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Geohydrologic Characterization of Proposed Solid Waste Storage Area (SWSA) 7

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ENVIRONMENTAL SCIENCES DIVISION
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CONTENTS

LIST OF FIGURES

Figure		Page

LIST OF TABLES

ABSTRACT

To supplement other waste disposal operations on the Department of Energy (DOE) Oak Ridge Reservation (ORR), the geohydrology at a potential site for shallow-land burial of low-level radioactive waste has been characterized. The proposed Solid Waste Storage Area (SWSA) 7 is located in Melton Valley east of the current burial facilities in the valley. This report documents the geology, hydrology, and background water quality of the site.

The geologic investigation was carried out through field mapping, the drilling of three deep core holes, geophysical investigations, and chemical analyses. The study area is underlain by the Nolichucky Shale, the Maryville Limestone, the Rogersville Shale, and the Rutledge Limestone; all are formations of the Conasauga Group. Lithologically, the formations are variable and range from clean limestones, calcareous shales and siltstones, to noncalcareous mudstones. The area is structurally complex and small-scale features are common; these include several joint systems, small-scale faulting, and folding. Several linear features cross the site and appear to be tear faults or fracture zones; no offset is apparent across these features, but they do appear to be conductors of water in the subsurface. A large-scale thrust fault or zone was encountered in one of the core holes. The result of this feature is the doubling in thickness of the Rogersville Shale beneath part of the site. Samples of cuttings collected during the drilling of monitoring wells were analyzed for chemical and radionuclide

exchange properties. The saprolite and unweathered rock both exhibit high adsorption values, but a general decrease in K_d coefficients with depth is noted.

A critical flow flume and several temporary gaging stations were installed on the site to characterize the surface water system. The site is drained by a central stream that flows into Melton Branch. Two smaller tributaries are located on either side of the site. The site lies within the White Oak Creek watershed, thus drainage from the site is monitored by the established system for the drainage basin.

A monitoring well network of 18 wells was installed on site to characterize the groundwater flow regime and to collect data on the aquifer properties. The aquifer underlying the site is relatively low in permeability (2.57×10^{-5} cm/sec), anisotropic, and flow is controlled by the secondary porosity formed by the pervasive jointing. The surrounding tributaries are the local discharge areas for the groundwater system, but, based on the water budget and the geologic investigations, it appears that part of the groundwater discharge may directly enter Melton Branch. Water samples collected from the wells and streams indicate that the site is uncontaminated by surrounding activities on the ORR.

The geohydrologic data collected for the site can be used to assist in the design and evaluation of the proposed waste disposal facility and as input for a detailed pathways analysis. This report and a companion document (ORNL/TM-9326) on the soils of the study area, constitute a physical characterization of the site.

1. INTRODUCTION

As part of the waste management program of the ORR, a potential SWSA is being investigated for future use. The area known as SWSA-7 lies within Melton Valley, west of the High Flux Isotope Reactor (HFIR) facility, on the ORR. Additional low-level radioactive waste disposal facilities will be required at Oak Ridge National Laboratory (ORNL) to replace current areas (SWSA-6) as they become filled and to supplement other waste disposal activities (Central Waste Disposal Facility) when they become available. Suitable waste disposal areas on the ORR are limited, and after a broad overview of possible locations (Lomenick, Byerly, and Gonzales 1983), the Melton Valley location was chosen as the prime area for future development.

The proposed SWSA-7 is underlain by rocks of the Conasauga group. Most of the current and past waste disposal operations at ORNL have taken place within these same geologic formations. These operations include ORNL SWSAs 4-6, the low-level radioactive waste pits and trenches, and the hydrofracture facility. Thus, past experience at ORNL can be used to develop and manage waste disposal operations at this proposed location.

Site characterization is a critical first step in the development of a future waste disposal facility. Data collected during the site characterization can be utilized to determine background conditions as input to pathways analyses and for evaluating the potential use and design of the site. The characterization phase is generally an initial step in site development, and supplementary data can be collected as required in the future. This report documents the characterization of the geohydrology of the proposed SWSA-7. The characterization of the soils of the site has been included in a separate document (Rothschild et al., 1984a).

The Conasauga Group weathers in such a fashion that a thick residuum is not formed. In the near surface, the carbonate cement present throughout most of the group is leached out, but the bedding and structures of the original rock are still present. This upper, chemically weathered zone is generally referred to as saprolite. Overlying the saprolite is a thin veneer of soil that is generally less than 1 m (3 ft) thick. The boundaries between soil, saprolite, and unweathered rock are not distinct but gradational and arbitrary. This report focuses on the lower two horizons, the saprolite and the unweathered rock. This document also covers the hydrologic regime of the site, including the local climate, surface water and groundwater hydrology, and water chemistry.

The characterization of the geohydrology of a proposed shallow-land burial site is critical because the burial takes place in the shallow earth materials and because water is the primary pathway for off-site contaminant migration. The geohydrology dictates how a site can be utilized and how the facility should be monitored. The geology of the site has been investigated and a detailed geologic map produced. The investigation included field mapping, core drilling, geophysical surveys, and a topographic analysis. The chemical and radionuclide adsorption properties were investigated, and data were collected to document both areal and vertical variations. The hydrologic regime of the site was also characterized. Data were gathered on the local climate, site-specific information on stream flow was collected through the installation of a flume and temporary gaging stations, a water budget for the site was calculated, data on groundwater level fluctuations and aquifer properties were collected through an extensive monitoring well network, and background stream and groundwater chemistry were determined.

The characterization performed on site generally follows the format as described in Lutton, Malone et al. (1982) and Lutton, Butler et al. (1982). Further data may be required as the site is developed. The characterization of any site is an iterative process: site utilization depends on the site characteristics, and proposed designs indicate if and where further data are required.

2. SUMMARY

The proposed SWSA-7 is underlain by rocks of the Conasauga Group in the eastern portion of Melton Valley. The area is characterized by gently rolling to steep topography. The site lies in the White Oak Creek watershed, and surface runoff and groundwater discharge enter Melton Branch. The site is drained by several first-order tributaries; these tributaries are the primary groundwater discharge areas for the study area.

The site topography is a result of the differential weathering of the underlying strata. The strata do not weather to a thick residuum but to a saprolite that retains the structure of the parent rock. The saprolite is chemically leached but is structurally coherent. The saprolite grades into unweathered rock, and the water table of the site is generally located at this boundary.

The geology of the site was determined through a series of core holes, field mapping, and geophysical investigations. The site is underlain by four formations of the Conasauga Group: the Nolichucky Shale, the Maryville Limestone, the Rogersville Shale, and the Rutledge Limestone (from youngest to oldest). The lithology of the formations is very complex and is composed of interbedded limestones, shales, and siltstones. The formations are distinct and can be defined within cored sections but are difficult to locate in the field because of the weathering characteristics of the strata.

The structural geology of the area is controlled by the large-scale thrust faults in the region. Regional thrusting has resulted in small-scale deformation within the rock units and a pervasive joint and

fracture system. Folding is common throughout the Conasauga Group, and the fold axes generally parallel geologic strike. Jointing and fractures follow several orientations ranging from parallel to and normal to geologic strike, to orientations at acute angles, to strike.

Large-scale faulting normal to thrusting also appears to be a common feature of the region. Several topographic linears can be identified on site that may be faults and/or fracture zones. A strong linear that runs through the center of the site was investigated through coring, geophysics, and a topographic analysis. The data from the core holes indicate that no significant movement has occurred along the proposed fault/fracture zone, but the geophysical surveys show that the linear may be a conduit for subsurface water movement. Identified within the cores were numerous fault zones; these include a major thrusting zone that resulted in a doubling of the thickness of the Rogersville Shale beneath part of the site.

The chemical and radionuclide adsorption properties of the subsurface materials were analyzed by testing drill cuttings from a number of borings. A batch methodology was used to determine distribution coefficients (Kds) for Sr, I, Cs, Co, Am, and total hardness. Chemical analyses on the earth materials included exchangeable cations, exchangeable acidity, equilibrium pH, and total carbonate content. The 54 samples analyzed included two long boreholes sampled at 1.5 m (5 ft) intervals, and five shorter borings that were sampled at three different depths. The results of the analyses indicate that the chemical and adsorption properties of the saprolite and the unweathered rock can be differentiated and, in general, that the cation and radionuclide adsorption potential decreases with depth (although the exchange properties are quite high throughout the sections sampled).

The climate of the site is partially controlled by the valley and ridge topography of the area. On-site meteorological data were not collected, but data were gathered from surrounding monitoring stations. The average annual precipitation for the site is estimated to be 130 cm (51 in.). Regionally, about 55% of the annual precipitation is estimated to be lost through evapotranspiration, while the rest recharges the groundwater system that feeds the local surface-water system.

The surface-water system was investigated through the installation of a flume on the central drainageway of the site and through the use of temporary gaging stations on the tributaries that surround the study area. Continuous flow data have been collected at the flume beginning in January 1983 through 1984. The peak instantaneous flow rate recorded was 370 L/s (April 5, 1983), and the mean flow rate was determined to be 2.70 L/s. Zero flow conditions occurred on 21 d or about 4.6% of the monitored period. The eastern tributary bounding the site and the headwaters of Melton Branch are dry for extended periods of time and can be considered ephemeral in nature. The western tributary bounding the site is strongly influenced by discharge from the HFIR facility adjacent to the proposed SWSA-7. Based on regional studies, it does not appear that flooding is a problem for site development.

To characterize the site hydrology, a detailed water budget was performed. Data for the water budget were gathered from on-site investigations as well as from regional estimates. The budget was calculated for 1983, which had approximately 1144 mm of precipitation. It is estimated 582 mm of precipitation are accounted for by surface water and groundwater runoff, 567 mm were lost from the site through evapotranspiration, and there was a slight decline in groundwater storage. In evaluating the water budget and the observed surface-water runoff, about 12% of the on-site recharge is leaving by way of underflow.

The groundwater system was evaluated by installing a monitoring-well network on site. The wells were used for aquifer testing and for water level monitoring. The average hydraulic conductivity calculated from the aquifer tests was 2.57×10^{-5} cm/s. This value is consistent with other data collected for the Conasauga Group on the ORR. Aquifer properties not sampled on site were estimated from other nearby studies in the same formations. In general, groundwater movement is controlled by the structural geology of the site with secondary porosity and the strike and dip of the strata playing important roles. Large-scale structural anomalies are also important, such as the observed on-site thrust faulting and the fault/fracture zones that are identified on the study area. Maps of the potentiometric surface have been produced for high and low groundwater conditions. The depth to water is greatest beneath the ridges and near the surface in the valleys. The depth to water ranges from 0 to 15 m (0 to 50 ft). Water levels fluctuate from 2 to 5 m

(6 to 15 ft) over a yearly cycle. Fluctuations are greatest beneath ridges on site. The groundwater beneath the site appears to discharge into the first-order tributaries on and around the site, but underflow is likely. The flow not seen in the small tributaries is likely to discharge directly into Melton Branch.

To determine background water chemistry, two sets of samples were collected from the monitoring wells and the major surface-water drainages. The water on site is generally of the Ca/HCO_3 type, but several of the wells in the northern portion of the site exhibit Ca/SO_4 type waters. Radionuclide analyses were run on all samples, and it was determined that the site appears to be uncontaminated by local activities on the ORR.

The basic data collected on the geohydrologic system of the proposed SWSA-7 can be used to assist in the evaluation and design of the site. The data can also serve as input to a detailed pathways analysis for the proposed waste facility. As the use of the site becomes better defined, further data may be required to supplement this initial characterization. This document represents a major portion of the total site characterization but should be combined with assessments of the soils and biota of the site.

3. GEOLOGY

3.1 INTRODUCTION

The ORR lies within the valley and ridge physiographic province of East Tennessee. Differential erosion of the northeast-striking Paleozoic strata has influenced the topography and is largely responsible for the development of the subparallel ridges and valleys. Regionally, the structural strike of the strata ranges from about N45 to 60°E, and the dip ranges from 20 to 40° to the southeast. The area is characterized by a series of major thrust faults that developed during the Allegheny orogeny, about 250 million years ago. Although minor earthquakes do occur, the area is seismically inactive (Algermissen and Perkins 1976).

The proposed SWSA-7 is located in Melton Valley, east of SWSA's 4, 5, and 6. The valley lies within the Copper Creek fault block (Fig. 1) and is underlain by strata of the middle to late Cambrian Conasauga Group. The Conasauga Group consists of six formations that were deposited as part of a major marine transgression over a subsiding carbonate-rimmed tidal flat (Hasson and Haase 1984). Within Melton Valley, the Conasauga Group is approximately 550 m (1800 ft) thick (Fig. 2). It is both intra and interformationally heterogeneous, consisting primarily of siltstones, argilaceous limestones, calcareous siltstones, and mudstones. The six formations comprise a sequence of alternating limestones and shales (Fig. 2). The proposed SWSA-7 is underlain by the middle four formations of the Conasauga Group: the

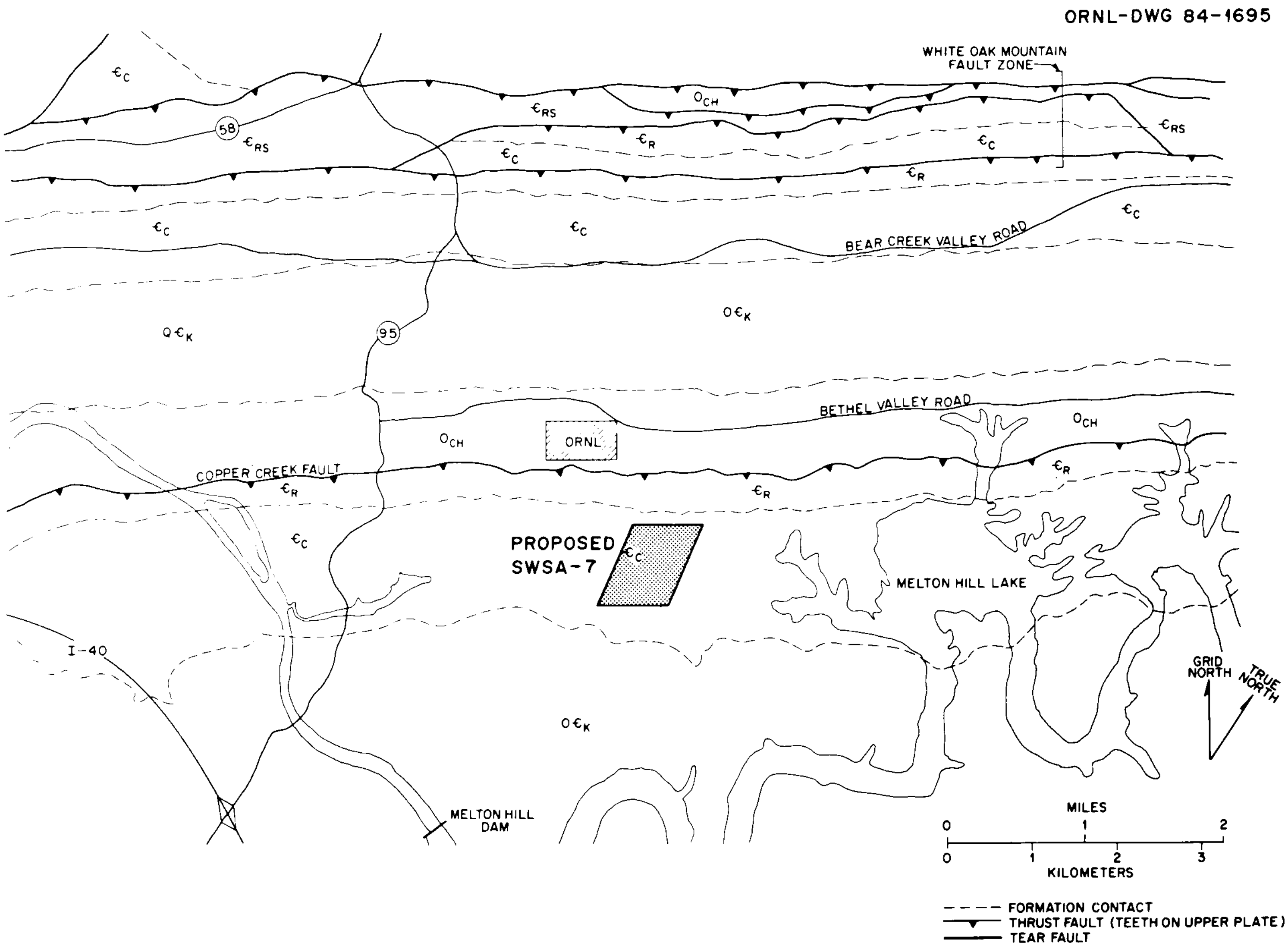

Fig. 1. Approximate location of the proposed SWSA-7, Oak Ridge, Tennessee.

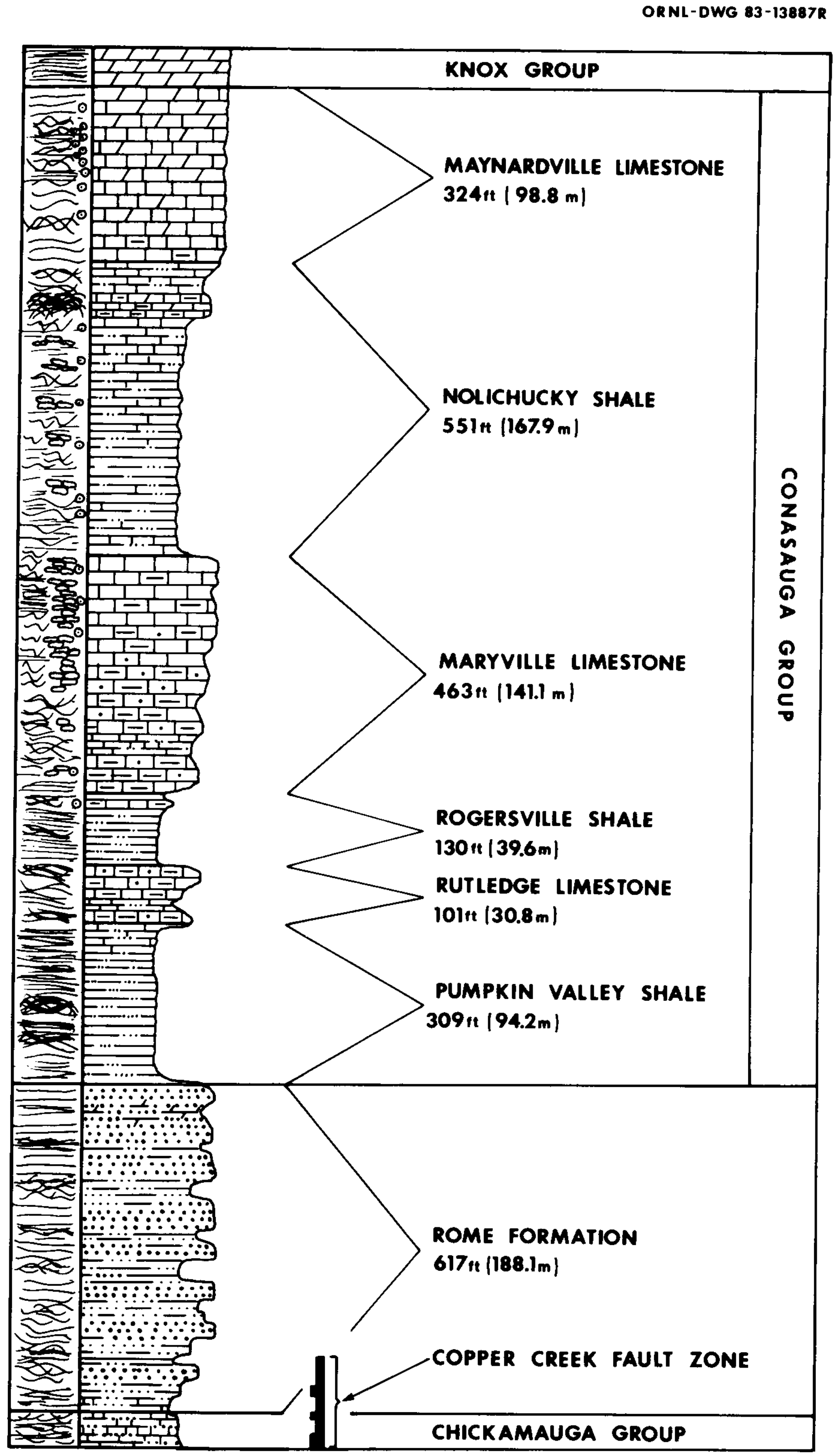

Fig. 2. Geologic column for the Oak Ridge Reservation.

Nolichucky Shale, the Maryville Limestone, the Rogersville Shale, and the Rutledge Limestone (from youngest to oldest). The lowermost formation of the group, the Pumpkin Valley Shale, crops out north of the proposed site; and the uppermost formation, the Maynardville Limestone, crops out south of Melton Branch on Copper Ridge.

Structural features within Melton Valley are related to fault motion along the Copper Creek fault, a regionally significant thrust fault that strikes N50 to 60°E and dips to the southeast. Significant deformation features within the Conasauga Group include: numerous low amplitude folds, small-scale thrust faults, ubiquitous bedding plane faults, reverse high-angle faults, and several pervasive joint sets.

Strata of the Conasauga Group have been studied in Melton Valley, primarily because of their relationship to the waste disposal operations at ORNL. The waste operations that make use of the Conasauga Group include: SWSA's 4, 5, and 6; the Low Level Waste (LLW) pits and trenches; and the hydrofracture facility. Because of this extensive use by ORNL, Conasauga Group strata have been the subject of several studies which include: McMaster (1963); Lomenick and Wyrick (1965); McMaster and Waller (1965); Sledz and Huff (1981); Lomenick, Byerly, and Gonzales (1983); Haase (1983, 1984); Olsen et al. (1983); Davis et al. (1984); Haase et al. (1984); and Hasson and Haase (1984).

3.2 WEATHERING CHARACTERISTICS

The degree of erodibility of the formations comprising the Conasauga Group is generally reflected in the topography of the area; the ridges are underlain by more resistant formations than the valleys. Weathering of the Conasauga Group does not produce a thick residuum. Carbonate cements present throughout most of the group leach, leaving bedding and structures of the original rock material preserved. This chemically weathered zone is generally referred to as saprolite. Overlying the saprolite is a thin veneer of soil that is generally less than 1 m (3 ft) thick. Soil properties of the site are described in a separate soils characterization report (Rothschild et al. 1984a). The boundary between horizons (soil, saprolite, and bedrock) is not distinct, but gradational and arbitrary.

The base of the chemically weathered zone is generally reflected as a color change with depth (brown near the surface to gray at depth). The color change associated with this transition is commonly found at about the same depth as the water table. Well logs included in Appendix II indicate the approximate depth to weathering. As an approximation, the depth to water map (Fig. 33) can also be used as an indicator of the depth of weathering. Both the map and the logs indicate that the extent of the weathered horizon is greatest beneath the ridges as opposed to the valleys.

Chemical aspects of the weathering process will be discussed further in a subsequent section. Engineering properties of the near-surface materials are discussed in Rothschild et al. (1984a). The chemical extent of weathering is not a direct indicator of the physical extent of weathering (construction properties for instance). Although the distinction between the saprolite and unweathered rock is vague, the differences between the horizons are important chemically, hydraulically, and geophysically.

3.3 STRATIGRAPHY AND LITHOLOGY

A generalized geologic map of the site is illustrated in Fig. 3. It is based on lithologic and geophysical logs from three rock cores taken on site, logs of drill cuttings taken during well installation, field mapping, and geophysical investigations. The proposed SWSA-7 is underlain by four formations of the Conasauga Group: the Nolichucky Shale, the Maryville Limestone, the Rogersville Shale, and the Rutledge Limestone. The stratigraphically uppermost unit, the Nolichucky Shale, crops out in the channel of Melton Branch on the southern part of the study area. Beneath the Nolichucky Shale is the Maryville Limestone; it is a relatively resistant formation that underlies a major portion of the site and supports much of the higher relief. The headwaters of the central drainage on the proposed SWSA-7 are found near the contact of the Maryville Limestone with the underlying Rogersville Shale. The relationship of this contact with the headwaters of cross-strike, first-order tributaries has also been noted in Bear Creek Valley (Law Engineering 1983), which is also underlain by the Conasauga Group. Stratigraphically beneath the Rogersville Shale is the Rutledge Limestone, a relatively resistant unit that appears to hold up the northern ridge in the study area.

Because of rock weathering and a limited number of outcrops, field mapping was only marginally useful in the production of a geologic map; it and the lithologic descriptions depended heavily on the cores taken on site. Three NC-sized rock cores were obtained (see Fig. 25 for locations); two are about 90 m (300 ft) long and the third core is 200 m (650 ft) long. The core holes were located: (1) such that a

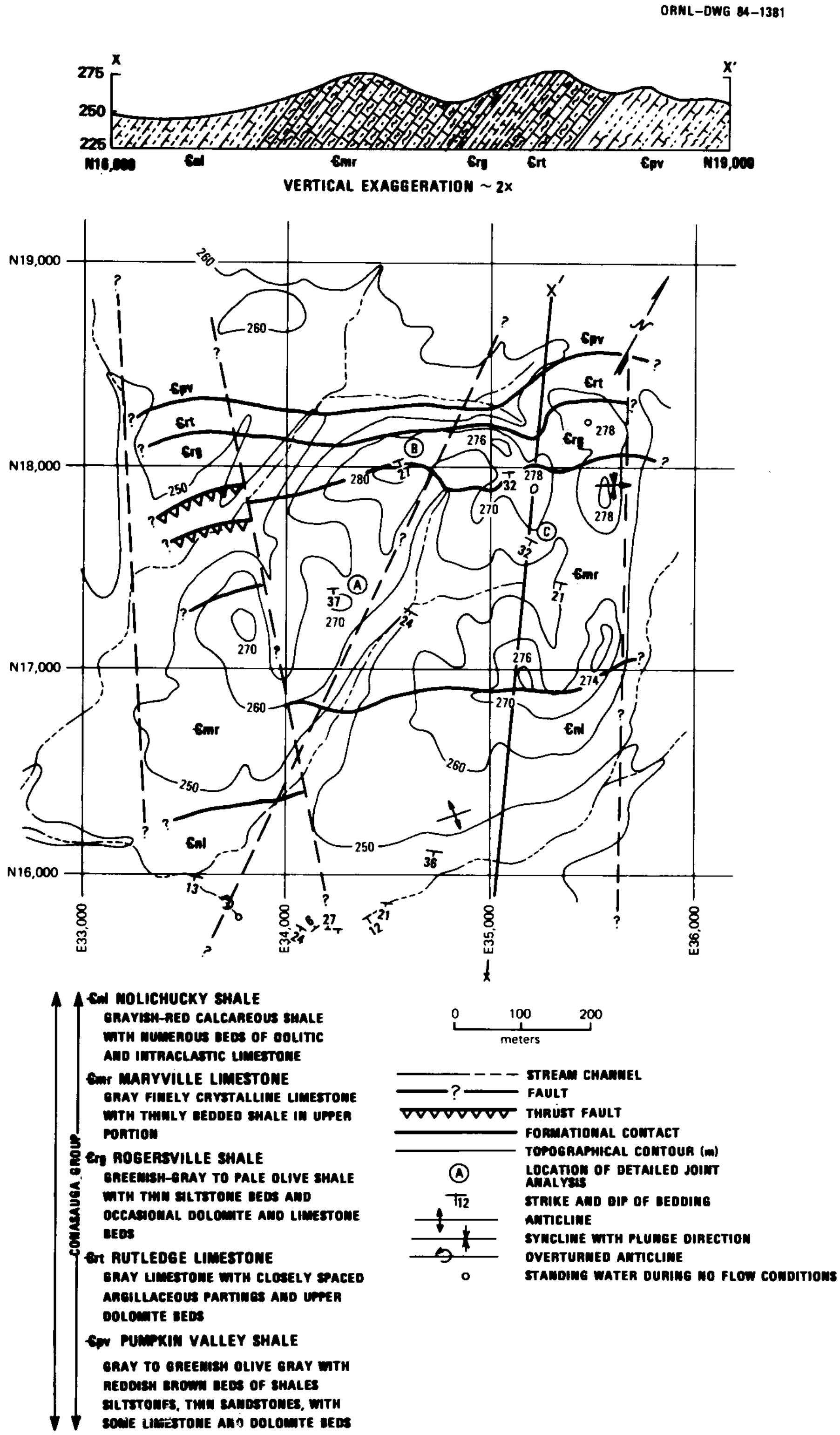

Fig. 3. Geologic map of the proposed SWSA-7.

relatively complete section of the site geology was obtained and (2) so that variations down dip and along strike could be examined. The longer core (C3) was taken down dip of core C2, and its greater length was needed to permit correlation between holes. After coring was completed, a suite of geophysical logs was run on the core holes. Lithologic logs for the three core holes are shown in Figs. 4-7, and geophysical logs are contained in Appendix II. Logs were also obtained for holes completed as monitoring wells on site; these are included in Appendix II. The lithologic descriptions that follow are based on site-specific work as well as a deep core hole drilled on Copper Ridge through the complete Conasauga Group section underlying Melton Valley (Haase et al. 1984).

3.3.1 Nolichucky Shale

The Nolichucky Formation underlies the southern portion of the proposed burial area but was not encountered in the core holes drilled on site. The core from Copper Ridge indicated an apparent thickness of 169 m (553 ft) for the formation.

The upper portion of the Nolichucky Shale consists of complexly interbedded calcareous shale/mudstone and limestone lithologies. The limestones are typically oolitic. Underlying these upper beds is the Bradley Creek Member, which consists of intraclastic and oolitic grainstones and algal packstones[1]. The lowermost portion of the

[1]Carbonate rock nomenclature is generally that of Dunham (1962) with one exception: fine-grained carbonates are called micrites instead of mudstones to avoid confusion with the fine-grained clastic sediment that is called mudstone. In this report, mudstone refers to a clastic rock.

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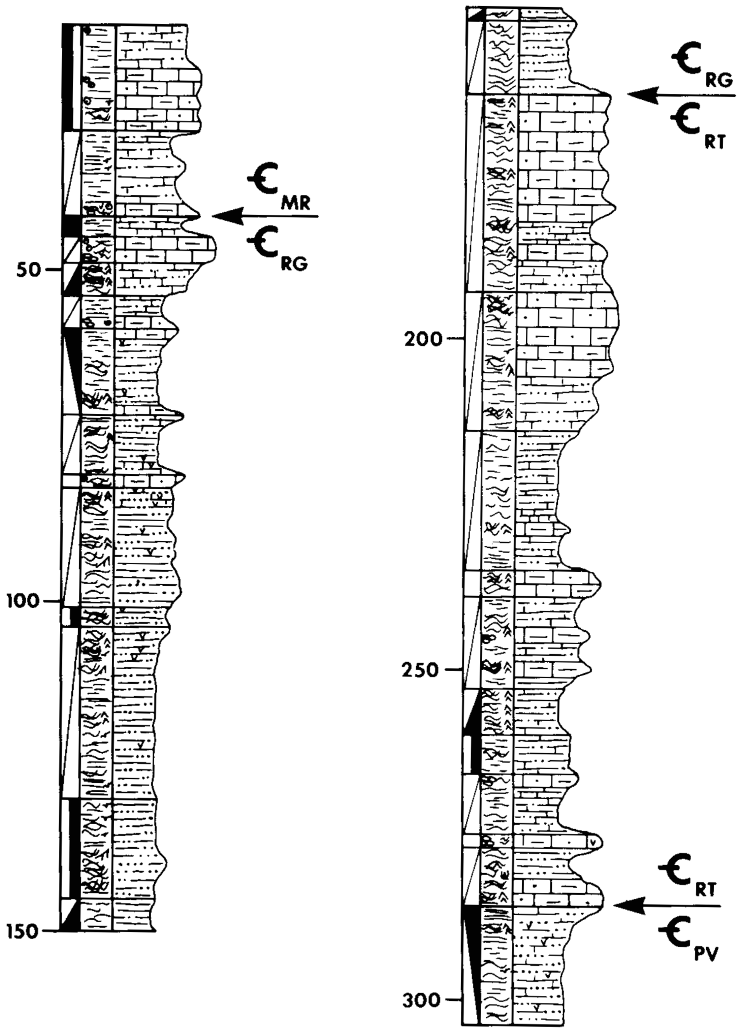

Fig. 4. Columnar section of the portion of the Conasauga Groups penetrated in borehole C1. The column consists of three parts illustrating, from left, rock color, bedding and stratification patterns, and lithology (symbols summarized in Appendix II). The columnar section is based on detail core logging at 1 ft intervals. Numbers to the left of the column are downhole footages. Arrows to the right of the columns indicate formational contacts: MR = Maryville Limestone; RG = Rogersville Shale; RT = Rutledge Limestone; PV = Pumpkin Valley Shale.

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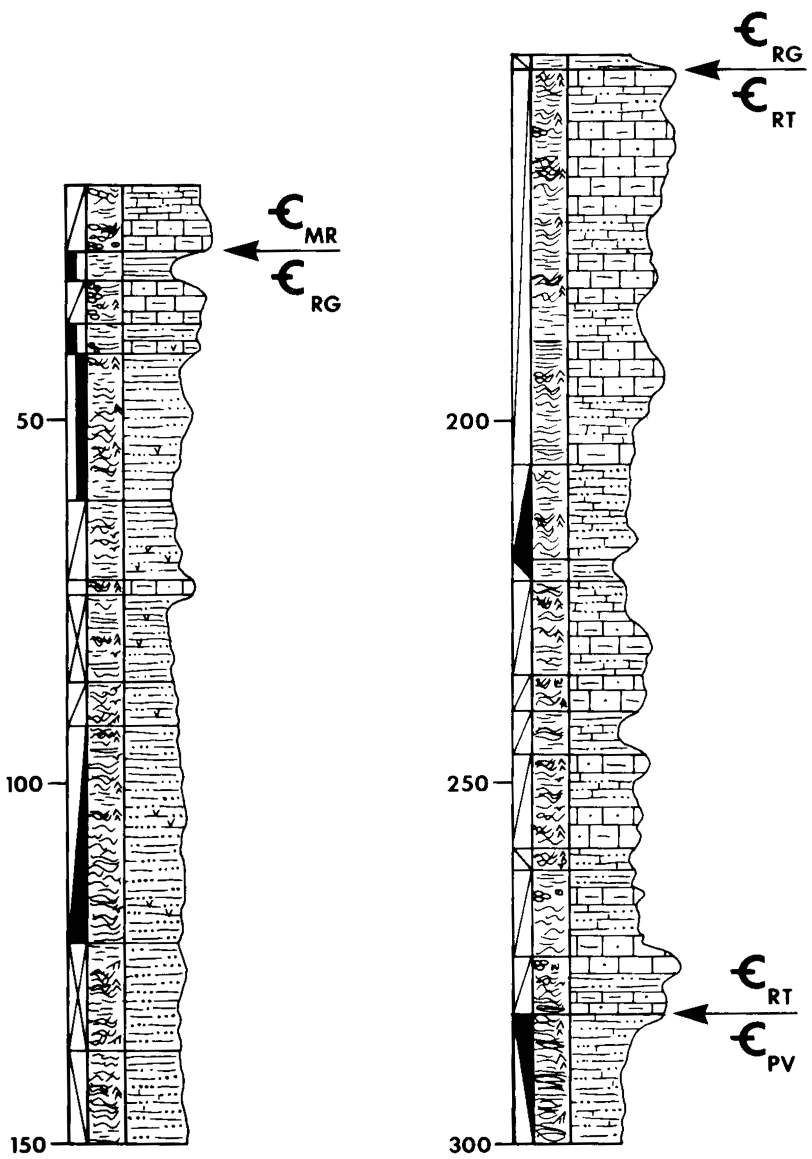

Fig. 5. Columnar section of the portion of the Conasauga Groups penetrated in borehole C2. The column consists of three parts illustrating, from left, rock color, bedding and stratification patterns, and lithology (symbols summarized in Appendix II). The columnar section is based on detail core logging at 1 ft intervals. Numbers to the left of the column are downhole footages. Arrows to the right of the columns indicate formational contacts: MR = Maryville Limestone; RG = Rogersville Shale; RT = Rutledge Limestone; PV = Pumpkin Valley Shale.

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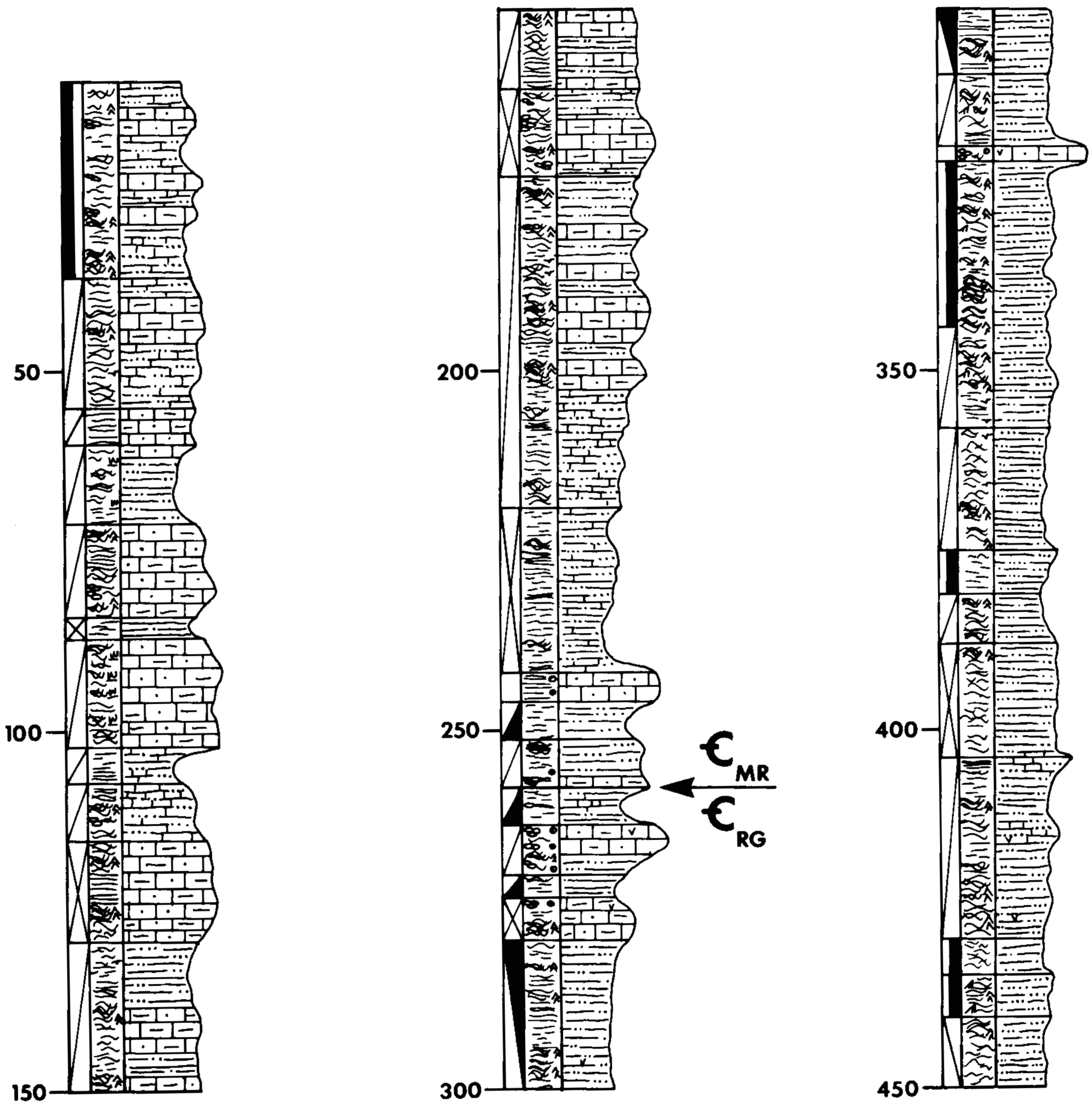

Fig. 6. Columnar section of the portion of the Conasauga Groups penetrated in borehole C3 (10 to 450 ft). The column consists of three parts illustrating, from left, rock color, bedding and stratification patterns, and lithology (symbols summarized in Appendix II). The columnar section is based on detail core logging at 1 ft intervals. Numbers to the left of the column are downhole footages. Arrows to the right of the columns indicate formational contacts: MR = Maryville Limestone; RG = Rogersville Shale; RT = Rutledge Limestone; PV = Pumpkin Valley Shale.

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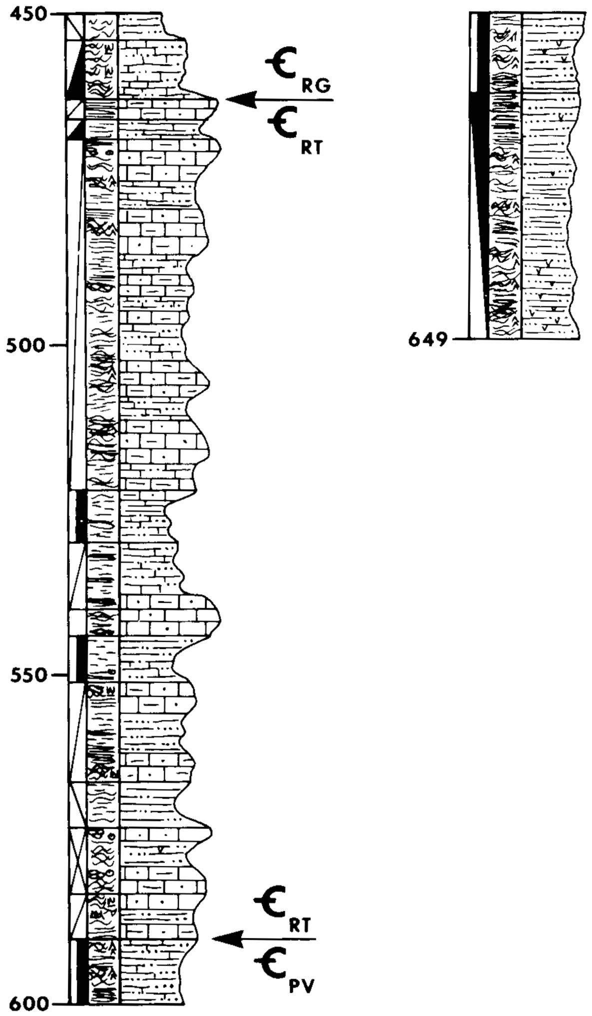

Fig. 7. Columnar section of the portion of the Conasauga Groups penetrated in borehole C3 (450 to 649 ft). The column consists of three parts illustrating, from left, rock color, bedding and stratification patterns, and lithology (symbols summarized in Appendix II). The columnar section is based on detail core logging at 1 ft intervals. Numbers to the left of the column are downhole footages. Arrows to the right of the columns indicate formational contacts: MR = Maryville Limestone; RG = Rogersville Shale; RT = Rutledge Limestone; PV = Pumpkin Valley Shale.

formation is composed of numerous repeated cycles of shale and limestone. Limestone-rich horizons comprise 20 to 40% of this lower zone, and the remainder is composed of calcareous mudstones and shales. The limestones in this lower zone are generally calcarenites, oolitic, and intraclastic packstones that occur in distinct 0.3 to 1 m (1- to 3-ft) thick upward-coarsening cycles.

The lower contact of the Nolichucky Shale with the Maryville Limestone is gradational over about 15 m (50 ft). This zone is characterized by increasing carbonate content within the Nolichucky Shale. Intraformational conglomerates are rare in most of this interval, and the base of the interval is marked by a rapid increase in the intraclast content of the limestones and a decrease in the amount of mudstone.

3.3.2 Maryville Limestone

The coring on the study area did not cover the entire Maryville Limestone, but C3 did penetrate the lower half of the formation. Based on the drilling on Copper Ridge, the formation is about 141 m (463 ft) thick. This value is somewhat larger than the true thickness because of internal deformation that is common within the formation.

The upper portion of the Maryville Limestone is characterized by beds of 'flat pebble' or intraclastic conglomerates. These beds are found in other parts of the Conasauga Group but not to the same extent as in the Maryville Limestone. Interbedded with the conglomeratic beds are beds of calcareous mudstones, calcareous wackestones, calcarenites, and fossiliferous pellet packstones. The strata are commonly lenticularly to wavy bedded. The abundance of intraclastic conglomerate beds decreases with depth from about 80 to 40%.

The lower part of the Maryville Limestone are characterized by thinly bedded calcareous mudstones that are intrastratified with oolitic and fossiliferous wackestones and packstones, calcarenites, and calcareous siltstones. The limestone lithologies occur in 5 to 20 cm (0.2 to 0.7 ft) beds comprising upward-coarsening cycles. These cyclic beds are thinner but similar to those found in the Nolichucky Shale. A complete description of these cyclical beds can be found in Haase et al. (1984).

The lowermost 15 m (50 ft) of the formation are characterized by an increase in the calcareous mudstone content and a proportional decrease in the thickness and number of limestone beds (Fig. 6). The contact with the Rogersville Shale is placed beneath the lowermost ooid-bearing upward coarsening cycle.

3.3.3 Rogersville Shale

The thickness of the Rogersville Shale in C1 and C2 is 37 m (121 ft) and 38 m (124 ft), respectively. This is comparable to the 39.6 m (130 ft) measured within the Copper Ridge core hole. The thickness of the formation in C3, approximately 62 m (205 ft) is almost double that observed in C1 and C2. This abrupt thickness increase is due apparently to an imbrication of the Rogersville Shale associated with a series of thrust faults that can be observed within the C3 core. The uppermost limestone unit observed within the Rogersville

Shale is commonly seen throughout East Tennessee and is known as the Craig Member (Hasson and Haase 1984). At the study site, the Craig Member ranges in thickness from 3 to 4 m (10 to 12 ft).

Lithologically, the Rogersville Shale consists primarily of noncalcareous mudstones, calcarenites, and subarkosic siltstones. A distinctive, massive red mudstone can generally be found immediately underlying the Craig Member and serves as an excellent marker bed on the ORR. Glauconite pellets are common in the siltstones throughout the formation and locally may comprise 10 to 30% of a siltstone horizon. Although glauconite can be found in the Maryville Limestone, zones of such high contents are not extant. Carbonates within the formation occur mainly in the Craig Member, which is comprised of an upward-coarsening cycle. The cycle begins with calcareous siltstones that gradually coarsen to oolitic and intraclastic limestones.

The lower contact of the Rogersville Shale with the Rutledge Limestone is abrupt and is defined by a sharp transition from mudstone having minor amounts of interbedded siltstone to calcarenites, silty wackestone, and micrite. The color change at the contact is also distinct, changing from the red-gray mudstones of the Rogersville Shale to the light gray to gray limestones and siltstones of the Rutledge Limestone.

3.3.4 Rutledge Limestone

Complete sections of the Rutledge Limestone were retrieved from all three core holes on site. The apparent thicknesses of the formation are 38 m (123 ft), 40 m (130 ft), and 39 m (127 ft) for holes C1 to C3, respectively. These values compare well with the down-the-hole thickness of 31 m (101 ft), observed in the Copper Ridge borehole. A prominent clastic-rich interval in the central portion of the formation divides the Rutledge Limestone into an upper and lower limestone-rich part as well as the central clastic unit. This division seems to persist throughout the ORR (Haase 1984).

The limestones in the upper part of the formation are primarily micrites, pellet wackestones and packstones, and silty calcarenites. The clastic-rich lithologies in the central portion of the formation consist of red-brown, red-gray, and gray mudstones and shales containing laminae and lenses of subarkosic siltstone. The lowermost portion of the Rutledge Limestone consists of wackestones and calcarenites. The limestones are interbedded with shales and mudstones similar to those found in the central portion of the formation.

These lithologies combine to form a sequence of three gray limestone horizons separated by two red-gray mudstone-rich horizons. This interval is referred to as the "three limestone beds" by deLaguna et al. (1968) and is a good marker horizon that is apparent on geophysical logs (Appendix II).

The contact between the Rutledge Limestone and the Pumpkin Valley Shale is gradational and is characterized by a decrease in the carbonate content of the strata. The contact is placed at the bottom of the lowermost limestone horizon of the "three limestone bed" horizon.

3.3.5 Pumpkin Valley Shale

A short section of the Pumpkin Valley Shale was encountered at the bottom of the three core holes, and, in part, this contact was used as a basis for total-drilling depth. Although the Pumpkin Valley Shale does not actually crop out in proposed waste storage areas, it does underlie and bound the study site (it crops out north of Melton Valley Drive).

The portion of the formation that was encountered consists of red-brown, red-gray, and gray mudstones and shales interbedded with subarkosic siltstones.

3.4 STRUCTURE

The geologic structures within the proposed SWSA-7 appear to be similar to those of other areas in Melton Valley underlain by strata of the Conasauga Group. The structural geology of the site was investigated by detailed field mapping, core logging, and geophysical investigations. In general, small-scale folds are common throughout the area, and jointing is pervasive. These small-scale features, in combination with larger on-site faults, are likely to control water movement.

3.4.1 Folds and Fractures

Although outcrops on site are scant, several folds were mapped, most being on the eastern region of the site. They are all relatively small scale, being several meters in wavelength and amplitude. Studies elsewhere in Melton Valley (e.g., Davis and Stansfield 1984) suggest that folding is likely to be encountered throughout the proposed burial ground. Such folds can affect groundwater movement, especially where they are very tight and fractured as documented at LLW Trench 7 to the west of the proposed SWSA-7 (Olsen et al. 1983). An overturned and faulted fold is exposed in the sidewall of Melton Branch; this style of structure will have the greatest impact on groundwater movement.

Fracturing and jointing within the Conasauga Group are extensive, and several joint sets can be defined. Joint orientations, measured mainly within the Pumpkin Valley Shale in Melton Valley (Sledz and Huff 1981), indicate that at least two major joint sets exist; one is about parallel to geologic strike, and the other is perpendicular to it. Site-specific data on fracture/joint orientations were obtained from three outcrops on the proposed SWSA-7. The data are presented as lower hemisphere projections of poles to joint planes (Fig. 8), and the location of the sites is shown on the geologic map (Fig. 3).

Data from Sledz and Huff (1981) indicate that in the Melton Valley outcrop belt of the Conasauga Group on the ORR, joints parallel to and normal to (a to c joint set) geologic strike predominate; such joints formed by extension. However, an orthogonal joint set resulting from shear forces is also recognizable. Orthogonal jointing, apparently the result of shearing, also occurs within the Bear Creek Valley outcrop belt of the Conasauga group (Sledz and Huff 1981 and Rothschild et al. 1984b). Jointing resulting from shear stresses causes joints to form at acute angles to the principal directions of stress rather than perpendicular to such directions as in extensional jointing (Hobbs, Means, and Williams 1976). The principal direction of stress in the study area must have been perpendicular to strike, parallel to the direction of thrust motion. The exact nature and history of jointing within the rocks is difficult to determine because of the long and complex deformational history of the region. The orientation of joints is likely to vary across strike because of ramping of thrust blocks

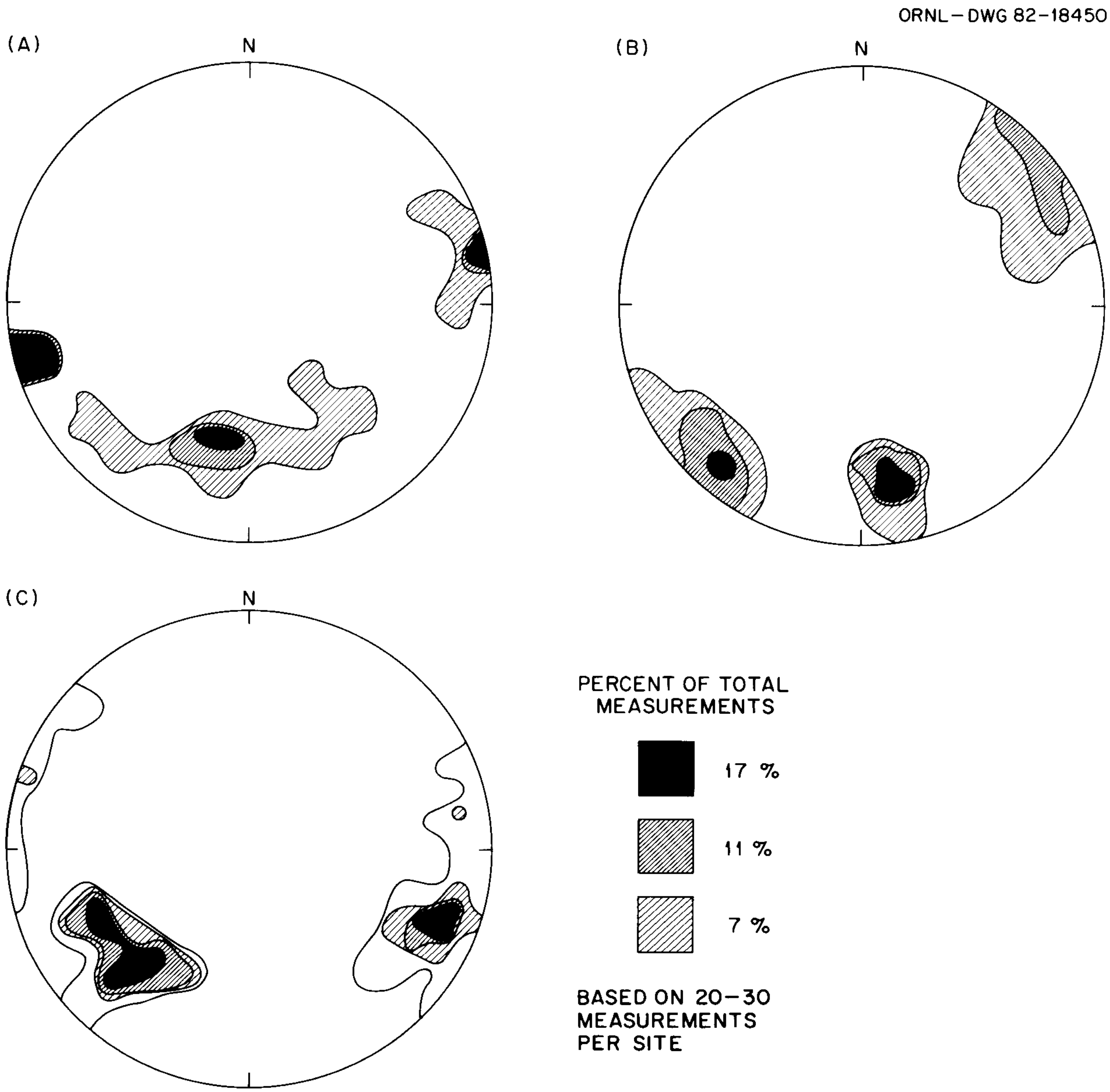

Fig. 8. Lower hemisphere equal area projections of poles to joint planes.

between thrust blocks and near small-scale structural features, such as tear faults or folds. The data from Sledz and Huff (1981) indicate that even along strike fracture orientations are highly variable.

At Site A on the proposed SWSA-7, two joint sets predominate, a set that strikes between N70 and 90°W, and a set that strikes about N20°W. The set striking N20°W dips at a very high angle (ca 80°); the second set dips about 50° to the NE. The approximate strike and dip of bedding at this site is N55°E and 35°SE, respectively. At Site B, two joint sets are also recognized. One joint set strikes about N30°W and dips at a high angle; the second set strikes between N70 and 90°E and dips approximately 63°NW. The orientation of bedding at this site averages N40°E, dipping 26°SE. At Site C, the two joint sets strike about N20 to 40°W and N20 to 30°E and dip about 66°NE and 74°NW, respectively. The average strike of bedding at Site C is N89°W, having a dip of 37° to the south.

At each of the three localities within the study site, the joint sets form an approximate angle of 120° between their strike directions. This angle is approximately bisected by the orientation of bedding at each respective location. Such a relationship indicates an orthogonal joint set at each site that formed under shear. Data are limited, however, and variations occur throughout the site; therefore, interpretation of joint data is tenuous. It is interesting to note the consistency of the results from Sites A and B, although an apparent rotation of the data occurs at Site C. This rotation can be correlated to a shift of the orientation of bedding at that site. The shift in bedding may be a result of folding near the site or possibly a result of the existence of movement along a tear fault on site (see next section). Site data are consistent with Sledz and Huff (1981); measurements at their nearest localities to the proposed SWSA-7 (Sites S3 and S6) yield very similar results to those presented previously. Site data do not indicate a prominent joint set parallel to strike; however, field measurements do suggest the presence of an additional joint set parallel to bedding planes. This set was not measured because of the difficulty in distinguishing bedding plane surfaces and joint surfaces. Core retrieved from the site also indicated the presence of bedding plane joints or bedding plane parallel faults.

3.4.2 Large-Scale Faulting and Geophysics

The steep topography and linear valleys on the proposed SWSA-7 suggest that the area may be underlain by a series of faults or fracture zones. Tear faults oriented perpendicularly to regional thrust faults have been identified in the vicinity of the ORNL Hydraulic Fracturing Facility, which is 2.5 km (1.55 miles) west of the study site (Haase, unpub. data), and such faults might be expected on site. Four linear features (possible faults) are shown on the site geologic map (Fig. 3). Identification is based on photo linears interpreted from air photos. To gain a better understanding of these features, a detailed investigation of the prominent linear feature through the center of the site was carried out. After general geologic mapping of the site, geophysical surveys were run, cores taken, and a topographic analysis of the area made.

3.4.3 Field Mapping

Structural field mapping on site is limited by the number of outcrops. Data are too limited to delineate any systematic variations in the attitude of bedding over the area. Measurements of the strike of bedding range from N19°E to N85°W, and dips vary from 50°SE to 27°NW. The mean strike and dip of bedding on site is N58°E, 23°SE (represents the mean of 29 measurements).

3.4.4 Coring

The coring program was laid out with two purposes in mind: the first was to define the stratigraphy of the site, and the second was to examine if any structural offset exists on opposite sides of the central drainageway. To carry out the first task, a pair of holes on the west side of the site were drilled (C2 and C3); these holes were of sufficient length so cross correlations could be made and most of the section was encountered. The northern two holes (C1 and C2) were drilled along strike on opposite sides of the north-south trending valley. If any offset was caused by faulting, it should be apparent within these corings. All the holes were drilled to a sufficient depth such that identifiable and correlatable contacts or beds were encountered. The core holes were all logged after drilling (work was performed by Tennessee Valley Authority under Interagency Agreement DE-AI05-83OR21386) to allow geophysical properties of the strata to be studied and to set up a data base so that future borings can be geophysically logged without coring and so correlations still can be made.

The lithologic logs for the core holes are shown in Figs. 4-7 (geophysical logs are included in Appendix II). The logs of holes C1 and C2 indicate that no significant offset has occurred between opposite sides of the central drainageway. This conclusion is based on using formation boundaries as marker horizons and comparing relative elevations between the holes. Both C1 and C2 encountered three formation boundaries, and both showed almost identical formation thicknesses for the Rogersville Shale and the Rutledge Limestone.

Within each core hole, faults could be identified. This is very dramatically illustrated in C3, where the Rogersville Shale is greatly thickened in comparison to C1, C2, and other borings on the ORR. Based on the lithology, the Rogersville Section appears to repeat itself starting at a point approximately 110 m (360 ft) deep. Faults in boring C3 have been identified at depths in meters (ft) of: 26 (84), 37 (121), 42 (138), 45 (147), 64 (210), 66 (217), 73 (241), 88 to 90 (289 to 294), 93 (305), 97 (318), 103 (338), 116 (381), 120 to 121 (393 to 395), 122 to 124 (400 to 405), 142 (467), 148 (485), 151 (494), 156 (513), 191 (626), 193 (632), and 197 (646). The 88 to 90-m (289 to 294 ft) and 122 to 124-m (400 to 405 ft) intervals are major fault zones with significant disturbance to the rock. The caliper log for C3 shows a very large spike at a depth of about 123 m (402 ft), indicating the faulted material in that zone is soft and friable. Therefore, this zone is probably open to some extent and may be a conductor of groundwater. In boring C1, five possible faults were identified. None of the faults appeared to be extensive, and the deepest of the features was at a depth of 53 m (174 ft). Five possible faults were also identified in boring C2, none of which were major features. The deepest fault zone encountered was at the bottom of the core hole. One fault zone, at 25 m (83 ft), did cause a spike on the caliper log for boring C2.

Formational contacts identified in the core holes were used to produce the geologic map of the site (Fig. 3). The geometry of the bedrock on the site was determined using the Rogersville Shale/Rutledge Limestone and the Rutledge Limestone/Pumpkin Valley Shale contacts in simple three-point analyses. These analyses indicated that the formation contacts are oriented at N59°E, 23°SE and N61°E, 24°SE, respectively. These large-scale orientations agree with the limited surface measurements taken and with regional data. The third lithologic contact encountered in the core holes, the Maryville Limestone/Rogersville Shale contact, could not be analyzed because of the structural disturbance and thickening observed in boring C3.

3.4.5 Surface Geophysics

To complement the downhole work performed on site, a series of surface geophysical surveys were performed. The primary objectives of the program were to: (1) detect any anomalous conditions that may be indicative of seepage pathways for groundwater (cavities, faults, or fracture zones), (2) determine the depth to sound rock, and (3) determine the geophysical properties of the various rock types on site. The focus of the surveys was to investigate the central drainageway of the site. The first survey run on the site was an electromagnetic survey. After this initial survey, additional surveys were performed in cooperation with the U.S. Army Corps of

Engineers, Waterways Experimental Station (performed under Interagency Agreement #DE-AI05-830R-21384. Results are reported in Llopis et al. 1984 and reproduced in total within this report). The second phase of surveys included seismic refraction, horizontal electrical profiling, vertical electrical sounding, spontaneous potential (SP), and electromagnetic (EM).

3.4.5.1 Very Low Frequency-Electromagnetic Resistivity Survey

The initial electromagnetic survey run on site was an instrument that uses transmissions from very low Frequency (VLF) antennae located around the country as an energy source. Electromagnetic surveys are used to detect subtle changes in local magnetic fields along a survey line. These changes or anomalies are a result of the response of local conductors in the subsurface that alter fields generated by man-made or natural currents, depending on the receiver being used. These conductors can range from man-made objects (such as metal pipes) to ore bodies. Responses may also occur near fault zones if the fault acts as a conductor; this may occur if mineralization occurs within the fault or fault zone, or if significantly more water is moving within the zone because of increased porosity in comparison to the surrounding rock. This method has been used in the past primarily as a tool for the location of conductive ore bodies (Paterson and Ronka 1969), and electromagnetic techniques in general are commonly used for the investigation and delineation of conductive, subsurface plumes of contaminated groundwater (e.g., Slaine and Greenhouse 1982). The general theory of VLF-EM will not be discussed in this document, but further information on the technique can be found in Geonics Ltd.

(1979). The advantages of VLF-EM over other geophysical methods are as follows: they are extremely rapid, require very little manpower, are inexpensive, and interpretation and manipulation of the raw data is simple and rapid.

Six VLF-EM survey lines were run on the proposed SWSA-7; their locations are shown in Fig. 9. The results of the survey are shown in Fig. 10. The data have been mathematically filtered prior to presentation using the method described in Fraser (1969). Filtering serves several purposes: (1) it shifts the field data so that anomalies are indicated by peaks in the data, (2) it filters out general background noise, (3) it filters out most topographic effects, and (4) it filters out large-scale, deep conductors. The location of VLF-EM anomalies are shown in Figs. 9 and 10. A very strong pair of linear features can be seen in the data, and a third feature may be present on the western portion of site. Other features might occur on the site but were not encountered because of the limited extent of the survey. The results appear to indicate that there is a subsurface conductor that runs in or parallel to the central drainageway on site. These anomalies are likely to be caused by a fracture zone that is a conductor of groundwater. Note that the approximate depth of investigation using this technique in this area is 20 to 30 m (65 to 100 ft) (using a resistivity of 95 ohm/m (320 ohm/ft) as determined by the electrical surveys). That is, the zone of influence is relatively deep but does integrate all anomalies occurring to that depth.

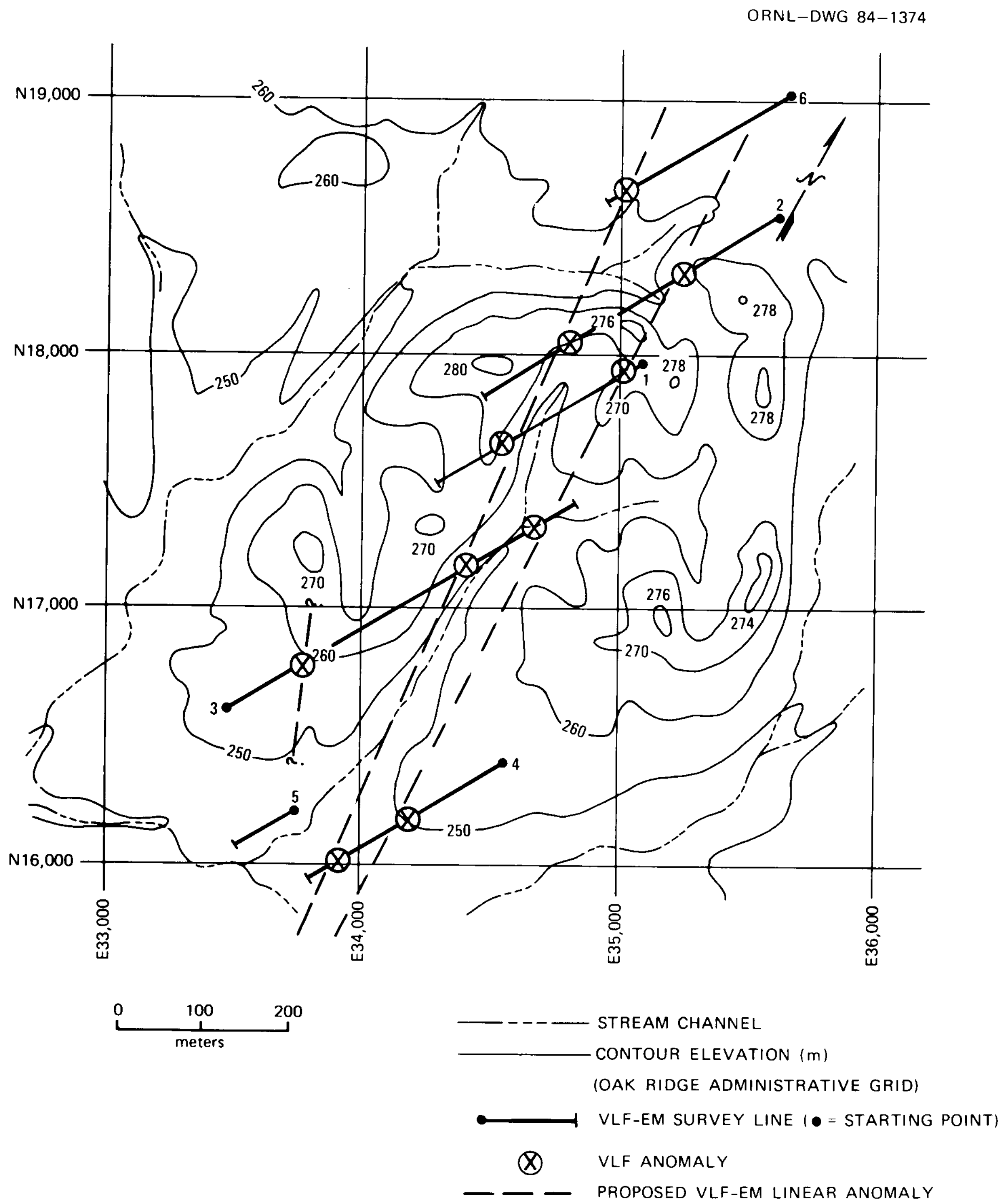

Fig. 9. VLF-EM survey lines and results.

