Enclosure E

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Attachment 1

Hydrogeologic Characterization Study

NFS Facility, Erwin, Tennessee,

March, 1989

HYDROGEOLOGIC CHARACTERIZATION STUDY
NFS FACILITY, ERWIN, TENNESSEE
VOLUME 1

TECHNICAL OVERVIEW

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1.0 EXECUTIVE SUMMARY

1.1 Overview

License Condition 48 of SNM-124 requires Nuclear Fuel Services, Inc., (NFS), to submit a report describing results and conclusions of a groundwater monitoring program. This condition allows NFS to conduct the groundwater monitoring program, as necessary, to adequately define the detailed hydrological and geological characteristics of the area in the immediate vicinity of the waste water retention ponds in support of pond remediation activities. This report presents findings and conclusions of the groundwater monitoring program in support of License Condition 48.

During the hydrogeologic characterization investigation, existing soil and rock characteristics, groundwater level variations, groundwater occurrence, groundwater/surface water relationships, and water and soil chemistry were evaluated at approximately 65 groundwater and 13 surface water sites in the ponds and general areas of the NFS facility. The information was obtained by:

- Evaluating regional and local hydrogeology.
- Constructing a network of observation wells for measuring seasonal variations in groundwater levels.
- Performing field and laboratory tests to determine soil characteristics.
- Collecting water and soil samples for chemical testing.

The information obtained during the investigation was used to:

- Evaluate seasonal trends in groundwater levels.
- Determine groundwater flow characteristics.
- Determine the effect of geology and physical soil properties on groundwater occurrence.
- Identify groundwater recharge and discharge mechanisms.
- Evaluate the relationship of groundwater and surface water occurrence.
- Determine the distribution, concentration and sources of chemicals in soils and water.
- Identify hydrogeologic and geochemical processes that exert influence on the occurrence of the chemicals beneath the ponds area and plant.
- Evaluate the effects of the pond remediation activities on groundwater and surface water distribution and quality.

Key findings of the hydrogeologic studies are:

- Leachate migrating from Ponds 1-3 occupies an area of limited lateral and vertical extent in the immediate vicinity of the ponds and downgradient beneath a portion of the plant. Field measurements of water chemistry indicate that general chemicals emanating from Ponds 1-3 have not migrated beyond the facility boundary. Radiochemicals occupy a more restricted area within the general chemical plume.
- "Pond 4" has been identified as an area containing concentrated contamination of soils and groundwater. Based on field observations, the type, volume and extent of the wastes in "Pond 4" as well as the distribution of related groundwater contamination is not evident.
- Based on the results of laboratory tests, water from Well 70 located

between the Building 200 and 300 complexes, contains elevated technetium-99 concentrations. Water from Wells 71 and 72 near Building 111 exhibits elevated concentrations of kerosene, tributyl phosphate and radiochemicals. The sources and detailed distribution of chemicals in these areas are not readily apparent from the results of this investigation.

- The waste burial ground adjacent to the ponds area and Banner Spring Branch were determined to be of secondary importance as pathways for current pond leachate migration from the ponds. The majority of the burial ground is up-gradient from Ponds 1-3 and only receives direct effect from the ponds immediately adjacent to Pond 3. The small concentrations of radiochemicals measured in the waters of Banner Spring Branch are not directly attributed to active seepage of pond leachate through the soils.
- Sludge removal from the ponds will reduce the mounding effects exhibited by the groundwater table. Removal of the relatively impermeable sludge materials from the pond bottoms and embankments may increase leakage of pond water into adjacent soils. Any additional decrease in groundwater quality due to sludge removal is expected to be temporary. Pumping of water from the ponds following remediation is expected to recover leachate which does migrate into the adjacent soils during remediation.

1.2 Specific Conclusions

1.2.1 Hydrogeology

Ponds 1-3 were excavated into alluvial soils within the confines of a small stream bed and marsh. The unconsolidated clays, silts, sands and gravels are approximately 9 to 13 feet thick near the ponds and repose as a thin veneer upon the bedrock surface. The unconsolidated deposits are predominantly sand and gravel, and a small buried channel is filled with these relatively permeable deposits adjacent to Ponds 1 and 2 in a downgradient direction. Sand and gravel deposits also occur downgradient from Pond 3.

The unconsolidated deposits are underlain by shales, siltstones, sandstones and carbonate rocks of the Rome Formation. Bedding layers strike northeast-southwest, dip southerly and are highly fractured and folded. The weathered bedrock is broken into small fragments by numerous joints. Major fracture zones cross beneath the site. Enlarged fractures are filled with a mixture of clay, silt, sand and gravel materials to depths of at least 40 feet.

Groundwater occurs in the unconsolidated aquifer under water table (unconfined) conditions and conditions of primary permeability and porosity. Groundwater in the Rome aquifer is under weakly artesian (confined) conditions and its occurrence is controlled by secondary features such as fractures and bedding planes. Both aquifers are hydraulically connected and are relatively permeable. Lateral groundwater movement is generally toward the direction of plant west-southwest. The vertical hydraulic gradient in the Rome aquifer is estimated to prevent downward movement below 40 to 50 feet, or less. The general trend of groundwater movement is interrupted by mounding in the area of the ponds and beneath the operating plant. Groundwater levels quickly respond to intermittent and seasonal rainfall infiltration.

1.2.2 Banner Spring Branch

Measurements of streamflow along Banner Spring Branch confirm that there are neither significant gains nor losses of water in the stream bed between Banner Spring and the confluence of the creek with Martin Creek. Overall, a slight loss of streamflow may occur. The reach of the stream bed above the middle staff gage adjacent to the ponds appears to gain water in response to natural seepage, tributaries and plant water discharges. The stream bed reach below the middle gage may lose water due to natural infiltration. Water quality of the creek water appears to be only slightly affected by active leaching of sediments in the stream bed or by influx of pond leachate based on samples collected during this investigation. However, all water samples and streamflow measurements were collected during very dry climatic conditions.

1.2.3 Geochemical Processes

Uranium isotopes were the most abundant, based on activity measurements of the groundwater beneath the ponds area. The pond water/sludge environment has been determined to have high concentrations of carbonate/bicarbonate alkalinity. In addition, high phosphate concentrations are present. In carbonate/bicarbonate alkaline or phosphate enriched solutions, uranium may form soluble complexes. These complexes appear to have entered the groundwater regime and migrated in the downgradient direction. A relatively low pH zone exists in the groundwater downgradient from the ponds. The low pH water reduces the water alkalinity to very low levels and may cause the uranium to precipitate.

The chemistries of other radionuclides that have been identified indicate that technetium-99 is also mobile. On the other hand, thorium and plutonium isotopes, are relatively immobile.

1.2.4 Migration Pathways

The primary leachate migration pathways that have been identified are sand and gravel deposits in the unconsolidated aquifer, and bedding planes, joint surfaces, and fault planes in the Rome aquifer. The shallow bedrock channel filled with sand and gravel downgradient from Ponds 1 and 2 beneath the plant and an area of sand and gravel downgradient from Pond 3 are estimated to be significant pathways.

The major fracture zones in the bedrock are also pathways for leachate migration. Where steeply dipping impermeable bedrock strata are located downgradient from the ponds, they impede groundwater flow and chemical migration. However, increased chemical concentrations may also occur in these zones. An area of this type is downgradient from Pond 3 and encompasses the area bounded by Wells 11, 12, 30, 31, 36 and 77. In this area, bedrock permeabilities are relatively low and chemical and radionuclide concentrations are elevated for several constituents.

1.2.5 Effects of Remediation

Pond and sludge remediation activities will have a beneficial effect on the hydrogeologic environment beneath the ponds area. Groundwater level mounding effects currently associated with the ponds will be eliminated. The groundwater quality should improve following removal of the source term and flushing of the groundwater system by natural recharge. A slight decrease in groundwater quality immediately adjacent to the ponds may occur during remediation activities. However, pumping of water from the ponds following sludge removal should recover the pond solutions from the groundwater. Banner Spring Branch may also experience a slight, but temporary, decrease in water quality during pond remediation if leachate seepage occurs.

2.0 INTRODUCTION

This report describes the hydrogeology and water quality beneath the Nuclear Fuel Services, Inc. (NFS) Erwin, Tennessee, facility. EcoTek, Inc. as project manager for the ponds area decommissioning project provided study objectives and scope, management and performance of field activities, and data reduction and interpretation. EcoTek was supported during the geologic portion of the investigation and construction of observation wells by Nuclear Assurance Corporation (NAC), working as a subcontractor to EcoTek. This investigation was authorized under EcoTek Work Requests ESD07018.001 and ESD07018.002. The discussion, herein, includes descriptions of geology; physical characteristics of soils; design, construction and operation of a groundwater observation well system; groundwater level variations and flow patterns; soil and rock permeabilities; groundwater flow velocities; interactions between groundwater and surface water; and soils and water chemistry. Study objectives, scope and products are outlined below:

2.1 Objectives

The hydrogeological studies were designed to meet the following primary objectives:

- Review existing hydrogeologic information and collect new data to interpret soil, groundwater, surface water and water quality characteristics to develop a basic understanding of site hydrology.
- Evaluate remedial alternatives for ponds area decommissioning and effects of pond remediation on the hydrological system.
- Design intermediate (during pond remediation) and long-term (post pond remediation) groundwater monitoring plans.

This study was determined to be necessary based on the results of a preliminary review of site hydrogeologic data during fall 1987. The results of the preliminary review are included in the Pond Decommissioning Work Plan submitted to NRC on November 25, 1987. That report proposed that additional hydrogeologic studies were needed to obtain adequate data to evaluate remedial alternatives for ponds decommissioning and to develop a long-term groundwater monitoring program for the stabilization period. This report provides the hydrogeologic information that was required to accomplish the identified objectives.

2.2 Scope of Investigation

The following tasks were required to meet the objectives of the investigation:

- EcoTek performed an extensive data search of internal files; NFS files; and files of private, state and federal agencies as well as review of published and open-file reports. Several site reconnaissance visits were performed between July and December 1987 during the project design phase. Intensive field work occurred between March and October 1988. Laboratory analysis, data interpretation and report preparation occurred from October 1988 to April 1989.

- A network of observation wells was established to measure seasonal groundwater level and quality variations, and the relationship between groundwater and surface water levels. In addition to approximately 33 observation wells that were in place, this investigation installed 32 observation wells and boreholes. Of the total 65 wells, 40 wells are constructed within, or immediately adjacent to, the ponds area. Water levels were measured weekly in all wells and surface water locations in the system.
- Soil permeabilities were measured by field and laboratory techniques. Two long-term constant discharge pumping tests were performed using Wells 67 and 77 and multiple observation wells to determine aquifer characteristics. In addition, approximately 23 wells were tested by the injection (slug) technique. "Undisturbed" soil cores were recovered at two locations above the groundwater table for laboratory testing of permeability.
- Physical characteristics of the soil were measured to determine soil moisture, bulk density and porosity.
- Soil and water samples from boreholes and observation wells were submitted to the analytical laboratory for chemical testing. The soils were recovered by split-spoon sampling from boreholes constructed during this investigation. Water samples from 55 wells and 13 surface water sites in the observation system were collected. Water was collected from the unsaturated zone by lysimeters at three locations. Chemical tests for general chemicals, heavy metals, radiochemicals and organic chemicals were performed.
- Flow measurements were taken in Banner Spring Branch to assist in determining the interaction between surface water and groundwater in the ponds area.
- The data were analyzed to correlate observations of groundwater and surface water occurrence, geology, topography, climate, and soils and water chemistry. In addition, the effects of pond remediation activities on the hydrogeologic regime were identified.

2.3 Products

Listed below are the primary products of the hydrogeologic characterization study:

- Development of a valid hydrogeologic model for the distribution of soils, rocks and water beneath the facility.
- Identification of regional and local hydrogeologic conditions affecting the ponds area.
- Measurements of seasonal and diurnal variations in groundwater and surface water levels.
- Determination of groundwater and surface water flow characteristics beneath the ponds area and facility.
- Measurements of physical and chemical properties of soils and water.
- Identification of the distribution and concentration of leachate migration within and from the ponds area.
- Determination of hydrochemical systems and migration pathways controlling leachate composition and distribution.

- Identification of the effects of pond sludge removal activities on the hydrogeologic regime.

3.0 BACKGROUND

3.1 Project History

Prior to 1978, NFS used three ponds (Ponds 1-3) to retain liquid wastes generated from plant processes. The liquids collected were discharged from the ponds into Banner Spring Branch after settling of sediment. During 1978, the NFS waste water treatment plant was constructed and use of Ponds 1-3 was discontinued. A fourth disposal area ("Pond 4") also occupied a depression within the ponds area in which miscellaneous plant wastes were disposed during early days of facility operation.

Beginning in 1984, NFS monitored both groundwater and surface water to detect potential chemical migration from the ponds and the waste burial ground in accordance with Condition 48 of License No. SNM-124. Condition 48 required regular sampling of 14 groundwater monitoring wells and approximately six surface water locations, and analysis of the water samples for radioactivity and certain general chemical parameters. Action limits for investigation and reporting were also established.

During November 1987, a plan for decommissioning a portion of NFS Erwin Plant facilities was submitted to the U. S. Nuclear Regulatory Commission (USNRC). One of the areas to be decommissioned included the waste water retention ponds. Based on a review of the results of previous investigations, NFS determined that additional information was needed to: adequately define the pond sediment matrix; characterize the ponds area, including hydrogeology; and identify alternative remedial technologies.

One of the first tasks under the NFS project plan for pond closure was to conduct a hydrogeologic characterization investigation in the area of the ponds. The specific objectives of the investigation included the determination of hydraulic gradients, aquifer hydraulic characteristics, soil and water chemistry properties, and potential groundwater flow patterns. NFS indicated that although the existing monitoring wells (specified by Condition 48) in the ponds area had been sampled in detail in past years, the sampling had not allowed NFS to obtain the desired hydraulic parameters to support pond remediation activities.

Therefore, on April 28, 1988, NFS requested that Condition 48 be amended so that NFS would have a more flexible groundwater monitoring program relative to locations of wells, measurement frequency and analytical parameters prior to and during the period of pond decommissioning. On July 20, 1988, NRC amended Condition 48, per the NFS request.

This investigation formally began during late March 1988. Construction of new observation wells continued through mid-July 1988. Water level measurements were collected from March 1988 to February 1989. Aquifer testing and water quality sampling primarily occurred between late July and October 1988. Laboratory testing, data analysis and report preparation continued through April 1989. The total elapsed time for the study to be completed was 13 months.

3.2 Site Description

The NFS facility is located on Banner Hill Road within the city limits of Erwin, Unicoi County, Tennessee. The facility is immediately west of the unincorporated community of Banner Hill (Figure 3-1).

The NFS site encompasses 57.2 acres. The plant facility protected area occupies approximately 21 acres within the site boundary. The site is bounded on the east and south by Banner Hill Road and privately-owned residences. On the south, the housing density is relatively low as the houses occupy tracts of approximately three to five acres. The CSX Railroad right-of-way parallels the site boundary on the west. A light industrial park is located opposite the site on the other side of the railroad. Martin Creek bounds the site on the north, with privately-owned, vacant and low-density residential land on the opposite side.

The site is located at the base of the valley wall (hill slope) in a relatively narrow segment of Nolichucky River valley, approximately 300 yards from the main channel. Surface drainage from the site primarily flows into Banner Spring Branch, which is tributary to Martin Creek. Martin Creek is tributary to North Indian Creek, which enters Nolichucky River approximately 1.5 miles downstream from the site boundary. The surrounding upland region is rugged, with mountains rising from an elevation, at the site, of approximately 1,650 feet to elevations ranging between 3,500 and 5,000 feet within a few miles.

NFS operates nuclear fabrication and scrap recovery processes at the Erwin facility. Since beginning operations in 1957, a variety of processes have been used. Current activities, as well as those that are discontinued, include:

- Conversion of uranium hexafluoride to uranium oxides.
- Conversion of uranium hexafluoride to uranium tetrafluoride and to uranium metal.
- Production of fuel containing highly enriched uranium.
- Fabrication of fuel pins or rods containing pellets of uranium and/or thorium oxides.
- Recovery of thorium, low-enriched uranium and highly-enriched uranium, either internally generated or generated at other facilities.
- Production of thorium metal, metal powder and metal pellets.
- Production of mixed oxide fuel.

Of primary interest to this study are three waste retention ponds that were used from startup of operations until 1978 (Figure 3-2). Ponds 1 and 2 were constructed from 1957 to 1958, and Pond 3 was constructed during 1963. Ponds 1 and 2 were created by constructing earthen embankments across the former channel of Banner Spring Branch. The unlined depressions immediately upstream quickly filled with water due to the marsh like conditions of the stream channel. Pond 3 was excavated to a depth of approximately six feet, is enclosed by low earthen berms, and is unlined. The sludges are located below the water table in Pond 1 and the lower few feet of the sludges are below the water table in Ponds 2 and 3.

Ponds 1-3 received waste liquids and suspended solids from plant processes at volumes as great as 20,500 gallons per day (Table 3-1 and Figure 3-3). Approximate total capacity of the three basins is 1.6 million gallons. The details of pond operation are not known. However, the ponds were used as stilling basins where suspended solids were allowed to settle. Most waste solutions were routed directly to Ponds 2 and 3, where they were allowed to settle before being transferred to Pond 1 by controlled gravity. Most discharge of clarified water to Banner Spring Branch is believed to have occurred from Pond 1 at a controlled rate. Since the ponds are unlined, hydraulic communication with and seepage to groundwater occurs.

The ponds area contains a buried 55 gallon drum on its perimeter adjacent to the 110 Building that previously contained chemical wastes from the plutonium laboratory. This drum will be removed as a portion of decommissioning of the plutonium facility. Also, wastes and residues are buried at shallow depths in a portion of the former channel of Banner Spring Branch near the incinerator pad within the ponds area ("Pond 4"). Little is known of the composition and distribution these materials. Previously, TLG Engineering performed geophysical studies to attempt to define their boundaries. This investigation has identified the need to further characterize the "Pond 4" area based on the soil and water chemistry results.

In addition to the waste retention ponds, and other activities within the ponds area, the facility comprises numerous process buildings and units, process pipelines, chemical and raw materials receiving and storage areas, wastewater facility, incinerators, storm runoff sewers, buried utilities and solid waste burial pits. The historical and current operation and maintenance of these facility components are relevant to the scope of required decommissioning activities in the ponds area. Figure 3-4 shows the outfall locations of liquid effluents currently released from the plant site.

The plant obtains the major portion of its water supply from the city of Erwin. Therefore, significant withdrawals of groundwater from beneath the plant are not known to have occurred. Banner Spring, located along the southeastern site boundary, discharges water into Banner Spring Branch within the ponds area.

Banner Spring Branch crosses the ponds area between Ponds 1 and 2 on one side, and Pond 3 on the other side, entering Martin Creek about 1,500 feet downstream. The current position of Banner Spring Branch is altered from its original position. Initially, the creek crossed the site in the area now occupied by Ponds 1 and 2. When the ponds were constructed, the channel was straightened through the ponds area and flowed directly from Banner Spring to the northwestern site boundary. Subsequently, during 1966, the lower portion of the channel was re-routed to leave the facility through the northeastern site boundary, rather than the northwestern boundary.

In early years, storm drainage was allowed to infiltrate or runoff without control. Based on the land slope, runoff was toward the west and north. Since approximately 1983, storm runoff has been controlled by storm drains that discharge at three locations into Banner Spring Branch within the ponds area.

Raw materials commonly imported to the plant site are presented in Table 3-2. Materials have been received at and transported from the facility by both truck and rail car. Major products produced by the facility and associated processes have been previously summarized.

Available records at the facility were reviewed and informal discussions were held with plant personnel for evidence of leaks and spills of chemicals. However, detailed information on the type and volume of spilled chemicals was not available.

Chemical leaks and spills that have occurred within the ponds area may be inferred from the available data. Chemical leaks have occurred in the form of leachate seepage through the unlined floors of Ponds 1-3. Also, leachate seepage that previously occurred beneath the eastern berm of Pond 2 and eastern and western berms of Pond 3 is a potential cause of chemicals in the groundwater. In addition, the buried materials in the vicinity of the incinerator ("Pond 4") contribute to groundwater contamination in that portion of the ponds area. Leakage from the waste solution storage tank near the plutonium laboratory or chemical pipe rack may have contributed to soil and water contamination in that portion of the ponds area.The effects of buried utilities, including storm sewers, sewer lines, water lines and waste solution discharge pipes, are largely unknown.

3.3 Review of Historical Data

3.3.1 Introduction

Historical data for this hydrogeologic evaluation were collected from approximately 20 published and open-file references. In addition, numerous NFS file data and project correspondence were reviewed. The regional and local geology were evaluated using results of field investigations on NFS property, geologic logs of water wells in the area, and published and unpublished reports (Appendices B, J and K). The historical data reviewed are briefly discussed below.

3.3.2 Geology

Forty soil borings were known to have been drilled on the site since 1983 at the time field work began. These borings were converted into observation wells at 35 of the drilling sites (4 wells installed in 1983 and 10 wells installed in 1984 by NFS; and 21 wells installed in 1986 by TLG Engineering). Of the remaining five borings, four were backfilled and surface casing was installed in one boring intended as a bedrock observation well. This well was completed as Well 76 during this investigation. Subsequent, to initiating this field investigation it was determined that more than 80 additional boreholes had been drilled beneath the facility, but none were completed as wells.

The historical soil borings ranged in depth from approximately 5 to 39 feet and the technical information from each boring has been considered during this investigation. Soils were sampled and described from all borings. The borings by TLG Engineering were sampled in great detail and samples collected from approximately one meter intervals were tested in the laboratory for radiochemicals and heavy metals. Testing of the soils in the laboratory for physical characteristics, such as permeability, is not known to have been performed. The results of this investigation have corrected many of the soil descriptions made by TLG based on more complete information.

The historical monitoring wells were completed by installing either two or four-inch diameter PVC and galvanized steel pipe in the boreholes. The screened interval normally fully penetrates the water bearing zone, extending from the water table to bedrock. The screens are gravel packed with an overlying bentonite seal. Above the bentonite, grout extends to the ground surface. Although it is reported that the wells were developed following construction, the reported turbid appearance of water collected from the wells indicted that development may not have been adequate.

The site topography of the NFS facility was surveyed prior to this investigation. In addition, the elevations (Z coordinate) of previously constructed monitoring wells had been measured.

3.3.3 Hydrogeology

The hydrogeology was initially evaluated using published literature, for the regional aquifers, and the data collected from the on-site observation wells, for the local shallow hydrogeology. In addition to the existing observation wells, the geologic logs from the soil borings were reviewed for notes on seepage and stabilized water levels in the borings.

Even though as many as 14 monitoring wells were installed and in operation since 1983-84, only four distinct sets of water level data were identified for the period 1983 to 1986. Measurements collected in January 1984, January 1985 and April 1985 are presented as maps in various source documents but are not supported by field notes. These measurements were collected for the 14 original NFS monitoring wells. December 1986 measurements by TLG Engineering are adequately documented, but include only the more recent TLG Engineering wells. Adequate historical data were not available to determine the direction and gradient of groundwater flow.

Slug tests were performed by TLG Engineering in several of the monitoring wells to evaluate the approximate horizontal permeability of the aquifers. In addition, a "long-term" pumping test was performed. Based on review of the test data, many analytical inconsistencies are inherent. Therefore, these data are not used this evaluation.

Surface water flows have been estimated in the literature for Nolichucky River, Martin Creek and Banner Spring Branch based on field gaging of flows.

3.3.4 Water Quality

Water samples are collected monthly by NFS from selected monitoring wells and daily from surface water stations. Beginning in 1981, Well A (former domestic well near Well 1) and Well B (shallow well near Building 303) were sampled. Sampling of Wells 1-14 began in 1983-84 and has continued through the present. During fall 1987, sampling of the wells installed by TLG Engineering was begun by NFS. Extensive sampling of surface water began during 1981; although some sampling was performed as early as 1968.

