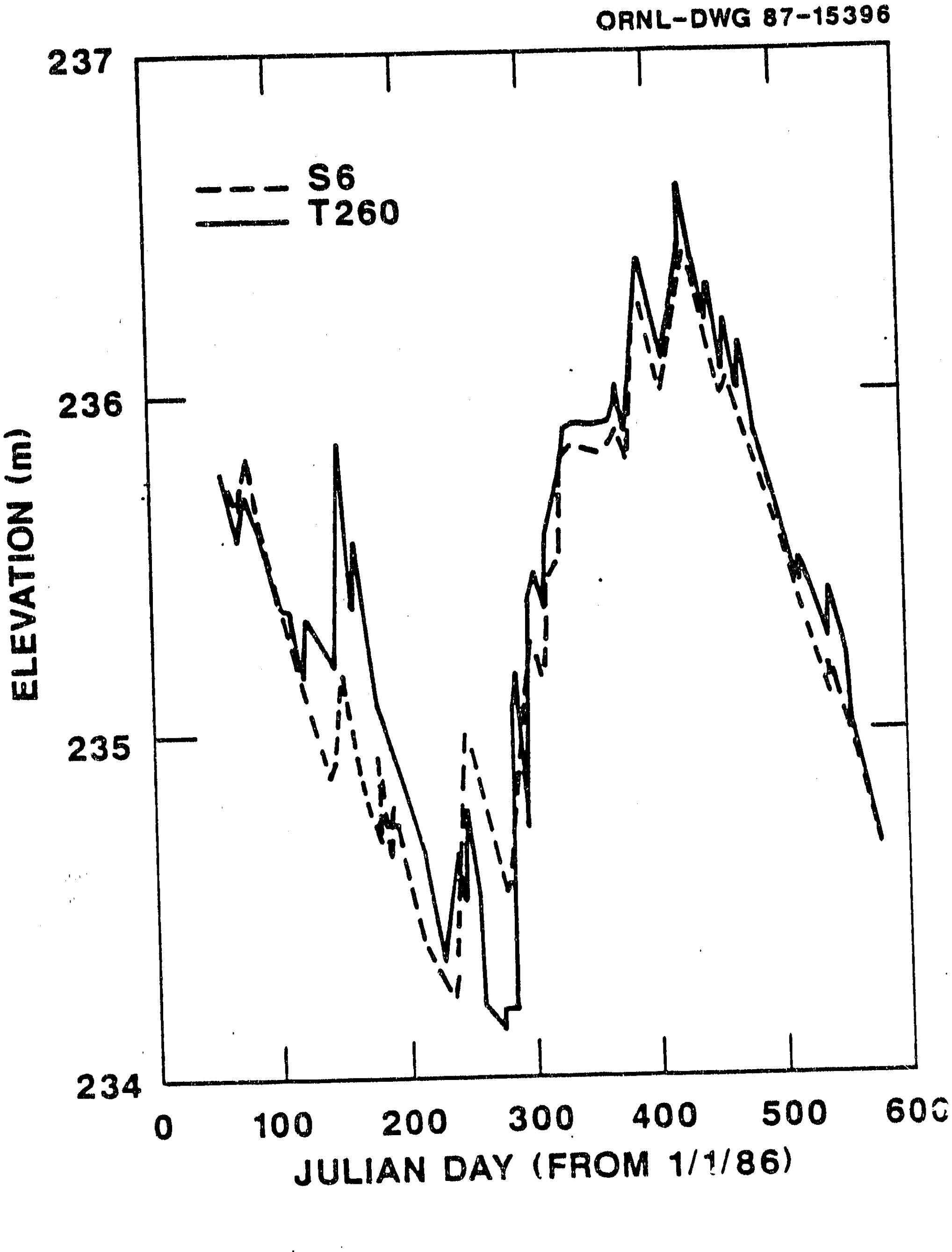


Figure 7.5 Hydrographs for monitoring wells T260 and S6 in SWSA 6.

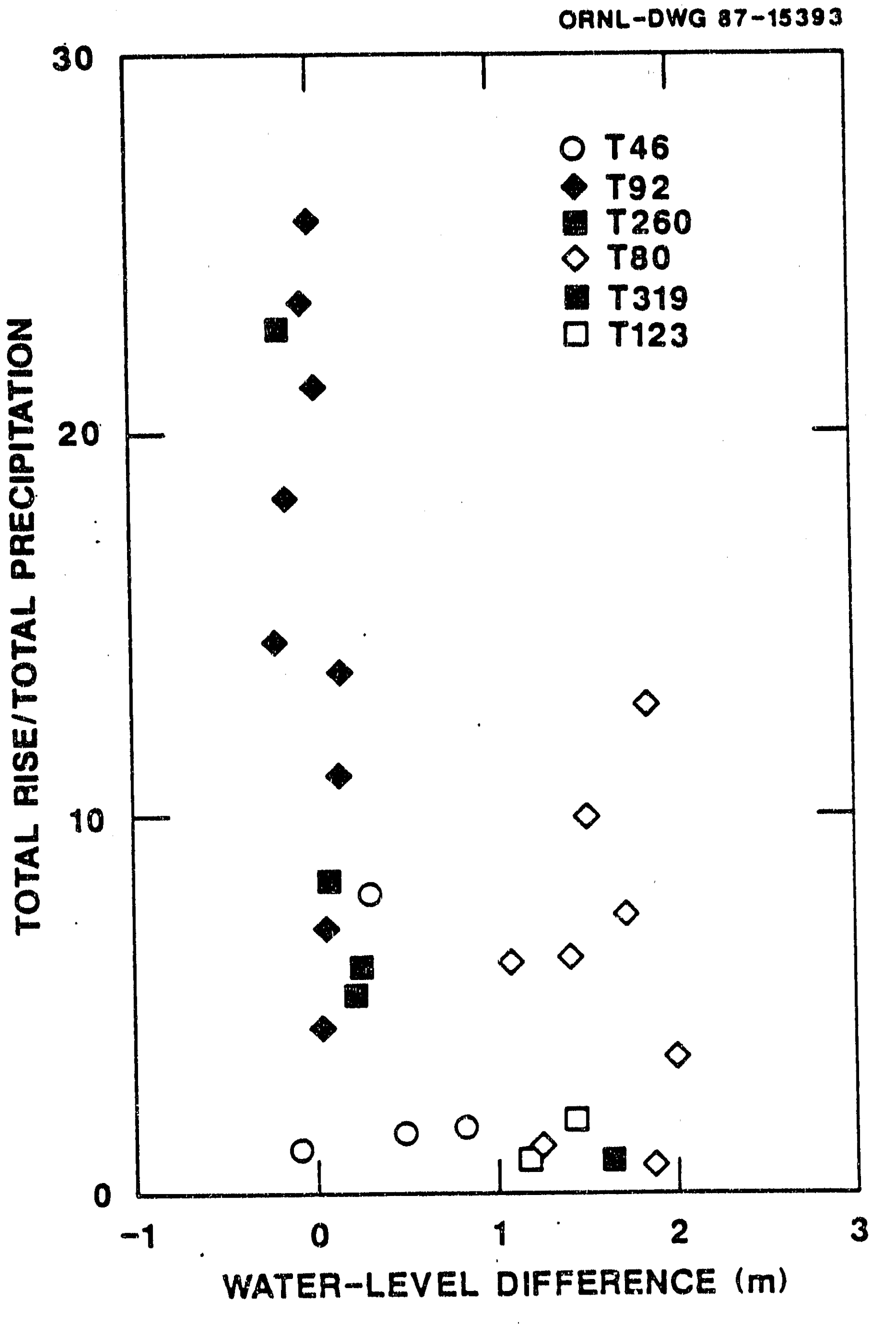


Figure 7.6 Relation of trench water-level rise normalized by total precipitation to the water-level difference between trench and adjacent water-table elevations.