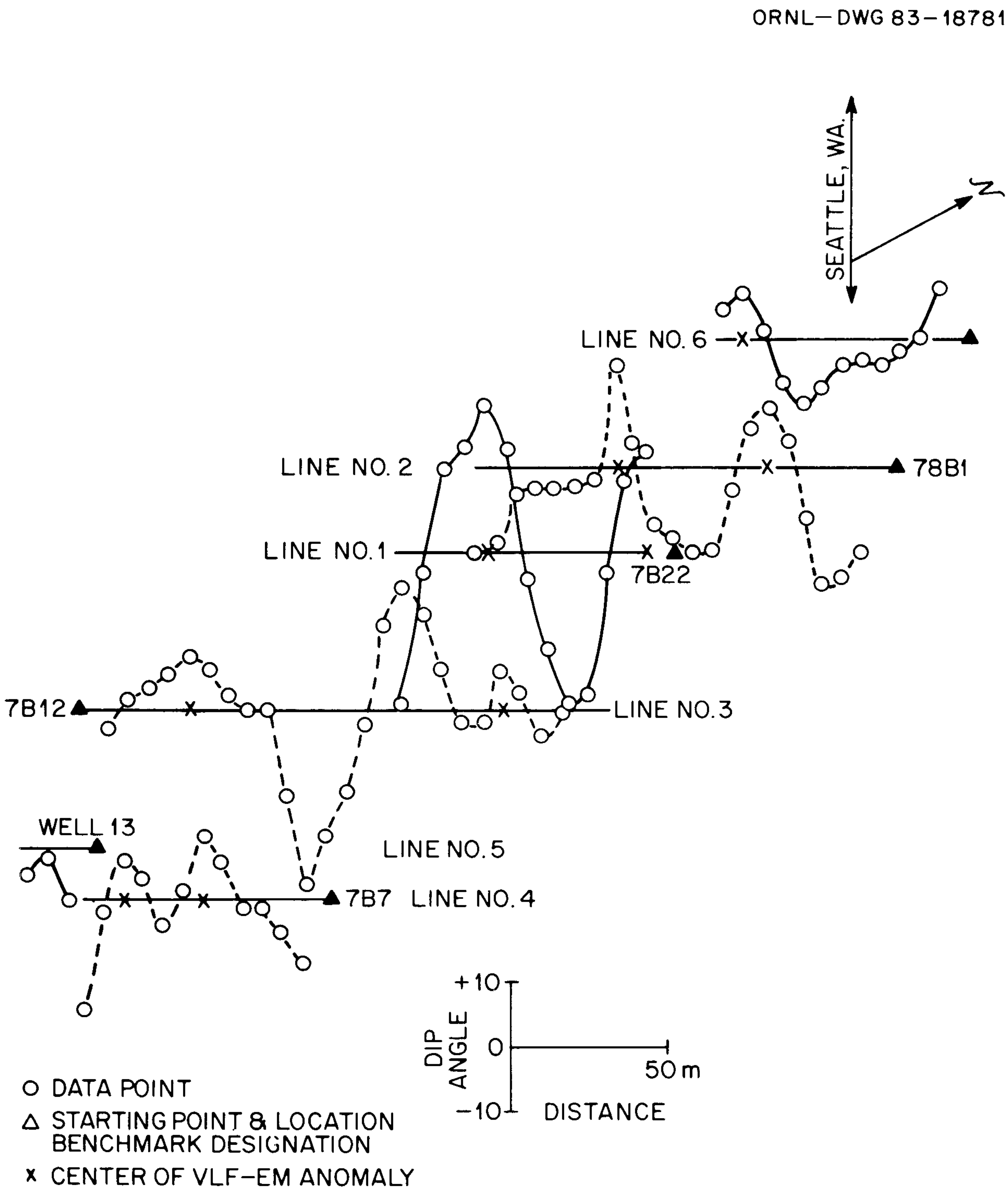

Fig. 10. Filtered dip-angles data for VLF-EM survey on the proposed SWSA-7.

3.4.5.2 Spontaneous Potential Survey

After the VLF-EM survey, a more intensive geophysical investigation was carried out on the proposed SWSA-7. The location of transects across the site are shown in Fig. 11. The survey lines were laid out to investigate the possible fault zone running through the center of the site. In addition to examining the central structure, one survey line (Site 1) crossed a possible structure on the eastern boundary of the site. Four methods of investigation were used at some or all of the sites; these included electrical resistivity, seismic refraction, spontaneous potential, and electromagnetics. The procedures and interpretation methods used in these surveys are discussed in detail in Telford et al. (1976); Engineer Manual 1110-1-1802 (Department of Army 1979).

Two SP survey lines were run, and their locations are shown in more detail in Fig. 12. Both survey lines are located at Site 4 and serve as duplicates for the area. The objective of the SP survey was to detect potential differences (voltages) on the surface generated by flowing water in the subsurface. The mechanism by which this technique works (SP) is reviewed in Telford et al. (1976) and Cooper et al. (1980). The field procedure consisted of emplacing electrode arrays in a profile pattern and measuring voltages between each of the electrodes in the array and a reference electrode. The reference electrode was placed in an area away from the array at a location where the potential remained constant relative to the array. The electrode arrays consisted of 1.2-m- (4-ft-) long copper rods that were driven into the ground about 0.5-m (1-1/2 ft) at 6-m (20-ft) spacings. The reference

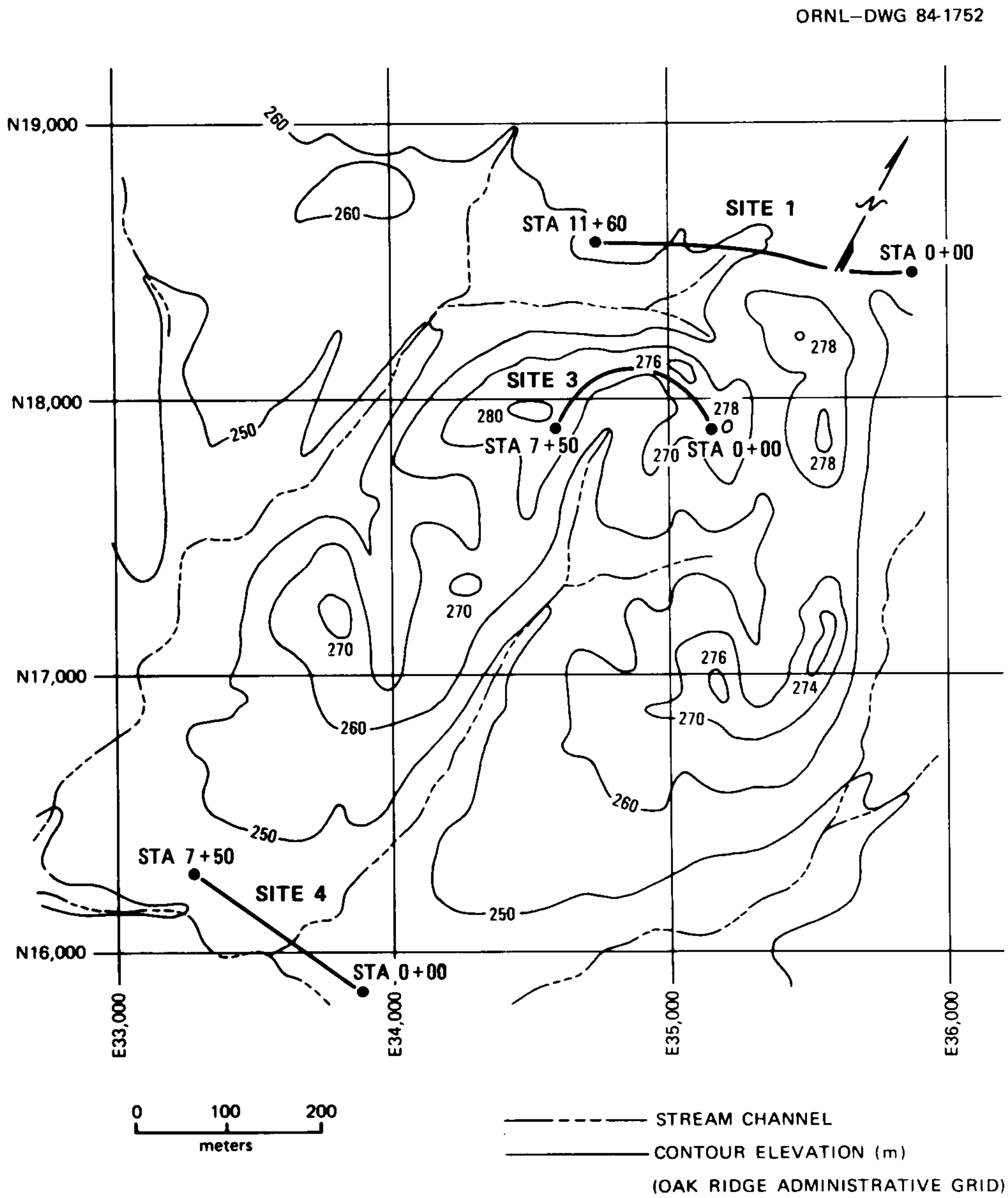

Fig. 11. Location of geophysical lines on the proposed SWSA-7.

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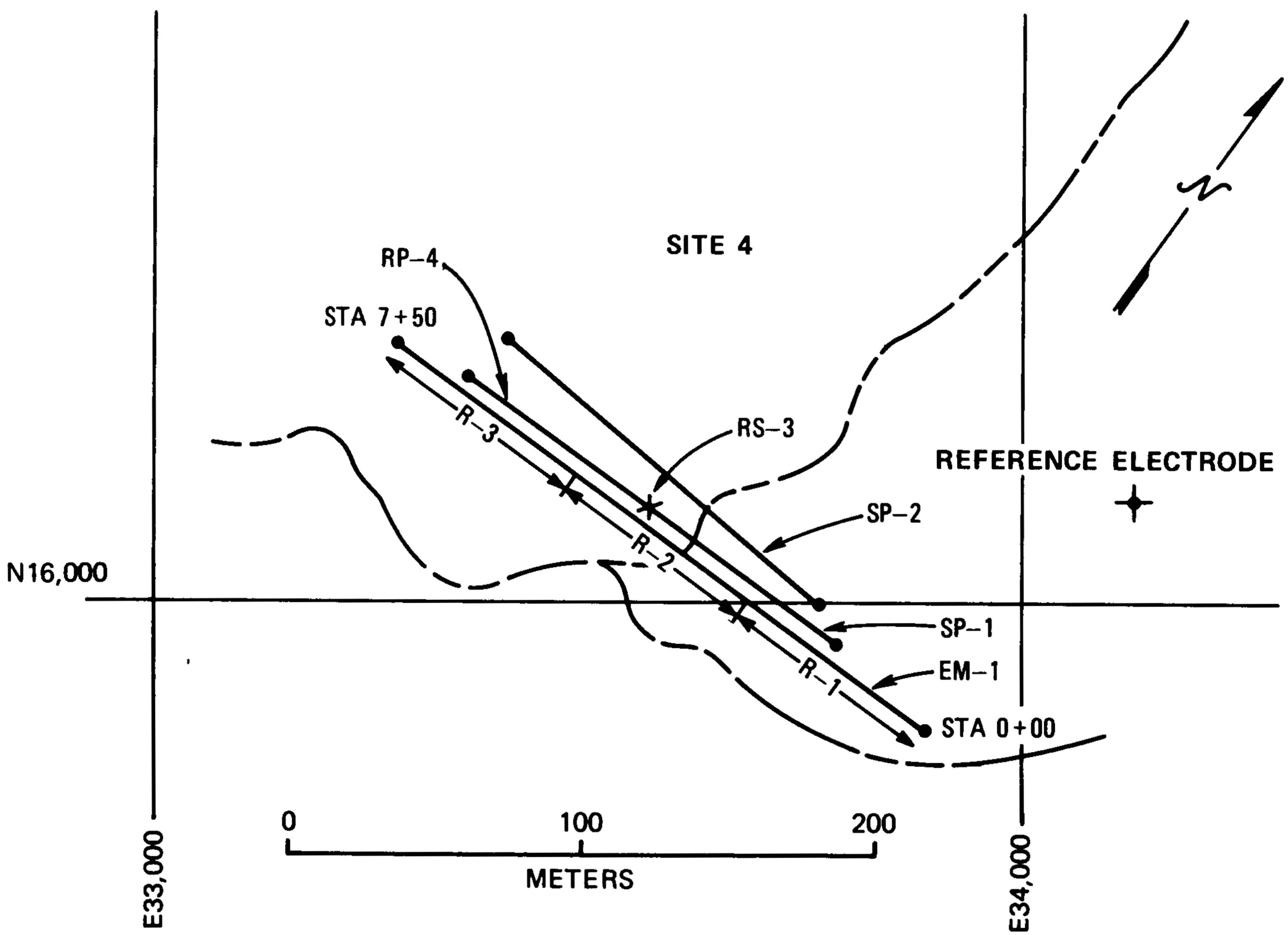

Fig. 12. Layout of Site 4.

electrode was connected to the arrays by 18-gauge, multistrand copper wire. Spontaneous potential measurements were then obtained by connecting clip leads of a digital multimeter (50 Megaohm internal resistance) to both the reference electrode and the measurement electrode. The array length for SP-1 was 158 m (520 ft) and was 146 m (480 ft) for SP-2. Several measurements at each SP array were made intermittently during the period of September 21-30, 1983. Each set of measurements (both arrays) took about 1 h.

The results of the SP surveys can be examined in two ways: as a profile at a given time or as a time sequence before and after a storm event. Areas on the surface under which water is moving should yield negative voltage anomalies. Changes in subsurface flow resulting from a storm event or pumping should also result in negative changes in voltage relative to the reference electrode. The results of the SP surveys are presented in Appendix I in both tabular and graphical form. For array SP-1, five relative negative regions occur, these are: Station 1+80, Station 3+40, Station 4+20, Station 5+20, and Station 6+00. The first set of readings (0900 on September 21, 1983) are considered reference readings (prior to rain). A heavy rainfall occurred from 0930 to 1600 on September 21. Four prominent negative anomalies are seen in the static profiles for array SP-2. They are at Station 1+80, Station 3+00, Station 3+80, and Station 5+80 to 6+00. The reference reading for this array is considered to be that taken at 1330 on September 30, 1983 (8 d after a major rainfall event).

The parallel SP arrays [18 m (60 ft) apart] were run to test the consistency of the data in the area. It was found that, in general, the data between the arrays do correspond very well. Note that the data for September 21 to 22, 1983, show a general trend in the readings in the negative direction. After September 22, 1983, the readings become more positive. Thus, the data support the hypothesis of increased flow in the subsurface in discrete pathways and the fact that these pathways are continuous across both arrays. The locations of the three largest anomalies are included in Fig. 17.

3.4.5.3 Electromagnetic Resistivity Survey

EM surveys were conducted at Sites 3 and 4 (Fig. 11) on the proposed SWSA-7, and their locations are shown in Figs. 12 and 13. The objective of the EM surveys was to measure terrain conductivity. The theory and approach used in the VLF-EM survey is similar except that the energy source is a hand-held transmitter. A transmitter coil that generates an alternating current at an audio frequency is placed on the ground, and a short distance away a receiver coil is placed on the ground. Measurements were made at various intercoil spacings and in both the vertical (coils flat on the ground) and horizontal (coils vertical) dipole configurations. The instrument used was the EM-34, manufactured by Geonics Ltd. More detailed information regarding the theory and use of this instrument can be found in McNeill (1980).

The survey lines at both Sites 3 and 4 were 158 m (520 ft) long, and readings were taken at 12-m (40-ft) intervals. Readings were taken at intercoil spacing of 10, 20, and 40 m (33, 66, and 131 ft) in both the vertical and horizontal dipole directions. The results of the EM

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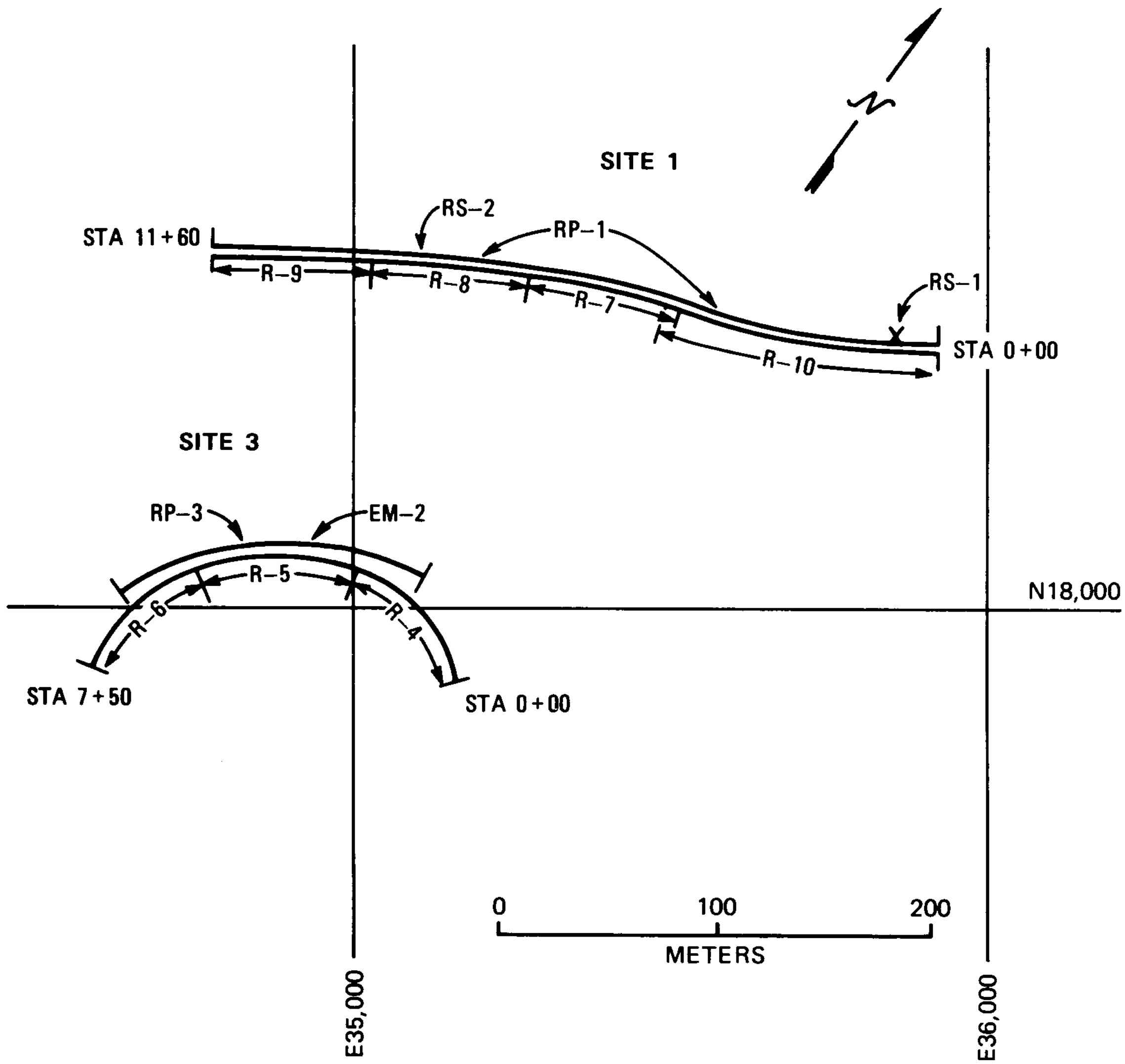

Fig. 13. Layout of Sites 1 and 3.

surveys are included in Appendix I. The horizontal dipole readings for Site 3 show a very distinct increase in conductivity near the center of the survey line. The vertical dipole readings do not show this trend, but they do show a general decrease in conductivity with intercoil spacing and, therefore, with depth of investigation. No clear anomalies were observed in the data from Site 4; but again, a general decrease in conductivity with depth can be seen. The anomaly seen at Site 3 is included in Fig. 17.

3.4.5.4 Electrical Resistivity Surveys

Resistivity surveys were run at Sites 1, 3, and 4 (Figs. 12 and 13). Two types of surveys were conducted: a vertical resistivity sounding (Schlumberger array) and a horizontal resistivity profile (Wenner array). Both survey types are discussed in detail in Engineer Manual 1110-1-1802 (Department of Army 1979). Briefly, the Schlumberger array consists of two potential electrodes separated by a distance 'S' and two current electrodes, each at a distance 'L' from the centerpoint. Soundings are performed by expanding the current electrodes along a line about the centerpoint. The survey results in a vertical profile of resistivity variation with depth. The Wenner array consists of two current and two potential electrodes placed along a line with a space 'A' between each. In general, for a given 'A' spacing, the resistivity determination is influenced by all materials more shallow than a depth 'A'. Resistivity profiling involves moving the entire Wenner array along a line, keeping 'A' constant, and determining horizontal variations of resistivity for a given depth horizon.

In total, three resistivity soundings were performed and three horizontal profiles were conducted; the results of these are included in Appendix I. The soundings at Site 1 (RS-1 and RS-2) were centered at Stations 0+60 and 8+20. Assuming a three-layer case, a computer code was used to calculate layer thicknesses and corresponding resistivities. The results are shown in Table 1. In general, the soundings indicate a relatively high-resistivity surface zone 0.9 to 1.2 m (3 to 4 ft), underlain by a thick 5.2 to 16.8 m (17 to 55 ft) low resistivity zone and a higher resistivity zone at depth. These zones probably represent unsaturated soil and weathered rock, saturated weathered rock, and saturated unweathered rock. The horizontal profile at Site 1 (RP-1) used two 'A' spacings: 6.1 and 12.2 m (20 and 40 ft). The data obtained from the 12.2-m (40-ft) spacing show minor fluctuations in resistivity along the profile, having values of resistivity centering around a value of 100 ohm-m (330 ohm-ft). The data from the 6.1-m (20-ft) spacing show much more scatter. The differences between the two spacings might be explained by the highly variable nature of near-surface materials [less than 6.1 m (20 ft)] because of varying soil type and thickness.

The horizontal profile at Site 3 (RP-3) was conducted using spacings of 6.2 and 12.2 m (20 and 40 ft). The results for the 6.1-m (20-ft) spacing indicate a prominent low between Stations 3+40 and 4+40 and a high at Station 6+10. The 12.2 m (40 ft) spacing profile showed less variation in resistivity; however, a low is indicated at Station 3+80. Depth of water in this area is deep; therefore, the

Table 1. Layer thickness and corresponding resistivities

	Layer	Depth to top of interface m	ft	Apparent resistivity ohm-m	ohm-ft
Line RS-1					
	1	0	0	449	1473
	2	1	3	95	312
	3	18	58	182	598
Line RS-2					
	1	0	0	301	988
	2	1.2	4	63	207
	3	6.5	21	118	388
Line RS-3					
	1	0	0	212	694
	2	1	3	23	76
	3	2.7	9	82	270
	4	28	91	352	1155

variations in resistivity are probably the result of variations in the extent of rock weathering (low resistivity zones indicating greater weathering). This weathering may be a result of faulting or jointing.

The resistivity profile at Site 4 (RS-3) was centered about Station 4+00. Assuming a four-layer case based on inspection of the sounding curve, the thicknesses and resistivities shown in Table 1 can be calculated. The additional layer in this profile is probably the result of the presence of colluvium or alluvium in the valley at this site. That is, the layers represent: unsaturated soil (alluvium), saturated alluvium, saturated weathered rock, and saturated unweathered rock. Note the significant depth of weathering at this site [about 28 m (91 ft)]. The results of the horizontal profiling at this site do show slight variations, but no prominent anomalies are present. The variations that occur probably reflect variations in the overburden material.

3.4.5.4 Seismic Refraction Surveys

The location of the ten refraction survey lines are shown in Figs. 12 and 13 (R1-R10). All refraction lines were 76 m (250 ft) long having 3-m (10-ft) geophone spacings, with the exception of R-10, which was 114 m (375 ft) long and used 4.6-m (15-ft) geophone spacings. The surveys were conducted using two 12-channel seismographs coupled together to form a 24-channel system. Energy sources for the survey were 0.25-kg (1/2-lb) TNT-equivalent two-component explosives. Shotholes were approximately 0.6 m (2 ft) in depth.

Basic data acquired from seismic refraction surveys are conventionally displayed as time-distance plots. The data for all lines are displayed in Appendix I. The seismograph records were analyzed to determine the time of first arrival of the compression (P) wave at each geophone location, and then the time-distance plots prepared. Straight-line segments were fit to the data and analyzed using standard procedures given in Telford et al. (1976) and Engineer Manual 1110-1-1802 (Department of Army 1979) to yield velocities and depths to interfaces between materials of differing velocities. Interpreted profiles for the three sites are shown in Figs. 14-16. The results from Site 1 indicate three different velocity layers as shown in Fig. 14. The first layer corresponds to a soil cover and has a velocity between 440 and 550 mps (1450 and 1800 fps). The second layer probably represents the weathered bedrock or saprolite and has relatively constant velocity ranging between 1400 and 1480 mps (4600 and 4850 fps). The third layer, unweathered bedrock, has a velocity that ranges between 3400 and 3630 mps (11,150 and 11,900 fps). The easternmost survey line on site indicated that only two layers were present: soil and unweathered rock. Based on the time-distance plots, delays were noted at Stations 7+00, 9+90, and 3+00, which may be indicative of rock fractures or depressions.

Three refraction lines were run at Site 3, and the interpreted results are shown in Fig. 15. Three velocity zones are indicated by the data and are similar in nature to those described for Site 1, except that the velocities were slightly higher in the two shallow zones. The data for the unweathered bedrock layer at this site shows a

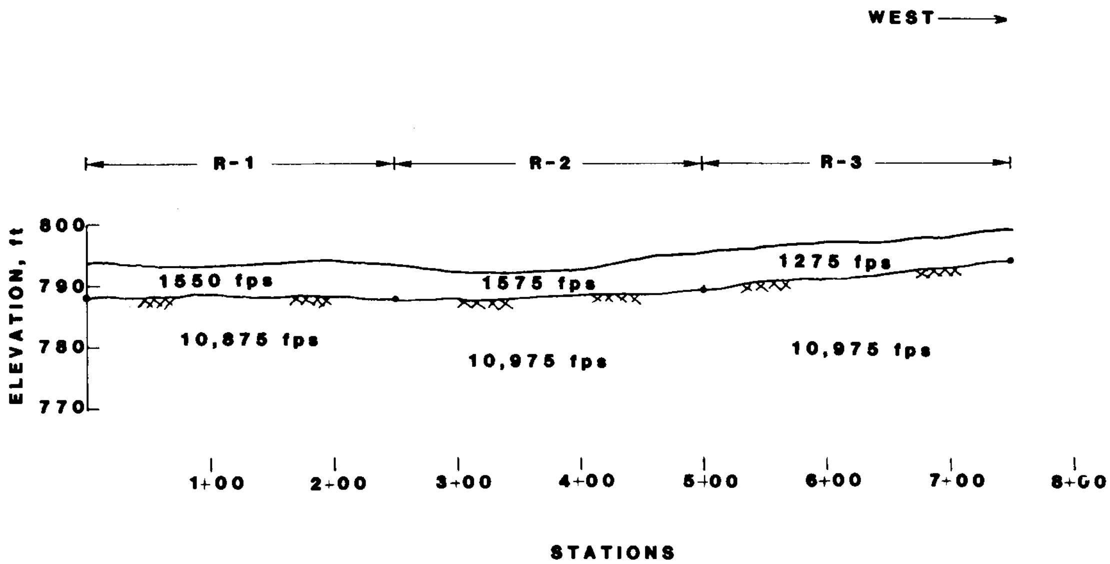

Fig. 14. Seismic velocity profile between station 0+00 and station 7:50, Site 4, SWSA-7.

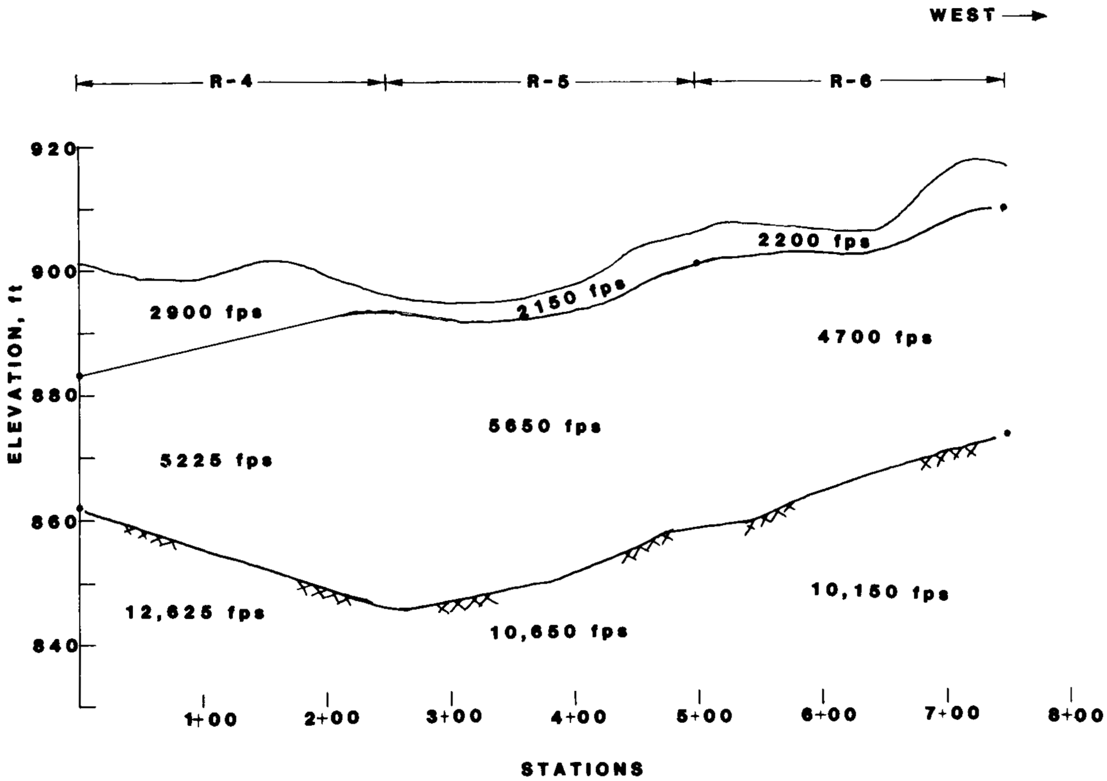

Fig. 15. Seismic velocity profile between station 0+00 and station 7+50, Site 3, SWSA-7.

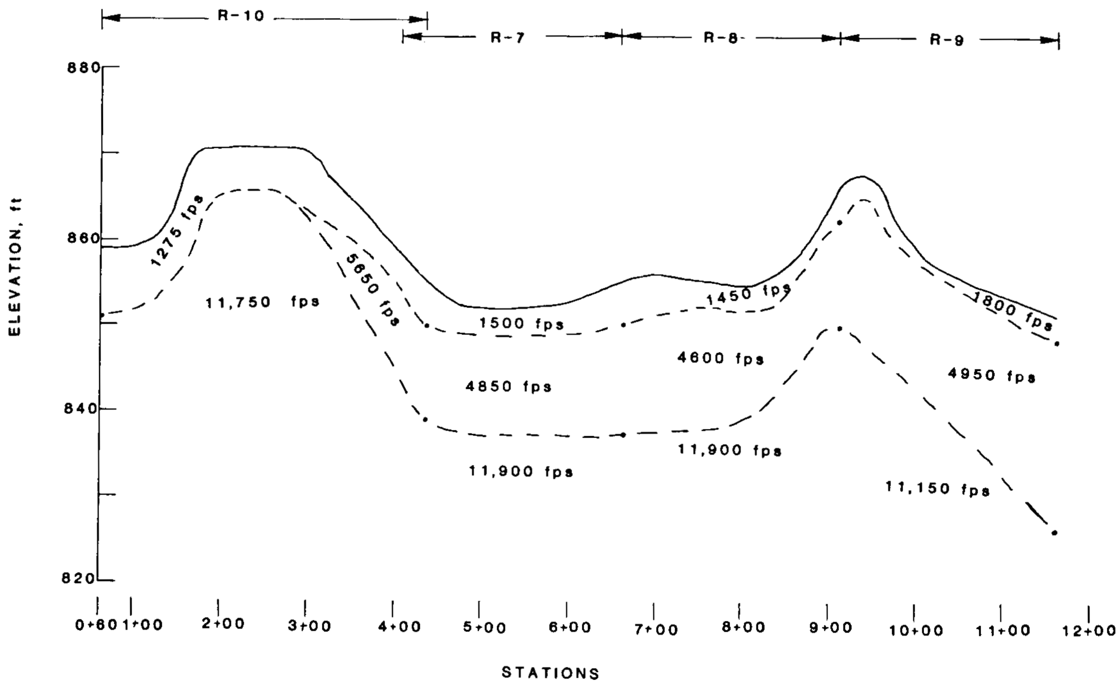

Fig. 16. Seismic velocity profile between station 0+60 and station 11+60, Site 1, SWSA-7.

general increase in velocity towards the east. This may be an artifact of the changing orientation of the survey line (due to its relative orientation to jointing) or may be a result of changes in lithology. Several small anomalies can be seen in the delay times for the survey lines at this site.

The results of the three refraction lines at Site 4 are presented in Fig. 16. The data indicated two different velocity zones at this site. These velocities averaged 450 and 3340 mps (1475 and 10,950 fps) which correspond to overburden material (soil and alluvium) and bedrock. Two anomalies in the form of delay times appear to be in the area of Stations 1+50 and 3+30. These may be a result of fracture zones or depressions.

Note that the results of the seismic and resistivity surveys differ. In part, that is because 'unweathered rock' for electrical response may be quite different from that for seismic response. The results of the surveys at Sites 1, 3, and 4 are summarized in Fig. 17. In general, no major faults or anomalies are apparent from the data, but several smaller anomalies were encountered during the investigation. The anomalies were most apparent in the surveys investigating electrical properties of the subsurface materials, which may indicates that fracture zones, as opposed to faults, may be present and result in shallow zones of more highly weathered, therefore porous, materials. The lack of response in the seismic surveys indicates that no significant offset is present along any structures, which is consistent with the findings from the core holes. The results are also consistent with the VLF-EM survey; at least one zone through the central part of

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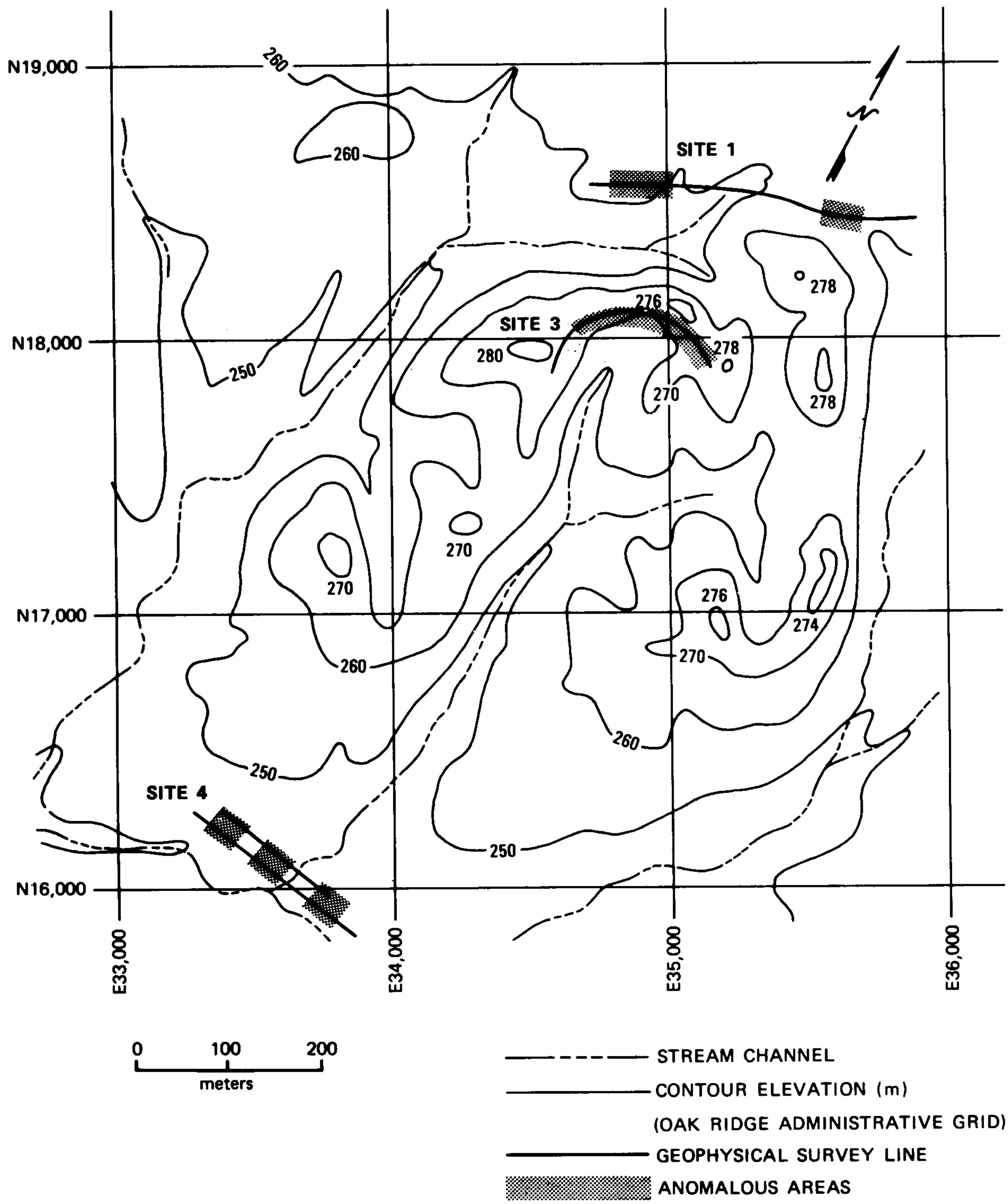

Fig. 17. Location of geophysical anomalies on the proposed SWSA-7.

the site appears to be a subsurface conductor of water. A line connecting the easternmost anomaly at Site 4 through the anomalous zone at Site 3 to the western anomaly at Site 1 corresponds with the western linear in the central drainage seen in the VLF-EM data. The results at Site 1 also indicate that a fracture zone may occur along the base of the steep ridge counting the eastern portion of the proposed SWSA-7. This feature coincides with that seen in air photos (Fig. 3).

3.5 TOPOGRAPHIC ANALYSIS

The very regular geometry of the proposed SWSA-7 site and Melton Valley, in general, may be a result of faults or fracture zones that are aligned at an acute angle to geologic strike. That is, the NW-SE trending valleys are very regular in shape and orientation, and they run at an angle with the general ridge alignment of the area. To assess the regularity of the topography, two topographic cross sections were made (Fig. 18). Both cross sections run east to west on the ORNL grid system (approximately along geologic strike). The two sections cross the proposed SWSA-7 site and run the length of the valley. The northern cross section follows the N18,000 ORNL grid line from E24,000 to E37,000. The second cross section follows the N17,000 grid line from E23,000 to E38,000.

The most striking feature of the cross sections is the regularity of the slopes. The east facing slopes are much steeper than the west facing slopes. This relationship is borne out in the data presented in Table 2, which indicates that the east-facing slopes are about 10° steeper than the west-facing slopes. These results are not direct indications of fracture zones or faults, but they do seem to support

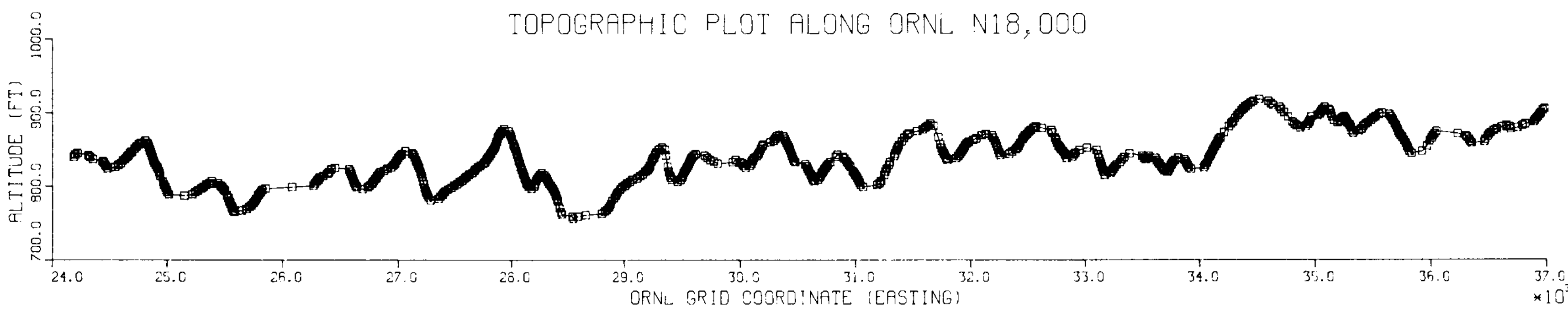

Fig. 18. Topographic plots along Melton Valley. The upper plot is along ORNL N18,000 and the lower, along ORNL N17,000. Vertical exaggeration approximately 6:1. Proposed SWSA-7 is located between E33,000 and E36,000.

Table 2. Topographic analysis

Cross section	Slope (facing)	No. of measurements	Mean of slope	Standard deviation
N17,000	east	12	17.25	5.66
N17,000	west	14	9.26	3.41
N18,000	east	18	19.10	5.40
N18,000	west	20	10.80	3.60

the hypothesis that the valleys are structurally controlled, thus explaining their uniform nature. That is, the slopes may be controlled by the orientation of a fault, fracture pattern, or the intersection of two fracture sets.

3.6 RADIONUCLIDE ADSORPTION CHARACTERISTICS

A basic question that must be addressed by any site characterization is determining the rate with which radionuclides, or other contaminants, will move from their initial point of contact with earth materials to the biosphere by way of the hydrologic system. One of the major factors in the attenuation of radionuclide migration is the degree of adsorption to the soil or rock at the disposal site. The adsorption properties of the soils on the proposed SWSA-7 have been addressed in a separate volume (Rothschild et al. 1984a). To assess the properties of the saprolite and unweathered rock zones on the site, a total of 54 samples were collected. Most of the samples collected comprise two suites of samples taken with depth from two relatively deep holes. The remainder of the samples were taken at three depth increments from five drill holes.

The samples were collected in conjunction with the installation of monitoring wells for the site. The samples analyzed are grab samples of drill cuttings that were blown from the borehole during the drilling process. An air-rotary rig was used for drilling, and samples were collected at approximately 1.5-m (5-ft) intervals. The samples analyzed have all been sieved and only the finer-than-2-mm portion used for analysis. A batch methodology was used to determine the Kds for ^{85}Sr, ^{125}I, ^{134}Cs, ^{58}Co, ^{241}Am, and total hardness (Ca+Mg). The details of the methodology used have been discussed in the soils characterization report for the proposed SWSA-7 (Rothschild et al. 1984a) and will not be discussed in this report.

Detailed vertical profile samples were collected and analyzed for well sites 1 and 10. The results of these analyses are presented in Figs. 19 and 20. Variations with depth are the result of weathering and lithologic variations. The lithologic logs for all wells are included in Appendix II as is the approximate extent of weathering in each hole. In both boreholes, a decrease in the Kds for Sr, Cs, and hardness can be seen; these trends are probably a direct result of the extent of weathering at each site. The Kds for the other isotopes are more consistent throughout the profile with the exception of the first shallow sample (soil). More variation is evident in borehole 1 than borehole 10; this is because of the heterogeneity of the rock encountered.

Three depth increments from five boreholes were sampled and analyzed (well sites 2, 11, 12, 13, and 14). The results of these profiles are presented in Table 3. With the exception of well 13, all the samples were collected in the weathered zone of rock. Well 13 was completed in relatively unweathered shale and limestone of the Nolichucky Shale formation. Within these short profiles, similar trends for the longer profiles can be observed; because of the lack of weathering, the analyses for Well 13 show much less variation with depth.

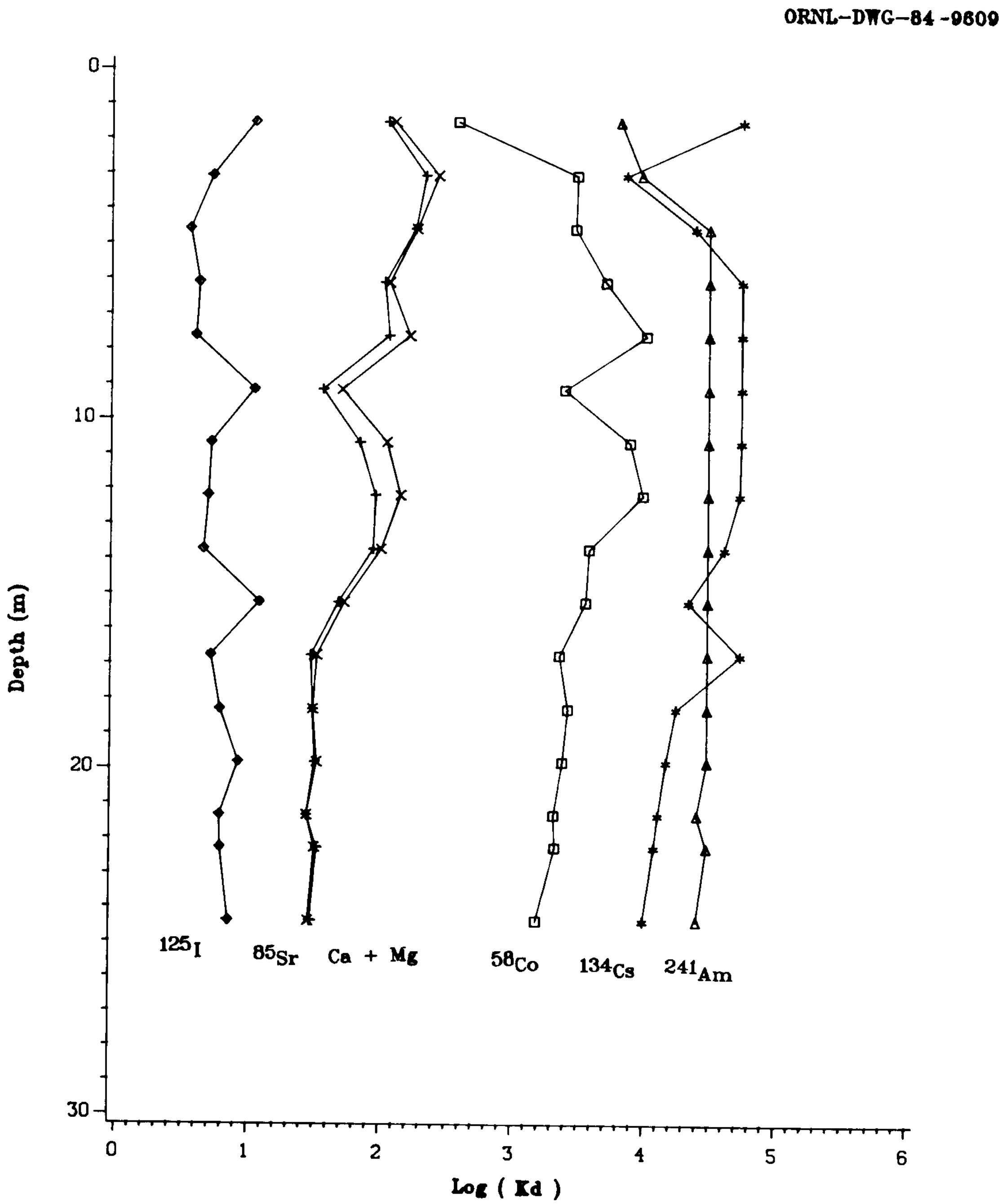

Fig. 19. Kds vs depth for cuttings sampled during drilling of Well 1.

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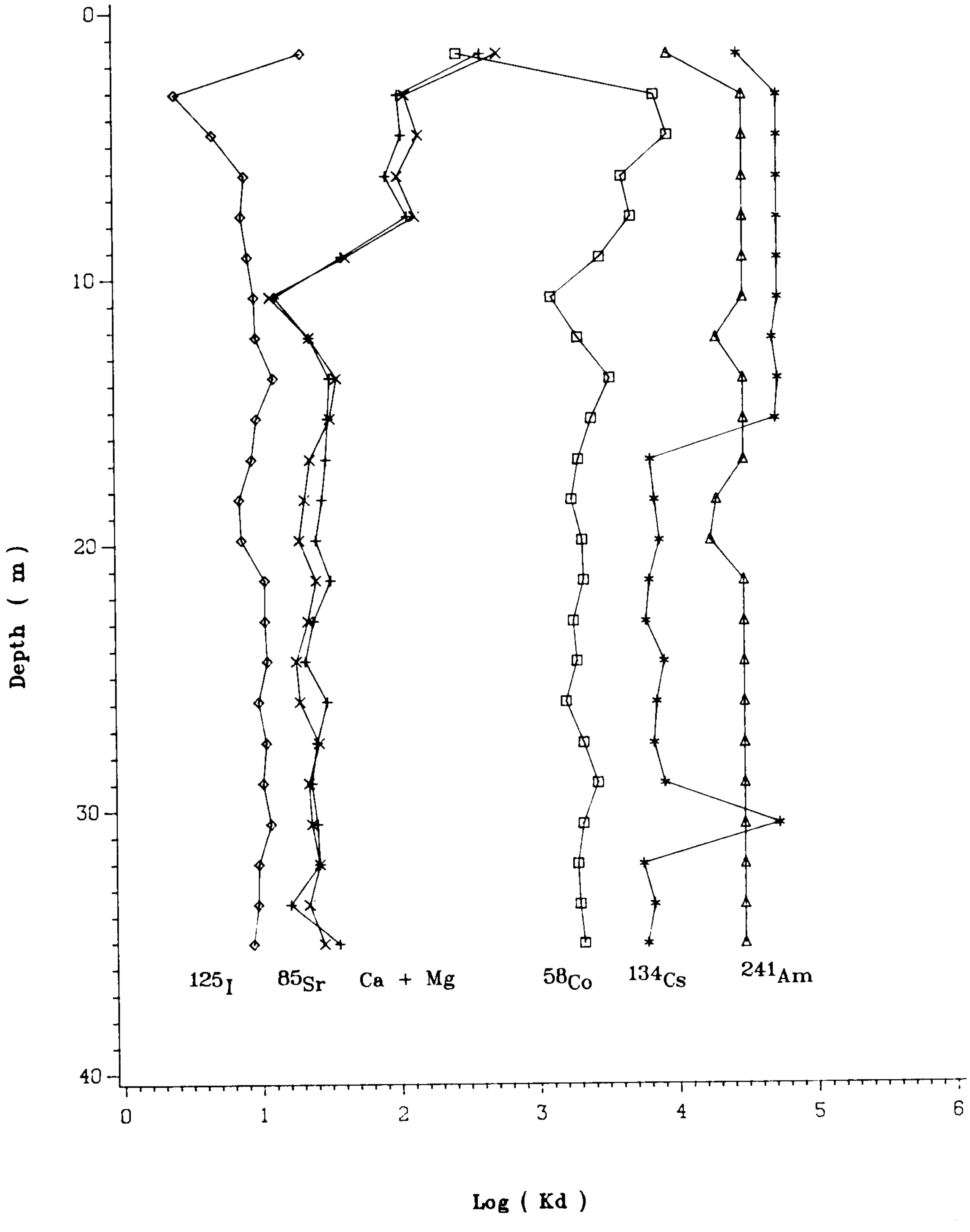

Fig. 20. Kds vs depth for cuttings sampled during drilling of Well 10.

Table 3. Radionuclide exchange properties of rock samples from the proposed SWSA-7

Well number	Depth M	Depth ft	mL/g Kds Sr	Cs	Co	I	Am	hardness
2	1.5	5	403	53000	149	43.6	4490	108.1
	4.6	15	48.4	53000	25.7	62.9	1750	40.8
	7.6	25	70.5	53000	2930	4.8	30000	35.8
11	1.5	5	1030	27800	424	32.4	5070	409.0
	4.6	15	151	40400	6640	5.2	30000	125.0
	7.6	25	188	53000	5200	3.9	30000	115.0
12	1.5	5	95.6	53000	2960	4.3	30000	80.8
	4.6	15	102	53000	4970	10.3	30000	49.0
	7.5	25	89.3	53000	2540	8.4	25200	55.3
13	1.5	5	49.2	53000	2420	14.3	25200	53.5
	4.6	15	27.1	14000	2030	12.7	30000	27.1
	7.6	25	37.6	11600	2140	10.6	30000	41.9
14	1.5	5	119	52000	203	10.1	9170	88.1
	4.6	15	42.0	53000	1370	8.1	30000	245.0
	7.6	25	88.4	53000	1160	17.6	19100	60.8

In general, it can be concluded that the weathered rock and the unweathered rock have different exchange properties and should be treated separately in a detailed analysis of the site. The differences between these zones are discussed further in the following section on chemical properties. Note that the samples characterized are treated (sieved) and do not necessarily represent field conditions. In the field, the actual rock surface accessible for exchange will be predominantly limited to the walls of fractures. The surface area of analyzed samples is likely to be greater than that for in situ samples; therefore, samples probably represent maximum values for Kds. In addition, the samples represent the bulk chemistry of the rock; within a single fracture, the wall chemistry may differ from the bulk chemistry. Investigating the differences between fracture wall and bulk sample properties is beyond the scope of this study and is technically problematic because of the difficulty in collecting appropriate samples.

3.7 CHEMICAL PROPERTIES

The chemical nature of earth materials on the proposed burial site control not only the water quality in the subsurface but also the chemical reactions that may be expected with introduced contaminants. The chemical nature of the rocks on site are a direct indication of the extent and type of weathering processes that have occurred. The samples that were collected for Kd analyses were also analyzed for various chemical properties. The analyses included exchangeable cations, exchangeable acidity, equilibrium pH, and total carbonate content.

The methods used for chemical analyses are discussed in the soils characterization report for the proposed SWSA-7 (Rothschild et al. 1984a). The samples analyzed were collected, treated, and handled in the same way as were the Kd analyses. The data for the two boreholes examined (well sites 1 and 10) are presented in Figs. 21 and 22 and Table 4. The results show that there is a decreasing cation exchange capacity (CEC) with depth. Based on the behavior of the major cations, it appears that Ca is the dominant element on the cation exchange complex. The total amount of $CaCO_3$ in the samples is a direct indication of weathering of the carbonate cement of the rock. The weathering process results in an increase in exchangeable acidity of the earth materials. The soil samples on site contained essentially no $CaCO_3$ (Rothschild et al. 1984a); this is also the case in the near-surface saprolite. Below the zone of weathering, the carbonate content is controlled by the rock lithology. This relationship can be seen in a comparison of the rock chemistry data with the lithologic logs (Appendix II).

The short profiles collected from the five additional well sites (Table 5) exhibited similar trends as the longer profiles; but, because most of the samples were from the saprolite or weathered zone, less variation with depth is apparent. As with the Kd analyses, the chemical analyses for Well 13 show little variation because only unweathered rock was encountered.

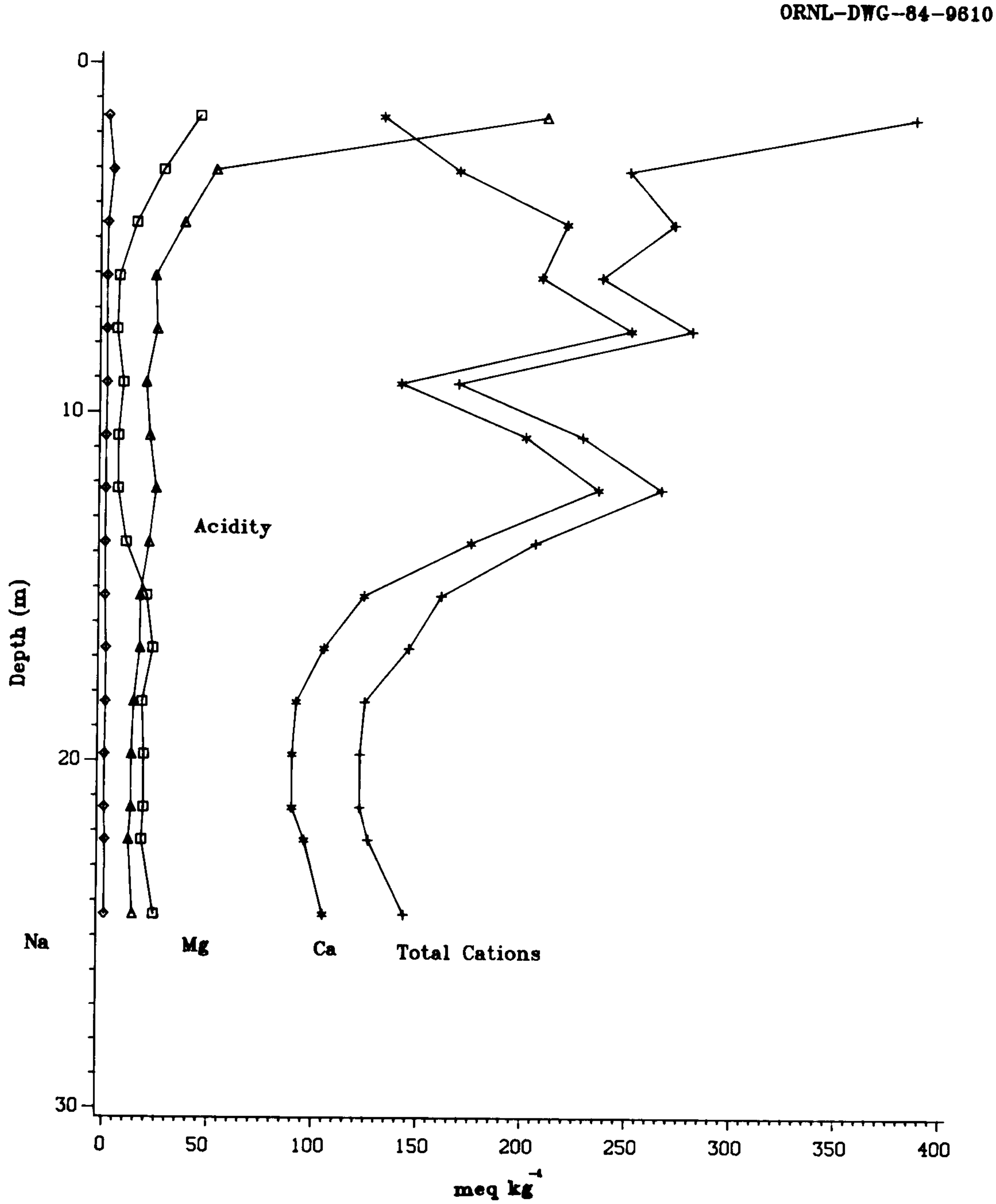

Fig. 21. Chemical properties vs depth for cuttings sampled during drilling of Well 1.

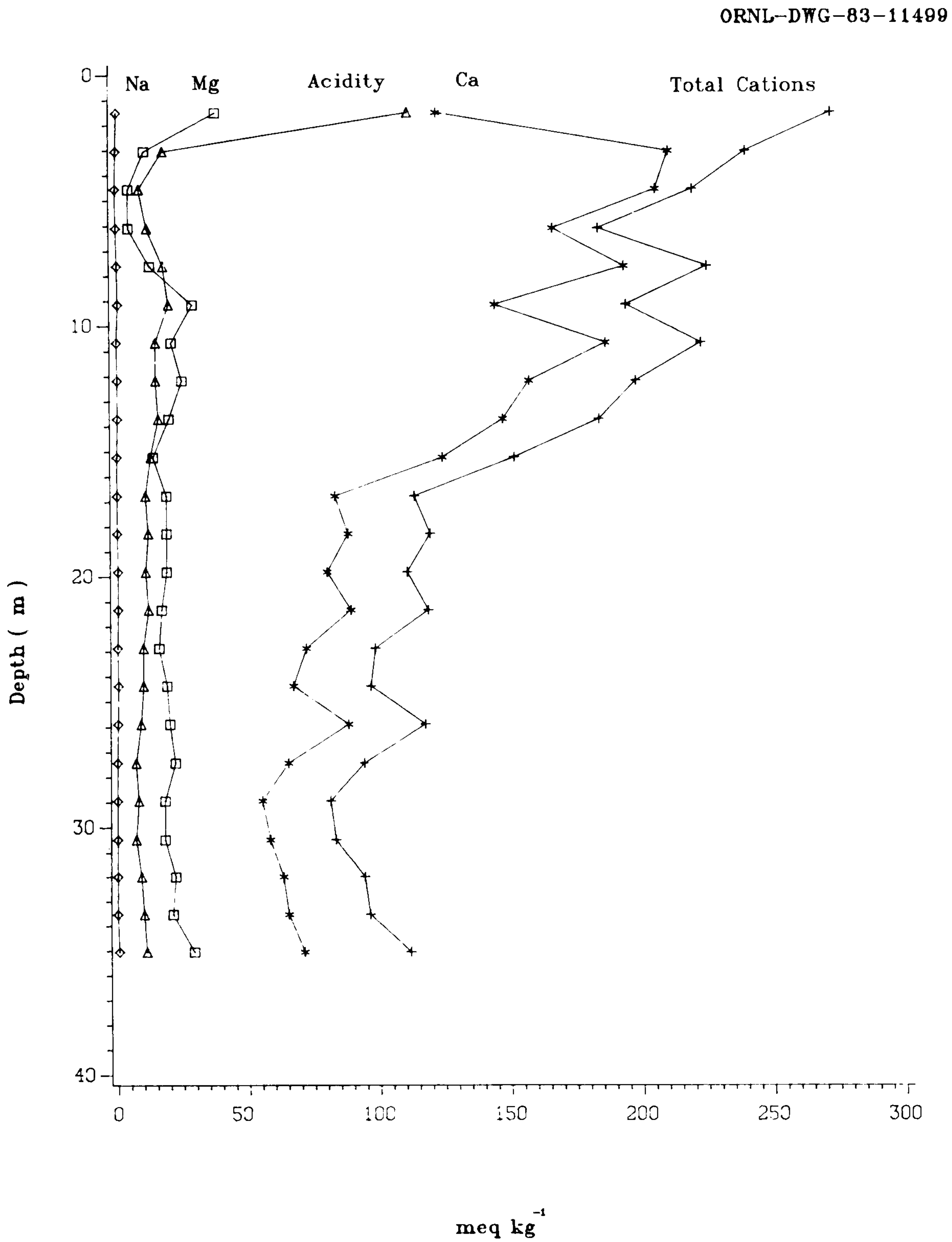

Fig. 22. Chemical properties vs depth for cuttings sampled during drilling of Well 10.

Table 4. Chemical properties of cuttings taken during drilling of wells 1 and 10

Well 1				Well 10			
Depth m	Depth ft	pH	$CaCO_3$ (%)	Depth m	Depth ft	pH	$CaCO_3$ (%)
1.5	5	6.5	0.2	1.5	5	5.4	0.2
3.0	10	6.7	0.1	3.0	10	7.7	6.4
4.6	15	6.7	0.3	4.6	15	7.7	18.2
6.1	20	8.0	10.5	6.1	20	7.7	27.9
7.6	25	7.3	7.1	7.6	25	7.6	21.9
9.1	30	7.6	35.6	9.1	30	7.7	5.4
10.7	35	7.6	10.8	10.7	35	7.6	27.2
12.2	40	7.6	11.1	12.2	40	7.3	25.8
13.7	45	7.8	7.9	13.7	45	7.4	18.9
15.2	50	7.7	2.0	15.2	50	7.4	16.7
16.8	55	7.7	2.0	16.8	55	7.6	10.6
18.3	60	7.7	2.0	18.3	60	7.6	7.3
19.8	65	7.6	1.9	19.8	65	7.8	6.7
21.3	70	7.7	1.1	21.3	70	7.8	9.1
22.2	73	7.4	1.3	22.9	75	7.8	18.9
24.4	80	7.6	0.9	24.4	80	7.9	26.8
				25.9	85	7.8	26.2
				27.4	90	7.8	26.2
				29.4	95	8.0	22.3
				30.5	100	7.7	26.0
				32.0	105	7.9	11.7
				33.5	110	7.7	21.0
				35.0	115	7.9	10.9

Table 5. Chemical properties of rock samples from proposed SWSA-7[d]

		Exchangeable								Available	
Location (Well ID)	Depth M (ft)	Ca[a]	Mg[a]	Na[a]	Acidity[a]	CEC[a]	pH	% $CaCO_3$	Total hardness[b]	Mn[c]	Fe[c]
2	1.5 (5)	2.6	1.8	0.00	20.0	24.4	4.5	0.3	20	825	405
	4.6 (15)	6.1	3.3	0.36	11.2	21.0	4.6	0.0	116	1650	825
	7.6 (25)	13.0	6.3	0.51	2.1	21.6	7.7	0.2	266	550	297
11	1.5 (5)	4.2	4.0	0.30	8.4	16.9	4.9	0.0	10	615	382
	4.6 (15)	19.0	0.65	0.10	1.4	21.5	7.7	20.4	80	535	160
	7.6 (25)	22.0	0.53	0.06	1.5	24.6	7.9	11.5	100	990	261
12	1.5 (5)	12.0	5.5	0.05	1.4	19.2	7.6	0.7	110	447	232
	4.6 (15)	8.5	6.2	0.18	1.6	16.5	7.9	1.0	150	160	136
	7.6 (25)	8.3	5.6	0.18	1.8	15.8	8.0	1.3	126	231	192
13	1.5 (5)	16.0	1.7	0.01	1.0	18.6	8.0	2.0	164	540	308
	4.6 (15)	9.6	2.0	0.03	1.2	12.9	7.6	14.3	214	450	443
	7.6 (25)	10.0	2.9	0.08	1.1	14.6	7.6	7.1	160	268	390
14	1.5 (5)	4.5	12.0	0.30	5.0	21.5	6.8	0.1	92	137	44
	4.6 (15)	6.7	14.0	0.68	3.2	24.4	7.1	0.1	42	425	100
	7.6 (25)	5.2	12.0	0.26	5.1	22.4	7.2	0.0	140	915	355

[a]Meq/100 mg.

[b]Mg $CaCO_3$/L.

[c]Mg/Kg.

[d]Material finer than 2 mm.

Based on the chemical and Kd analyses, the conclusion can be drawn that the rock formations underlying the proposed SWSA-7 generally become less active for cation and radionuclide adsorption with depth. values of kd were generally still quite high at depth though not as large as those for the near-surface samples. These data indicate that three chemical and physical zones can be identified in the earth material profile for the site: soil, saprolite, and unweathered rock.

4. HYDROLOGY

4.1 INTRODUCTION

The proposed SWSA-7 lies within the White Oak Creek watershed in Melton Valley. The drainage from the area enters Melton Branch by way of several first-order tributaries that bound and bisect the site. The first-order tributaries generally follow the dip of the underlying strata, although Melton Branch follows the strike of the Conasauga Group. Because of its location in the White Oak Creek watershed, surface runoff from the site enters the established environmental monitoring system for the watershed.

Characterization of the hydrologic regime on site is a critical factor to site development and proper site maintenance. The most important pathway in a humid environment for contaminants to reach the biosphere from shallow-land burial facilities is likely to be through the hydrologic system. The hydrologic system of the proposed SWSA-7 is controlled by the local and regional geology: weather patterns are a result of the valley and ridge topography of the area; the streams surrounding the site are a good example of trellis drainage typical of the physiography of the area; and groundwater flow patterns are dominated by the geologic structure of the site.

The surface-water and groundwater systems were investigated as part of the site characterization. Data for the ultimate source of water on the site, the local climate, were gathered from local monitoring stations. The surface-water system on the proposed waste facility was monitored by way of a flume installed on the central drainageway on site and supplemented by temporary gaging stations on the tributaries surrounding the site. Flow data from the streams were collected, and in combination with climatic and soils data, a water budget for the site was calculated. The groundwater system was investigated through the installation of a monitoring-well network on the study area. Water-level fluctuations were monitored over several seasons, and data on aquifer properties were collected. In general, the groundwater system is controlled by the secondary porosity of the underlying strata, which is a result of the local structural geology.

Hydrologic systems on the ORR have been investigated for a variety of reasons, and some of the studies germane to this investigation include: McMaster (1967), Sheppard (1974), Webster (1976), Huff et al. (1982), Law Engineering (1983), Rothschild et al. (1983), and Davis et al. (1984).

4.2 CLIMATE

At the proposed SWSA-7 site, no climatic measurements have been made to date; so the following synopsis was derived from observations made in different parts of the Oak Ridge area. The wind data that follows were measured at the 30-m (98-ft) elevation of a meteorological in Bethel Valley (Tower B of ORNL monitoring network). Precipitation has been collected in the Oak Ridge township by the National Weather Service since 1947. The town is situated about 15 km (9 miles) to the north of the SWSA-7. A more detailed, but shorter, meteorological data base has been developed at the experimental watershed at Walker Branch, about 5 km (3 miles) to the north.