3.3.4.1 Surface Water. Surface water sampling has been performed on Banner Spring Branch, upstream and downstream from the ponds area; Martin Creek, upstream and downstream from its confluence with Banner Spring Branch; and Nolichucky River, upstream and downstream from its confluence with Martin Creek/ North Indian Creek. Sampling has occurred on at least a monthly basis since 1981. It has been reported that additional sampling was performed for the period 1959 to 1980. However, the only records reviewed for this period were for the years 1968 to 1971.

The samples of water historically collected from the wells and streams have been analyzed for gross alpha, gross beta, nitrate, ammonia, fluoride and mercury. If reported concentrations of any of these parameters were above prescribed limits, appropriate followup investigations were conducted, including testing of selected isotopes.

Other than the above chemical parameters, data for general chemicals, heavy metals, and organic chemicals in groundwater and surface water are available only on a limited basis for the site. Data for these parameters that are available have been collected during 1984, or later.

Gross alpha and gross beta concentrations in Banner Spring Branch are presented for the years 1981-86 in Figure 3-5. Gross alpha and beta concentrations decreased during the period 1981-86 (Figure 3-5). A sharp increase in gross alpha concentration occurs during January/February of each year. However, the reason for this occurrence is not apparent. The data prior to 1984 are potentially indicative of inconsistent sample collection procedures (i.e., unfiltered vs. filtered). In addition, laboratory instrumentation and procedures were upgraded during 1981-86.

As for the Banner Spring Branch data, water tested from the waste disposal ponds has decreased in gross alpha and beta concentrations in recent years. However, concentrations of gross alpha were still as high as 37,300 pCi/l in Pond 3 in 1983 (NFS Files, 1986), indicating that pond water quality is influenced by the sludges. Historical general chemical data for pond water is not readily available. However, samples collected during December 1987 resulted in parameter concentrations, in mg/l, as follows:

Pond	Fluoride	Chloride	Sulfate	Nitrate	Ammonia
1	20	100	6700	<0.1	1.9
2	94	37	1800	<0.1	1.8

3.3.4.2 Local Groundwater. Prior to 1984, on-site groundwater monitoring consisted of sampling two wells. One of these wells is a former domestic supply well (Well A) near Well 1. The other well (Well B) is located between two 6,000 gallon underground waste storage tanks north of Building 303. Beginning in 1984, Wells 1-14 were constructed and regularly sampled. Sampling of the 21 wells installed by TLG did not begin until fall 1987.

Table 3-3 presents annual average and quarterly composite groundwater radioactivity for Well B near Building 303. The radioactivity measured in the well is above background for the area, the value of which is defined subsequently, herein, as less than 1 pCi/l. The average concentration of uranium in liquid wastes in the tanks was about 0.94 mg/l (94,000 pCi/l) in 1985 (NFS Files, 1986). Non-radiological parameters, such as ammonia and fluoride, are also reported to be elevated in concentration. Therefore, tank leakage could have caused the contamination.

Wells 1-14 (exclusive of Wells 7 and 9, which are abandoned) have been tested historically on a monthly basis for gross alpha and gross beta radioactivity and for ammonia, nitrate, fluoride and mercury. The results of tests indicate that Wells 1, 4, 7, 11, 12 and 14 contain water with elevated radiochemical concentrations. In 1984, the average gross alpha radiation for Wells 4, 7, 11, 12 and 14 was 74.8, 15.9, 168.4, 458.8 and 760 pCi/l, respectively (NFS Files, 1986). These values are significantly higher than the background gross alpha value of 0.4 pCi/l (NFS Files, 1986) measured in water from Banner Spring during 1983.

Wells 1 and 4 have been shown by this investigation to be hydrologically related to the burial ground area. Well 7, currently abandoned, was located in the contaminated soil area within the former channel of Banner Spring Branch. Water in Wells 11, 12 and 14 contains elevated concentrations of radiochemicals most probably due to leachate seepage through the embankments of Ponds 2 and 3.

4.0 METHODS

The study methods utilized in this investigation are described below. Procedures are summarized for hydrogeologic evaluation, soil sampling and testing, observation well network design and construction, measurement of groundwater levels and soil permeability, stream gagings and collection of water samples. Details of field procedures are included in Appendix L.

4.1 Hydrogeologic Evaluation

Initially, reports of previous site-specific geological and hydrological investigations were reviewed to obtain a preliminary understanding of regional and local geology and hydrogeology. During the investigation design phase, several reconnaissance visits were made to the facility to determine the general hydrogeologic properties of the surficial unconsolidated soils and bedrock. Detailed characteristics of the soils and groundwater were determined during the boring and soil testing programs.

4.2 Soil Sampling and Testing

Soil and bedrock samples were collected during March to July 1988 from 32 boreholes used for construction of the observation wells (see section 4.3, below) to test a range of physical and chemical characteristics. Physical soil measurements at two locations included:

- Bulk density
- Moisture content
- Permeability
- Specific gravity (total porosity)

The soil samples were recovered at locations near Wells 64 and 74. Additional soil recovery attempts were unsuccessful due to resistance to penetration of the sampling device. Soil samples for the tests were recovered from various intervals within the 5.5 feet immediately below ground level. Soil was recovered in an aluminum sampling tube (Shelby tube) 3-inches in diameter and 24-inches in length. Before sampling the soil, a borehole was drilled to the top of the subsurface zone of interest. Then the tubes were gently pushed by the drill rig vertically into the undisturbed soil below to the desired depth. The tubes were then pulled out of the ground with the recovered soil inside and sealed with plastic end caps and tape to prevent moisture loss. Samples were gently handled and kept cool during transmittal to the testing laboratory (Chen and Associates, Denver, Colorado).

4.3 Observation Well Network Design and Construction

An observation well network was installed to determine physical subsurface soil and bedrock characteristics, hydrologic and hydraulic characteristics of the aquifers, seasonal groundwater level variations, groundwater occurrence, and to collect samples for groundwater quality testing. A total of 32 boreholes were drilled with a Speedstar 5000 air rotary drilling rig equipped with a pneumatic hammer, and 29 observation wells were installed.

The location of each observation well was coordinated at the NFS facility with EcoTek/NAC investigators and the NFS project managers. Based on the goals of the project, observation well locations were selected that test a wide range of hydrogeologic conditions. These conditions include:

- Unconsolidated soils and bedrock
- Seasonal variations in groundwater levels
- Relatively steep and shallow groundwater gradients
- Soil and bedrock permeability
- Groundwater quality

The observation wells were designed and constructed to be functional under water table and artesian conditions for the primary uses of water level measurement, aquifer testing and water quality sampling. The locations of wells constructed during this investigation as well as historical wells in place during the field work are shown in Figure 4-1. A summary of well construction characteristics for each well is included in Table 4-1. Details of well construction, including a geologic log of each borehole, are included in Appendices A, C, D, E and F.

The original scope of the drilling program consisted of constructing 18 to 20 wells. Based on the available results of previous drilling at the site, the initial program was primarily designed to characterize the unconsolidated alluvial soils overlying the bedrock. During the drilling program it was determined that bedrock occurs at shallower depths than expected. Strong hydraulic connection between the unconsolidated sediments and the bedrock was identified. Therefore, the scope of the program was expanded to include a total of 29 wells. The additional wells were used to test shallow and deeper bedrock water.

All borings were drilled with a truck-mounted air rotary drilling rig. Drilling water was obtained from the on-site potable water supply system. Also, water from the potable supply system was used to steam clean drilling equipment between borings. Drilling began in the up-gradient direction to reduce the potential for cross-contamination of boreholes. Undisturbed soil samples were obtained by hydraulically pushing a 3-inch diameter split spoon sampler. Generally, soil samples were taken continuously in the upper 10 feet, or until encountering bedrock, and thereafter, at 5-foot intervals.

A trained hydrogeologist was present full-time during the field operations to log the borings, take photographs of samples, collect samples for visual examination and laboratory testing, and direct the well installation. The drilling contractor (S&ME of Raleigh, NC) also maintained a drillers log of each borehole. Subsequent to either completing the open borehole or observation well, the boreholes were probed with a portable downhole natural gamma logging unit mounted in a Blazer. Initially, the split spoon soil samples were split into representative samples and stored in glass canning jars. Beginning with Borehole 70, the entire recovered core was wrapped in aluminum foil for storage.

A total of 27 well casings were set in 8-inch diameter borings. Two wells (Nos. 67 and 82) are constructed in boreholes ranging from 12-inches in diameter near the ground surface to 8-inches at depth. Larger diameter surface casing was cemented in these boreholes at shallow depths to prevent downward migration of chemicals along the borehole.

Temporary surface casing was required in most of the boreholes to prevent collapse of the soil materials including sand, gravel and rock. The temporary casing became lodged in Boreholes 79 and 82 and was left in the boreholes. Typically, the drilling was accomplished by utilizing a combination of a tri-cone rotary bit and a pneumatic hammer bit. Borehole 69 was drilled by coring with a 2-inch diameter diamond bit to a depth of about 37 feet to recover a continuous rock core.

Each borehole was converted into a cased observation well upon completion of drilling. The wells are constructed of 4-inch diameter Schedule 40, PVC, flush-threaded Johnson well screen and casing. The screen has factory machined 0.020-inch slots. Threaded bottom caps were used. The casing and screen were delivered to the site in a pre-wrapped and sterilized condition. No glue or solvents were used on the well materials. The wells were completed by backfilling opposite the well screen with "torpedo" sized sand for gravel pack, bentonite pellets for a seal above the sand and a portland cement/bentonite mixture above the bentonite seal. The complete wells were covered with 6-inch steel protective casings with locking caps and concrete surface seals. All wells, including the historical wells, and surface water gages were surveyed following construction (Appendix D).

The wells were developed utilizing compressed air and water from the drilling rig. Typically, development consisted of a series of continuous air or air/water injections. Depending upon well yield and clarity of the discharge water, development was performed for as long as one hour.

A backhoe was utilized to confirm the results of Borehole 64 which indicated the presence of bedrock at a depth of nine feet below ground surface. Two trenches were dug in the vicinity of Borehole 64 and intercepted rock at depths of approximately nine feet. The results of these excavation are included in Appendix A.

The drilling rig was used to construct shallow boreholes in the unsaturated zone at three locations. These boreholes were used for lysimeter installation. The lysimeters were placed in each borehole with water recovery tubing extending to the surface. Backfill consisting of very fine sand was placed around the porous ceramic tip of the lysimeter. Above this sand fill, a bentonite pellet seal was placed. After wetting the bentonite and allowing swelling to occur, the borehole was backfilled with the natural soil materials.

4.4 Groundwater Level Measurements

Groundwater levels in the observation wells were measured on a regular frequency approximating one week intervals (Appendix G). The primary period of measurement extends from March 8, 1988 to February 22, 1989. Additional measurements were made in Wells 23 and 41 during fall 1987.

The height of surface water on staff gages in Ponds 1-3, Banner Spring Branch and the marshes were recorded during each groundwater level observation period. The surface water measurements were correlated with the groundwater levels.

Groundwater level measurements were taken using an electrical sounder device. The water level measurements are estimated to be accurate to 0.01 foot.

Continuous groundwater and surface water level information was obtained at a location near Pond 1. A battery powered digital recorder with two transducer probes was located between Pond 1 and Well 33. The transducers were installed in both Pond 1 and Well 33 and the instrumentation was calibrated to correspond to manual measurements of water levels in the sources. Water levels were collected at one-hour intervals for a period extending from May to October 1988. Subsequently the transducer in Well 33 was moved to Well 79.

The continuous recorder was serviced approximately once each month. On one occasion the recorder batteries failed and the record was lost for a short period.

4.5 Aquifer Permeability Measurements

Aquifer tests were performed on approximately 34 observation wells to determine the permeability/hydraulic conductivity of the soils and rocks. At 23 wells water injection (slug) tests were performed to quickly test the horizontal permeability of the aquifers. Near Wells 67 and 77 a cluster of 4 wells was utilized to perform long-term pumping tests ranging from 7.5 to 48-hours in length. The results of the tests are provided in Appendix H.

Measurements of water level drawdown and recovery and the time of each measurement were recorded at predetermined intervals. Measurements during most recovery tests continued until the groundwater level recovered to within 80 percent of the initial static water level. The test data were analyzed by a variety of techniques as appropriate for water table and artesian conditions. Additional details of the aquifer test procedures are provided in Section 6.0, herein.

4.6 Streamflow Measurements

Several direct flow measurements were made at the upper, middle and lower staff gages along Banner Spring Branch (Appendix I). The measurements were made at as wide a range of discharge as possible to allow correlation of discharge with water stage. Discharge was measured using the mid-section method. The top width of a channel cross-section was initially divided into subsections with no more than 10 percent of the total discharge within a subsection. The average depth of each subsection was measured with a top-setting wading rod. Water velocity was also measured in each subsection with a Price Type AA current meter. Because the water depth was less than 1.5 feet, velocity was measured at six-tenths of the total depth.

Three staff gages were installed at the flow measurement stations along Banner Spring Branch. The staffs measured height of water level in the channel and were utilized to determine the relationship between stream stage and rate of discharge. The staff gages were measured at various rates of streamflow during the investigation and these measurements allowed the development of a stage versus discharge rating curve for each staff gage.

4.7 Water Samples

Water samples were collected for analysis of general chemicals, heavy metals, radiochemicals and organic chemicals. The samples were obtained by pumping with Well Wizard equipment or with teflon bailers. The pumping and/or bailing apparatus was rinsed with de-ionized water between sample locations. Specific conductance, pH and temperature readings were made in the field.

Water samples were placed in containers appropriate for the required tests. The containers were cleaned and fixed with required preservatives by Accu-Labs, Inc., EcoTek's contract analytical laboratory. During the October 1988 sampling, the samples were filtered at the wellhead prior to contacting the preservatives to remove minor particulate concentrations. Collected samples were transported to the analytical laboratory in coolers packed with ice as required.

The water and soil samples were tested by Accu-Labs, Inc., Wheat Ridge, Colorado. The results of these tests are presented in Appendices J and K. The results of the tests are discussed in Section 7.0.

5.0 GEOLOGY

5.1 Introduction

Geologic observations have been made to estimate hydrologic properties of the soils and rock strata and to identify subsurface geologic structures that may affect groundwater occurrence. Specific objectives of this analysis include:

- Investigate regional geology to confirm site geology.
- Collect soil samples for chemical testing.
- Physically characterize unsaturated soils above the water-bearing zones to assist in determination of potential downward migration of contaminants through the unsaturated soil zone.
- Establish the presence and physical properties of "bedrock" identified by some previous investigations.
- Characterize the uppermost water-bearing zones including any less permeable layers above which "perched" water might occur.
- Determine if relatively impermeable soil and rock units act as confining layers in the uppermost water-bearing zones.

Extensive detailed soils and geotechnical engineering investigations have been previously performed at the NFS facility. However, when this investigation was begun, only a small portion of the previous information was available for review. A significant contribution of this study was to locate and consolidate the results of previous investigations within Appendix B.

During summer 1982, Radiation Management Corporation completed 16 boreholes in the burial ground northeast of the plant and completed five of these borings as monitoring wells. In January 1984, additional borings and monitoring wells were completed by NFS in the burial ground and ponds areas to evaluate potential groundwater impacts caused by Ponds 1-3 and other plant activities.

During 1986, TLG Engineering and R. E. Wright Associates, Inc. collected subsurface soils information from 22 borings, 21 of which were completed as monitoring wells. Also, during 1986, the Tennessee Solid Waste Division completed three boreholes in the burial ground. However, the geologic information on the boring logs for these investigations is not detailed, and based on the findings of this investigation, is often inaccurate with respect to soils and rock identification.

Oak Ridge Associated Universities completed a total of 34 borings in the burial ground during 1986 to determine physical and chemical soil characteristics. In addition, numerous boring records are available for engineering properties of the soils for building locations within the plant. This summary of regional and site geology is, in part, based on the results of the above studies.

5.2 Physiography

The NFS facility is located in an elongated valley near the boundary of two physiographic provinces in northeastern Tennessee (Figure 5-1). The crest of Rich Mountain, a portion of the Buffalo Mountain thrust sheets on the northwestern side of the valley, marks the boundary of the Valley and Ridge

Province and the Unaka Province (DeBuchananne and Richardson, 1956). The Unaka Province is characterized by northeastward-trending ridges composed primarily of quartzite, arkose, and sandy and silty shales of the basal Paleozoic rock sequence (King and Ferguson, 1960). The valleys between the ridges were eroded into less resistant carbonate rocks and shales. The valley floors are covered by residual clays and bouldery wash from the neighboring ridges. In areas where the valley floors are wide and flat, particularly near Erwin, Tennessee where Nolichucky River follows the valley, sand and gravel terrace deposits cover much of the valley floor.

West of Rich Mountain, the Valley and Ridge Province consists of closely spaced northeastward-trending ridges. Near its border with the Unaka Province, the Valley and Ridge is composed of folded and faulted Cambrian and Ordovician rocks. Many of the ridges are continuous for several miles without a break. Maximum relief in the vicinity of Erwin is approximately 5,000 feet.

Figure 5-2 shows the locations of Erwin, the NFS facility, Nolichucky River and major creeks in the area. North Indian Creek and South Indian Creek form a flood plain which parallels the strike of the valley floor. Nolichucky River cuts across the Unaka Mountains south and northwest of the NFS facility but generally trends parallel to the strike of the valley where North Indian Creek and South Indian Creek join the river. Martin Creek and Banner Spring Branch flow northwestward along the northeastern edge of the NFS property and enter North Indian Creek just above its confluence with Nolichucky River.

Banner Spring Branch is fed by Banner Spring, a currently unused spring that discharges approximately 300 gallons per minute. Banner Spring Branch flows through the disposal pond and burial ground areas on the northeastern side of the NFS facility where it discharges into Martin Creek.

5.3 Regional Geology

5.3.1 Stratigraphy

Regional stratigraphy is dominated by alternating sedimentary sequences of limestone, dolomite, shale and sandstone. Table 5-1 summarizes the prominent lithologies and geologic sequence of each formation. The areal distribution of these strata is shown on Figure 5-2. The Chilhowee Group comprises the oldest rocks exposed in the vicinity of the NFS facility and consists of the Unicoi, Hampton and Erwin Formations. These formations are resistent to erosion and repose beneath a major portion of the mountains northwestward and southeastward of the facility. The most prominent exposures of these formations are south of the facility in Nolichucky River Valley at Unaka Springs.

The Shady Dolomite and Rome Formations are younger than the Chilhowee Group and occur directly above these rocks in sequence. These formations are softer and less resistant to erosion and valleys often form on these rocks. Both the Shady Dolomite and Rome Formation readily weather to form residual clay deposits. Clays formed from the Rome Formation are typically acidic and charged with chips of shale and sandstone. Residual clays from the Shady Dolomite sometimes contain economically recoverable manganese deposits.

The Rome Formation forms the bedrock surface directly beneath the NFS facility (Figure 5-2). Regionally, the Rome Formation is a mixture of sandstone, siltstone, shale, dolomite and limestone. Rodgers (1953) described the eastern exposures of the Rome in the Valley and Ridge Province as predominantly carbonates and shale with minor to absent sandstone. King and Ferguson (1960) described the Rome in northeastern Tennessee as primarily silty shales with interbedded limestones, dolomites and siltstones grading to sandstones. Red and maroon are the dominant colors in the shales with brown, green and gray as less common colors. Some sandstones weather orange to yellow, and the carbonates are generally medium to light gray.

Thickness of the Rome Formation is quite variable. Thrust faults commonly terminate the top and base of the Rome. Because this formation was overall less competent than the overlying and underlying formations, stresses created during the Appalachian Orogeny produced complex folding and faulting within the Rome. The shale is moderately to strongly jointed throughout the region.

The uppermost and youngest strata shown on Figure 5-2 belong to the Honaker Dolomite, which crops out along the southeastern slope of Rich Mountain. The Honaker is a blue-gray limestone and dolomite that weathers to a thick (greater than 100 feet), yellowish plastic clay. Regionally, these strata are moderately to strongly fractured. Like the Shady Dolomite, the Honaker is subject to erosion and typically is poorly exposed. A rock quarry across the valley from the NFS facility has exposed a steeply dipping section of the Honaker Dolomite.

In the river valleys, recent unconsolidated alluvial deposits repose on the bedrock surface. These deposits consist of clay, silt, sand, gravel and cobbles. A large amount of the detritus is quartzite fragments eroded from the adjacent ridges and mountains. In general, a gradation of unconsolidated deposits occurs from coarse sediments just above the bedrock surface to silts and clays just below the ground surface.

5.3.2 Structure

Regional geologic structure is dominated by low angle thrust faults that have been warped by later folding. Four major faults occur in the Valley and Ridge and Unaka Provinces and are, from west to east, the Holston Mountain, Buffalo Mountain, Iron Mountain and Stone Mountain thrust faults (Figure 5-1). The Buffalo Mountain and Iron Mountain faults are located near the valley walls, northwestward and southeastward from the NFS facility, respectively.

The faults all strike northeasterly. However, the Buffalo Mountain and Iron Mountain faults dip southeasterly while the Holston Mountain and Stone Mountain faults dip toward the northwest, probably as a result of later folding which rotated the thrust sheets from their original southeasterly dip (Ordway, 1959).

On the southeasterly side of the valley at the NFS facility, the Iron Mountain fault occurs approximately where the valley slope begins to steeply rise toward the outcrops of the older Chilhowee Group. In this area, the fault plane appears to be dipping steeply toward the southeast and may be overturned. Steeply dipping fault traces are common in the Unaka Province (Rodgers, 1953). Figure 5-3 shows a generalized subsurface profile from northwest to southeast through the facility and approximately locates the major thrust faults.

Joints are evident in the rocks at virtually every outcrop in the region. Some joints exhibit slikensides indicating movement. Other joints are filled with calcite. Weathering accentuates joints; and in carbonate rocks, the fractures are enlarged by dissolution in many places. In relatively flat-lying rocks, joints generally are more regular in direction and dip than in areas of folded and faulted rocks. Since most of the rock units in the region are tilted and otherwise deformed, the joint patterns often are random and haphazard. The spacing of joints ranges from less than an inch to several feet. Dips of joint planes range from vertical to horizontal. Curved joint planes tend to be more common in the massively bedded units. The joints are significant factors in adding openings, or conduits, to the rocks. Therefore, the rocks in the region may readily transmit fluids by secondary permeability even though their primary permeability may be low.

5.4 Site Geology

5.4.1 Site Stratigraphy

5.4.1.1 Rome Formation. Sandstones, siltstones, shales, dolomites and limestones of the Rome Formation comprise the bedrock beneath the NFS facility (Figure 5-4). Silty to sandy shale is the dominant rock type. Limestone, dolomite and dolomitic shale are also present. Based on regional descriptions, sandstone and siltstone do not occur in great quantities in the Rome Formation. However, an apparently significant amount of sandstone and some siltstone was encountered during drilling. It is possible that a portion of the sandstone belongs to the older Unicoi Formation. However, the observed geologic relationships are not conclusive in this regard.

Observation of the shale outcrops below the contractors' parking lot near Banner Spring revealed that the Rome shale dips southeastward 70-80 degrees. Also, a core of sandstone recovered from Borehole 69 revealed moderately to steeply dipping beds within the cross-bedded sandstone. If an average dip of 70 degrees is used for the Rome Formation across the entire site, the true thickness of the different rock types encountered during drilling is one third the apparent thickness in the boring logs. For example, an apparent thickness in a borehole of 30 feet for a rock strata equates to a true thickness of about 10 feet.

The shale encountered in the borings (see Appendix A) is generally silty to sandy. The dominant colors are brown, tan and purple. Other colors include red, maroon, green, gray and white. Fracture zones and faults cut through much of the shale and generally yield a noticeable increase in water when encountered during drilling. Where fracture-controlled water bearing zones occur in the shale, the shale is generally less resistent than non-fractured shale, evidenced by achieving rapid drilling footage using air rotary techniques and a greater tendency for the strata to cave into the borehole.

The limestone and dolomite range in color from light and dark gray to brown. The limestone in Borehole 66 consisted of interlayered light and dark blue bands, and more than 20 feet of apparent thickness of limestone was logged in this boring which terminated in limestone. Between depths of 27 and 88 feet in Borehole 67, an apparent thickness of 26 feet of dark gray dolomite was logged.