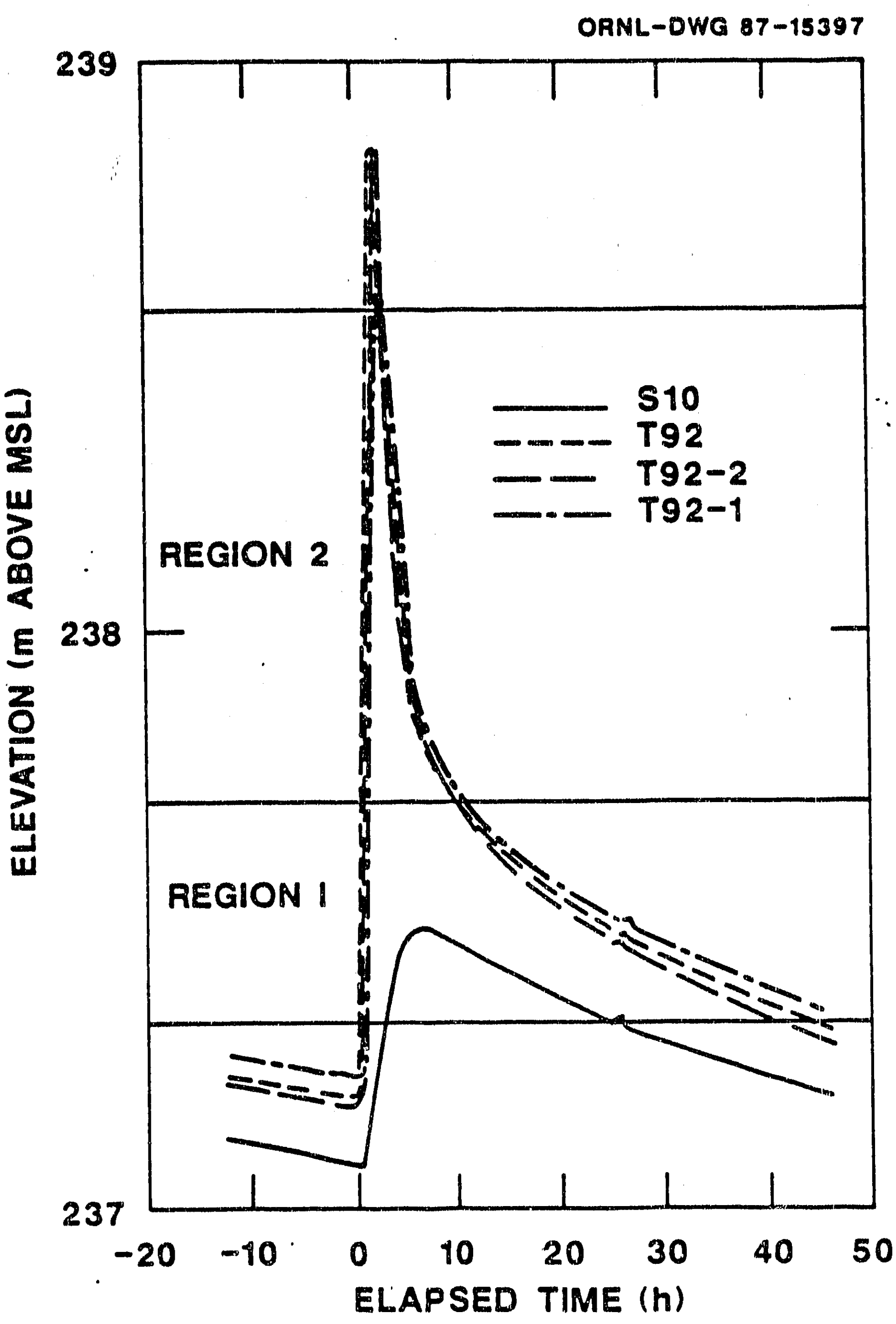


Figure 7.7 Hydrograph of pump test on trench 92 in SWSA 6.

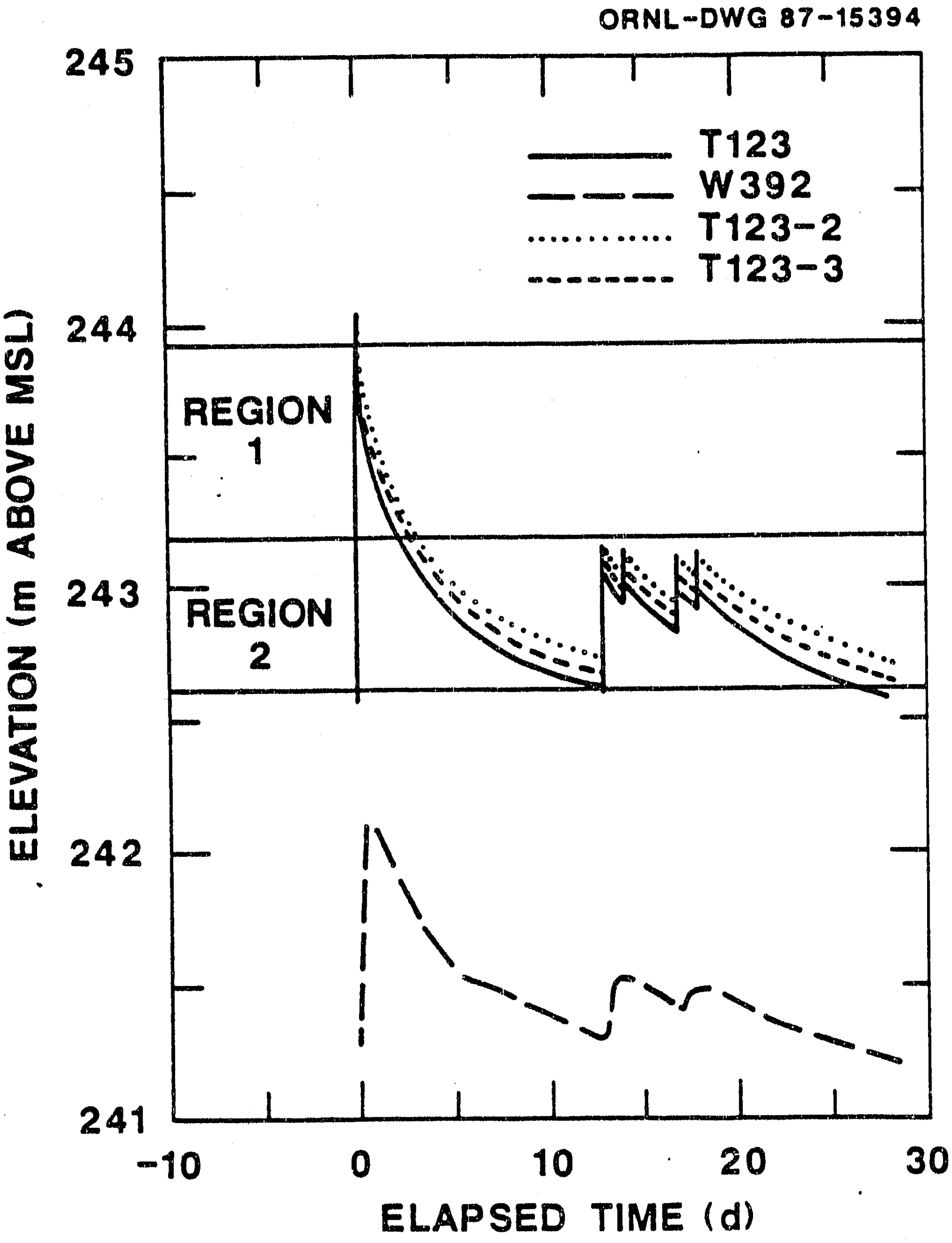


Figure 7.8 Hydrograph of pump test on trench 123 in SWSA 6.