The climate is classified as humid subtropical; the Cumberland Plateau is to the northwest and the Smoky Mountains to the southwest, tending to reduce the intensity of storm activity. Wind directions are highly conditioned by the ridge-valley topography, as can be inferred by the wind roses in Fig. 23. When synoptic weather patterns are not dominant, up-valley winds come from the west-southwest during the daytime. At night, down-valley winds from the northeast are most common. These bidirectional trends are apparent in Figs. 23b and c where unstable conditions correspond to surface heating during the period from mid-morning until late afternoon. Stable conditions occur at night and during overcast days. Table 6 classifies the available record for 1983 according to stability with 71% of the observations classified as neutral or stable.

Figures 23d-f group wind direction according to season. The strongest winds occur in the winter and spring, whereas light winds prevail in the summer. Fall conditions are intermediate between those of summer and winter.

4.2.1 Precipitation

From 1947 to 1978, the mean annual precipitation at the Oak Ridge township was 137 cm (54 in). Regional trends suggest that the average at the SWSA-7 may be about 7 cm (3 in) less. Monthly rainfall is highest during the period of December through March, when extratropical storms are most frequent, and again in July because of frequent thunderstorms. October is the driest month. Mean annual snowfall is 25 cm (10 in). Daily precipitation for Walker Branch Watershed is given in Fig. 24.

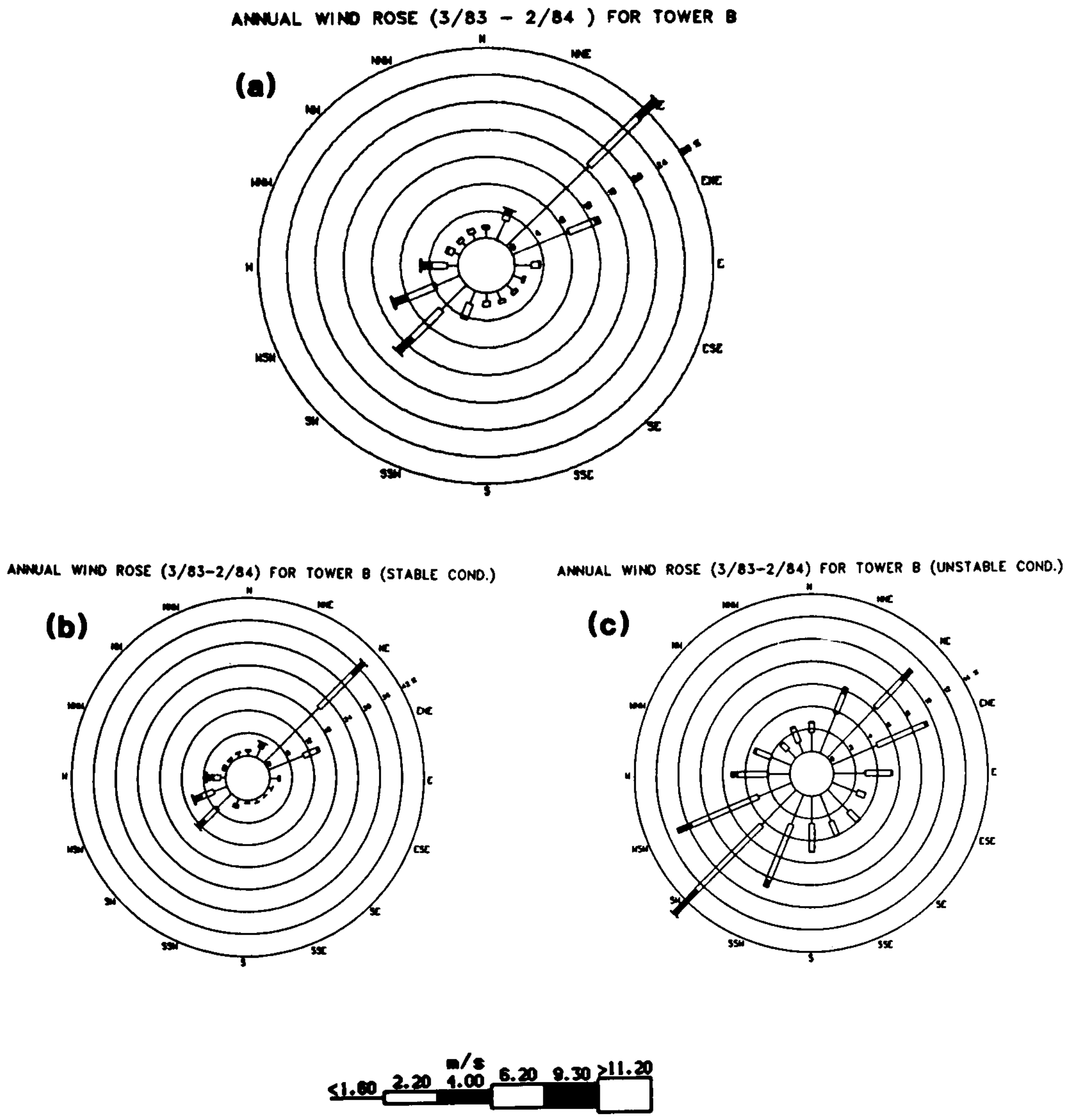

Fig. 23. Annual and seasonal wind roses for ORNL Tower B under varying conditions.

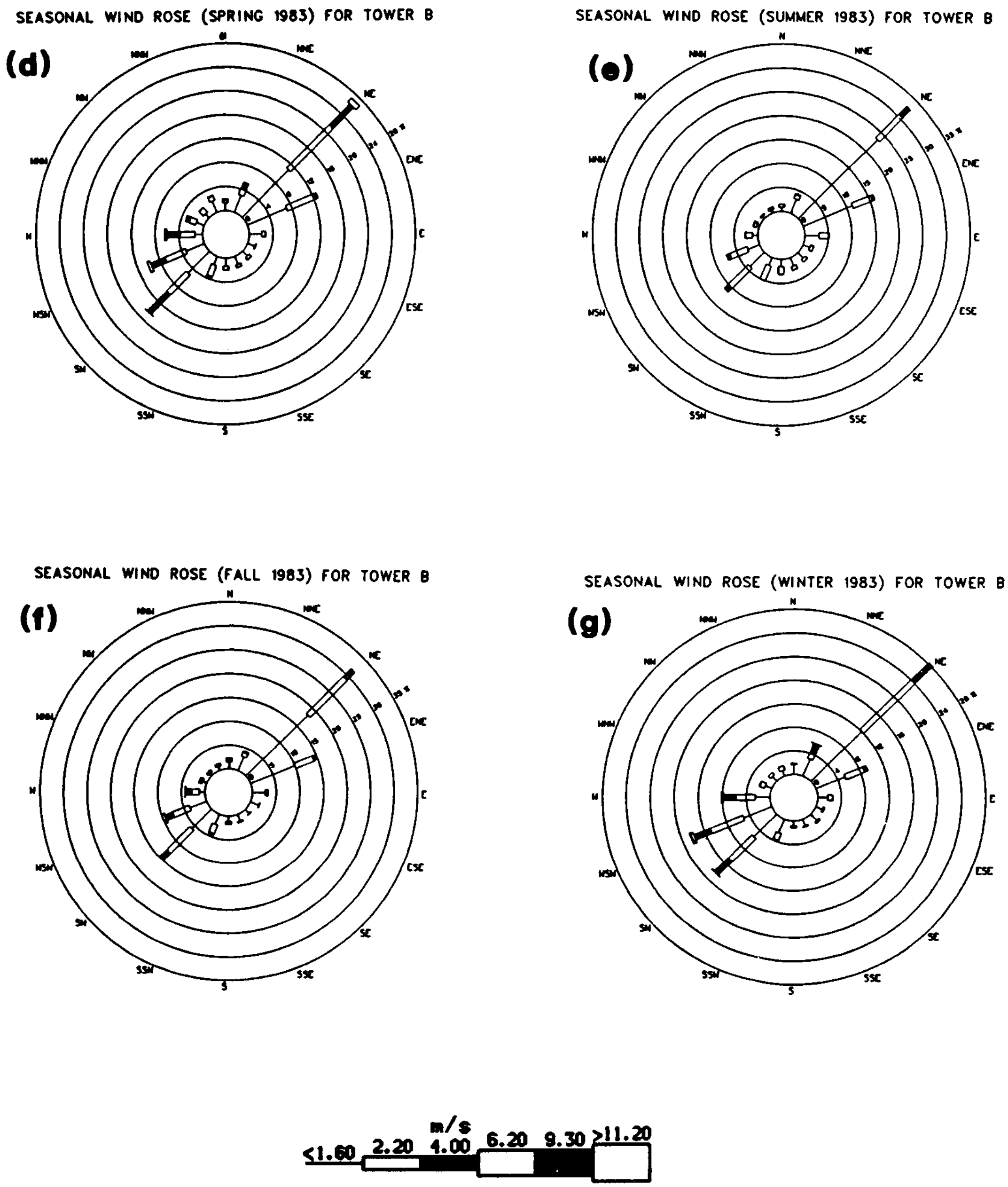
SEASONAL WIND ROSE (SPRING 1983) FOR TOWER B
(d)
SEASONAL WIND ROSE (SUMMER 1983) FOR TOWER B
(e)
SEASONAL WIND ROSE (FALL 1983) FOR TOWER B
(f)
SEASONAL WIND ROSE (WINTER 1983) FOR TOWER B
(g)
m/s
≤1.60
2.20
4.00
6.20
9.30
≥11.20

Fig. 23. Cont'd

Table 6. Wind stability-class frequencies [measured at 30 m (98 ft), ORNL Tower B, 1983]

	Class	Duration (h)	Frequency (%)
Very unstable	A	279	4.2
Unstable	B	559	8.5
Slightly unstable	C	1087	16.5
Neutral	D	2151	32.7
Slightly stable	E	1698	25.8
Stable	F	582	8.8
Very stable	G	217	3.3
Total record		6571	100

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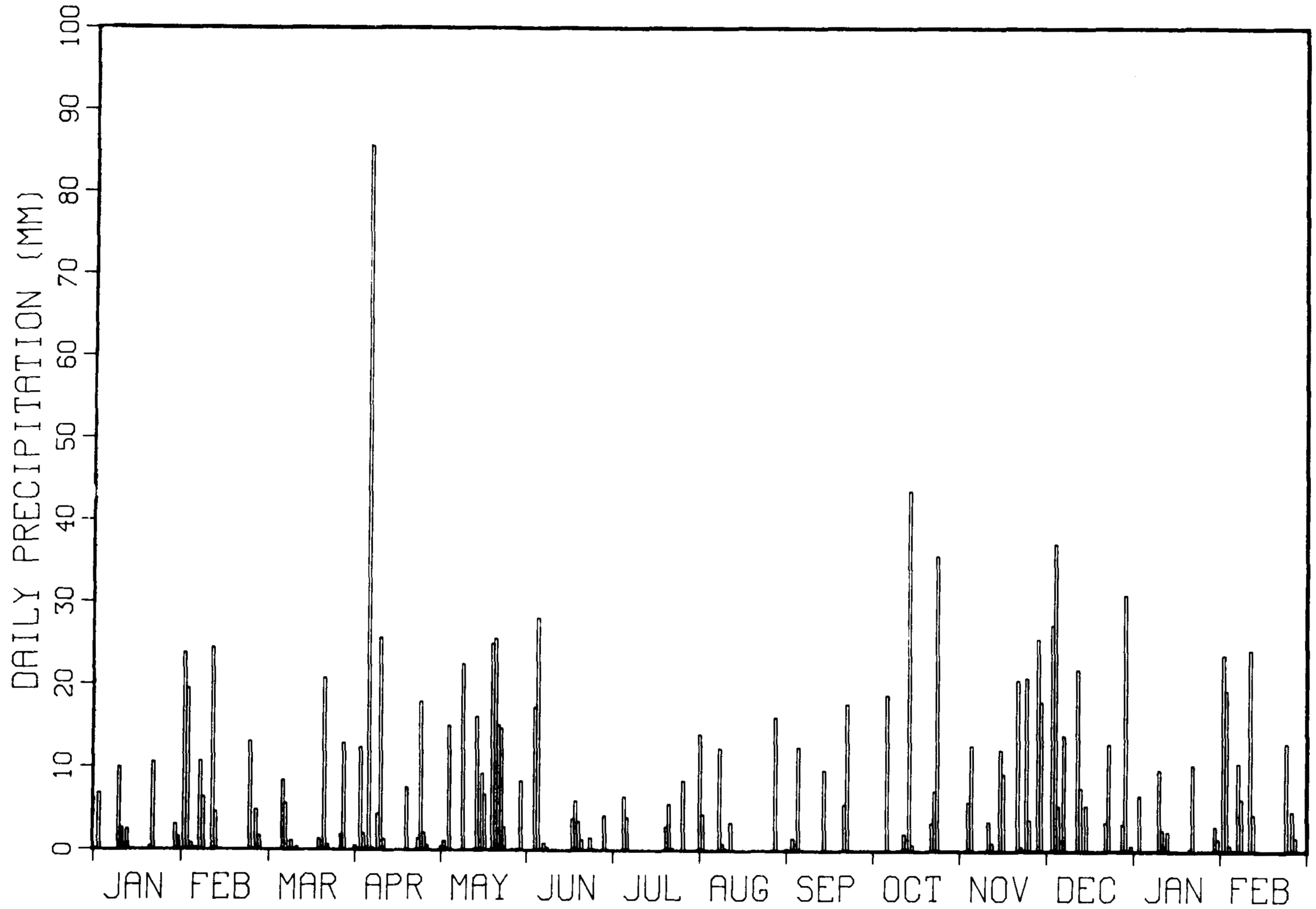

Fig. 24. Daily precipitation record from 1983 to 1984 for Walker Branch Watershed.

4.2.2 Recharge

An estimate of the annual rate of recharge to the watertable aquifer can be obtained from regional measurements of precipitation and streamflow. Because of deep weathering throughout the region, infiltration is large, and the percentage of rainfall reaching the stream as quick flow is probably small. Assuming that percentage to be negligible and using the annual regional runoff value of 61 cm (24 in), an upper limit on the average recharge rate is 45% for the region in general.

4.2.3 Evapotranspiration

Using the same approach and assuming no accumulation of stored water, the annual evapotranspiration is estimated to be 76 cm (30 in) or about 55% of annual precipitation. Seasonal variation corresponds to the growing season with the maximum in late summer and the minimum in mid-winter.

SWSA-7 probably does not exhibit significant local variations in evapotranspiration. The main channel is oriented north-south, thus the adjoining slopes face east and west to that exposure to solar radiation is roughly uniform. Consequently, evapotranspiration is expected to be uniform also. The eastern subwatershed has predominately north- and south-facing slopes so some differential drying of the soils will occur there.

4.3. SURFACE WATER

4.3.1 Drainage Map and Flow-Monitoring Sites

The details of the surface-water drainages in and around the proposed SWSA-7 are shown in Fig. 25. Also shown are the location of a flume that was installed in late fall 1982 and sites selected for intermittent monitoring of flows to aid in the general site hydrology characterization. The SWSA-7 flume site was selected to allow measurement of flows from the primary area proposed for future disposal operations. The data are the basis for estimation of a water budget for the site. Also the data characterize the expected ranges of flows in the basin. The latter data are important for design of a more permanent flow-measuring and flow-monitoring installation at a later stage of site development and for characterization of erosion potential. The temporary sites (C, D, E) were selected to provide supplementary information on the uniformity of runoff production. Data will also provide a limited basis for design of weirs or flumes for monitoring purposes if needed at the time the site is used.

4.3.2 Flow Measurements

4.3.2.1 SWSA-7 Flume Installation and Operation

The flume installed at SWSA-7 was specially designed to allow accurate measurement of flow over a wide range of conditions. It is in a general class of complex shaped, critical flow flumes. The lowest section in the flume is in the form of a V-shape so that small flow changes correspond to easily measured changes in water level. At higher flows, water-level changes are small for similar relative increases. The calculated rating table for the flume is given in

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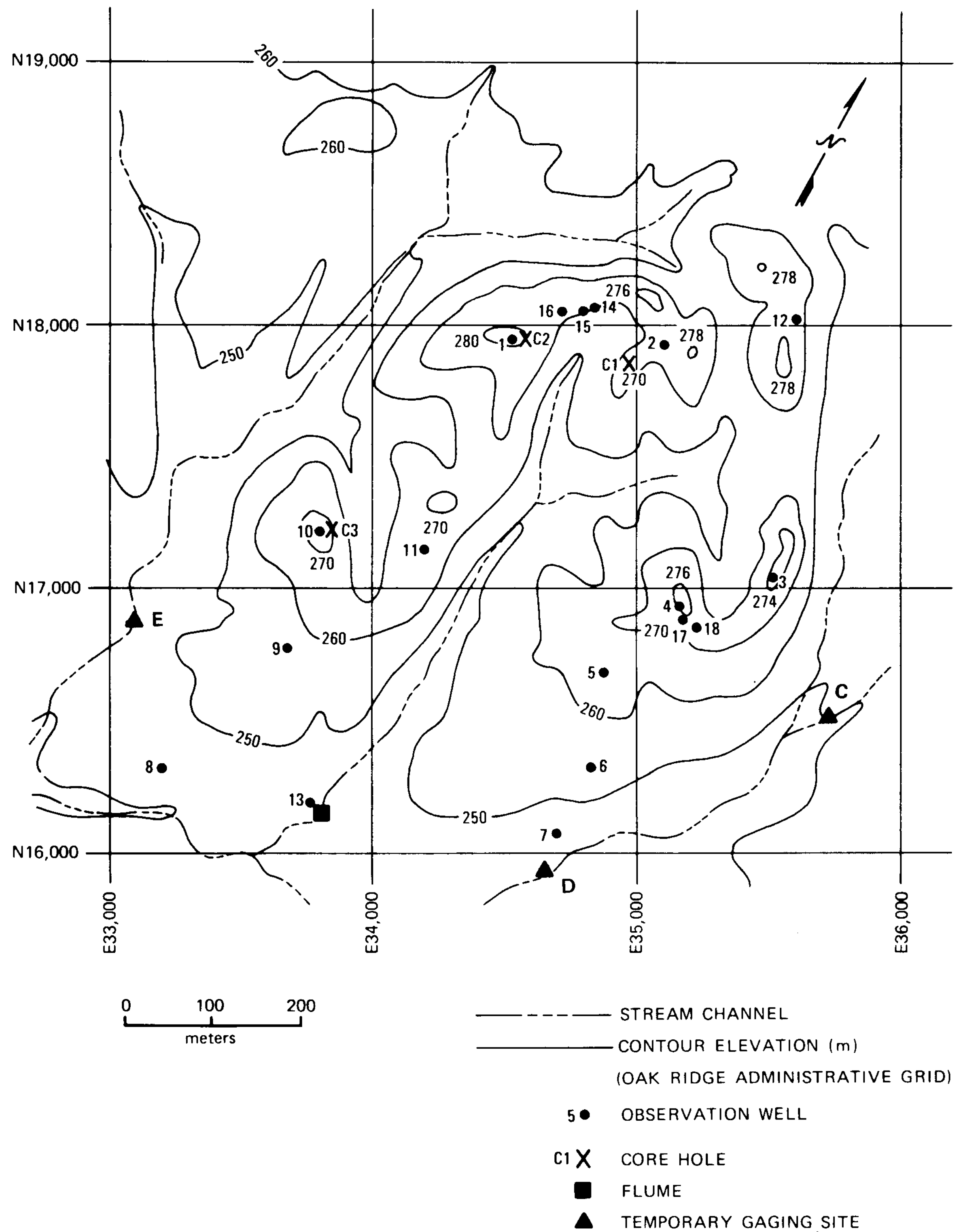


Fig. 25. Location of hydrologic observation points and core holes.

Table 7, although better resolution is used for calculations. The computer program used to develop the rating table was taken from a paper by Replogle (1975). The flume was designed to ensure that submergence would not be a problem at any flow within the design range, and visual inspection during storm events has verified that submergence does not occur. Submergence here refers to "drowning" or backwater effects from limited downstream channel capacity that would cause a change in the rating curve for the flume.

Data at the site are collected using a Manning flow totalizer (Dipper model). Records consist of a circular chart that contains a continuous pen trace of percent of maximum flow rate vs time. These values are relative to a maximum stage height setting that is periodically checked and can be manually reset. Charts are collected weekly. At the time the charts are changed, the stage height is independently measured and recorded, and when flow is low enough, a volumetric flow measurement is also made. As a component of field verification of the computed rating curve, the corresponding computed and volumetrically measured flow rates have been compared. A summary of those comparisons is given in Table 8 and is plotted in Fig. 26. Generally, the ratio of values estimated from chart readings to those measured volumetrically averages 1.33 ± 0.32 ($n = 37$). However, the measured values are biased toward lower flow rates where errors expressed as a fraction of observed flow tend to the largest. Because of the nonlinear character of the rating relationship (stage vs flow), systematic errors are usually better expressed in terms of a stage shift. This is simply the correction that must be added to the

Table 7. A computed rating table for the critical-flow flume at the proposed SWSA-7

Stage (cm)	Flow Rate (L/s) — Proportional parts (cm) 0	1	2	3	4	5	6	7	8	9
0	0.0	.002	0.02	0.07	.16	0.29	0.47	0.70	0.99	1.33
10	1.75	2.23	2.80	3.45	4.19	5.04	5.97	7.01	8.16	9.42
20	10.8	12.3	13.9	15.6	17.5	19.5	21.6	23.9	26.3	28.8
30	31.5	34.3	37.2	40.3	43.5	46.9	50.4	54.1	58.0	62.2
40	66.7	34.3	37.2	40.3	32.5	46.9	50.4	54.1	58.0	62.2
50	128	136	145	158	162	172	181	190	200	210
60	220	230	241	252	262	274	285	297	309	322

Table 8. A comparison between computed and measured flows and stage heights for the flume at the proposed SWSA-7

Date	Measured flow (L/s)	Measured head (cm)	Computed flow (L/s)	Computed head (cm)	Rating shift (cm)
10-18-82	.34	5.4	.36	5.3	- .1
11-02-82	2.62	12.3	2.98	12.3	0
11-09-82	.72	7.0	.70	7.1	+ .1
11-18-82	4.70	14.6	4.69	14.6	0
11-29-82	11.61	21.9	13.74	20.6	-1.3
11-29-82	8.39	18.6	8.90	18.2	- .4
01-06-83	2.05	11.6	2.56	10.7	- .9
01-13-83	2.73	13.0	3.45	11.9	-1.1
03-18-83	0.83	8.4	1.12	7.5	- .9
03-31-83	0.78	7.0	.70	7.3	+ .3
04-29-83	1.95	11.0	2.23	10.4	- .6
05-06-83	1.31	9.7	1.62	8.9	- .8
05-12-83	1.63	10.5	1.98	9.7	- .8
06-10-83	.68	7.8	.92	6.9	- .9
06-29-83	.49	7.5	.84	6.1	-1.4
07-06-83	.41	6.8	.65	5.7	-1.1
07-13-83	.25	6.0	.47	4.7	-1.3
07-20-83	.36	6.0	.47	5.4	- .6
08-04-83	.17	5.1	.31	4.1	-1.0
08-26-83	.22	5.4	.36	4.5	- .9
09-15-83	.10	4.3	.20	3.4	- .9
09-22-83	.12	4.2	.18	3.6	- .6
10-14-83	.18	5.4	.36	4.2	- .8
11-09-83	.30	6.8	.65	5.1	-1.7
11-16-83	.57	7.0	.70	6.5	- .5
11-23-83	.46	6.5	.58	6.0	- .5
11-30-83	1.32	9.3	1.45	9.0	- .3
12-15-83	2.54	12.2	2.92	11.6	- .6
12-22-83	8.25	20.0	10.80	18.1	-1.9
01-05-84	1.43	10.0	1.75	9.3	- .7
02-02-84	1.12	10.0	1.75	8.4	-1.6
01-24-84	2.39	11.4	2.45	11.3	- .1
03-01-84	3.55	13.3	3.66	13.1	- .2
03-08-84	2.20	11.4	2.45	10.9	- .5
03-16-84	4.01	15.0	5.04	13.8	-1.2
03-23-84	4.41	14.7	4.77	14.3	- .4
03-30-84	5.77	16.2	6.17	15.8	- .4

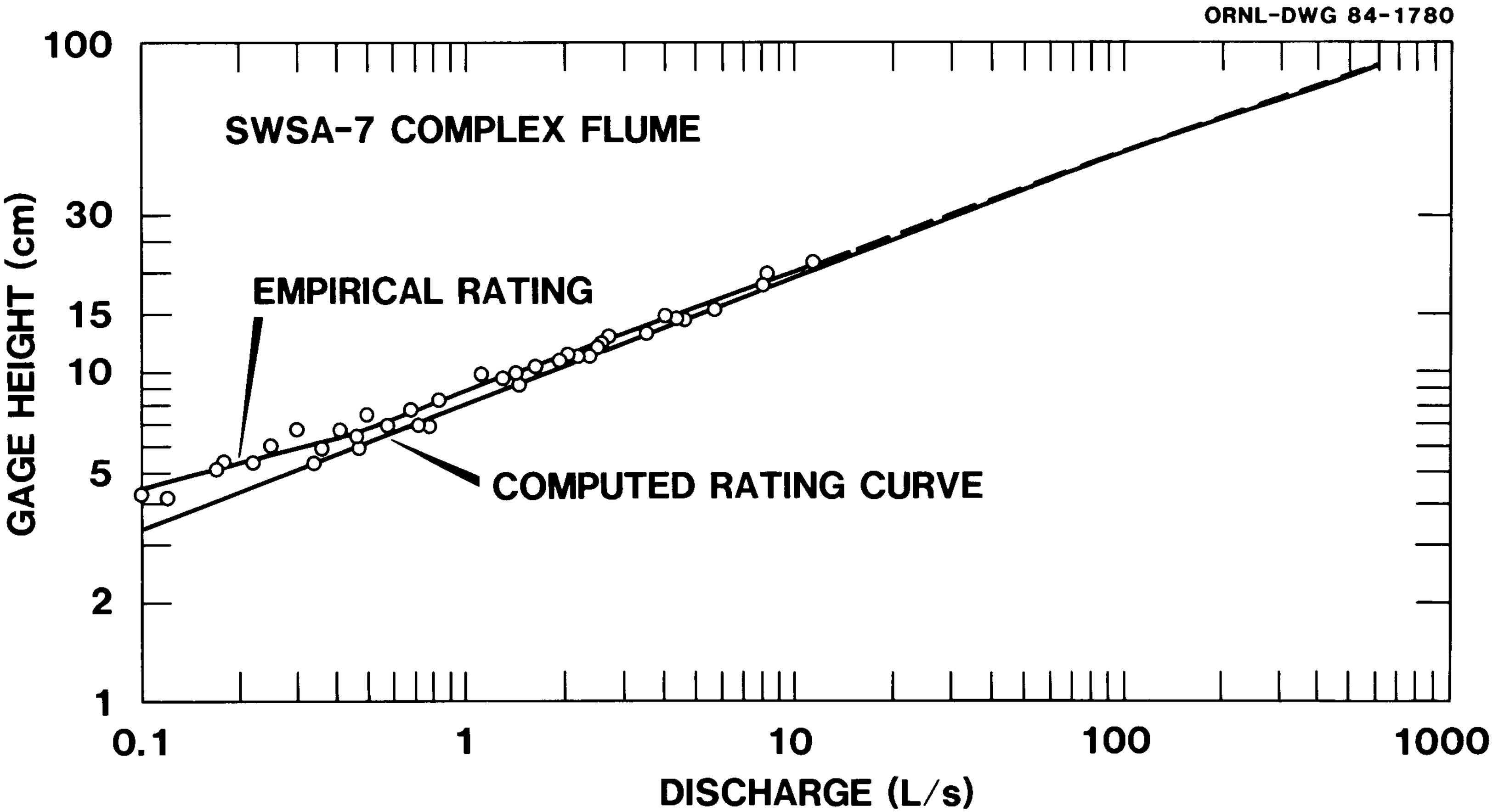


Fig. 26. Comparison of theoretical and empirically measured rating for complex flume at the proposed SWSA-7.

measured head to obtain an adjusted head value for use with the computed rating. Estimated rating shift values are also shown in Table 8. A systematic bias appears to be present that translates into a stage shift of about -0.7 cm (-0.02 ft) for most flows. For computational purposes, the rating shift corrections may be expressed as:

$$\hat{H} = H - 0.7 \qquad \text{for } H \geq 5.7 \text{ cm}$$

$$\hat{H} = H - 0.7 - 0.174*(5.7-H) \qquad \text{for } H \quad 5.7 \text{ cm},$$

where $\hat{H}$ is measured head, and H is the adjusted head to be used with the theoretical rating to obtain flow rate. These equations were derived from a plot of the empirical and theoretical rating curves.

The shift correction for the computed rating curve has been factored into all flow calculations. It results in about a 10% decrease in computed flow volumes when compared to unadjusted data.

Computer data processing begins with an input of flow rate expressed as a fraction of the maximum flow setting. It converts the fraction of maximum flow to a corresponding stage height, applies the stage-shift correction previously described, then recomputes an absolute flow rate using the theoretical rating table. The data are stored in break-point format. That means that any significant changes in flow rate result in a transition point being recorded (break-point). Values between break points are determined by linear interpolation. The continuous break-point data are integrated over time to obtain daily and monthly totals, and individual storm event records are available for hydrograph analysis if so desired. All data are stored in SYSTEM 1022 data base management files, and software has been developed to allow generation of mean hourly flow values, daily and monthly summaries, and association of water chemistry analyses with specific flow rates. This collection of programs has been used to generate monthly summary tables that are listed in Appendix III.

An overview of the tabulated results is given in Table 9, which includes daily maximum and minimum flows, mean daily flow rate, and monthly flow volume totals. In a few instances, where equipment problems occurred or the flume capacity was briefly exceeded, records have been estimated using data taken at a nearby station. Such estimates have been necessary for a period of less than 1% of the record interval.

4.3.2.2 Peak Flows

Work by Sheppard (1974) in Oak Ridge catchments, such as White Oak Creek, which includes the SWSA-7 area, produced the relationship

$$Q = 4.7\ A^{0.8}\ P^{2} \quad ,$$

where Q = peak flow rate (cfs),

A = catchment area ($mile^2$),

P = dormant season 48-h duration precipitation (in).

The relationship should only be used for $3 \leq P \leq 10$ in. For recurrence intervals of 2, 5, 10, 50, and 100 years, the expected 48-h rainfalls are approximately 5.1, 6.3, 6.9, 8.4, and 9.1 in., respectively. If Sheppard's relationship is used on the 0.08 $mile^2$ SWSA-7 catchment, the respective flows are 16.2, 24.7, 29.7, 44.0, and

Table 9. Overview summary of mean monthly flow conditions at the SWSA-7 flume (1983-1984)

Year	Month	Flow volumes (m3)	(cm)	Flow rate (L/s)	Maximum (L/s)	Minimum (L/s)
1983	Jan	6,327	3.00	2.36	3.21	1.75
1983	Feb	15,780	7.48	6.52	46.82	1.68
1983	Mar	4,126	1.96	1.54	6.00	0.84
1983	Apr	21,870	10.36	8.44	113.41	1.52
1983	May	13,447	6.37	5.02	40.57	1.10
1983	June	2,317	1.10	0.89	3.82	0.40
1983	July	667	0.32	0.25	0.52	0.00
1983	Aug	397	0.19	0.15	0.28	0.00
1983	Sept	237	0.11	0.09	0.35	0.00
1983	Oct	1,285	0.61	0.48	1.79	0.00
1983	Nov	3,475	1.65	1.34	15.77	0.03
1983	Dec	15,138	7.17	5.65	24.27	0.92
1984	Jan	8,838	4.19	3.30	13.06	0.95
1984	Feb	7,894	3.74	3.15	14.95	0.90

Peak instantaneous flow rate: 370 L/s (estimated; Apr 5, 1983).
Calendar year 1983 mean flow rate: 2.70 L/s.

51.6 cfs, ± 45%. For reference purposes, the peak instantaneous flow in 1983 was estimated to be 13.1 cfs (370 L/s). That value was derived by extrapolating the rising and falling limbs of the portion of the hydrograph that was not off scale. The estimated peak flow rate corresponds to a recurrence interval of about 1.5 years and should have resulted from about 11.6 cm (4.6 in.) of precipitation. Actual 48-h total rainfall was 8.6 cm (3.4 in) at Walker Branch Watershed, which is the nearest station where records are available. For a 8.6 cm (3.4 in.) 48-h duration event, the expected peak flow would be 7.2 ± 3.2 cfs. Given the uncertainties associated with the estimation equation and with the approximated peak flow rate, these results suggest that peak flows for a specific recurrence interval may be computed satisfactorily using the estimation equation. However, as additional data are gathered, the estimates can be refined.

Regarding flooding of the site, the Oak Ridge Safety Analysis Data Report by Fitzpatrick (1982) confirms that the proposed SWSA-7 site is higher in elevation than the high water level for the probable maximum flood for the area. Thus, inundation of the disposal site would not be expected to occur.

4.3.2.3 Flow Duration

Although length of record data are limited, all available daily flow rate data have been analyzed to provide a statistical distribution of observed flow rates. Summaries of the cumulative distribution of flow for both the total record and for calendar year 1983 are as follows:

Cumulative percentile	Flow rate (L/s)	
	Calendar year 1983	Total record 12/82 - 3/84
100	113.4	113.4
99	31.9	26.2
95	10.1	10.7
90	4.8	5.1
75	2.3	2.5
50	1.1	1.5
25	0.26	0.40
10	0.10	0.13
5.8	0.0	0.04
4.6	–	0.0

The cumulative flow duration curve for the full period of record is shown graphically in Fig. 27. Note that for the available record (December 17, 1982 - March 15, 1984), zero flow conditions occurred on 21 d or 4.6% of the time. All of those dates were in calendar year 1983, so the frequency of occurrence was 5.8%. The dates were distributed between late July and early October.

4.3.2.4 Temporary Monitoring Stations

In addition to the flume at the main tributary from the proposed SWSA-7 site, temporary flow-measuring stations were set up at three other sites shown in Fig. 25. To obtain flow measurements at these sites, the stream cross-sectional area was determined from water depth at 5-cm (2-in.) intervals across the channel. The maximum surface velocity was determined by measuring the time required for a small disk of paper to float a known distance along the stream. Empirical correction from maximum-surface velocity to mean-section velocity was

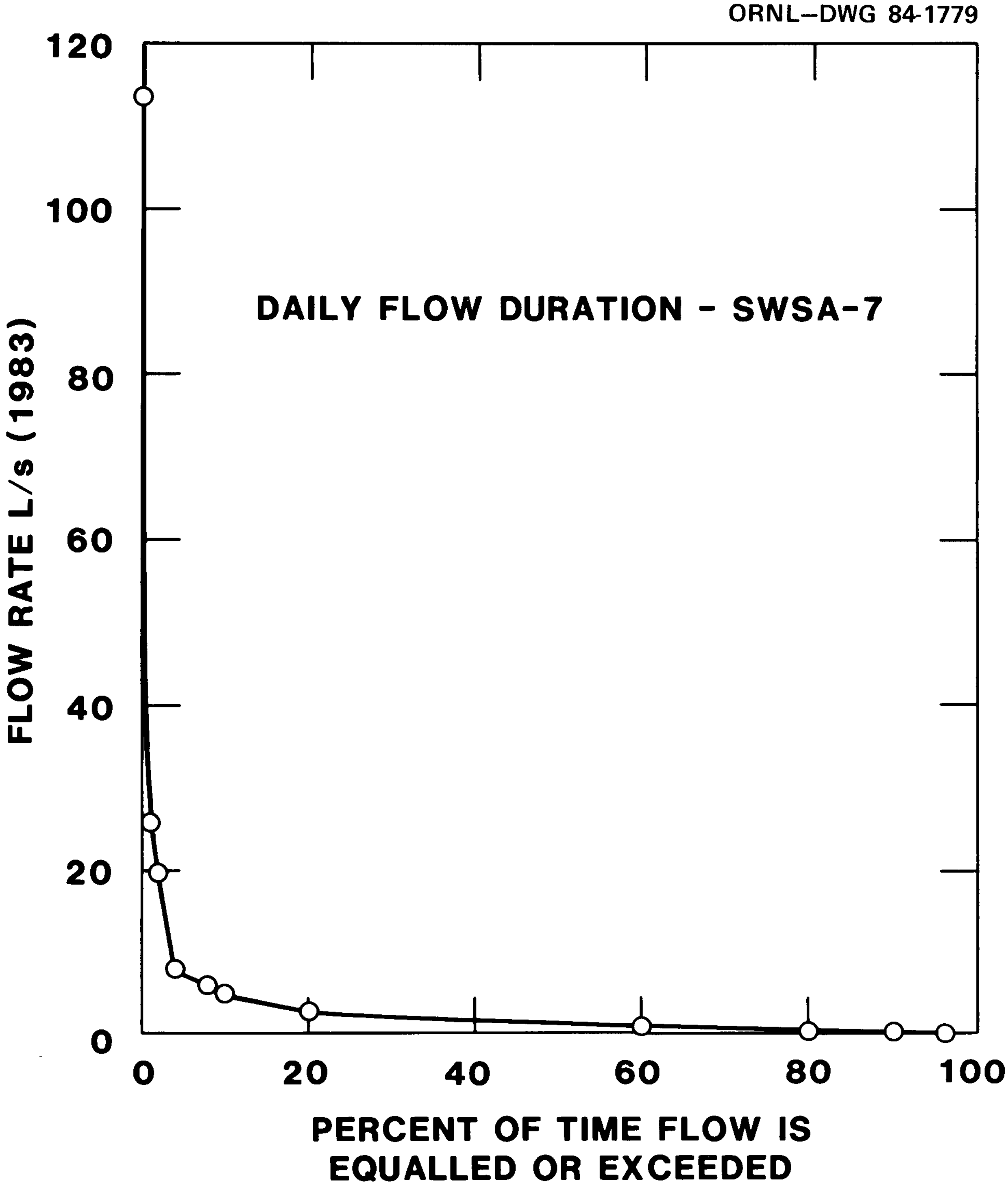


Fig. 27. A flow duration curve for mean daily flows at the flume at the proposed SWSA-7.

made using results from independent studies. Errors in discharge measurement using this method are generally within about 25% and the largest fractional errors occur at the lowest discharge rates. Table 10 presents results of these studies. The values shown in the table provide a general pattern of flow rates to be expected at these sites.

Perhaps the most important conclusions are that both sites 4C and 4D cease to flow in July (early summer), and flow does not return until November or December, depending on early winter rainfall totals. At site 4E, flow is strongly influenced by releases from nearby reactor operation, and the water discharged was observed to be considerably warmer than other streams in the area. No direct temperature measurements were made, however. Contributing areas were 15.5 ha and 55.9 ha for sites 4C and 4D, respectively. Although there is considerable variability in runoff per unit area among sites for a given date at the highest observed flows (4/7/83), the runoff per unit area is essentially the same at sites 4C and 4D. However, runoff per unit area at these two sites on that date is about 60% greater than that measured at the SWSA-7 flume. This may result from differences in runoff dynamics on the various basins, measuring inaccuracies, or a combination of both factors.

4.4 THE WATER BUDGET

The water budget provides a convenient way to characterize the hydrologic regime of a particular area. In the following exercise, the budget is used to determine, in at least a rough fashion, whether or not there is significant flow that is not being measured at the flume (i.e., groundwater loss to either Melton Branch or a deeper aquifer).

Table 10. Intermittent measurements of flow on SWSA-7 streams

Date	Flows at monitoring sites							
	4C		4D		4E		SWSA-7	
	ℓ/s	ℓ/s/km^2	ℓ/s	ℓ/s/km^2	ℓ/s	ℓ/s/km^2	ℓ/s	ℓ/s/km^2
3/18/83	2.2	14.2	14.0	25.0	---	---	0.98	4.6
3/23/83	---	---	11.5	20.6	30.6	45.4	1.25	5.9
4/07/83	717	49.7	25.7	46.0	57.0	84.6	6.20	29.4
6/08/83	0.35	2.2	2.14	3.8	18.1	26.8	0.97	4.6
6/19/83	0.02	0.1	0.49	0.9	2.3	3.4	0.49	2.3
7/13/83	0	0	0	0	10.3	15.3	0.36	1.7

To accomplish this objective, the budget was calculated using the standard method of Thornthwaite and Mather (1957) as reported by Dunne and Leopold (1978, Chaps. 5 and 8). The approach was to answer the question indirectly because the key parameters could not be estimated from the limited data. First, the water budget was computed many times for different parameter values, and an optimal combination was identified. When the optimal parameters did not agree with either limited measurements or suggested published values, reasonable "compromise" values were designated and used to calculate the water budget, allowing the computed runoff to be compared to observations at the weir.

4.4.1 Method

The water budget for June 1982 through February 1984 was computed using the program WATERBALANCE described in Appendix IV. In it, potential evapotranspiration (PET) is calculated by the technique of Thornthwaite using mean monthly temperatures, which, in this case, were derived from measurements at the 100-m tower near Bethel Valley Road (tower C). Based on PET and monthly precipitation measured at Walker Branch Watershed, the model calculates the actual evapotranspiration (AET) and, subsequently, the runoff.

The three key parameters in the model are

the ratio of direct runoff to precipitation, F;

the detention storage factor, F1; and

the available water capacity. AWC.

The ratio F approximates the relative source area within the watershed. It was set at 5%, which yielded reasonable results in the summer when groundwater contribution to storm flow was insignificant. The factor F1 represents the proportion of stored water delayed until next month's runoff. In a large watershed, it includes storage in lakes and marshes, and it is usually set at 0.5. For small watersheds, such as SWSA-7, it represents the delayed release of groundwater storage, and it is expected to be less than 0.5. Because it must be derived empirically, F1 was calibrated using the known monthly runoff values.

The AWC is the maximum water storage in the root zone that is available for evapotranspiration. Initially, it was treated as an unknown, similar to F1, and allowed to vary between 150 and 400 mm. These are the limits of the values suggested by Thornthwaite and Mather (1957) for deep rooted plants as shown in Table 11; however, other researchers have found the suggested rooting depths to be too large, as was the case here.

4.4.2 Computed Water Budget

As an indicator of goodness-of-fit, the root mean square (rms) error between the calculated and observed monthly runoff values was used to obtain optimal parameter values. The response surface shown in Fig. 28 indicates that the monthly water budget is sensitive to both F1 and AWC and that the model yields the best results for F1 = .15 and AWC = 400 mm.

The AWC was also calculated independently based on soil moisture relationships and the estimated depth of the root zone. For fine-textured soils, such as those in SWSA-7, the available water

Table 11. Suggested available water capacities (condensed from Thornthwaite and Mather 1957)

Vegetation	Soil texture	Available water content (% volume)	Rooting depth (m)	Avail. Water Cap. of root zone (mm)
Deep rooted crops (alfalfa, pasture grass, shrubs)	Fine sand	10	1.00	100
	Fine sandy loam	15	1.00	150
	Silt loam	20	1.25	250
	Clay loam	25	1.00	250
	Clay	30	0.67	200
Orchards	Fine sand	10	1.50	150
	Fine sandy loam	15	1.67	250
	Silt loam	20	1.50	300
	Clay loam	25	1.00	250
	Clay	30	0.67	200
Mature forest	Fine sand	10	2.50	250
	Fine sandy loam	15	2.00	300
	Silt loam	20	2.00	400
	Clay loam	25	1.60	400
	Clay	30	1.17	350

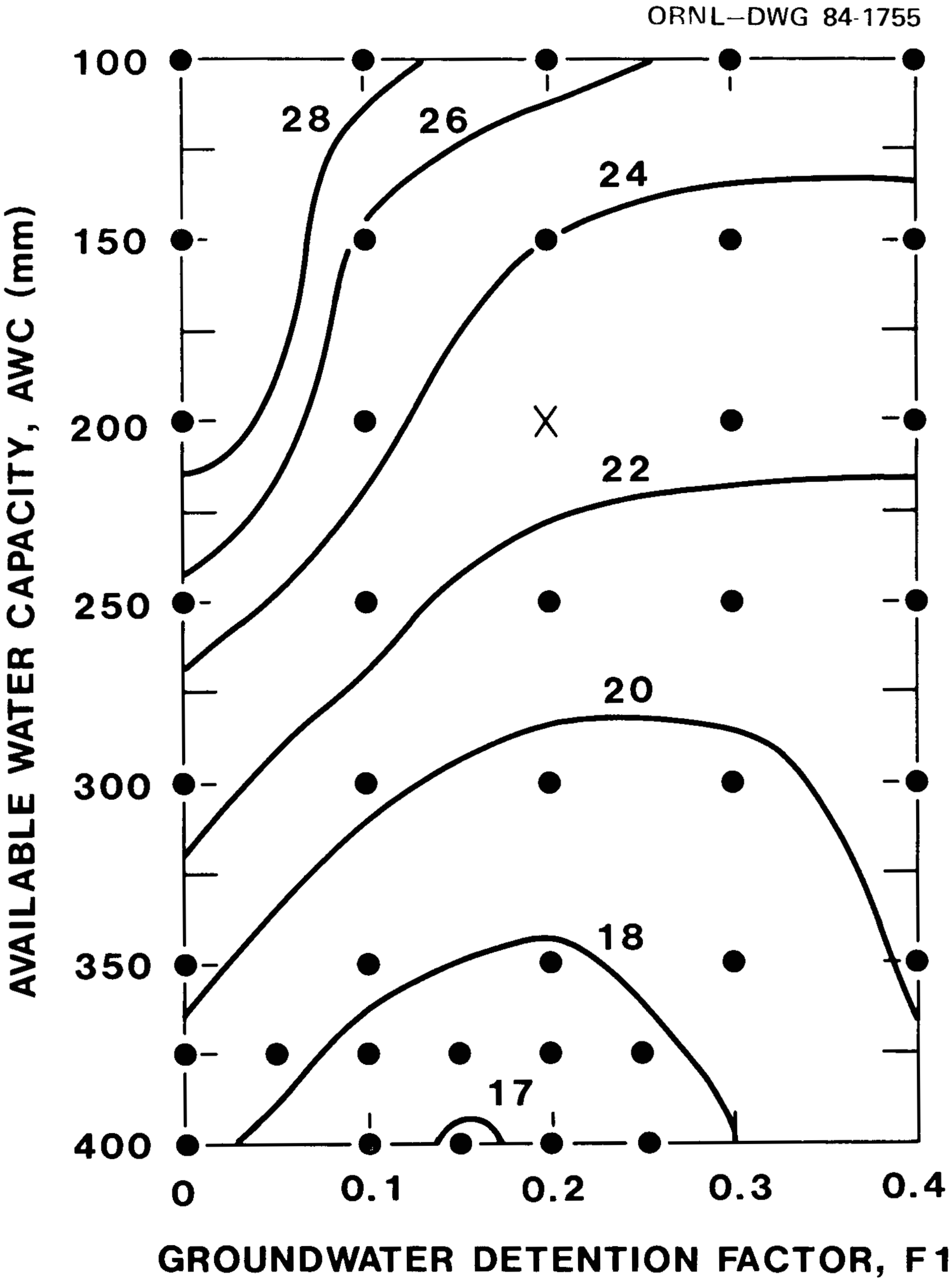


Fig. 28. Response surface for the water budget. Contour lines represent the root mean square error (RMSE) for the monthly runoff. The parameters at X were used in the subsequent analysis. (Because the observed runoff values were later found to be slightly in error, the RMSE are slightly inaccurate, but a check indicated that the relationship among parameters in not affected.)

content of the soil can be estimated as the water held between pressure potentials of -100 to -15,000 cm (-40 to -5900 in.) because of available data, the lower limit was changed to -10,000 cm (-3900 in.). From the moisture characteristics for the six main soil types in the watershed reported by Rothschild et al. (1984a), the mean available water content was determined to a depth of 1 m (3.3 ft), slightly deeper than the estimated 0.9-m (3-ft) root zone for Walker Branch Watershed. By weighting the values for each soil type according to area, the AWC based on measured soil properties is 162 mm (6.4 in.), well below the optimal values listed above.

In light of the different estimates of AWC from optimization, point measurements of soil properties, and Table 11, a compromise value of 200 mm (7.9 in.) was selected. With F1 = .20, the water budget was computed.

The monthly components plotted in Fig. 29 indicate that during the summer, when PET rates are high and below-average precipitation occurs, monthly stream flow decreases to near zero; and indeed, periods of no-flow were observed. During this period the observed and computed flows are in good agreement.

During the nonsummer months, actual evapotranspiration is equivalent to the potential rate, and stream flows--both calculated and observed--increase relative to summer values. However, observed flows are significantly less than computed ones. This is a systematic bias that appears in all the simulations regardless of the parameter values used in the model. For increased AWC, there is a moderate decrease in computed runoff; and thus, there is better agreement, but the bias remains.

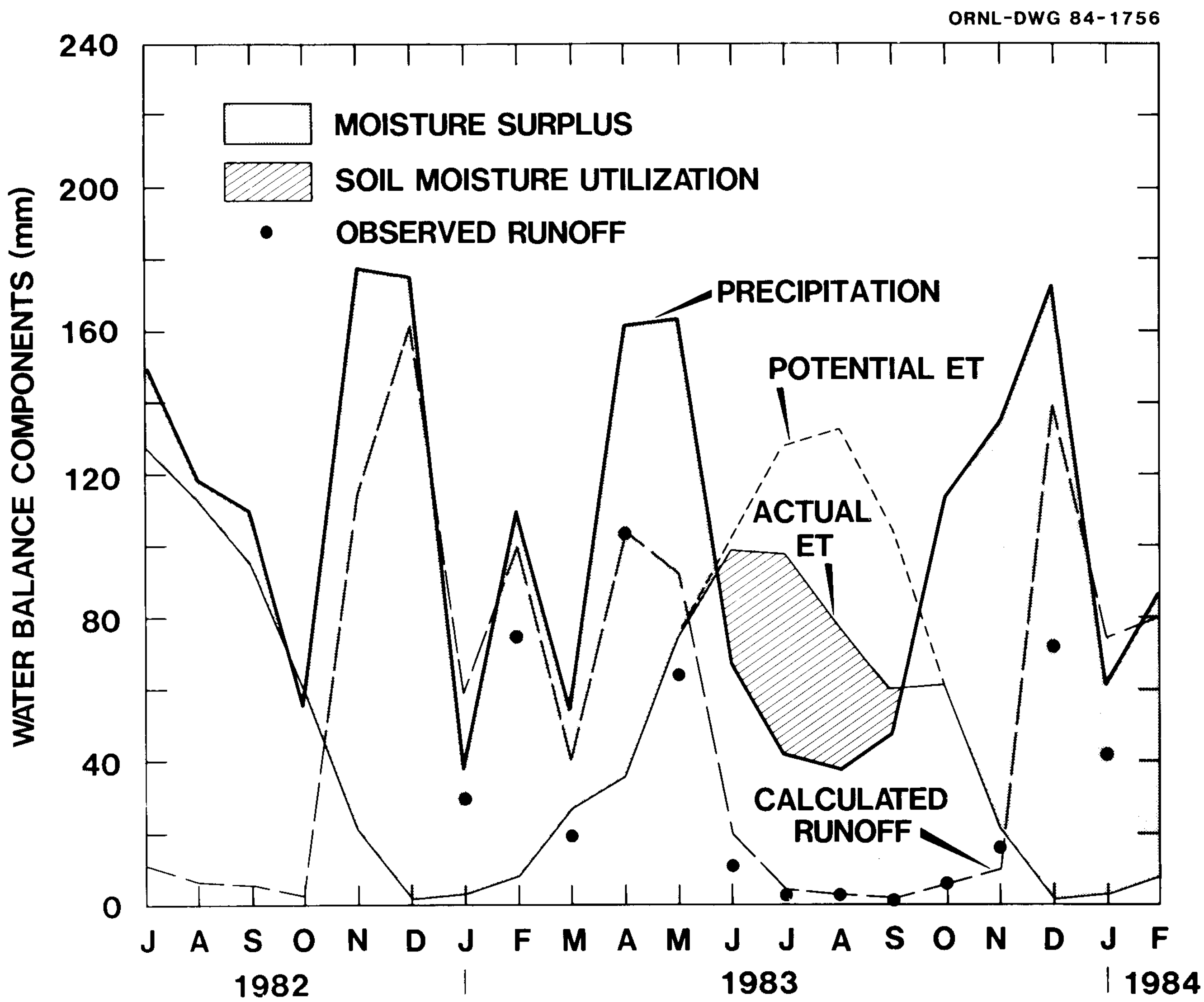


Fig. 29. Computed monthly water budget for the proposed SWSA-7.

Naturally, the bias is also evident in the annual water budget for 1983 listed in Table 12. The difference in computed and observed runoff is 179 mm (7.9 in.) or 16% of the annual precipitation. To put the simulated results in a regional perspective, the simulated runoff-precipitation ratio is 51%, which compares favorably with the regional ratio of 45% mentioned previously in Sect. 4.2. Based on measurements for 1983, the ratio for SWSA-7 was only 35%. Therefore, it is reasonable to conclude that there is groundwater flow from the watershed that is not measured.

4.4.3 Discussion

There are several important sources of uncertainty that should be reviewed before estimating the bounds on groundwater loss. The first source is model error. The model used is admittedly simplistic; furthermore, in some lysimeter studies, the method of Thornthwaite for determining PET has been shown to significantly underestimate measured values (ASCE 1973), although these studies were conducted in environments different from the humid eastern United States where the model was developed. The calculated mid-winter monthly PET rates of less than 10 mm/month are unrealistically low, especially when computed interception losses for Walker Branch Watershed average about that level (Huff et al. 1977). Consequently, the total PET for December, January, and February was adjusted for 10 to 30 mm (0.4 to 1.2 in.). Although PET may be underestimated at other times of the year, there are no objective methods for altering the model.

Table 12. Computed 1983 water budget for SWSA-7

	Losses (mm)	Gain (mm)
Precipitation		1144
Surface runoff	57	
Groundwater runoff	525	
(Observed total runoff = 403 mm)		
Actual ET	567	
Change in soil moisture storage	0	
Change in groundwater storage	-5	
Totals	1144	1144

As for AWC, the "compromise" value of 200 mm (7.9 in.) may be too small. Using typical moisture characteristics, the available water content for silt loams and clay loams are 0.33 and 0.23, respectively (Clapp and Hornberger 1978). If a simple mean value is chosen and the root depth is maintained at 1 m, then AWC is approximately 275 mm (10.8 in.).

With the adjusted PET and new AWC, the adjusted runoff is 542 mm (21.3 in.) or 47% of the annual precipitation. This estimate seems reasonable because it is in closer agreement the regional runoff-precipitation ratio. Consequently, the groundwater loss is 139 mm (5.5 in.) or about 12% of the precipitation. This estimate is based on a simplistic model, and it should be used cautiously. Nevertheless, it is appropriate to investigate this apparent loss from the watershed. This investigation should include the following: (1) monitor groundwater levels in alluvium at the outlet to SWSA-7; (2) measure, to the extent possible, the depth and hydraulic conductivity of the infill to estimate flows; (3) investigate Melton Branch for possible subsurface inputs; (4) investigate fracture patterns for preferential flow paths (see Geology section); (5) determine AWC based on in-situ moisture measurements using neutron probes; and (6) compare weekly rainfall inputs to those measured at Walker Branch.

4.5 GROUNDWATER

The characterization of the groundwater flow system on proposed SWSA-7 is critical to the proper use of the site. In general, the depth to water will determine how and where waste burial may take place. In addition, chemical transport within the groundwater flow system is an extremely important pathway for waste migration. As part of characterization, a monitoring-well network was installed. The wells were used to monitor water-level fluctuations throughout the year, determine aquifer properties, and collect baseline water chemistry data.

4.5.1 Monitoring-Well Network

For the purpose of evaluating the groundwater flow system and determining aquifer properties, a network of 18 monitoring wells was installed on the study site. The locations of the wells are shown in Fig. 25, and the details of the construction for each well are included in Appendix II.

The monitoring-well network is in the form of a ring surrounding the potentially usable area on site. Two areas are instrumented with three closely spaced wells that can be used for large-scale aquifer testing. The wells vary slightly in construction, in particular: some of the wells are 15.2 cm (6 in.) in diameter and others are 10.2 cm (4 in.) in diameter; and some wells have multiple level screens, while most have just a single-screened interval. The wells are all constructed of PVC. The boreholes in which the wells were installed were drilled using air rotary, water rotary, or auger drill rigs (Appendix II). Prior to well installation, the boreholes were cleaned by circulating drilling fluid. The wells were completed by backfilling the annulus surrounding the screened intervals with clean sand, sealing the screened interval with bentonite, backfilling the annulus to within several meters of the ground surface with drill cuttings, and finally emplacing a collar/surface seal with cement (see Appendix II for diagram of well completion technique). After installation, the wells were developed by over pumping and by rapidly removing water and entrapped silt and clay using an air compressor. A measuring point for each well was determined and was surveyed for exact location and elevation (Table 13).

During drilling, cuttings were collected from each well at approximately 1.5-m (5-ft) intervals. The cuttings and general observations made during drilling were used to construct the lithologic logs for the drill holes included in Appendix II. The drill cuttings were also used for the chemical and radionuclide adsorption testing discussed in previous chapters. Also included in Appendix II are geophysical logs for each of the wells that were taken through the casing after the wells were completed. Several of the boreholes were drilled so that engineering properties of the near-surface earth materials could be determined; these data are discussed in the soils characterization report for the site (Rothschild et al. 1984a).

Five of the monitoring wells were completed with multiple-screened intervals. Each interval is isolated within the annulus of the borehole. One or more of the zones can be isolated within the casing by using a straddle packer system or semipermanent single packers. These wells can be used to determine variations in water levels, aquifer properties, and water chemistry with depth. Without the isolation of individual zones, the wells can be considered indicative of the entire vertical extent of screen coverage. The utility of these wells will be demonstrated in a subsequent section.

Table 13. Monitoring well survey data

Well number	Elevation of top of casing (m)	Elevation of top of casing (ft)	ORNL northing	ORNL easting	Length (m)	Measuring point aboveground (m)	Ground elevation (m)
7-1	282.363	926.388	17940.447	34551.350	37.32	0.69	281.67
7-1 (old)	282.540	926.968	17917.163	34544.283	9.83	0.45	
7-2	274.591	900.890	17938.852	35114.641	30.33	1.02	273.57
7-2 (old)	273.774	898.210	17942.368	35106.392	9.80	0.43	
7-3	275.778	904.784	17034.558	35534.531	27.79	0.81	274.97
7-3 (old)	275.598	904.194	17039.184	35537.313	9.30	0.51	
7-4	277.340	909.908	16930.316	35158.225	28.51	0.87	276.47
7-4 (old)	277.413	910.148	16955.131	35166.586	10.42	0.50	
7-5	264.506	867.802	16678.694	34885.187	30.52	0.89	263.62
7-5 (old)	263.921	865.884	16658.029	34909.884	9.80	0.69	
7-6	257.800	845.802	16308.837	34841.713	9.80	0.45	257.35
7-7	246.934	810.152	16055.724	34706.903	8.90	0.56	246.37
7-8	243.475	798.802	16314.777	33181.638	9.88	0.54	242.94
7-9	256.667	845.364	16771.390	33663.520	9.87	0.60	257.07
7-10	274,239	899.734	17215.092	33799.048	38.02	1.05	273.19
7-10 (old)	273.605	897.654	17208.870	33786.706	9.78	0.46	
7-11	269.630	882.614	17145.111	34191.334	27.54	0.83	268.80
7-11 (old)	269.137	884.994	17156.904	34190.298	9.82	0.46	
7-12	273.264	896.535	18037.992	35614.705	21.34	0.66	272.60
7-13	243.855	800.050	16159.569	33757.812	9.92	0.75	243.11
7-14	274.354	900.112	18070.913	34863.308	22.50	1.10	273.25
7-15	275.499	903.869	18068.815	34822.896	21.51	.73	274.77
7-16	277.843	911.558	18064.712	34724.681	22.05	.62	277.22
7-17	276.15	905.890	16887.568	35172.520	21.39	.63	275.49
7-18	274.541	900.726	16858.117	35236.032	20.85	.70	273.84
C1[a]	270	887	17,830	34,975	(92.5)	0	270.
C2[a]	280	918	17,945	34,580	(91.5)	0	280
C3[a]	272	891	17,220	33,830	(197.9)	0	272

[a]Locations and elevations are approximate.

4.5.2 Aquifer Properties

In order to assess the rate and direction of water and/or solute movement in the subsurface, certain properties of the geologic media must be known. These properties include: hydraulic conductivity, aquifer thickness, storage coefficient, porosity, dispersivity, and an understanding of the heterogeneity of the flow system. In general, the Conasauga Group is locally heterogeneous, both lithologically and as an aquifer. The primary porosity of the group is quite low; therefore, the secondary porosity (fracture system) controls groundwater flow in the subsurface.

To determine the hydraulic conductivity (K) of the subsurface materials, slug (instantaneous displacement) tests were conducted in 12 of the monitoring wells. The principle behind the slug test is that by monitoring the decay in water levels within a well from the instantaneous injection of water (or displacement of water), the hydraulic conductivity of the aquifer can be determined. This test is particularly suitable for low-permeability rocks, such as those of the Conasauga Group. Slug tests have a short radius of influence; that is, the hydraulic conductivity values are only applicable to the zone immediately surrounding the well screen or open interval. The results of the slug tests are given in Table 14, with the geometric mean of the values being 2.57×10^{-5} cm/s. The analysis used to determine hydraluic conductivity is that of Hvorslev (1951). This value is relatively low, but is reasonable for a fractured media.

Data on the hydraulic conductivity of the aquifer underlying the site is extremely important, but other aquifer characteristics must also be known. Few of these other characteristics were measured on

Table 14. Hydraulic conductivity (K) from slug tests

Well Number	Results of slug test (K in cm/s) Test 1	Test 2	Test 3	K (avg.)
1	3.86×10^{-6}			3.86×10^{-6}
2	2.17×10^{-5}	8.02×10^{-5}		5.10×10^{-5}
3	3.06×10^{-4}	2.80×10^{-4}		2.98×10^{-4}
4	1.05×10^{-5}			1.05×10^{-5}
5	3.76×10^{-5}	3.92×10^{-5}		3.84×10^{-5}
6				
7	9.50×10^{-5}	1.29×10^{-4}		1.12×10^{-4}
8	2.29×10^{-5}			2.29×10^{-5}
9	6.80×10^{-5}	6.37×10^{-5}		6.59×10^{-5}
10				
11	1.30×10^{-5}			1.42×10^{-5}
12	9.16×10^{-7}	1.34×10^{-6}		1.13×10^{-6}
13	8.55×10^{-5}	1.18×10^{-4}	2.36×10^{-4}	1.47×10^{-4}
14	8.21×10^{-6}			8.21×10^{-6}
			Geometric mean	2.57×10^{-5} cm/s

site but were extrapolated from other data for the Conasauga Group. To test the applicability of off-site data, a comparison of hydraulic conductivity data from various sites was made. Table 15 lists hydraulic conductivity data from five sites that are all underlain by the Conasauga Group. The data indicate that the variability of the strata throughout the ORR is quite low, less than one order of magnitude, with the exception of values obtained solely from wells completed in unweathered rock in the Bear Creek Valley Burial Grounds. The geology throughout Bear Creek Valley and Melton Valley are so similar, both lithologically and structurally, it can be expected that aquifer properties will not vary greatly from one area to another. This is borne out by the hydraulic conductivity data. The actual flow systems will vary from one site to another because of differences in topography and because of large-scale perturbations in the aquifer (faults, folds, solution activity, and the presence of surface-water bodies).

An important characteristic of the groundwater flow system is the actual thickness of the aquifer(s). In the case of the Conasauga Group, this is difficult to define. The aquifer is a continuum from near-surface materials (saprolite) to great depth. A decrease in aquifer permeability with depth appears to be present (Table 15), but there is no clear-cut boundary between permeable and impermeable strata. The differences between saprolite and unweathered rock are not great enough to designate them as separate aquifers. The general decrease in permeability with depth is probably a result of a combination of two factors: (1) the effect of weathering decreases with depth and (2) the number and extent of unhealed fractures

Table 15. Hydraulic conductivity data for the Conasauga Group on the ORR

Location	No. of measurements[a]	Geometric mean (K in cm/s)	Comments	Source
ETF[b], Melton Valley	36	6.31×10^{-5}		Davis et al. 1984
SWSA-7, Melton Valley	12	2.57×10^{-5}		(this report)
BCVBG[c], Bear Creek Valley	26	8.2×10^{-5}	Weathered rock and alluvium	Bechtel National, Inc. 1984a
BCVBG[c], Bear Creek Valley	35	1.3×10^{-6}	Unweathered rock	Bechtel National, Inc. 1984a
Oil landform, Bear Creek Valley	12	1.2×10^{-4}	Weathered rock	Bechtel National, Inc. 1984b
Bear Creek Valley	16	1.7×10^{-4}		Law Engineering 1983

[a]Slug and packer tests.

[b]Engineered test facility.

[c]Bear Creek Valley Burial Grounds.

decreases with depth. At depth, individual structures are likely to control subsurface movement of water in contrast to the pervasive joint system found nearer to the ground surface. The fault zone encountered in core hole C3 at a depth of 123 m (402 ft) is a zone in which water is likely to move. In general, the aquifer system underlying the proposed SWSA-7 is a continuum with depth, but most of the water movement probably occurs within the top 50 to 75 m (165 to 245 ft).

Transmissivity (hydraulic conductivity x aquifer thickness) has been determined at several sites underlain by the Conasauga Group. Transmissivity (T) and the storage coefficient (S) are generally determined at the same time through the analysis of a large-scale pumping test. A pumping test run at the Engineered Test Facility (Davis et al. 1984) located on SWSA-6 determined an aquifer transmissivity of approximately 3.7 m^2/d (40 ft^2/d) and a storage coefficient of 0.01. The average T value determined from a pumping test in Bear Creek Valley (Law Engineering 1983) was 0.32 m^2/d (34.8 ft^2/d), and the average value of S was 0.003. The cone of depression around the pumping wells in both pumping tests indicated that the aquifer was anisotropic with respect to hydraulic conductivity. The ratio of along strike (east-west) to strike normal (north-south) was found to be approximately 3:1 for both tests. This ratio is based solely on the direction of strike and does not take into account aquifer dip. The ratio of maximum (along strike) to minimum (normal to strike plane) conductivity is likely to be higher. Data reported in Webster (1976) indicate that the anisotropy ratio for the Conasauga Group may be as high as 10 to

20:1 in some areas. The values of S indicate that the formation has a rather low storage capacity for an unconfined aquifer but not as low as a truly confined aquifer.

To estimate the velocity of groundwater movement, the effective porosity of the aquifer must be known. This porosity can be determined in several ways, such as: (1) lab measurements, (2) tracer tests, (3) field estimates, and (4) estimates based on S values. The porosity in the rocks underlying the site can be divided into primary and secondary openings. The primary porosity is composed of pore spaces between grains of the rock. The total primary porosity is likely to be quite high, but it is not effective in transmitting water. The secondary porosity in this case is primarily open fractures. The total secondary porosity is likely to be low, but the fractures are very effective in transmitting water. Law Engineering (1983) reports an effective porosity of 0.002 based on a tracer test run in Bear Creek Valley. Based on measurements of fractures, Sledz and Huff (1981) report a fracture porosity of 0.0007. Based on the range of storage coefficients for the Conasauga Group, these low porosity values are reasonable. Based on tracer tests, groundwater velocities within the Conasauga Group have been found to range from 0.6 to 18 m/d (2 to 60 ft/d) [Law Engineering (1983) and Webster (1976)]. To estimate the travel time of a contaminant within groundwater, the mechanical dispersion of the aquifer must be known. Law Engineering (1983) reports a dispersivity of 3 m (10 ft) based on the Bear Creek Valley tracer test.