Dark brown and gray dolomite was logged in 10.5 feet of the bottom 16 feet in Borehole 70. Thin carbonate beds ranging from two to seven feet in apparent thickness were encountered in several other borings.

Dark gray siltstone approximately five feet in apparent thickness was encountered only in Boreholes 60, 61 and 77. The siltstone was at the bedrock surface in Boreholes 60 and 61 and seven feet below bedrock surface in Borehole 77.

Sandstone was logged at or near the bedrock surface in many of the borings. In borings where the measured sandstone thickness was three feet, or less, the thin sandstone layers may represent partially cemented recent sand deposits. Thicker sandstone units are interpreted as sandstone lenses within the Rome Formation. The Rome sandstone units are characterized by fine to medium grain subangular to rounded sand consisting primarily of quartz with some feldspar and occasional mica. The sandstone is generally light to dark gray and weathers to orange, pink and red. Coarse sand grains were scarce except in some of the thin (less than three feet) sandstone units.

The best sandstone samples were recovered by coring in Borehole 69 to a depth of 37 feet. A sandstone approximately 28 feet thick (i.e., approximately nine feet true thickness) was encountered. Examination of the core revealed that the strata dipped as much as 70 degrees and cross-bedding was apparent. Sand, gravel and silt were present along weathered bedding planes and in joint fractures as much as 18 feet below bedrock surface. The source of these sediments is apparently the unconsolidated deposits above. This observation of the depth of penetration of the unconsolidated sediments helps to explain the rather large quantities of these sediments that were mixed with bedrock samples during drilling.

Figure 5-5 shows the configuration of the bedrock surface beneath a portion of the facility. Maximum relief across the facility is approximately 67 feet from Borehole 58 in the burial ground to Borehole 22 in the contractor's parking area. Local bedrock relief within the ponds area is only about eight feet. The overall slope of the bedrock surface is from the valley edge (southeast) toward Nolichucky River (northwest). Locally, low areas on the bedrock surface occur along Martin Creek, the northwestern portion of the ponds area and along the boundary of the ponds area and plant. The bedrock lows in the area of the ponds are believed to correspond to former positions of Banner Spring Branch prior to diversion of the creek during pond construction in the early days of plant operations. The bedrock low near Martin Creek corresponds to the present position of Martin Creek.

Bedrock highs occur beneath the central portion of the burial ground, Ponds 1 and 3 and the central portion of the plant. These highs are divides between the former positions of drainages such as Martin Creek and Banner Spring Branch. The bedrock high in the burial ground extends beneath Pond 3 to the area of Pond 1. From the results of the drilling program and sampling of sludge in Ponds 1-3, it is apparent that the elevation of the base of the pond sludge corresponds very closely to the elevation of the bedrock surface. Thus, the sludges in Ponds 1-3, are in close, if not direct contact, with the bedrock.

5.4.1.2 Unconsolidated Deposits. A veneer of unconsolidated alluvial material of Recent and Quaternary age overlies the Rome Formation beneath the facility (Figure 5-6). The deposits range from less than one foot to approximately 21 feet and comprise clay, silt, sand, gravel and cobbles (Figure 5-7). The alluvial deposits are thickest near Martin Creek on the north and at the extreme southern end of the plant. In addition, the alluvial deposits fill the bedrock low along the boundary of the ponds area and plant with thicknesses exceeding 13 feet.

The distribution of the sand and gravel component of the alluvial deposits is of significance to this investigation due to the greater permeability of these materials. In general, the greatest thicknesses of sand and gravel lie directly on the bedrock surface. The distribution of these materials beneath a portion of the facility is shown in Figure 5-8. Sand and gravel are in greatest abundance in the area of Martin Creek where their thickness exceeds 18 feet. These deposits appear to be absent in the southern portion of the plant near Well 74.

Sand and gravel deposits range between six and nine feet in thickness beneath Ponds 1-3 and comprise as much as 75 percent of the total thickness of unconsolidated deposits. They are in greatest abundance in the bedrock low that represents the former channel of Banner Spring Branch adjacent to Ponds 1 and 2. They are also present in the area near and downgradient from Pond 3. These sand and gravel deposits are saturated with groundwater and apparently intersect the impoundment walls and floors of Pond 3. The high content of excavated sand, gravel and cobbles in the Pond 3 embankments is evidence of this fact. The former marsh soils within Ponds 1 and 2 may separate the sand and gravel deposits in this area from direct connection with the ponds due to the relatively low permeability of the marsh soils. The areas of thinnest unconsolidated deposits, including sand and gravel, generally correspond to the areas underlain by bedrock highs.

Interbedded with and overlying the sand and gravel deposits are less permeable silts and clays ranging in thickness from 0.5 to 18.5 feet. Secondary structures are rare in the silts and clays. Some layers contain isolated lenses of sand, gravel, rocks and dense organic materials below old and present soil surface horizons. The occurrence of organic silts and clays at depth below the present surface soils is believed to correlate with the locations of previous stream channels and marshes.

Fill materials are widely distributed throughout the facility (Figure 5-6). This material consists of clay, silt, sand and gravel mixtures. In some areas the fill is comprised of gravel parking lot base and in other areas a clay/brick debris. In the vicinity of the burial ground the fill is probably associated with the pit cover material. In other areas, fill materials were probably placed to raise and level areas during construction of the facility. Also fill materials have been used to raise and strengthen the pond embankments, especially directly northwest of Pond 3 and southeast of Pond 2. The fill has been derived from several sources including on-site reworked material, the borrow pit near the contractor's parking area and various off-site areas.

During this investigation, three separate occurrences of soil subsidence were observed. It appears that the subsidence has occurred in close relationship to man's activities at the plant. In one case, the subsidence occurred in a disposal pit in the burial ground. The other areas of subsidence are closely related and occurred in an area of extensive fill northwest of Pond 3 as well as being related to fill along a buried pipeline.

The subsidence occurred when thin (less than two feet thick) layers of soil directly beneath the ground surface collapsed into a dome shaped cavity. The cavity in all cases was void of soil materials. It appears that the soils that were previously in place winnowed downward into cavities and fractures in the bedrock as well as settled through incomplete compaction of the backfill during construction. In all three cases the subsidence occurred after significant periods of rainfall which apparently loosened the thin soil cover. In addition, it is possible that the air rotary drilling operations during this investigation helped to loosen the soils. However, it is improbable that the drilling created the cavities by physically removing the soils.

5.4.2 Soil Characteristics

Reconnaissance sampling and laboratory testing of physical characteristics of soil were performed on undisturbed soil recovered from the 5.5 feet immediately below ground level at two locations beneath the facility. Attempts to recover undisturbed soils at three additional locations were unsuccessful due to damage to the sampling equipment by large cobbles in the soils. Parameters that were tested in the laboratory include moisture, dry density, specific gravity (total porosity) and coefficient of permeability. The physical characteristics of the laboratory test results are presented in Appendix J, Section 2.

5.4.2.1 Soil Moisture. The soil moisture values reported in Appendix J are 19.2 and 36.2 percent. These values are relatively low and reflect the clayey composition of the soils tested and the relatively dry climatic conditions at the time of sampling. In addition to the laboratory tests, soil moisture was measured at three tensiometers located in the ponds area. The wettest soil conditions measured were near Pond 1 and Banner Spring Branch, at depths just above the groundwater level. The lowest soil moisture measured was in shallow fill several feet above the water table near Pond 3. The dry moisture condition as measured by the tensiometers was confirmed by the fact that water could not be recovered from nearby lysimeters until extended rainfall occurred during January 1989.

The soil moisture results should be considered only as a general indicator of soil moisture condition. The wide variability of test results appears to indicate that soil moisture is a function of several local conditions and variables such as rainfall, snowmelt, groundwater levels, stream levels, air temperature and soil texture.

5.4.2.2 Bulk Density. Bulk density values of dry soil materials reported in Appendix J were 86.0 and 113.0 pounds/cubic foot (pcf). It is probable that less dense material occurs beneath the facility in former marshy areas (peat, organic soils). The bedrock and sand and gravel beneath the zone that was tested probably represent more dense material. The values measured fall within the range of values expected for the silty clay soil types tested.

$\text{porosity} = 1 - \frac{\text{dry density}}{(62.4)(\text{specific gravity})} \times 100\%$

Fournier

5.4.2.3 Specific Gravity (Total Porosity). Specific gravity values reported in Appendix J are 2.69 and 2.76. Total porosity calculations based on an average specific gravity of 2.73 and the soil density measurements resulted in a total porosity estimate of approximately ~~60~~ 40 percent. This value is only considered representative of the near surface silty clay soils that were tested. Porosity values selected for the sand and gravel deposits and bedrock may require appropriate adjustments, perhaps to values ranging between 20 and 30 percent.

5.4.2.4 Coefficient of Permeability. Appendix J presents coefficient of permeability values measured in the laboratory on the shallow clayey and silty soils. The values measured represent vertical permeability and are 4.2E-7 and 3.6E-6 cm/sec. The measured laboratory values are representative of low permeability material such as clay. In addition the laboratory values are consistent with vertical leakage values measured in the field by the Well 77 aquifer test (see Section 6.0). Estimates of permeability of the sand and gravel materials and bedrock are greater than for the clays and are also derived in Section 6.0.

5.4.3 Local Geologic Structures

Local geologic structures in the Rome Formation were determined from observations of the condition of cuttings and cores collected during drilling. Strongly oxidized zones in shale and sandstone, quartz fracture fillings in sandstone, calcite fracture fillings in limestone and pulverized shale indicated the presence of faults and fracture zones. In addition, loss of drilling water circulation or marked increase in water produced from a boring during drilling indicated probable faults. In several boreholes, drilling proceeded through the dry unconsolidated surface deposits and on into dry bedrock until water was encountered in a major fracture zone in bedrock. Groundwater would then rise quickly above the fracture zone and sometimes above the bedrock surface due to confining pressures within the fracture zone.

Two surface manifestations of the bedrock faulting and fracturing were identified from the results of the drilling operation. Banner Spring, which produces approximately 300 gallons per minute of water, is most likely a fault-controlled spring, as are similar springs in the area of Erwin, Tennessee (First Tennessee Development District, March 1987). Another indicator of the presence of a second fault is the fluctuation of the water level in Pond 1 which reacts somewhat differently than the water levels in Ponds 2 and 3. This phenomenon is interpreted as representing discharge from a fault or fracture zone spring, below, which maintains a consistently uniform water level in the pond despite the fact that natural precipitation recharges and evaporation withdraws water from the Pond 1 water surface.

Figure 5-4 shows generalized bedrock surface expressions of two faults and five fracture zones. Additional fracture zones are probably present but cannot be accurately located. The bedrock surface locations of fracture zones were determined by constructing subsurface profiles and noting borehole evidence of fractures in the Rome Formation. Faults were interpreted along fracture zones where rock was extensively pulverized, clay/shale fillings are very soft and fractured, and where a large increase in groundwater produced from a boring during drilling was observed. The water contained by some fractures is under artesian pressure and quickly rises to a level higher than the depth initially encountered when penetrated by boreholes such as Boreholes 60 and 70. The identified faults and fracture zones strike approximately N45E and dip 10 to 12 degrees toward the southeast. Evidence suggests that a second set of fractures, perpendicular to this set, may exist beneath the site. This fracture set is expected to strike approximately N45W and be steeply dipping. The detailed orientation of this fracture set is very difficult to accurately identify by drilling and has not been depicted by this investigation.

Figure 5-4 shows the locations of nine subsurface profiles labeled A-A′ through I-I′ (Figures 5-9 through 5-17) and five hydrogeologic profiles labeled J-J′ through N-N′ (Figures 5-18 through 5-22) that characterize various portions of the facility. Figures 5-9 through 5-17 depict the bedrock geology throughout the entire facility. The stratigraphy and structure of the rocks are emphasized. Figures 5-18 through 5-22 present the hydrogeologic relationships specifically beneath the pond area. Details are shown for the unconsolidated aquifer stratigraphy, water levels, ponds and pond sediment, and soils and water uranium concentrations.

The fault that transects profiles A-A′, B-B′, C-C′,E-E′,F-F′, and G-G′ is the same fault that produces abundant water in Well 82 and produces the first water encountered in the boreholes at Wells 60 and 62. This fault also appears on I-I′ where it is characterized on the log for Borehole 75 by a tan to white unit of soft pulverized shale in which the drilling lost circulation. In other borings, this fault is characterized by up to 12 feet of soft fractured shale.

The fault shown on profile B-B′ which intersects Borehole 51 at the bedrock surface is interpreted to be the same fault from which Banner Spring discharges. The Rome shale that was encountered in this boring was so soft and fractured that the percussion hammer penetrated 20 feet using only minimal drilling action. Borehole 54 did not penetrate deep enough to encounter the fault, and Borehole 52 was drilled just northwest of the fault trace.

6.0 HYDROLOGY

6.1 Groundwater

6.1.1 Regional Occurrence

Abundant groundwater supplies occur in the immediate vicinity of the NFS facility. However, there is no single, extensive aquifer underlying the region that consistently yields adequate supplies of groundwater to wells. Instead, yields from wells and springs in the region largely depend on locally penetrating either a large fracture or solution cavity, or numerous small, interconnecting voids in the rock which can act as conduits for groundwater flow. These secondary openings are comprised largely of fractures and solution cavities along bedding planes and are primarily related to the folding and faulting throughout the region. The primary porosity and permeability of the rocks in the area are relatively small and do not account for significant yields of water to wells.

The secondary openings permit the rapid entrance and infiltration of chemically reactive surface water and groundwater, which can significantly modify the size and shape of the openings through which the water passes. Because the acidity of groundwater moving downward through limestone decreases as calcium carbonate is dissolved, the rate of dissolution decreases with depth. This results in the enlargement of fractures by dissolution nearer the land surface, and under certain conditions, in the closing of deeper fractures by chemical precipitation. Most limestone dissolution in eastern Tennessee is believed to occur at depths of less than approximately 300 feet.

Aquifers composed primarily of carbonate rocks such as the Shady and Honaker Dolomites exhibit more groundwater flow along solution channels than in the fracture controlled conduits. However, solution cavities tend to develop along fractures as well as along weaker zones in the formations such as shaley sequences or where depositional beds are relatively thin.

The Rome Formation exhibits relatively great thicknesses of clastic rocks rather than carbonate rocks. The shales and siltstones are formed by the compaction and consolidation of sediments chiefly comprised of particles of clay and silt. These rocks normally have relatively little primary interconnected pore space. However, where secondary openings along fractures exist, the shale yields small quantities of water to wells. The rocks of eastern Tennessee have been folded and faulted extensively. Therefore, shales that are hard and brittle generally exhibit greater densities of fractures and may be among the more productive aquifers of the area. In general, fractures in the shale are much more closely spaced than those in limestone and dolomite. As a result, the hydrologic properties of the shales are relatively uniform.

The Rome Formation may contain appreciable quantities of calcium carbonate, locally. Where the limestones and dolomites are present, the formation will yield more groundwater than in the zones of clastic rocks, as the fractures in the carbonates are susceptible to chemical enlargement.

The sandstones in eastern Tennessee are also highly fractured and groundwater follows the secondary openings. However, these rocks also have greater primary permeability than other rock types and groundwater movement is facilitated by this property. In this regard, the hydrologic properties of the sandstones are more uniform than the other Rome Formation rock types.

Unconsolidated deposits comprised of clay, silt, sand and gravel fill the major stream valleys in eastern Tennessee. These deposits were not subject to the structural movements in the region. Thus, any permeability that is present is considered primary. The unconsolidated aquifers are in direct hydraulic connection with the bedrock aquifers and intercept groundwater moving into the valleys through bedrock below the valley floors as well as from the hill slopes. This groundwater inflow is largely responsible for maintaining the permanent groundwater levels in the unconsolidated aquifers. As such, the unconsolidated aquifers act as conduits for either recharging the bedrock aquifers or receiving water discharging from the bedrock. In addition, the unconsolidated aquifers can be directly recharged by water flowing in the stream channels or by direct precipitation. This investigation has determined from review of the literature that there may be a tendency for water flowing in Nolichucky River near the NFS Facility to infiltrate into the unconsolidated and bedrock aquifers. However, this process occurs downgradient from the NFS facility.

6.1.2 Regional Water Use

The area within approximately five miles of the facility appears to have abundant domestic, industrial and public supplies of water. Most water is pumped from wells or discharged by springs. A 1987 water-use survey for Unicoi County indicated that the Erwin Utilities Board averages daily usage of 2,000,000 gallons, all of which is from springs and wells (First Tennessee Development District, March 1987). The nearest water withdrawal by the Erwin Utilities Board is approximately one-half mile north of the northern NFS Facility boundary at "Railroad Well." In addition to the Erwin Utilities Board, other users of groundwater in Unicoi County consume approximately 3,000,000 gallons per day (NFS 1984).

Most public and industrial supply wells tap the fractures and solution cavities in the limestone and sandstone aquifers. Domestic water supplies generally obtain water from the alluvium and shallowest bedrock. However, only a few wells in the area pump adequate supplies of water from depths less than 50 feet.

Wells and springs used for water supply within a radius of approximately five miles of the facility as determined by literature review are listed in Table 6-1. Also, the Tennessee Division of Groundwater Protection was contacted to identify all registered water supply wells within the immediate area. Only five wells were identified. All of the wells are located in the outer reaches of the five-mile radius and are not listed, herein. The on-site well (Well A) previously used for domestic water supply was not registered.

None of the springs and wells utilized by the Erwin Utilities Board were listed by the Division of Groundwater Protection. The characteristics of these water sources are shown below. However, some of these water sources such as Banner Spring may not be actively used:

Spring/Well	Type of Source	Potential Yield (gpm)	Water Source
Anderson-McInturff	Spring	450	Fractured rock/Buffalo Mtn Fault
Birchfield	Spring/ Well	1500	Surface infiltration into fractured upslope bedrock and bedrock beneath stream alluvium
O'Brien	Spring/ Well	630	Fractured rock associated with Iron Mountain Fault
Railroad	Well	315	Solution cavities recharged by Nolichucky River and Indian Creek
Banner	Spring	350	Fractured bedrock beneath terrace deposits of Nolichucky River

Source: First Tennessee Development District, March 1987

The majority of springs listed above exhibit quick response (within about one day) to local precipitation. In particular, the springs show a measurable increase in flow and the water often becomes turbid. Banner Spring water rarely has storm-related turbidity, signifying relatively deep groundwater circulation. Banner Spring water was tested by the First Tennessee Development District (March 1987) for metals content as an indicator of possible contamination from the NFS facility. The sample contained barium, which may be attributed to the natural rock formations. Mercury concentration in the sample was reported to exceed the quality standards for a domestic water supply. First Tennessee Development District did not identify any source for the mercury. However, this investigation has demonstrated that Banner Spring is upgradient from the ponds area. Therefore, the pond sludges are not a probable source.

In addition, the District evaluated potential contamination sources for Banner Spring. The up-gradient area is densely populated. Potential contaminant sources that were identified include septic tank failures, numerous underground storage tanks, "back-yard" and commercial garages, a small industrial park, and spills along U.S. Route 23/19, which passes near the spring.

Surface water in the region is not commonly used for water supplies. Streams and rivers primarily serve recreational purposes. The nearest public water intake downstream from the NFS facility along Nolichucky River is at Jonesboro approximately eight miles distant.

6.1.3 Local Occurrence

6.1.3.1 Aquifers. Beneath the NFS facility, groundwater is known to occur in the unconsolidated and Rome aquifers. The following discussion summarizes the occurrence of groundwater in these aquifers:

6.1.3.1.1 Unconsolidated Aquifer. Water in the unconsolidated aquifer occurs under water table (unconfined) conditions. The unconsolidated aquifer is primarily recharged by infiltration of rainfall from the ground surface as well as upward seepage of water into the unconsolidated deposits from the bedrock beneath. A secondary local source of groundwater recharge is seepage from the floors of ponds, marshes and streambeds. Groundwater recharge may also occur on an intermittent basis from leaking storm drains and pipelines.

Groundwater discharges from the unconsolidated aquifer beneath the site by seepage into streambeds, springs, and evapotranspiration. Also, discharge may occur into the Rome aquifer where the vertical hydraulic gradient is downward. In addition, the unconsolidated aquifer yields limited quantities of water to wells. Well A, a previous domestic supply well located in the burial ground, is estimated to yield 3 to 5 gpm from sand and gravel deposits with saturated thickness of about 10 feet. However, the yield of most observation wells constructed in the unconsolidated aquifer is less than 3 gpm.

Locally, the unconsolidated aquifer may be hydraulically isolated from the Rome aquifer, below. Overall, a strong hydraulic connection exists. Because of the intensity of fracturing in the upper Rome, filling of these fractures with sediments and hydraulic connection of the two aquifers, the unconsolidated aquifer has been defined to include the uppermost 10 feet of the Rome aquifer for determining the distribution of chemicals in Section 7.0.

The distribution of sand and gravel in the unconsolidated aquifer has been previously presented in Figure 5-8. A direct correlation appears to exist in the thickness of sand and gravel and thickness of groundwater saturation of the unconsolidated deposits. The greatest soil saturation of approximately 13 feet occurs along the northern edge of the burial ground near Martin Creek. In addition, the sand and gravel in the area of the former Banner Spring Branch channel near Ponds 1 and 2 is saturated to thicknesses as great as eight feet. These values represent nearly complete saturation of the sand and gravel deposits in these areas. Elsewhere, saturated thickness is as much as nine feet in the areas of the eastern and western edges of the burial ground and ponds areas.

Areas of relatively low saturated thickness correspond to both the areas of thinner sand and gravel deposits and bedrock highs. In general, these areas are located in the central portion of the burial ground and central and southern portions of the plant. Zero saturated thickness of the unconsolidated deposits in these areas was not an uncommon occurrence due to the very dry climatic conditions during this investigation.

Figures 5-18 to 5-22, and 6-1, 6-2, and 6-3 present the detailed distribution of saturation of the unconsolidated aquifer for representative dry, average and wet conditions. Figure 6-1 is based on water level measurements on July 1, 1988 following approximately four weeks of essentially no rainfall. The area throughout the southern one-half of the plant exhibited zero saturation in the majority of the unconsolidated aquifer. Groundwater levels that were measured in wells in this area corresponded to depths as great as seven feet below the bedrock surface.

Soils saturation reached a maximum thickness of about 13 feet in the Martin Creek and upper burial ground areas. In addition, saturated thickness of as much as 7.5 feet was measured in the buried channel adjacent to Ponds 1 and 2. Between the buried channel and Martin Creek, saturated thickness decreased to less than two feet in the central portion of the burial ground.

Figure 6-2 presents saturated thickness on September 21, 1988 based on rainfall conditions and groundwater levels that represent a somewhat average condition of wetness for the period of record. In general, the same pattern of saturation occurs as is depicted by Figure 6-1. However, slightly greater saturated thicknesses were measured beneath the southern portion of the plant, in the central burial ground area, and adjacent to Ponds 1 and 2 in the buried channel.

Figure 6-3 presents saturated thickness on February 8, 1989 for the wettest conditions observed during the period of record. The pattern of saturation previously depicted was observed again on February 8. However, saturated thickness of the unconsolidated aquifer significantly increased in localized areas. Beneath the southern portion of the plant, increased saturation is especially apparent in the areas of Wells 8 and 51. It is possible that water moving upward along fracture planes from the Rome aquifer below was recharging the sand and gravel. Elsewhere beneath the ponds area and burial ground, saturated thickness of the unconsolidated deposits had increased between one and three feet over the previous measurements.

Although seepage through the embankments and floors of Ponds 1-3 enters the unconsolidated aquifer, apparent localized water level mounding sometimes present beneath Ponds 1-3 appears to have little influence on maintaining the saturation of the unconsolidated aquifer in consideration of the information presented on Figures 5-18 to 5-22 and 6-1 to 6-3. Instead, saturation is apparently more highly dependant on factors such as thickness of the sand and gravel deposits, recharge from the underlying Rome aquifer and recharge by direct rainfall infiltration. The current channel of Banner Spring Branch exerts little apparent influence on saturated thickness.