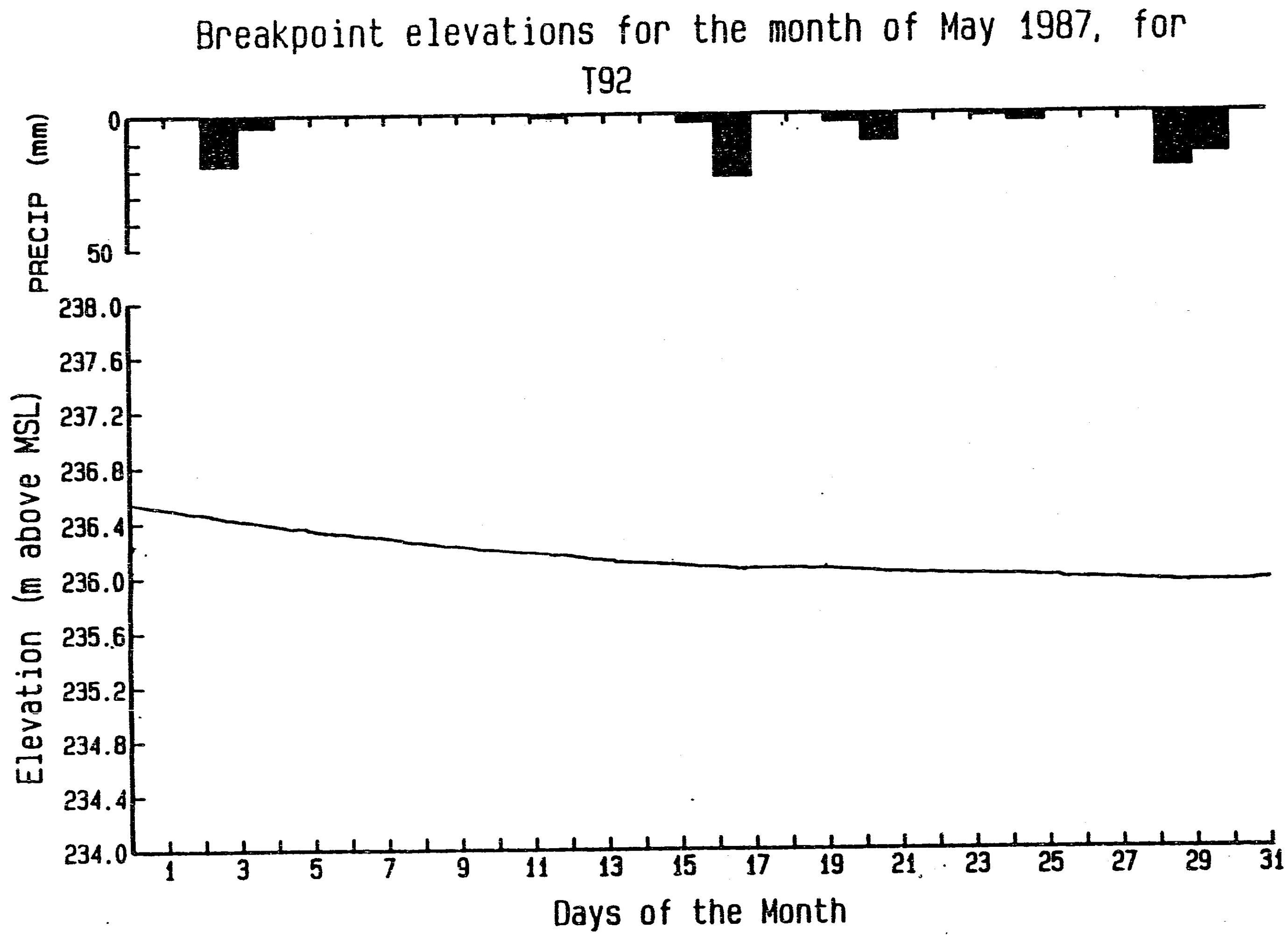


Figure 7.9 Hydrograph of trench 92 during May 1987.

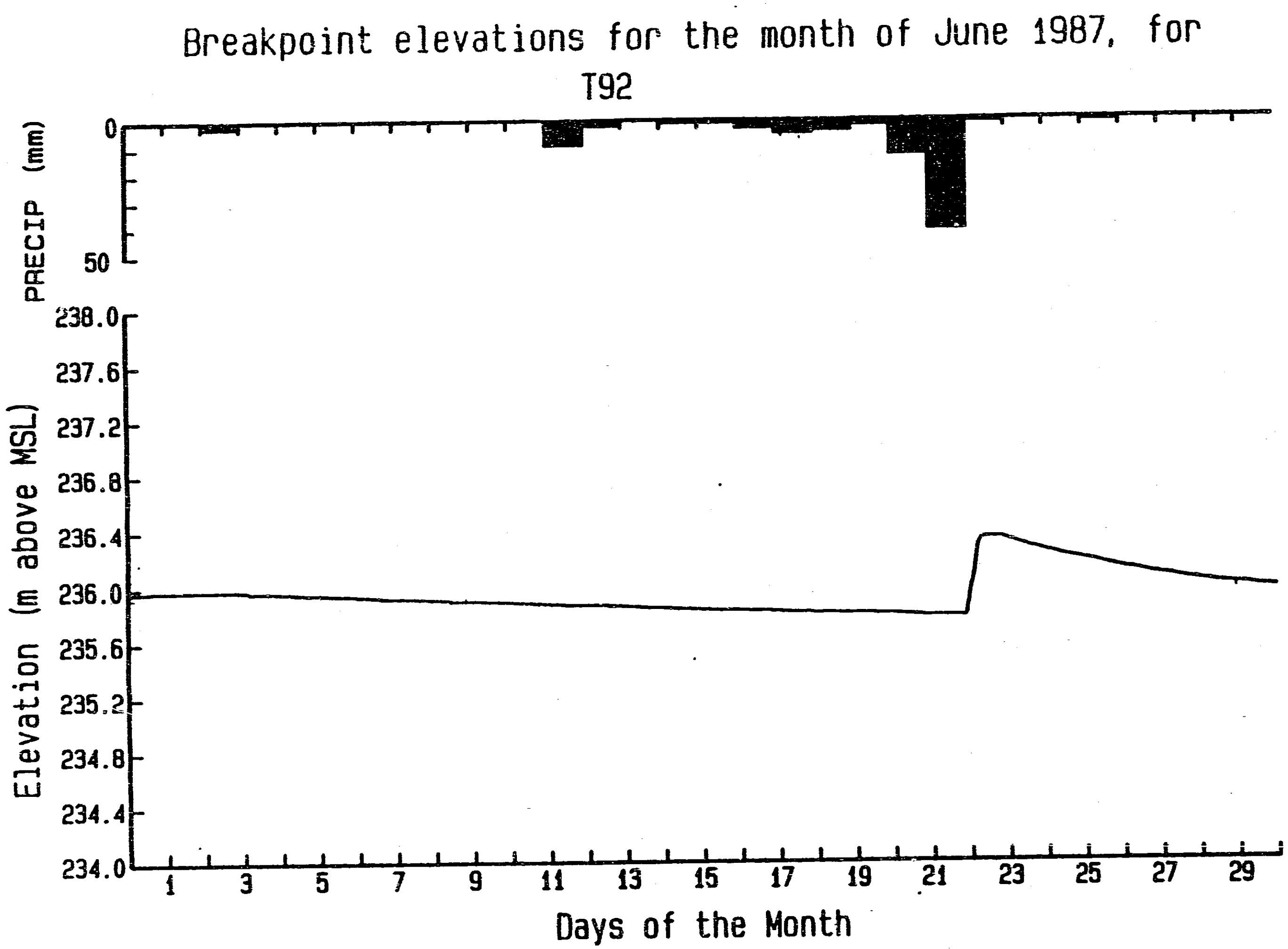


Figure 7.10 Hydrograph of trench 92 during June 1987.