4.5.3 Groundwater Flow System

In order to assess the direction and rate of groundwater movement, as well as determining temporal variations in the flow system, water-level measurements were gathered from the monitoring-well network. Water-level measurements were taken on a weekly basis from all wells, and certain wells were equipped with continuous strip chart recorders. The results of these measurements are presented as hydrographs in Appendix V.

The hydrographs show that annual water fluctuations range between 2 to 5 m (6 to 15 ft) and that fluctuations are greatest below ridges where groundwater is deep and least where it is shallow. Short-term fluctuations (response to precipitation events) are more apparent on the hydrographs of shallow wells. Well 6 shows a rapidly fluctuating system; it appears that this well is controlled by a solution cavity system. In general, the water levels are highest in late spring and lowest in the fall.

Several of the wells have undergone some extremely rapid and large fluctuations (such as the 4-m (13-ft) drop in water level seen in Well 17). These rapid fluctuations are not easily explained, but the dates when they occur seem to coincide with injections of waste at the Hydrofracture Facility. The Hydrofracture Facility is 2.5 km (1.5 miles) to the west of the proposed SWSA-7 in Melton Valley. The wells that do respond it appears are all relatively deep, but the same wells do not respond to all injection events. The cause and response of these rapid fluctuations need to be studied further to better understand the groundwater flow system in Melton Valley.

Included in the Appendix V are the hydrographs for the upper- and lower-screened intervals in Well 13 (the well was equipped with a packer between the upper and lower screen). The data from this site indicate that a strong upward gradient exists; that is, water is discharging into the central creek on site. Water-level reversals do occur within this well, and these are probably associated with recharge events.

The water-level data were used to construct three maps for the site. The first map is the potentiometric surface under high groundwater conditions (Fig. 30). The map indicates that water is highest beneath the ridges on site and that water discharges into the creeks surrounding the site. In an isotropic aquifer, the direction of groundwater movement would be normal to potentiometric contours. In the case of an anisotropic aquifer (such as at the study site), the direction of flow will be at some angle to potentiometric contours. Data for low groundwater conditions are presented in Fig. 31. The groundwater flow system does not appear to vary greatly throughout the year.

It is important to define the boundaries or discharge areas of the groundwater flow system. The shallow creeks surrounding the proposed SWSA-7 appear to be the major groundwater discharge areas, but based on the geologic and geophysical investigations on site, underflow is likely to occur beneath these first-order creeks. This situation is supported by the water budget presented earlier. Most of the groundwater beneath the site is likely to discharge into Melton Branch, either indirectly by way of the first-order creeks, or directly. The nature of the groundwater discharge areas should be taken into account

ORNL-DWG 84-1380

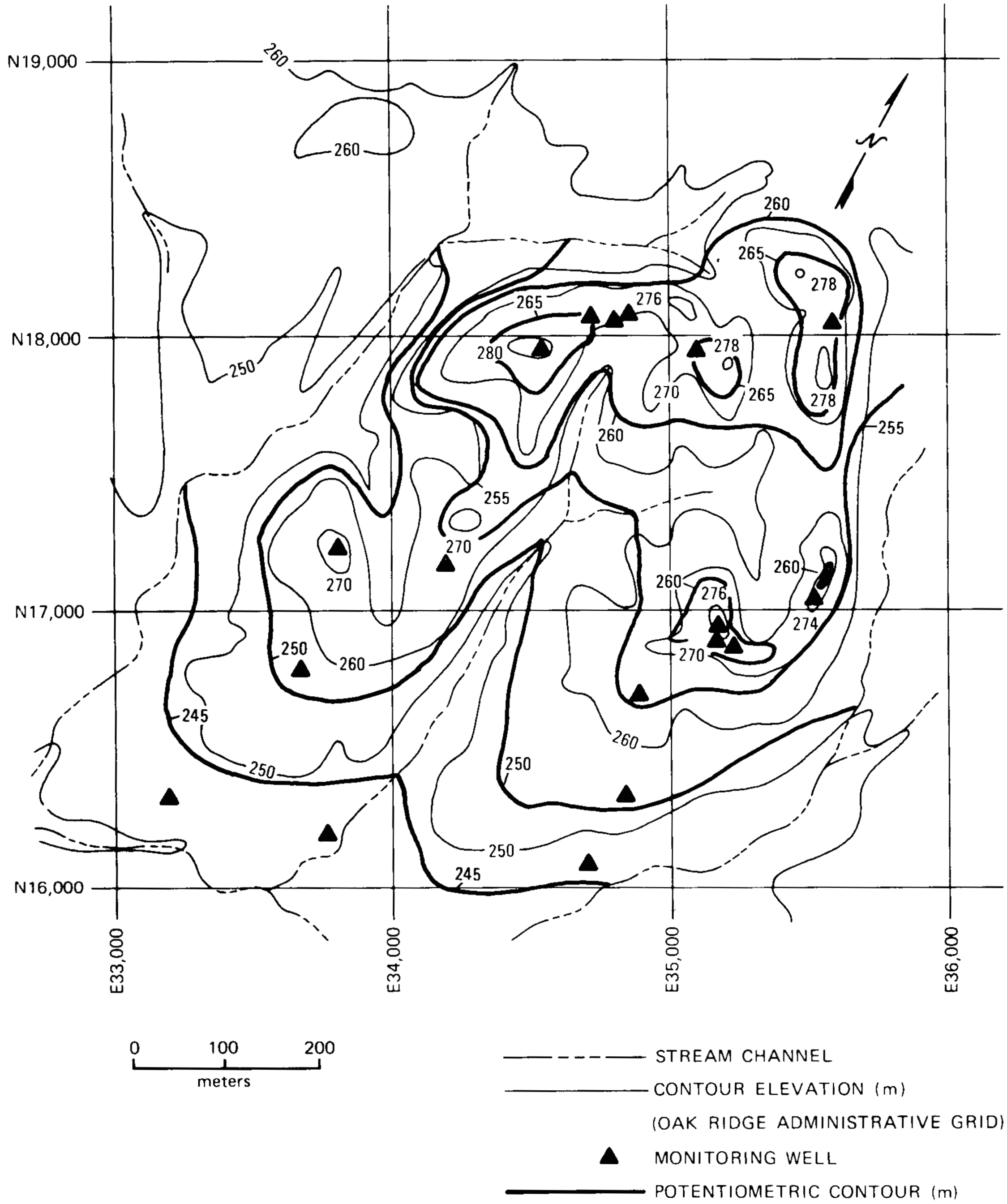


Fig. 30. Potentiometric surface at the proposed SWSA-7 for April 27, 1983, representing high groundwater conditions.

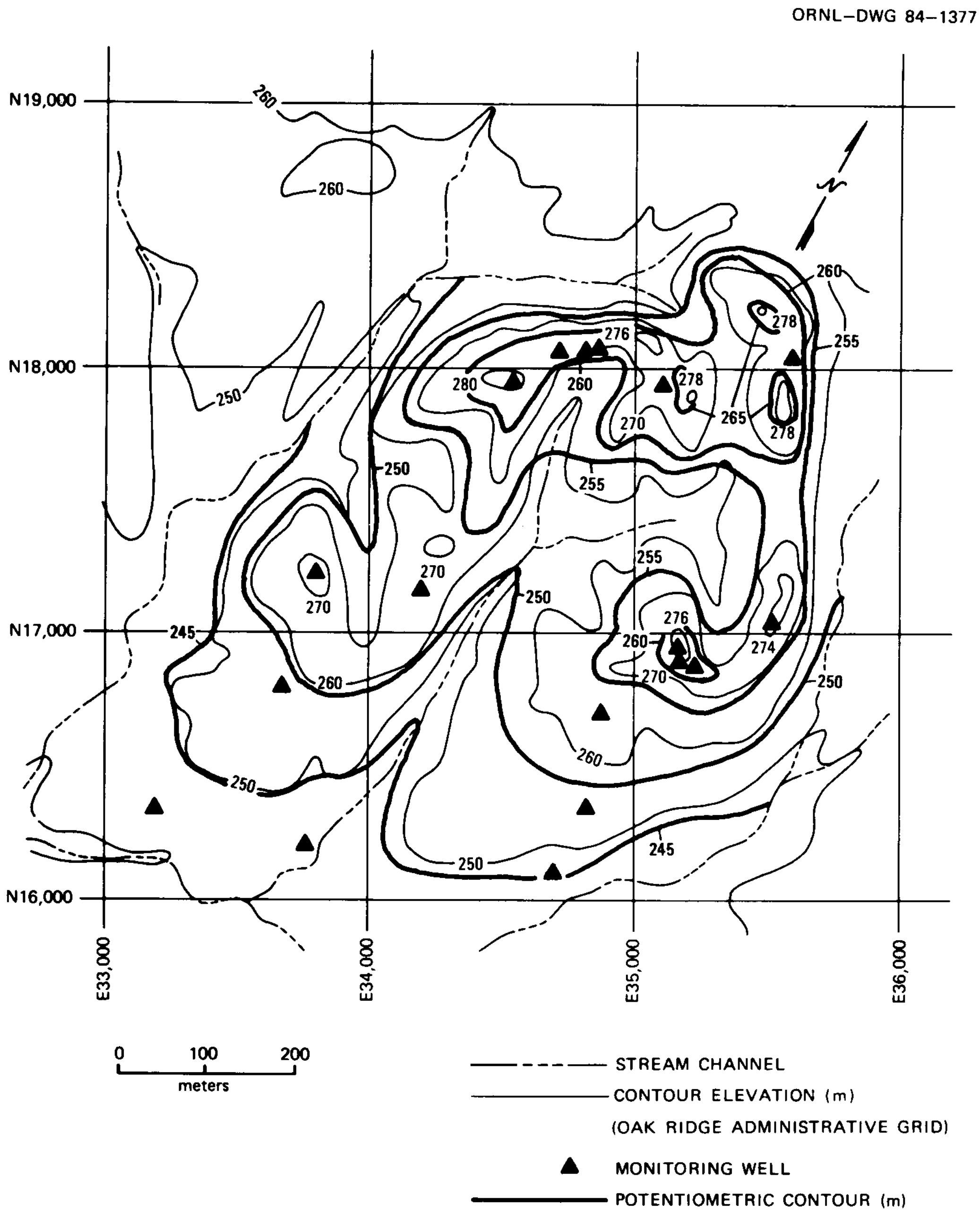


Fig. 31. Potentiometric surface at the proposed SWSA-7 for November 11, 1983, representing low groundwater conditions.

in designing a monitoring program for the site in the future. The nature of any deep groundwater movement was not investigated, but it is apparent from the geologic logs that deep zones of water movement are likely to occur. The total flow in these zones is probably very low; therefore, they are only a concern for contaminant migration if: (1) waste is emplaced at a great depth, or (2) waste is placed in an area where a major geologic structure crops out, resulting in a direct subsurface pathway.

The depth to groundwater is critical for designing a sound waste-disposal facility. Figure 32 shows the depth to water under high groundwater conditions; that is, this map shows the minimum depth to water as determined from the field measurements. On a short-term basis, water may rise higher in response to storm events.

The general configuration of the water table underlying the site is presented in the cross sections in Fig. 33. The water table is generally a subdued reflection of the topography of the site. The cross sections also show that the water table is generally located near the boundary between the saprolite and unweathered rock.

The quality of potentiometric surface maps is limited by the number of data points, that is, the number of wells. To aid in filling in missing data, either on site or off site, the relationship between water-level and topographic elevations was determined. This relationship is presented in Fig. 34. The relationship between the two variables is good, and, for a given elevation, the depth or elevation of the potentiometric surface can be estimated. There are several

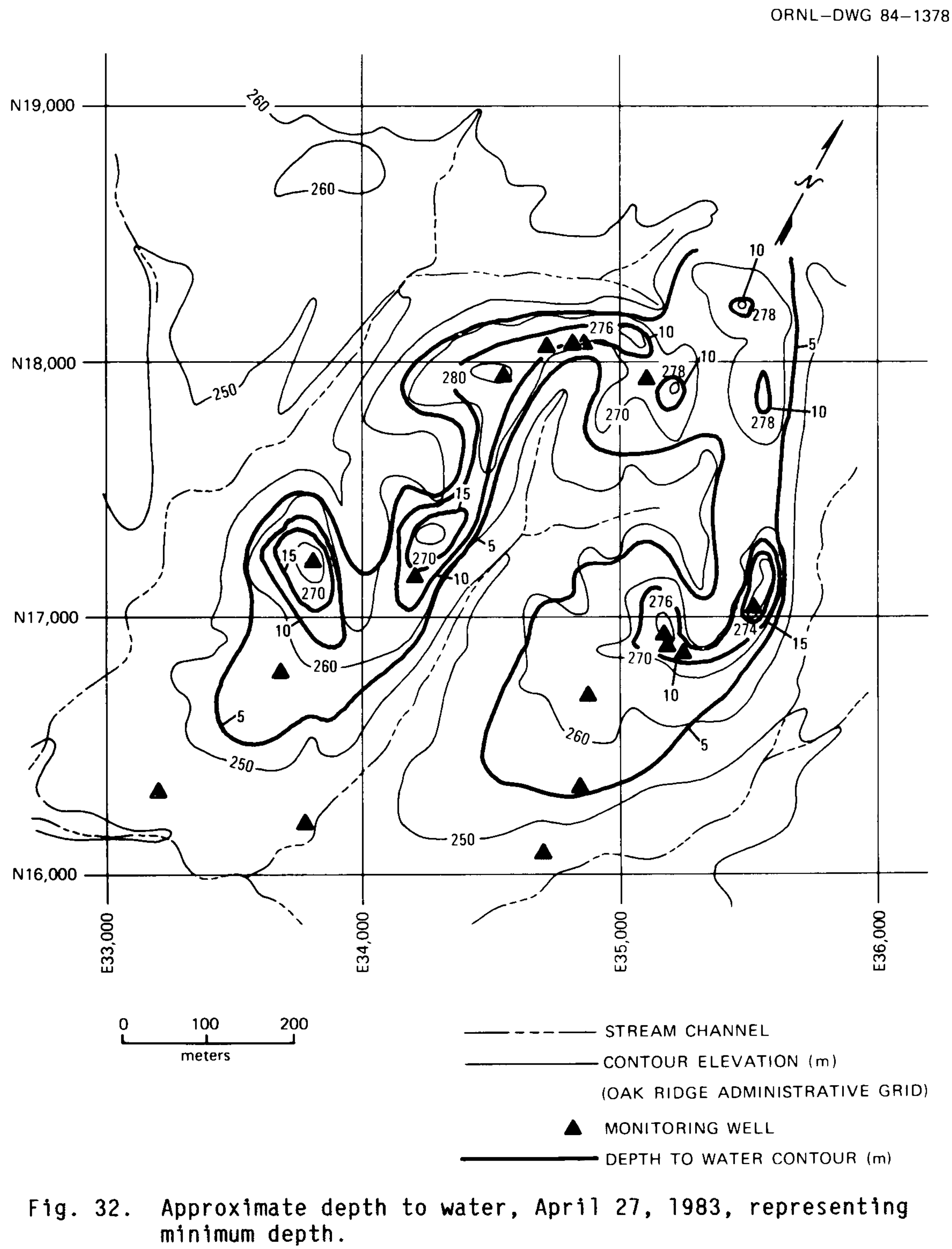


Fig. 32. Approximate depth to water, April 27, 1983, representing minimum depth.

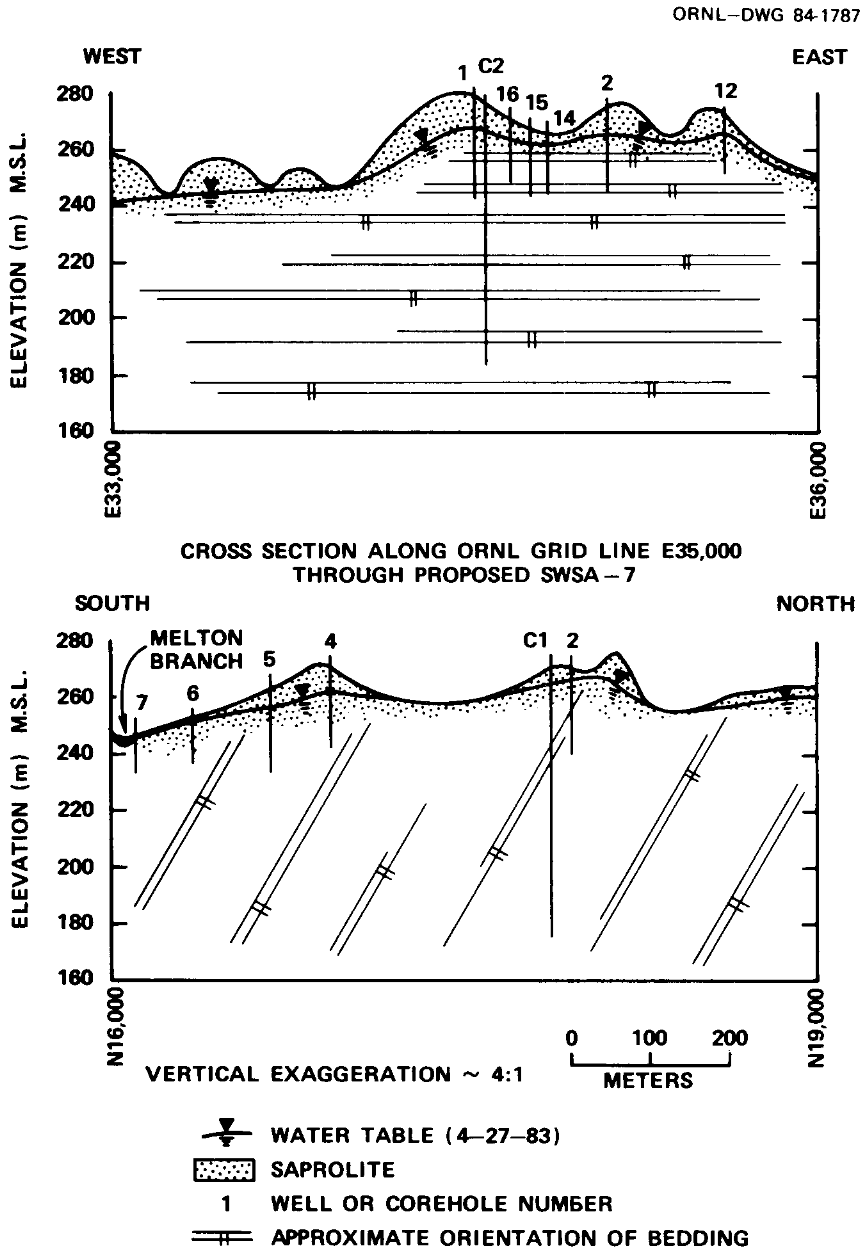
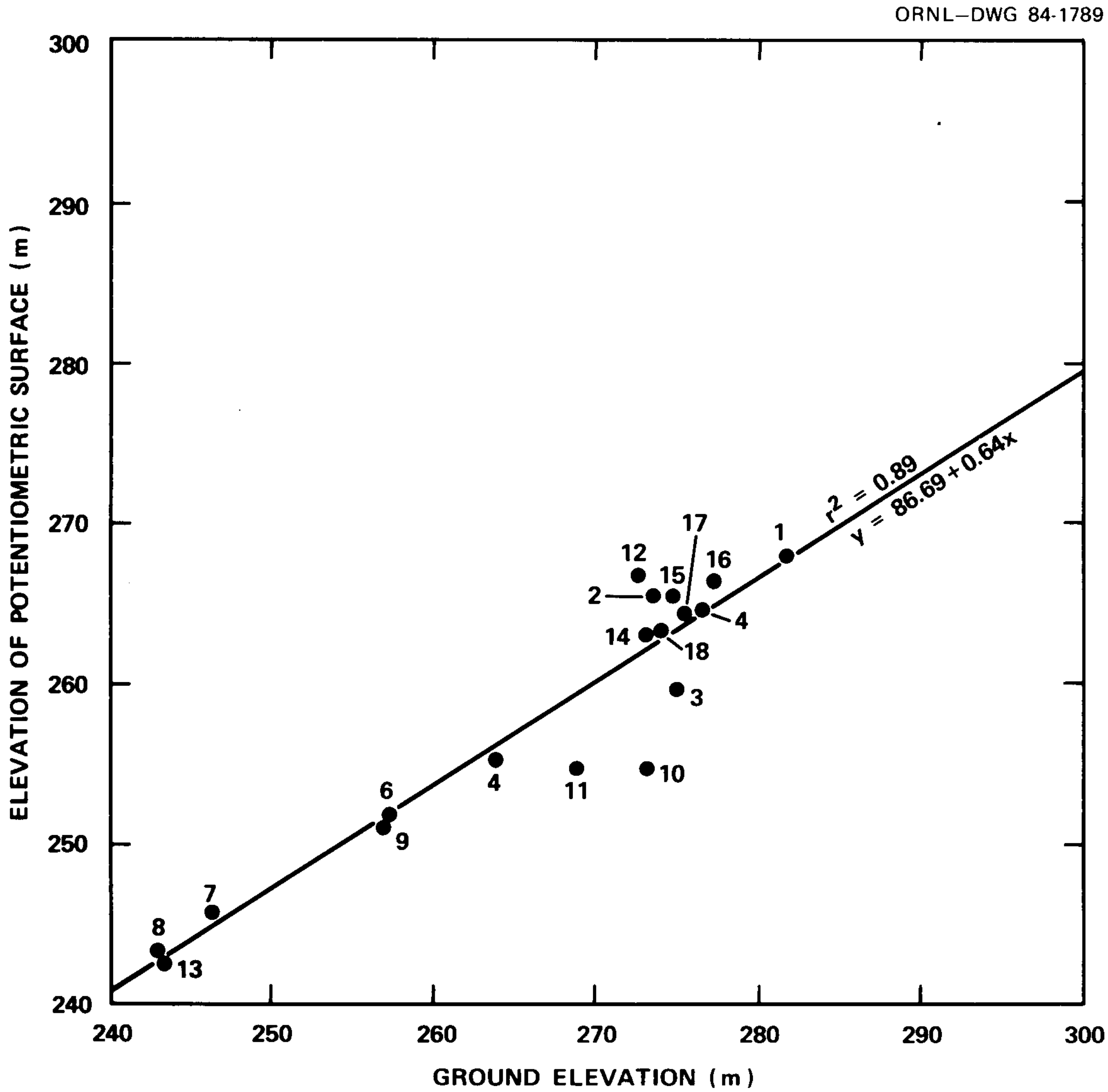


Fig. 33. Hydrologic cross sections along ORNL grid lines N18,000, upper, and E35,000, lower, through the proposed SWSA-7.



GROUND ELEVATION vs MEAN MAXIMUM POTENTIOMETRIC SURFACE ELEVATION

Fig. 34. Plot of topographic elevation vs mean maximum water level for wells on the proposed SWSA-7.

outliers on the plot in Fig. 34 such as wells 10, 11, and 12. The variation of these wells from the linear relationship for the site is probably because of their close proximity to steep topographic features.

4.5.4 Water Chemistry

To determine the chemistry of surface waters and groundwaters on the proposed SWSA-7, two sets of samples were collected. The samples were analyzed for major anions and cations, trace metals, and radionuclides (Appendix VI). Samples were collected from each well (after well development and purging), from the on-site flume, and from Melton Branch (south of Well 8).

The radionuclide data indicate that the site is essentially uncontaminated, with the exception of trace amounts of tritium. There are also no indications of contamination based on the metals concentrations of the samples.

Included in Appendix VI are the number and percentages of equivalents for the major anions and cations for each sampling location. Several trends can be gleaned from the data. First, the surface waters and groundwaters on site are predominantly of the Ca/HCO_3 type. Second, the northernmost wells on site have much higher SO_4 and total dissolved ion concentrations than the other sampling locations. This trend may be the result of the length of the flow path of the groundwater sampled at each well or may be a result of variations in rock chemistry surrounding those sampling sites. The data are limited; therefore, no firm conclusions can be drawn about groundwater flow paths or spatial and temporal variations of water chemistry.

5. SUPPORTING PROJECTS

5.1 CLEAR-CUTTING EFFECTS ON WATER BUDGET

As a part of the SWSA-7 characterization, an experiment to determine the effects of vegetation removal (clear-cutting) on the water budget is underway. The primary objective of this work is to determine the magnitude of changes in recharge to the groundwaters and the associated rise in water-table elevations to be expected. This study is of special importance for areas where depth to the water table is a prime determinant of usable disposal area. For example, at SWSA-7 under mixed hardwood-forest cover, roughly half of the total area is not available for belowground disposal or storage of wastes because of high water-table conditions. Earlier hydrologic simulation studies in similar climatic and edaphic settings suggest that conversion of mixed hardwoods to grass cover, which is typical of developed disposal sites, could result in as much as a 25% increase in recharge to the aquifer system. For the porosity and permeability that is typical of the Conasauga Group, the increased recharge could result in as much as a 2-m (6.6-ft) rise in mean water-table elevation, assuming typical topographic conditions. It is expected that such a rise in water table would result in further reduction of site-usable area. Currently, the information and simulation models are available to explore the question of water-table rise, and such work will be continued as part of a longer-term-characterization effort for Conasauga Group formations. However, predictions must be compared with actual field observations before the methodology can be evaluated. Thus, a clear-cutting experiment is underway at the SWSA-7 site. The first stage includes developing baseline measurements of water-table fluctuation, water-budget components, and control sites for post-treatment comparisons. A set of four shallow-monitoring wells has been established at the planned clear-cutting site, and data are being gathered to relate water-table elevation to climate and levels in nearby (control) wells. It is anticipated that a small site of about 1 ha will be cleared and replanted in grass cover. These determinations of rise in water-table elevation associated with clearing will be made and compared to predictions that are to be developed prior to the treatment.

It is anticipated that the result of this work will provide a general methodology for use in assessing the effects of site development on usable area.

5.2 HYDROLOGIC MODELING

As part of the hydrologic characterization of the site, a computer model is being developed to simulate groundwater flow and mass transport. Initial modeling efforts have used the computer code FEWA (Yeh and Huff 1983) to simulate steady-state groundwater conditions. The same code will be used to simulate transient flow conditions, and eventually a code to simulate mass transport in the groundwater system will be used. The computer model ties together many aspects of the site-characterization work on the proposed SWSA-7 and will be an aid to site utilization and design, as well as indicate where data gaps may lie.

5.3 SUBSURFACE TRANSPORT RESEARCH

As part of a separate research activity of the Environmental Sciences Division, a small watershed on the proposed SWSA-7 is being studied. The study is divided into two tasks: hydrogeochemical transport processes and hydrologic transport of buried trace elements in contrasting watersheds. The first task involves detailed computer modeling that will combine geochemical and hydrologic processes. The second task involves field research on two small watersheds, one of which is on the proposed waste facility. Hydrologic properties of the soils and saprolite will be measured, and their spatial distribution determined. Detailed meteorological data will be collected, and surface-water flows will be measured. The field studies, in combination with in-situ tracer tests, will be used to model the site and to investigate the ongoing hydrologic/geochemical processes.

The data collected will be directly applicable to the proposed SWSA-7 site, and the processes investigated will be an important contribution to current and future waste disposal operations on the ORR.

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APPENDIX I

GEOPHYSICAL SURVEY DATA

APPENDIX I

SP MEASUREMENTS (MILLIVOLTS), SP-1, SITE 4, SWSA-7

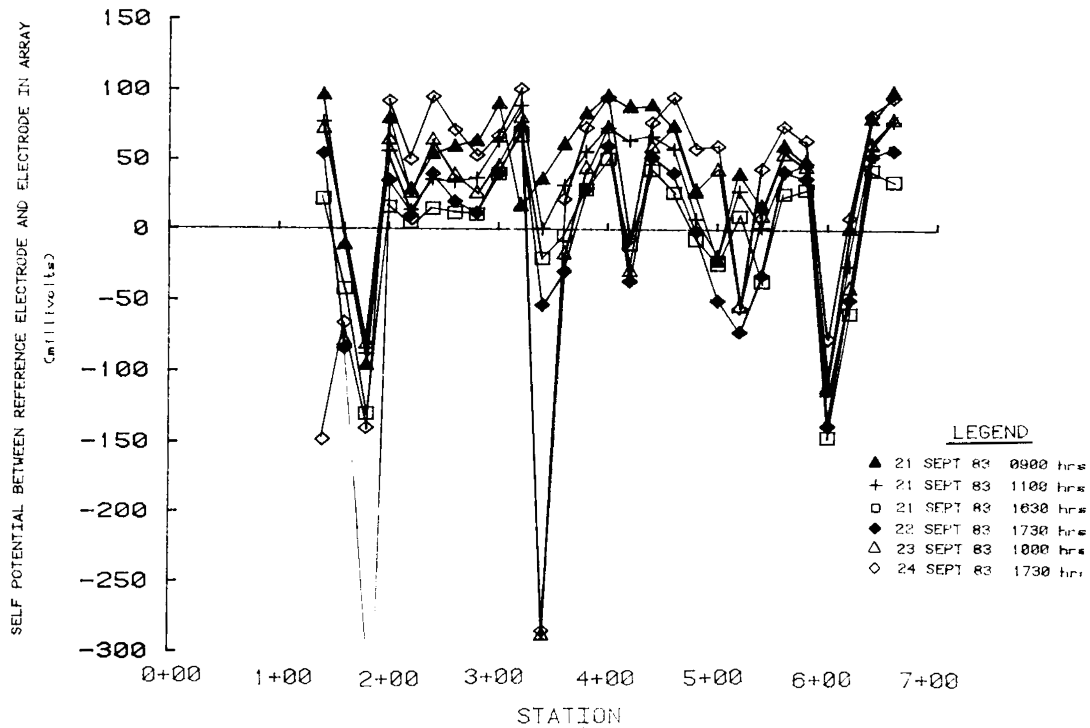
Station number	SPONTANEOUS POTENTIAL, MILLIVOLTS D.C. 0900 Hrs 21 Sep 83	1100 Hrs 21 Sep 83	1630 Hrs 22 Sep 83	1730 Hrs 23 Sep 83	1330 Hrs 30 Sep 83	1730 Hrs 24 Sep 83
1+40	+97	+77	+22	+54	+73	-148
1+60	-10	+0	-42	-84	-78	-66
1+80	-95	-88	-130	-439	-80	-140
2+00	+80	+56	+16	+35	+65	+92
2+20	+29	+14	+5	+10	+27	+50
2+40	+55	+36	+15	+40	+65	+95
2+60	+60	+34	+12	+20	+40	+71
2+80	+64	+37	+11	+12	+27	+53
3+00	+91	+63	+40	+40	+46	+67
3+20	+18	+89	+67	+73	+81	+101
3+40	+37	+01	-20	-53	-287	-285
3+60	+62	+32	-04	-29	-16	+22
3+80	+84	+56	+29	+29	+45	+73
4+00	+97	+73	+51	+60	+74	+95
4+20	+89	+64	-10	-36	-18	-06
4+40	+90	+67	+43	+52	+60	+77
4+60	+75	+58	+27	+41	+75	+95
4+80	+28	+08	+07	-01	+29	+58
5+00	-21	-18	-24	-50	+44	+60
5+20	+41	+28	+10	-72	-53	-55
5+40	+18	+02	-36	-32	+11	+44
5+60	+61	+41	+26	+42	+55	+74
5+80	+50	+48	+29	+37	+46	+64
6+00	-110	-113	-146	-138	-112	-77
6+20	+02	-25	-59	-49	-40	+09
6+40	+81	+59	+43	+53	+62	+82
6+60	+100	+78	+35	+57	+80	+95

APPENDIX I (continued)

SP MEASUREMENTS (MILLIVOLTS), SP-2, SITE 4, SWSA-7

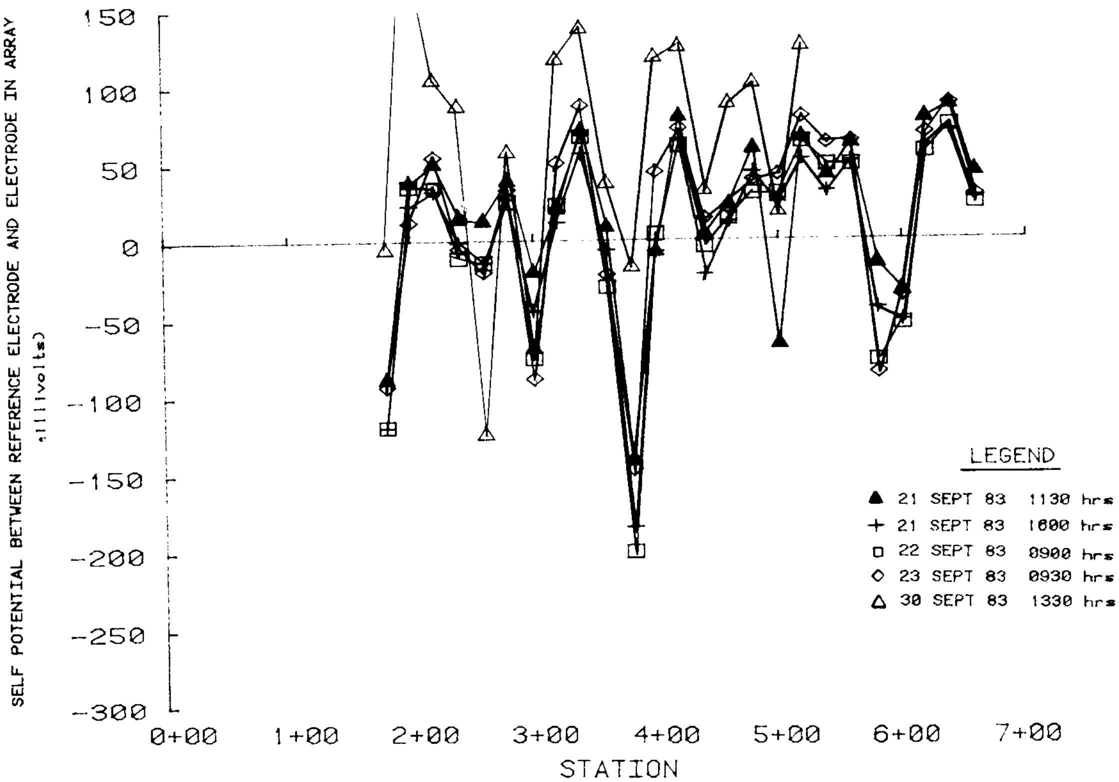
Station number	SPONTANEOUS POTENTIAL, MILLIVOLTS D.C. 1130 Hrs 21 Sep 83	1600 Hrs 21 Sep 83	0900 Hrs 22 Sep 83	0930 Hrs 23 Sep 83	1330 Hrs 30 Sep 83
1+80	-88	-120	-120	-94	-04
2+00	+39	+23	+07	+12	+182
2+20	+51	+32	+35	+54	+105
2+40	+15	-01	-11	-05	+88
2+60	+14	-14	-14	-20	-124
2+80	+40	+27	+25	+33	+58
3+00	-19	-45	-76	-89	-68
3+20	+22	+12	+23	+50	+118
3+40	+72	+56	+67	+87	+138
3+60	+10	-06	-30	-22	+38
3+80	-140	-185	-201	-148	-16
4+00	-06	-07	+04	+44	+119
4+20	+81	+64	+61	+72	+126
4+40	+05	-22	-04	+14	+33
4+60	+24	+12	+14	+20	+89
4+80	+60	+44	+30	+39	+102
5+00	-66	+24	+30	+42	+19
5+20	+67	+52	+63	+79	+126
5+40	+43	+31	+48	+62	Meter Quit
5+60	+63	+50	+48	+63	↑
5+80	-14	-44	-78	-86	
6+00	-32	-52	-54	-36	
6+20	+79	+60	+56	+68	
6+40	+87	+70	+73	+87	
6+60	+44	+26	+23	+28	
					↓

APPENDIX I (continued)



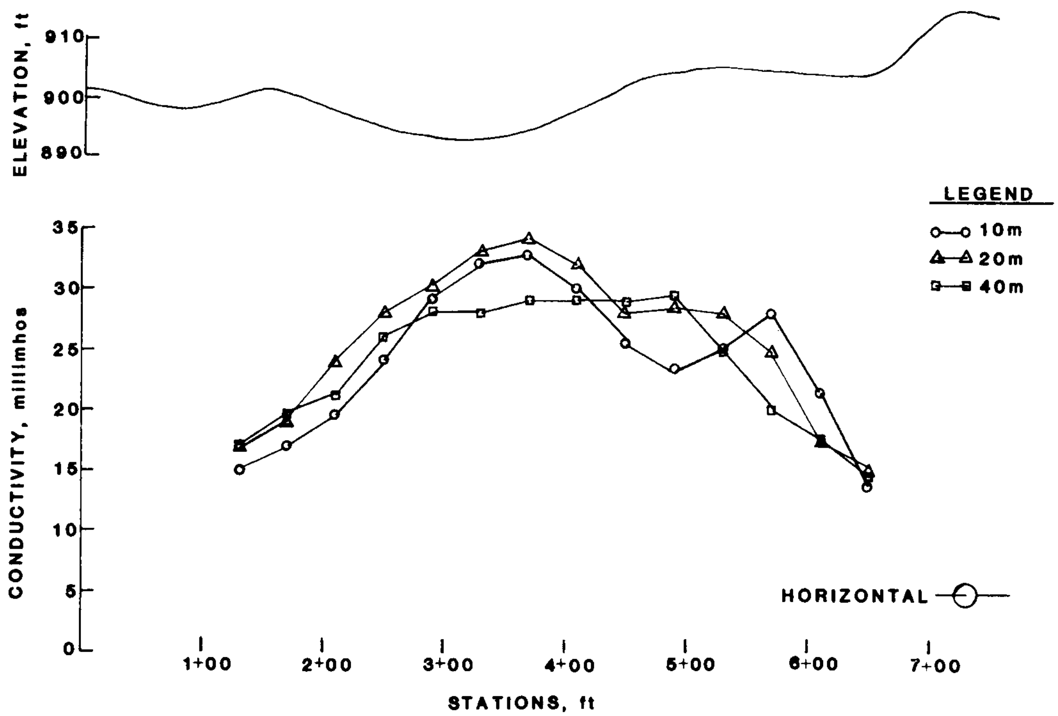
Static SP Profiles for SP-1, Site 4, SWSA-7

APPENDIX I (continued)



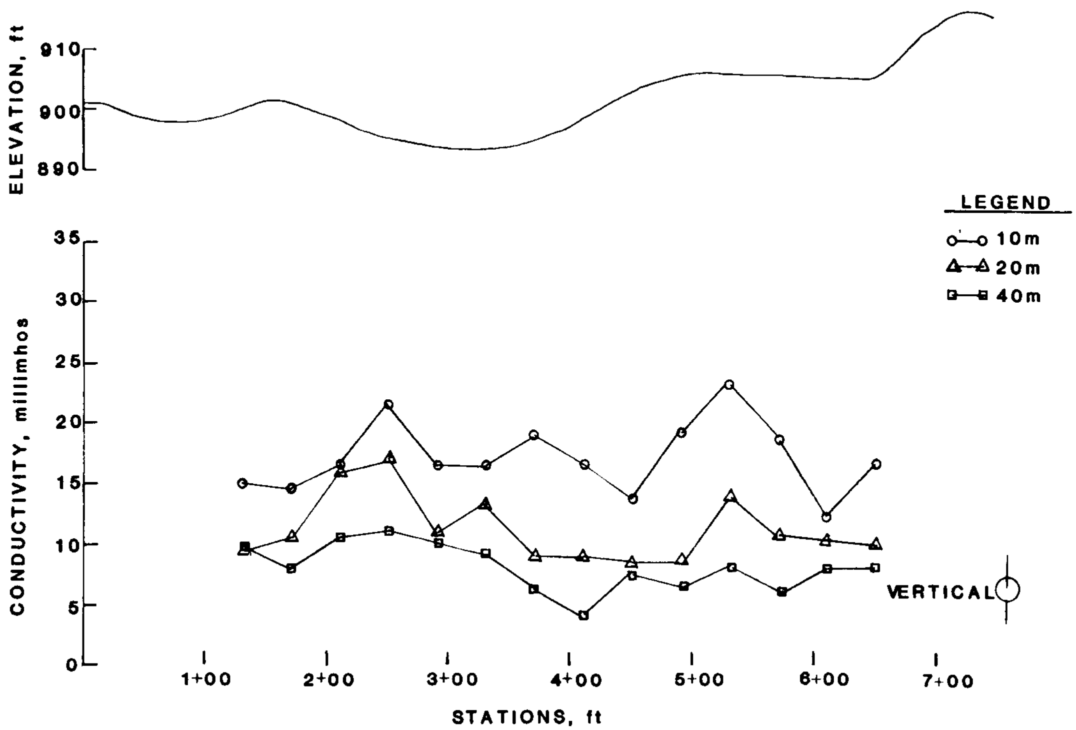
Static SP Profiles for SP-2, Site 4, SWSA-7

APPENDIX I (continued)



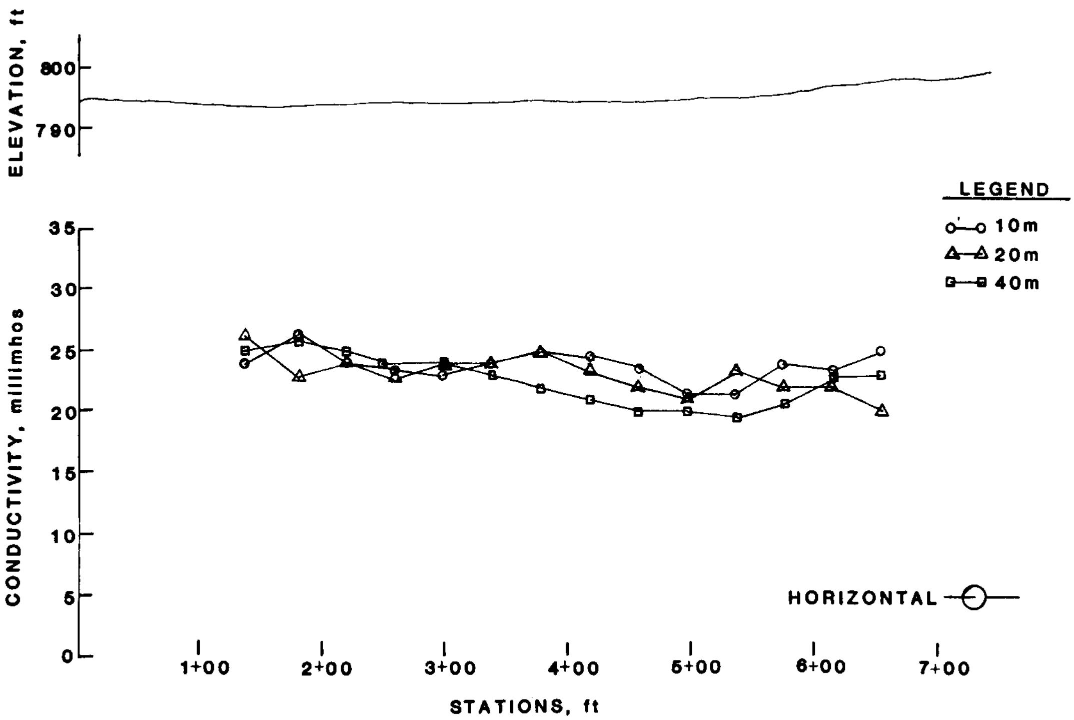
EM Survey, Site 3, SWSA-7

APPENDIX I (continued)



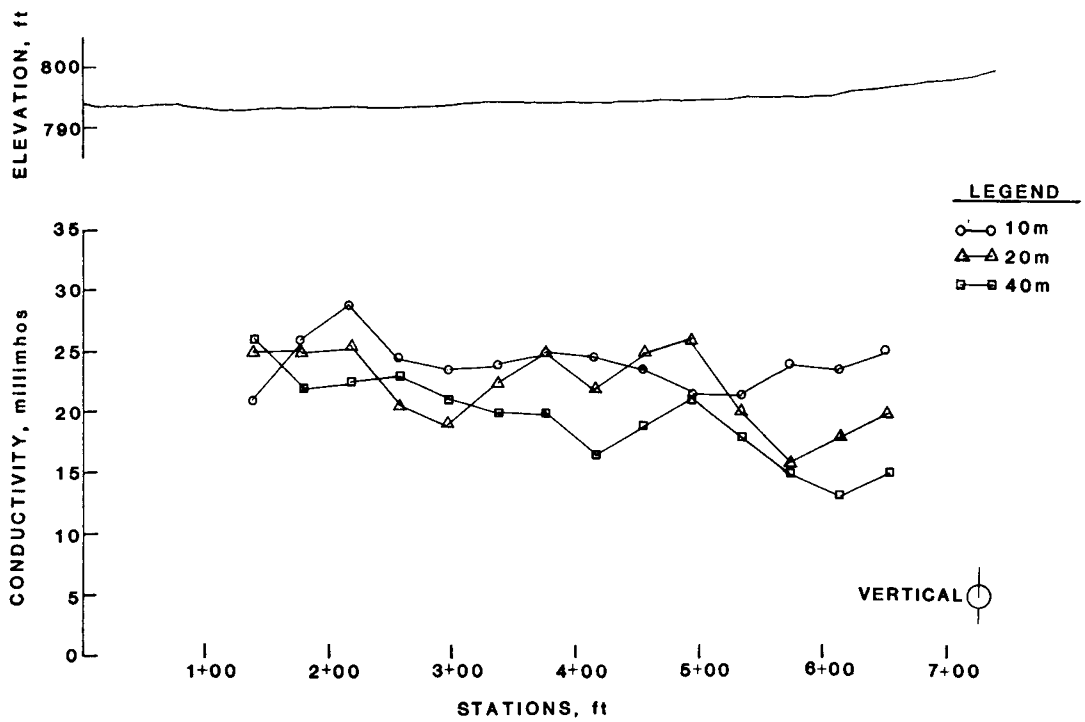
EM Survey, Site 3, SWSA-7

APPENDIX I (continued)



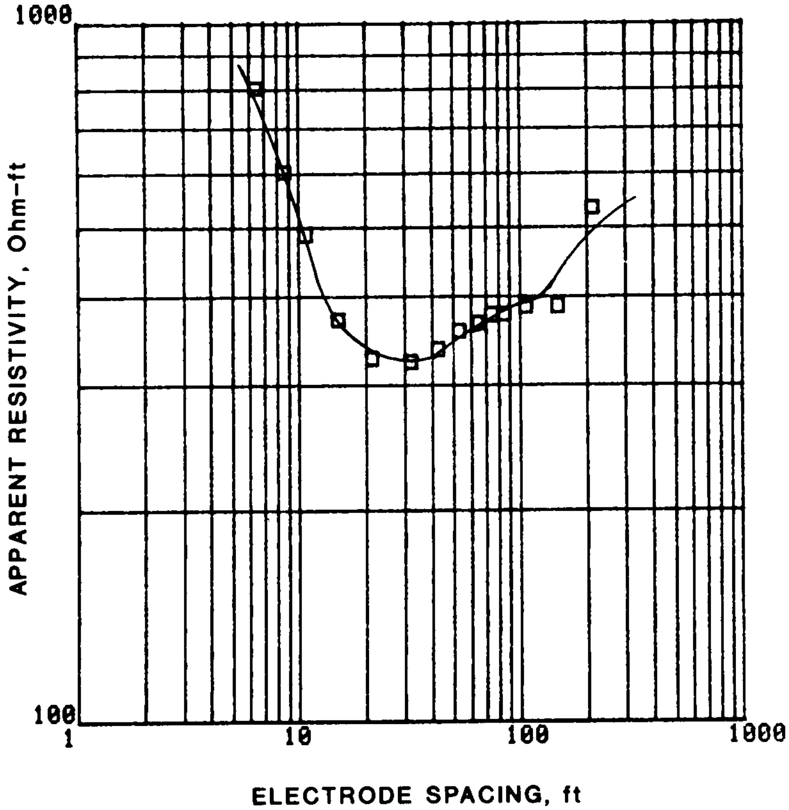
EM Survey, Site 4, SWSA-7

APPENDIX I (continued)



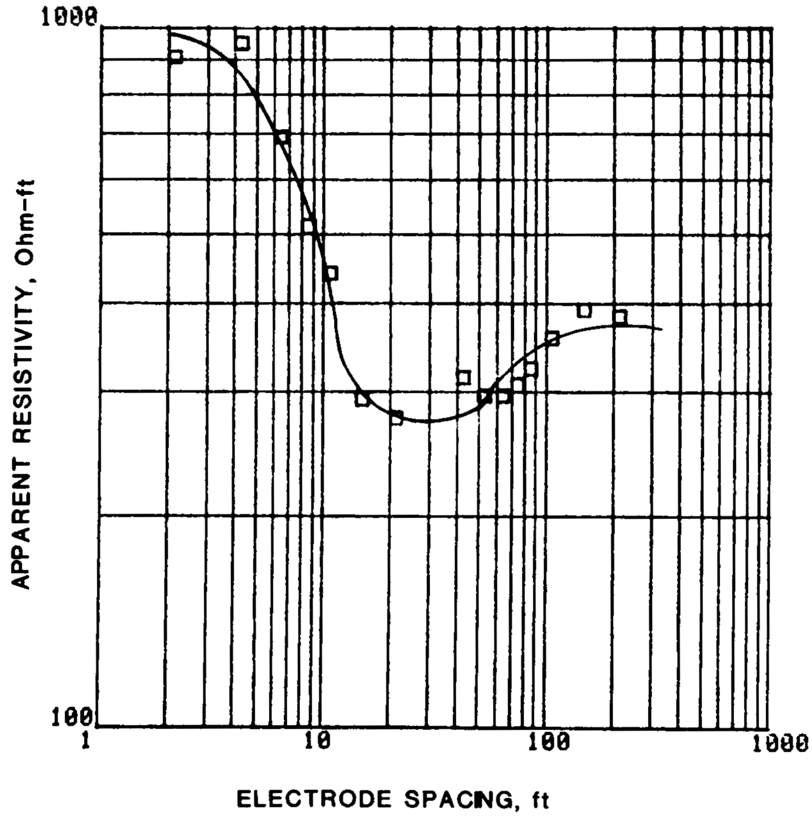
EM Survey, Site 4, SWSA-7

APPENDIX I (continued)



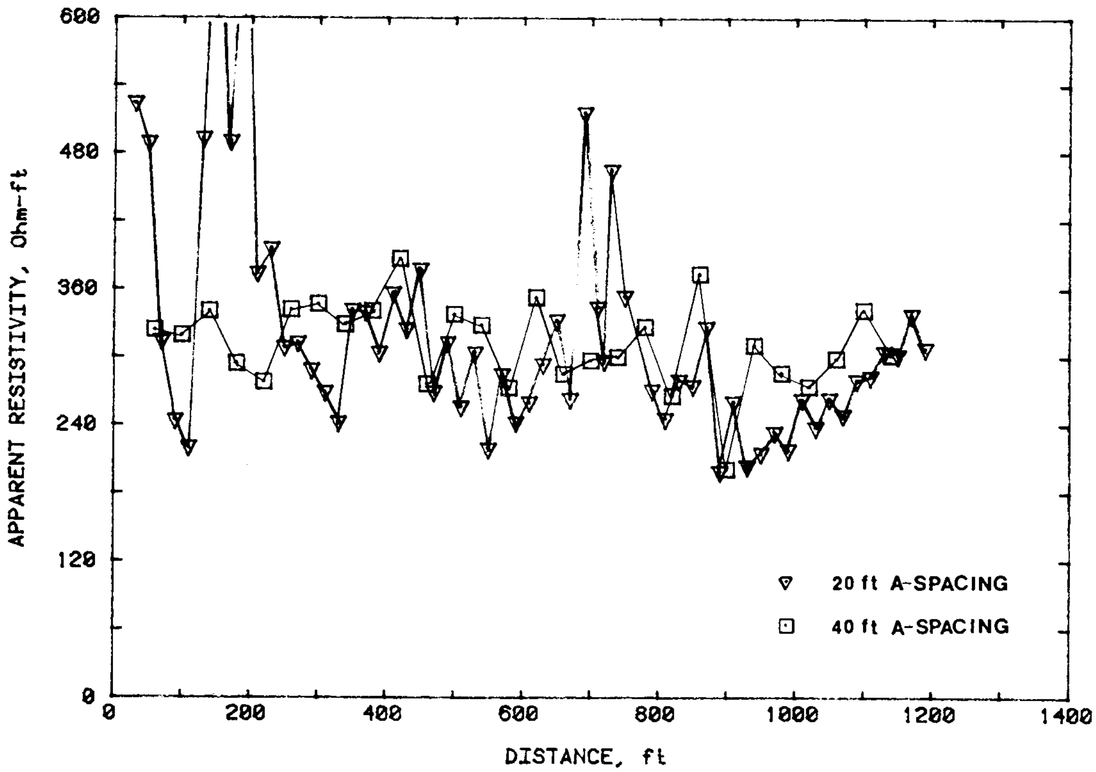
Vertical Resistivity Sounding (Schlumberger Array), RS-1, Centered on Station 0 + 60, Site 1, SWSA-7

APPENDIX I (continued)



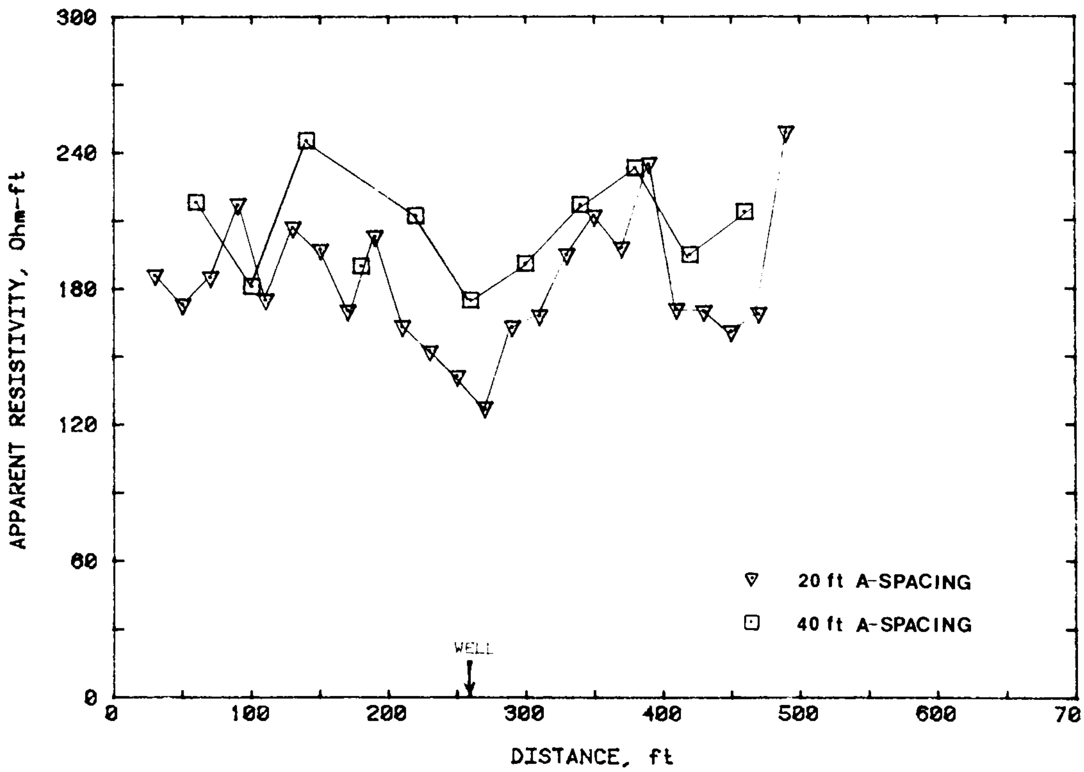
Vertical Resistivity Sounding (Schlumberger Array), RS-2, Centered on Station 0 + 20, Site 1, SWSA-7

APPENDIX I (continued)



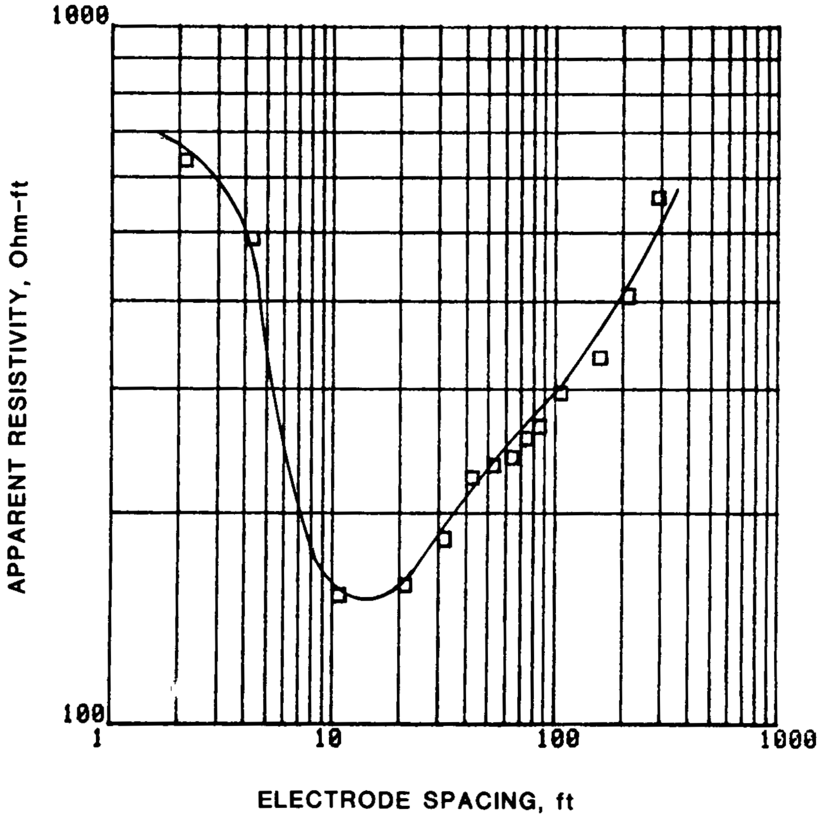
Horizontal Resistivity Profile (Wenner Array), RP-1, Site 1, SWSA-7

APPENDIX I (continued)



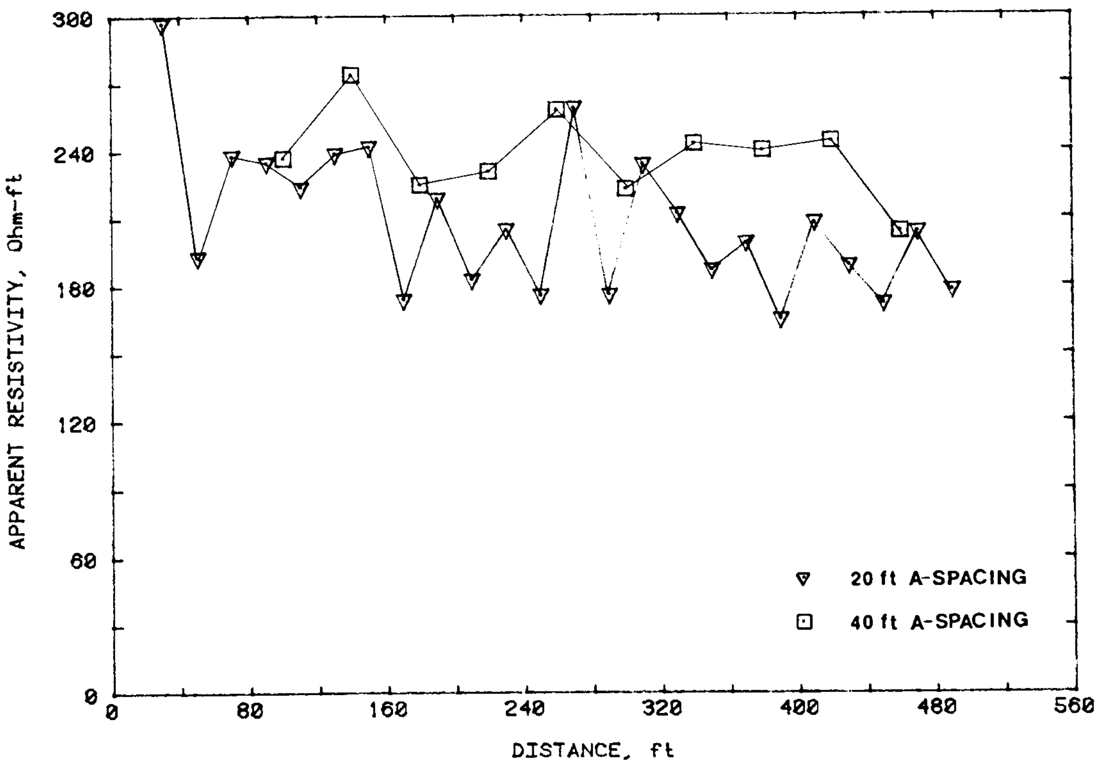
Horizontal Resistivity Profile (Wenner Array), RP-3, Site 3, SWSA-7

APPENDIX I (continued)



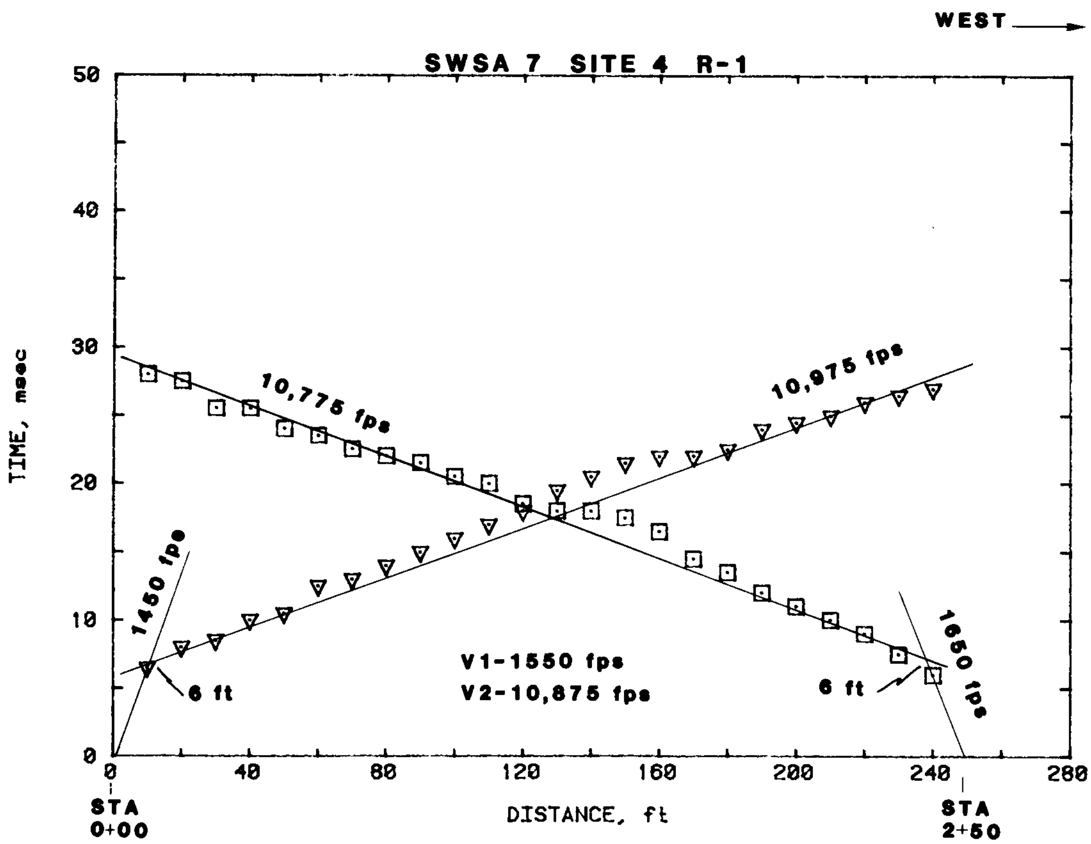
Vertical Resistivity Profile (Schlumberger Array), RS-3, Centered on Station 4 + 1000, Site 4, SWSA-7

APPENDIX I (continued)



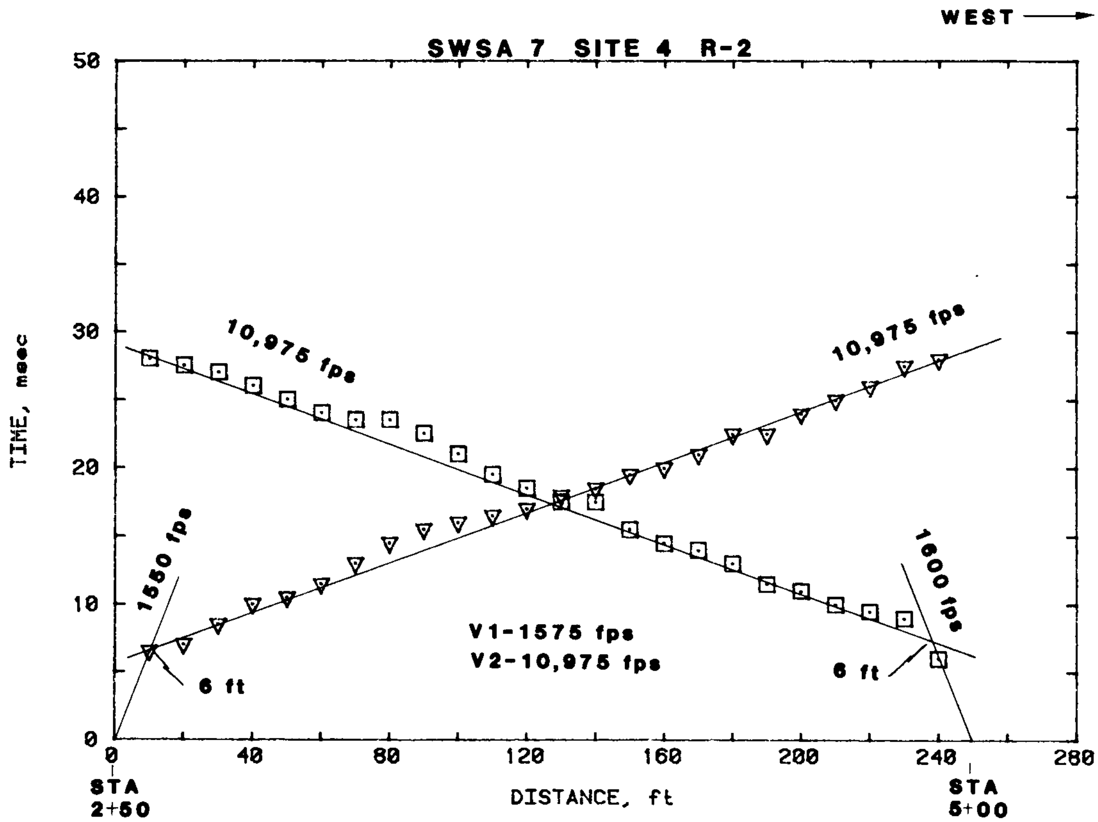
Horizontal Resistivity Profile (Wenner Array), RP-4, SWSA-7

APPENDIX I (continued)