<u>6.1.3.1.2</u> Rome Aquifer. Water in the Rome aquifer occurs under weak artesian (confined) conditions for the range of depths investigated. Locally, where the Rome surface is in direct contact with the unconsolidated aquifer, water table conditions may prevail. In addition, extended pumping of the uppermost portions of the Rome aquifer may induce a temporary change from confined to unconfined conditions. Based on physical and hydraulic conditions the uppermost 10 feet of the Rome aquifer has been defined as belonging to the unconsolidated aquifer in the previous section.

The Rome aquifer beneath the facility is primarily recharged by subsurface movement of water from beneath the adjacent hillslopes. Rainfall directly infiltrates into the Rome aquifer as well as other aquifers on the hillslopes and moves downgradient in the subsurface through extensive fracture and solution zones. The higher elevations of the recharge areas help to create the hydraulic head that creates the artesian pressures in the valleys.

A secondary localized source of recharge to the Rome aquifer beneath the facility is downward infiltration of water from the unconsolidated aquifer into the Rome. Evidence developed during the Well 77 pumping test suggests that the localized pumping of the Rome aquifer induced downward leakage (i.e., recharge) of the unconsolidated aquifer water into the Rome aquifer.

Discharge of water from the Rome aquifer primarily occurs where the elevation of the hydraulic head of the Rome water exceeds the elevation of the bedrock surface. Thus, the water which is under artesian pressure discharges into the overlying veneer of unconsolidated deposits. Although this discharge occurs throughout the facility, its effects are most apparent along the identified fracture zones (Figure 5-4) as determined by water level and water quality data. Locally, water also discharges from the Rome aquifer along streambeds or from springs such as Banner Spring.

The Rome aquifer yields small to large quantities of water to wells beneath the site. For example, Well 30 completed to a depth of about 35 feet can be pumped dry within approximately two hours at pumping rates of less than 5 gpm. On the other hand, Well 77, which is approximately 50 feet deep, is capable of yielding a minimum of 20 to 25 gpm on a sustained basis. Well 82 is estimated to yield 50 gpm from a depth of 113 feet while the open borehole of Well 67 yielded an estimated 300 gpm in the interval from 60 to 120 feet during drilling. Furthermore, Banner Spring discharges approximately 300 gpm from the Rome aquifer. Although well yield is to some degree a function of depth of penetration of the Rome aquifer, large yields are more frequently the result of encountering permeable water bearing fracture zones with the well bore.

Occurrence of groundwater in the Rome aquifer beneath the facility is primarily a function of the intensity of secondary (fracture controlled) permeability. Groundwater appears to move selectively along fracture zones. Although the sandstones within the Rome aquifer appear to have relatively great primary permeability, the observed distribution of groundwater and well yields can not be entirely explained by the primary porosity and permeability of the rocks.

Because of the relatively great intensity of fracturing of the rocks, the Rome aquifer appears to be completely saturated to the bedrock surface beneath the pond area and immediately adjacent portions of the burial ground and plant. Beneath the southern portion of the facility, the groundwater level commonly resides a few feet below the top of the Rome. Locally, the degree of saturation of the Rome may depend upon the intensity of fracturing and distribution of impermeable shale. For example, the low yield of Well 30, previously mentioned, is apparently due to predominance of shale that has been only sparsely fractured. Also, during drilling of Wells 60 and 70, free water was not encountered until impermeable shale had been penetrated for several feet. When water was encountered, it was under artesian pressure in water bearing fractures below confining shales. Therefore, occurrence of water in the Rome aquifer is highly dependant upon the degree of fracturing. Locally, where impermeable shales are not highly fractured, the Rome is less saturated and the shales may act as aquitards for groundwater movement.

Ponds 1-3 appear to have little influence on maintaining the saturation of the Rome aquifer. However, seepage from Ponds 1-3 is estimated to have entered the Rome aquifer in as much as the floors of the ponds are in direct contact, or nearly so, with the upper Rome surface (Figures 5-18 to 5-22). The movement of pond seepage within the groundwater regime is discussed in following sections, herein.

6.1.3.2 Groundwater Level Variations.

6.1.3.2.1 Seasonal Trends. Extensive sampling of groundwater levels was performed at all observation wells and surface water sites in the NFS observation system during a one year period to develop a record of measurements representative of average and extreme groundwater conditions. Water levels measured for each location in the observation network for the period March 1988 through February 1989 are presented in Appendix G. Field notes, tabulated summaries and hydrographs have been included for each sampling site. In addition, these data have been used to construct maps of the configuration of the potentiometric groundwater surface for dry, average and wet conditions during the sampling period (Figures 6-4, 6-5, and 6-6).

The groundwater levels observed during 1988-89 have been summarized to show their minimum depths, maximum depths and range of variation for the observation period (Table 6-2). The hydrographs (Appendix G, Figures G1-G19) graphically depict the groundwater level trends. Groundwater level trends exhibited three basic types of variations (Figure 6-7). The first trend appears to be a function of the hydraulic controls exerted by the Rome aquifer, especially in areas strongly influenced by confined water movement along fracture zones. The range of water level variation was normally less than two feet for the observation period. Although the overall range of variation for Well 23 was 1.45 ft, more than one foot of variation occurred during one especially heavy period of rainfall (approximately two inches) on May 17, 1988. At the time of water level measurement on May 18, the water level inside the well casing was 0.65 feet above the ground surface reflecting the effects of the artesian pressure in the Rome aquifer. During the remainder of the observation period, response to rainfall was detected. However, the variations were very subtle and indicate both the ability of the Rome aquifer to quickly adsorb local recharge due to its relatively high permeability and the continuing steady input of water from the regional recharge area.

A second unique groundwater level trend is exhibited by measurements from Well 27 (Figure 6-7). This trend is indicative of wells primarily completed in the unconsolidated aquifer and less subject to artesian pressures from the Rome aquifer below. Overall, the water level variations reflect the seasonal trend of wetter conditions in winter and spring 1988 and winter 1988-89, and drier conditions during summer and fall 1988. In addition, periodic increases in water level are apparent due to infiltration from intermittent rainfall events. The overall range of water level variation in wells exhibiting this trend was generally between one and three feet. The water levels exhibited the same trend as for deeper wells completed in the Rome aquifer. However, the variations are more pronounced. This may be due to the somewhat smaller permeability of the unconsolidated aquifer and its relative inability to accept recharge quickly as well as the more immediate response of groundwater levels to rainfall in the unconsolidated aquifer.

A third group of wells exhibited water level trends very similar to the second trend described for the unconsolidated aquifer, but the variations were even more pronounced. In addition, the water level trend is sometimes out of synchronization with rainfall. The overall range of water level variation in wells in this group was usually between three and six feet, although Well 51 exhibited a range of variation of 11.3 feet. The hydrograph for Well 73 (Figure 6-7) is typical of this trend. In general, the water level variations in Well 73 appear to be in response to rainfall infiltration related to plant structures such as building foundations or storm sewers.

For the observation period, the minimum depth to groundwater levels below the ground surface throughout the facility ranged between zero and 22.9 feet (Table 6-2). However, beneath the ponds area, groundwater level depths of approximately four to six feet were common. The minimum water level depths were reached during periods of relatively intense rainfall during the winter and early spring months.

The groundwater levels measured during June and early July 1988 are considered to have reached maximum depths relative to local base levels. This was primarily due to the lack of any measurable rainfall for more than eight weeks during this period based on NFS facility rainfall data. In addition, this dry period occurred following an extended drought throughout the region. Although the groundwater hydrographs did show a short-term increase in groundwater levels due to sudden influxes in rainfall beginning in mid-July, sustained increases did not occur until late October 1988.

The variations of water levels during the measurement period in Ponds 1-3, the marsh areas and Banner Spring Branch have been compared to the groundwater levels to determine the influence of surface water on groundwater levels. It is believed that water levels in Ponds 1-3 were at somewhat higher levels during pond operations. Ponds 1-3 (Appendix G, Figure G-17) exhibit very uniform water level trends with little pronounced response to intermittent rainfall events. However, the long-term response to rainfall was generally the same as for groundwater. The water level in Pond 1 increased approximately one foot following significant rainfall in mid-May. Subsequently, the water level decreased in response to the drier conditions during June and July 1988. Rainfall during July 1988 and winter 1988-89 caused slight increases in water level.

The water level trends in Ponds 2 and 3 are similar to the trend in Pond 1. However, Pond 2 was completely dry for a short time in both June and August 1988. The abrupt rise in water level in Pond 2 during late August (Figure G-17) was due to discharge of approximately 41,000 gallons of water into Pond 2 from the Well 77 pumping tests. Pond 3 was dry for extensive periods between mid-May and late October 1988.

Based on review of the water level data for Ponds 1-3, recharge occurs from direct rainfall and inflow from groundwater. Discharge occurs through evaporation and infiltration into the soils through the pond embankments and bottoms. In Pond 1, it appears that groundwater inflow from natural springs in the pond bottom provides the primary source of recharge. Effects of direct rainfall on pond water levels are quickly dampened by the ability of the underlying aquifer to accept water influx. Conversely, evaporation withdrawals are quickly replaced by groundwater inflow. Some water probably infiltrates laterally into and from the ponds through the embankments. However, the current volume of seepage appears to be very small due to the relatively impermeable layer of sludge and former marsh soils coating the embankments.

Pond 1 may act as a large diameter tightly cased well with its water level primarily responding to artesian groundwater influence associated with a fracture zone which is in direct contact with the pond floor. On the other hand, Pond 1 may receive recharge from groundwater originating in the Banner Spring area upgradient, that is moving through the sand and gravel deposits filling the former creek channel adjacent to Pond 1. Because Pond 1 is in close hydraulic connection with the water table, water level mounding exhibited by the surrounding groundwater is closely related to the mechanism that maintains pond levels.

The water levels in Ponds 2 and 3 respond to the same hydrologic influences that affect Pond 1. However, based on the somewhat higher topographic positions of Ponds 2 and 3, respectively, recharge by groundwater inflow and groundwater mounding are not as dominant (Figures 5-18 to 5-22). While the water table does reside within the pond sludges near the pond floor, the free water level in these ponds does not appear to be a primary function of the water table. Instead, the primary contribution to the recharge of free water is rainfall. Subsequently, either evaporation, or infiltration, cause lowering of the Ponds 2 and 3 water levels, with the ponds losing all free water during extended dry periods. However, probes through the dry pond floor have indicated saturation of sludge materials above the base of the sludge due to the water table.

The marshes in the area of the ponds exhibited very uniform water level trends. This is due to the combined effects of the primary source of recharge which are springs of relatively constant discharge and marsh outlets of fixed elevation. Temporary increases in marsh water levels and discharge volumes were observed. However, these effects were due to short-term rainfall and not apparent from the field measurements. Water level mounding effects caused by the marshes have not been observed.

Water level trends in Banner Spring Branch are similar to those exhibited by the marshes. The primary source of recharge to the creek is Banner Spring, the marsh outfall and other small springs and seeps along the channel. The discharge from these sources is relatively constant. Thus, the water levels measured in Banner Spring Branch are also constant. As for the marshes, recharge due to rainfall was very sporadic and not observed by the routine sampling. In addition, no seasonal trend was apparent based on the uniform discharge from Banner Spring.

6.1.3.2.2 Diurnal Trends. The continuous groundwater and surface water levels measured at Wells 33 and 79, and Pond 1 resulted in a record of diurnal (daily) water level trends. The effects of rainfall, groundwater recharge, infiltration and evaporation were all observed on an hourly basis. Initially, it was anticipated that various diurnal water level events might be observed as small peaks and valleys exhibiting 24-hour cycles on the seasonal hydrograph. However, any diurnal variations due to the above hydrologic factors were not measurable in either Pond 1 or Wells 33 and 79. Instead, the continuous hydrographs were depicted by very smooth trends with essentially no variation indicative of the seasonal trend of water levels (Appendix G, Figures G-1 to G-19).

During the observation period, individual rainfall events of more than 1.5 inches occurred. However, for the entire period of record, rainfall was sparse with less than 20 inches reported by NFS for a 12 month period. Evaporation, especially during the dry summer days is assumed to have occurred on a regular daily cycle. However, these variations were not observed on the free water surface in Pond 1. Therefore, it appears that groundwater recharge and/or aquifer permeability are large enough to cause an essentially instantaneous equalization of water levels to accommodate either recharge or withdrawals of water to the pond surface.

The groundwater levels in Wells 33 and 79 maintained a seasonal trend that was similar to Pond 1. The groundwater levels differed from the Pond 1 levels only

in that the range in variation was somewhat larger. Occasional very small random oscillations are present on the hydrograph. These variations are probably due to sporadic infiltration of rainfall.

<u>6.1.3.3 Hydraulic Gradients.</u> Maps depicting the configuration of the potentiometric groundwater surface were prepared to estimate general groundwater flow directions and hydraulic gradients (Figures 5-18 to 5-22 and 6-4 to 6-6). These maps show the groundwater surface configuration that corresponds to base, average and peak groundwater level conditions. The combined information for water levels in wells, the elevation of spring discharge locations and pond water levels, and stream levels have been used for preparation of the maps. With the exception of Well 67, all wells have been used to construct the potentiometric surfaces regardless of degree of well penetration into unconsolidated or Rome aquifers. This is based on the great degree of hydraulic connection of these aquifers documented, herein.

Using all of the available information, including the subsurface geologic profiles, the water level data indicates that the overall groundwater hydraulic gradient is toward the western plant boundary. However, depending on the condition of wetness several local variations in flow direction and gradient exist. The primary cause of groundwater gradients (i.e., flow) toward the northwestern plant boundary appears to be that the topography generally slopes toward the northwest and that significant recharge to the alluvial soils occurs along the valley wall at upgradient seepage locations such as near Banner Spring.

The overall slope of the water table is disrupted by Banner Spring Branch. The water table configuration indicates that the upper segment (i.e., above the bend in the creek near Well 79) is a gaining stream. In the lower segment, below Well 79, Banner Spring Branch is a losing stream, except near its confluence with Martin Creek, as evidenced by groundwater levels that reside below the level of the stream bed. This is believed to be the result of rerouting of the creek bed from its natural channel into a channel that was not excavated as deep as the water table. The former location of the creek channel in marshes in the lower ponds area is evidenced by the water table configuration near Wells 26 and 81 which is a subdued extension and a flattening of the pattern for the upper stream segment. During periods of higher water levels, it appears that the water table steepens near the gaining reach of the creek suggesting a more direct flow of groundwater toward the creek than for base level conditions.

The apparent groundwater mounding near Ponds 1-3, locally, disrupts the overall hydraulic gradient. The mounding is more continuously present in Pond 1, than for Ponds 2 and 3, apparently in response to the more direct connection to groundwater recharge from below. From measurements made during the dry climatic conditions that were observed, it is apparent that the mounds may disappear completely as Ponds 2 and 3 dry out. In fact, even though hydraulic connection appears to exist between the free pond water and water table, the apparent groundwater mounding is not considered to occur in the more classical sense.

When the pond mounding is present, water flow from each affected pond infiltrates downward and radially outward depending on conditions of permeability and hydraulic gradient. However, as evidenced by Figures 6-4 to 6-6, the direct influence of pond mounding is felt for only a few feet laterally in any direction from the ponds. The relatively impermeable former marsh soils lining the ponds are believed to limit the amount of seepage moving radially from the ponds.

In addition to Banner Spring Branch and Ponds 1-3, the overall water table configuration also appears to be disrupted by a groundwater mound beneath the central portion of the plant. The exact source of mounding is not certain although mounding of this type is common beneath industrial facilities. Concentrated rainfall runoff and infiltration, leaking storm sewers, and reduced evapotranspiration from soils due to extensive paved areas all tend to cause moisture buildup in the soils. In addition, it appears that the mounding near Wells 8 and 73 may also be due to natural causes from upward moving water in the Rome aquifer.

In some localized areas, steepening of the hydraulic gradient occurs during the wetter periods. In particular, these areas include Well 51, Well 63, and an apparent trend along a line connecting Wells 62, 24, 27 and 73. It appears that the hydraulic gradient in these areas is primarily controlled by upward moving water along the linear fracture zones outlined in Section 5.0.

Specific values of hydraulic gradient for the groundwater table beneath the facility are not presented in this section because of the wide range in slope of the water table surface. Values of hydraulic gradient for specific computational purposes are dependent upon the local area of interest. Closely spaced groundwater level contours represent steeper hydraulic gradients and widely spaced contours represent lesser gradients. Overall, for the ponds area and facility, hydraulic gradients of the water table primarily range between approximately 0.007 and 0.06. An average gradient of 0.015 has been estimated. The steepest gradients are located immediately adjacent to Ponds 1-3 when the ponds contain water; Well 63; the areas of mounding along the alignment of Wells 62, 24, 27 and 73; and occasionally at Well 51 during wet periods. Areas of gentler gradients occur near Well 39 and the water treatment plant; along the northwestern ponds area boundary near Wells 10, 59 and 81; between Wells 34 and 79 downgradient from Pond 3; and between Wells 27 and 75 downgradient from Pond 1.

In general it appears that hydraulic gradients steepen from the southeastern to northwestern facility boundaries during groundwater level recessions. This steepening primarily occurs because the greatest water level decline tends to occur along the northwestern boundary of the ponds area and burial ground. Near this area the water table flattens and gradually rises toward the southeastern facility boundary. Near the southeastern boundary, groundwater recharge from the Rome aquifer as well as seepage and spring discharge causes maintenance of, and less variation in, groundwater levels. However, no significant change in configuration of groundwater level contours (i.e., flow direction) was observed beneath the facility on a seasonal basis, or from peak to base level conditions.

The vertical hydraulic gradient is an important factor in determining the potential for downward groundwater movement from the water table and the depth of such movement. To identify the potential depth of movement, observation wells were constructed to depths of approximately 10, 36 and 120 feet at Wells 64 (unconsolidated aquifer), 37 (Rome) and 67 (Rome), respectively. Water level elevations for these wells are presented in Figure 6-8. It is apparent that the water level elevation for Well 67 (deepest well) is normally more than one foot higher than for the nearby shallower Wells 37 and 64. The water levels in Wells 37 (unconsolidated) and 64 (Rome) normally are at the same elevation, or Well 64 is slightly higher potentially indicating downward movement. From the water level trends for these wells, it is apparent that an upward hydraulic gradient occurs in the range between approximately 35 and 100 feet. From similar comparisons of water levels in other clustered wells it appears that an upward hydraulic gradient reversal is most likely to occur at depths ranging between 40 and 50 feet. In particular, chemical data from wells that are approximately 50 feet deep indicate that water at this depth is generally of background quality. Therefore, it is concluded that a transition from downward to upward hydraulic gradient occurs in the range of 40 to 50 feet beneath most of the facility.

<u>6.1.3.4 Velocity of Groundwater Flow.</u> Flow velocity is an important component in determining the rate and extent of chemical contaminant migration. Soil permeabilities and porosities, and groundwater hydraulic gradients are important factors affecting the rate and quantity of flow of groundwater. The water level data (Appendix G) and the groundwater level elevation maps (Figures 6-4 to 6-6) indicate that the water level surface beneath the facility generally slopes from southeast to northwest. Locally, water level mounds may occur a portion of each year such as beneath Ponds 1-3. Based on the water level measurements, the normal range of hydraulic gradients of the water table beneath the facility is 0.007 to 0.06. For the Rome aquifer rock materials, the average horizontal permeability is estimated to be 36.8 feet/day (1.3E-2 cm/sec) using data obtained by the Well 77 aquifer tests described elsewhere in this report. Locally, the bedrock permeability may be less than 7 feet/day (2.5E-3 cm/sec). Permeability of the unconsolidated aquifer silty sands and gravels determined by injection tests averages approximately 10 feet/day (3.5E-3 cm/sec), or less. The effective porosity of the bedrock and sand and gravel materials is estimated to be 30 percent. The modified Darcy equation shown below can be used to estimate groundwater flow velocities through the aquifer materials. Even though the bedrock is fractured and groundwater flow occurs along fractures, it has been assumed that due to the apparently great intensity of fracturing and the

sediments which fill the open fractures, permeability of the bedrock aquifer, as well as the unconsolidated aquifer, is homogeneous for broad areas:

$$\text{Calculated Particle Velocity (ft/day)} = \frac{\text{(permeability, ft/day)(hydraulic gradient, ft/ft)}}{\text{effective porosity, \%}} \quad (1)$$

Particle velocities for a range of hydraulic conditions are summarized below:

Aquifer	Estimated Permeability (ft/day)	Hydraulic Gradient (ft/ft)	Effective Porosity (%)	Calculated Particle Velocity (ft/day)	(ft/year)
Rome	37	0.007	30	0.86	315
		0.06	30	7.40	2701
Rome/Unconsolidated	10	0.007	30	.23	84
		0.06	30	2.00	730

The estimates provided are generalized and are not intended to apply to specific situations. Each unique area of interest must be separately evaluated. However, the calculated particle velocities are relatively large and indicate the potential for groundwater movement away from Ponds 1-3. In addition, the estimated groundwater flow velocities confirm the observations of rapid groundwater level response to hydraulic influences such as rainfall.

Comparison of the estimated rates of groundwater flow with the distribution of chemical contaminants originating from the ponds (see Section 7.0) indicates either that the flow velocities may be overestimated or that chemical distribution should be more extensive. However, the reduction of chemical migration due to chemical reactions with the soil materials limits the extent of chemical transport. In addition, the estimated permeabilities, above, are average values. Locally, such as the area near Wells 30, 31 and 77 downgradient from Pond 3, relatively impermeable aquifer materials occur. Based on the above assumptions and the measured permeability in these wells during the Well 77 test, groundwater flow velocity immediately down gradient from Pond 3 is estimated to be less than 0.15 ft/day. These zones potentially act as barriers and reduce the rate of groundwater movement. Furthermore, the zone of least permeability is at or just below the water table where most groundwater flow is expected to occur. Although this zone appears to contain the highest concentrations of chemicals, they should not be transported over great distances due to the reduced permeability.

<u>6.1.3.5 Groundwater/Surface Water Relationships.</u> From the water level measurements made at the observation wells, direct rainfall infiltration and subsurface recharge from the Rome aquifer are the primary factors influencing groundwater levels at the facility. When rainfall occurs, extensive overland runoff from the hillslopes is uncommon because most water directly contacting the soils and highly fractured rocks infiltrates and becomes groundwater. Eventually this water may become surface water by moving to and discharging from springs in the valleys.

The fracture systems in the bedrock serve as conduits that transmit the groundwater beneath the hillslopes. The groundwater generally moves downslope under water table and artesian conditions and surfaces from the bedrock into unconsolidated alluvial soils in the valleys. Locally, this discharge may occur as seepage areas, springs or through the beds of gaining streams. Beneath the facility, these discharge sources manifest themselves as the marsh areas, Banner Spring and other unnamed springs, and the upper reach of Banner Spring Branch.

Discharge from the above sources is more highly dependant upon groundwater recharge on the hillslopes than local rainfall. Therefore, groundwater levels can be maintained in the vicinity of groundwater discharge areas, even in the absence of local rainfall, if adequate rainfall occurs on the hillslopes. This factor generally explains historical observations of pond water levels that tend to fluctuate without correspondence with local rainfall events. In addition, discharge that occurs from the marsh areas represents the upward discharge of groundwater rather than maintenance by direct rainfall.

Field observations of direct rainfall indicate that only small amounts of overland runoff occur. Infiltration into the surface soils is relatively rapid as evidenced by the groundwater level response. Flow in Banner Spring Branch increases for only a short duration due to both rainfall infiltration and its limited catchment area. Runoff from direct rainfall onto the free water surfaces of the marshes is also of short duration. Occasionally, the discharge from Banner Spring will increase in response to hillslope flows. However, these increases are normally delayed until after the actual rainfall event.