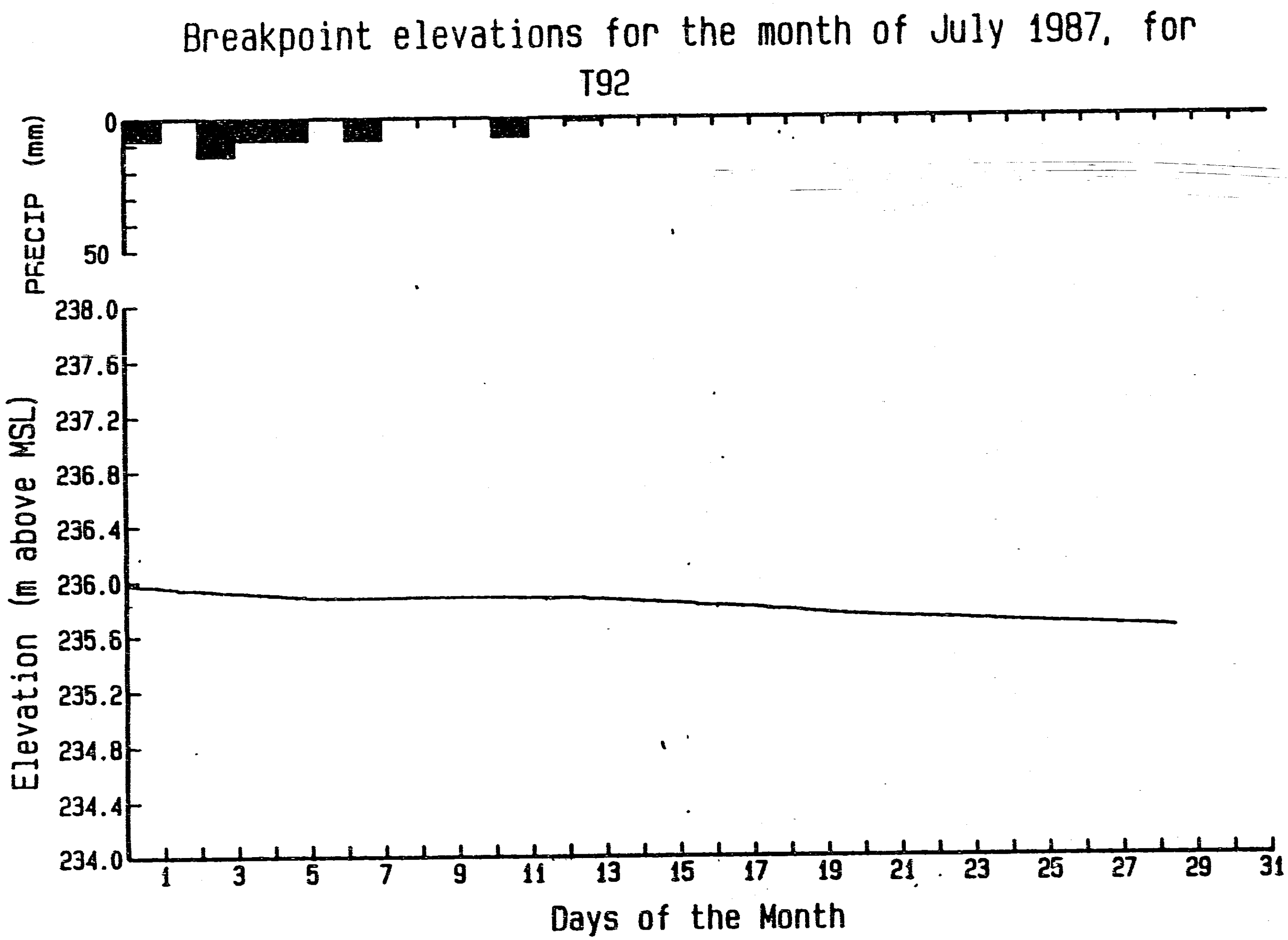


Figure 7.11 Hydrograph of trench 92 during July 1987.

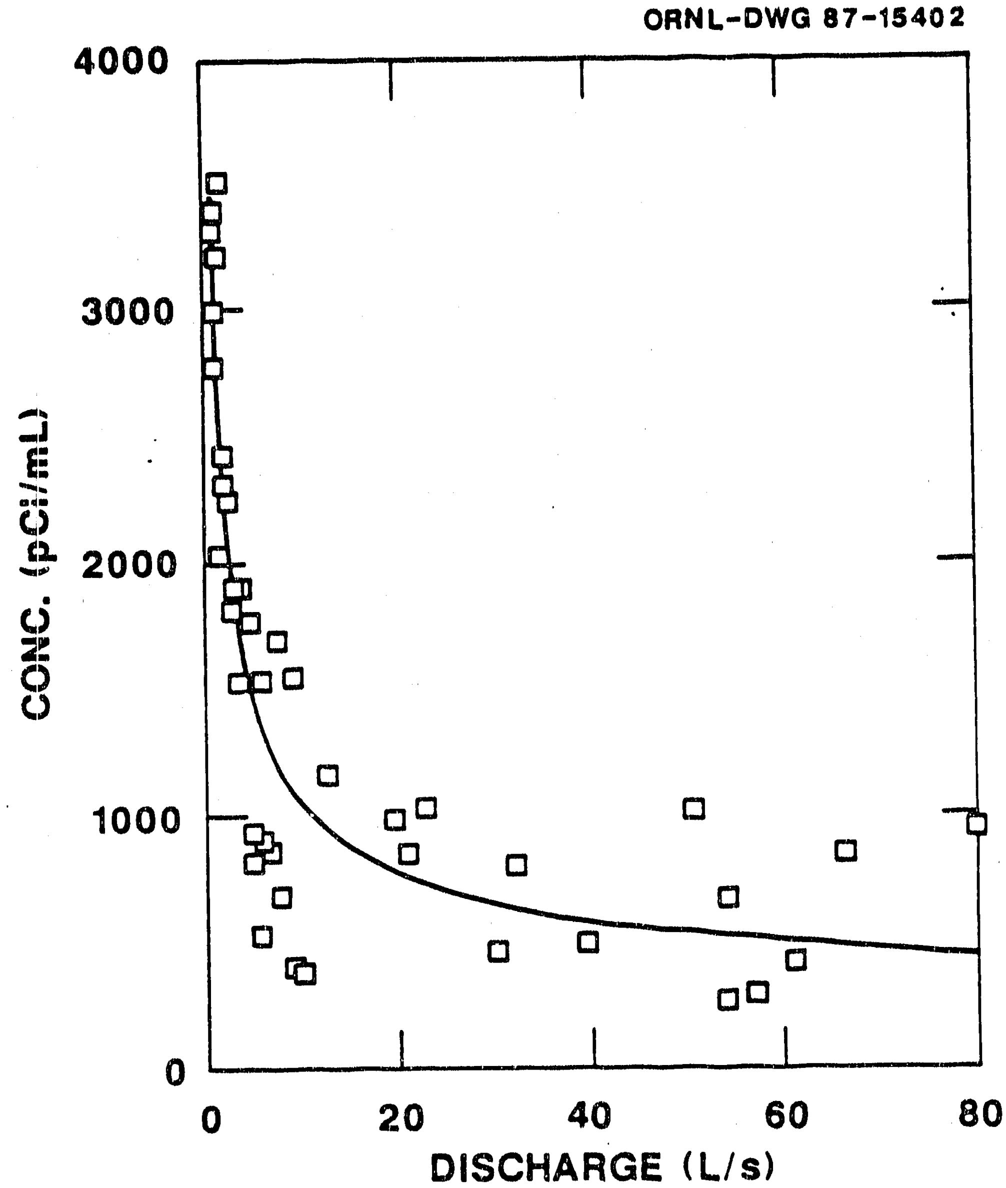


Figure 7.12 Relation of tritium concentration to stream discharge at monitoring station 3 in SWSA 6.