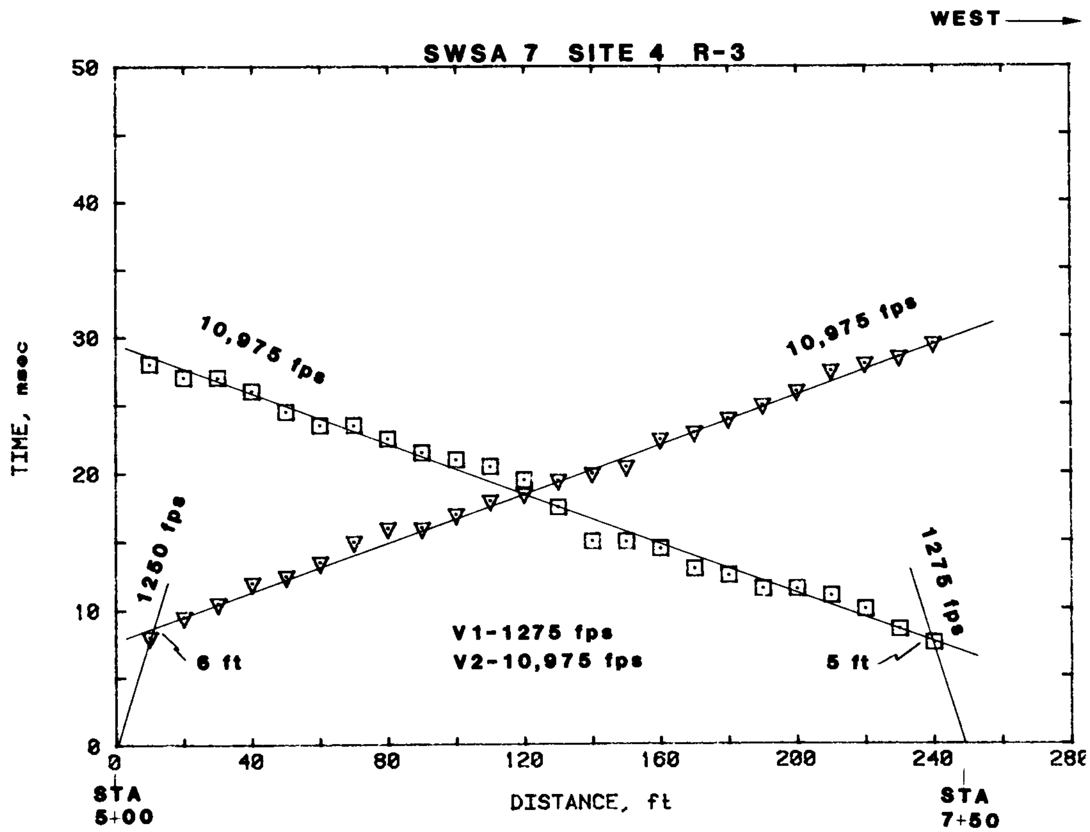
Seismic Refraction Line R-1, Site 4, SWSA-7

APPENDIX I (continued)



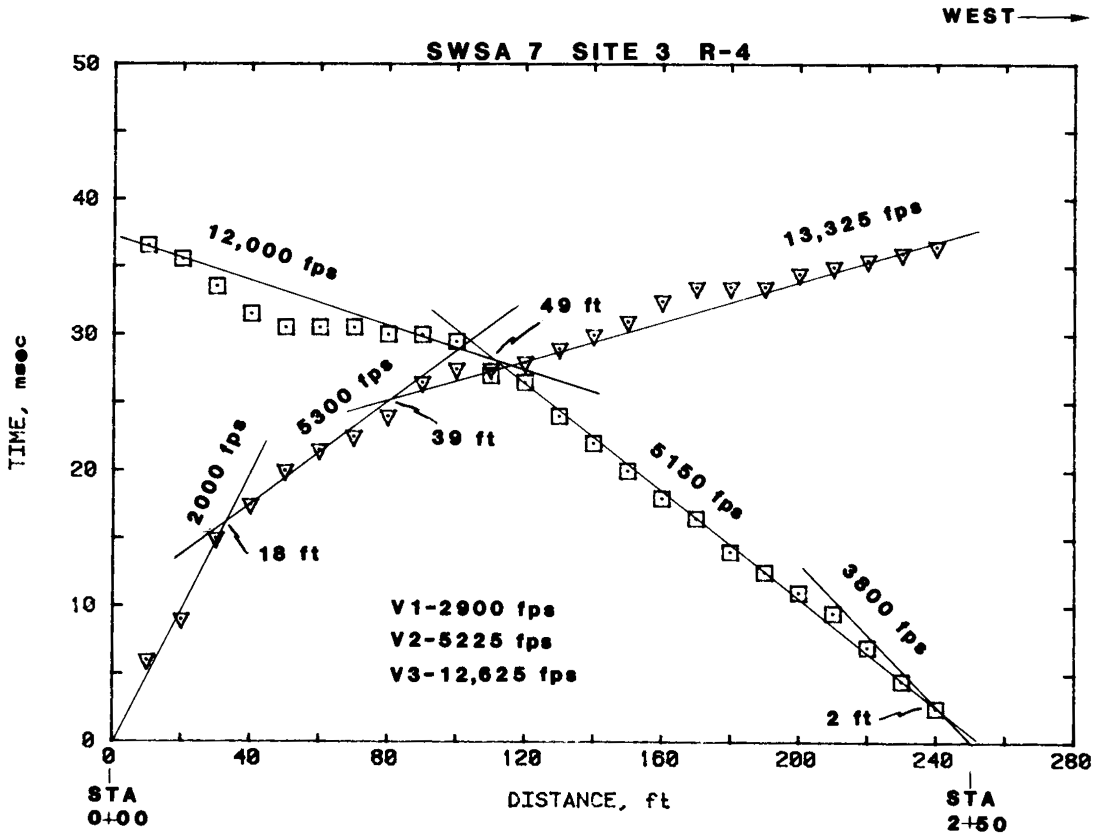
Seismic Refraction Line R-2, Site 4, SWSA-7

APPENDIX I (continued)



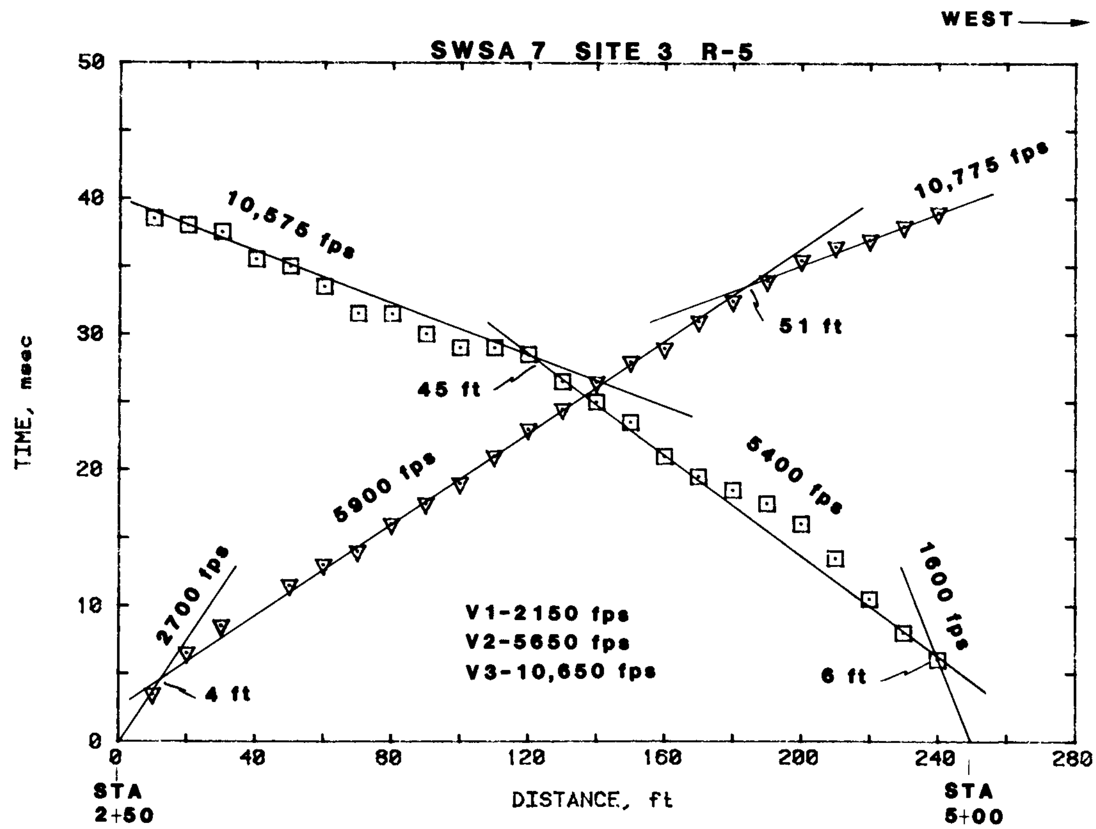
Seismic Refraction Line R-3, Site 4, SWSA-7

APPENDIX I (continued)



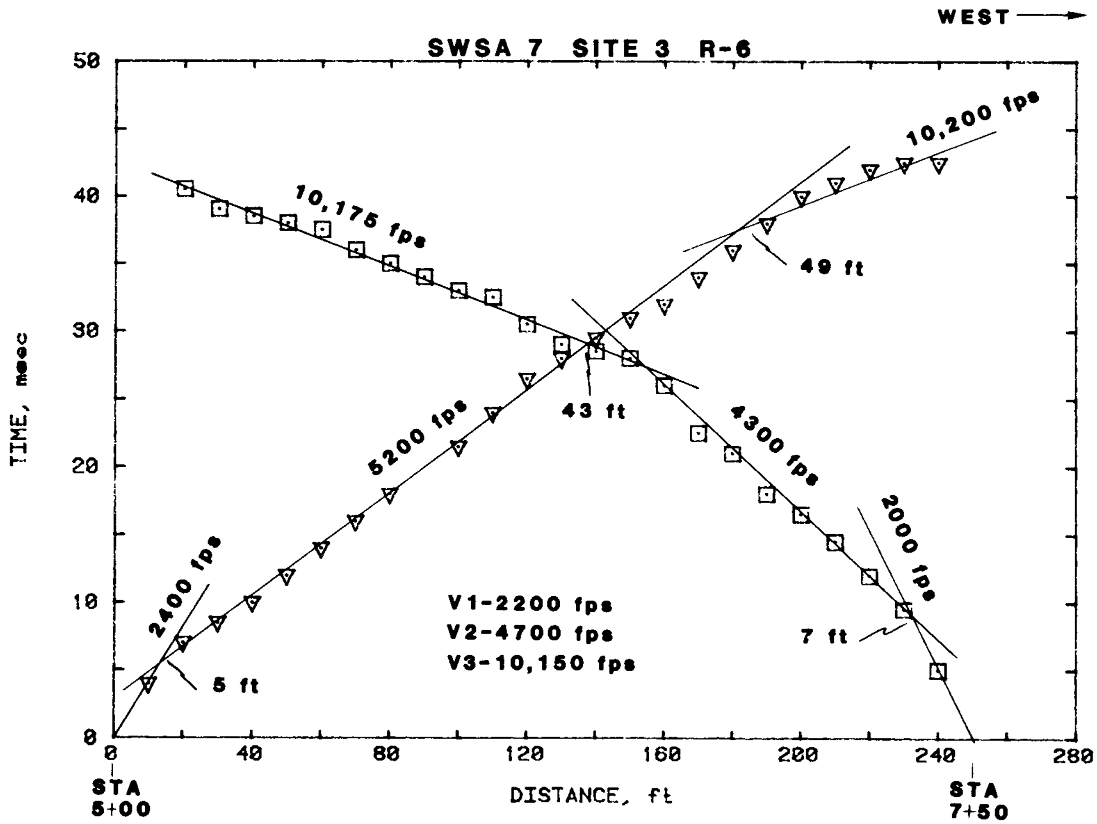
Seismic Refraction Line R-4, Site 3, SWSA-7

APPENDIX I (continued)



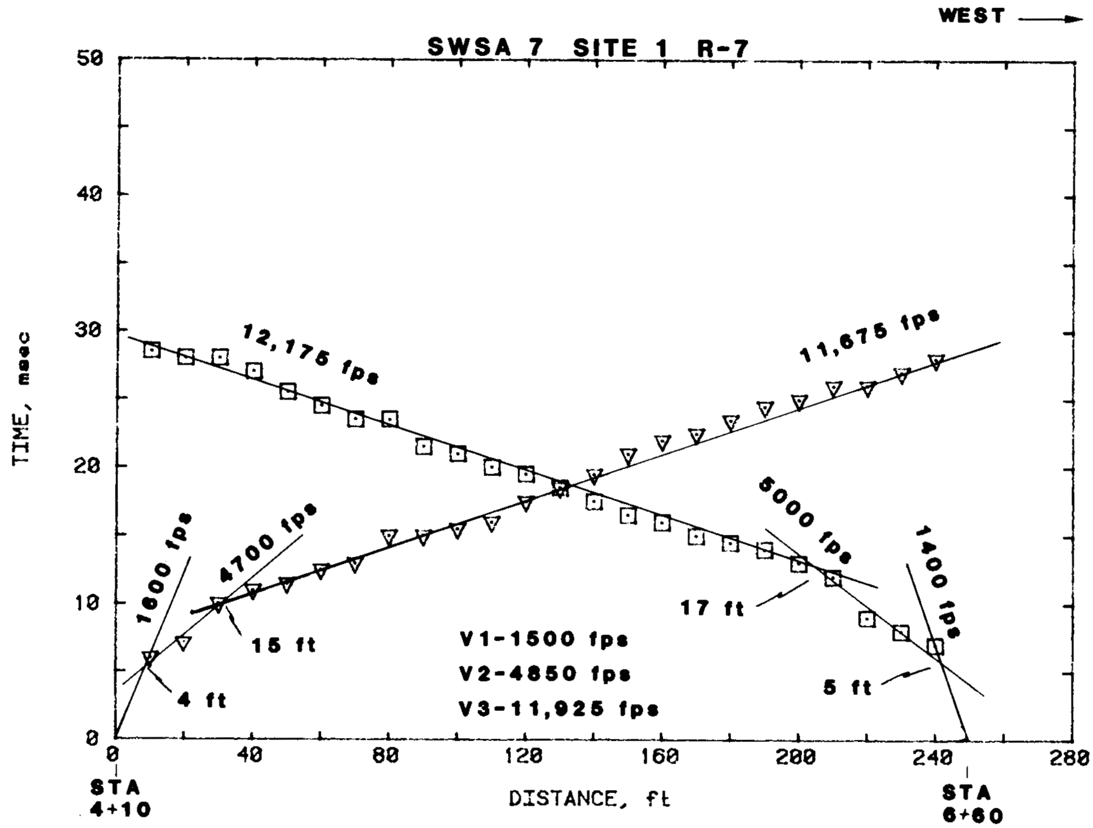
Seismic Refraction Line R-5, Site 3, SWSA-7

APPENDIX I (continued)



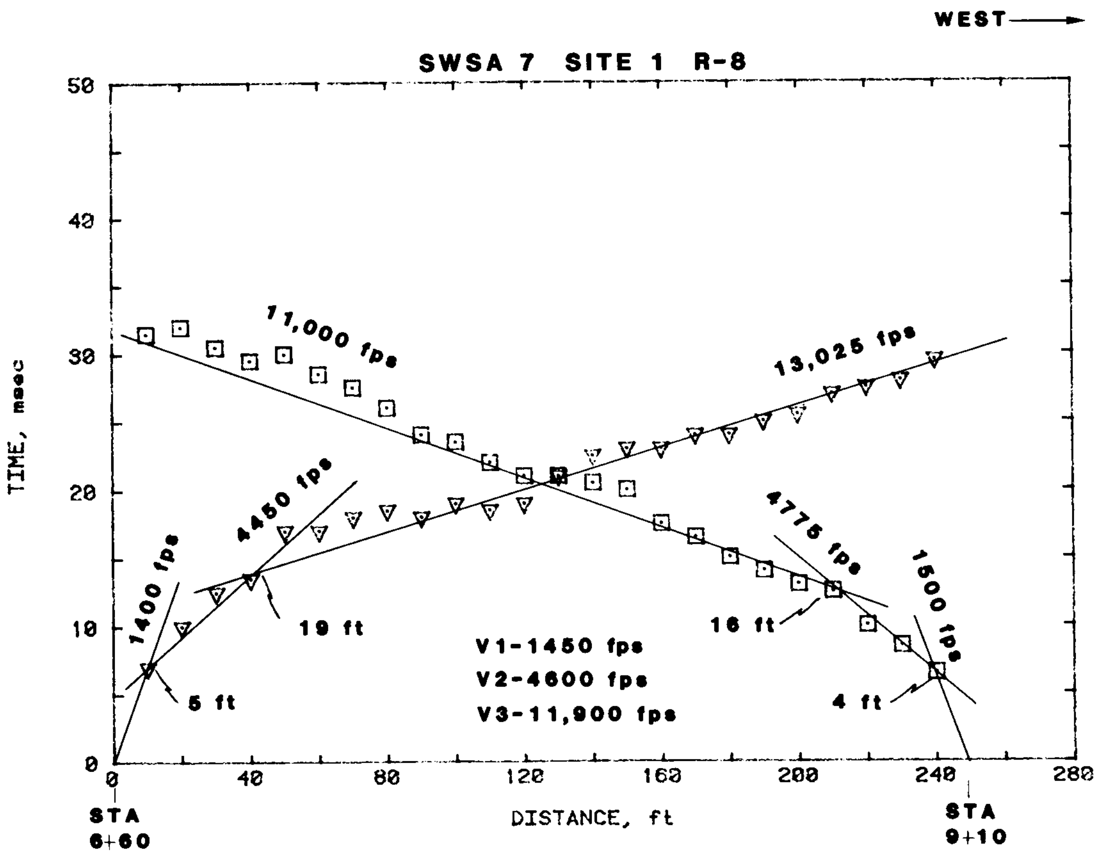
Seismic Refraction Line R-6, Site 3, SWSA-7

APPENDIX I (continued)



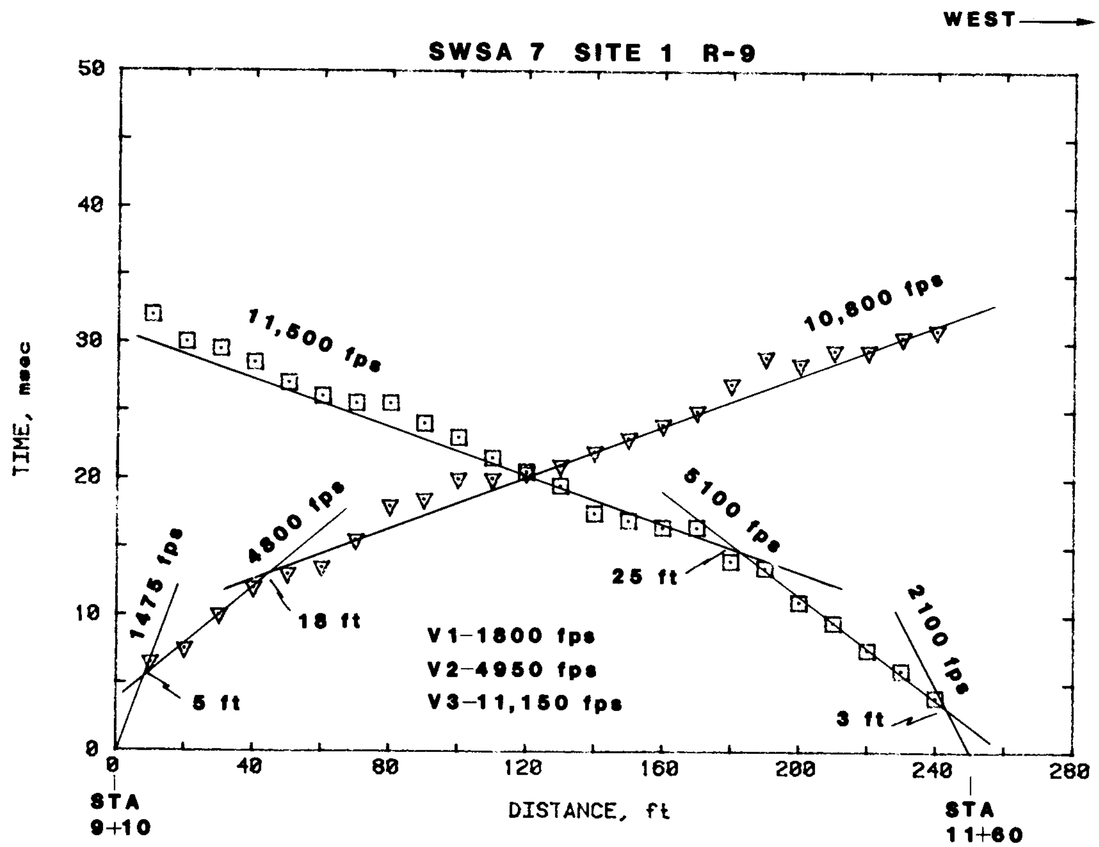
Seismic Refraction Line R-7, Site 1, SWSA-7

APPENDIX I (continued)



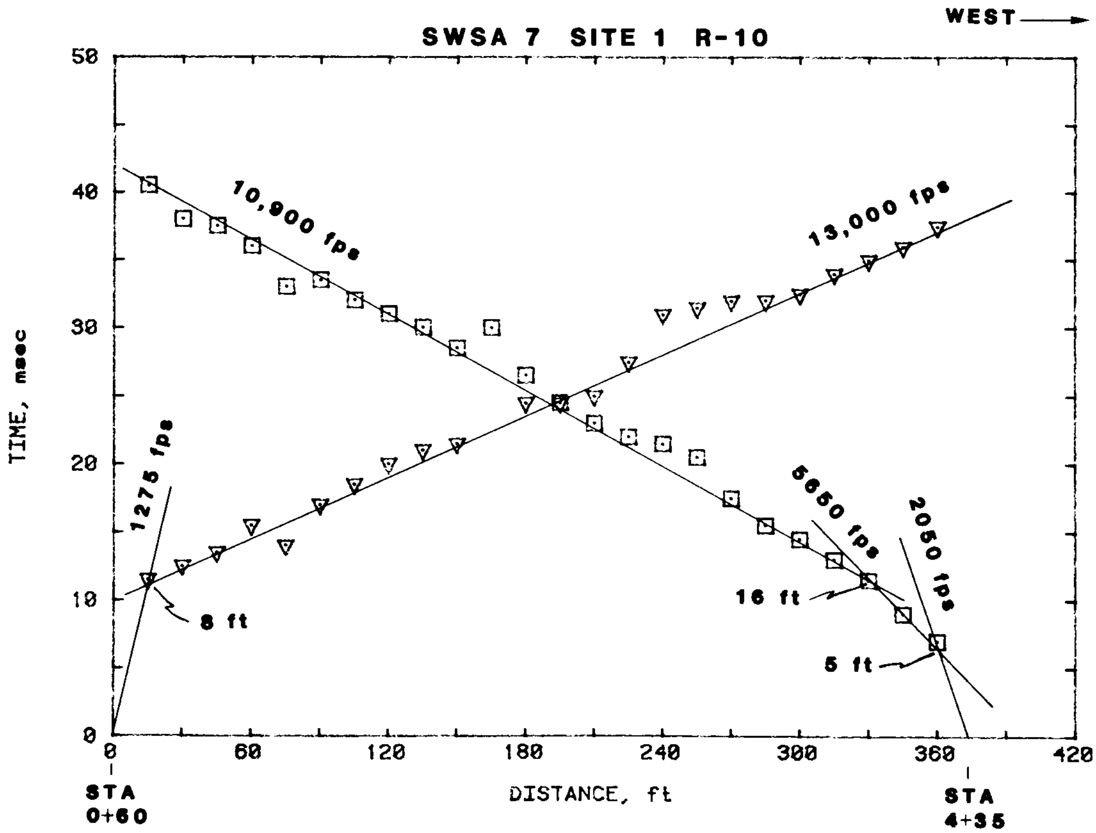
Seismic Refraction Line R-8, Site 1, SWSA-7

APPENDIX I (continued)



Seismic Refraction Line R-9, Site 1, SWSA-7

APPENDIX I (continued)



Seismic Refraction Line R-10, Site 1, SWSA-7

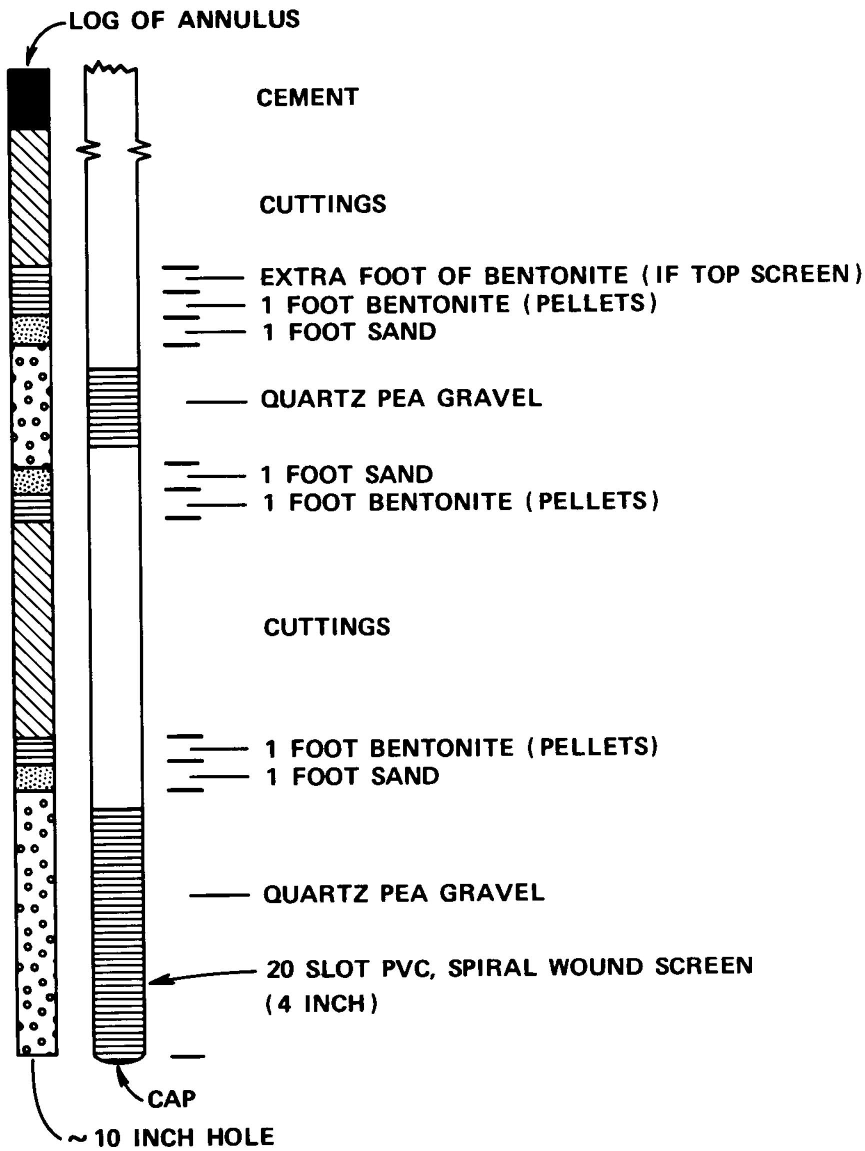
APPENDIX II

LITHOLOGIC AND GEOPHYSICAL WELL LOGS AND WELL COMPLETION DATA

APPENDIX II

LITHOLOGIC AND GEOPHYSICAL WELL LOGS AND WELL COMPLETION DATA

ORNL–DWG 84-1788

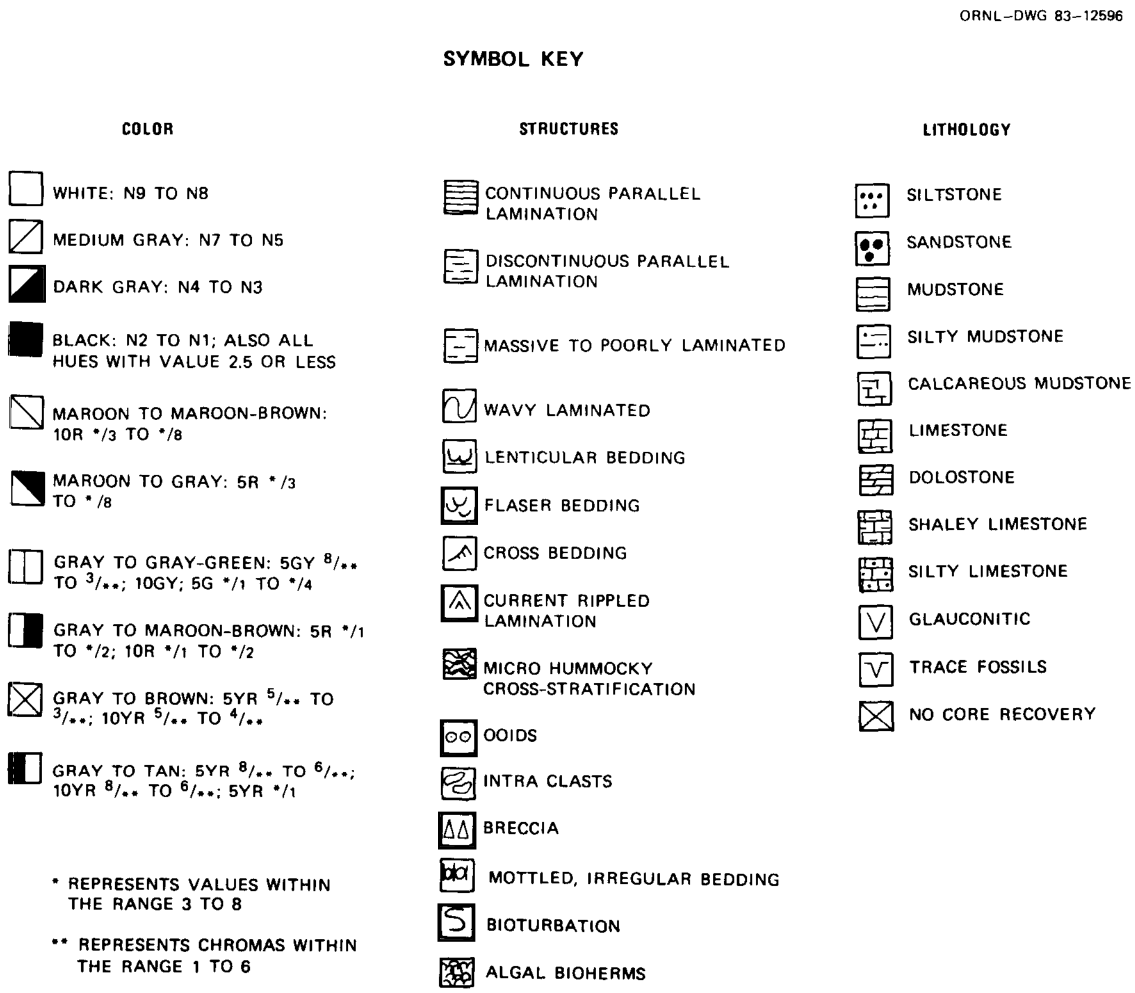


TYPE 1 – AS ABOVE

TYPE 2 – SEAL ABOVE SCREEN IS COMPOSED OF BENTONITE/CUTTINGS MIXTURE

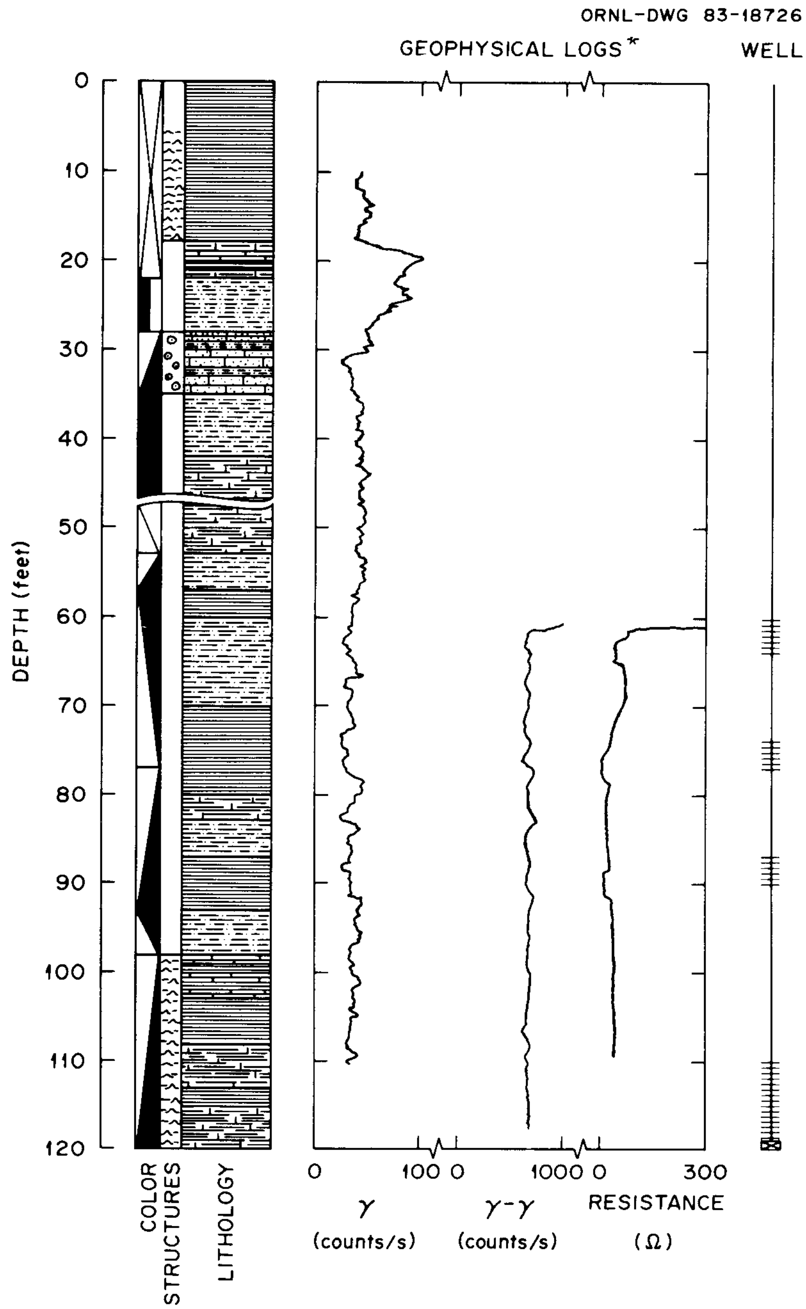
Monitoring Well Completion

APPENDIX II (continued)



Symbol Key

APPENDIX II (continued)

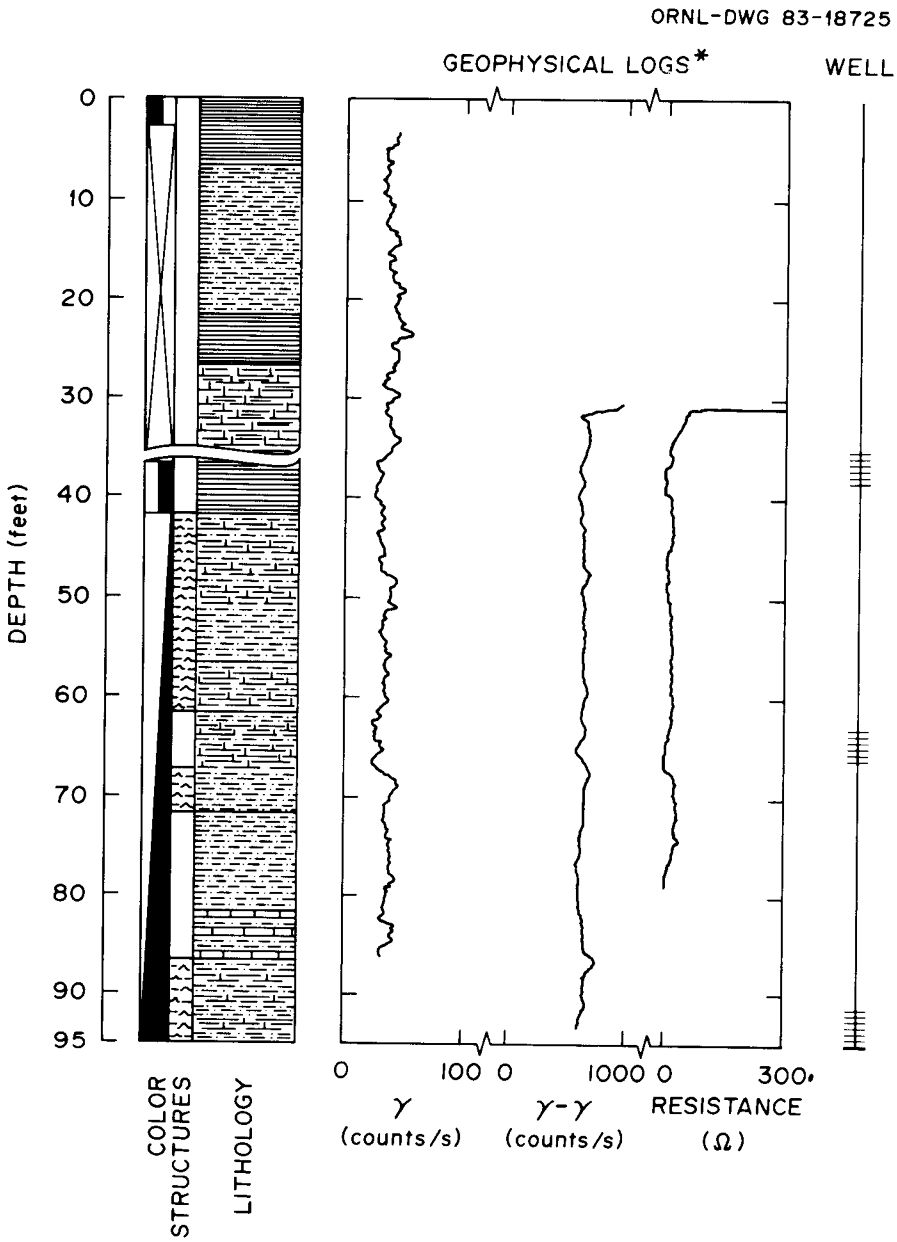


DRILLING DATA
DATE: 9-82
HOLE SIZE: 10"
DRILLING FLUID: AIR
CUTTINGS SAMPLED AT ~ 5' INTERVAL

WELL DATA
CASING: 4" SCH. 40 PVC
SCREEN(S): 20 SLOT PVC SPIRAL-WOUND
COMPLETION: TYPE 1 - SEE FIG.

Well 7-1 Geophysical Logs*

APPENDIX II (continued)



DRILLING DATA

DATE: 9-82

HOLE SIZE: 10"

DRILLING FLUID: AIR

CUTTINGS SAMPLED AT ~ 5' INTERVALS

WELL DATA

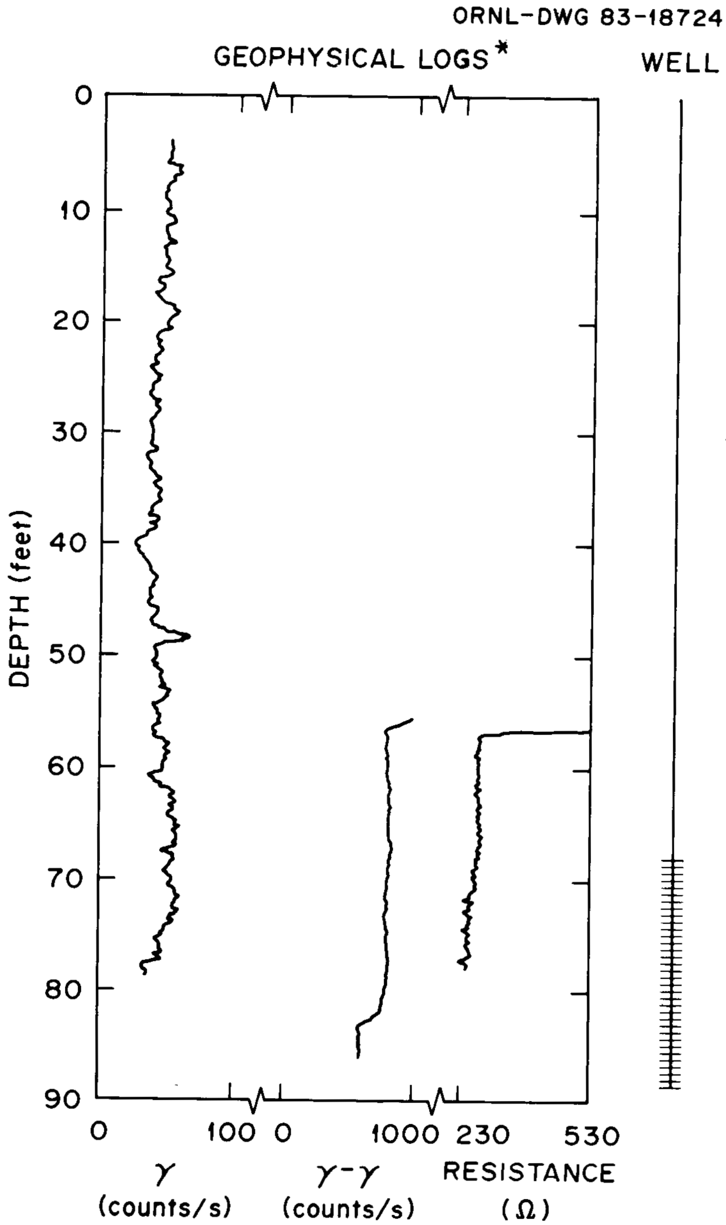
CASING: 4" SCH. 40 PVC

SCREEN(S): 20 SLOT PVC SPIRAL-WOUND

COMPLETION: TYPE 1-SEE FIG.

Well 7-2 Geophysical Logs*

APPENDIX II (continued)



DRILLING DATA

DATE: 6-82 (?)

HOLE SIZE: 6"

DRILLING FLUID: AIR

WELL DATA

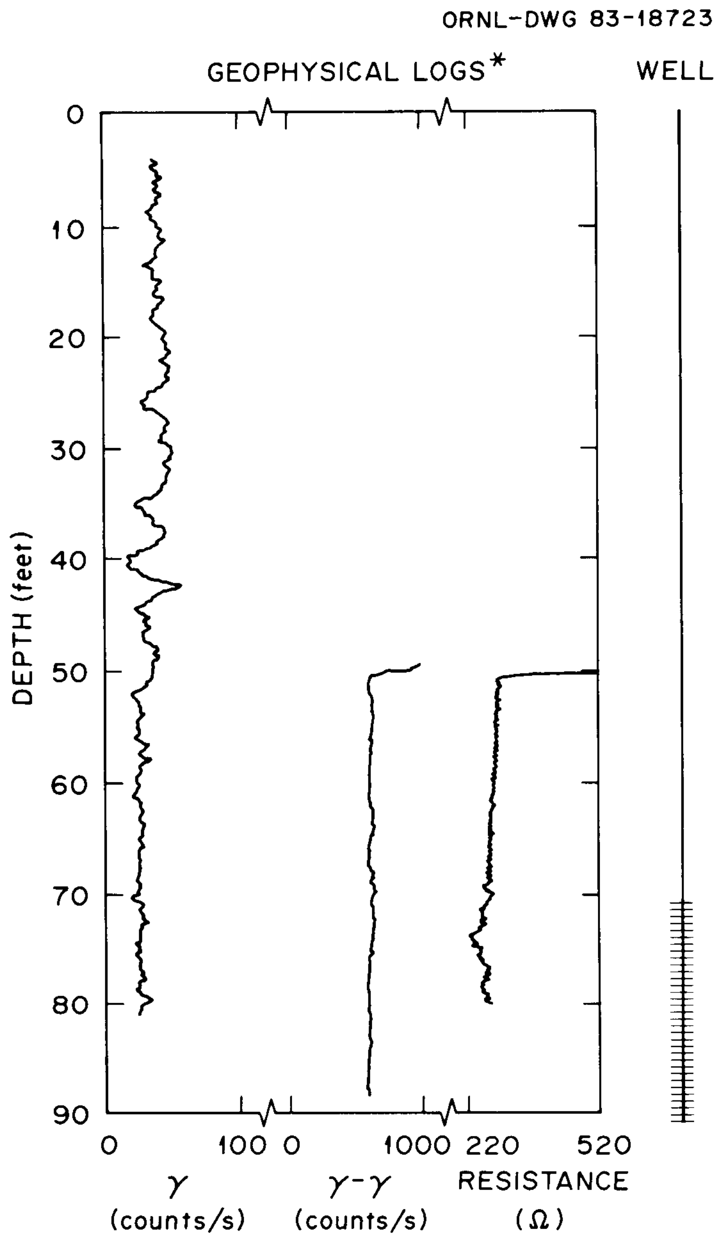
CASING: 4" SCH. 40 PVC

SCREEN(S): HAND-SLOTTED SCH. 40 PVC

COMPLETION: TYPE 2-SEE FIG.

Well 7-3

APPENDIX II (continued)



DRILLING DATA

DATE: 6-82

HOLE SIZE: 6"

DRILLING FLUID: AIR

WELL DATA

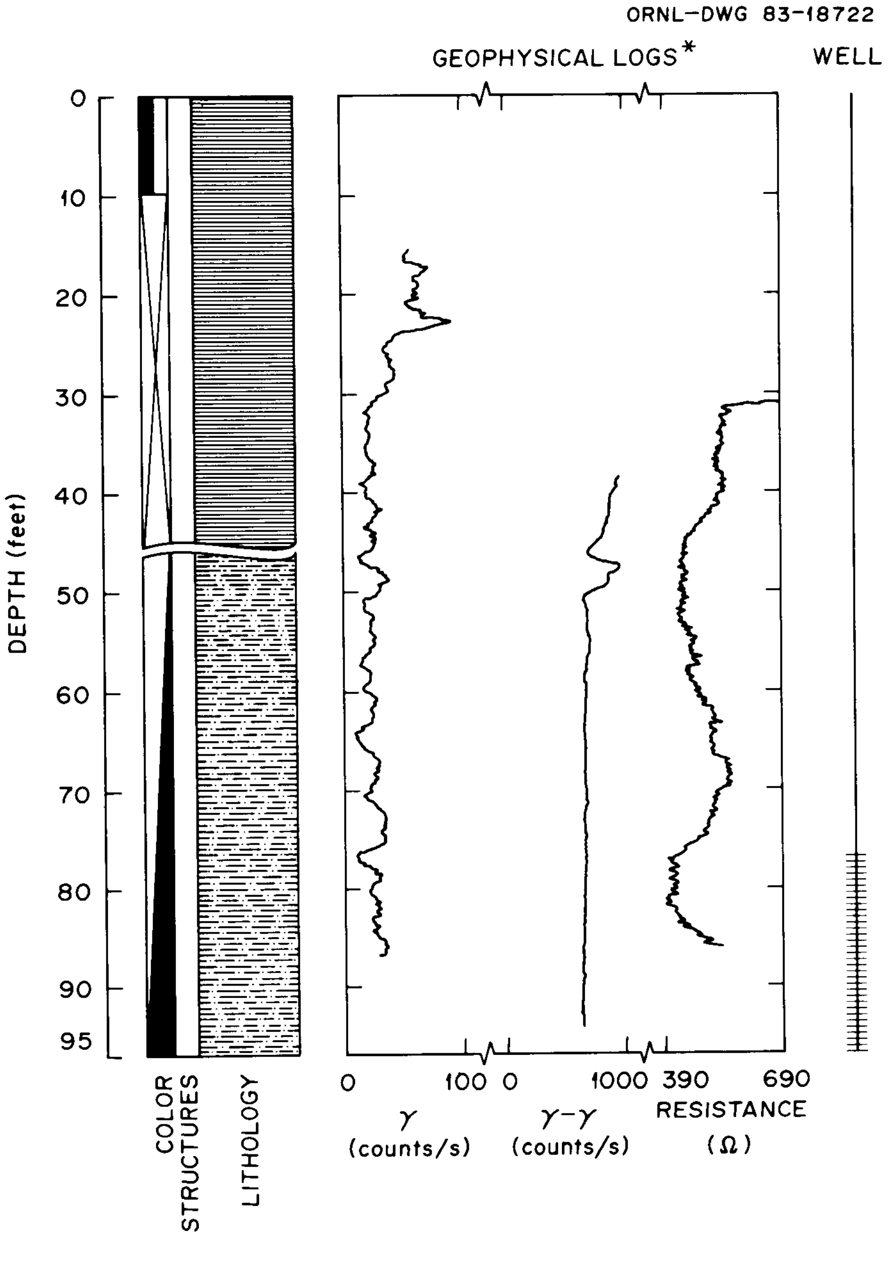
CASING: 4" SCH. 40 PVC

SCREEN(S): HAND-SLOTTED SCH. 40 PVC

COMPLETION: TYPE 2—SEE FIG.

Well 7-4

APPENDIX II (continued)

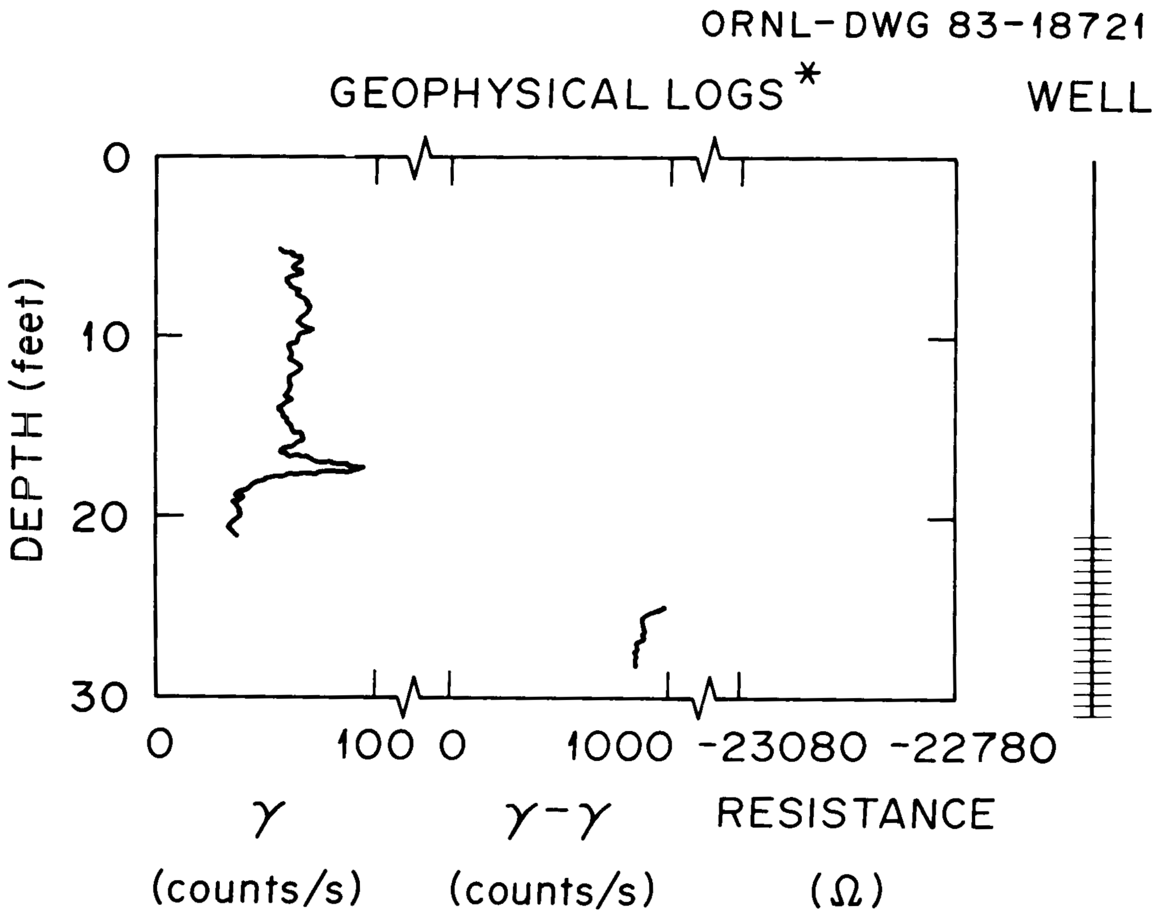


DRILLING DATA
- DATE: ~6-82
- HOLE SIZE: 6"
- DRILLING FLUID: AIR

WELL DATA
- CASING: 4" SCH. 40 PVC
- SCREEN(S): HAND-SLOTTED SCH. 40 PVC
- COMPLETION: TYPE 2 - SEE FIG.

Well 7-5

APPENDIX II (continued)



DRILLING DATA

DATE: 6-80 (?)

HOLE SIZE: 8"

DRILLING FLUID: WATER

WELL DATA

CASING: 6" SCH. 40 PVC

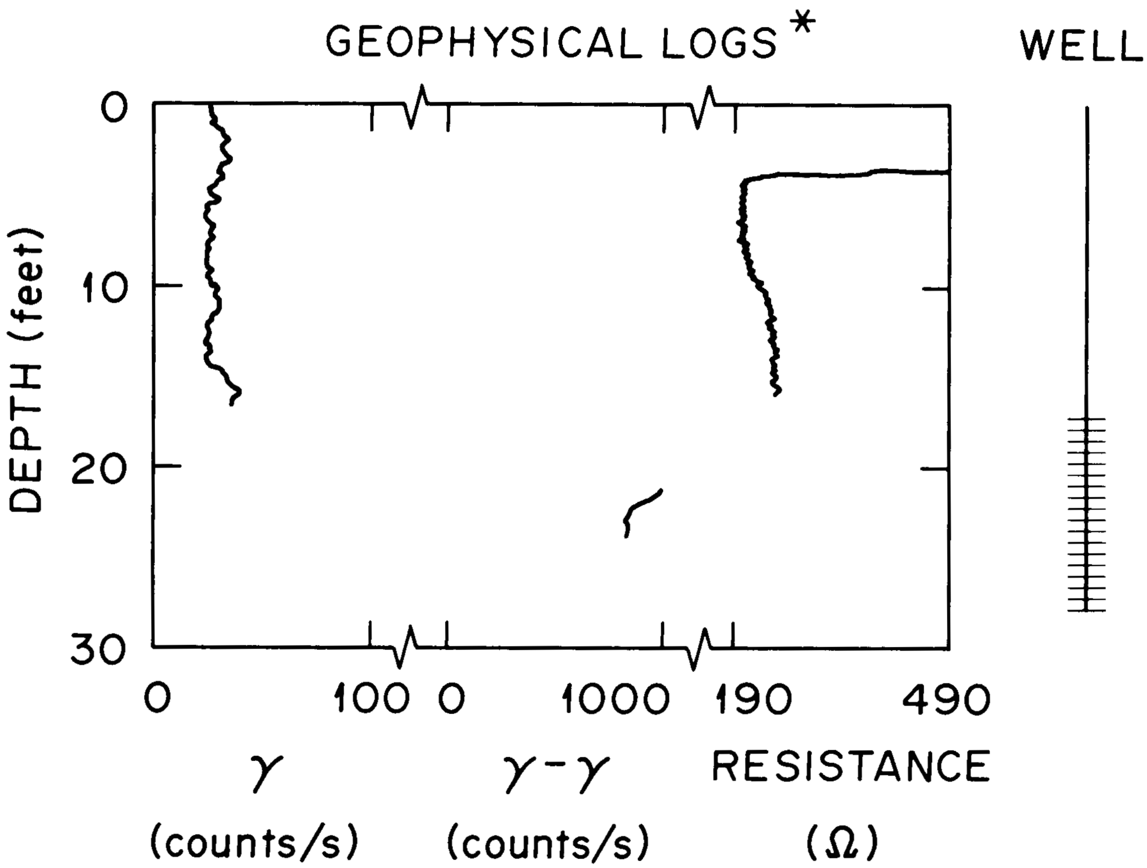
SCREEN(S): HAND-SLOTTED SCH. 40 PVC

COMPLETION: TYPE 2-SEE FIG.

Well 7-6

APPENDIX II (continued)

ORNL-DWG 83-18719



DRILLING DATA

DATE: 6-80 (?)

HOLE SIZE: 8"

DRILLING FLUID: WATER

WELL DATA

CASING: 6" SCH. 40 PVC

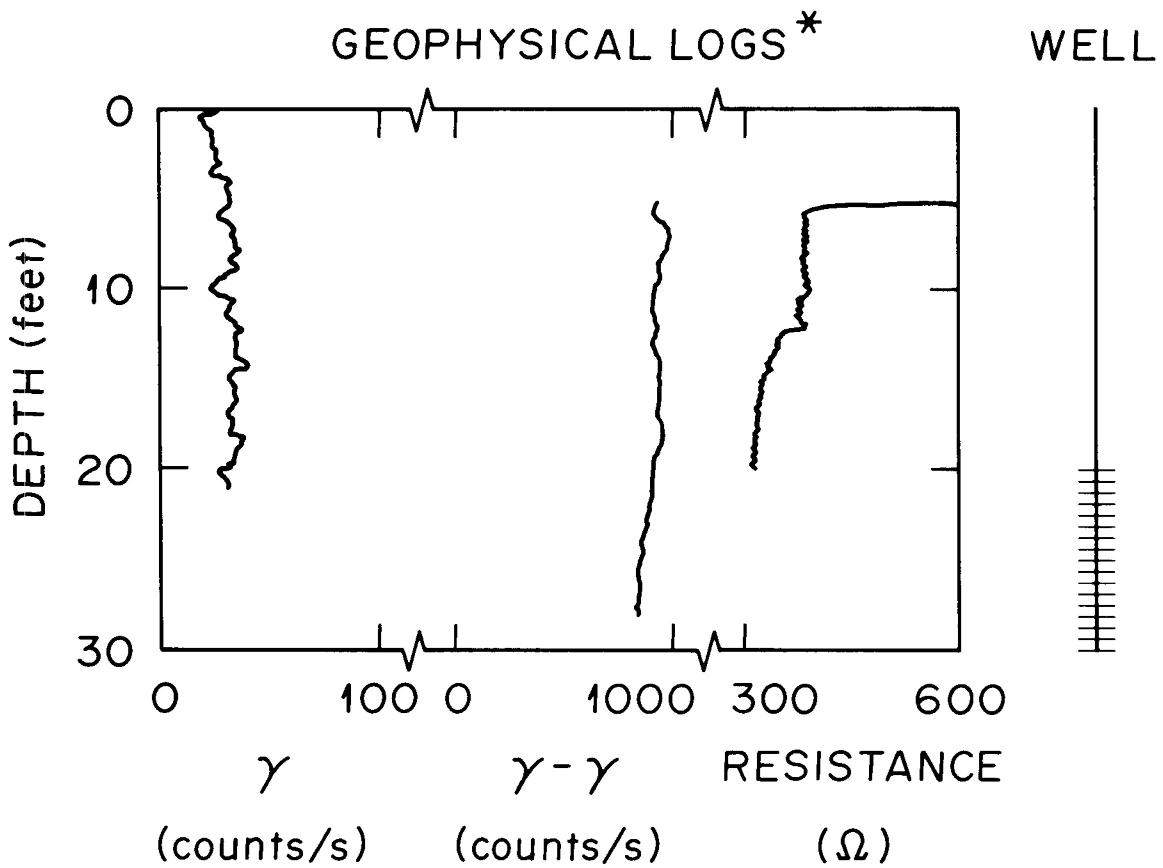
SCREEN(S): HAND-SLOTTED SCH. 40 PVC

COMPLETION: TYPE 2-SEE FIG.

Well 7-7

APPENDIX II (continued)

ORNL-DWG 83-18720



DRILLING DATA

DATE: 6-80(?)

HOLE SIZE: 8"

DRILLING FLUID: WATER

WELL DATA

CASING: 6" SCH. 40 PVC

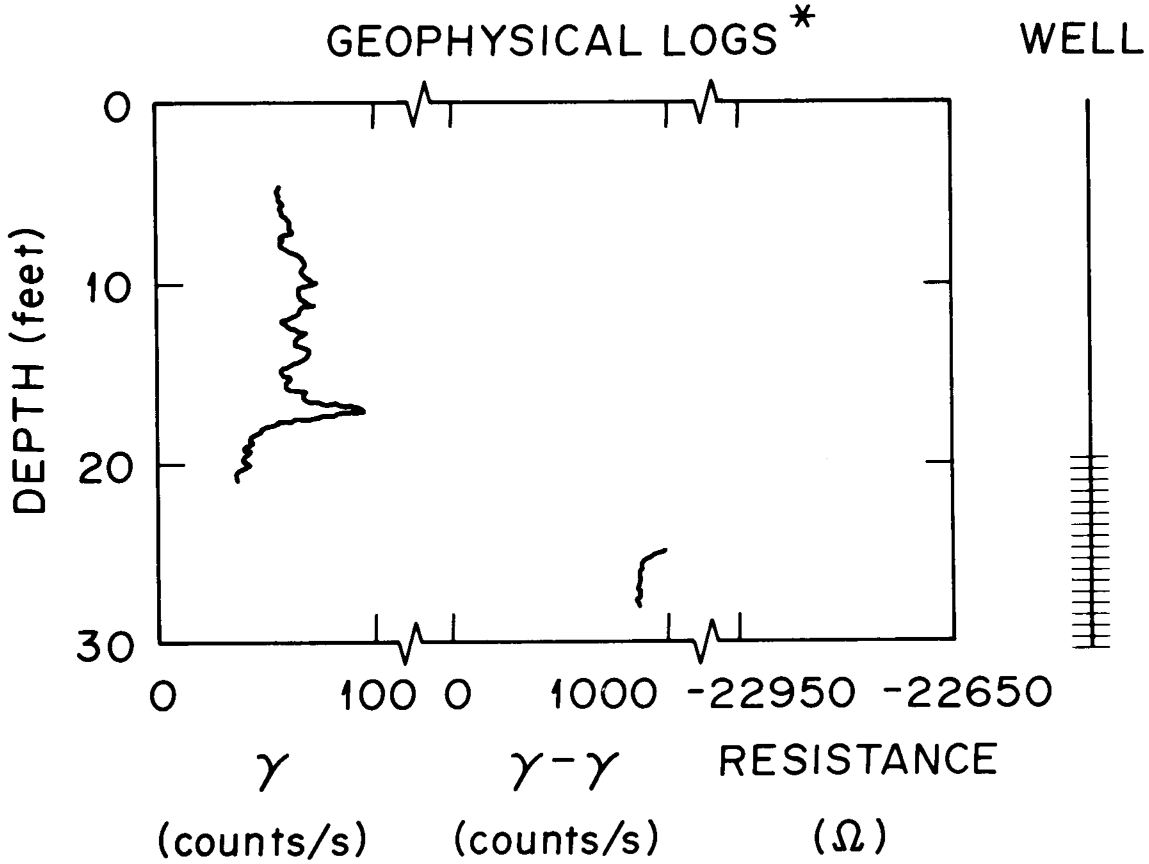
SCREEN(S): HAND-SLOTTED SCH. 40 PVC

COMPLETION: TYPE 2-SEE FIG.

Well 7-8

APPENDIX II (continued)

ORNL-DWG 83-18718



DRILLING DATA

DATE: 6-80 (?)

HOLE SIZE: 8"

DRILLING FLUID: WATER

WELL DATA

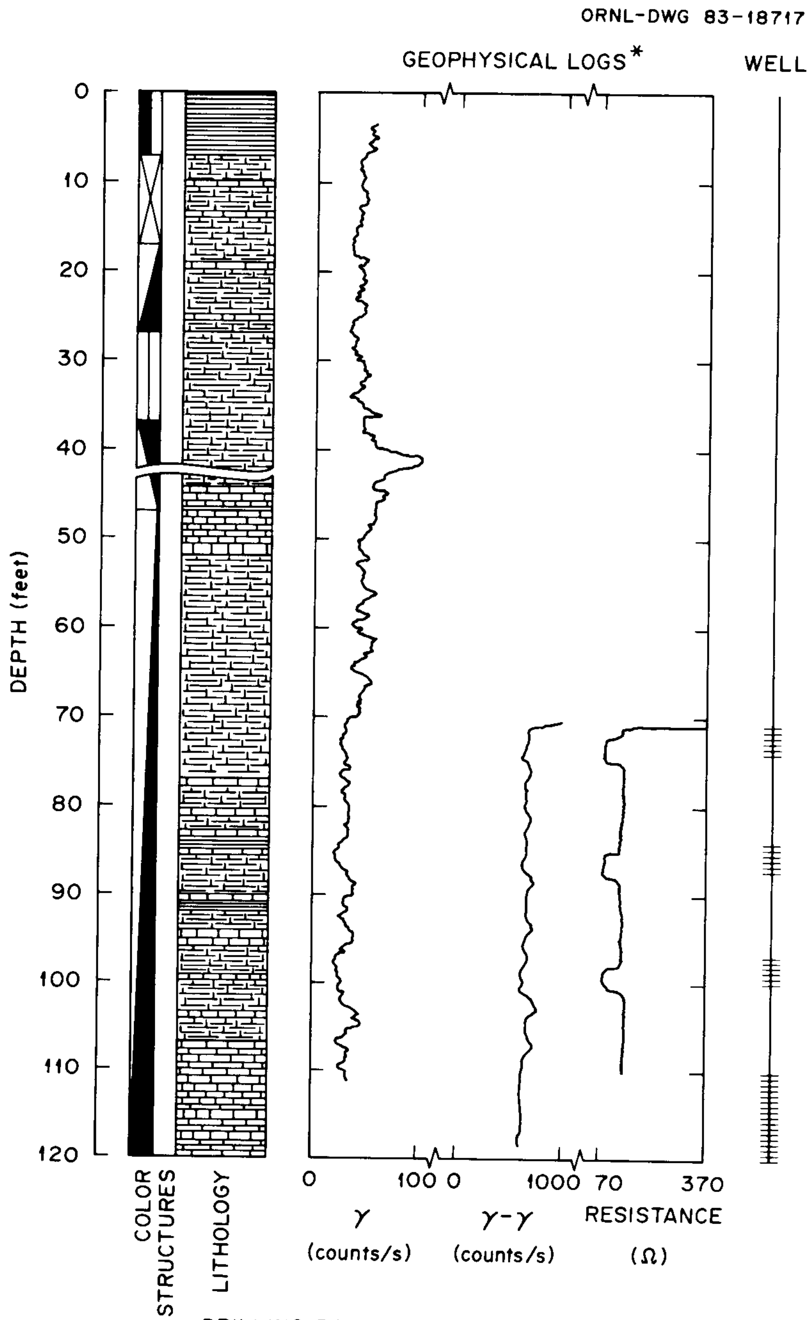
CASING: 6" SCH.40 PVC

SCREEN(S): HAND-SLOTTED SCH.40 PVC

COMPLETION: TYPE 2- SEE FIG.

Well 7-9

APPENDIX II (continued)

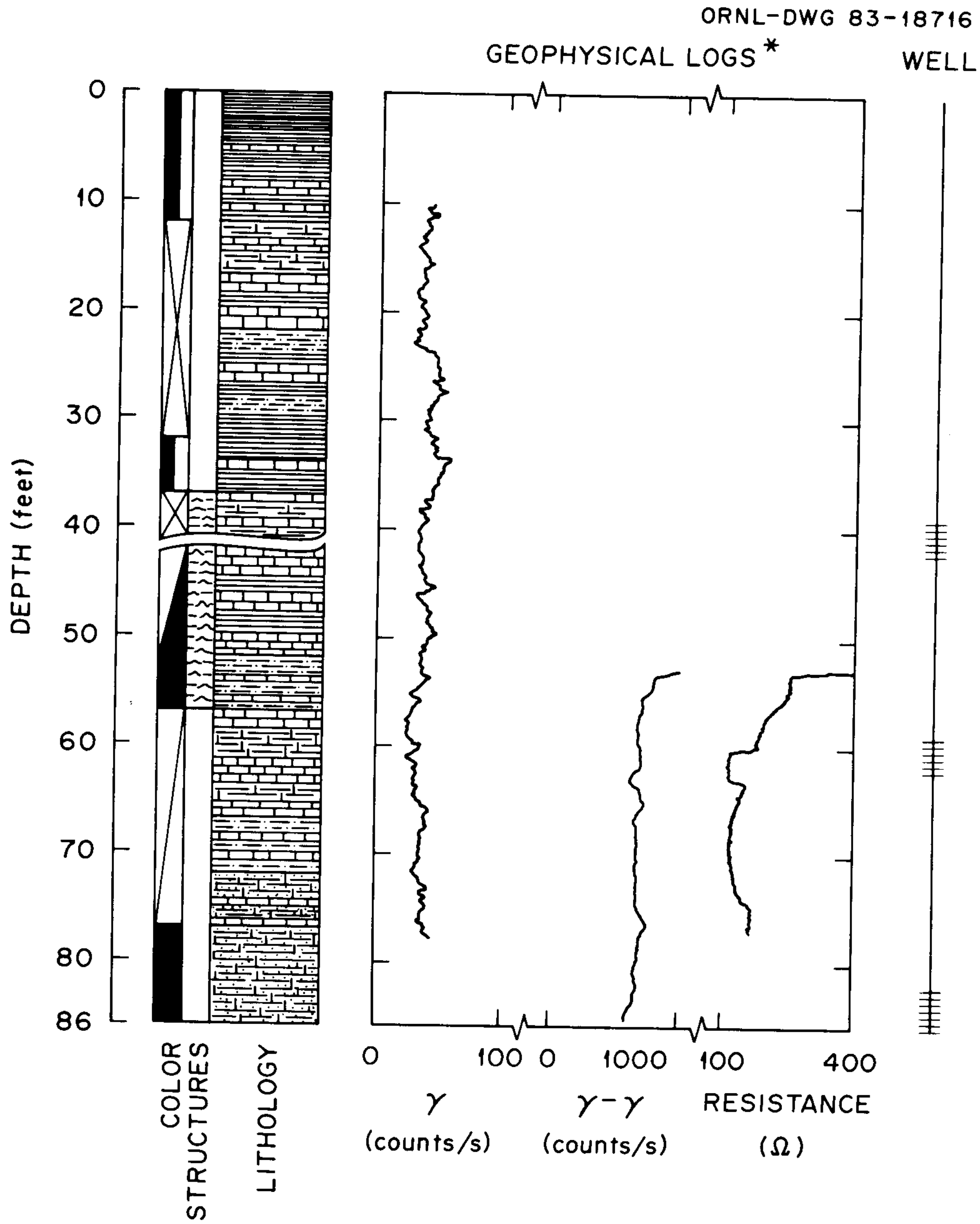


DRILLING DATA
- DATE: 9-82
- HOLE SIZE: 10"
- DRILLING FLUID: AIR
- CUTTINGS SAMPLED AT 5' INTERVALS

WELL DATA
- CASING: 4" SCH. 40 PVC
- SCREEN(S): 20 SLOT PVC SPIRAL-WOUND
- COMPLETION: TYPE 1-SEE FIG.