6.1.4 Aquifer Characteristics

Several aquifer tests have been performed on the bedrock and unconsolidated aquifers beneath the NFS facility. The tests and extensive analysis have been performed to develop a basis for estimating the extent of pond leachate migration and acquire information necessary for aquifer restoration. Prior to this investigation, during April 1987, a two-hour pumping test using Well 30 (pumping well) and six additional observation wells was performed by TLG to make preliminary estimates of aquifer properties beneath the ponds area (TLG, 1987). Also, five single well injection tests were performed by TLG during April 1987 to evaluate the areal permeability distribution. The results of the tests performed by TLG provide insights to the overall character of the Rome aquifer, but detailed information needed for pond remediation was not developed.

During this investigation, Wells 30, 31, 32, 36, 37, 60, 62, 64, 76, 67 (pumping and observation well), and 77 (pumping well) were tested to make comprehensive estimates of aquifer properties. On August 22 and 27, 1988, the tests included 1.5-hour and 3.5-hour step-drawdown tests, respectively, of Well 77 to establish the well efficiency and potential long term well yield. Also, during August 23-26, 1988, two longer term pumping/recovery tests were performed using the 10 observation wells listed above to estimate detailed aquifer characteristics. These tests included a 14-hour (7.5-hours pumping/6.5-hours recovery) test pumping at an average rate of 32.2 gpm followed by a 48-hour (24-hours pumping/24-hours recovery) test pumping at a more feasible rate of 12.9 gpm.

Previous to the August 22-27, 1988 tests, a 7.5-hour (4-hours pumping/3.5-hours recovery) test was performed on May 25, 1988 during development of Well 67. Wells 37 and 64 were observation wells for this test. In addition, during the period from May to October 1988, 23 single well injection tests were performed throughout the facility to estimate the regional distribution of permeability. The following discussion presents well construction characteristics, wellfield layout, test procedures, data analyses and results for the tests performed during this investigation.

6.1.4.1 Well Construction. The eleven wells listed above comprise the wellfields used for the aquifer tests in the ponds area. Seven of these wells were completed within different vertical intervals of the bedrock (Rome) aquifer. Two wells were completed only within the unconsolidated aquifer and two wells are completed in portions of both aquifers. Well 77 was designed and located to serve as the pumping well for the tests performed in August. While the remaining 10 observation wells had been previously located primarily to optimize groundwater quality sampling, their completion intervals were also adequate for the aquifer testing. Well completion data for these wells are provided in Table 6-3.

A generalized well completion diagram showing well construction techniques and materials is shown by Figure 6-9. Construction details of each well are shown in Volume II, Appendix A. A detailed discussion of well construction procedures is included in Section 4.0, Methods.

6.1.4.2 Wellfield Layout. The wellfield layout used for the aquifer test is shown by Figure 6-10. Hydrogeologic sections across the wellfield are presented in Figures 6-11 to 6-13. Within the limits of physical layout of the ponds area and plant security, the wells are completed in a pattern that allows determination of hydrologic aquifer characteristics such as transmissivity, storage coefficient, anisotropy, hydraulic boundaries and the radius-of-influence of pumping. The wells may also serve as the basis for subsequent injection/recovery tests if that need is identified.

Well 77 penetrates and tests approximately 50 percent of the shallow Rome aquifer to a depth 50 feet below the ground surface and was used as a producing well during the August 22-27, 1988 tests. Well 67 was the production well for the May 25, 1988 tests; and also, was a deep observation well during the August Well 77 tests. This well is completed in the Rome aquifer at a depth of 113.5 to 120 feet. The remaining wells in the pattern either penetrate 10 to 40 percent of the Rome aquifer at intervals equal to or shallower than Well 77, or fully penetrate the unconsolidated aquifer to depths not exceeding 15 feet below ground surface.

Wells 31, 36, 64 and 67 were included in the well pattern to observe the potential hydraulic connection between strata that are shallower and deeper than the Well 77 completion depth. Specifically, the primary purpose of these wells was to aid in the determination of the presence or absence of leakage between the shallow bedrock test zone and the shallow unconsolidated or deeper Rome aquifer, and to establish baseline water quality for these aquifers.

Prior to the aquifer testing, the wells were developed to remove sediment in the wells due to construction. Development consisted of washing the wells with clear water and airlift pumping. Water was pumped from each well for approximately one hour until the water appeared reasonably free of sediment.

In addition to developing wells constructed during this investigation, previously constructed wells were developed including Wells 30, 31, 32, 36 and 37. All of these wells appeared to function adequately during development. However, all contained significant amounts of sediment and a very fine sand used for the filter pack was washed from the wells. The yields of Wells 30 and 36 were relatively small. The small yield of Well 36 is believed to be due to the shallow depth and small saturated thickness. However, the screen in Well 30 may be partially clogged due to the small grain size of the filter pack, unsatisfactory previous development and pumping during the April 1987 test.

It appears that all observation wells used for the aquifer tests are adequately constructed and developed. Although Well 30 may be partially clogged, the water level in the well responded to the pumping influence during the tests and data acquired from Well 30 during the tests are considered to be valid.

6.1.4.3 Aquifer Test Procedures. Specific test procedures are described in Section 4.0, Methods. The following summary outlines the sequence of tests that were performed. The aquifer test field data, including water level readings, time of water level measurements and discharge rates are presented for each of the 11 wells in Appendix H.

A 7.5-hour air-lift pumping test was performed on May 25, 1988 using Wells 37, 64 and 67. Well 67 was pumped for 4-hours and water levels were observed in Wells 37 and 64. Because of the airlift method of pumping, water levels could not be measured in Well 67 during pumping. However, frequent measurements were made in Wells 37 and 64. During water level recovery following pumping, frequent measurements were made in all wells. The information gained from this test was used to define the wellfield layout and procedures used for the Well 77 tests.

A 1.5-hour step-drawdown test was performed on August 22 to determine the efficiency and optimum yield of Well 77. Well 77 was pumped at three different pumping rates (6.1, 16.4 and 41.3 gpm) of 0.5-hour duration each during the 1.5-hour period. A fourth pumping rate had been anticipated, but was omitted due to mechanical problems with the pump generator. Frequent measurements were made of the water level in Well 77 and the time of each measurement was noted. From these data, the well efficiency was calculated and the optimum pumping rate for the long term pumping test was estimated. Although the primary interest during the step-drawdown test was the pumping well, water levels were observed in the observation wells to obtain information on their potential response to the pumping during the longer term tests.

The initial long term Well 77 pumping test began at 10:43 a.m. on August 23, 1988 following approximately 20-hours of water level recovery from the step-drawdown test. The pumping period continued for approximately 7.5-hours at an average rate of 32.2 gpm. The test was discontinued at 5:53 p.m. due to severe water level drawdown that was suddenly encountered in Well 77. Water levels were monitored continuously during both the pumping period and a 6.5-hour recovery period. The information gained during this test was used to select a more optimum pumping rate for a subsequent long-term test.

The second long-term Well 77 pumping test began at 5:25 p.m. on August 24, 1988 following 23.5-hours of water level recovery from the August 23 test. The pumping period for this test was 24-hours in length followed by a water level recovery period of 24-hours. The average pumping rate of Well 77 was 12.9 gpm and water levels were measured continuously during the entire pumping/recovery period.

On August 27, following the second long-term test, a second 3.5-hour step-drawdown test was performed. The information gained was used to reevaluate well efficiency and optimum yield of Well 77 following the extended period of pumping. In particular, the effects of excessive pumping and well development during early phases of the August 23 long-term test were of concern. Also, this test allowed acquisition of supplemental data not possible to obtain during the first step-drawdown test due to the generator malfunction.

During the period from May through October 1988, a total of 25 single well injection (slug) tests were performed at 23 wells throughout the facility. Duplicate tests were performed at two wells to evaluate the reproducibility of results. Data from the injection tests were used to evaluate the distribution of transmissivity and permeability beneath the facility in regard to both areal proximity to the ponds area and by aquifer.

<u>6.1.4.4 Aquifer Test Results.</u> The hydrologic properties of the bedrock and unconsolidated aquifers have been evaluated from data collected during the aquifer tests. Four methods of analysis for unsteady and steady radial flow to a well were used for the evaluation. A fifth method was also used to determine well and aquifer losses. These methods are: (1) Theis superposition, (2) Jacob Modified, (3) residual drawdown recovery, (4) distance drawdown, and (5) step-drawdown. Graphical solutions of these tests are presented in Appendix H.
The data analyses provided values for aquifer hydrologic parameters such as transmissivity, T; storage coefficient, S; and leakage factor, r/B. The Theis analysis is considered to have provided the most reliable results with regard to transmissivity and storativity. However, all methods show close agreement. The results of the long-term pumping test data analyses are summarized in Tables 6-4, 6-5 and 6-6. The values shown for the May 25 and August 23-26 tests have not been corrected for partial penetration effects because analysis indicated that this was not necessary. Data included in Tables 6-5 and 6-6 have been used only to confirm the validity of the data for the August 24-26 test and have not been analyzed in detail.

Transmissivity values presented in Table 6-4 for the August 24-26 test range from 1022 gpd/ft (Well 77) to 21,119 gpd/ft (Well 76). The average values of T determined by the Theis, Jacob and residual drawdown methods are 11,016, 10,550 and 9,431 gpd/ft, respectively. A wide range of transmissivity values exists in the wellfield with the lower values distributed closer to and at the pumping well. The April 1987 test of Wells 30 and 31 also indicated that these wells measured low transmissivity. It appears that the low transmissivity measured in these wells is due to the presence of relatively impermeable and tightly fractured strata in the vicinity. The wide range and lack of distinct trend of transmissivity values indicates the heterogeneous nature of the aquifer due to variable lithology, structural attitude of the strata and rock fracturing.

The average storage coefficient values calculated by the Theis, Jacob and distance drawdown methods show good correlation and are of the same order of magnitude (Table 6-4). The storativity values range from E-2 to E-3 and the average value is about 1.3E-2. These values based on the early time test data indicate that the hydraulic system tested is weakly artesian.

The calculated hydraulic conductivity for individual wells ranges from 38.7 to 528.0 gpd/ft^2. The average hydraulic conductivity value was calculated based on an effective aquifer thickness of 40 feet and is about 275.4 gpd/ft^2. A value of 40 feet was selected based on the thickness of the test interval between the bedrock surface and the bottom of Well 77. The use of any other aquifer thickness based on thickness or depth of strata, structural feature or hydraulic connection of strata due to fracturing would be speculative.

The test analyses summarized in Tables 6-5 and 6-6 confirm the results of the August 24-26 test. The aquifer transmissivities determined by pumping the hydraulic system at 32.2 gpm on August 23 (Table 6-5) were slightly higher for some individual wells, and the average for all wells, than for the 12.9 gpm pumping test. However, a comparison of individual wells indicates great similarity of results. The August 23-24 results are considered valid only for the first several minutes of pumping. This is due to the decline in well yield and steady state condition achieved in the pumping well later in the test. Therefore, these data have not been used to estimate leakage, directional permeability or other aquifer parameters.

Data for the Well 67 test on May 25 (Table 6-6) generally confirm the Well 77 test data although larger variation in transmissivities was measured. Although the observation wells tested are common to both wells 67 and 77, Well 67 is completed in a much deeper zone. The variation in results is largely attributed to stratigraphic and structural heterogeneity of the hydraulic system and to errors inherent to the airlift pumping technique.

Table 6-7 and Figure H-70 present values of transmissivity (1742 gpd/ft) and storage coefficient (0.016) determined from the distance-drawdown method for the time 1440 minutes at the end of the test. These results correlate well with the results of the other methods, especially the results of observation wells close to Well 77. From the distance-drawdown method, the estimated radius-of-influence of significant water level drawdown resulting from the test was only about 200 feet.

Utilizing the distance-drawdown analysis (Figures H-65 to H-70), it is apparent that significant anisotropy of the data exists. The anisotropy is especially pronounced in Wells 30,31,76, 36, 67 and 60. These wells tested a wide variety of stratigraphic and hydrologic conditions. Well 36 is completed in the shallow unconsolidated aquifer. Conversely, Well 67 is completed in a deeper bedrock zone strongly influenced by fractures. Wells 30 and 31 are located in a shallow bedrock low permeability zone. Wells 60 and 76 are strongly influenced by fractures. The best fit through all of the observation wells for the time of 1440 minutes of pumping resulted in an "envelope" of radius-of-influence ranging from approximately 100 to 275 feet from the pumped well. Theis calculations for the same aquifer conditions confirm this result. This is a somewhat small radius-of-influence and reflects the effects of the moderately high transmissivity.

Using the distance-drawdown method, a consistent trend in transmissivity and storage coefficient is apparent throughout the pumping test (Table 6-7). The analysis was performed for times of 100, 200, 500, 800, 1000 and 1440 minutes of pumping. Transmissivity consistently decreased during this period from a high value of 6079 gpd/ft (100 minutes) to a low value of 1742 gpd/ft (1440 minutes). At the same time the storage coefficient increased from 0.003 (100 minutes) to 0.016 (1440 minutes). A probable interpretation of these relationships is that continued pumping of Well 77 caused a change from the static weakly artesian condition to a water table condition, as evidenced by the change in storage coefficient. This interpretation is further supported by the progressive decrease in transmissivity as the aquifer was dewatered and the saturated thickness decreased. Leakage as indicated by the r/B factor presented in Table 6-4 may have been due to groundwater moving downward into the zone of pumping influence through partially confining strata above, or from delayed gravity drainage of the unconfined water table in the unconsolidated aquifer, above.

The overall effect of various operational dewatering rates on the radius-of-influence created by pumping water from, or around, the ponds has been calculated for a variety of pumping situations (Table 6-8). The drawdown projections were determined by using the Theis non-equilibrium equation. For example, the radius-of-influence for which drawdowns are estimated to be greater than one foot after dewatering any individual pond for 180 days at a pumping rate of 25 gpm is approximately 990 feet. The maximum radius-of-influence created by the dewatering influence for the examples shown in Table 6-8 is approximately 6755 feet. However, the sludge removal operations will pump water from the ponds only during final cleanup of pond water for only a few days. The calculations do not estimate the effects of heterogeneous conditions related to fractures, geologic structure, lithology or boundary conditions due to local creeks and Nolichucky River which might be expected to influence long-term pumping.

The analysis of transmissivity identified that leaky artesian conditions exist in the bedrock aquifer beneath the ponds area. The most likely source of leakage was the saturated unconsolidated aquifer reposing on non-continuous and fractured confining strata just below the bedrock surface. The rate of vertical leakage of groundwater through a confining bed in response to a given vertical hydraulic gradient is dependent upon: (1) the vertical hydraulic conductivity (k') of the confining layer, and (2) the thickness (b') of this layer. The vertical hydraulic conductivity is defined (Walton, 1962) as the rate of vertical flow (leakage) in gallons per day, through a unit cross-sectional area of one square foot)(gpd/ft^2). The pumping test data collected during the August 24-26 24-hour pumping period were analyzed by curve matching of field data (drawdown vs. time) against the solution of the leaky artesian formula as presented by Hantush and Jacob (Walton, 1970):

$$s = \frac{114.6\ Q\ W(u,r/B)}{T} \qquad (2)$$

where, $$u = \frac{2693\ r^2 S}{Tt} \qquad (3)$$

and, $$r/B = \sqrt{r/T/(k'/b')} \qquad (4)$$

The terms and units of special interest to leakage determination are the terms W(u,r/B) in equation (2) and r/B in equation (4). W(u,r/B) is defined as the well function for leaky artesian aquifers. The leakage coefficient (r/B) is a function of the distance (r) from the pumped well to the observation well, transmissivity (T), and the ratio of k'/b' (defined above).

Leaky artesian conditions are detected when drawdown-time field data match the flat portions of the leaky artesian curves (Appendix H). To each leaky artesian curve, an r/B value is assigned (for standard type curves r/B values range from 2.5 to 0.01). At the end of the 24-hour pumping period, all observation wells except Wells 36, 60 and 67 exhibited some degree of leakage. Well 60 was located near the outer limits of pumping influence where leakage should not have been noticeable. Well 36 is located at a moderate distance from Well 77 and leakage effects may have been influenced by local stratigraphy. Well 67 may have been influenced by leakage due to its completion interval which is at a relatively great depth below the zone of pumping.

Well 64 exhibited a leakage factor of 0.20 at a pumping time of 450 minutes. However, this phenomenon is not entirely explained in that Well 64 is completed in the unconsolidated aquifer from which the leakage appears to have occurred after approximately 900 minutes of pumping. Measurements in Well 62 completed in both the unconsolidated and bedrock aquifers may also have resulted in an anomalous r/B value.

For the remaining wells (30, 31, 32, 37 and 76) it appears that r/B varies with the distance of the observation wells from the pumping well. Therefore, results have been grouped as: (1) r/B = 0.1 for the nearby wells (33.0 to 88.4 feet), (2) r/B = 0.075 for Well 37 located 118.4 feet from the pumping well, and (3) r/B = 0.05 for Well 32 located 179.9 feet from the pumping well. From the graphical curve matching it appears that the leakage effect was detected in all of the wells following about 800 to 950 minutes of pumping.

Based on available data, it appears that the direction of leakage was downward from the unconsolidated aquifer. The distance-drawdown transmissivity and storage coefficient imply that the upper portion of the bedrock aquifer was dewatered as the test progressed. Thus, a downward hydraulic gradient was created that allowed water in the unconsolidated aquifer to move downward into the zone of pumping influence. If this downward movement was, instead, a delayed gravity response of the bedrock aquifer to pumping, the following analysis of leakage rate may be invalid. Using a range of average r/B values, transmissivity values of 2,000 and 11,000 gpd/ft, a range of b' values of 10 to 20 feet, and the appropriate distances between the observation wells and the pumped well (33, 88, 118 and 180 feet) the calculated vertical hydraulic conductivity for the confining layer(s) separating the confined shallow bedrock test zone and the unconsolidated aquifer is from 0.009 gpd/ft^2 (4.2E-7 cm/sec) to 0.37 gpd/ft^2 (1.7E-5 cm/sec). Thus, it is apparent that the vertical hydraulic conductivity of the confining layer is only slightly permeable to impervious under natural groundwater flow conditions. In fact, unless a significant measurable head differential exists between the aquifer units, only a small rate of vertical flow will take place. This fact is evidenced by the relatively shallow depth of penetration of pond chemicals due to the measured gradient reversal in hydraulic head at a maximum estimated depth of about 50 feet below the ground surface.

An analysis could not be made from field data to determine the order of magnitude of the ratio Kh/Kv (horizontal to vertical hydraulic conductivities). Partially penetrating wells placed at optimum distances from each other allow such a determination. However, the primary purpose of the observation well network was to identify the distribution of chemicals in the groundwater. From knowledge of the results of vertical permeability determinations elsewhere, the ratio Kh/Kv generally ranges between 1.5 and 5; although ratios exceeding 10 may not be uncommon.

In addition to the distribution of transmissivity within the zone of pumping influence, the drawdown distribution during and at the end of the 24-hour pumping period also indicated significant anisotropic conditions. For example, water level drawdown in Well 31 which is 43.9 feet from Well 77 was 3.50 feet relative to a drawdown of 2.74 feet in Well 30 which is only 33 feet from Well 77. Well 30 would have been expected to exhibit a greater drawdown than Well 31. Contouring of equal drawdowns around the pumping well indicated the following qualitative features: (1) drawdown distribution has the form of an ellipse, (2) ratio of major to minor axis is about two, and (3) an abrupt yet irregularly defined transition to drawdowns less than 0.5 foot occurs at the perimeter of the drawdown influence. The configuration of the drawdown cone and transition zone may be affected by the aquifer leakage and aquifer heterogeneities, such as fractures, identified as a result of the test.

The horizontal anisotropy in the vicinity of the pumping well was computed in detail using the Papadopulos method (1965). A minimum of three observation wells is required to carry out the Papadopulos analysis. However, the additional seven observation wells in the test pattern, as well as various combinations of observation wells, were utilized to calculate more reliable average values of anisotropy for the test site. In order to find the principal transmissivities of the hydrologic system tested, their direction, and the storage coefficient, an x-y coordinate system was selected to parallel east-west (x-axis) and north-south (y-axis) with its origin at Well 77. For each observation well, the appropriate parameter was selected and used as outlined by Papadopulos (1965).

The results of the anisotropy analysis for the test site are presented in Table H-1. For the 10 wells tested, there are 120 three well combinations. Due to the strongly heterogeneous nature of the Rome aquifer and areal distribution of observation wells in the test pattern, only 21 values of major and minor transmissivities were obtained. The mean transmissivity for these values is approximately 9600 gpd/ft which is in the range defined by the pumping test using other techniques. The mean values for the major and minor transmissivity directions are 720,000 and 157 gpd/ft, respectively. While the value of minor transmissivity appears reasonable based on the other analyses of the data, the calculated value of major transmissivity is very large and potentially unrealistic based on the overall characteristics of the aquifer. Nevertheless, the analysis indicates a very strong preference for the major transmissivity values to be aligned within a narrow zone. The major axis of anisotropy was calculated to occur within the range of N30°E to N45°E. This orientation corresponds to the inferred orientation of fracture planes and the strike of rock strata beneath the ponds area. Preferential movement of groundwater might be expected along this fracture zone and similar zones beneath the ponds area.

Although the preferential direction of groundwater movement and bedrock lineations are relatively consistent, the anisotropy analysis for the shallow bedrock at the Well 77 test site should not be applied to a larger area of the NFS Facility. Additional analyses should be performed on a site specific basis if that need arises due to the great variability of bedrock controls. In addition, the anisotropy analysis should not be considered applicable to the unconsolidated aquifer, above, which is considered to be more homogeneous and less anisotropic.

Based on data collected during the 1.5- and 3.5-hour step-drawdown tests, calculations of well-loss, well efficiency and specific capacity have been made (Appendix H). Using the method outlined by Jacob (1946), well losses for the various pumping rates that were evaluated ranged from 0.08 ft for 6.1 gpm to 62.17 for 43.9 gpm. The equivalent well efficiencies measured by both tests range from 95 to 0 percent.

The step-drawdown test performed prior to the long-term pumping tests indicated the pumping efficiency of Well 77 ranged between 73 to 95 percent for pumping rates ranging between 41.3 and 6.1 gpm, respectively. The step-drawdown test performed subsequent to the long-term tests indicated the pumping efficiency of Well 77 had dropped to zero for all pumping rates tested between 12.1 and 43.9 gpm. It is concluded that significant well development that occurred early during the August 23-24 test caused clogging of the well screen in Well 77 with significantly increased screen entrance velocities and well loss. The relatively high initial pumping rate selected for the August 23-24 test is believed to have caused the over development of Well 77. In addition, the well screen slot size and gravel pack grain size may not have been compatible.

Specific capacities calculated for various stages of the tests are shown in Table 6-9. At the end of the 24-hour pumping period, a specific capacity value of 1.27 gpm/ft of drawdown is calculated. Thus, for the conditions of the test, a maximum long-term well yield of approximately 24 gpm should be possible.

<u>6.1.4.5 Injection Test Results</u> Water injection tests were performed on 23 observation wells throughout the facility to estimate horizontal permeabilities of the soil and rock materials below the water table. Injection "slug" tests were selected for use because they produce an order-of-magnitude quantification of permeability without requiring elaborate equipment or extensive time to perform the tests. However, injection test results should be used with caution since the estimated permeability is representative of only a small influence zone near each well.

The permeability calculated for each injection test is representative only of horizontal permeability for the saturated screened interval in the well that occurs below the water table. For the wells tested, this zone extended from as shallow as one foot for Well 23 to as great as 120 feet for Well 67. The test results for individual wells are generally considered valid for the expressed order of magnitude of the power of ten.

The injection test results are summarized in Table 6-10. The estimated mean permeability value for all wells tested is approximately 3.3E-3 cm/sec. Calculated permeabilities range from 3.7E-4 to 7.5E-3 cm/sec. There is a slight trend for smaller values of permeability to correspond to measurements in the unconsolidated aquifer. Values of E-3 cm/sec generally are representative of relatively permeable coarse sand and bedrock. Values of E-4 cm/sec appear to represent silts or sandy silts of finer texture.