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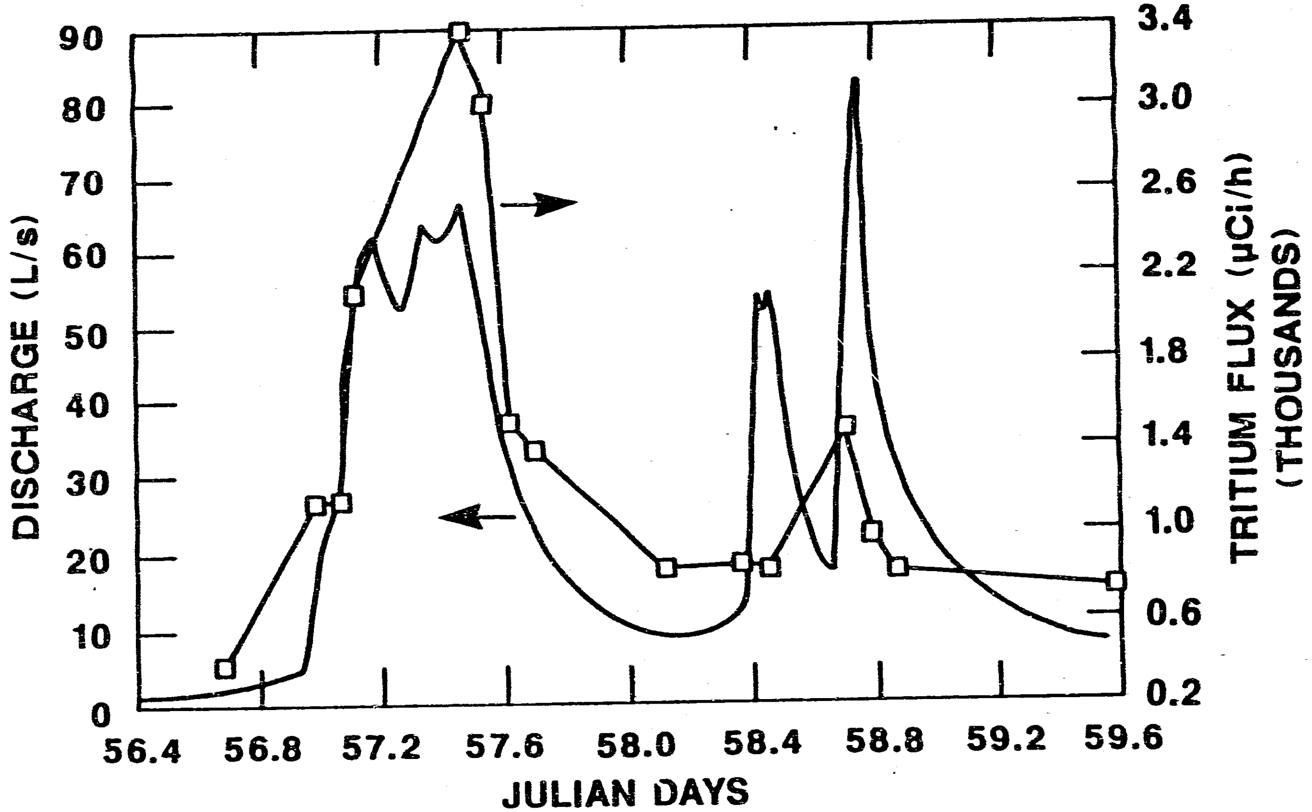

Figure 7.13 Variation of tritium flux and stream discharge at monitoring station 3 in SWSA 6 during February 1987 storm event.

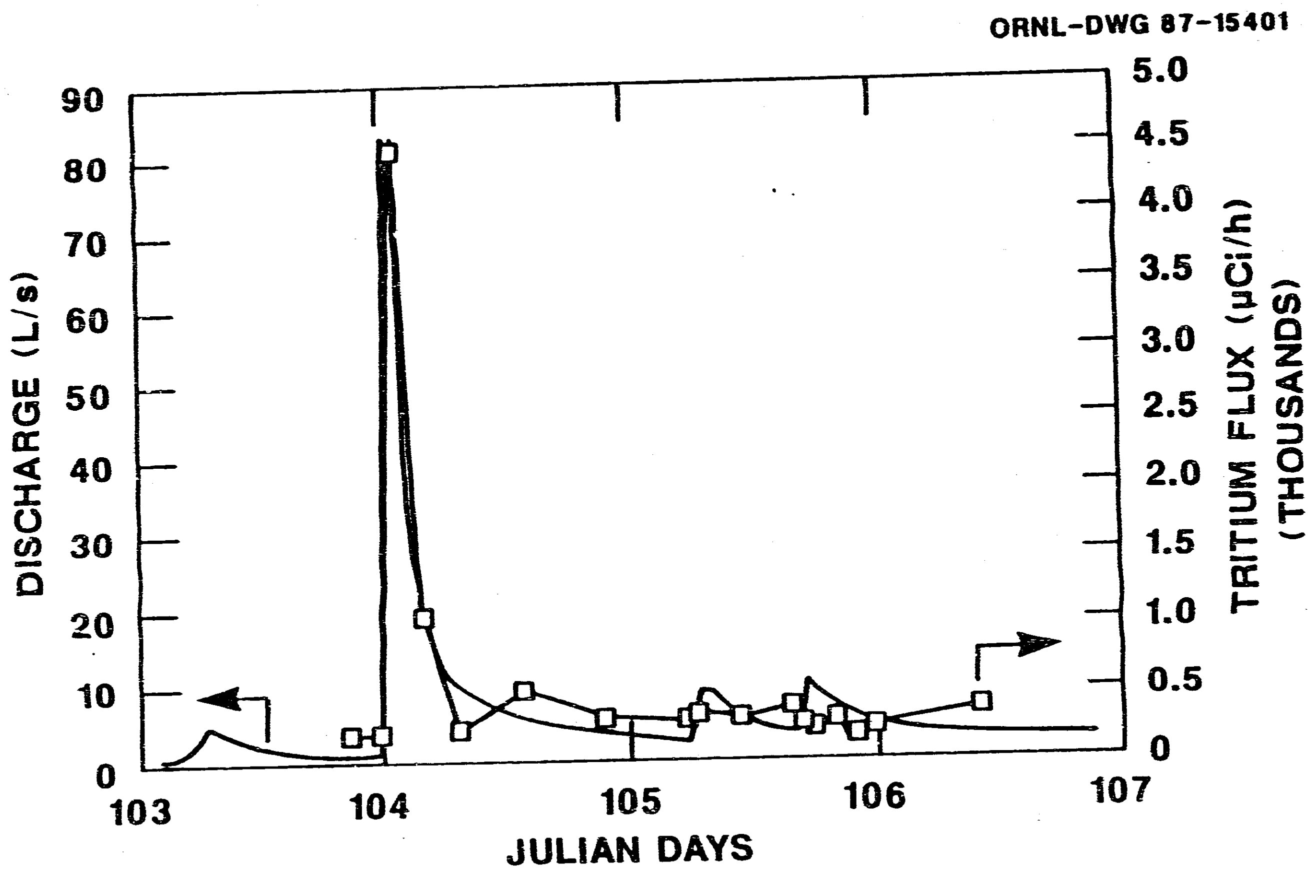

Figure 7.14 Variations of tritium flux and stream discharge at monitoring station 3 in SWSA 6 during April 1987 storm event.

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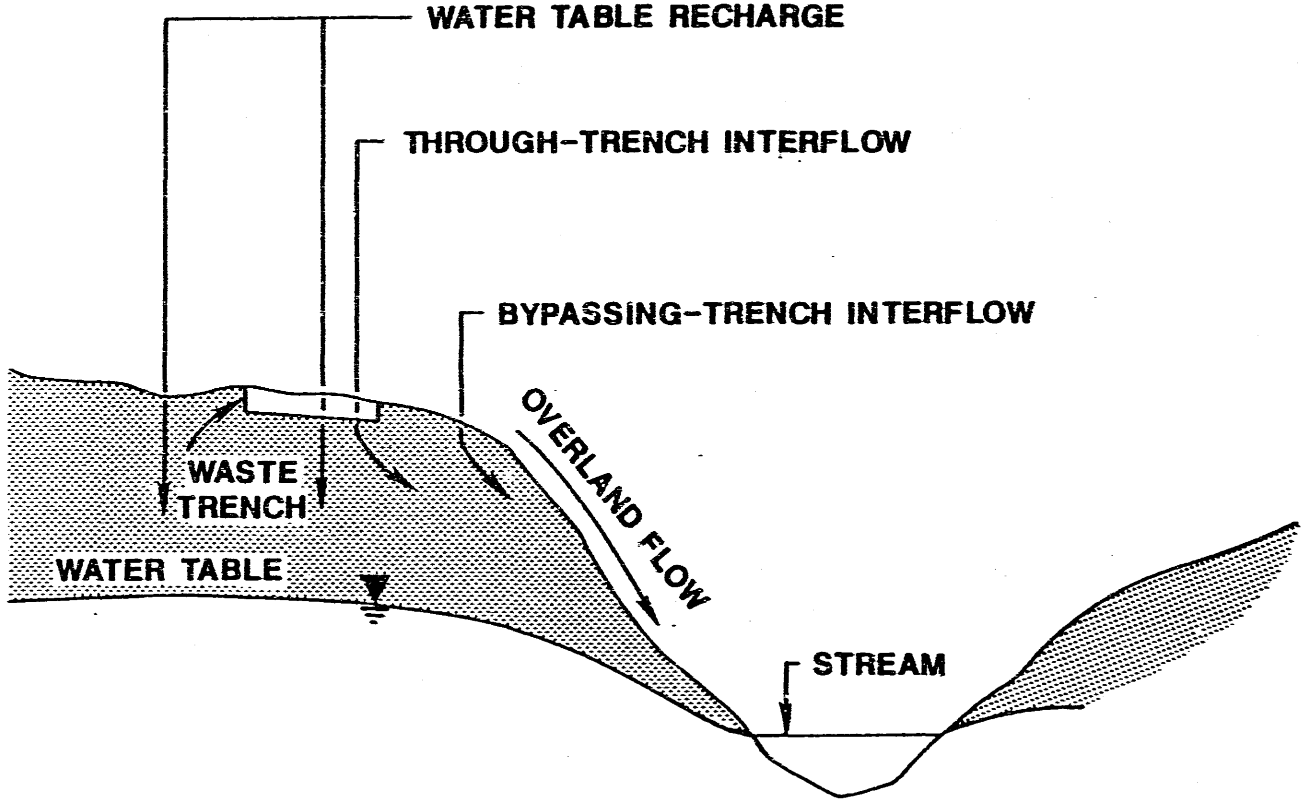