Well 7-10

APPENDIX II (continued)



DRILLING DATA

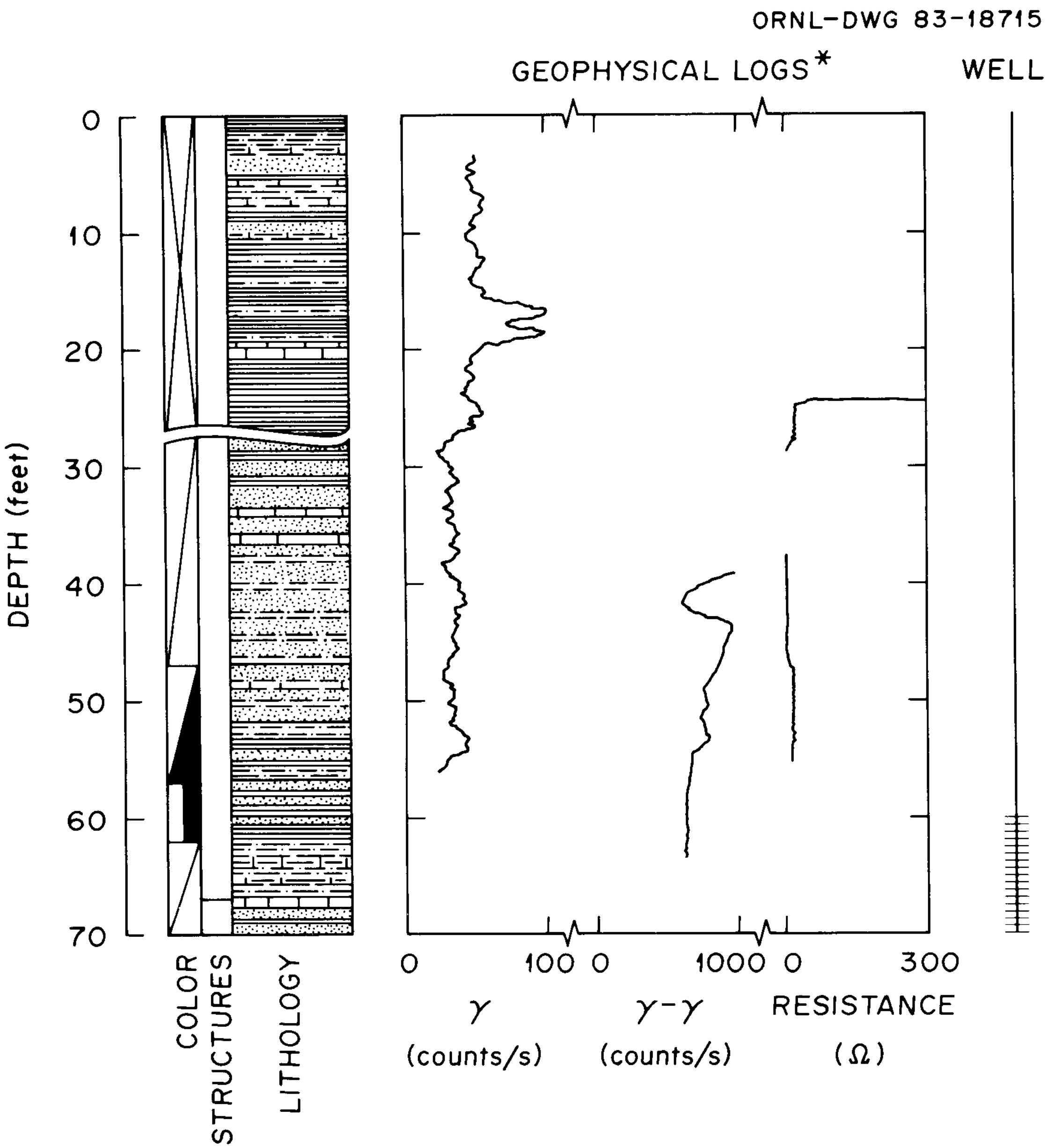
DATE: 9-82
HOLE SIZE: 10"
DRILLING FLUID: AIR
CUTTINGS SAMPLED AT 5' INTERVALS

WELL DATA

CASING: 4" SCH. 40 PVC
SCREEN(S): 20 SLOT PVC SPIRAL-WOUND
COMPLETION: TYPE 1-SEE FIG.

Well 7-11

APPENDIX II (continued)



DRILLING DATA

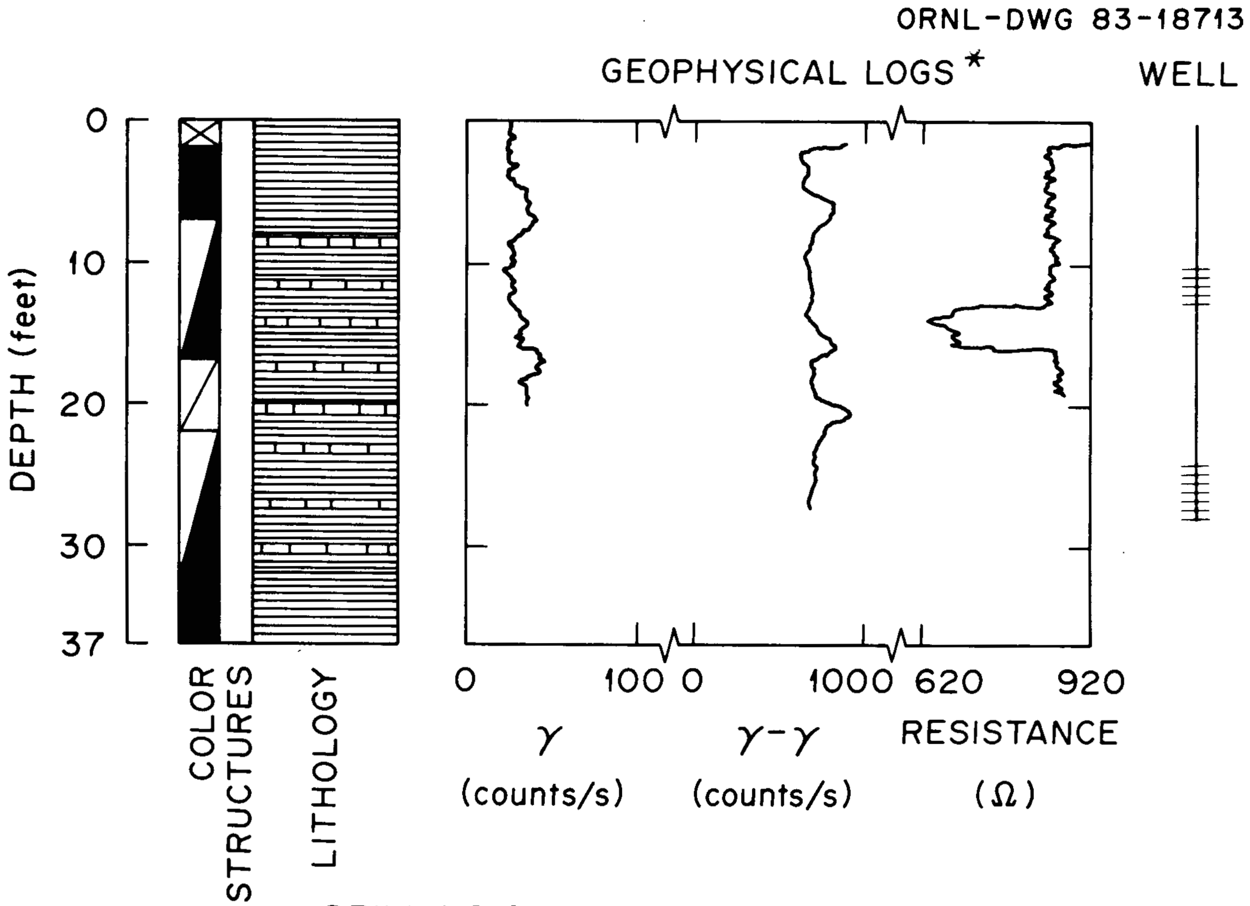
DATE: 9-82
HOLE SIZE: 10"
DRILLING FLUID: AIR
CUTTINGS SAMPLED AT ~ 5' INTERVALS

WELL DATA

CASING: 4" SCH. 40 PVC
SCREEN(S): 20 SLOT PVC SPIRAL-WOUND
COMPLETION: TYPE 1 - SEE FIG.

Well 7-12

APPENDIX II (continued)



DRILLING DATA

DATE: 9-82

HOLE SIZE: 10"

DRILLING FLUID: AIR

CUTTINGS SAMPLED AT 5' INTERVALS

WELL DATA

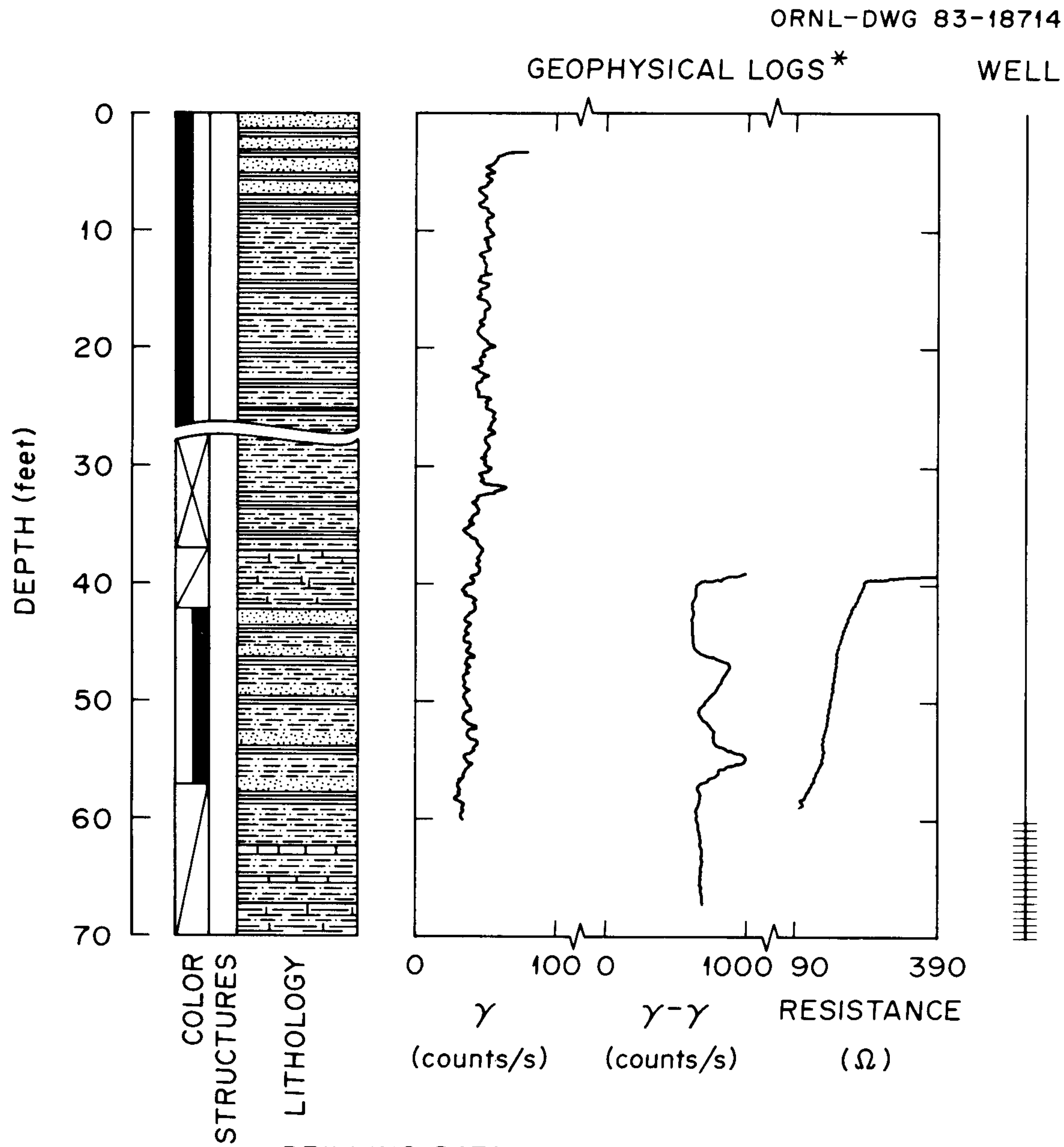
CASING: 4" SCH. 40 PVC

SCREEN(S): 20 SLOT PVC SPIRAL-WOUND

COMPLETION: TYPE 1 - SEE FIG.

Well 7-13

APPENDIX II (continued)



DRILLING DATA

DATE: 9-82

HOLE SIZE: 10"

DRILLING FLUID: AIR

CUTTINGS SAMPLED AT ~ 5' INTERVALS

WELL DATA

CASING: 4" SCH. 40 PVC

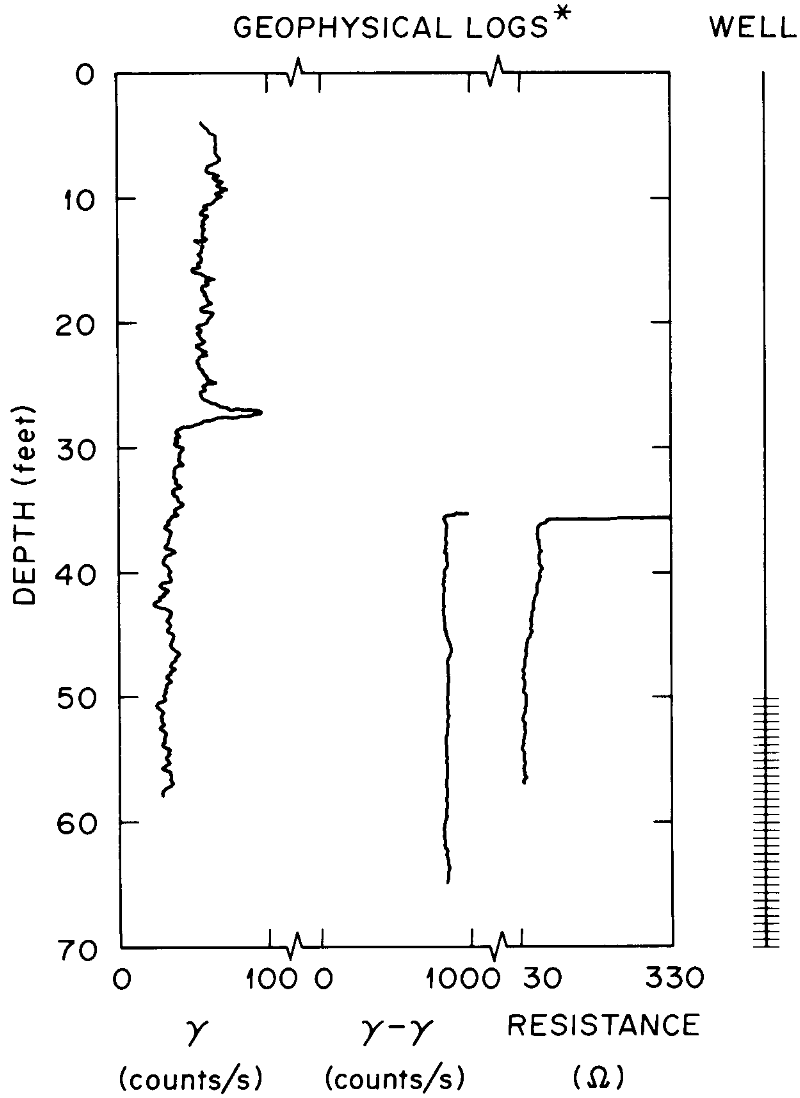
SCREEN(S): 20 SLOT PVC SPIRAL-WOUND

COMPLETION: TYPE 1-SEE FIG.

Well 7-14

APPENDIX II (continued)

ORNL-DWG 83-18712



DRILLING DATA

DATE: 4-83

HOLE SIZE: 8"

DRILLING FLUID: AIR

WELL DATA

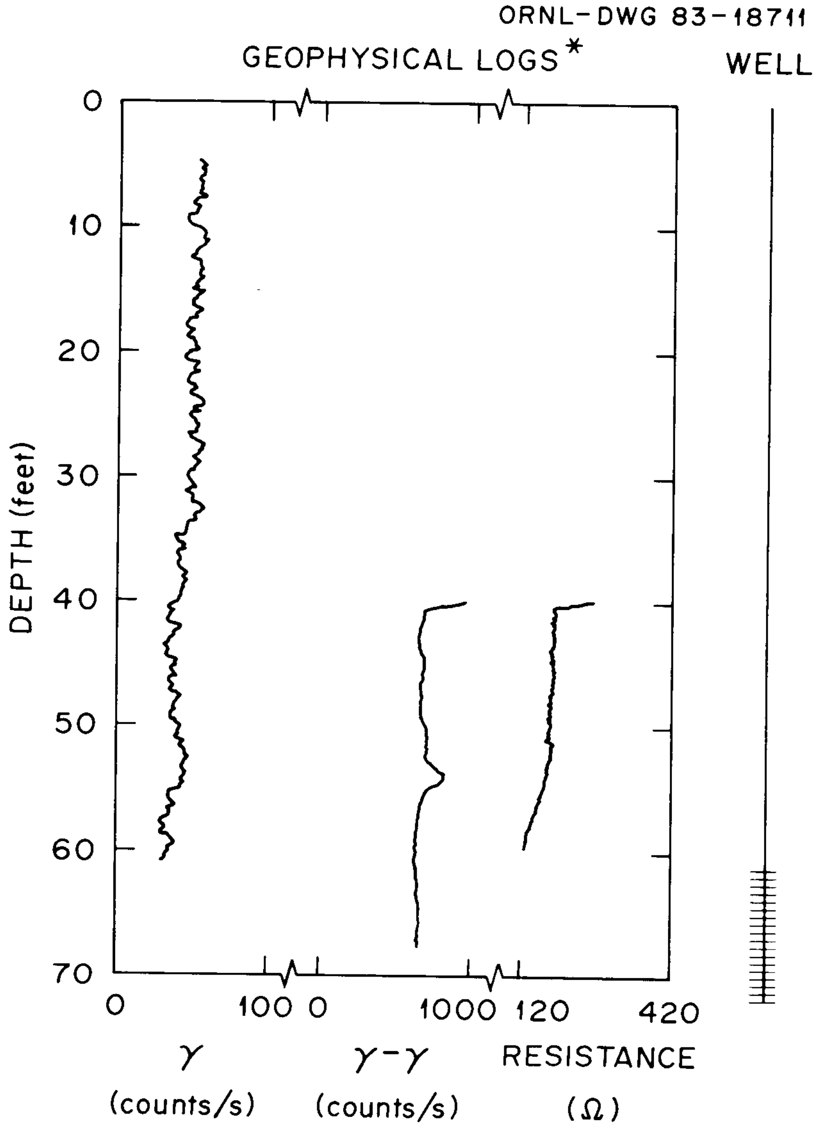
CASING: 6" SCH. 40 PVC

SCREEN(S): HAND-SLOTTED SCH. 40 PVC

COMPLETION: TYPE 1-SEE FIG.

Well 7-15

APPENDIX II (continued)



DRILLING DATA

DATE: 4-83

HOLE SIZE: 8"

DRILLING FLUID: AIR

WELL DATA

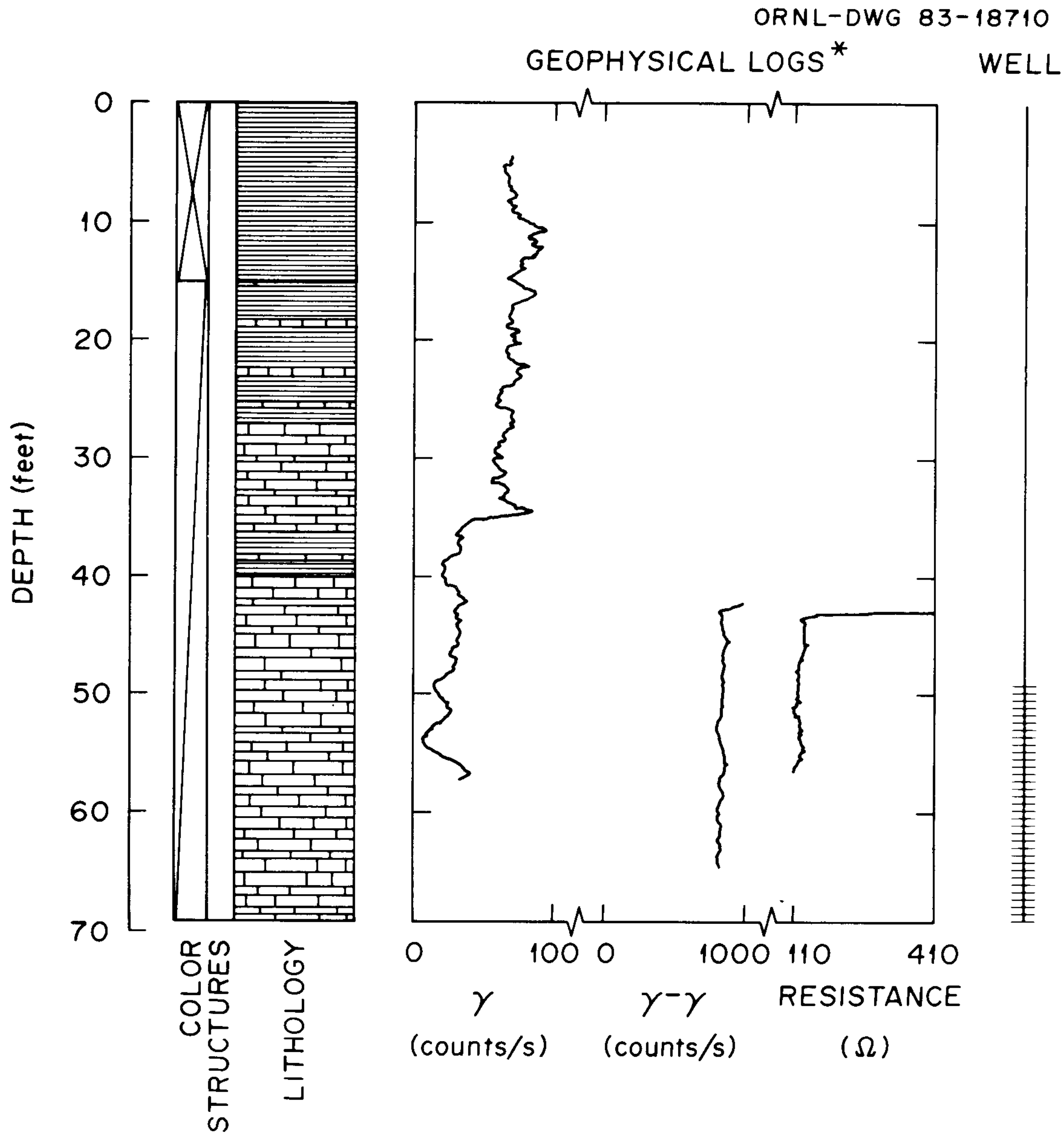
CASING: 4" SCH. 40 PVC

SCREEN(S): HAND-SLOTTED SCH. 40 PVC

COMPLETION: TYPE 1 — SEE FIG.

Well 7-16

APPENDIX II (continued)



DRILLING DATA

DATE: 3-83

HOLE SIZE: 8"

DRILLING FLUID: AIR

WELL DATA

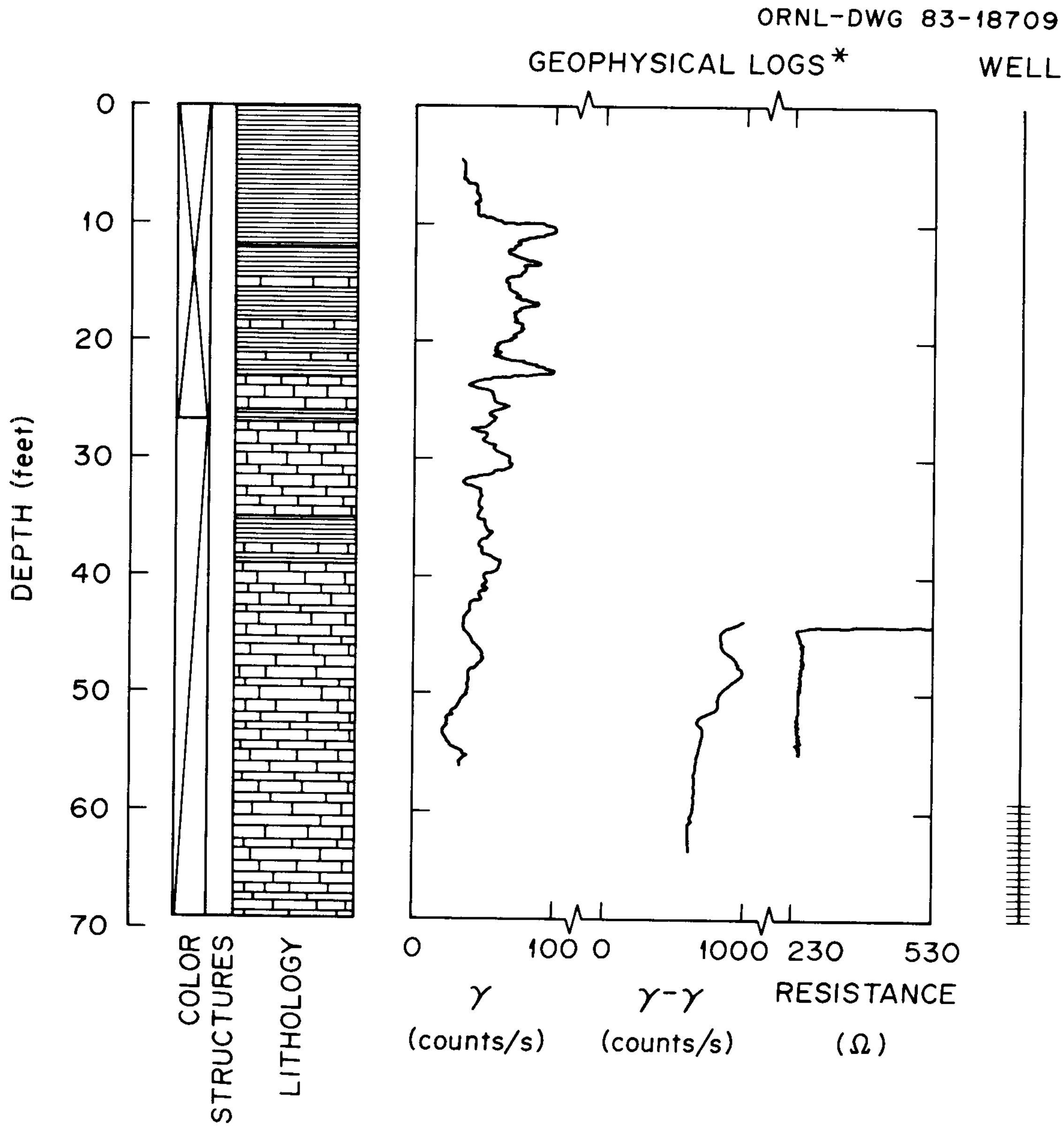
CASING: 6" SCH. 40 PVC

SCREEN(S): HAND-SLOTTED SCH. 40 PVC

COMPLETION: TYPE 1-SEE FIG.

Well 7-17

APPENDIX II (continued)



DRILLING DATA

DATE: 3-83

HOLE SIZE: 8"

DRILLING FLUID: AIR

WELL DATA

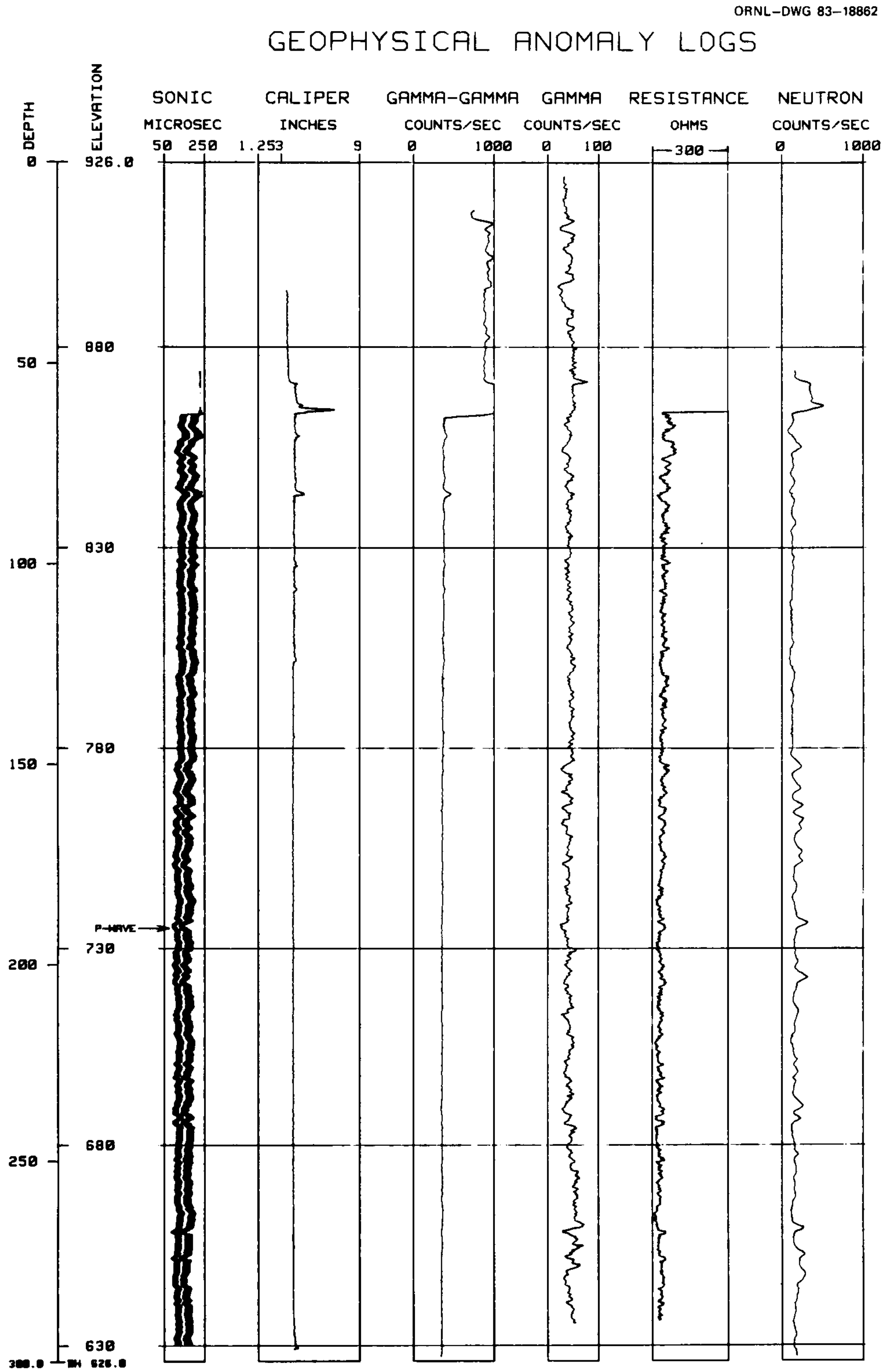
CASING: 4" SCH. 40 PVC

SCREEN(S): HAND-SLOTTED SCH. 40 PVC

COMPLETION: TYPE 1-SEE FIG.

Well 7-18

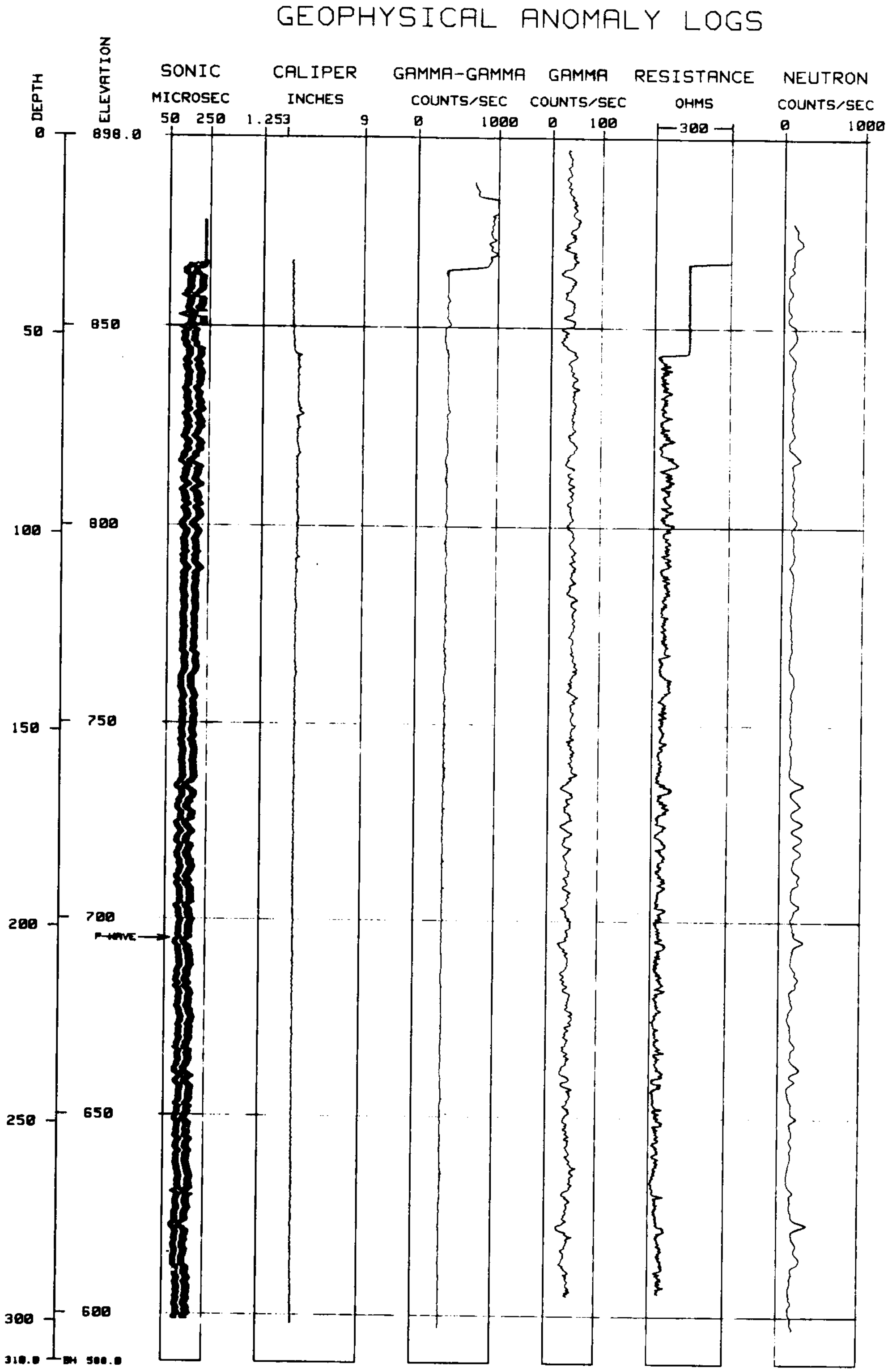
APPENDIX II (continued)



Corehole C1

APPENDIX II (continued)

ORNL-DWG 84-1300

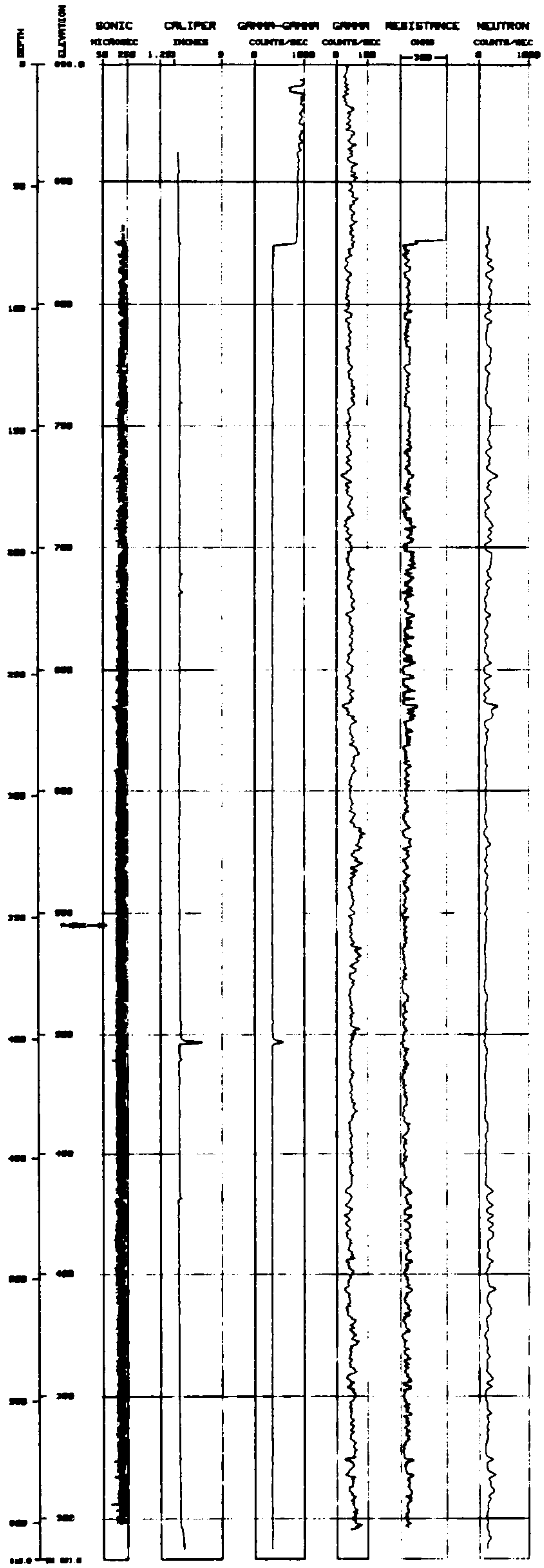


Corehole C2

APPENDIX II (continued)

ORNL-DWG 83-18861

GEOPHYSICAL ANOMALY LOGS



Corehole C3

APPENDIX III

MONTHLY SUMMARIES OF HYDROLOGIC CONDITIONS

APPENDIX III

MONTHLY SUMMARIES OF HYDROLOGIC CONDITIONS

SITE: SWSA-7
MONTH AND YEAR: January 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
1/01/1983	223.67
1/02/1983	218.48
1/03/1983	227.16
1/04/1983	212.36
1/05/1983	197.24
1/06/1983	189.25
1/07/1983	178.99
1/08/1983	159.77
1/09/1983	186.62
1/10/1983	251.71
1/11/1983	274.28
1/12/1983	277.20
1/13/1983	259.13
1/14/1983	270.18
1/15/1983	254.41
1/16/1983	231.05
1/17/1983	167.18
1/18/1983	155.52
1/19/1983	150.84
1/20/1983	157.93
1/21/1983	244.01
1/22/1983	222.91
1/23/1983	189.94
1/24/1983	172.80
1/25/1983	177.98
1/26/1983	183.31
1/27/1983	163.62
1/28/1983	159.88
1/29/1983	167.29
1/30/1983	189.25
1/31/1983	213.34
MONTHLY TOTAL	6327.30

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: February 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
2/01/1983	356.47
2/02/1983	4045.64
2/03/1983	771.12
2/04/1983	412.63
2/05/1983	323.03
2/06/1983	407.92
2/07/1983	512.82
2/08/1983	577.30
2/09/1983	435.64
2/10/1983	1493.93
2/11/1983	2182.14
2/12/1983	689.94
2/13/1983	426.02
2/14/1983	316.12
2/15/1983	271.76
2/16/1983	216.79
2/17/1983	173.45
2/18/1983	164.02
2/19/1983	157.28
2/20/1983	142.56
2/21/1983	138.24
2/22/1983	198.00
2/23/1983	287.10
2/24/1983	292.25
2/25/1983	272.70
2/26/1983	216.00
2/27/1983	154.04
2/28/1983	145.22
MONTHLY TOTAL	15780.13

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: March 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
3/01/1983	123.48
3/02/1983	114.30
3/03/1983	99.40
3/04/1983	95.29
3/05/1983	110.66
3/06/1983	271.55
3/07/1983	173.74
3/08/1983	189.25
3/09/1983	154.26
3/10/1983	145.22
3/11/1983	132.73
3/12/1983	113.51
3/13/1983	79.09
3/14/1983	70.60
3/15/1983	73.98
3/16/1983	76.54
3/17/1983	72.43
3/18/1983	79.92
3/19/1983	72.07
3/20/1983	210.92
3/21/1983	518.47
3/22/1983	196.16
3/23/1983	111.96
3/24/1983	88.24
3/25/1983	63.43
3/26/1983	48.71
3/27/1983	254.77
3/28/1983	153.32
3/29/1983	91.01
3/30/1983	62.39
3/31/1983	78.98
MONTHLY TOTAL	4126.38

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: April 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
4/01/1983	131.47
4/02/1983	252.76
4/03/1983	203.44
4/04/1983	169.56
4/05/1983	9798.41
4/06/1983	1862.17
4/07/1983	562.86
4/08/1983	440.17
4/09/1983	2374.56
4/10/1983	776.02
4/11/1983	409.32
4/12/1983	319.79
4/13/1983	262.69
4/14/1983	232.38
4/15/1983	198.29
4/16/1983	179.71
4/17/1983	162.04
4/18/1983	217.98
4/19/1983	196.81
4/20/1983	177.19
4/21/1983	170.68
4/22/1983	188.96
4/23/1983	680.72
4/24/1983	599.94
4/25/1983	335.88
4/26/1983	261.76
4/27/1983	203.65
4/28/1983	178.49
4/29/1983	164.12
4/30/1983	158.22
MONTHLY TOTAL	21870.04

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: May 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
5/01/1983	150.08
5/02/1983	139.18
5/03/1983	239.98
5/04/1983	156.17
5/05/1983	126.14
5/06/1983	111.10
5/07/1983	94.64
5/08/1983	469.51
5/09/1983	235.76
5/10/1983	173.77
5/11/1983	155.27
5/12/1983	140.72
5/13/1983	197.53
5/14/1983	164.48
5/15/1983	188.50
5/16/1983	272.66
5/17/1983	185.40
5/18/1983	136.58
5/19/1983	1063.55
5/20/1983	1190.16
5/21/1983	3505.07
5/22/1983	1937.88
5/23/1983	922.28
5/24/1983	445.64
5/25/1983	231.98
5/26/1983	182.59
5/27/1983	146.20
5/28/1983	129.10
5/29/1983	134.46
5/30/1983	111.42
5/31/1983	109.15
MONTHLY TOTAL	13446.95

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: June 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
6/01/1983	85.28
6/02/1983	74.95
6/03/1983	66.46
6/04/1983	329.76
6/05/1983	89.14
6/06/1983	84.67
6/07/1983	102.24
6/08/1983	84.74
6/09/1983	73.58
6/10/1983	58.97
6/11/1983	47.81
6/12/1983	37.84
6/13/1983	43.92
6/14/1983	55.80
6/15/1983	67.64
6/16/1983	71.60
6/17/1983	87.52
6/18/1983	118.98
6/19/1983	94.79
6/20/1983	76.54
6/21/1983	49.00
6/22/1983	93.06
6/23/1983	68.08
6/24/1983	48.67
6/25/1983	39.96
6/26/1983	48.85
6/27/1983	62.82
6/28/1983	72.14
6/29/1983	47.70
6/30/1983	34.78
MONTHLY TOTAL	2317.29

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: July 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
7/01/1983	34.56
7/02/1983	34.56
7/03/1983	34.56
7/04/1983	38.63
7/05/1983	42.62
7/06/1983	40.18
7/07/1983	33.70
7/08/1983	34.49
7/09/1983	28.87
7/10/1983	18.22
7/11/1983	17.57
7/12/1983	21.46
7/13/1983	19.55
7/14/1983	8.42
7/15/1983	17.32
7/16/1983	11.88
7/17/1983	8.64
7/18/1983	18.90
7/19/1983	44.78
7/20/1983	25.42
7/21/1983	20.41
7/22/1983	14.15
7/23/1983	7.96
7/24/1983	4.32
7/25/1983	33.34
7/26/1983	23.83
7/27/1983	14.98
7/28/1983	0.00
7/29/1983	0.00
7/30/1983	0.00
7/31/1983	13.64
MONTHLY TOTAL	666.96

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: August 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
8/01/1983	19.26
8/02/1983	22.54
8/03/1983	24.12
8/04/1983	16.96
8/05/1983	9.94
8/06/1983	3.02
8/07/1983	0.00
8/08/1983	0.00
8/09/1983	0.00
8/10/1983	0.00
8/11/1983	12.38
8/12/1983	17.28
8/13/1983	17.28
8/14/1983	17.28
8/15/1983	17.28
8/16/1983	17.28
8/17/1983	17.21
8/18/1983	17.28
8/19/1983	17.28
8/20/1983	17.28
8/21/1983	17.28
8/22/1983	17.28
8/23/1983	17.28
8/24/1983	17.28
8/25/1983	17.28
8/26/1983	11.63
8/27/1983	3.46
8/28/1983	22.39
8/29/1983	8.96
8/30/1983	0.00
8/31/1983	0.00
MONTHLY TOTAL	396.51

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: September 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
9/01/1983	0.00
9/02/1983	6.23
9/03/1983	0.00
9/04/1983	5.33
9/05/1983	1.76
9/06/1983	0.00
9/07/1983	30.02
9/08/1983	20.56
9/09/1983	1.66
9/10/1983	0.00
9/11/1983	0.00
9/12/1983	0.00
9/13/1983	4.68
9/14/1983	4.25
9/15/1983	3.17
9/16/1983	0.00
9/17/1983	3.49
9/18/1983	8.64
9/19/1983	8.64
9/20/1983	9.94
9/21/1983	27.76
9/22/1983	13.39
9/23/1983	9.94
9/24/1983	11.20
9/25/1983	12.46
9/26/1983	13.61
9/27/1983	14.98
9/28/1983	16.09
9/29/1983	8.89
9/30/1983	0.00
MONTHLY TOTAL	236.69

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: October 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
10/01/1983	0.00
10/02/1983	0.00
10/03/1983	0.00
10/04/1983	0.00
10/05/1983	70.06
10/06/1983	43.09
10/07/1983	80.17
10/08/1983	73.48
10/09/1983	66.78
10/10/1983	60.05
10/11/1983	53.39
10/12/1983	46.69
10/13/1983	154.40
10/14/1983	24.91
10/15/1983	22.82
10/16/1983	28.76
10/17/1983	34.81
10/18/1983	40.75
10/19/1983	46.76
10/20/1983	45.72
10/21/1983	43.20
10/22/1983	43.20
10/23/1983	43.20
10/24/1983	43.20
10/25/1983	43.20
10/26/1983	43.20
10/27/1983	43.20
10/28/1983	29.81
10/29/1983	18.58
10/30/1983	20.09
10/31/1983	21.53
MONTHLY TOTAL	1285.05

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: November 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
11/01/1983	22.97
11/02/1983	24.55
11/03/1983	25.78
11/04/1983	49.75
11/05/1983	29.20
11/06/1983	32.76
11/07/1983	36.32
11/08/1983	39.89
11/09/1983	35.10
11/10/1983	26.46
11/11/1983	22.93
11/12/1983	17.28
11/13/1983	17.28
11/14/1983	17.86
11/15/1983	108.22
11/16/1983	37.91
11/17/1983	17.28
11/18/1983	6.73
11/19/1983	2.74
11/20/1983	131.11
11/21/1983	68.58
11/22/1983	31.21
11/23/1983	106.96
11/24/1983	406.12
11/25/1983	103.68
11/26/1983	56.16
11/27/1983	346.21
11/28/1983	1362.89
11/29/1983	184.86
11/30/1983	106.38
MONTHLY TOTAL	3475.17

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: December 1983

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
12/01/1983	79.99
12/02/1983	410.72
12/03/1983	2097.22
12/04/1983	1761.01
12/05/1983	368.93
12/06/1983	959.47
12/07/1983	403.52
12/08/1983	227.48
12/09/1983	124.09
12/10/1983	94.54
12/11/1983	717.34
12/12/1983	913.50
12/13/1983	513.76
12/14/1983	338.44
12/15/1983	225.65
12/16/1983	204.55
12/17/1983	193.97
12/18/1983	183.46
12/19/1983	172.80
12/20/1983	162.40
12/21/1983	153.43
12/22/1983	537.98
12/23/1983	267.84
12/24/1983	188.17
12/25/1983	121.93
12/26/1983	115.34
12/27/1983	158.58
12/28/1983	1836.04
12/29/1983	1018.48
12/30/1983	376.34
12/31/1983	210.67
MONTHLY TOTAL	15137.64

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: January 1984

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
1/01/1984	167.33
1/02/1984	148.32
1/03/1984	141.98
1/04/1984	135.50
1/05/1984	127.80
1/06/1984	115.70
1/07/1984	102.71
1/08/1984	89.89
1/09/1984	82.40
1/10/1984	199.55
1/11/1984	287.24
1/12/1984	249.91
1/13/1984	230.00
1/14/1984	211.18
1/15/1984	192.35
1/16/1984	186.05
1/17/1984	156.42
1/18/1984	1128.56
1/19/1984	759.89
1/20/1984	270.79
1/21/1984	134.17
1/22/1984	160.52
1/23/1984	249.34
1/24/1984	805.57
1/25/1984	679.36
1/26/1984	519.23
1/27/1984	385.45
1/28/1984	280.33
1/29/1984	245.23
1/30/1984	213.34
1/31/1984	181.44
MONTHLY TOTAL	8837.55

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: SWSA-7
MONTH AND YEAR: February 1984

OBSERVATION DATA

DAILY FLOW (M**3)

DATE	FLUME 7
2/01/1984	149.54
2/02/1984	132.12
2/03/1984	147.17
2/04/1984	133.06
2/05/1984	100.22
2/06/1984	90.22
2/07/1984	97.78
2/08/1984	105.34
2/09/1984	108.83
2/10/1984	125.89
2/11/1984	120.96
2/12/1984	120.96
2/13/1984	1038.60
2/14/1984	1138.10
2/15/1984	191.23
2/16/1984	130.46
2/17/1984	139.57
2/18/1984	120.53
2/19/1984	103.68
2/20/1984	86.40
2/21/1984	77.76
2/22/1984	77.76
2/23/1984	180.65
2/24/1984	175.28
2/25/1984	149.54
2/26/1984	121.61
2/27/1984	1291.93
2/28/1984	1014.37
2/29/1984	424.30
MONTHLY TOTAL	7893.86

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 9, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: January 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
1/01/1983	0.00	0.00	0.00
1/02/1983	7.35	6.27	6.81
1/03/1983	0.00	0.00	0.00
1/04/1983	0.00	0.00	0.00
1/05/1983	0.00	0.00	0.00
1/06/1983	0.00	0.00	0.00
1/07/1983	0.00	0.00	0.00
1/08/1983	0.00	0.00	0.00
1/09/1983	9.92	***	***
1/10/1983	2.62	***	***
1/11/1983	0.51	0.84	0.68
1/12/1983	2.80	2.03	2.41
1/13/1983	0.00	0.00	0.00
1/14/1983	0.00	0.00	0.00
1/15/1983	0.00	0.00	0.00
1/16/1983	0.00	0.00	0.00
1/17/1983	0.00	0.00	0.00
1/18/1983	0.00	0.00	0.00
1/19/1983	0.00	0.00	0.00
1/20/1983	0.51	0.26	0.39
1/21/1983	10.64	10.42	10.53
1/22/1983	0.00	0.00	0.00
1/23/1983	0.00	0.00	0.00
1/24/1983	0.00	0.00	0.00
1/25/1983	0.00	0.00	0.00
1/26/1983	0.00	0.00	0.00
1/27/1983	0.00	0.00	0.00
1/28/1983	0.00	0.00	0.00
1/29/1983	2.71	3.36	3.04
1/30/1983	2.06	0.98	1.52
1/31/1983	0.00	0.00	0.00
MONTHLY TOTAL	39.12	36.70 *********	37.92 *******

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: February 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
2/01/1983	***	23.85	***
2/02/1983	***	19.51	***
2/03/1983	***	0.79	***
2/04/1983	***	0.24	***
2/05/1983	***	0.24	***
2/06/1983	***	10.72	***
2/07/1983	***	6.39	***
2/08/1983	0.00	0.00	0.00
2/09/1983	0.00	0.00	0.00
2/10/1983	23.68	25.24	24.46
2/11/1983	4.81	4.21	4.51
2/12/1983	0.00	0.00	0.00
2/13/1983	0.00	0.00	0.00
2/14/1983	0.00	0.00	0.00
2/15/1983	0.00	0.00	0.00
2/16/1983	0.00	0.00	0.00
2/17/1983	0.00	0.00	0.00
2/18/1983	0.00	0.00	0.00
2/19/1983	0.00	0.00	0.00
2/20/1983	0.00	0.00	0.00
2/21/1983	0.00	0.00	0.00
2/22/1983	13.08	***	***
2/23/1983	0.00	***	***
2/24/1983	4.83	***	***
2/25/1983	1.68	***	***
2/26/1983	0.00	***	***
2/27/1983	0.00	***	***
2/28/1983	0.00	***	***
MONTHLY TOTAL	109.82	110.78	110.30
	*********	*********	*******

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: March 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
3/01/1983	0.00	0.00	0.00
3/02/1983	0.00	0.00	0.00
3/03/1983	0.00	0.00	0.00
3/04/1983	0.00	0.00	0.00
3/05/1983	7.98	8.86	8.42
3/06/1983	5.63	5.62	5.62
3/07/1983	0.00	0.00	0.00
3/08/1983	0.99	1.16	1.08
3/09/1983	0.00	0.00	0.00
3/10/1983	0.51	0.23	0.37
3/11/1983	0.00	0.00	0.00
3/12/1983	0.00	0.00	0.00
3/13/1983	0.00	0.00	0.00
3/14/1983	0.00	0.00	0.00
3/15/1983	0.00	0.00	0.00
3/16/1983	0.00	0.00	0.00
3/17/1983	0.00	0.00	0.00
3/18/1983	1.27	1.29	1.28
3/19/1983	0.26	0.26	0.26
3/20/1983	21.09	20.56	20.83
3/21/1983	0.47	0.75	0.61
3/22/1983	0.00	0.00	0.00
3/23/1983	0.00	0.00	0.00
3/24/1983	0.00	0.00	0.00
3/25/1983	0.00	0.00	0.00
3/26/1983	1.78	1.82	1.80
3/27/1983	12.70	13.18	12.94
3/28/1983	0.00	0.00	0.00
3/29/1983	0.00	0.00	0.00
3/30/1983	0.00	0.00	0.00
3/31/1983	0.48	0.51	0.50
MONTHLY TOTAL	53.16	54.24	53.71

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: April 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
4/01/1983	0.00	0.30	0.15
4/02/1983	12.22	12.68	12.45
4/03/1983	2.17	1.78	1.97
4/04/1983	0.26	0.26	0.26
4/05/1983	84.95	86.21	85.58
4/06/1983	0.51	0.00	0.25
4/07/1983	0.00	0.00	0.00
4/08/1983	4.16	4.57	4.37
4/09/1983	25.14	26.42	25.78
4/10/1983	1.02	1.60	1.31
4/11/1983	0.00	0.00	0.00
4/12/1983	0.00	0.00	0.00
4/13/1983	0.00	0.00	0.00
4/14/1983	0.00	0.00	0.00
4/15/1983	0.00	0.00	0.00
4/16/1983	0.00	0.00	0.00
4/17/1983	0.00	0.00	0.00
4/18/1983	7.37	7.81	7.59
4/19/1983	0.00	0.00	0.00
4/20/1983	0.00	0.00	0.00
4/21/1983	0.00	0.00	0.00
4/22/1983	1.51	1.28	1.40
4/23/1983	17.52	18.46	17.99
4/24/1983	2.26	1.90	2.08
4/25/1983	0.52	0.66	0.59
4/26/1983	0.00	0.00	0.00
4/27/1983	0.00	0.00	0.00
4/28/1983	0.00	0.00	0.00
4/29/1983	0.00	0.00	0.00
4/30/1983	0.26	0.68	0.47
MONTHLY TOTAL	159.87	164.61	162.24

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: May 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
5/01/1983	1.27	1.02	1.14
5/02/1983	0.00	0.00	0.00
5/03/1983	14.39	15.88	15.13
5/04/1983	0.00	0.00	0.00
5/05/1983	0.00	0.00	0.00
5/06/1983	0.00	0.00	0.00
5/07/1983	0.08	0.04	0.06
5/08/1983	22.66	22.56	22.61
5/09/1983	0.00	0.00	0.00
5/10/1983	0.00	0.00	0.00
5/11/1983	0.00	0.00	0.00
5/12/1983	0.00	0.39	0.20
5/13/1983	15.87	16.63	16.25
5/14/1983	0.18	0.00	0.09
5/15/1983	8.52	10.13	9.32
5/16/1983	7.34	6.11	6.73
5/17/1983	0.00	0.00	0.00
5/18/1983	0.00	0.00	0.00
5/19/1983	24.92	25.22	25.07
5/20/1983	25.32	26.03	25.68
5/21/1983	15.09	15.31	15.20
5/22/1983	14.40	15.24	14.82
5/23/1983	1.85	3.71	2.78
5/24/1983	0.00	0.00	0.00
5/25/1983	0.00	0.00	0.00
5/26/1983	0.00	0.00	0.00
5/27/1983	0.00	0.00	0.00
5/28/1983	0.00	0.00	0.00
5/29/1983	9.59	7.21	8.40
5/30/1983	0.00	0.00	0.00
5/31/1983	0.00	0.00	0.00
MONTHLY TOTAL	161.48	165.48	163.48

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: June 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
6/01/1983	0.00	0.00	0.00
6/02/1983	0.00	0.00	0.00
6/03/1983	18.16	16.51	17.34
6/04/1983	27.94	28.47	28.20
6/05/1983	0.00	0.00	0.00
6/06/1983	0.70	1.02	0.86
6/07/1983	0.44	0.25	0.34
6/08/1983	0.00	0.00	0.00
6/09/1983	0.00	0.00	0.00
6/10/1983	0.00	0.00	0.00
6/11/1983	0.00	0.00	0.00
6/12/1983	0.00	0.00	0.00
6/13/1983	0.00	0.00	0.00
6/14/1983	0.00	0.00	0.00
6/15/1983	0.00	0.00	0.00
6/16/1983	3.96	3.63	3.80
6/17/1983	6.11	5.84	5.98
6/18/1983	3.56	3.35	3.46
6/19/1983	1.24	1.22	1.23
6/20/1983	0.00	0.00	0.00
6/21/1983	0.00	0.00	0.00
6/22/1983	1.22	1.78	1.50
6/23/1983	0.00	0.36	0.18
6/24/1983	0.00	0.00	0.00
6/25/1983	0.00	0.00	0.00
6/26/1983	0.00	0.00	0.00
6/27/1983	4.20	4.17	4.19
6/28/1983	0.00	0.00	0.00
6/29/1983	0.00	0.00	0.00
6/30/1983	0.00	0.00	0.00
MONTHLY TOTAL	67.53	66.60	67.08

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OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: July 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
7/01/1983	0.00	0.00	0.00
7/02/1983	0.00	0.00	0.00
7/03/1983	0.00	0.00	0.00
7/04/1983	4.95	8.10	6.53
7/05/1983	3.46	4.55	4.00
7/06/1983	0.00	0.00	0.00
7/07/1983	0.00	0.00	0.00
7/08/1983	0.00	0.00	0.00
7/09/1983	0.00	0.00	0.00
7/10/1983	0.00	0.00	0.00
7/11/1983	0.00	0.00	0.00
7/12/1983	0.00	0.00	0.00
7/13/1983	0.00	0.00	0.00
7/14/1983	0.00	0.00	0.00
7/15/1983	0.00	0.00	0.00
7/16/1983	0.00	0.00	0.00
7/17/1983	0.00	0.00	0.00
7/18/1983	0.00	0.00	0.00
7/19/1983	2.64	3.07	2.85
7/20/1983	4.08	7.11	5.60
7/21/1983	0.00	0.50	0.25
7/22/1983	0.00	0.00	0.00
7/23/1983	0.00	0.00	0.00
7/24/1983	0.00	0.00	0.00
7/25/1983	8.47	8.43	8.45
7/26/1983	0.00	0.00	0.00
7/27/1983	0.00	0.00	0.00
7/28/1983	0.00	0.00	0.00
7/29/1983	0.00	0.00	0.00
7/30/1983	0.00	0.00	0.00
7/31/1983	14.23	13.97	14.10
MONTHLY TOTAL	37.83	45.73	41.78

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: August 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
8/01/1983	3.61	5.10	4.36
8/02/1983	0.00	0.00	0.00
8/03/1983	0.00	0.00	0.00
8/04/1983	0.00	0.00	0.00
8/05/1983	0.00	0.00	0.00
8/06/1983	0.00	0.00	0.00
8/07/1983	9.53	15.31	12.42
8/08/1983	1.37	0.24	0.80
8/09/1983	0.35	0.10	0.23
8/10/1983	0.00	0.00	0.00
8/11/1983	3.81	2.97	3.39
8/12/1983	0.00	0.00	0.00
8/13/1983	0.00	0.00	0.00
8/14/1983	0.00	0.00	0.00
8/15/1983	0.00	0.00	0.00
8/16/1983	0.00	0.00	0.00
8/17/1983	0.00	0.00	0.00
8/18/1983	0.00	0.00	0.00
8/19/1983	0.00	0.00	0.00
8/20/1983	0.00	0.00	0.00
8/21/1983	0.00	0.00	0.00
8/22/1983	0.00	0.00	0.00
8/23/1983	0.00	0.00	0.00
8/24/1983	0.00	0.00	0.00
8/25/1983	0.00	0.00	0.00
8/26/1983	0.00	0.00	0.00
8/27/1983	15.88	16.51	16.19
8/28/1983	0.00	0.00	0.00
8/29/1983	0.00	0.00	0.00
8/30/1983	0.00	0.00	0.00
8/31/1983	0.00	0.51	0.25
MONTHLY TOTAL	34.55	40.74	37.64

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: September 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
9/01/1983	0.00	0.00	0.00
9/02/1983	1.66	1.31	1.48
9/03/1983	0.89	0.74	0.81
9/04/1983	12.04	13.13	12.58
9/05/1983	0.00	0.00	0.00
9/06/1983	0.00	0.00	0.00
9/07/1983	0.00	0.00	0.00
9/08/1983	0.00	0.00	0.00
9/09/1983	0.00	0.00	0.00
9/10/1983	0.00	0.00	0.00
9/11/1983	0.00	0.00	0.00
9/12/1983	0.00	0.00	0.00
9/13/1983	9.65	9.91	9.78
9/14/1983	0.00	0.00	0.00
9/15/1983	0.00	0.00	0.00
9/16/1983	0.00	0.00	0.00
9/17/1983	0.00	0.00	0.00
9/18/1983	0.00	0.00	0.00
9/19/1983	0.00	0.00	0.00
9/20/1983	6.12	5.07	5.59
9/21/1983	17.00	18.53	17.77
9/22/1983	0.00	0.00	0.00
9/23/1983	0.00	0.00	0.00
9/24/1983	0.00	0.00	0.00
9/25/1983	0.00	0.00	0.00
9/26/1983	0.00	0.00	0.00
9/27/1983	0.00	0.00	0.00
9/28/1983	0.00	0.00	0.00
9/29/1983	0.00	0.00	0.00
9/30/1983	0.00	0.00	0.00
MONTHLY TOTAL	47.36	48.69	48.01

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OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: October 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
10/01/1983	0.00	0.00	0.00
10/02/1983	0.00	0.00	0.00
10/03/1983	0.00	0.00	0.00
10/04/1983	0.00	0.00	0.00
10/05/1983	19.56	18.29	18.92
10/06/1983	0.00	0.00	0.00
10/07/1983	0.00	0.00	0.00
10/08/1983	0.00	0.00	0.00
10/09/1983	0.00	0.00	0.00
10/10/1983	0.00	0.00	0.00
10/11/1983	1.90	2.29	2.09
10/12/1983	1.52	1.37	1.44
10/13/1983	43.81	43.70	43.75
10/14/1983	0.90	0.63	0.77
10/15/1983	0.00	0.00	0.00
10/16/1983	0.00	0.00	0.00
10/17/1983	0.00	0.00	0.00
10/18/1983	0.00	0.00	0.00
10/19/1983	0.00	0.00	0.00
10/20/1983	0.00	0.00	0.00
10/21/1983	3.17	3.57	3.37
10/22/1983	8.00	6.52	7.26
10/23/1983	34.46	37.22	35.84
10/24/1983	0.00	0.00	0.00
10/25/1983	0.00	0.00	0.00
10/26/1983	0.00	0.00	0.00
10/27/1983	0.00	0.00	0.00
10/28/1983	0.00	0.00	0.00
10/29/1983	0.00	0.00	0.00
10/30/1983	0.00	0.00	0.00
10/31/1983	0.00	0.00	0.00
MONTHLY TOTAL	113.32	113.59	113.44

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: November 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
11/01/1983	0.00	0.00	0.00
11/02/1983	0.00	0.00	0.00
11/03/1983	6.13	5.69	5.91
11/04/1983	11.00	14.62	12.81
11/05/1983	0.00	0.00	0.00
11/06/1983	0.00	0.00	0.00
11/07/1983	0.00	0.00	0.00
11/08/1983	0.00	0.00	0.00
11/09/1983	0.00	0.00	0.00
11/10/1983	3.43	3.80	3.62
11/11/1983	1.02	1.00	1.01
11/12/1983	0.25	0.00	0.13
11/13/1983	0.00	0.00	0.00
11/14/1983	11.35	13.26	12.31
11/15/1983	9.97	8.84	9.40
11/16/1983	0.00	0.00	0.00
11/17/1983	0.00	0.00	0.00
11/18/1983	0.00	0.00	0.00
11/19/1983	0.00	0.00	0.00
11/20/1983	20.33	21.08	20.71
11/21/1983	0.51	0.63	0.57
11/22/1983	0.00	0.00	0.00
11/23/1983	20.15	21.89	21.02
11/24/1983	4.35	3.27	3.81
11/25/1983	0.00	0.00	0.00
11/26/1983	0.00	0.00	0.00
11/27/1983	25.97	25.54	25.75
11/28/1983	17.61	18.62	18.12
11/29/1983	0.00	0.00	0.00
11/30/1983	0.00	0.00	0.00
MONTHLY TOTAL	132.07	138.24	135.17

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: December 1983

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
12/01/1983	0.00	0.00	0.00
12/02/1983	27.07	27.79	27.43
12/03/1983	37.49	37.14	37.32
12/04/1983	4.83	6.21	5.52
12/05/1983	1.02	1.59	1.30
12/06/1983	14.45	13.71	14.08
12/07/1983	0.00	0.00	0.00
12/08/1983	0.00	0.00	0.00
12/09/1983	0.00	0.00	0.00
12/10/1983	0.00	0.00	0.00
12/11/1983	22.30	21.84	22.07
12/12/1983	6.98	8.43	7.71
12/13/1983	0.00	0.00	0.00
12/14/1983	5.33	5.84	5.59
12/15/1983	0.00	0.00	0.00
12/16/1983	0.25	0.00	0.13
12/17/1983	0.00	0.00	0.00
12/18/1983	0.00	0.00	0.00
12/19/1983	0.00	0.00	0.00
12/20/1983	0.00	0.00	0.00
12/21/1983	3.59	3.62	3.60
12/22/1983	13.16	12.92	13.04
12/23/1983	0.00	0.00	0.00
12/24/1983	0.00	0.00	0.00
12/25/1983	0.00	0.00	0.00
12/26/1983	0.00	0.00	0.00
12/27/1983	3.32	3.31	3.31
12/28/1983	30.97	31.23	31.10
12/29/1983	0.26	0.00	0.13
12/30/1983	0.89	0.51	0.70
12/31/1983	0.00	0.00	0.00
MONTHLY TOTAL	171.91	174.14	173.03

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: January 1984

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
1/01/1984	0.00	0.00	0.00
1/02/1984	0.00	0.00	0.00
1/03/1984	0.00	0.00	0.00
1/04/1984	1.51	0.25	0.88
1/05/1984	0.00	0.00	0.00
1/06/1984	0.00	0.00	0.00
1/07/1984	0.00	0.00	0.00
1/08/1984	0.00	0.00	0.00
1/09/1984	0.00	0.00	0.00
1/10/1984	18.79	12.95	15.87
1/11/1984	1.52	1.78	1.65
1/12/1984	0.00	0.00	0.00
1/13/1984	0.00	0.00	0.00
1/14/1984	0.00	0.00	0.00
1/15/1984	0.00	0.00	0.00
1/16/1984	3.55	4.06	3.81
1/17/1984	0.00	0.00	0.00
1/18/1984	19.55	19.33	19.44
1/19/1984	0.00	0.00	0.00
1/20/1984	0.00	0.00	0.00
1/21/1984	0.00	0.00	0.00
1/22/1984	0.00	0.00	0.00
1/23/1984	7.14	6.11	6.63
1/24/1984	13.70	14.49	14.09
1/25/1984	0.00	0.00	0.00
1/26/1984	0.00	0.00	0.00
1/27/1984	0.00	0.00	0.00
1/28/1984	0.00	0.00	0.00
1/29/1984	0.00	0.00	0.00
1/30/1984	0.00	0.00	0.00
1/31/1984	0.00	0.00	0.00
MONTHLY TOTAL	65.76	58.97	62.37

CUSTOM REPORT BY D.D. HUFF
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OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: February 1984

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
2/01/1984	0.00	0.00	0.00
2/02/1984	0.00	0.00	0.00
2/03/1984	1.27	1.27	1.27
2/04/1984	0.00	0.00	0.00
2/05/1984	5.85	5.20	5.52
2/06/1984	1.77	1.66	1.72
2/07/1984	0.00	0.00	0.00
2/08/1984	0.00	0.00	0.00
2/09/1984	0.00	0.00	0.00
2/10/1984	7.12	7.37	7.25
2/11/1984	1.77	1.40	1.58
2/12/1984	0.00	0.00	0.00
2/13/1984	27.42	27.93	27.67
2/14/1984	0.00	0.00	0.00
2/15/1984	0.00	0.00	0.00
2/16/1984	0.00	0.00	0.00
2/17/1984	0.00	0.00	0.00
2/18/1984	0.00	0.00	0.00
2/19/1984	0.76	1.27	1.02
2/20/1984	0.00	0.00	0.00
2/21/1984	0.00	0.00	0.00
2/22/1984	0.00	0.00	0.00
2/23/1984	10.67	11.29	10.98
2/24/1984	1.40	1.27	1.34
2/25/1984	0.00	0.00	0.00
2/26/1984	0.00	0.00	0.00
2/27/1984	27.33	27.44	27.39
2/28/1984	2.65	3.30	2.97
2/29/1984	0.13	0.00	0.07
MONTHLY TOTAL	88.14	89.40	88.78

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX III (continued)

SITE: WBW
MONTH AND YEAR: March 1984

OBSERVATION DATA

PRECIPITATION (MM)

DATE	RG 1	RG 3	AVERAGE
3/01/1984	0.00	0.00	0.00
3/02/1984	0.00	0.00	0.00
3/03/1984	0.00	0.00	0.00
3/04/1984	0.00	0.00	0.00
3/05/1984	6.53	5.85	6.19
3/06/1984	1.62	3.02	2.32
3/07/1984	0.00	0.00	0.00
3/08/1984	0.00	0.00	0.00
3/09/1984	0.00	0.00	0.00
3/10/1984	0.00	0.00	0.00
3/11/1984	0.00	0.00	0.00
3/12/1984	0.00	0.00	0.00
3/13/1984	4.18	4.83	4.50
3/14/1984	0.00	0.00	0.00
3/15/1984	0.00	0.00	0.00
3/16/1984	6.99	8.38	7.69
3/17/1984	3.43	1.90	2.67
3/18/1984	0.00	1.27	0.63
3/19/1984	0.00	0.00	0.00
3/20/1984	30.63	30.63	30.63
3/21/1984	7.90	7.90	7.90
3/22/1984	0.00	0.00	0.00
3/23/1984	0.00	0.00	0.00
3/24/1984	1.02	1.02	1.02
3/25/1984	0.89	0.89	0.89
3/26/1984	0.00	0.00	0.00
3/27/1984	1.98	1.98	1.98
3/28/1984	44.87	43.17	44.02
3/29/1984	0.00	0.00	0.00
3/30/1984	0.00	0.00	0.00
3/31/1984	0.00	0.00	0.00
MONTHLY TOTAL	110.04	110.84	110.44

CUSTOM REPORT BY D.D. HUFF
ENVIRONMENTAL SCIENCES DIVISION
OAK RIDGE NATIONAL LABORATORY

THIS SUMMARY PREPARED ON April 15, 1984

APPENDIX IV

PROGRAM WATERBALANCE

APPENDIX IV
PROGRAM WATERBALANCE

Documentation for the WATERBALANCE Program

An interactive program WATERBALANCE computes the main components of the water budget. It uses the techniques of Thornthwaite and Mather (1957), as described in Chapter 8 of Dunne and Leopold (1978). The purpose of this section is to briefly describe the salient aspects of the model, specific capabilities of the coded version, and input/output specifications.