The permeability values measured by the injection tests are somewhat smaller but consistent with values measured by the Well 77 pumping tests. Average permeability for the August 24-26 test is 1.1E-2 cm/sec. The calculated permeabilities for the Well 77 observation wells range from 1.8E-3 to 2.5E-2 cm/sec. The larger permeabilities calculated from the Well 77 test probably are the result of testing a larger (i.e., deeper and longer screened interval) segment of the Rome aquifer. Therefore, these calculated values represent an average of a greater portion of the aquifer than each individual injection test. In addition, it is likely that portions of the aquifer less than 35 feet in depth are somewhat less permeable than deeper portions, or zones in which fractures are encountered.

6.2 Surface Water

6.2.1 Regional Streamflow

The ponds area of the NFS Facility is transected by Banner Spring Branch. This creek is perennial and is fed by Banner Spring with average reported flow of approximately 300 gpm adjacent to the eastern boundary of the ponds area. Currently, Banner Spring Branch is confined to a straight, incised channel between Ponds 1 and 2 and Pond 3 that was excavated at the time of pond construction. Formerly, the channel left the ponds area along its western boundary. However, additional channelization by NFS diverted the creek from its current bend near Well 79 (Figure 6-14) directly beneath the northern ponds area boundary to its confluence with Martin Creek.

Review of regional topographic maps created prior to facility construction indicate that the Banner Spring Branch channel formerly occupied marshes in a position beneath the locations of Ponds 1 and 2 and the area of "Pond 4." Historical reports from long-time plant employees indicate that the former channel was not well defined and flowed through the marshes which occupied the entire ponds area except near Pond 3. The marshes located near Pond 3 and in the burial ground did not initially exist until they were created at approximately the time of construction of Pond 3.

Because the channel of Banner Spring Branch is completely man-made, the groundwater flow directions in the vicinity of the creek have been altered. From Figures 6-4 to 6-6, it is apparent that the creek is a gaining stream relative to groundwater flow in its upper reaches. Below the bend in the channel the creek is a losing stream except for the area near its confluence with Martin Creek. In this area the channelization probably left the channel floor a few feet above the natural water table. The former position of the creek channel appears to be indicated by the subdued water level contours in the western portion of the ponds area. In the area of Ponds 1 and 2, water mounding has apparently reversed any control the former stream channel adjacent to the ponds may have had on groundwater flow.

Banner Spring Branch flows into Martin Creek near the northwestern corner of the burial ground. Martin Creek is estimated to have an average flow of 7 cfs. During this investigation, it was determined that Martin Creek derives essentially all of its base flow from a spring at the fish hatchery upstream near Banner Hill Road and from groundwater seepage along another branch, also in the vicinity of Banner Hill Road. While the spring discharge remained relatively constant, the seepage through the channel floor in the other stream branch varied in proportion to rainfall.

Downstream a few thousand feet, Martin Creek joins with North Indian Creek. Subsequently, North Indian Creek flows into Nolichucky River after flowing through a series of abandoned gravel pits. The flow in North Indian Creek averages approximately 100 cfs and the flow in Nolichucky River is 1347 cfs. Historically, NFS has monitored water quality in Nolichucky River upstream and downstream from its confluence with North Indian Creek. The upstream sampling site is above the confluence of South Indian Creek and Nolichucky River, and does not consider the influence of South Indian Creek, and the downstream site is more than one mile below the confluence of North Indian Creek and Nolichucky River.

6.2.2 Field Procedures

Streamflows along Banner Spring Branch were measured with a current meter on five separate dates between May 3 and June 16, 1988, to determine the gains and/or losses in flow between Banner Spring and Martin Creek. During this period, rainfall was sparse with the exception of May 17 when approximately 1.5 inches occurred. In fact, rainfall was sparse throughout the entire investigation with less than 20 inches of rainfall reported by the NFS weather station. The flow measurements were consistently made at three staff gage locations along the creek (Figure 6-14). The gage locations are (1) upper (upstream approximately 200 feet downstream from Banner Spring), (2) middle (immediately downstream from the ponds within the ponds area), and (3) lower (just above the confluence with Martin Creek). In addition, flow measurements were taken at the culvert just upstream from the upper staff gage where the creek passes beneath the ponds area perimeter road. Streamflow measurements were taken with a pygmy current meter. The flow measurements are summarized on Table 6-11 and Appendix I. Figure 6-15 presents streamflow gains and losses for various reaches of the stream. In addition to direct-flow measurements, the water height on the staff gage was read weekly when groundwater levels were measured. These data were compared against the current meter data using rating curves.

6.2.2.1 Banner Spring Branch Physical Characteristics. A traverse was made along Banner Spring Branch between Banner Spring and Martin Creek to visually evaluate channel geometry, streambed soils, the presence of side tributaries including plant discharges and natural seepage and streamflow gains and losses. At the staff gage locations, the base flow channel is relatively uniform and straight with the water surface ranging in width between approximately 2.5 and 5.0 feet. Elsewhere, base flows occupy a channel width of as much as 10 feet and may meander due to the slight gradient of the channel.

Above the middle staff gage the channel gradient is apparently 0.002 and baseflow velocities move relatively slowly in this reach. Downstream from this gage, the gradient steepens to 0.006 and the baseflow velocities increase with the gradient.

During storm runoff, the water volume expands to occupy a wider and more well-defined channel that has been straightened by previous channel diversion activities. Based on measurements during May 17 and subsequent visual observations during the investigation, storm flows accumulate relatively rapidly from the facility. However their influence dissipates equally rapidly following the rainfall.

Upstream from the middle staff gage, the streambed soils are fine to coarse sand and gravel. In the vicinity of the middle staff gage and downstream to the northern ponds area boundary, the soils are generally fine silty clay and fine to medium sand. Downstream from the ponds area fence, the soils grade back to sand and gravel. Borehole information indicates that the sand and gravel in the streambed represents the sand and gravel layer resting directly on the bedrock surface below. Aquifer test information indicates that the sand and gravel permeability is 10^{-3} centimeters/second and that the permeability of the silty clay may be as small as 10^{-6} centimeters/second.

The only continuously flowing natural tributary entering Banner Spring Branch is the discharge from a marsh in the ponds area adjacent to Pond 3 (Figure 6-14). A second marsh adjacent to the burial ground is connected to the ponds area marsh by a culvert and discharge from a small spring in this marsh is the source of this water. Baseflows from the marsh range from approximately 3 to 5 gallons. However, following the rainfall on May 17 the marsh discharge was more than 100 gpm for a short period.

The streambed of Banner Spring Branch was observed for the presence of springs and seepage. Only one small area of seepage was observed just downstream from the upper staff gage and upstream from Ponds 2 and 3. Measurements of the seepage were not possible, but the volume is relatively small.

Plant personnel who have observed the creek during a longer period of time report that several additional areas of seepage occur along the streambed. However, these areas were not observed during this investigation, and it appears that these seeps may have dried up due to the lack of rainfall during the past several years.

Three storm drains channel runoff from the plant area through the ponds area into Banner Spring Branch. These culverts are located in the upper, middle and lower portions of the ponds area. The upper and middle drains are buried culverts while the lower drain is an open concrete lined ditch.

Plant runoff can be controlled in these culverts. For example, no storm water was observed to be discharging from the middle culvert following the May 17 rainfall. All runoff was apparently being routed through the open drain. Natural seepage has continually discharged from the upper culvert at a rate of approximately 1 to 5 gpm. This discharge apparently represents groundwater leakage into the culvert where the culvert is located below the water table.

A relatively continuous flow ranging from approximately 5 to 40 gpm discharges from a buried culvert into the creek near the east end of Pond 2. This outfall is Building 220 cooling water discharge. Makeup for the cooling water is withdrawn from the creek immediately upstream from the outfall location.

6.2.2.2 Streamflow Characteristics. The results of streamflow measurements presented in Table 6-11 and Figure 6-15 indicate that neither significant gains nor losses occur throughout Banner Spring Branch during baseflow conditions. Overall, from Banner Spring to the lower staff gage a slight decrease in streamflow was consistently measured.

During baseflow the creek appear to lose water slightly in the short distance between the upper road culvert and the upper staff gage. This may be due to the capacity of the sand and gravel streambed to accept water immediately after virtually all of the creek's flow discharges back into the natural channel after being diverted through the road culvert.

From the upper staff gage to the middle staff gage, slight gains in streamflow were measured corresponding to the amount of water being discharged by the marsh tributary, plant cooling water and groundwater seepage. The measured gain in flow is also supported by the water level configuration maps (Figures 6-4 to 6-6) which indicate that this portion of the creek is a gaining stream with respect to the groundwater system.

Downstream from the middle staff gage streamflow losses to groundwater appear to occur, perhaps due to the position of the channelized stream bed above the water table. The water level maps support this relationship.

Streamflow losses are summarized in Table 6-11 for baseflow conditions on May 3, May 12, June 2 and June 16, 1988. The net streamflow loss from upstream to downstream did not exceed 62 gpm for any of the periods of baseflow measurements. For these measurement periods, at the upper staff gage, the maximum flow from Banner Spring was about 300 gpm, but was as low as 250 gpm. At the lower staff gage, the flow ranged from 207 to 269 gpm for the same periods.

The trends and influence of groundwater levels on the streamflow during relatively dry climatic conditions have been determined. During this investigation, groundwater levels were at relatively low levels. The configuration of the groundwater table indicates that the upper reach of Banner Spring Branch should receive a gaining (recharging) influence from the groundwater table.

During extended periods of abundant rainfall, the groundwater table will rise. A resultant increase in streamflow would be expected as the groundwater moves toward and seeps from the stream bed. Because most measurements have been made during baseflow conditions, little is known of the actual streamflow characteristics during a sustained period of abundant moisture.

The May 17 measurements indicate that significant but brief, gains in streamflow occur as a result of intense thunderstorms. Although the Banner Spring discharge did not increase as a result of the rainfall, the gain in streamflow due to runoff at the lower staff gage was approximately 2.5 times greater than at the spring more than one hour after the rain ceased. The gain in flow was primarily due to discharge from the marsh near Pond 3 and plant runoff through the lower storm drain. The large volume of discharge from the lower storm drain backed up due to the culverts beneath the ponds area perimeter road and caused backwater effects upstream to the middle staff gage.

7.0 SOIL AND WATER CHEMISTRY

7.1 Soil Chemistry

The results of metals and radiochemical testing of soils are reported on Tables J-2 and J-3, respectively. A more detailed discussion of the distribution of chemicals in the soils is provided in Appendix J, Soil Chemistry Notes. The soil sampling for chemical testing was a secondary objective of this investigation and is of a reconnaissance nature. The sampling was performed to supplement the results of the water quality investigation, and to correlate the presence of pond related chemicals in the unconsolidated soils with dissolved concentrations of the chemicals in the groundwater.

Relative to inorganic chemistry, Ponds 1-3 and "Pond 4" appear to have had measurable effects only on pH, mercury and fluoride. Background soils pH in the region ranges between 4 and 6. Within the area of pond/plant influence soil pH commonly ranges between 7 and 9.4. Where these values occur in close proximity to the ponds, it appears that the bicarbonate alkalinity of pond waters and sludges has raised the pH of nearby soils. Laterally, the variation in soil pH is great due to local areas of acidic groundwater with which the soils have been in contact. In addition, there is a tendency for soil pH to decrease with depth to background levels indicating that the influence of pond leachate dissipates with depth.

Distribution of elevated concentrations of mercury in soils is limited to the immediate area of Ponds 1-3 and "Pond 4." Fluoride is also dispersed in soils near Ponds 1-3 and "Pond 4" and at isolated locations beneath the plant and burial ground. In general, the areal distribution of elevated concentrations of these chemicals in soils corresponds to their distribution in groundwater.

nuclides

The most wide spread radiochemicals in the soils are uranium-234, uranium-235 and uranium-238 (Appendix J). In addition, soils from boreholes located near "Pond 4" and from Banner Spring Branch stream bed exhibit above background concentrations of plutonium-238, plutonium-239, thorium-228, thorium-230, thorium-232 and americium-241. Based on the available limited information, there appears to be a decrease in radiochemical concentrations with increasing depth in most boreholes. However, the more elevated chemical concentrations generally occur below the water table. The depth of occurrence of uranium in the soils is also a function of the depth of sludge in adjacent pond(s) or depth of waste materials in "Pond 4."

As described above, the soils recovered from Banner Spring Branch stream bed exhibited elevated radiochemical concentrations. The sample locations are located within the Ponds 1-3 chemical plume. Therefore, the presence of radiochemicals in the soils may be due to precipitation of chemicals from the groundwater plume, or may be residual material left by previous pond operations. Active leaching of these soils does not appear to be occurring or was undetected based on the results of chemical tests on water collected from Banner Spring Branch.

7.2 Water Chemistry

7.2.1 Introduction

Water samples were collected from essentially all observation wells and surface water locations in the NFS monitoring system. Tables K-4, K-5 and K-6, (Appendix K) summarize the analytical results for general chemical parameters and heavy metals, organic chemicals and radiochemicals, respectively. Chemical test results are shown in these tables for all sampling periods. Also included in Appendix K, are the completed laboratory reports for all samples collected. In addition, Appendix K contains summaries of all historical general chemistry and radiochemical analyses made available by NFS during this investigation.

Extensive statistical and graphical analyses of the data have been performed. Numerous tabulations, graphs and maps have been prepared and reviewed. Notes outlining details of the water chemistry analysis are included in Appendix K and may be used as further explanation for chemical distribution maps presented in this section.

7.2.2 General Chemistry and Metals

The results of general chemical and heavy metals analyses are reported on Table K-4. Background waters in the unconsolidated and Rome aquifers are moderately hard and of the calcium-magnesium bicarbonate type. Waters in these aquifers are very similar with relatively low total dissolved solids concentrations. The similarity of chemical type may indicate that the waters have comparative freedom of movement both laterally and vertically between the two aquifers. This fact has been verified by the analysis of groundwater occurrence beneath the facility (see Section 6.0).

Based on the degree of aquifer interconnection, it is reasonable to assume that waters of similar composition should occur everywhere within the relatively small area beneath the facility. However, the results of chemical testing and analysis have shown that this does not occur. Pattern diagrams (Figure 7-1) showing quality of samples of water from the unconsolidated and Rome aquifers indicate that several unique water chemistries occur beneath the ponds area and facility. A potential source for each of the water chemistries has been indicated on Figure 7-1.

Figure 7-1A depicts the general calcium-magnesium bicarbonate character of background water in Well 55. This pattern is representative of all well waters identified as background in Appendix K. The water pattern shown for Well 59 (Figure 7-1B) is very similar to background water but with slightly higher total dissolved solids and representative of wells completed in the unconsolidated aquifer downgradient from the burial ground.

A primary objective of this investigation was to identify effects on groundwater chemistry associated with Ponds 1-3. Figures 7-1C and 7-1D show two primary water chemistries associated with the ponds. One of the water types is sodium bicarbonate, often with a sulfate component and with high total dissolved solids. In several downgradient wells such as Well 33, the predominant chemistry is sodium bicarbonate with elevated concentrations of potassium, sulfate and chloride. Elsewhere, a second water type may be almost entirely comprised of potassium bicarbonate. These unique water types appear directly related to Ponds 1-3 and may be traced through the groundwater regime downgradient from the ponds. For example, Well 72 (Figure 7-1E) is downgradient from the ponds and exhibits a predominantly sodium-potassium bicarbonate water type but with less total dissolved solids than pond water. Well 72 also exhibits a strong tendency toward chloride and this is likely the result of mixing of pond water and water of sodium chloride characteristics from beneath the plant (Figure 7-1F).

"Pond 4" area waters exhibit unique chemical types that appear unrelated to any other potential source. These waters may range from magnesium bicarbonate-chloride to calcium-magnesium chloride (Figures 7-1G and 7-1H). Total dissolved solids of these waters is high. Waters emanating from Ponds 1-3 appear to mix with "Pond 4" waters (i.e., Well 24). However, waters from each source generally tend to retain their individual character. In addition, it is possible to distinguish upgradient from downgradient water movement near Ponds 1-3 based predominantly on mixing of the background calcium-magnesium bicarbonate with the sodium-potassium bicarbonate waters and the relative concentration of total dissolved solids.

Subsequent to analysis of chemical water types, further review of the data was performed by preparing trilinear plots of the data (Figure 7-2). Figure 7-3 shows the well locations by aquifer from which data were collected to prepare the following analysis. Based on the high degree of hydraulic connection of the unconsolidated and upper Rome aquifers, the unconsolidated aquifer has been defined to include the upper 10 feet of the Rome aquifer. A unique linear relationship is apparent on the triangular plot of calcium, magnesium, and sodium plus potassium. In general, background wells occupy one endpoint of the trend and Ponds 1-3 waters (sampled directly from ponds) occupy the other endpoint. Water concentrations from wells downgradient from the ponds occur along the trend as do all other waters sampled except for "Pond 4." "Pond 4" related waters tend to deviate from the trend reflecting the higher percentages of magnesium and calcium in these waters.

The triangular plot for bicarbonate plus carbonate, sulfate and chloride reflects a similar linear relationship but allows delineation of sources of water types other than the ponds. It is apparent that Ponds 1-3 occupy endpoints of the trend with high concentrations of sulfate, bicarbonate and chloride. Wells downgradient from Ponds 1-3 fall just above the background wells with regard to bicarbonate concentration. However, wells subject to influence of the sodium chloride water beneath the plant or the "Pond 4" area enriched in chloride or sulfate anions occupy unique positions on the plot. The diamond shaped graph in Figure 7-2 serves to further emphasize the various water chemistries previously identified in Figure 7-1. This plot also confirms that Ponds 1-3 waters occupy endpoints in water chemistry uniquely different from background waters and other source areas.

Figure 7-4 presents a summary of the distribution of general water chemistry beneath the NFS facility. The unique water chemistry of Ponds 1-3 occupies the central portion of the ponds area as well as downgradient adjacent portions of the plant. Identification of the area shown is based primarily on the distribution of chemicals as determined by field sampling and laboratory testing. Physical and chemical flow away from the ponds has primarily been in the direction of west-northwest, or toward Wells 71 and 72. The flow is most likely controlled by the permeable sand and gravel deposits in the small buried channel along the boundary of the ponds area and plant. Also, chemicals have a tendency to migrate through the sand and gravel deposits downgradient from Pond 3. However, some of the chemicals in this area are from infiltration of leachate that seeped through the embankment of Pond 3.

It is apparent that the Pond 1-3 plume has very little tendency to move in the direction of the burial ground or lower Banner Spring Branch. The chemical plume is very constricted in the upgradient direction due to groundwater flow and becomes constricted in the downgradient direction near its maximum extent. The constriction near the "Pond 4" area appears in part due to recharge of the unconsolidated aquifer by a fracture zone in the Rome aquifer that tends to control the direction of water flow in this area. Preliminary indications are that the Ponds 1-3 general chemistry plume has migrated in the unconsolidated aquifer to the area of Wells 71 and 72 but not off of the facility. Chemical migration in the Rome aquifer is more dependent upon the distribution of fractures and is not widespread.

Physical flow and chemical movement has also been briefly evaluated in the "Pond 4" area (Figure 7-4). Although the source is potentially smaller than for Ponds 1-3, it appears to be more highly concentrated. Movement of water away from "Pond 4" parallels and merges with water from Ponds 1-3 in the direction of Wells 71 and 72 and the west plant boundary.

(saline)
The distribution of sodium chloride water beneath the plant is based upon the results of the field sampling program (Figure 7-4). It is believed that the rather broad distribution of this plume in the hydraulically upgradient direction is due to groundwater mounding beneath the plant. This mounding causes short- and long-term gradient reversals as well as wider distribution of the sodium chloride water. It is apparent that the sodium chloride water merges with the Ponds 1-3 plume as evidenced by test results for Wells 71 and 72. The total dissolved solids of the sodium chloride water are commonly below 200 mg/l and are of little concern. The sodium chloride type appears to be maintained due to the relatively low groundwater pH beneath the plant that significantly reduces the bicarbonate alkalinity of the groundwater.

An area of slightly elevated total dissolved solids water of background chemical type appears to occupy only the central portions of the burial ground. Another area of elevated total dissolved solids in the northwestern portion of the burial ground area corresponds to the former position of Banner Spring Branch as well as underground facility utilities.

The distribution of chemical water types has been presented to identify as conclusively as possible the distribution of chemicals emanating from Ponds 1-3. By evaluating the field measurements for water types emanating from other areas of the facility operations, it is apparent that the chemical plume associated with Ponds 1-3 is limited to a small on-site area. The observations presented in this section are used later, herein, as the basis for identifying the distribution of radiochemicals resulting from Ponds 1-3.

In addition to the chemicals comprising the general water types, the distribution of additional general chemicals of interest has been presented in Figures 7-5 to 7-13. The chemical distributions are presented for both the unconsolidated and bedrock aquifers (defined by wells indicated in Figure 7-3). Data for Ponds 1-3 water concentrations have been included on each map for the unconsolidated aquifer and are considered representative of conditions directly beneath the ponds. The maps were created using GRIDZO software and the inverse distance squared technique.

The chemical distributions that are summarized are indicative of the influence of pond leachate and other sources and include specific conductance, sulfate, chloride, alkalinity, pH, phosphorous, fluoride, nitrate and total organic carbon. With only few exceptions, the Ponds 1-3 and "Pond 4" areas contain the primary elevated concentrations of these chemicals. The area of Wells 71 and 72 also exhibits elevated concentrations of some of these chemicals. It is apparent that the chemical distribution in the Rome aquifer is more localized although sometimes as concentrated as for the unconsolidated aquifer.

Specific conductance values above background are of limited extent and confined to the immediate area of the ponds and plant (Figure 7-5). The distribution of specific conductance supports comments presented earlier regarding the distribution of general water types.

The distribution of sulfate, chloride and carbonate anions (Figures 7-6 to 7-8) closely parallels the pattern for specific conductance. From these maps the distribution of chemicals relative to Ponds 1-3 and "Pond 4" is apparent.

The variation of pH in groundwater is affected by facility activities (Figure 7-9). Background pH values are approximately 7.0 to 8.0 units. Values of pH 8.0 to 10.0 are closely associated with the ponds areas and pH 4.5 to 6.5 values occur beneath the plant and in the downgradient direction. The distribution of pH has a strong effect on carbonate/bicarbonate alkalinity distribution (Figure 7-8).

Phosphorous, fluoride, nitrate and total organic carbon (Figures 7-10 to 7-13) are distributed in close proximity to the ponds. Of these parameters, phosphorous exhibits the most widespread distribution. In the area of Ponds 1-3, "Pond 4" and Well 72, phosphorous may be derived from tributyl phosphate, also distributed in these areas. Elsewhere, random occurrences of phosphorous are present and the potential sources are not well defined. Fluoride, nitrate and total organic carbon are closely distributed within the area of the ponds and appear to be the result of the sludge materials. However, Ponds 1 and 2 are located in the area of former marshes as evidenced by the borehole information and the total organic carbon concentrations may also be derived from organic materials in the former marsh soils beneath the ponds.

The Ponds 1-3 general chemical plume has migrated only a few hundred feet laterally down-gradient in the unconsolidated aquifer. The lateral chemical migration is much less extensive in the Rome aquifer and the maximum vertical depth of chemical movement has been limited to approximately 40 to 50 feet, or less. The confined groundwater conditions in the Rome aquifer tend to cause an upward hydraulic force against downward water movement at depths greater than these. Pond chemicals are not known to have migrated downward beyond the depth of hydraulic gradient reversal in areas where observation wells have been constructed to adequate depths to make this determination.

In summary, the general water chemistry indicates that chemicals migrating from Ponds 1-3 occupy a rather constricted area, laterally, in both up-gradient and down-gradient directions. Although the chemical plume is distributed in both unconsolidated and Rome aquifers, the base of the plume appears to be 40 to 50 feet, or less, below ground level. The pond's plume merges with other chemical plumes in the downgradient direction beneath the plant. Surface waters in local drainages are only slightly affected with regard to general water chemistry and reflect the background chemistry of groundwater.