Figure 7.15 Conceptual model used for hydrochemical separation of storm flow in SWSA 6.

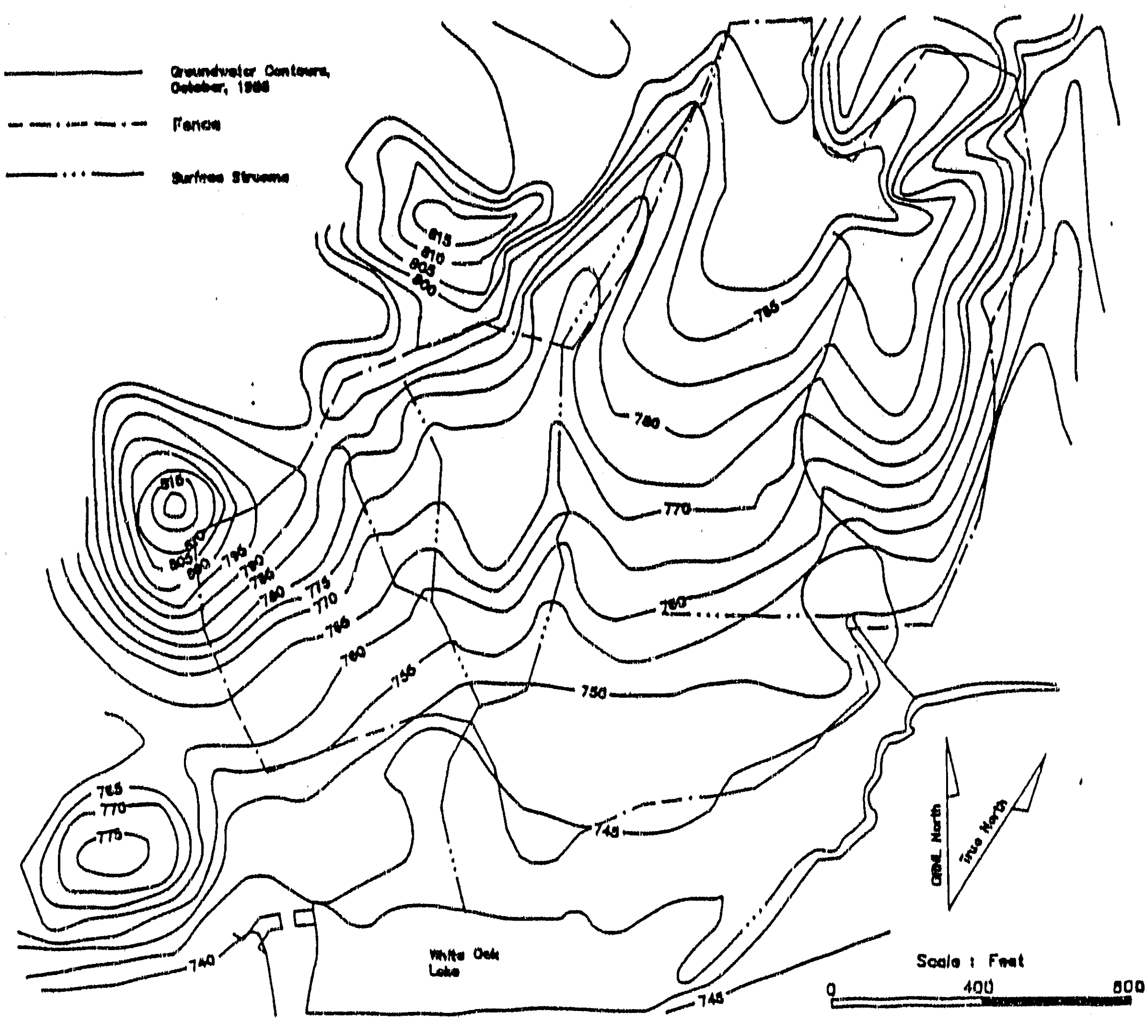

Figure 8.1 SWSA 6 with estimated groundwater contours in October 1986.

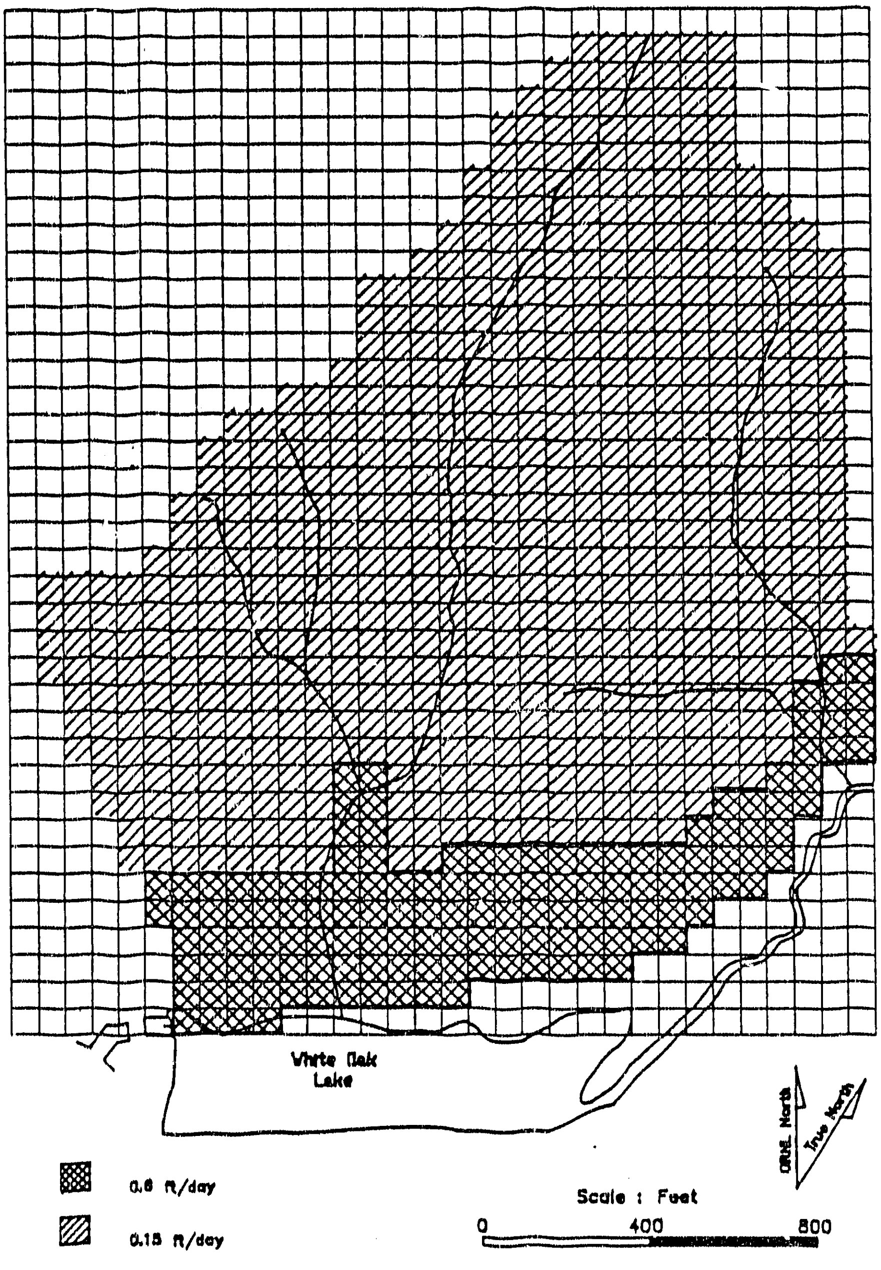

Figure 8.2 Location of K_a values over the active model area.