The mass balance equation for watershed hydrology can be written:

P = SRO + GWRO + AET + SM + GWS

where

P = precipitation,

SRO = surface (quick) runoff

GWRO = groundwater runoff

AET = actual evapotranspiration

SM = change in soil moisture storage

GWS = change in groundwater storage

with all terms having units of mm in the model. No distinction is made between evaporative losses from the soil, plants or interception storage. The key assumptions of the model are:

1. The monthly potential evaporation (PET) can be determined from mean monthly temperatures.
2. During the dry months the water retained in the soil against the evaporative demand is a simple function of the accumulated stress and the available water capacity (AWC) of the soil. The accumulated stress is determined by the first occurrence of a negative (P-PET) and a subsequent summation of this quantity throughout the dry season.

APPENDIX IV (continued)

3. A small portion of the precipitation is routed directly to the stream without significant storage time in the soil. In the model, this portion is given by the parameter F.
4. A portion of the water stored in the watershed, other than that stored in the root zone, is subject to a delay mechanism. In the model, this is parameter F1, and it specifies the fraction of water available for runoff that is delayed until the next month.

Input and Output

The required input is monthly precipitation and either monthly PET values or monthly temperatures. If supplied the latter, PET is calculated internally. Temperatures may be in Celsius or Fahrenheit, and all amounts must be in mm. The model requires 12 months of continuous data but can use a longer record. It has a wrap-around feature whereby the initial storages for the first month in the simulation are equated to the preceding month of the last year of record, e.g., if the first month of record is June, then initial storages are given by the residual storage computed for the last May in the record. This feature requires the model to loop through some sequences more than once.

The model also accepts monthly values of runoff for comparative purposes. For each calendar year, the sum of errors (calculated minus observed) is computed, and the root mean square error for the entire record is also computed. Missing values of runoff must be denoted by any negative number.

APPENDIX IV (continued)

Monthly values can either be input interactively during program execution, or they can be included in the code as data statements. Of course, the latter feature requires that the source code be recompiled with the updated values.

The necessary parameters are AWC, F, and F1 which are described above and in the main text of this report. In addition, there are other model parameters to identify the year and month of the first data increment and others to indicate whether the PET rate is input directly or must be computed from temperature. These model parameters are requested by the interactive model which supplies a brief description before each request. Output is written to FORTRAN units 6 and 40, allowing one to make an extra file to be output as a hard copy after the interactive session is over.

The ensuing pages list the program code and output from typical sessions. The examples include one from SWSA-7 and another directly from Dunne and Leopold (1978). The reader is strongly advised to consult the latter reference for details of the technique.

APPENDIX IV (continued)

```
C  PROGRAM WATERBALANCE
C  PROGRAM CORRESPONDS TO CHAPTER 8 IN DUNNE AND LEOPOLD.
C  IT IS ESSENTIALLY THE METHOD OF THORNTHWAITE, AND IT
C  REQUIRES AT LEAST ONE YEAR OF PRECIP AND TEMP (OR PET)
C  DATA.  IT CYCLES AROUND SO THAT CONDITIONS PRIOR TO THE
C  FIRST MONTH ARE EQUIVALENT TO THOSE AT THE END OF THE PRECEDING
C  MONTH OF THE LAST YEAR IN THE DATA SET.  IN THIS WAY, THE
C  THE PROGRAM CAN ACCOMMODATE MORE THAN 12 MONTHS OF DATA.
C
C
        DIMENSION TEMP(50),P(50),A(10),STE(10),AVT(10),PET(50)
        DIMENSION WASR(50),ACPWL(50),SM(50),DELSM(50),AET(50)
        DIMENSION SMDF(50),SMSR(50),TOTAL(50),GWS(50),GWRO(50)
        DIMENSION OBSRO(50),PS(50),OF(50),ERROR(50)
        DIMENSION TAR(50)
C
C
C  THIS DATA IS FOR SWSA-7.  ONE CAN EITHER ENTER DATA THROUGH
C  DATA STATEMENTS OR VIA THE TERMINAL.
        DATA F1V/0.,.05,.10,.15,.20,.25,.30,.35,.40,.45/
        DATA AWCV/100.,125.,150.,175.,200.,225.,250.,275.,300.,
     1  325.,350.,375.,400./
        DATA TEMP/77.9,73.9,69.4,59.4,45.7,34.4,
     1     35.4,38.6,47.7,51.2,63.8,71.5,77.9,79.2,69.4
     1    ,59.4,45.7,34.4
     2    ,35.4,38.6/
        DATA P/152.,119.,110.,56.,177.,176.,
     137.9,110.3,53.7,162.2,163.5,67.1,41.8,37.6,48.,
     1113.4,135.2,173.,62.,89./
        DATA OBSRO/6*-1.,30.,74.8,19.6,103.6,63.7,11.,3.2,
     1      1.9,1.1,6.1,16.5,71.7,41.9,37.4,6*-1./
C
        DATA SP,SPS,SAET,SOBSRO,SOF,SGWRO,SERR,STOT/8*0./
C
C  HEADING AND DATA INPUT.
        WRITE(6,1000)
        WRITE(40,1000)
1000    FORMAT('1WATER BUDGET PROGRAM'/' FROM DUNNE AND LEOPOLD,'
     1   ,' WATER IN ENVIRONMENTAL PLANNING,1978.'/
     2  ' PROGRAM WRITTEN BY R.B. CLAPP, MARCH 1984'//)
C  INPUT
        WRITE(6,1001)
        WRITE(40,1001)
1001    FORMAT( ' INPUT AWC,F,F1 -- WHERE'/
     1  ' AWC=AVAILABLE WATER CONTENT '/
     2  ' F=DIRECT RUNOFF COEFFICIENT (SUGGEST 0.)'/
     3  ' F1=PORTION OF RUNOFF DELAYED ONE MONTH (0. TO .5)?')
        READ(5,*)AWC,F,F1
```

APPENDIX IV (continued)

```
      WRITE(6,3000)AWC,F,F1
      WRITE(40,3000)AWC,F,F1
3000  FORMAT(/' ECHO'3F10.3)
C
      WRITE(6,1002)
      WRITE(40,1002)
1002  FORMAT(/' INPUT NM,IREAD,IPET,IFAHR,IFIRST,IYEAR,IOUT -- WHERE'/
     1 ' NM=NUMBER OF MONTHS IN THE ANALYSIS'/
     2 ' IREAD=0 FOR DO NOT READ DATA,=1 FOR READ DATA'/
     3 ' IPET=0 FOR USE TEMP TO CALCULATE PET,'/
     4 '     =1 FOR USE PET VALUES DIRECTLY'/
     5 ' IFAHR=0 IF TEMP DATA ARE IN DEGREES FAHRENHEIT,'
     6 /'     =1 IF TEMP DATA ARE IN DEGREES CENTIGRADE'
     7 /' IFIRST=INDEX OF FIRST MONTH(EX. 3=MARCH)'/
     8 ' IYEAR=DATE OF FISRT YEAR(EX. 1983)'
     9 /' IOUT=0 FOR NO OUTPUT FROM SUBR. SMOIST'
     1 /'      1 FOR INTERMEDIATE OUTPUT?')
      READ(5,*)NM,IREAD,IPET,IFAHR,IFIRST,IYEAR,IOUT
      WRITE(6,3001)NM,IREAD,IPET,IFAHR,IFIRST,IYEAR,IOUT
      WRITE(40,3001)NM,IREAD,IPET,IFAHR,IFIRST,IYEAR,IOUT
3001  FORMAT(/' ECHO'8I5)
C
C
C
C
      IF (IREAD.EQ.0)GO TO 5
      WRITE(6,1003)
      WRITE(40,1003)
1003  FORMAT(/' INPUT PET OR TEMP, NM VALUES')
      READ(5,*)(TEMP(I),I=1,NM)
      WRITE(6,1004)(TEMP(I),I=1,NM)
      WRITE(40,1004)(TEMP(I),I=1,NM)
1004  FORMAT(/' ECHO' 12F10.2)
      WRITE(6,1005)
1005  FORMAT(/' INPUT PRECIP, NM VALUES IN MM')
      WRITE(40,1005)
      READ(5,*)(P(I),I=1,NM)
      WRITE(6,1004)(P(I),I=1,NM)
      WRITE(40,1004)(P(I),I=1,NM)
      WRITE(6,1006)
      WRITE(40,1006)
1006  FORMAT(/' INPUT OBSERVED RUNNOFF, NM VALUES, NEG.=NO OBS')
      READ(5,*)(OBSRO(I),I=1,NM)
      WRITE(6,1004)(OBSRO(I),I=1,NM)
      WRITE(40,1004)(OBSRO(I),I=1,NM)
C
C
5     CONTINUE
C  CONVERT TO DEGREES CENTIGRADE, IF NECESSARY
C
      IF(IFAHR.EQ.1 .OR. IPET.EQ.1)GO TO 4
```

APPENDIX IV (continued)

```
      DO 3 I=1,NM
3     TEMP(I)=(TEMP(I)-32.)*5./9.
4     CONTINUE
C
      IF(IPET.EQ.0)GO TO 1
      DO 11 I=1,NM
      PET(I)=TEMP(I)
11    TEMP(I)=0.
      GO TO 22
1     CALL POTET(TEMP,PET,NM)
22    CONTINUE
C
C  SPECIAL LOOPING-------
C  IF SPECIAL LOOPING IS REQUIRED TO REPEAT THE COMPUTATIONS
C     PUT THE DO LOOP HERE.
C  DETERMINE INFILTRATED PRECIP(PS),OVERLAND FLOW (OF),
C     WATER AVAILABLE FOR SURFACE RUNOFF (WASR) FOR EACH MONTH
C
      DO 6 I=1,NM
      PS(I)=P(I)*(1.-F)
      OF(I)=P(I)*F
6     WASR(I)=PS(I)-PET(I)
C  (MAXDEC) IS THE INDEX OF THE LAST DECEMBER IN THE FILE TO BE
C     USED IN A WRAP AROUND FASHION FOR ANTECEDENT CONDITIONS IN
C     FIRST JANUARY.
C  PROGRAM AMMENDED TO START AT ANYMONTH AND WRAP AROUND,THEREFORE
C     MAXDEC IS THE INDEX OF THE (IFISRT-1) MONTH OF THE LAST YEAR.
      MAXDEC=12*IFIX(FLOAT(NM)/12.)
C
C  CALCULATE ACCUMULATED POTENTIAL WATER LOSS (ACPWL)
C  THIS REPEAT DO LOOP ENSURES THAT (ACPWL) IS ACCUMULATED FROM DEC TO
JAN
C  NOTE THAT ACPWL CAN BE CHANGED IN SUB. SMOIST FOR A SPECIAL CASE.
      DO 7 JCOUNT=1,2
      DO 7 I=1,NM
      IM1=I-1
      IF(I.EQ.1)IM1=MAXDEC
      IF(WASR(I).GE.0.)ACPWL(I)=0.
      IF(WASR(I).LT.0.)ACPWL(I)=ACPWL(IM1)+WASR(I)
7     CONTINUE
C
C  COMPUTE SOIL MOISTURE (SM)
      CALL SMOIST(SM,WASR,ACPWL,NM,AWC,MAXDEC,IOUT)
C
C  COMPUTE CHANGE IN SOIL MOISTURE (DELSM)
      DO 10 I=2,NM
      DELSM(I)=SM(I)-SM(I-1)
10    CONTINUE
      DELSM(1)=SM(1)-SM(MAXDEC)
C
C  COMPUTE ACTUAL EVAPOTRANSPIRATION (AET)
      DO 20 I=1,NM
```

APPENDIX IV (continued)

```
      IF(WASR(I).LT.0.)AET(I)=PS(I)+ABS(DELSM(I))
      IF(WASR(I).GE.0.)AET(I)=PET(I)
      IF(AET(I).GT.PET(I))AET(I)=PET(I)
C
C  COMPUTE SOIL MOISTURE DEFICIT (SMDF)
      IF(AET(I).LT.PET(I))SMDF(I)=PET(I)-AET(I)
      IF(AET(I).GE.PET(I))SMDF(I)=0.
C
C  COMPUTE SOIL MOISTURE SURPLUS (SMSR)
      IF(SMDF(I).GT.0.)SMSR(I)=0.
      IF(SMDF(I).EQ.0.)SMSR(I)=PS(I)-AET(I)-DELSM(I)
20    CONTINUE
C
C  FIND FIRST MONTH WITH POSITIVE SOIL MOIST. SURPLUS (SMSR)
      DO 30 I=2,NM
      IF(SMSR(I-1).EQ.0. .AND. SMSR(I).GT.0.)GO TO 40
30    CONTINUE
40    IF(SMSR(MAXDEC).EQ.0. .AND. SMSR(1).GT.0.)I=1
      ISTART=I
C
C  COMPUTE TOTAL AVAILABLE RUNOFF  (TAR), GROUND WATER RUN
C     OFF (GWRO), AND GROUNDWATER STORAGE (GWS).
C     NOTE THAT IN ORIGINAL ARTICLE (GWS) IS CALLED 'DETENTION'
      DO 45 IC=1,NM
C         ****I IS ADJUSTED TO CYCLE STARTING WITH I=ISTART
      I=ISTART+IC-1
      IF(I.GT.NM)I=I-NM
C
      IF(IC.EQ.1)TAR(I)=SMSR(I)
      IC1=I-1
      IF(I.EQ.1)IC1=MAXDEC
      IF(IC.GT.1)TAR(I)=SMSR(I)+GWS(IC1)
      GWRO(I)=TAR(I)*(1.-F1)
      GWS(I)=TAR(I)-GWRO(I)
45    CONTINUE
C
C  COMPUTE TOTAL RUNOFF(TOTAL) AND ERROR (ERROR)
      SUM=0.
      IERR=0
      DO 50 I=1,NM
      TOTAL(I)=OF(I)+GWRO(I)
      ERROR(I)=-99.
      IF(OBSRO(I).LT.0.)GO TO 50
      ERROR(I)=TOTAL(I)-OBSRO(I)
      IERR=IERR+1
      SUM=SUM+ERROR(I)**2
50    CONTINUE
C
C  (RMSE)IS ROOT MEAN SQUARED ERROR.
      RMSE=SQRT(SUM/IERR)
C
```

APPENDIX IV (continued)

```
C  OUTPUT SECTION.
C
       WRITE(6,2000)IFIRST,IYEAR
       WRITE(40,2000)IFIRST,IYEAR
2000   FORMAT('1WATER BUDGET (SEE PAGE 240,IN "DUNNE+LEOPOLD")'/
     1  ' STARTING MONTH 'I2', YEAR 'I4/
     1  '  I IM    PS   PET  WASR ACPWL    SM',
     1 ' DELSM   AET  SMDF  SMSR   TAR  GWRO   GWS'/)
C
       IM=IFIRST-1
       DO 101 I=1,NM
       IM=IM+1
       IF(IM.EQ.13)IM=1
       WRITE(40,2001)I,IM,PS(I),PET(I),WASR(I),ACPWL(I),SM(I),
     1  DELSM(I),AET(I),SMDF(I),SMSR(I),TAR(I),GWRO(I),GWS(I)
C
101    WRITE(6,2001)I,IM,PS(I),PET(I),WASR(I),ACPWL(I),SM(I),
     1  DELSM(I),AET(I),SMDF(I),SMSR(I),TAR(I),GWRO(I),GWS(I)
C
       WRITE(6,2020)
       WRITE(40,2020)
2020   FORMAT('1MONTHLY AND ANNUAL AMOUNTS'//
     1'  I IM PRECI  TEMP   PET    ET SURRO  GWRO TOTAL',
     1  ' OBSRO ERROR'/)
C
       IM=IFIRST-1
       IY=0
       DO 102 I=1,NM
       IM=IM+1
       IF(IM.EQ.13)IM=1
       WRITE(40,2030)I,IM,P(I),TEMP(I),PET(I),AET(I),OF(I),GWRO(I),
     1  TOTAL(I)
     1  ,OBSRO(I),ERROR(I)
       WRITE(6,2030)I,IM,P(I),TEMP(I),PET(I),AET(I),OF(I),GWRO(I),
     1  TOTAL(I)
     1  ,OBSRO(I),ERROR(I)
2030   FORMAT(' ',I2,I3,8F6.0,F6.1)
2001   FORMAT(' ',I2,I3,12F6.0)
C
C  SUM ANNUAL AMOUNTS
       SP=SP+P(I)
       SPS=SPS+PS(I)
       SAET=SAET+AET(I)
       IF(OBSRO(I).GE.0.)SOBSRO=SOBSRO+OBSRO(I)
       SOF=SOF+OF(I)
       SGWRO=SGWRO+GWRO(I)
       STOT=STOT+TOTAL(I)
       IF(ERROR(I).NE.-99.)SERR=SERR+ERROR(I)
       IF(IM.LT.12 .AND. I .NE.NM)GO TO 250
       IY=IY+1
       IYEAR1=IYEAR+IY-1
```

APPENDIX IV (continued)

```
      WRITE(6,8000)IY,IYEAR1,SP,SPS,SAET,SOF,SGWRO,STOT,SOBSRO,SERR
      WRITE(40,8000)IY,IYEAR1,SP,SPS,SAET,SOF,SGWRO,STOT,SOBSRO,SERR
      SP=0.
      SPS=0.
      SAET=0.
      SOBSRO=0.
      SOF=0.
      SGWRO=0.
      SERR=0.
      STOT=0.
250   CONTINUE
8000  FORMAT(/' ANNUAL TOTALS    YEAR='I2/
     1             '        'I4/
     1  ' PRECIP='F8.2' INFTRED PRECIP='F8.2
     1 ,' ACTUAL ET=',F8.2,/' SURF RO='F8.2,' GW RO=',F8.2,
     2 ' TOTAL RO='F8.2' OBS. RO='F8.2' ERROR='F8.2///)
C
102   CONTINUE
C
      WRITE(6,2040)AWC,F,F1,RMSE
      WRITE(40,2040)AWC,F,F1,RMSE
2040  FORMAT(' AWC=',F6.0,' DIR. RUNOFF FACTOR=',F6.3,
     1  ' GRDWTR DETENTION FACTOR=',F6.3' ROOT MEAN SQ ERR='
     2   ,F10.4)
C
C  END BIG LOOP-----
      SERR=0.
999   CONTINUE
00281 C  -----------
00282         END


      SUBROUTINE SMOIST(SM,WASR,ACPWL,NM,AWC,MAXDEC,IOUT)
C
C  PURPOSE-- TO DETERMINE THE SOIL MOISTURE (SM) GIVEN
C    THE ACCUMULATED POTENTIAL WAT. LOSS (ACPWL) AND THE
C    AVAILABLE WATER CONTENT (AWC).  THE ELEVEN SEMILOG
C    RELATIONSHIPS SHOWN IN FIG. 8.3 ARE USED TO DETERMINE
C    'WATER RETAINED IN THE SOIL'(WRS).  EACH RELATIONSHIP
C    CORRESPONDS TO A PARTICULAR (AWC) SO FIRST THE TWO
C    'BOUNDING' RELATIONSHIPS GIVEN THE ACTUAL AWC ARE
C    IDENTIFIED,  WRS IS DETERMINED FOR BOTH FUNCITONS,
C    THEN THE ACTUAL WRS IS DETERMINED BY LINEAR INTERPOLATION
C    OF THE LOG VALUES.
C
      DIMENSION SM(NM),ACPWL(NM),WASR(NM)
      DIMENSION X2(11),Y2(11),AWCV(11)
      DATA X2/70.,195.,302.,460.,580.,730.,1060.,1350.,3*1400./
      DATA Y2/8*1.,2.8,6.0,11.5/
      DATA AWCV/25.,50.,75.,100.,125.,150.,200.,250.,300.,
     1    350.,400./
```

APPENDIX IV (continued)

```
C
C  FIND INDICES (J,J+1) OF BOUNDING FUNCTIONS.
         DO 10 J=1,10
         IF(AWC.GE.AWCV(J) .AND. AWC.LT.AWCV(J+1))GO TO 20
10       CONTINUE
20       CONTINUE
C
C  PRINT HEADING FOR OUTPUT
C        THE OUTPUT IS INTENDED TO ALLOW CHECKING OF THE RELATIONSHIP
C        OF THE SOIL WATER RETAINED (SM(I)) AS A FUNCTION OF (AWC)
C        AND (ACPWL).
         IF(IOUT.NE.0)WRITE(6,3000)
         IF(IOUT.NE.0)WRITE(40,3000)
3000     FORMAT('1CHECK SM(I) AS FUNCTION OF AWC AND ACPWL'/)
C
C
C  REPEAT IN ORDER TO ACCUMULATE SOIL MOISTURE ACROSS DEC/JAN
         DO 200 JCOUNT=1,2
C  REPEAT FOR ALL MONTHS
         DO 200 I=1,NM
C
         IF(ACPWL(I).GE.0.)SM(I)=AWC
         IM1=I-1
         IF(I.EQ.1)IM1=MAXDEC
         SM(I)=WASR(I)+SM(IM1)
         IF(SM(I).GT.AWC)SM(I)=AWC
C
C  THE FOLLOWING SECTION PERTAINS TO THE SPECIAL CASE
C        WHERE THE SOIL MOISTURE (SM) IS NOT COMPLETELY
C        FILLED (LT AWC) AT THE END OF THE WET SEASON.
C        FOR THIS CASE, THERE IS SOME INITIAL STRESS
C        AT THE BEGINNING OF THE DRY SEASON, THUS
C        (ACPWL) IS RECALCULATED BASED ON THE COMPUTED
C        SOIL MOISTURE.  THIS FEATURE HAS NOT BEEN FULLY
C        TESTED BUT IT DOES CONFORM WITH THE SECOND EXAMPLE
C        GIVEN BY DUNNE AND LEOPOLD.
         IP=I+1
         IF(I.EQ.NM)IP=1
         IF(.NOT.  (WASR(I).GT.0.   .AND.
     1              WASR(IP).LE.0. .AND. SM(I).LT.AWC))
     2              GO TO 99
C
C  THIS ROUTINE IS THE REVERSE OF THE ONE BELOW, I.E.,
C        HERE ACPWL IS DETERMINED FROM SM.
         ACPWLX=ACPWL(I)
         WRSL=ALOG10(SM(I))
         AJ=(WRSL-ALOG10(AWCV(J)))*X2(J)/
     1              (ALOG10(Y2(J))-ALOG10(AWCV(J)))
         AJ1=(WRSL-ALOG10(AWCV(J+1)))*X2(J+1)/
     1              (ALOG10(Y2(J+1))-ALOG10(AWCV(J+1)))
         W1=(AWC-AWCV(J))/(AWCV(J+1)-AWCV(J))
```

APPENDIX IV (continued)

```
      W2=1.-W1
      A=AJ*W2 + AJ1*W1
      ACPWL(I)=-A
      WRITE(6,4000)I,SM(I),ACPWLX,ACPWL(I)
4000  FORMAT(/' SPECIAL CASE: END OF WET SEASON AND SM IS' ,
     1 ' LT AWC'/' PROG. CYCLES TWICE TO INCORPORATE THE',
     2 ' CHANGES TO ACPWL.'/
     3 ' MONTH='I2' SM='F7.1' OLD ACPWL='F7.1' NEW ACPWL='F7.1)
C  CHANGE SUBSEQUENT VALUES OF ACPWL TO ACCOMMODATE NEW ACPWL(I)
      II=I
101   II=II+1
      IF(II.GT.NM)II=II-NM
      IIM1=II-1
      IF(IIM1.EQ.0)IIM1=MAXDEC
      IF(ACPWL(II).EQ.0.)GO TO 102
      ACPWL(II)=ACPWL(IIM1)+WASR(II)
      GO TO 101
102   CONTINUE
      GO TO 100
C  END OF SPECIAL CASE.
C
99    CONTINUE
      IF(ACPWL(I).GE.0.)GO TO 100
C
C  THE ACTUAL LOG10 (WRS) WILL BE INTERPOLATED BETWEEN
C        (WRSLJ) AND (WRSLJ1)
C  (A) IS THE ABSOLUTE ACCUMULATED POT. WATER LOSS
      A=-ACPWL(I)
      WRSLJ=((ALOG10(Y2(J))-ALOG10(AWCV(J)))/X2(J))
     1      *A + ALOG10(AWCV(J))
      WRSLJ1=((ALOG10(Y2(J+1))-ALOG10(AWCV(J+1)))/X2(J+1))
     1      *A + ALOG10(AWCV(J+1))
C
C  ARITHMETIC WEIGHTS
      W1=(AWC-AWCV(J))/(AWCV(J+1)-AWCV(J))
      W2=1.-W1
      WRS=10.**(WRSLJ*W2 + WRSLJ1*W1)
      SM(I)=WRS
      GO TO 100
C
100   CONTINUE
      IF(SM(I).EQ.AWC) GO TO 150
      IF(IOUT.NE.0)WRITE(40,1000)I,J,AWC,W1,W2,WRSLJ,WRSLJ1,WRS,SM(I)
     1     ,ACPWL(I)
      IF(IOUT.NE.0)WRITE(6,1000)I,J,AWC,W1,W2,WRSLJ,WRSLJ1,WRS,SM(I)
     1     ,ACPWL(I)
1000  FORMAT(' I J AWC W1 W2 WRSLJ WRSLJ1 WRS SM ACPWL',2I3,9F8.2)
150   CONTINUE
200   CONTINUE
      END

      SUBROUTINE POTET(TEMP,PET,NM)
```

APPENDIX IV (continued)

```
C  PURPOSE-- TO CALCULATE POTENTIAL EVAPOTRANSPIRATION (PET)
C    FROM TEMPERATURE DATA FOR ALL MONTHS USING THORNTHWAITE
C    METHOD.
C
        DIMENSION TEMP(NM),PET(NM)
        DIMENSION AVT(10),A(10),STE(10)
C
        WRITE(6,1000)
        WRITE(40,1000)
1000    FORMAT('1PARAMETERS AND CALCULATED PET USING THORNTHWAITE'/)
C
        IY=0
        I=0
2       IY=IY+1
        STEMP=0.
        STE(IY)=0.
        IM=0
C
1       I=I+1
        IM=IM+1
        STEMP=STEMP+TEMP(I)
        STE(IY)=STE(IY)+(TEMP(I)/5.)**1.514
        IF(I.EQ.NM.OR. IM.EQ.12)GO TO 3
        GO TO 1
C
3       AVT(IY)=STEMP/IM
        A(IY)=.000000675*STE(IY)**3
     1        -  .0000771*STE(IY)**2
     2        +  .01792*STE(IY)+.49239
C
        IF(I.LT.NM)GO TO 2
C
        IF(IY.GE.2 .AND. IM.LT.12)STE(IY)=STE(IY-1)
C  LAST STATEMENT SETS STE FOR PARTIAL YEAR AT PREVIOUS VALUE
        IF(IY.GE.2. .AND. IM.LT.12)A(IY)=A(IY-1)
C
        DO 10 I=1,IY
        WRITE (6,1090)I,AVT(I),STE(I),A(I)
        WRITE (40,1090)I,AVT(I),STE(I),A(I)
10       CONTINUE
1090    FORMAT(' YEAR=',I2,' AVE.TEMP=',F6.2,' ANNUAL HEAT INDEX'
     1  , '=',F8.3,' A EXPONENT=',F6.2)
C
C  CALCULATE PET
        DO 80 I=1,NM
        IY=IFIX((FLOAT(I)-.05)/12. + 1.)
        PET(I)=16.*(10.*TEMP(I)/STE(IY))**A(IY)
        WRITE(40,1099)I,IY,TEMP(I),PET(I)
80      WRITE(6,1099)I,IY,TEMP(I),PET(I)
1099    FORMAT(' MONTH=',I2,' YEAR=',I2,' TEMP=',F6.2,
     1  ' PET=',F6.1)
        END
```

EXAMPLE I.
Water Budget for Kericho, Kenya
(Dunne and Leopold, 1978, pp. 238-244).

Note that data are long-term averages so that the year is arbitrarily set to 9999.

Echo prints of data entered at the terminal.

```
WATER BUDGET PROGRAM
FROM DUNNE AND LEOPOLD, WATER IN ENVIRONMENTAL PLANNING, 1978.
PROGRAM WRITTEN BY R.B. CLAPP, MARCH 1984
INPUT AWC,F,F1 -- WHERE
AWC=AVAILABLE WATER CONTENT
F=DIRECT RUNOFF COEFFICIENT (SUGGEST 0.)
F1=PORTION OF RUNOFF DELAYED ONE MONTH (0. TO .5)?
ECHO   200.000     0.000     0.500
INPUT NM,IREAD,IPET,IFAHR,IFIRST,IYEAR,IOUT -- WHERE
NM=NUMBER OF MONTHS IN THE ANALYSIS
IREAD=0 FOR DO NOT READ DATA,=1 FOR READ DATA
IPET=0 FOR USE TEMP TO CALCULATE PET,
    =1 FOR USE PET VALUES DIRECTLY
IFAHR=0 IF TEMP DATA ARE IN DEGREES FAHRENHEIT,
    =1 IF TEMP DATA ARE IN DEGREES CENTIGRADE
IFIRST=INDEX OF FIRST MONTH(EX. 3=MARCH)
IYEAR= DATE OF FISRT YEAR(EX. 1983)
IOUT=0 FOR NO OUTPUT FROM SUBR. SMOIST
    1 FOR INTERMEDIATE OUTPUT?
ECHO 12 1 1 0 1 9999 0
INPUT PET OR TEMP, NM VALUES
ECHO     138.00    138.00    150.00    108.00    114.00    114.00    108.00    108.00    114.00    126.00    114.00    132.00
INPUT PRECIP, NM VALUES IN MM
ECHO      65.00     95.00    155.00    270.00    250.00    155.00    150.00    180.00    155.00    140.00    130.00     95.00
INPUT OBSERVED RUNNOFF, NM VALUES, NEG.=NO OBS
ECHO      -1.00     -1.00     -1.00     -1.00     -1.00     -1.00     -1.00     -1.00     -1.00     -1.00     -1.00     -1.00
```

APPENDIX IV (continued)

WATER BUDGET (SEE PAGE 240,IN "DUNNE+LEOPOLD")
STARTING MONTH 1, YEAR 9999

I	IM	PS	PET	WASR	ACPWL	SM	DELSM	AET	SMDF	SMSR	TAR	GWRO	GWS
1	1	65.	138.	-73.	-110.	115.	-51.	116.	22.	0.	12.	6.	6.
2	2	95.	138.	-43.	-153.	93.	-22.	117.	21.	0.	6.	3.	3.
3	3	155.	150.	5.	0.	98.	5.	150.	0.	0.	3.	2.	2.
4	4	270.	108.	162.	0.	200.	102.	108.	0.	60.	60.	30.	30.
5	5	250.	114.	136.	0.	200.	0.	114.	0.	136.	166.	83.	83.
6	6	155.	114.	41.	0.	200.	0.	114.	0.	41.	124.	62.	62.
7	7	150.	108.	42.	0.	200.	0.	108.	0.	42.	104.	52.	52.
8	8	180.	108.	72.	0.	200.	0.	108.	0.	72.	124.	62.	62.
9	9	155.	114.	41.	0.	200.	0.	114.	0.	41.	103.	52.	52.
10	10	140.	126.	14.	0.	200.	0.	126.	0.	14.	66.	33.	33.
11	11	130.	114.	16.	0.	200.	0.	114.	0.	16.	49.	24.	24.
12	12	95.	132.	-37.	-37.	166.	-34.	129.	3.	0.	24.	12.	12.

This table corresponds to that published on page 240 in the reference. All units are mm.

Summary Table for Example I.

MONTHLY AND ANNUAL AMOUNTS

I	IM	PRECI	TEMP	PET	ET	SURRO	GWRO	TOTAL	OBSRO	ERROR
1	1	65.	0.	138.	116.	0.	6.	6.	-1.	-99.0
2	2	95.	0.	138.	117.	0.	3.	3.	-1.	-99.0
3	3	155.	0.	150.	150.	0.	2.	2.	-1.	-99.0
4	4	270.	0.	108.	108.	0.	30.	30.	-1.	-99.0
5	5	250.	0.	114.	114.	0.	83.	83.	-1.	-99.0
6	6	155.	0.	114.	114.	0.	62.	62.	-1.	-99.0
7	7	150.	0.	108.	108.	0.	52.	52.	-1.	-99.0
8	8	180.	0.	108.	108.	0.	62.	62.	-1.	-99.0
9	9	155.	0.	114.	114.	0.	52.	52.	-1.	-99.0
10	10	140.	0.	126.	126.	0.	33.	33.	-1.	-99.0
11	11	130.	0.	114.	114.	0.	24.	24.	-1.	-99.0
12	12	95.	0.	132.	129.	0.	12.	12.	-1.	-99.0

```
ANNUAL TOTALS     YEAR= 1
      9999
PRECIP= 1840.00 INFTRED PRECIP= 1840.00 ACTUAL ET= 1417.91
SURF RO=     0.00 GW RO=  420.57 TOTAL RO=  420.57 OBS. RO=     0.00 ERROR=    0.00
AWC=  200. DIR. RUNOFF FACTOR= 0.000 GRDWTR DETENTION FACTOR= 0.500 ROOT MEAN SQ ERR=**********
```

No error was calculated because no values of observed runoff were input.

Example II.
Water Budget for SWSA-7

The special constraint on mid-winter PET was not specified in this example so that the values computed here vary slightly with those given in the main text.

```
WATER BUDGET PROGRAM
FROM DUNNE AND LEOPOLD, WATER IN ENVIRONMENTAL PLANNING, 1978.
PROGRAM WRITTEN BY R.B. CLAPP, MARCH 1984
INPUT AWC,F,F1 -- WHERE
AWC=AVAILABLE WATER CONTENT
F=DIRECT RUNOFF COEFFICIENT (SUGGEST 0.)
F1=PORTION OF RUNOFF DELAYED ONE MONTH (0. TO .5)?
ECHO   275.000     0.050     0.200
INPUT NM,IREAD,IPET,IFAHR,IFIRST,IYEAR,IOUT -- WHERE
NM=NUMBER OF MONTHS IN THE ANALYSIS
IREAD=0 FOR DO NOT READ DATA,=1 FOR READ DATA
IPET=0 FOR USE TEMP TO CALCULATE PET,
    =1 FOR USE PET VALUES DIRECTLY
IFAHR=0 IF TEMP DATA ARE IN DEGREES FAHRENHEIT,
    =1 IF TEMP DATA ARE IN DEGREES CENTIGRADE
IFIRST=INDEX OF FIRST MONTH(EX. 3=MARCH)
IYEAR=DATE OF FISRT YEAR(EX. 1983)
IOUT=0 FOR NO OUTPUT FROM SUBR. SMOIST
     1 FOR INTERMEDIATE OUTPUT?
ECHO 20 0 0 0 7 1982 0
```

APPENDIX IV (continued)

PET values generated from temperature data.

```
PARAMETERS AND CALCULATED PET USING THORNTHWAITE
YEAR= 1 AVE.TEMP= 13.19 ANNUAL HEAT INDEX=  60.581 A EXPONENT=  1.45
YEAR= 2 AVE.TEMP= 12.78 ANNUAL HEAT INDEX=  60.581 A EXPONENT=  1.45
MONTH= 1 YEAR= 1 TEMP= 25.50 PET= 127.7
MONTH= 2 YEAR= 1 TEMP= 23.28 PET= 111.9
MONTH= 3 YEAR= 1 TEMP= 20.78 PET=  95.0
MONTH= 4 YEAR= 1 TEMP= 15.22 PET=  60.6
MONTH= 5 YEAR= 1 TEMP=  7.61 PET=  22.3
MONTH= 6 YEAR= 1 TEMP=  1.33 PET=   1.8
MONTH= 7 YEAR= 1 TEMP=  1.89 PET=   3.0
MONTH= 8 YEAR= 1 TEMP=  3.67 PET=   7.7
MONTH= 9 YEAR= 1 TEMP=  8.72 PET=  27.1
MONTH=10 YEAR= 1 TEMP= 10.67 PET=  36.2
MONTH=11 YEAR= 1 TEMP= 17.67 PET=  75.1
MONTH=12 YEAR= 1 TEMP= 21.94 PET= 102.8
MONTH=13 YEAR= 2 TEMP= 25.50 PET= 127.7
MONTH=14 YEAR= 2 TEMP= 26.22 PET= 133.0
MONTH=15 YEAR= 2 TEMP= 20.78 PET=  95.0
MONTH=16 YEAR= 2 TEMP= 15.22 PET=  60.6
MONTH=17 YEAR= 2 TEMP=  7.61 PET=  22.3
MONTH=18 YEAR= 2 TEMP=  1.33 PET=   1.8
MONTH=19 YEAR= 2 TEMP=  1.89 PET=   3.0
MONTH=20 YEAR= 2 TEMP=  3.67 PET=   7.7
```

WATER BUDGET (SEE PAGE 240,IN "DUNNE+LEOPOLD")
STARTING MONTH 7, YEAR 1982

I	IM	PS	PET	WASR	ACPWL	SM	DELSM	AET	SMDF	SMSR	TAR	GWRO	GWS
1	7	144.	128.	17.	0.	254.	17.	128.	0.	-0.	4.	3.	1.
2	8	113.	112.	1.	0.	255.	1.	112.	0.	-0.	1.	1.	0.
3	9	105.	95.	10.	-12.	264.	10.	95.	0.	0.	0.	0.	0.
4	10	53.	61.	-7.	-20.	255.	-10.	61.	0.	2.	2.	2.	0.
5	11	168.	22.	146.	0.	275.	20.	22.	0.	126.	126.	101.	25.
6	12	167.	2.	165.	0.	275.	0.	2.	0.	165.	191.	152.	38.
7	1	36.	3.	33.	0.	275.	0.	3.	0.	33.	71.	57.	14.
8	2	105.	8.	97.	0.	275.	0.	8.	0.	97.	111.	89.	22.
9	3	51.	27.	24.	0.	275.	0.	27.	0.	24.	46.	37.	9.
10	4	154.	36.	118.	0.	275.	0.	36.	0.	118.	127.	102.	25.
11	5	155.	75.	80.	0.	275.	0.	75.	0.	80.	106.	84.	21.
12	6	64.	103.	-39.	-39.	237.	-38.	102.	1.	0.	21.	17.	4.
13	7	40.	128.	-88.	-127.	171.	-66.	106.	22.	0.	4.	3.	1.
14	8	36.	133.	-97.	-224.	119.	-52.	88.	45.	0.	1.	1.	0.
15	9	46.	95.	-49.	-274.	99.	-20.	66.	29.	0.	0.	0.	0.
16	10	108.	61.	47.	0.	146.	47.	61.	0.	-0.	0.	0.	0.
17	11	128.	22.	106.	0.	252.	106.	22.	0.	0.	0.	0.	0.
18	12	164.	2.	163.	0.	275.	23.	2.	0.	140.	140.	112.	28.
19	1	59.	3.	56.	0.	275.	0.	3.	0.	56.	84.	67.	17.
20	2	85.	8.	77.	0.	275.	0.	8.	0.	77.	94.	75.	19.

Summary Table for Example II.

MONTHLY AND ANNUAL AMOUNTS

I	IM	PRECI	TEMP	PET	ET	SURRO	GWRO	TOTAL	OBSRO	ERROR
1	7	152.	25.	128.	128.	8.	3.	11.	-1.	-99.0
2	8	119.	23.	112.	112.	6.	1.	7.	-1.	-99.0
3	9	110.	21.	95.	95.	6.	0.	6.	-1.	-99.0
4	10	56.	15.	61.	61.	3.	2.	5.	-1.	-99.0
5	11	177.	8.	22.	22.	9.	101.	110.	-1.	-99.0
6	12	176.	1.	2.	2.	9.	152.	161.	-1.	-99.0

ANNUAL TOTALS YEAR= 1
1982
PRECIP= 790.00 INFTRED PRECIP= 750.50 ACTUAL ET= 419.23
SURF RO= 39.50 GW RO= 259.23 TOTAL RO= 298.73 OBS. RO= 0.00 ERROR= 0.00

I	IM	PRECI	TEMP	PET	ET	SURRO	GWRO	TOTAL	OBSRO	ERROR
7	1	38.	2.	3.	3.	2.	57.	59.	30.	28.8
8	2	110.	4.	8.	8.	6.	89.	95.	75.	19.7
9	3	54.	9.	27.	27.	3.	37.	40.	20.	20.0
10	4	162.	11.	36.	36.	8.	102.	110.	104.	6.2
11	5	164.	18.	75.	75.	8.	84.	93.	64.	29.0
12	6	67.	22.	103.	102.	3.	17.	20.	11.	9.3
13	7	42.	25.	128.	106.	2.	3.	5.	3.	2.3
14	8	38.	26.	133.	88.	2.	1.	3.	2.	0.7
15	9	48.	21.	95.	66.	2.	0.	3.	1.	1.4
16	10	113.	15.	61.	61.	6.	0.	6.	6.	-0.4
17	11	135.	8.	22.	22.	7.	0.	7.	17.	-9.7
18	12	173.	1.	2.	2.	9.	112.	121.	72.	49.0

ANNUAL TOTALS YEAR= 2
1983
PRECIP= 1143.70 INFTRED PRECIP= 1086.52 ACTUAL ET= 594.47
SURF RO= 57.19 GW RO= 502.16 TOTAL RO= 559.34 OBS. RO= 403.20 ERROR= 156.14

I	IM	PRECI	TEMP	PET	ET	SURRO	GWRO	TOTAL	OBSRO	ERROR
19	1	62.	2.	3.	3.	3.	67.	70.	42.	28.3
20	2	89.	4.	8.	8.	4.	75.	79.	37.	41.9

ANNUAL TOTALS YEAR= 3
1984
PRECIP= 151.00 INFTRED PRECIP= 143.45 ACTUAL ET= 10.71
SURF RO= 7.55 GW RO= 142.02 TOTAL RO= 149.57 OBS. RO= 79.30 ERROR= 70.27
AWC= 275. DIR. RUNOFF FACTOR= 0.050 GRDWTR DETENTION FACTOR= 0.200 ROOT MEAN SQ ERR= 23.3655

APPENDIX V

MONITORING-WELL HYDROGRAPHS

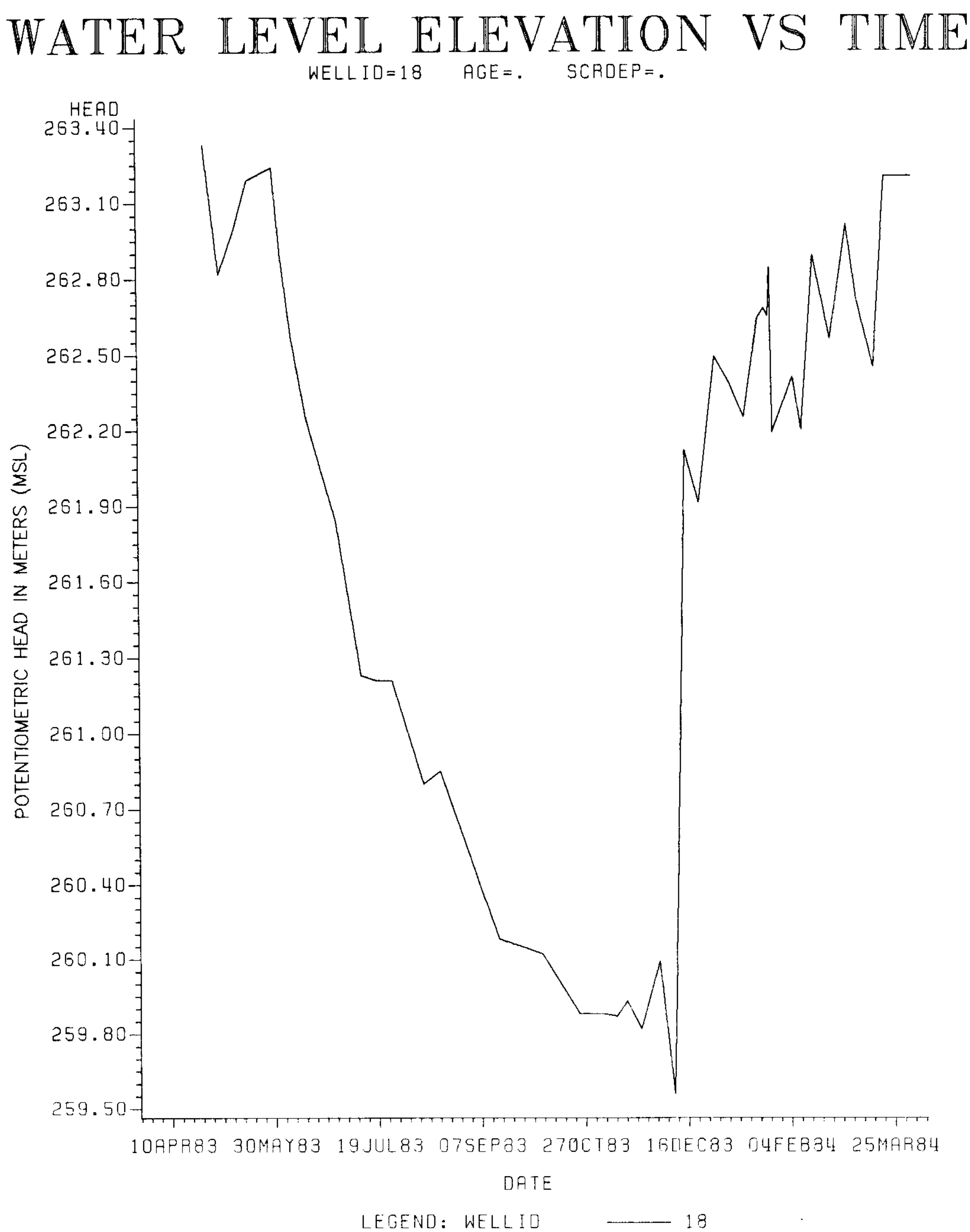
APPENDIX V

MONITORING WELL HYDROGRAPHS

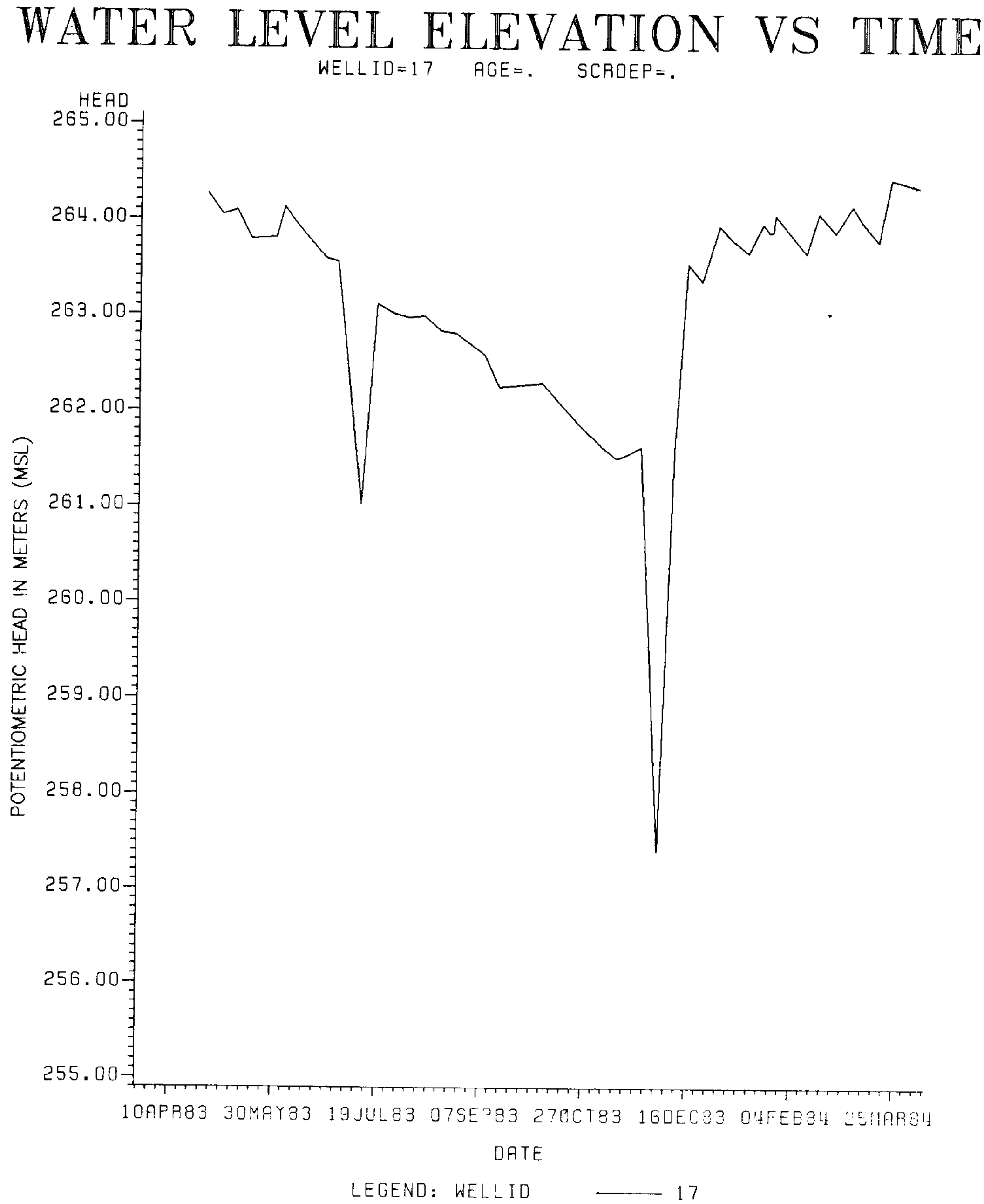
Key to Hydrographs

WELLID	=	Well Number	
SCRDEP	=	Screen Depth:	1 is shallow screen
			2 is deep screen
			blank is all zones

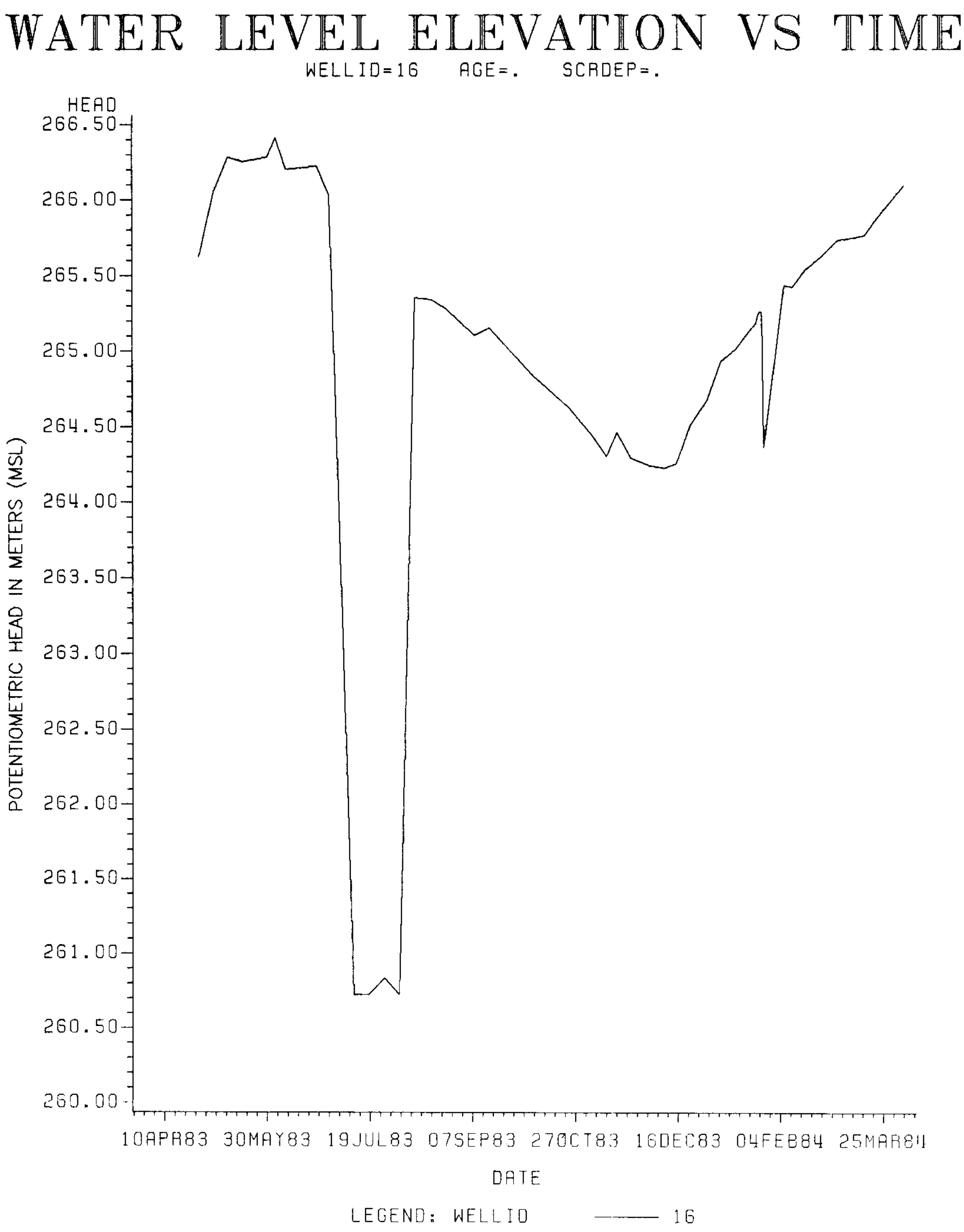
APPENDIX V (continued)



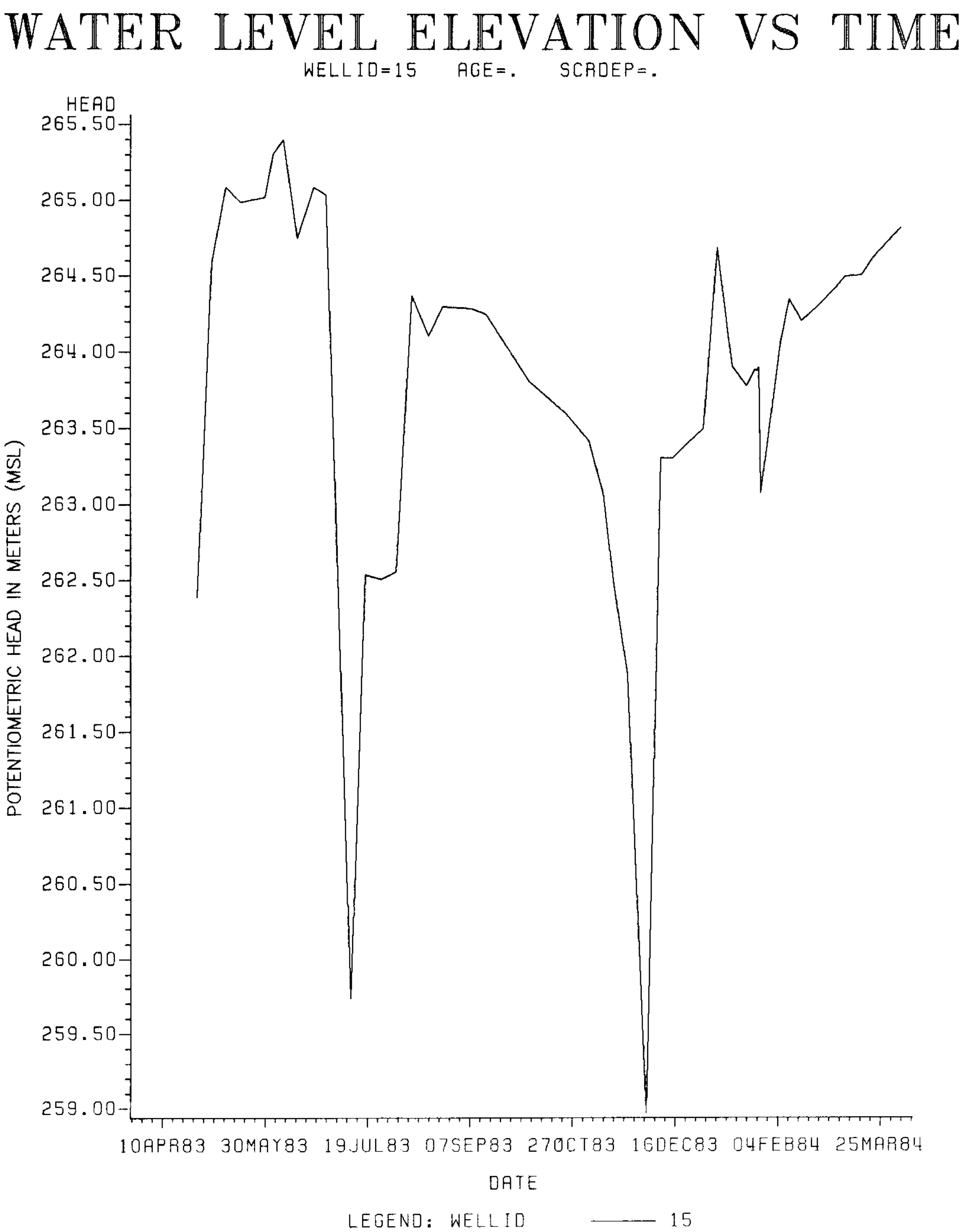
APPENDIX V (continued)



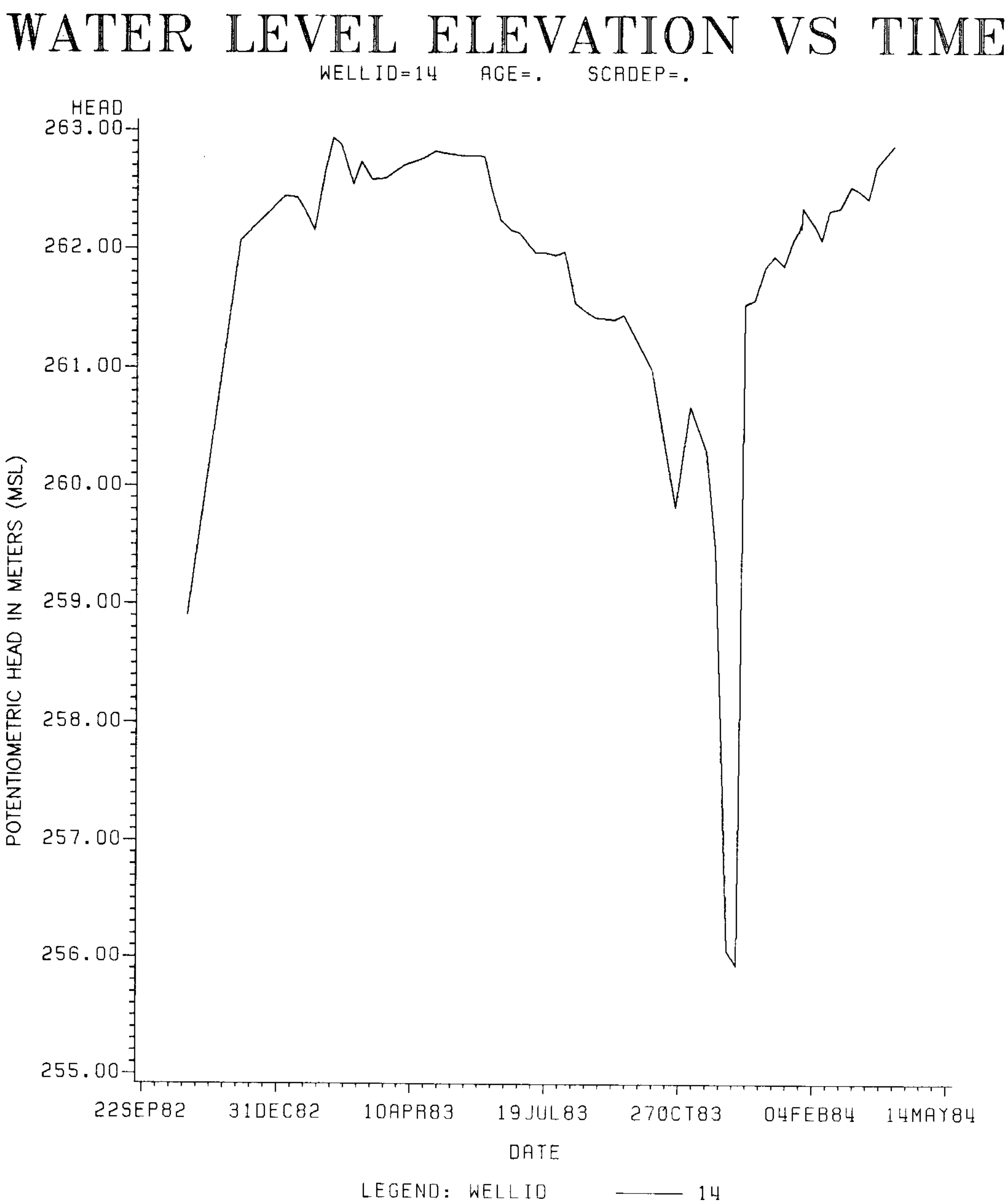
APPENDIX V (continued)