7.2.3 Organic Chemicals

Based on the results of preliminary screening of water samples for total organic halogens (TOX) (Figure 7-14), volatile and semi-volatile analyses were performed on water from 23 wells (Table K-5). These wells were primarily distributed within the Ponds 1-3 and "Pond 4" areas (Figure 7-14). Other areas where organic chemicals were detected in small concentrations were in the central burial ground area and in wells downgradient from the plant. Organic chemicals occur in both the unconsolidated and shallow Rome aquifers. However, they are absent in the deeper Rome aquifer and surface waters in the area of the facility.

The source of volatile organic chemicals (VOC) within the pond's chemical plume is not clear. While it is apparent that well waters in close proximity to the ponds exhibit these chemicals in low concentrations, the pond waters and sludges do not appear to contain similar concentrations based on historical sampling and testing. It is possible that the VOC's migrated away from Ponds 1-3 during their operation and are now retained by the surrounding soils and groundwater. However, the majority of VOC's were decanted and discharged with the pond water. The occurrence of tributyl phosphate (TBP) within the pond's plume appears to be for similar reasons.

The "Pond 4" area groundwaters appear to have the greatest concentrations of VOC's and TBP. While the exact location of the source materials is not evident, it appears that the source is uniquely distinct from Ponds 1-3. It is also probable that some of the chemicals found near "Pond 4" may have migrated from the general area of Pond 1.

The organic chemicals in the western portion of the plant are most likely related to the occurrence and source(s) of hydrocarbons and TBP identified in the groundwater in the area of Well 72. A herbicide, Bromacil, was identified in essentially all waters tested. It appears that this occurrence results from vegetation control activities related to pond embankments, "Pond 4", and frequently used plant areas.

7.2.4 Radiochemicals

The results of radiochemical testing are reported on Table K-6. A general correspondence has been identified with regard to the distribution of both general chemicals and radiochemicals. However, radiochemicals are more limited in distribution than general chemicals, both laterally and vertically. Therefore, the extent of the Ponds 1-3 general chemical plume (Figure 7-4) is somewhat more extensive than the Ponds 1-3 radiochemical plume (Figure 7-15).

Figure 7-15 presents the distribution of radiochemicals dissolved in groundwater in above background concentrations beneath the facility. The distribution based on field measurements has been confirmed with chemical modeling. The areas identified include the combined areas encompassed by isotopic concentrations of uranium, radium, technetium, thorium, plutonium and americium. The areas believed to be affected primarily by Ponds 1-3 and "Pond 4" have been delineated within the larger area.

Figures 7-16 to 7-35 present the distribution of radioactivity and radionuclides beneath the ponds area and other portions of the facility. As for the general chemicals, radiochemical distributions are presented separately for the unconsolidated and Rome aquifers.

The gross alpha values for two sampling periods (Figures 7-16 and 7-17) indicate that the highest concentrations in the unconsolidated aquifer occur beneath the ponds area, and downgradient beneath the plant and near Wells 71 and 72. Gross alpha concentrations in the Rome aquifer are localized as was observed for the general chemicals. Figure 7-18 demonstrates that the effects of the ponds area are localized and the radioactivity quickly dissipates away from the source.

Figures 7-19 to 7-21 demonstrate the same relationships for gross beta as presented for gross alpha. The beta and alpha distributions differ only where the relative concentrations of each vary according to a specific radionuclide source. However, it is apparent that Ponds 1-3 and "Pond 4" dominate the pattern as source areas.

The distribution of uranium isotopes based upon field observations is presented in Figures 5-18 to 5-22, 7-22 and 7-23. In addition, to groundwater in the Ponds 1-3 and "Pond 4" areas, uranium occurs in groundwater beneath the western portion of the plant. The distribution pattern is very much like that of gross alpha and appears, in part, to be controlled by areas of low pH and bicarbonate alkalinity. Total uranium concentrations near Ponds 1-3 rapidly decrease within very short distances from more than 700 pCi/l to less than 5 pCi/l. Uranium concentrations in the "Pond 4" area exceed those in the area of Ponds 1-3 and are as great as approximately 10,000 pCi/l. The uranium isotopes in order of activity abundance are 234, 238 and 235 (Figures 7-24 to 7-26). It is possible that some of the uranium-234 isotope is uranium-233.

Radium concentrations are primarily limited to the localized areas of Ponds 1-3, "Pond 4", former location of Banner Spring Branch, isolated locations in the burial ground, and Well 13 (Figure 7-27). However, radium concentrations are of little significance except in the area of "Pond 4" where total Radium-226/228 concentrations of 130.8 pCi/l were measured.

The distribution of technetium-99 is primarily confined to the area of Ponds 1-3 and portions of the plant (Figure 7-28). In particular, areas of highest concentration are downgradient of Pond 3 and near Well 70. Wells 11 and 12, downgradient of Pond 3, were not tested during this investigation, but have also exhibited relatively high technetium-99 concentrations, historically. Pond 3 is a logical source area for the waters downgradient from the pond, because technetium-99 concentrations have been measured at concentrations greater than 3000 pCi/l in the pond water.

The technetium-99 concentration in Well 70 water was measured at 2800 pCi/l during July 1988. On casual observation it appears that no apparent source exists for this isolated occurrence. However, based on possible hydraulic flow gradients, Well 70 is downgradient from Pond 2, Building 130, Building 200 complex or Building 303, all areas reported by NFS to be where technetium has been used. In addition, Well 70 is located near a former maintenance driveway and the presence of technetium may represent the location of a former spill.

Although thorium occurs in large concentrations in the sludges, its distribution in groundwater is not widespread due to its naturally low solubility and chemical form in the pond sludges (Figures 7-29 to 7-31). The occurrence of thorium is limited to low concentrations in the immediate areas of Ponds 1-3 and "Pond 4." Rather minor occurrences of thorium are located in the burial ground, former location of Banner Spring Branch and Well 10. The concentrations of thorium are not considered significant. However, they are indicators of the locations of source materials within the ponds area.

Plutonium-238 and 239/240 isotopes have only limited distribution beneath the facility (Figures 7-32 to 7-34). In particular, plutonium-239/240 only occurs near Ponds 1 and 3 and the area of "Pond 4." The concentrations of plutonium-238 and 239/240 are not significant. The measured concentrations of americium-241 above concentrations of 1 pCi/l were almost nonexistent (Figure 7-35).

Plutonium-241 was measured in an attempt to identify beta emitters beneath the facility. Based on the relative sparsity of plutonium-238 and 239/240, and americium-241, it was unanticipated that plutonium-241 would be present with relatively great frequency, if at all. However, plutonium-241 was consistently identified downgradient from Pond 3, in the area surrounding Ponds 1 and 2, "Pond 4" area, portions of the plant and isolated areas in the burial ground. The apparent distribution of Plutonium-241 (Figure 7-34) parallels the identified distribution of technetium-99, but is of more limited extent. The reason for the occurrence of plutonium-241 in the relative absence of other plutonium isotopes is unclear. However, plutonium-241 has been previously identified in the pond sludges and soils adjacent to Ponds 1-3 and "Pond 4" based on historical information provided by NFS. It is possible that some inaccuracies exist in analytical laboratory techniques used during this investigation as well as previous investigations.

Radiochemicals in area surface waters have limited distribution and primarily occur in background concentrations. It appears that any radiochemicals leaching from sediments in the ponds area or Banner Spring Branch stream bed have little effect on surface water in Banner Spring Branch. The primary radiochemical effect on Banner Spring Branch water quality was an elevated gross alpha concentration due to the presence of uranium isotopes. Even so, the gross alpha concentrations measured during this investigation represent an improvement over historical values. It was determined that water discharging from the plant cooling water outfall was primarily responsible for the elevated concentrations. However,the cooling water, itself, may not be the cause. It appears that groundwater leaking into the buried outfall conduit as it passes beneath the ponds area very close to Pond 2 may cause the elevated gross alpha concentrations. The pond remediation activities should resolve this problem.

Waters tested from the pond marsh have reflected relatively low concentrations of radiochemicals. The most probable explanation is that seepage through the embankment of Pond 3 migrated into the marsh across the ground surface.

Lysimeters were used to evaluate the effect of rainfall infiltration and soil moisture on leaching as this water percolates to the water table. Water filtered through the porous tips was collected for analytical testing from three lysimeters installed in the unsaturated zone near Ponds 1 and 3. Shallow soils in nearby boreholes were also tested to determine the relative amount of chemicals in the soils. Based on the results of one sampling event, dissolved metals concentrations in the water tested are essentially background. However, gross alpha and gross beta concentrations are elevated (Appendix K). Lysimeters 1, 2 and 3 are located near Wells 78, 34 and 77, respectively. The following concentrations (pCi/l) have been measured:

Parameter	Lysimeter 1	Lysimeter 2	Lysimeter 3
Gross Alpha	2,000±100	1,200±200	43,000±1,000
Gross Beta	260±100	100±90	220±100
Uranium-234	1,700±100	890±50	45,000±1,000
Uranium-235	74±20	25±8	1,200±100
Uranium-238	340±40	42±11	940±120
Technetium-99	20±2	880±10	1,500±100

These values are significantly greater than those measured either in nearby soils of equivalent depth or from the groundwater below. Isotopic testing of this water indicates that uranium isotopes are the greatest contributor to the alpha activity. Beta activity is also elevated and associated with technetium-99. The reasons for the elevated concentrations are not clear. However, it is probable that waste materials associated with "Pond 4" and seepage through the embankment of Ponds 1 and 3 are causes.

Conclusions regarding the distribution of radiochemicals beneath the facility parallel those for general water chemistry. Radiochemical distribution is related to the same unique sources within the ponds area and facility, but radiochemicals are less widespread than general water chemicals. The vertical distribution of radiochemicals appears to be 40 to 50 feet, or less. Radiochemicals emanating from Ponds 1-3 and "Pond 4" can be uniquely identified. Other potential radiochemical sources within the plant, extend the radiochemical plume beyond that attributed to the ponds.

7.3 Hydrogeologic and Geochemical Processes

Hydrogeologic and geochemical processes exert significant influence on the distribution of chemicals in the subsurface regime beneath the ponds area and plant. This section summarizes findings concerning the processes influencing the distribution of several radionuclides migrating from Ponds 1-3. Site-specific information collected and analyzed during this investigation is used to identify geochemical processes that promote or retard the migration of pond chemicals.

7.3.1 Summary of Site Hydrogeology

Ponds 1-3 were constructed in alluvial soils within the confines of a small stream bed. In particular, Ponds 1 and 2 are lined by naturally occurring organic enriched peat and "muck." Unconsolidated clays, silts, sands and gravels are approximately 9 to 13 feet thick near the ponds and repose as a thin veneer upon the bedrock surface. The unconsolidated deposits are predominantly sand and gravel, and a small buried channel is filled with these relatively permeable deposits adjacent to Ponds 1 and 2 in a downgradient direction along the pond area/plant boundary. The sand and gravel also occurs downgradient from Pond 3. Groundwater primarily moves in the sand and gravel deposits in the downgradient direction. These directions are westward beneath the plant downgradient from Ponds 1 and 2 and west/northwestward from Pond 3 in the general direction of Pond 1. A small component of flow from Ponds 1-3 also moves toward "Pond 4."

The unconsolidated deposits are underlain by shales, siltstones, sandstones and carbonate rocks of the Rome formation. Clay mineralogy has not been determined. Cementing materials in the rocks comprise calcite, silica and iron. Bedding layers extend northeast-southwest, dip southerly and are highly fractured and folded. The weathered bedrock is broken into small fragments by numerous joints. Major fracture zones cross beneath the site. Although the weathering process has leached soil materials and enlarged fractures, the bedrock appears to retain its structural features. The enlarged fractures are filled with a mixture of clay, silt, sand and gravel materials to depths of at least 40 feet. The ponds were randomly located on the land surface with primary consideration for topographic controls rather than consideration of underlying bedrock structures. Movement of groundwater in the Rome aquifer is selectively confined to fracture zones. Lateral movement appears to be generally westward. The Rome aquifer is hydraulically connected to the unconsolidated aquifer above. Upward artesian pressures in the Rome prevent downward water flow below depths of 40 to 50 feet, or less.

7.3.2 Hydrochemistry

The clay soils formed from the Rome formation are acidic (i.e., approximately pH 4-6) having low to moderate hydraulic conductivities. Beneath the site, the soil layer is as thick as 20 feet but averages about 10 feet in thickness beneath the ponds. Overall, the soil is generally organic-poor in that it is derived from mineral bedrock. However, thin organic-rich soil deposits are present locally near marshes or in old top soil horizons beneath fill. Organic remnants

soils are present beneath the sludge in Ponds 1 and 2 and are remanents of former marshes. Sorption capacities of the soils and bedrock have not been studied, but it is estimated that sorption capacities of the organic materials may be relatively high.

General chemical and radionuclide characteristics of the groundwater in the vicinity of Ponds 1-3 have been presented in this report. The data indicate that the groundwater chemistry is influenced by the chemical constituents of the sludges and waste liquids. Chemicals such as nitrate, fluoride and phosphorous occur in groundwater in a limited area near the ponds and often occur in wells having elevated radionuclide activities. In addition, concentrations of several other constituents of the waste liquids including sodium, magnesium, potassium, bicarbonate, carbonate, chloride and sulfate correlate well with regard either to distribution near Ponds 1-3 or to nuclide activities in the groundwater.

Typically, background water quality beneath the facility has pH values of 7 to 8. The effects of plant operations have created a zone of pH 4.5 to 6.5 downgradient from the ponds. Pond water pH and groundwater pH very close to the ponds may measure as high as 9 to 10.5 due to the treatment of the acid wastes discharged to the ponds during their operation.

In addition to general chemicals, the groundwaters were analyzed for isotopes of radium, uranium, thorium, plutonium, americium and technetium. With regard to the ponds, uranium and technetium comprise most of the radioactivity in the groundwater. The most abundant radionuclide in the groundwater with regard to activity is uranium-234. Other uranium isotopes in order of abundance are uranium-238 and uranium-235. Technetium-99 is abundant in the ponds area and, locally, beneath the plant.

7.3.3 Radionuclides In Soils and Rocks

The vertical distribution of gamma activity in the soils and weathered bedrock was measured by downhole gamma-logging in the majority of observation wells at the facility. Gamma peaks occur locally in discrete shallow layers and probably represent seepage pathways of the waste liquids. At some locations these peaks may represent a direct reading from sludge or buried materials in near-by ponds or pits. The identified pathways generally correspond to the position of sand and gravel deposits on the bedrock surface. In addition, the pathways reside below or at the surface of the water table. No gamma peak was identified below the bedrock surface. The absence of gamma peaks in the bedrock may indicate that leachate migration becomes more diffuse with increasing depth and distance from the pond sources.

The gamma peaks were frequently used as the basis for selecting soils for isotopic analysis. Measured sediment activities were greatest near Ponds 1-3 and "Pond 4."

7.3.4 Chemical Forms of Migrating Radionuclides

This investigation did not attempt laboratory measurement of distribution coefficients for soils underlying the NFS facilities in that many experiments of this nature cannot define true equilibrium distributions. Neither were in situ distribution coefficients determined by measuring the radionuclide concentrations on soil samples recovered from the saturated flow depths and comparing these to concentrations in groundwater samples collected at the same time as soil samples and from the same depths. Instead, distribution coefficients (i.e., retardation factors) were inferred based on radionuclide concentrations in soil samples taken below the water table and concentrations in filtered and unfiltered water samples collected at the same locations following well completion. Using this data, the distribution coefficients for uranium range between approximately 100 and 26,000 mL/g, plutonium between 1,000 and 140,000 mL/g, thorium between 1,000 and 120,000 mL/g and americium between 1,000 and 2,000 mL/g.

Because it occurs in greatest activity, uranium has been evaluated in greatest detail, herein. Uranium may occur in aqueous solutions in three oxidation states (U(IV), U(V), and U(VI)). U(VI) predominates in geochemical oxidizing environments with carbonate alkalinity when groundwater pH is greater than 5. Uranium (VI) is mobile and uranyl cations may form soluble complexes with common groundwater anions such as carbonates, phosphates or sulfates. Due to the relative abundance of carbonates and phosphates, high pH and oxidizing environment associated with the pond water, uranium has available a complexing environment. Conversely, dissolved uranium (VI) can be removed from groundwater by chemical reduction to uranium (IV) which precipitates as UO_2, or by sorption to geologic media.

The value of pH is considered to have strong influence on uranium complexing with carbonates under conditions of high pH. Uranium is considered to be somewhat mobile in the alkaline (i.e., high carbonate/bicarbonate/pH) pond environment. The presence of TBP and associated uranium in the pond water during operations may possibly have increased uranium mobility. Phosphorous concentrations believed to be derived from TBP in the groundwater near to and down-gradient from the ponds are relatively high. In addition, TBP has been identified in the groundwater. Therefore, two complexers were present to solubilize uranium. It is believed that phosphate may be especially important as a complexing agent at lower pH values. Determination of the exact relationships between uranium and the carbonate and phosphate complexes beneath the ponds area would require additional evaluation beyond the scope of this investigation. However, the following model of hydrochemical transport is possible.

The enriched alkaline complex migrates from the ponds along the identified physical transport pathways. Soon after reaching the water table a decrease in pH occurs to a value of 6.5 to 7.5 as controlled by background pH values for groundwater and relatively acidic soils. As the alkaline solutions have migrated from the ponds during longer time periods, the pH of downgradient soil and groundwater has increased throughout an expanding area.

With increasing distance from the ponds, the higher pH and alkaline (uranium enriched) chemical plume merges with the zone of lower pH groundwater downgradient from the ponds and plant (Figure 7-3). As pH values of 6 are reached, bicarbonate alkalinity decreases sharply. For pH values of 5, the bicarbonate is essentially gone from solution and is replaced by chloride as the dominant anion. Where TBP and the phosphate anion are present, uranium continues to complex even under the more acidic conditions and continue to migrate. However, due to the relative absence of TBP away from the close proximity of the ponds, it is most likely that the uranium will be precipitated in the acidic areas, especially in the areas of pH 5, or less. Furthermore, the uranium could be redissolved again when influxes of concentrated leachate (i.e., carbonate alkalinity, higher pH) occur.

Based on the above chemical interactions, the zone of lower pH downgradient from the facility is beneficial to limiting the migration of uranium. It is possible that a uranium concentration front is moving away from the ponds area. However, the long-term distribution and distance of migration of this front is limited by pH effects beneath the facility.

Although chemistries of the other radionuclides tested are not well understood, it is apparent that technetium-99 is also mobile. Technetium may most likely exist in aqueous solutions in a valence state of VII. In this state the distribution coefficient may be as low as 1 mL/g. In areas where the bedrock and soils lack significant quantities of organic matter, technetium may readily migrate. Conversely, abundant organic matter in the soils may cause technetium to be reduced and immobilized. Therefore, technetium may also accumulate in concentration front(s), similar to uranium, at some distance from the ponds. The abundant organic materials lining the Ponds 1 and 2 and "Pond 4" areas should have a significant effect on limiting the mobility of technetium in the ponds area.

Thorium and plutonium isotopes appear to be relatively immobile. In particular, the chemical complex in which thorium was placed in the pond sludges is known to render it highly immobile.

7.3.5 Transport Pathways of Migrating Radionuclides

Although geochemical factors affect nuclide sorption and solubility, nuclide migration is primarily influenced by hydrogeologic attributes such as folds, faults, zones of weathering and hydraulic gradients. The information developed by this investigation indicates that prominent migration pathways include: sand and gravel deposits on the bedrock surface, and bedding planes, joint surfaces, and fault planes beneath the bedrock surface. In particular, the sand and gravel deposits in the shallow bedrock channel downgradient from Ponds 1 and 2 beneath the plant are a potentially significant pathway. Migration in the bedrock is localized along fractures and does not appear to be extensive.

Where steeply dipping impermeable bedrock strata are located downgradient from the ponds they act as barriers and impede groundwater flow and chemical migration. Chemical accumulation due to geochemical processes in these zones may occur. This appears to be true of the area downgradient of Pond 3 that encompasses, at the least, the area included by Wells 11, 12, 30, 31, 36 and 77. In this area, bedrock aquifer permeabilities are the lowest that were measured and chemical and radionuclide concentrations are among the highest measured.

Chemical migration does not occur in the up-gradient direction from the ponds. Also, Banner Spring Branch was not observed to transport significant concentrations of chemicals. The lower reach of the stream is losing and inherently would not receive groundwater contributions. On the other hand the upper reach in the vicinity of the ponds is slightly gaining and could receive chemical contributions. Perhaps the creek did not receive significant contributions due to the drought (base level) conditions observed during this investigation and the impermeable natural soils and sludges that line the ponds.

Sampling frequency has not allowed evaluation of seasonal fluctuations in water quality. However, frequent sampling of the well discharge during the Well 77 pumping tests allowed comparison of the water quality for extended pumping conditions. The water quality improved during the early portion of the test. In general, contaminant concentrations near Well 77 appeared to decrease with replacement by better quality water moving toward the well. At about the same time that the leakage effects from the unconsolidated aquifer were observed, and a decrease in water quality was also measured. It appears that downward leakage of water from the uppermost saturated zones induced by the pumping had reached the well bore. Thus, pumping wells are an important influence on transport of chemicals in the groundwater.

8.0 EFFECTS OF POND REMEDIATION

The hydrogeology, surface water and soils and water chemistry have been evaluated to determine the potential impacts that may be caused by the proposed sludge removal from the ponds. Potential changes that may occur in the groundwater regime involve groundwater levels and water quality. The effects of remediation on Banner Spring Branch have also been evaluated. A discussion of potential effects of sludge removal is provided below:

8.1 Operational

8.1.1 Water Volume

Sediment will be removed by a slurry "mining" operation. Because the only water removed from the ponds will be associated with the slurry, itself, extensive dewatering operations will not be required. Clarified water extracted from the slurry will be returned to the ponds as it is recovered. Therefore, water inflow and outflow from the ponds will be essentially equal. Based on the equilibrium that will be maintained in free standing water levels, any influence of slurry "mining" activities due to water withdrawals on adjacent groundwater levels should be negligible.

Groundwater level mounding and pond water/groundwater interactions have been identified for Pond 1. These effects are less pronounced for Ponds 2 and 3. The mounding associated with Pond 1 appears to be a direct result of pond water/groundwater interconnection. In Ponds 2 and 3, the mounding is primarily a function of free water fed by rainfall that very slowly infiltrates to the water table residing near the base of the sludge. It is estimated that sediments in Pond 1 are located beneath the water table and that slurry operations will have little effect on dewatering the pond. The upper portion of sediments in Pond 3 may be located above the adjacent water table and slurry operations may require makeup water until reaching the water table for dry climatic conditions. Pond 2 is estimated to represent a mid-point between the two extremes.

The elevated groundwater levels in the area of the water mounds create a hydraulic pressure gradient that induces leachate migration away from the ponds. However, the primary effects of the mounding are confined to the near proximity of the ponds due to the relatively large permeability of the aquifers and the ability of these aquifers to adsorb large water influxes.

Removal of the impermeable sludge seal and to some degree the natural organic soils from the ponds will increase the effective permeability of the pond embankments and floors. Free water in the ponds should achieve greater equilibrium in level with the adjacent groundwater levels thereby reducing the hydraulic gradient associated with the ponds. The regional hydraulic gradient will then primarily control groundwater flow in the pond area.

Removal of the impermeable sediment may increase the permeability of the pond floors and embankments and the potential for leachate migration from the ponds will increase. Based on the measured rate of groundwater flow in the pond area and an operational period of six months, the extent of any leachate migration in the groundwater due to this cause should be limited to 50 feet, or less.

If increased seepage occurs, leachate might potentially move downgradient through the groundwater system to discharge locations. Leachate moving in the direction of the plant is not expected to encounter any near-field discharge location. It is possible that Banner Spring Branch represents a discharge location along the segment between the ponds. However, the sediments in Pond 3 are for the most part located above the water table and groundwater quality should not be significantly affected. Ponds 1 and 2 are located somewhat downgradient from Banner Spring Branch and extensive leachate migration toward the creek is not expected.

8.1.2 Water Quality

The proposed sediment extraction process will physically remove solid materials from the slurry by filter media. Subsequently, the clarified water will be returned to the ponds. The clarified water should be improved in quality and is expected to dilute water in the ponds.