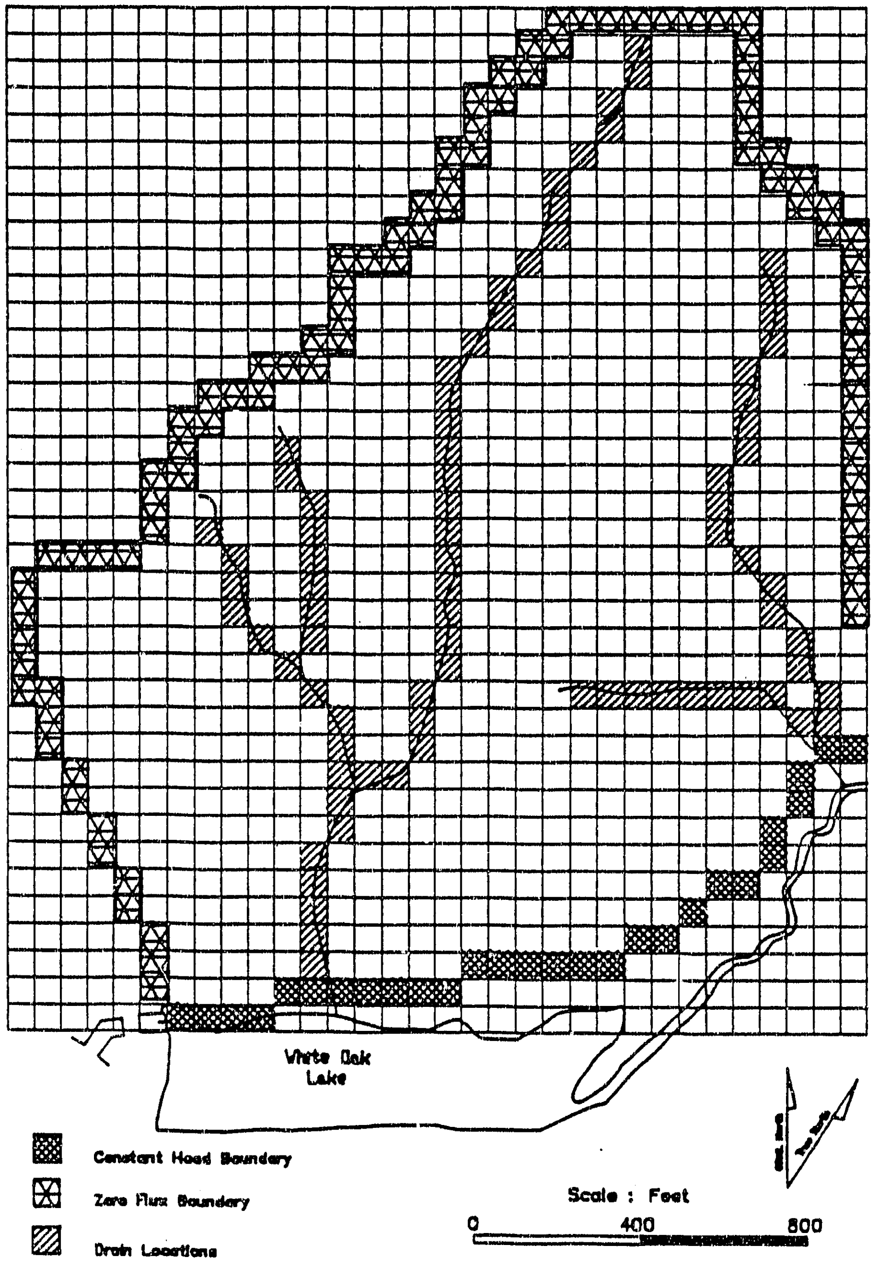

Figure 8.3 SWSA 6 model grid showing locations of drains and boundary conditions.

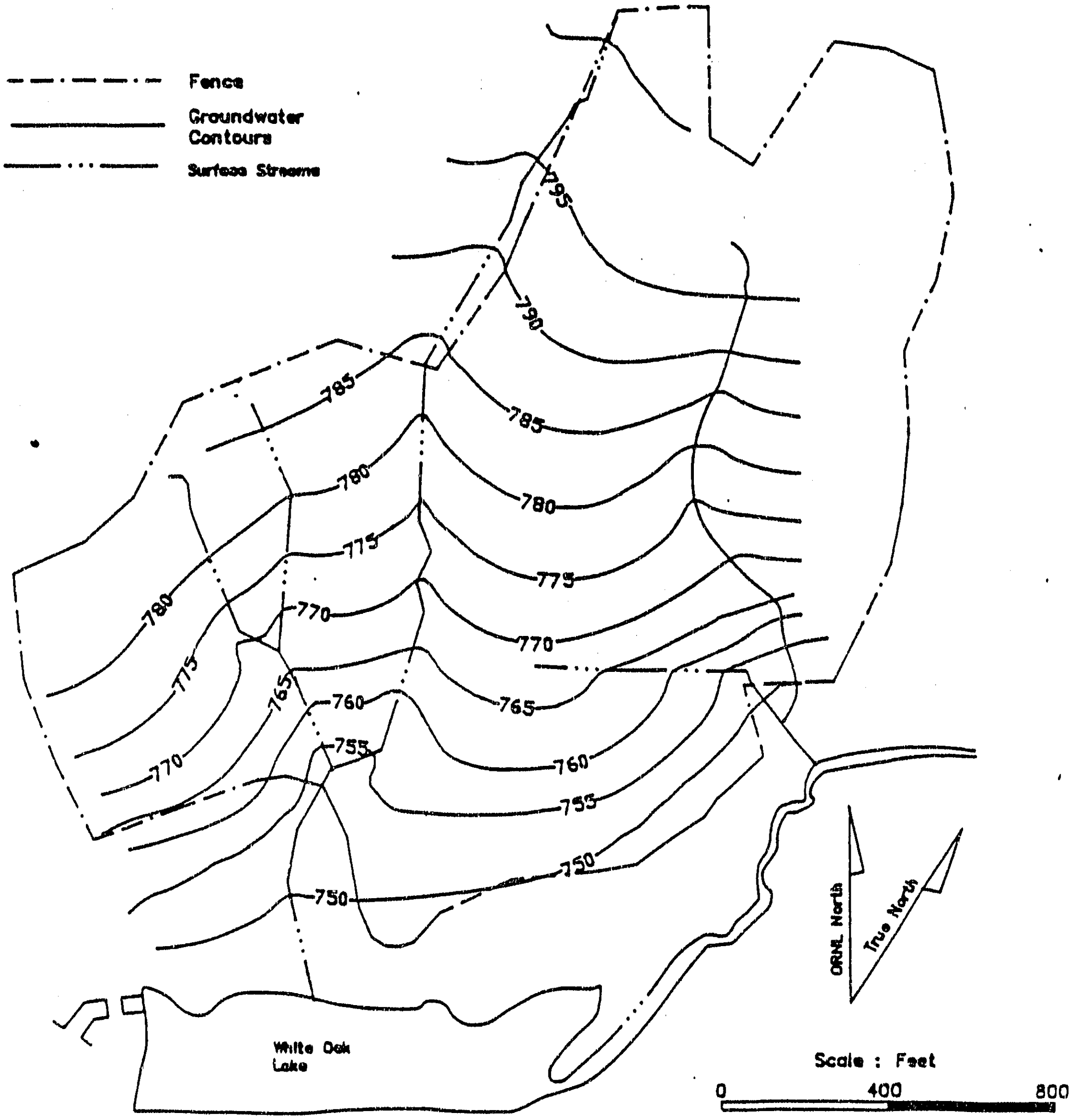

Figure 8.4 SWSA 6 calibrated MODFLO steady state water table.