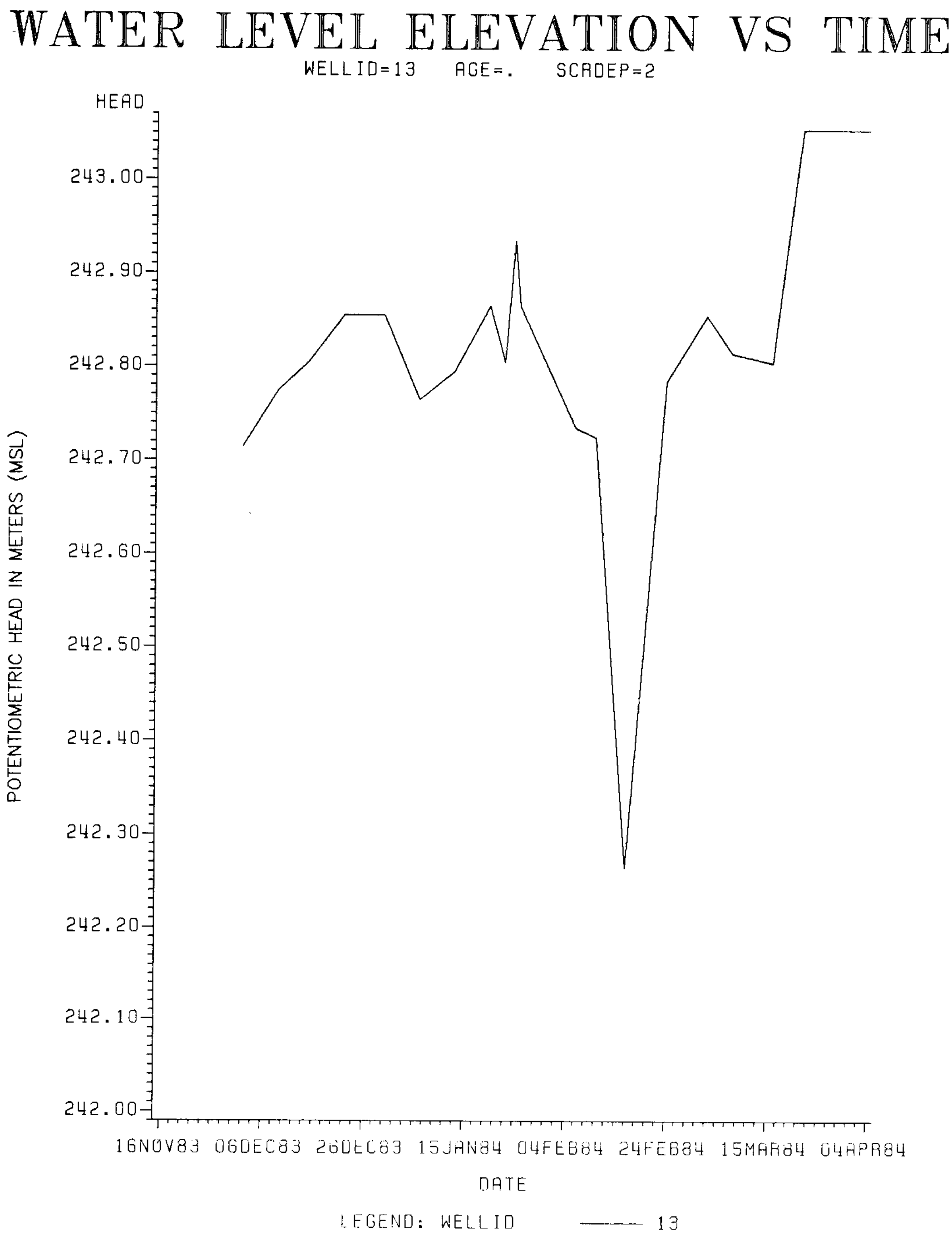
APPENDIX V (continued)



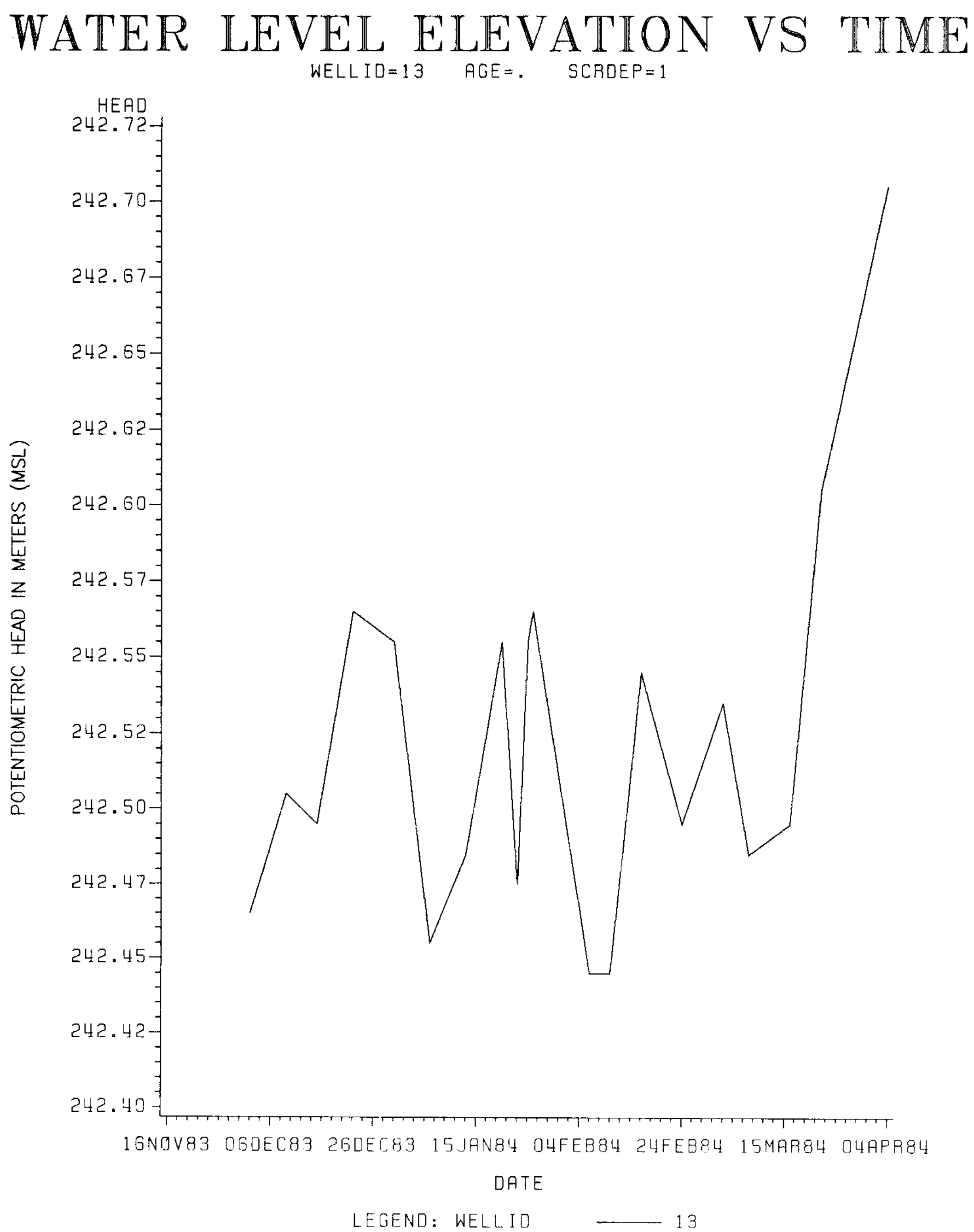
APPENDIX V (continued)



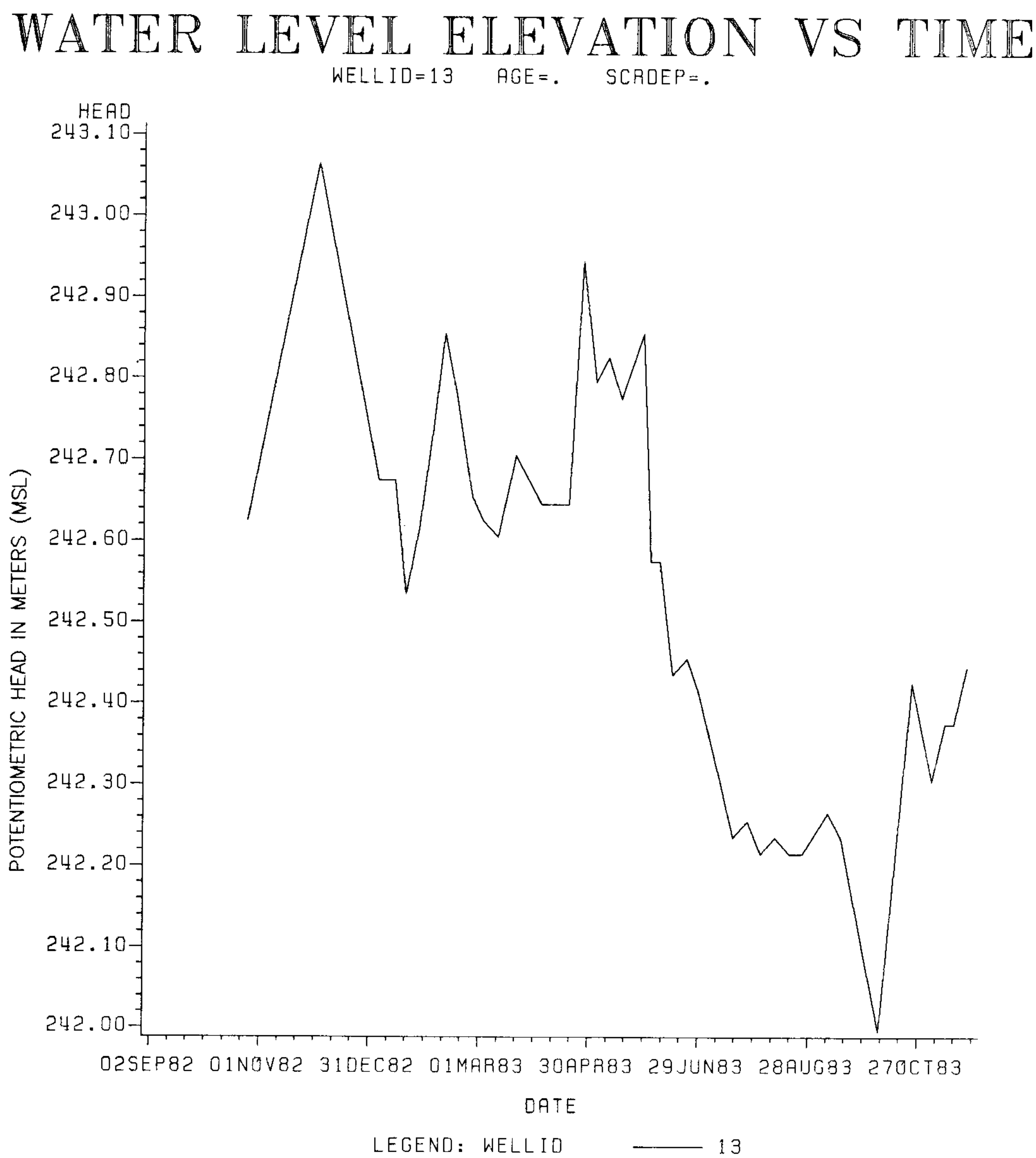
APPENDIX V (continued)



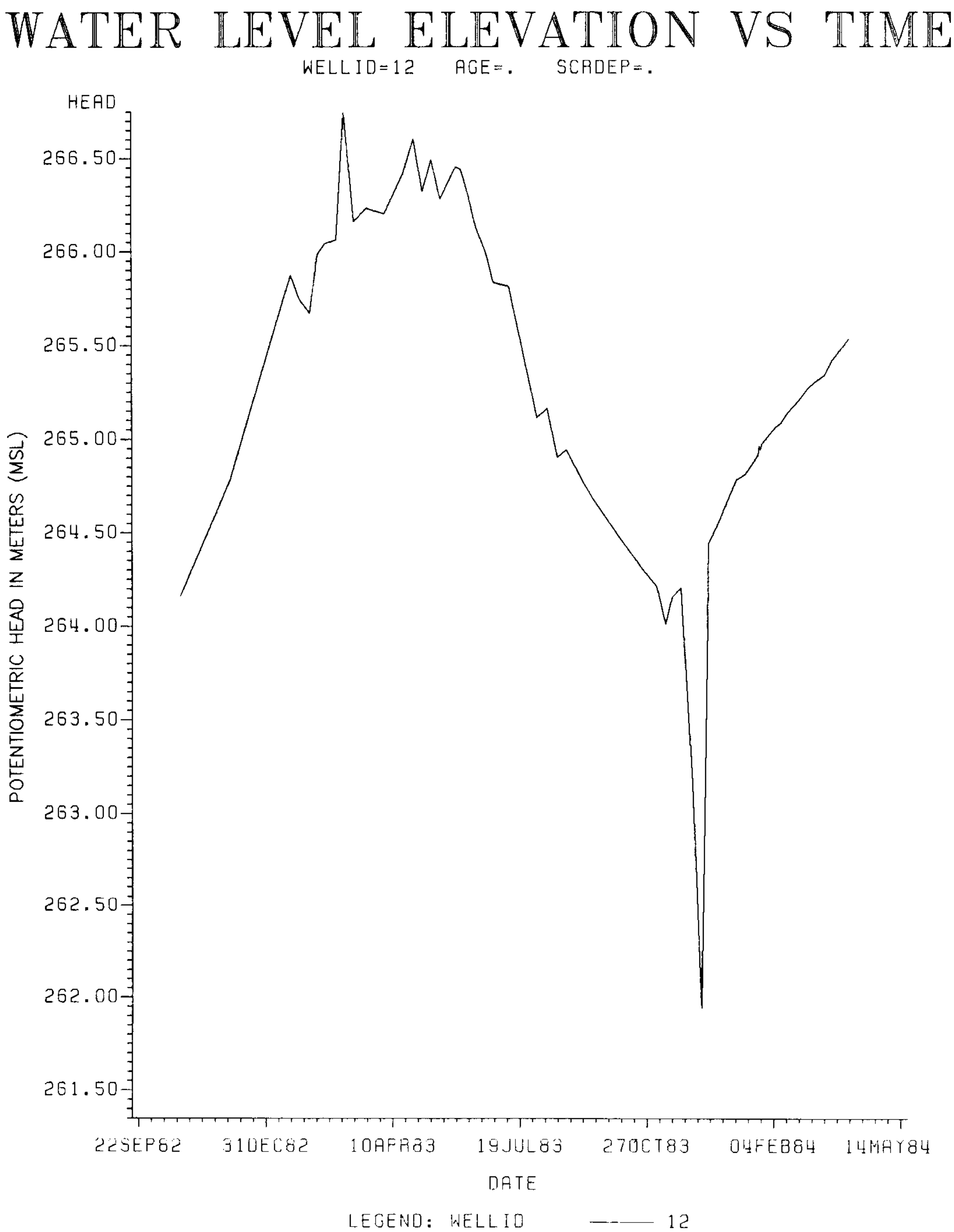
APPENDIX V (continued)



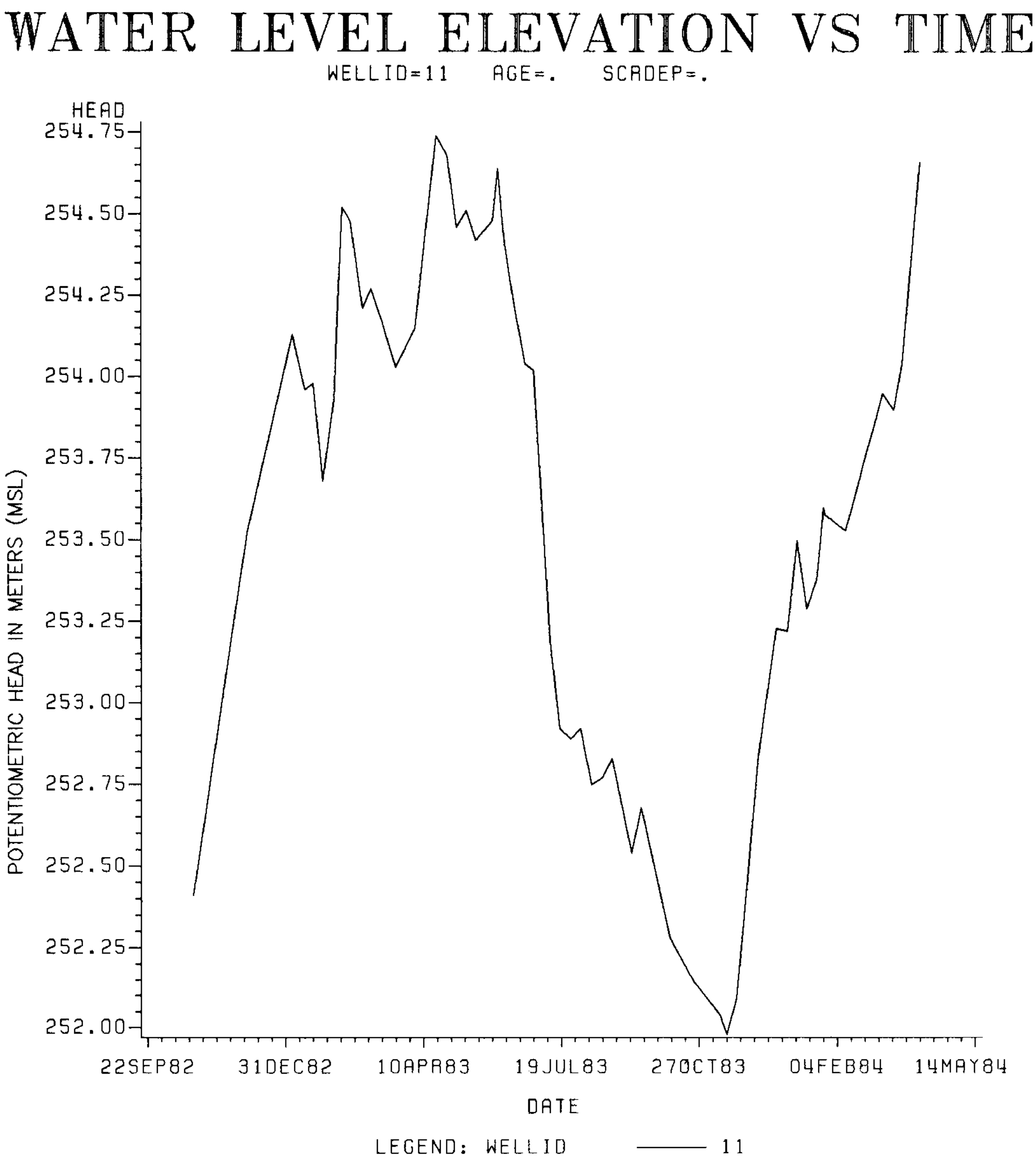
APPENDIX V (continued)



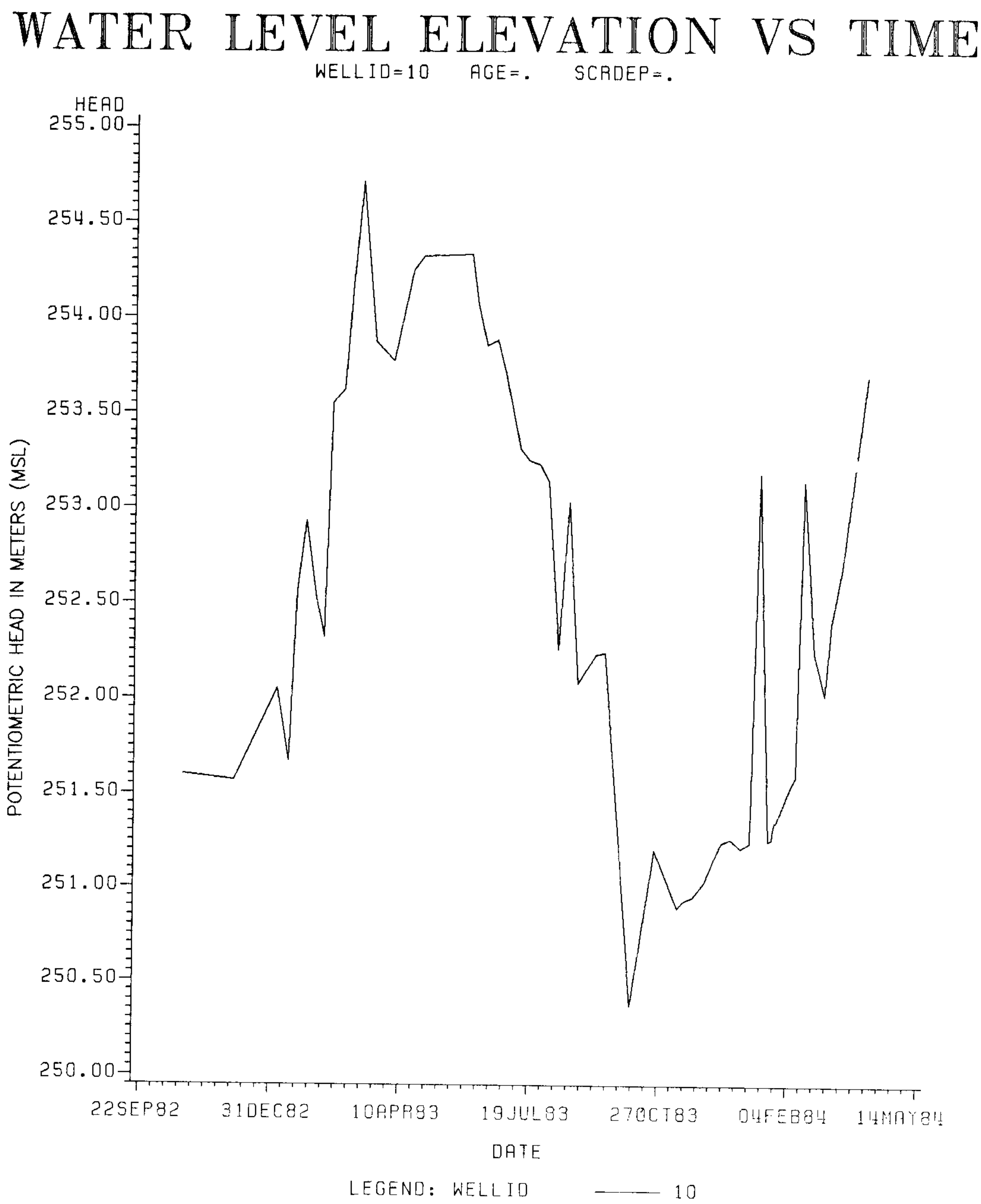
APPENDIX V (continued)



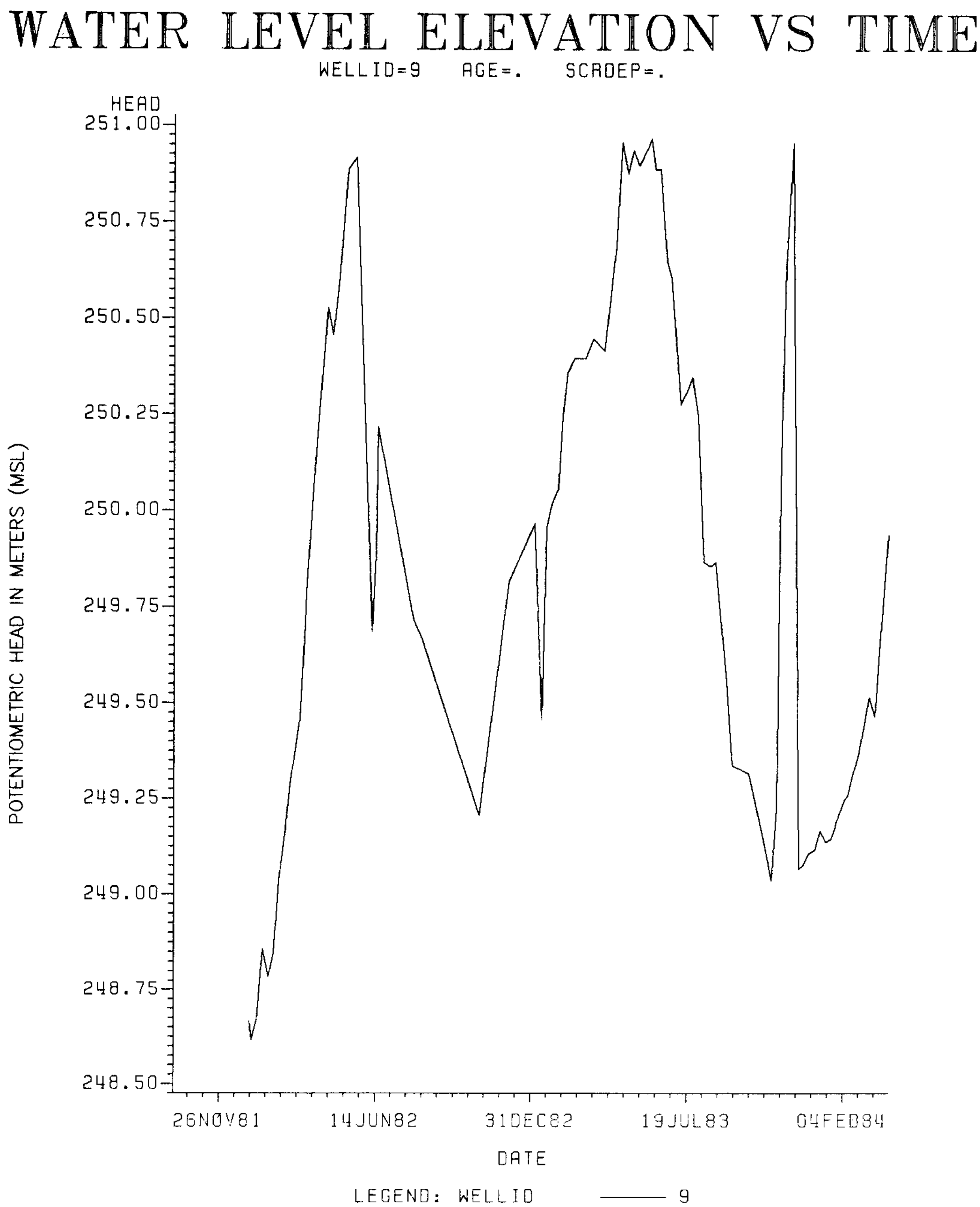
APPENDIX V (continued)



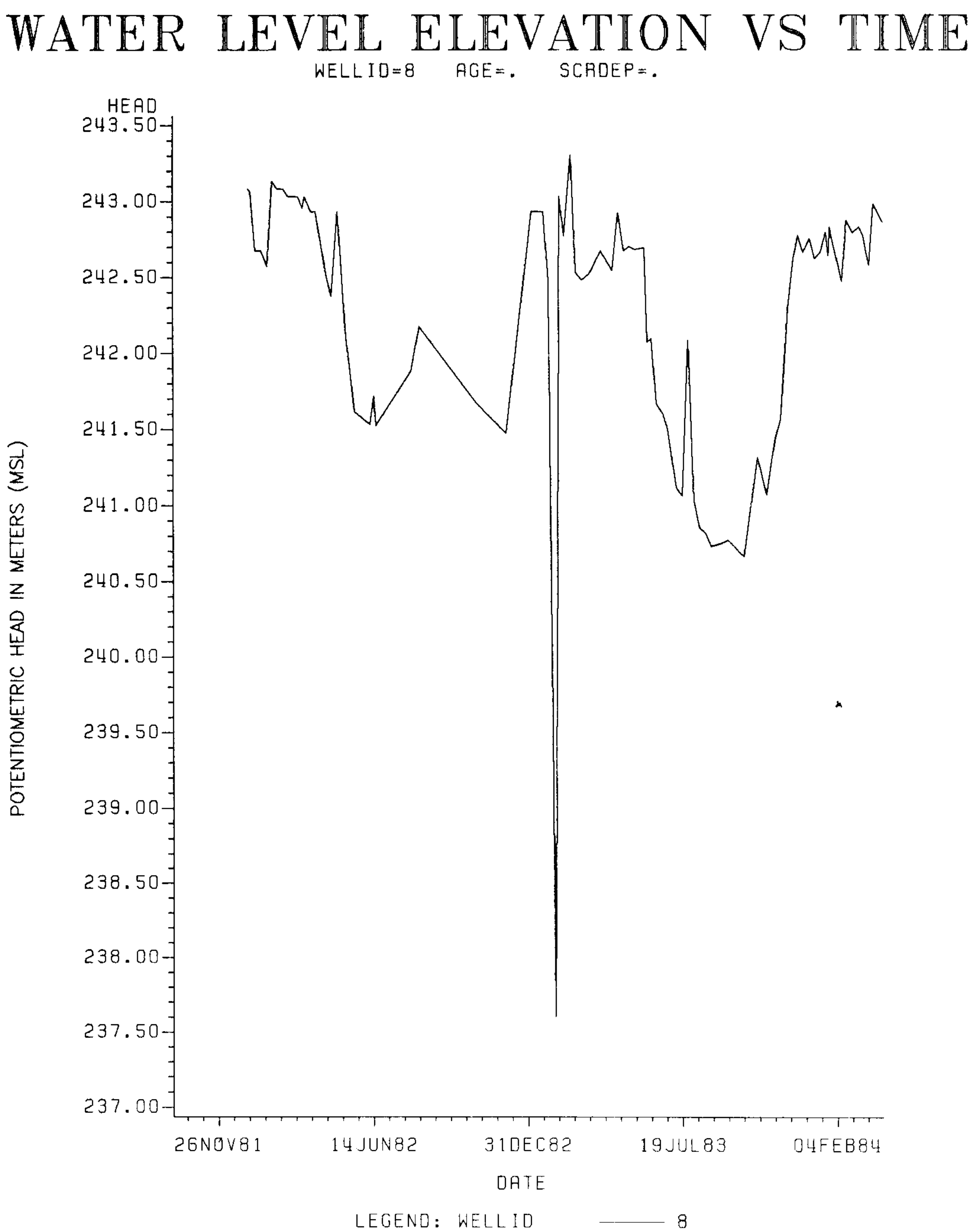
APPENDIX V (continued)



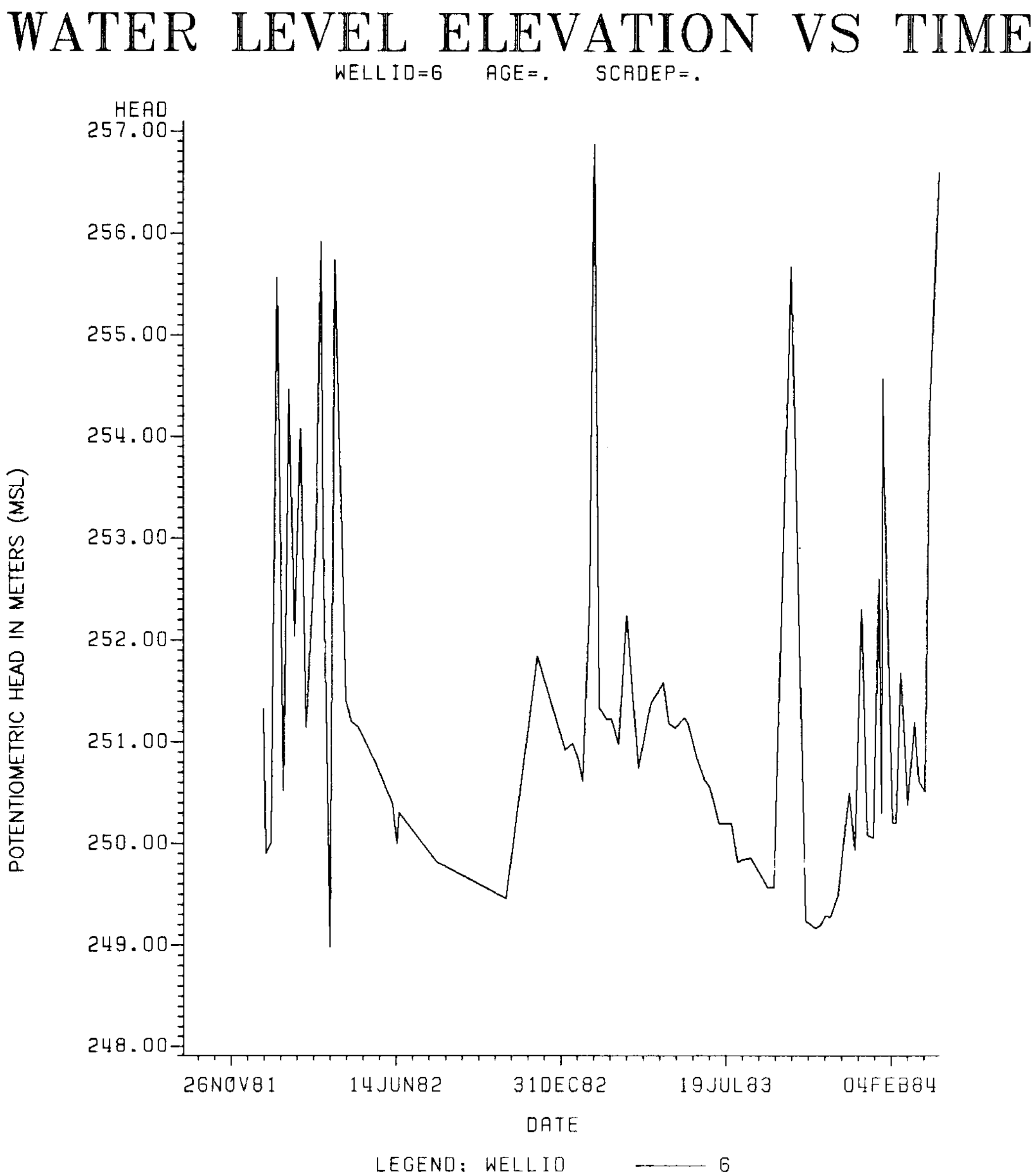
APPENDIX V (continued)



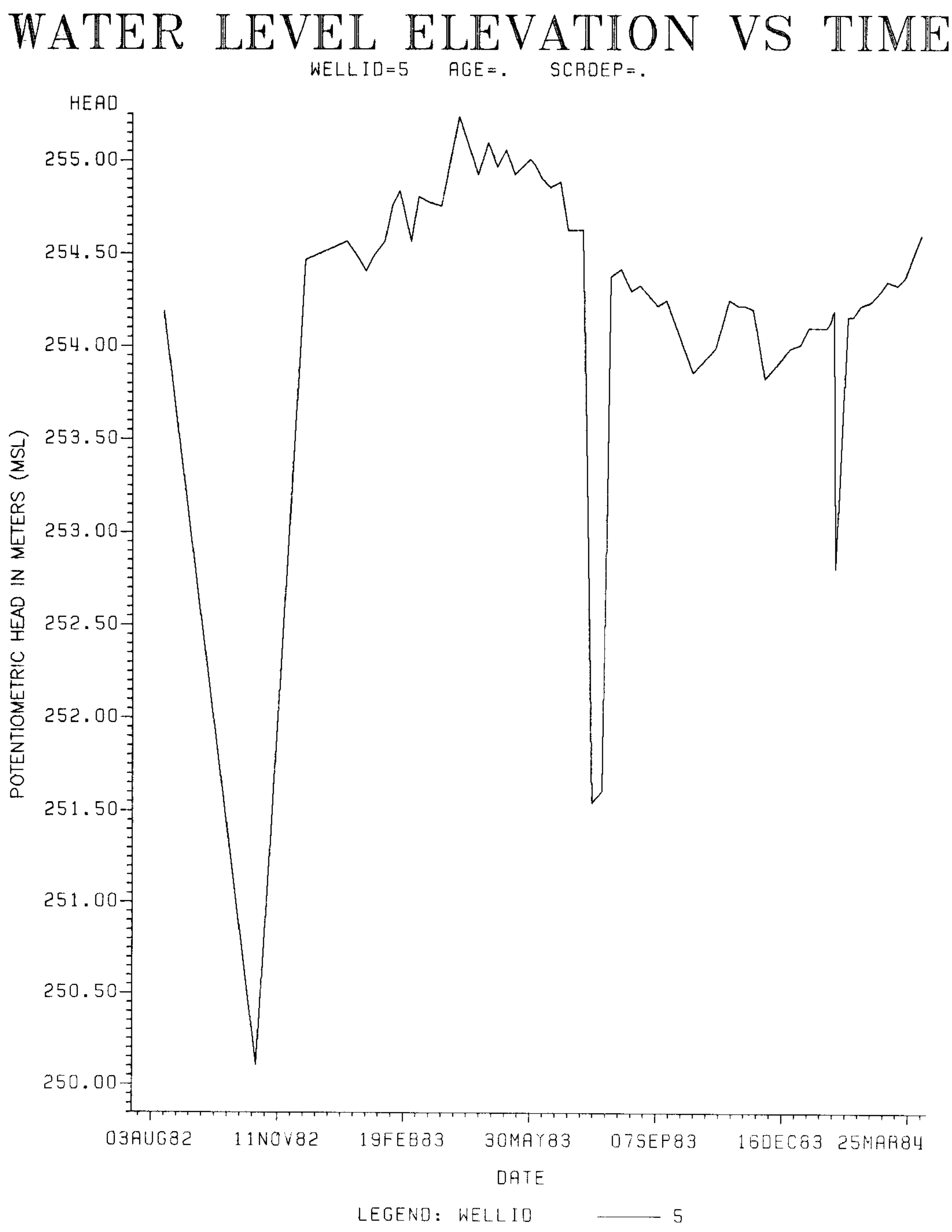
APPENDIX V (continued)



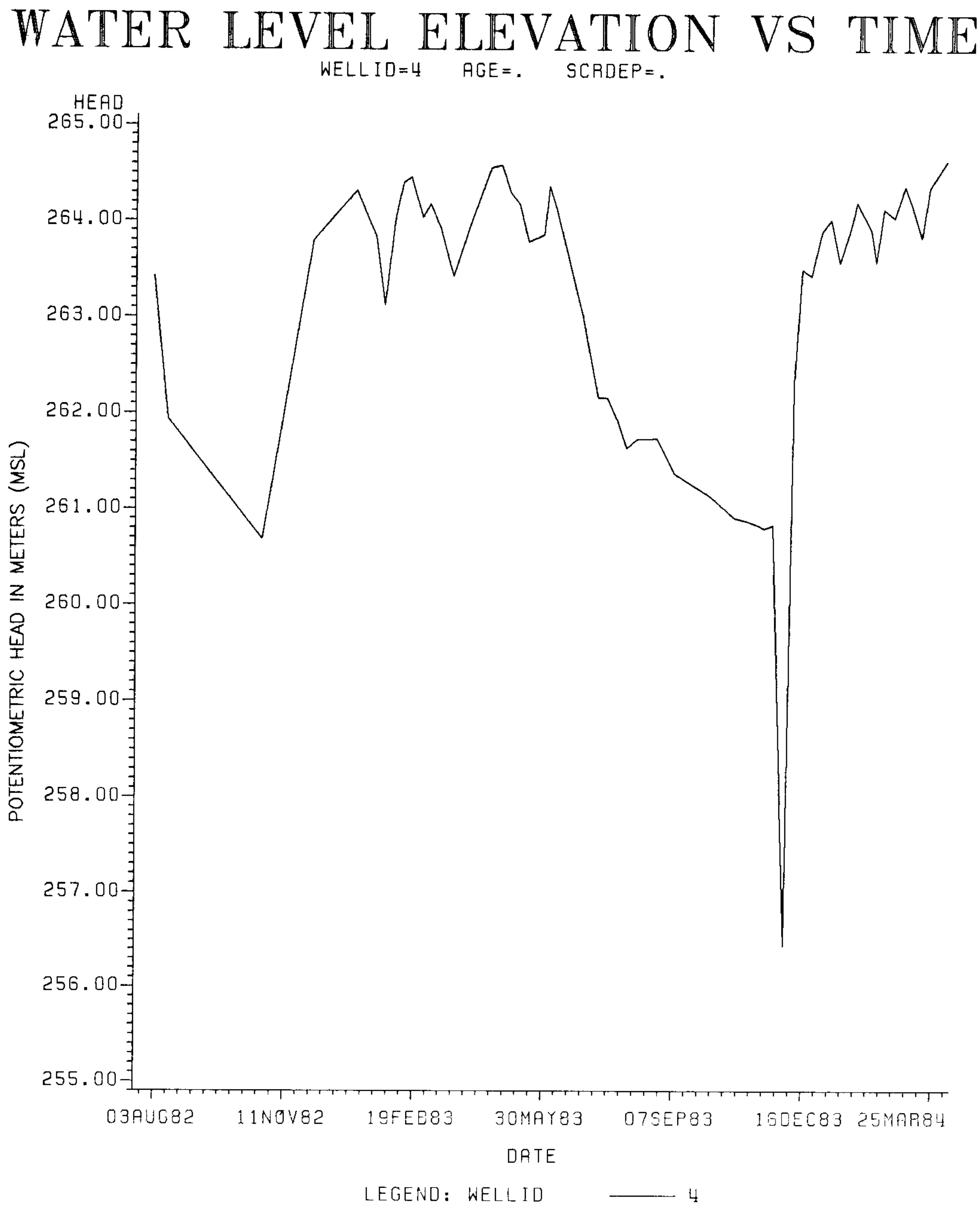
APPENDIX V (continued)



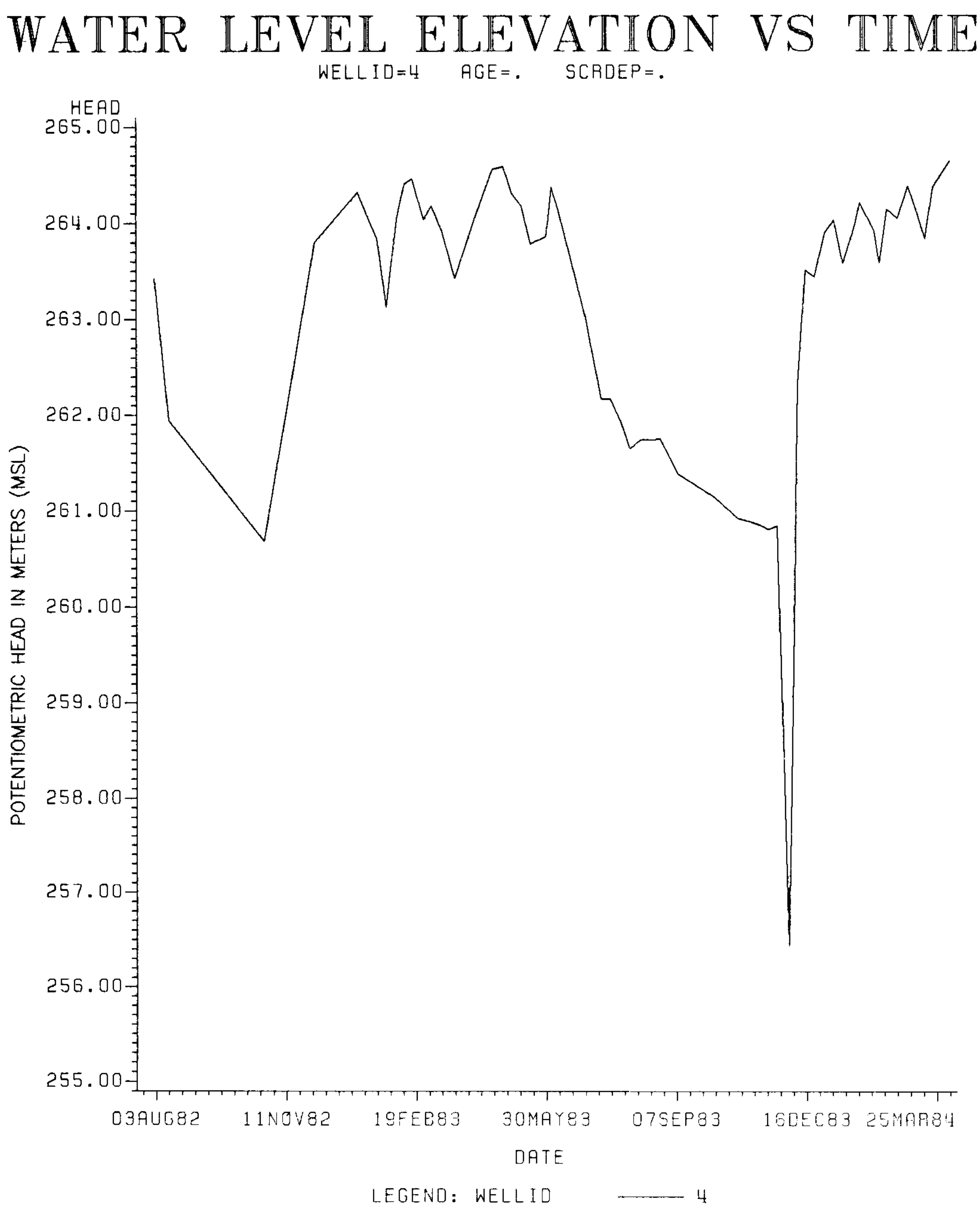
APPENDIX V (continued)



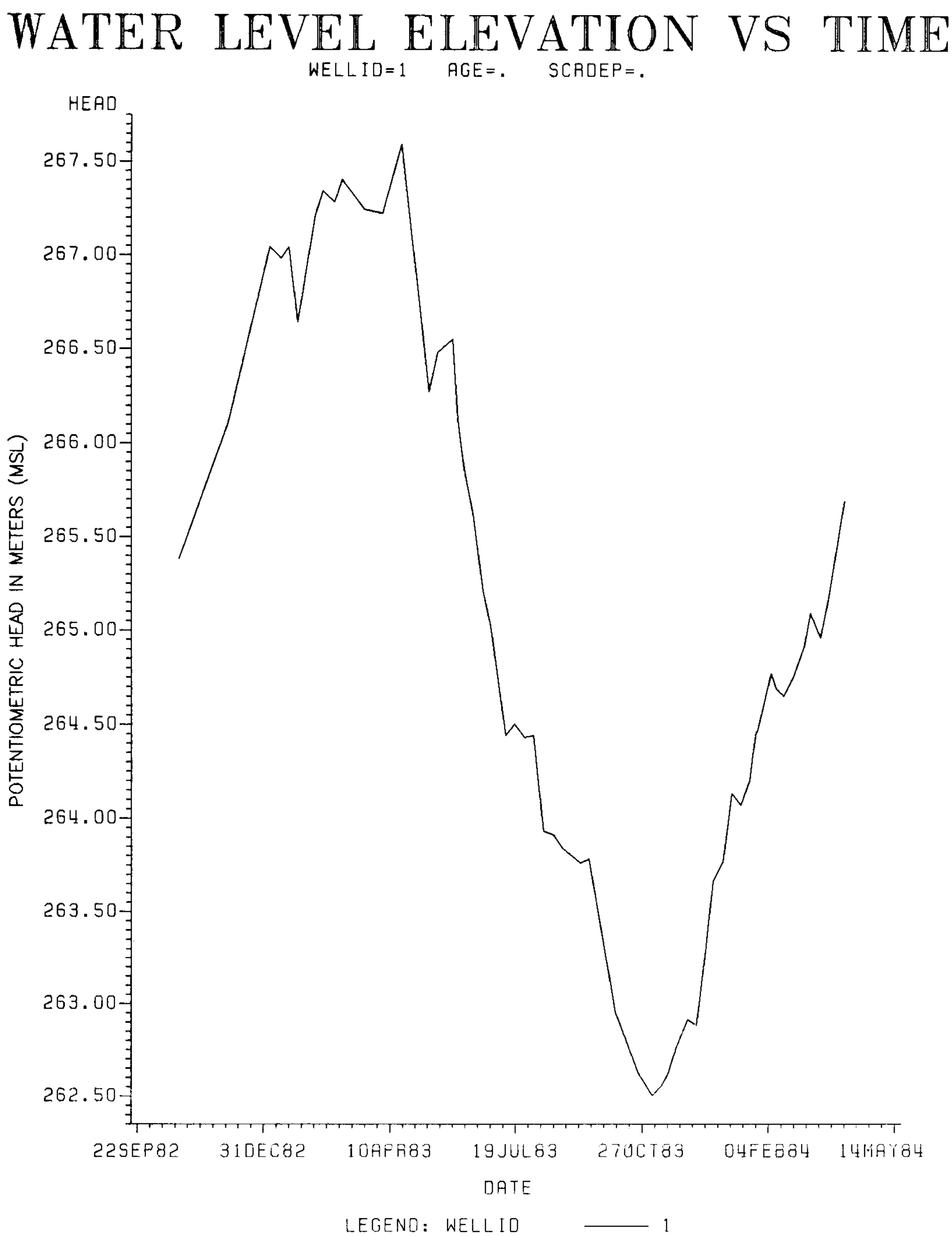
APPENDIX V (continued)



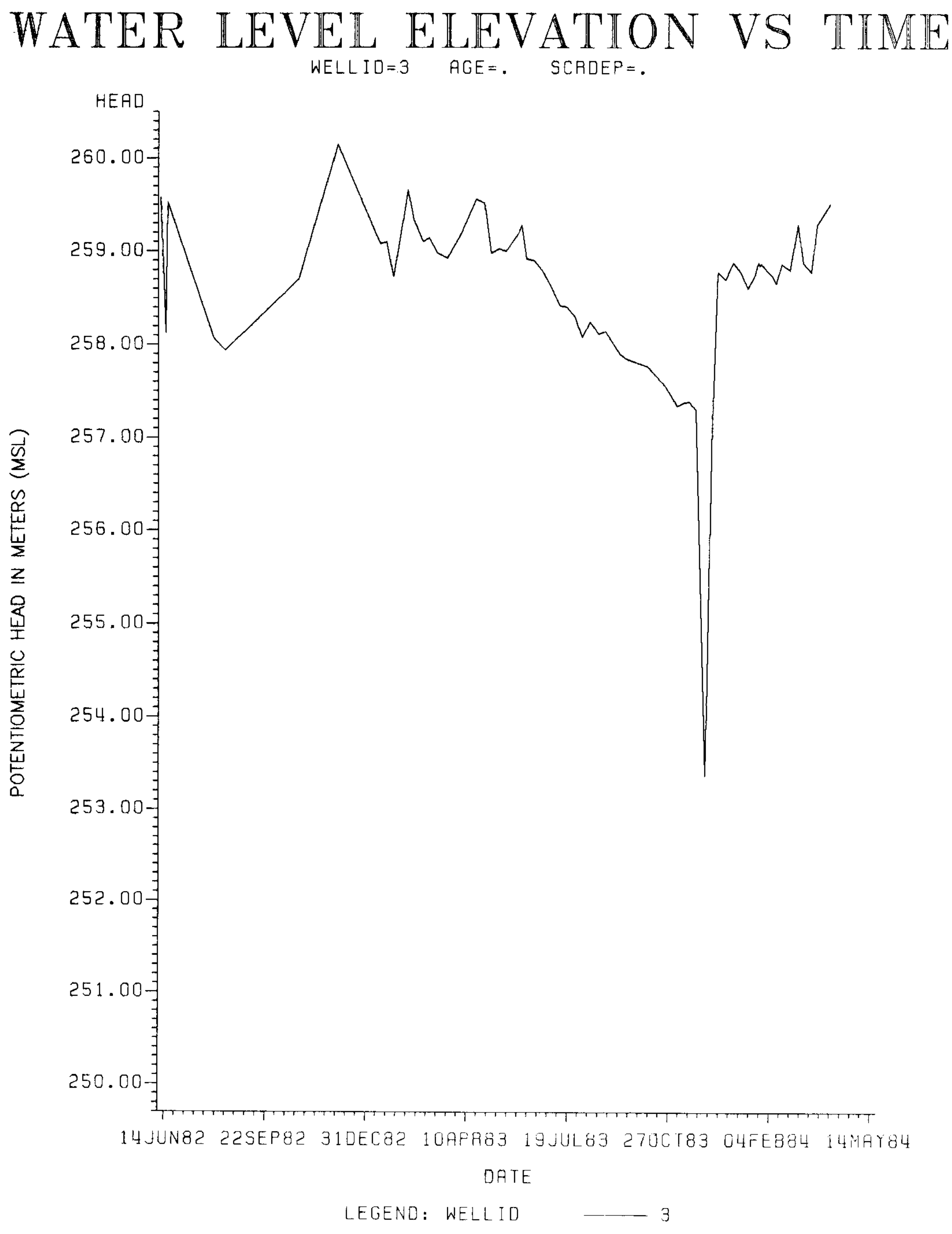
APPENDIX V (continued)



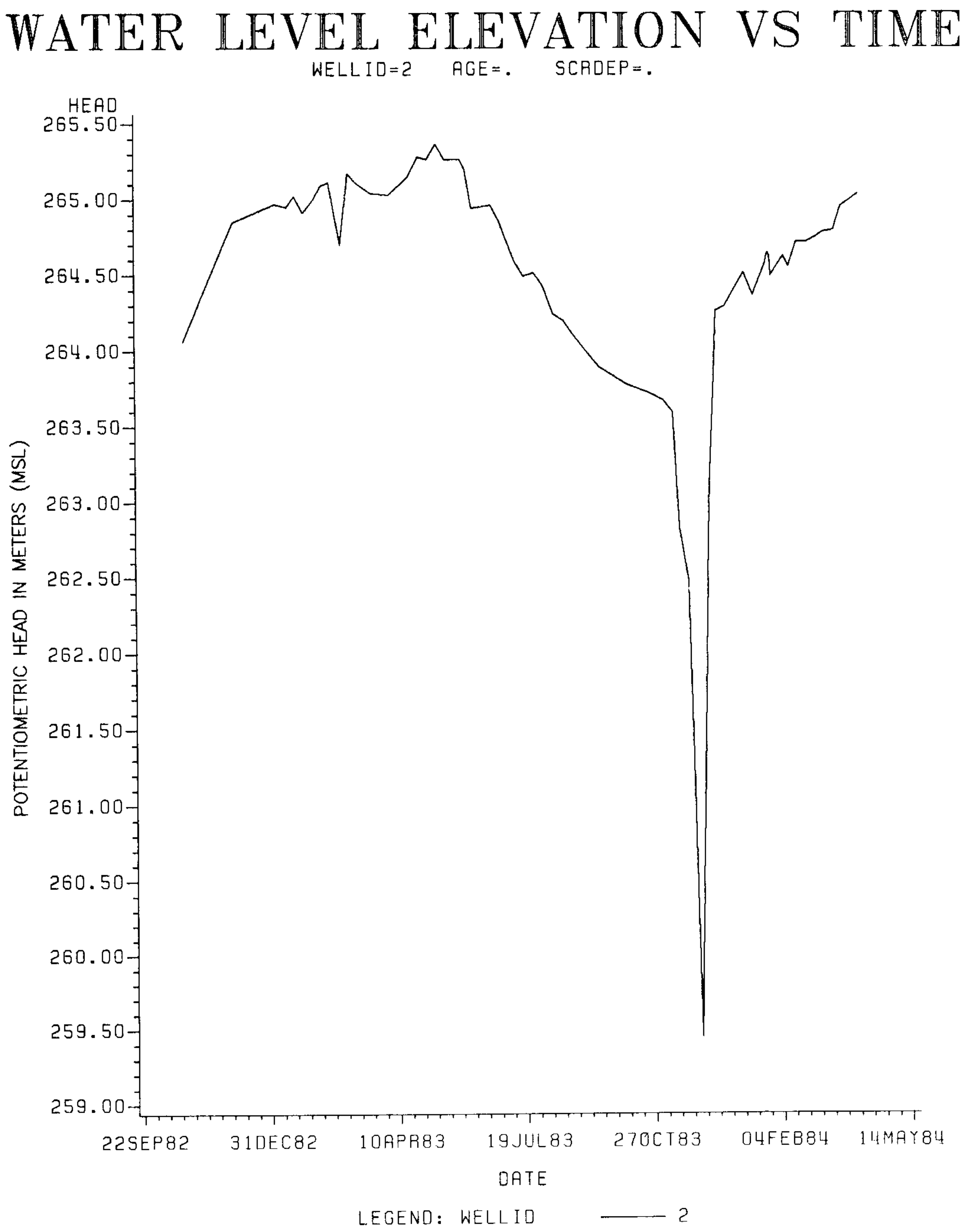
APPENDIX V (continued)



APPENDIX V (continued)



APPENDIX V (continued)



APPENDIX VI

WATER CHEMISTRY DATA

Water Chemistry Data

	Well 1		Well 2		Well 3		Well 4		Well 5		Well 6		Well 7		Well 8		Well 9	
	2/83	10/83	2/83	10/83	2/83	10/83	2/83	10/83	2/83	10/83	2/83	10/83	2/83	10/83	2/83	10/83	2/83	10/83
Al[1]	<0.058	0.121	<0.058	0.412	<0.058	0.078	0.078	0.074	<0.058	0.11		0.083	0.079	0.068	<0.058	0.077	0.093	0.073
B[1]	<0.076	<0.076	<0.076	<0.456	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076		<0.076	0.093	0.46	<0.076	<0.076	<0.076	<0.076
Ca[1]	120	166	52	225	100	76.9	69	78.8	51	73		63.4	26	8.99	50	44.8	38	45.3
Fe[1]	0.25	<0.02	0.074	<0.12	0.079	<0.02	0.1	<0.02	0.071	<0.02		<0.02	0.11	<0.02	0.15	<0.02	0.2	<0.02
K[1]	5	15.4	4	<24	3.4	<4	3.5	4.41	3.3	6.14		<4	4.5	15.5	3.4	<4	2.9	<4
Mg[1]	34	70.5	17	149	24	35.9	10	23.7	13	21.1		6.94	8.3	11.1	6.3	8.97	4.8	6.24
Mn[1]	0.66	<0.001	0.02	0.183	0.028	<0.001	0.084	<0.001	0.22	<0.001		0.211	0.027	<0.001	0.062	<0.001	0.055	0.669
Na[1]	55	63.2	45	58.6	16	10.4	10	5.97	11	6.77		2.52	53	116	7.2	4.48	6.3	2.34
Si[1,2]	9.0	9.14	3.0	3.19	5.4	5.75	5.3	5.9	4.9	6.24		5.09	5.3	6.79	5.3	6.38	6.0	7.86
Sr[1]	0.32	0.503	0.33	0.902	0.24	0.305	0.13	0.264	0.2	0.333		0.111	0.35	0.66	0.14	0.187	0.064	0.062
SO_4[1]	226	380	139	830	75	64	14	16	17	15		14	12	14	6	<5	6	<5
NO_3[1]	<4	<5	<4	<5	<4	<5	<4	<5	<4	<5		<5	<4	<5	<4	<5	<4	<5
NO_2[1]	<2	<1	<2	<1	<2	<1	<2	<1	<2	<1		<1	<2	<1	<2	<1	<2	<1
F[2]	<1		<1		<1		<1		<1				<1		<1		<1	
Cl[1]	7	9	6	21	2	3	2	4	1	2		1	7	7	2	2	2	1
Br[1]	<0.5	<1	<0.5	<1	<0.5	<1	<0.5	<1	<0.5	<1		<1	<0.5	<1	<0.5	<1	<0.5	<1
PO_4[1]	<4	<5	<4	<5	<4	<5	<4	<5	<4	<5		<5	<4	<5	<4	<5	<4	<5
I[1]	<0.5	<0.1	<0.5	<0.1	<0.5	<0.1	<0.5	<0.1	<0.5	<0.1		<0.1	<0.5	<0.1	<0.5	<0.1	<0.5	<0.1
Alkalinity[3]	338	293	162	334	296	216	264		204	216		234	202	257	162	216	134	133
Gross α[4]	1±1	4.2±5.0	.5±.7	5.4±6.1	.8±.8	3.8±4.1	.7±.6	6.2±5.2	.4±.7	1.2±2.8		12±8	.6±.7	23±8	.3±.6	1.8±3.3	.4±.6	2.5±2.9
^{3}H[4]	10±30	57±61	28±31	57±61	48±32	110±60	48±32	94±62	48±32	75±60		110±60	28±31	75±60	48±32	75±60	<30	130±60
^{90}Sr[4]	.50±.21	.10±.15	.27±.23	.10±.15	.03±.12	.20±.15	< .1	.23±.16	.21±.16	.19±.18		.11±.15	.08±.15	.15±.18	.16±.16	.29±.20	.10±.14	.17±.17
^{137}Cs[4]	< .06	< .4	.10±.06	<1	0.57±0.41	< .7	< .04	< .6	< .02	< .5		< .4	<.02	.35±.35	<.06	< .8	< .05	< .6
^{60}Co[4]	< .07	< .5	.77±.12	<1	.14±.06	< .8	3.0±.2	<1	0.35±0.32	< .7		< .5	.070±.030	<5	<.07	<1	<.07	<1

[1] µg/mL
[2] SiO_2 reported as Si
[3] µg/mL as $CaCO_3$
[4] Bq/L

	Well 10		Well 11		Well 12		Well 13		Well 14		Well 15	Well 16	Well 17	Well 18	Melton Branch (South of SWSA 7 input)		SWSA-7 Central drainage (flume)	
	2/83	10/83	2/83	10/83	2/83	10/83	2/83	10/83	2/83	10/83	10/83	10/83	10/83	10/83	10/83			
Al[1]	<0.058	<0.348	<0.058	0.084	<0.035	0.459	<0.058	0.0855	<0.058	0.091	0.364	0.128	0.090	0.097	<0.058	0.179	<0.058	0.084
B[1]	<0.076	<0.456	<0.076	<0.076	<0.046	<0.456	<0.076	<0.076	<0.076	<0.076	<0.456	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076	<0.076
Ca[1]	120	81.4	86	89.7	240	278	25	38.1	110	69.4	141	97.9	52.6	69	39	44	32	58.5
Fe[1]	0.16	<0.12	0.045	<0.02	0.33	<0.12	0.04	<0.02	0.26	<0.02	<0.12	<0.02	<0.02	<0.02	0.097	0.0512	0.12	<0.02
K[1]	6.4	<24	3.3	4.38	19	48	3.3	9.63	6.2	8.64	<24	9.15	5.41	8.13	2.9	5.09	2.9	5.65
Mg[1]	42	60.5	9	10.5	110	144	11	14.2	56	38.1	82.6	51.9	19.9	36.2	5.3	5.21	5.3	7.23
Mn[1]	0.4	<0.006	0.012	<0.001	0.47	<0.006	0.015	<0.001	0.31	<0.001	<0.006	<0.001	<0.001	<0.001	0.027	<0.001	0.19	<0.001
Na[1]	87	35.2	9.4	7.62	200	152	23	26.8	84	15.4	20	17.5	6.17	13.5	10	2.88	10	4.76
Si[1,2]	8.5	5.27	5.5	6.33	8.4	2.44	7.4	8.66	8	5.23	5.19	5.29	5.15	5.35	2.7	3.15	3.5	5.39
Sr[1]	0.68	0.51	0.18	0.207	2.4	2.71	0.66	0.727	0.67	0.335	0.696	0.429	0.196	0.33	0.084	0.0884	0.075	0.122
SO_4[1]	264	210	16	15	1255	1280	13	31	410	110	370	170	26	33	14	13	17	14
NO_3[1]	<4	<5	<4	<5	<4	<5	<4	<5	<4	<5	<5	<5	<5	<5	<4	<5	<4	<5
NO_2[1]	<2	<1	<2	<1	<2	<1	<2	<1	<2	<1	<1	<1	<1	<1	<2	<1	<2	<1
F[1]	<1		<1		<1		<1		<1						<1		<1	
Cl[1]	2	1	4	3	11	13	2	2	3	4	3	5	5	7	4	2	2	2
Br[1]	<0.5	<1	<0.5	<1	<0.5	<1	<0.5	<1	<0.5	<1	<1	<1	<1	<1	<0.05	<1	<0.05	<1
PO_4[1]	<4	<5	<4	<5	<4	<5	<4	<5	<4	<5	<5	<5	<5	<1	<4	<5	<4	<5
I[1]	<0.5	<0.1	<0.5	<0.1	<0.5	<0.1	<0.5	<0.1	<0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.5	<0.14	<0.5	<0.22
Alkalinity[3]	340	289	172	222	211	286	146	161	255	166	298	208	154	232	130	108	108	146
Gross α[4]	1±1	4.2±3.8	.4±.6	3.9±4.1	2± 2	5.3±6.5	.8±.8	3.5±3.9	1± 1	3.0±3.6	1.1±1.8	2.2±2.4	3.6±4.5	3.6±.4.4	.3±.4	3.5±4.2	.4±.4	4.8±5.0
^3H[4]	<3	75±60	10±30	75±60	<30	<60	<30	<60	10±30	<30	<30	8±31	8±31	<30	87±34	37±32	67±33	27±32
^{90}Sr[4]	.12±.14	0.5±.14	.09±.13	.70±.25	.27±.16	.14±.15	.29±/1816	.09±.17	.11±.16	1.3±.3	.05±.15	.04±.14	.48±.23	.22±.17	.10±.12	.25±.19	.06±.12	.32±.19
^{137}Cs[4]	< .06	< .6	<.05	<1	<.05	< .9	< .07	< .6	< .05	< .6	< .3	<.03	<.3	<.3	< .5	< .5	.091±.971	<.7
^{60}Co[4]	< .07	< .1	<.07	<1	.11±.08	<1	.12±.09	<.8	.10±.07	<.6	< .5	<.4	<5	<.06	<.6	<.6	0.87±.081	<.9

[1] μg/mL
[2] SiO_2 reported as Si
[3] μg/mL as $CaCO_3$
[4] Bq/L

Milliequivalents/liter (avg)

Well	Ca	Mg	Na	K	HCO_3	Cl	SO_4	Anion	Cation	Total
1	7.15	4.28	2.57	0.26	6.31	0.23	6.31	12.85	14.26	27.11
2	6.93	6.80	2.25	0.36	4.96	0.38	10.09	15.43	16.34	31.77
3	4.42	2.45	0.57	0.09	5.12	0.07	1.45	6.64	7.55	14.18
4	3.70	1.38	0.35	0.10	5.28	0.08	0.31	5.68	5.52	11.20
5	3.10	1.40	0.39	0.12	4.20	0.04	0.33	4.58	5.00	9.58
6	3.17	0.57	0.11	0.05	4.68	0.03	0.15	4.85	3.90	8.75
7	0.87	0.80	3.67	0.26	4.59	0.20	0.27	5.06	5.60	10.66
8	2.37	0.63	0.25	0.09	2.96	0.06	0.11	3.13	3.34	6.48
9	2.08	0.45	0.19	0.09	2.67	0.04	0.11	2.83	2.81	5.64
10	5.04	4.20	2.66	0.39	6.29	0.04	4.94	11.27	12.28	23.55
11	4.39	0.80	0.37	0.10	3.94	0.10	0.32	4.36	5.666	10.02
12	12.95	10.41	7.65	0.86	4.97	0.34	26.41	31.71	31.87	63.58
13	1.58	1.03	1.08	0.17	3.07	0.06	0.46	3.58	3.86	7.44
14	4.49	3.86	2.16	0.19	4.21	0.10	5.42	9.73	10.69	20.42
15	7.05	6.77	0.87	0.31	5.96	0.08	3.85	9.90	15.00	24.90
16	4.90	4.25	0.76	0.12	4.16	0.14	1.77	6.07	10.03	16.10
17	2.63	1.63	0.27	0.07	3.08	0.14	0.27	3.49	4.60	8.09
18	3.45	2.97	0.59	0.10	4.64	0.20	0.34	5.18	7.11	12.29
Flume	2.26	0.51	0.32	0.11	2.54	0.06	0.32	2.92	3.21	6.13
Melton Branch	2.08	0.43	0.28	0.10	2.38	0.08	0.28	2.75	2.89	5.63

Fraction of total cation content				Fraction of total anion content		
Ca	Mg	Na	K	HCO_3	SO_4	Cl
0.50	0.30	0.18	0.02	0.49	0.49	0.02
0.42	0.42	0.14	0.02	0.32	0.65	0.02
0.59	0.33	0.08	0.01	0.77	0.22	0.01
0.67	0.25	0.06	0.02	0.93	0.06	0.01
0.62	0.28	0.08	0.02	0.92	0.07	0.01
0.81	0.15	0.03	0.01	0.96	0.03	0.01
0.16	0.14	0.66	0.05	0.91	0.05	0.04
0.71	0.19	0.08	0.03	0.95	0.04	0.02
0.74	0.16	0.07	0.03	0.94	0.04	0.01
0.41	0.34	0.22	0.03	0.56	0.44	0.00
0.78	0.14	0.07	0.02	0.90	0.07	0.02
0.41	0.33	0.24	0.03	0.16	0.83	0.01
0.41	0.27	0.28	0.04	0.86	0.13	0.02
0.42	0.36	0.20	0.02	0.43	0.56	0.01
0.47	0.45	0.06	0.02	0.60	0.39	0.01
0.49	0.42	0.08	0.01	0.69	0.29	0.02
0.57	0.35	0.06	0.02	0.88	0.08	0.04
0.49	0.42	0.08	0.01	0.90	0.07	0.04
0.71	0.16	0.10	0.03	0.87	0.11	0.02
0.72	0.15	0.10	0.04	0.87	0.10	0.03

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