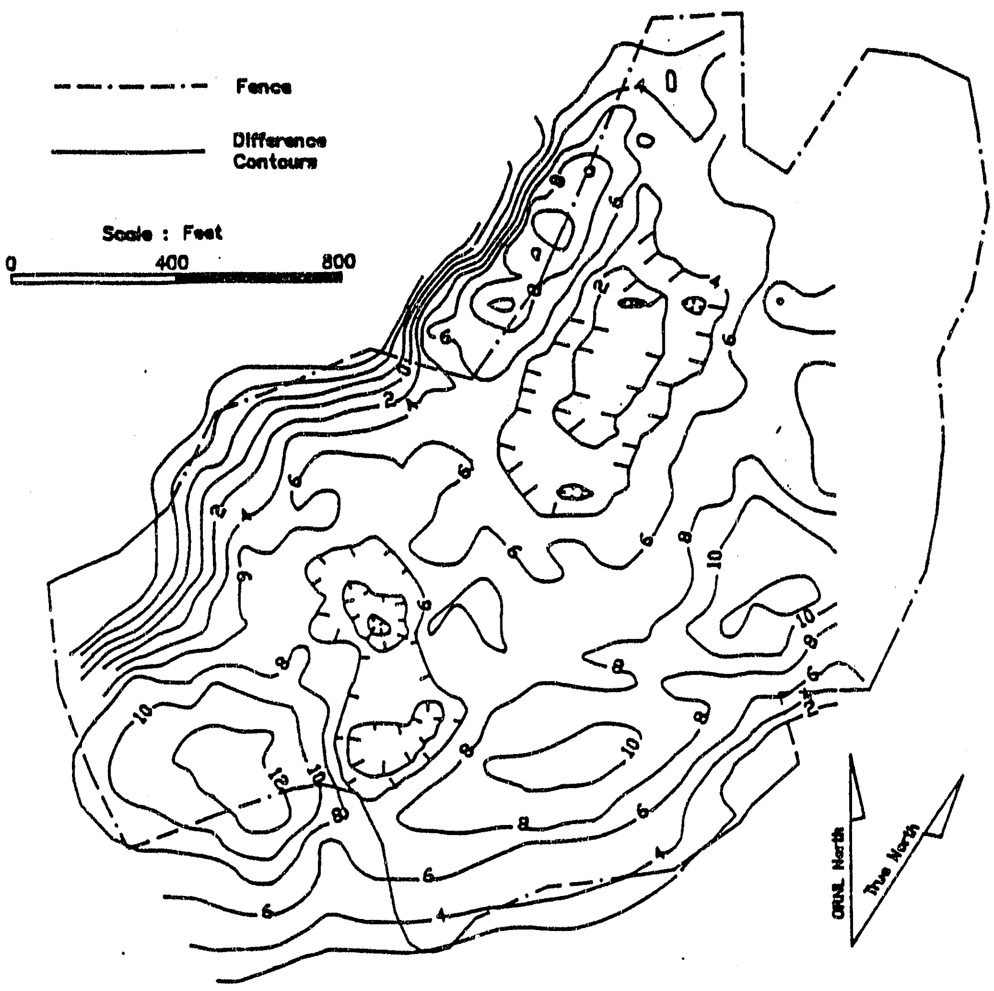

Figure 8.5 Differences in calibrated and estimated water table.

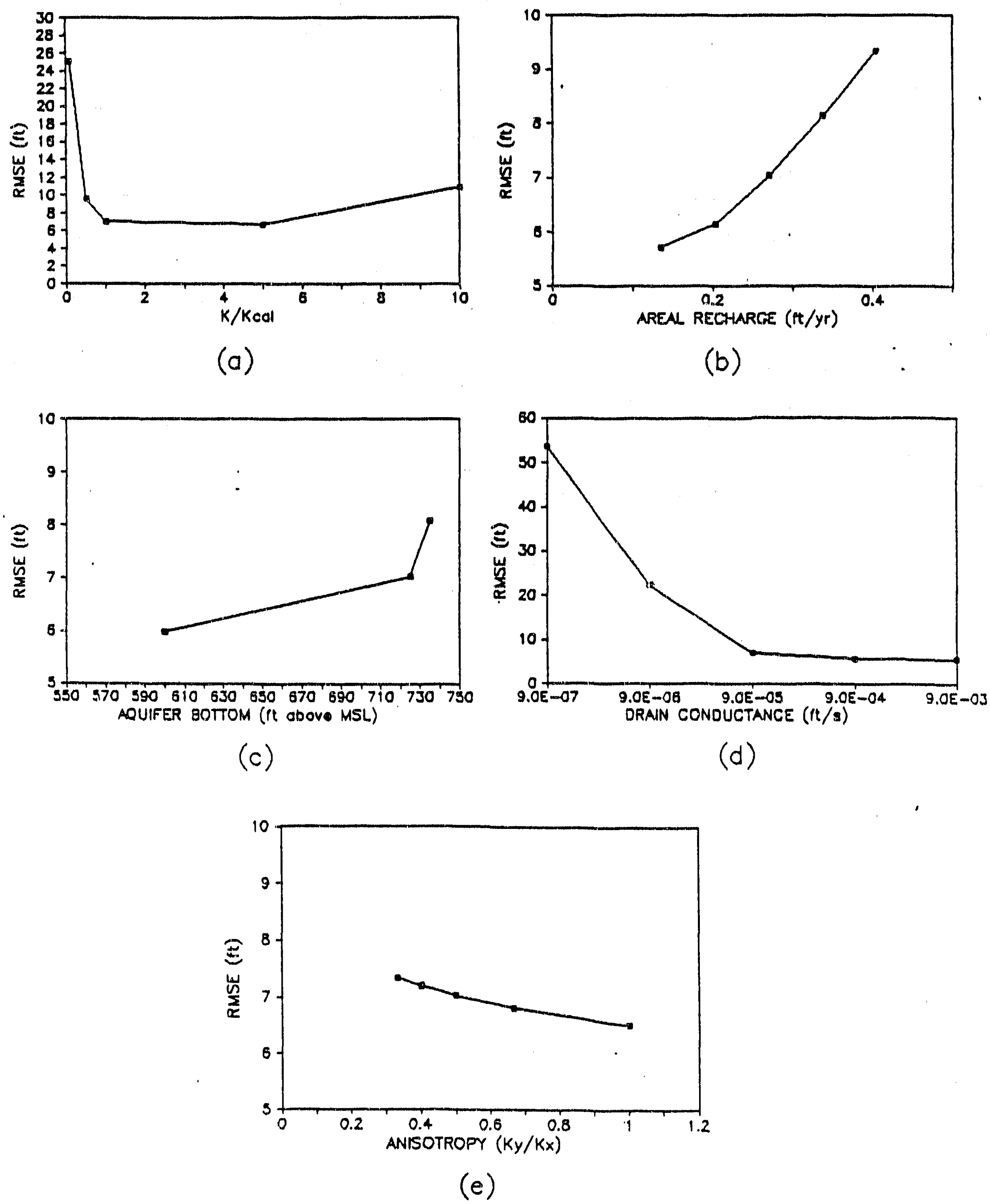

Figure 8.6 Sensitivity analysis results of five parameters.

Distribution

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J. S. Baldwin, 3047, MS 023
W. J. Boegly, 1505, MS 038
T. W. Burwinkle, 3047, MS 023
K. W. Cook, 3047, MS 023
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E. C. Davis, 1505, MS 036,
R. B. Dreier, 3504, MS 317
C. S. Haase, 3504, MS 317
D. D. Huff, 1505, MS 036
A. D. Kelmers, 4500S, MS 268
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