Creating the sludge slurry may decrease overall pond water quality. Agitation of the sludge particles will expose fresh surfaces on the particles to the water and induce leaching. In addition, the introduction of oxygen into the pond water may cause pH adjustments with precipitation of some chemicals and dissolution of others.

It is possible that the chemistry of free water in the ponds will be out of equilibrium with groundwater adjacent to the ponds. Therefore, a short-term decrease in groundwater quality may occur in near-field (within 50 feet) locations. However, the adjacent groundwater is already contaminated and the effects will be short-term during sludge removal. Pumping of a minimum of one pond volume of water from each of the ponds following sediment removal will remove the operational water from the ponds and induce flow of any adverse quality groundwater that has been created to flow back into the ponds for recovery. Groundwater quality should be closely monitored during sediment removal operations.

Banner Spring Branch should be monitored during operations to determine if pond leachate is discharging into the creek.

8.2 Post-Operational

8.2.1 Water Volume

Subsequent to sludge removal the pond depressions are expected to contain varying depths of water in physical equilibrium with adjacent groundwater levels. Water in Pond 1 may reach as much as seven feet in depth and Pond 3 may contain 1 to 3 feet of water, or remain dry. The depth of water in Pond 2 is expected to range between Ponds 1 and 3. Backfill should be placed in the ponds such that relatively permeable materials will be placed below the water table. This will alleviate any future tendency for mounding in the backfill and allow natural groundwater movement across the pond area.

Based on the presence of water table (unconfined) conditions in the shallowest aquifer, it does not appear likely that groundwater levels will rise to the ground surface through the pond backfill. Instead, rising groundwater levels induced by rainfall infiltration or artesian flow from below will spread laterally in the unconsolidated aquifer. Banner Spring Branch will serve as a near-field discharge point for this water. Based on observations of groundwater occurrence during the hydrogeologic investigation, it appears improbable that soil saturation will ever break through the pond backfill at the ground surface.

8.2.2 Water Quality

Removal of the sediment source term from the ponds will have a beneficial effect on groundwater quality. The amount of benefit is being evaluated and reported under a separate pathway/risk investigation.

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FIGURES

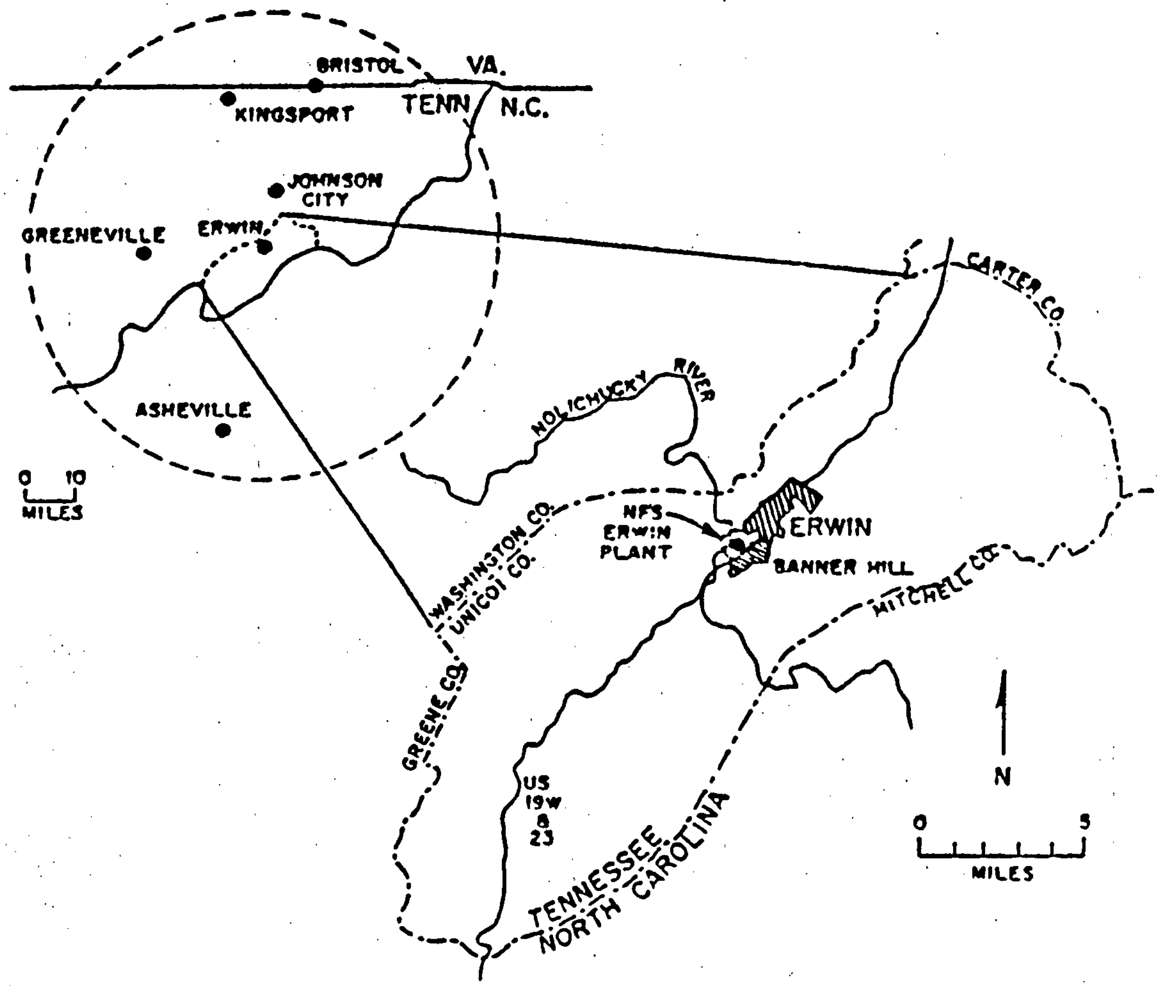
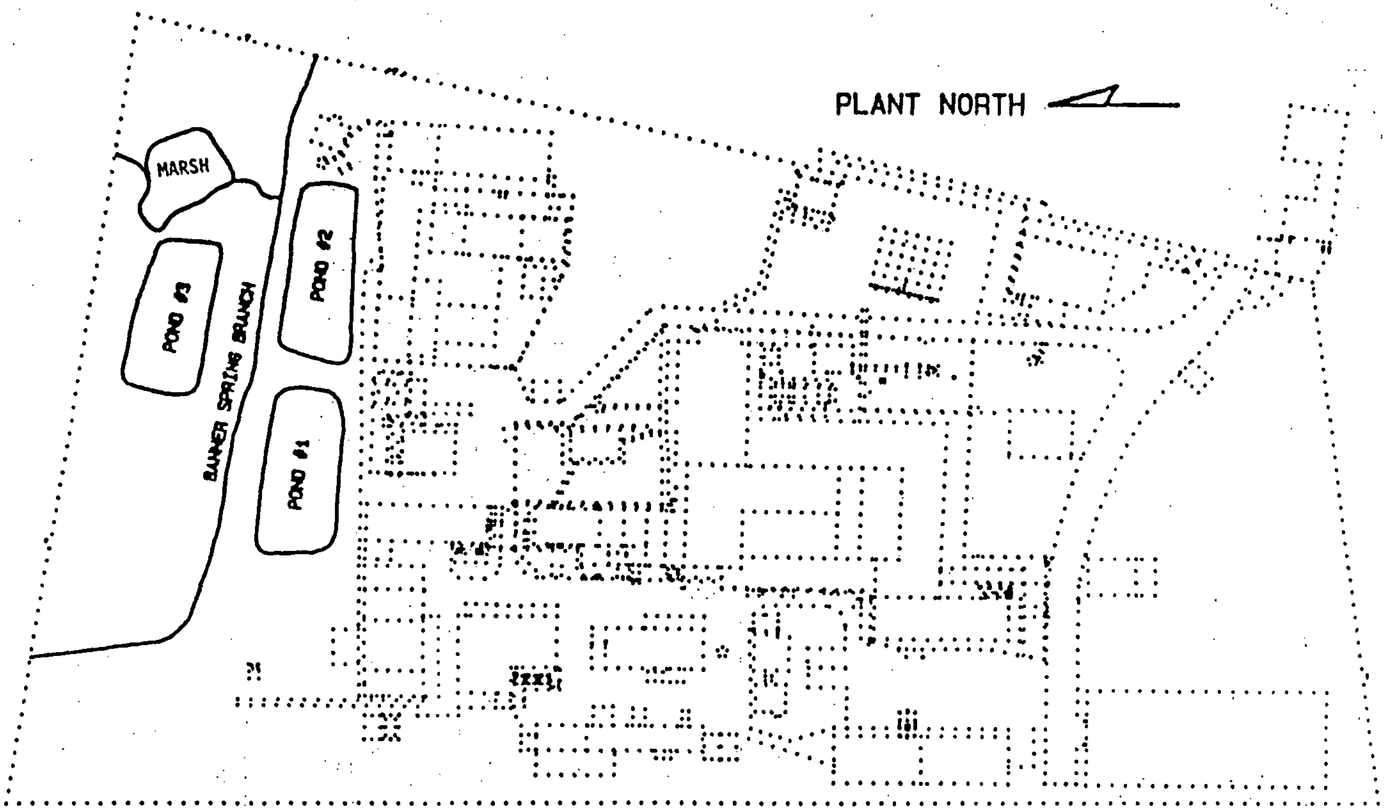


Figure 3-1 Location of the NFS Plant at Erwin, Tennessee

Figure 3-2

NFS POND AREA



BY	DATE	REVISION	LET

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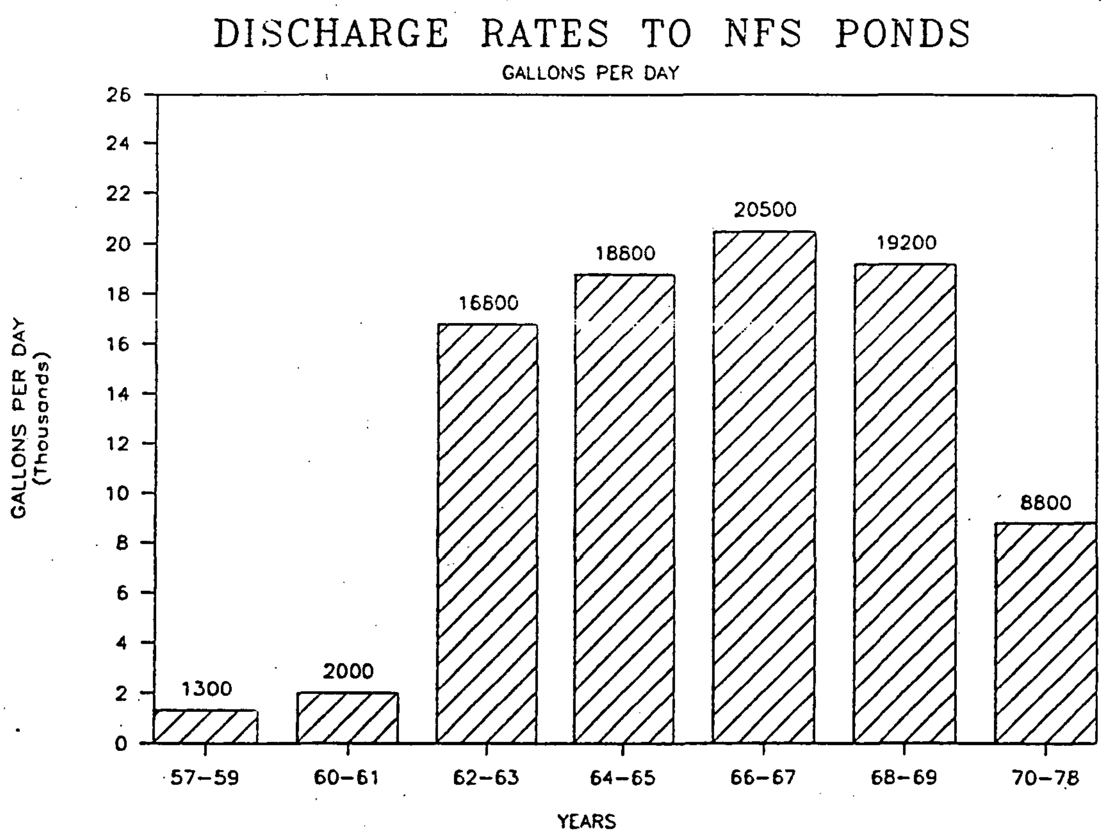
NUCLEAR FUEL SERVICES, INC.
ERWIN, TENNESSEE

NAME: NFS POND AREA

MADE BY R. P. STOREY	SCALE 1" = 180'	DATE 2-18-88
TRACED BY		
CHECKED BY	DRAWING NO. RMG-1185A	
APPROVED BY		

Figure 3-3



Source: Modified after Nuclear Fuel Services, Inc. Lagoon Historical Data, August 30, 1985.

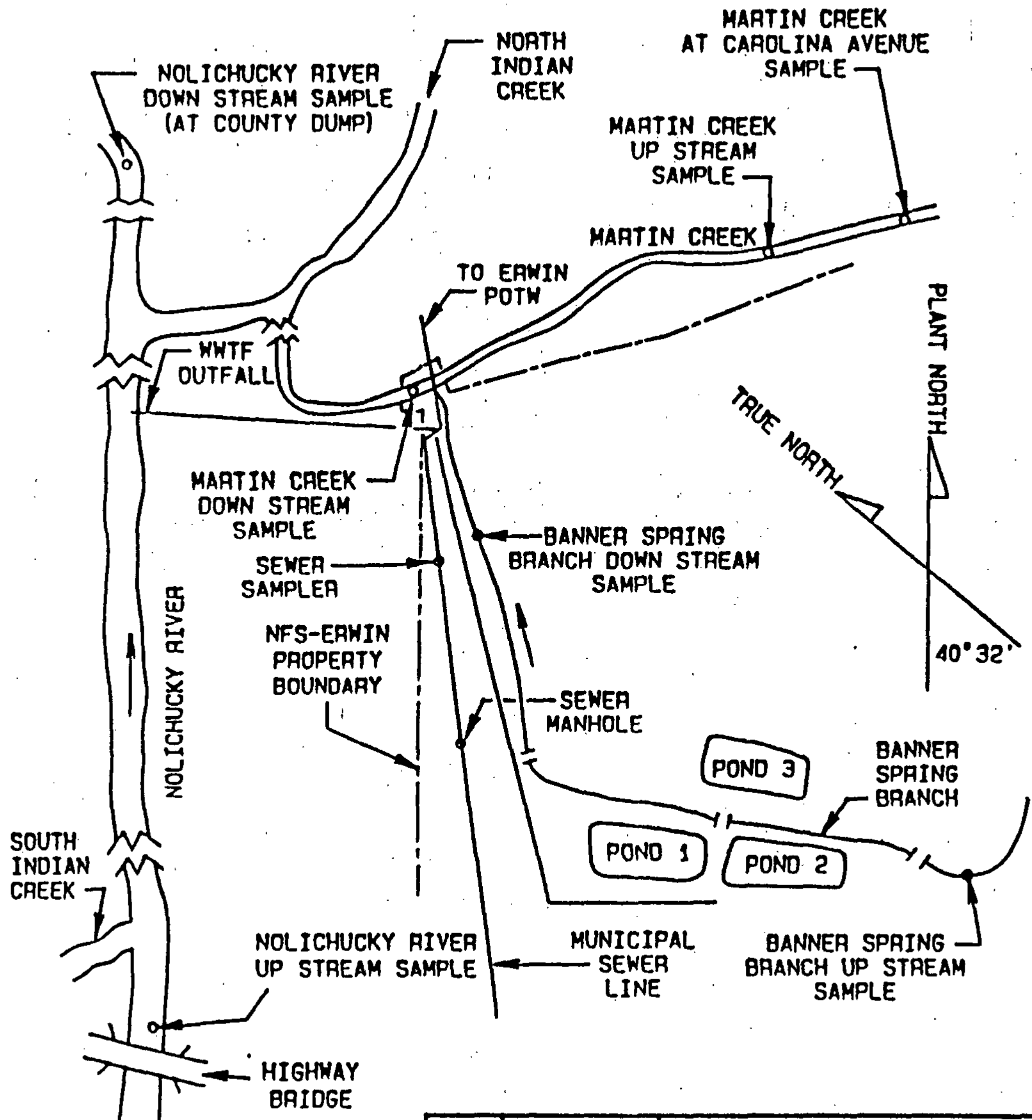


Figure 3-4

SURFACE WATER SAMPLING
& LIQUID EFFLUENT RELEASE LOCATIONS

BY	DATE	REVISION	LET
RPS	3-1-88	REV'NS TO RIVER, LABELS	A

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NUCLEAR FUEL SERVICES, INC.
ERWIN, TENNESSEE

NAME: SURFACE WATER SAMPLING & LIQUID EFFLUENT RELEASE LOCATIONS

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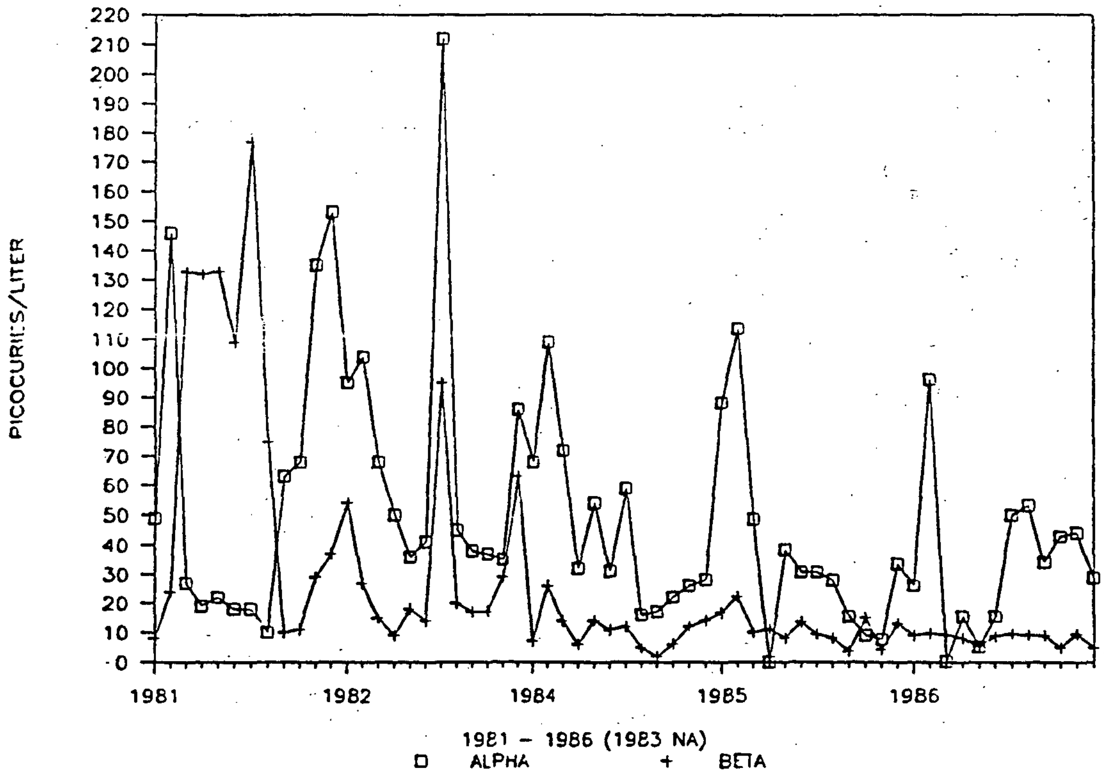
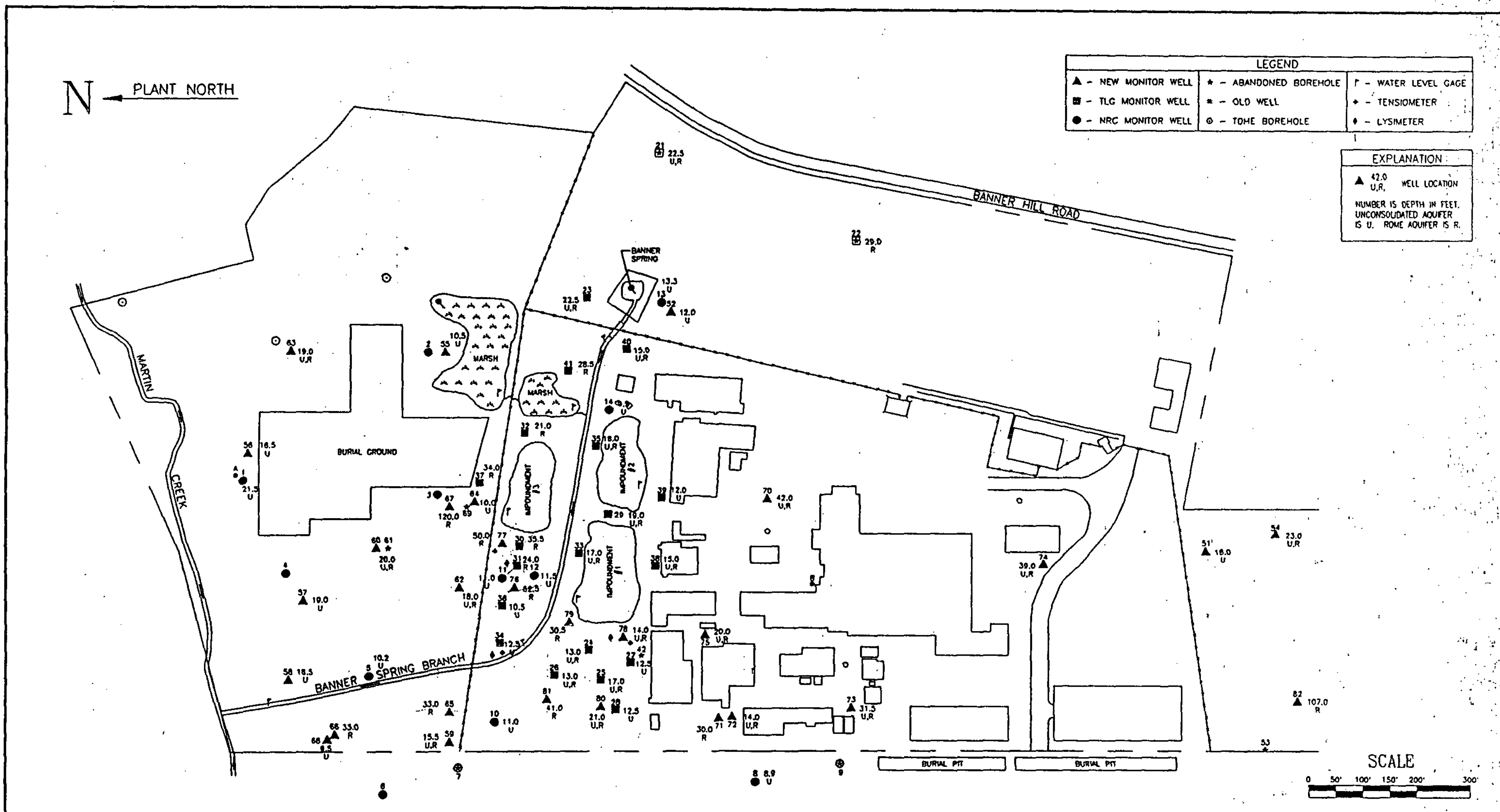
TRACED BY
CHECKED BY
APPROVED BY
DRAWING NO. RMG-1184A

Figure 3-5

LOWER BANNER SPRING
BRANCH GROSS ALPHA
AND GROSS BETA CONCENTRATIONS





A	10-13-89	ORIGINAL DRAWING	CWT	SJT	JRW
REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.

EcoTek NFS

ECOTEK, INC.
NFS PONDS PROJECT
ERWIN, TENNESSEE

FIGURE 4-1 – NFS ERWIN PLANT SITE OBSERVATION WELL LOCATIONS

SCALE	DRAWN BY	DESIGNED BY	DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
SHOWN	CHARLES W. TALLMAN	ECOTEK	7-13-89	NFS-PONDS	NFOC001	1 OF 1	A

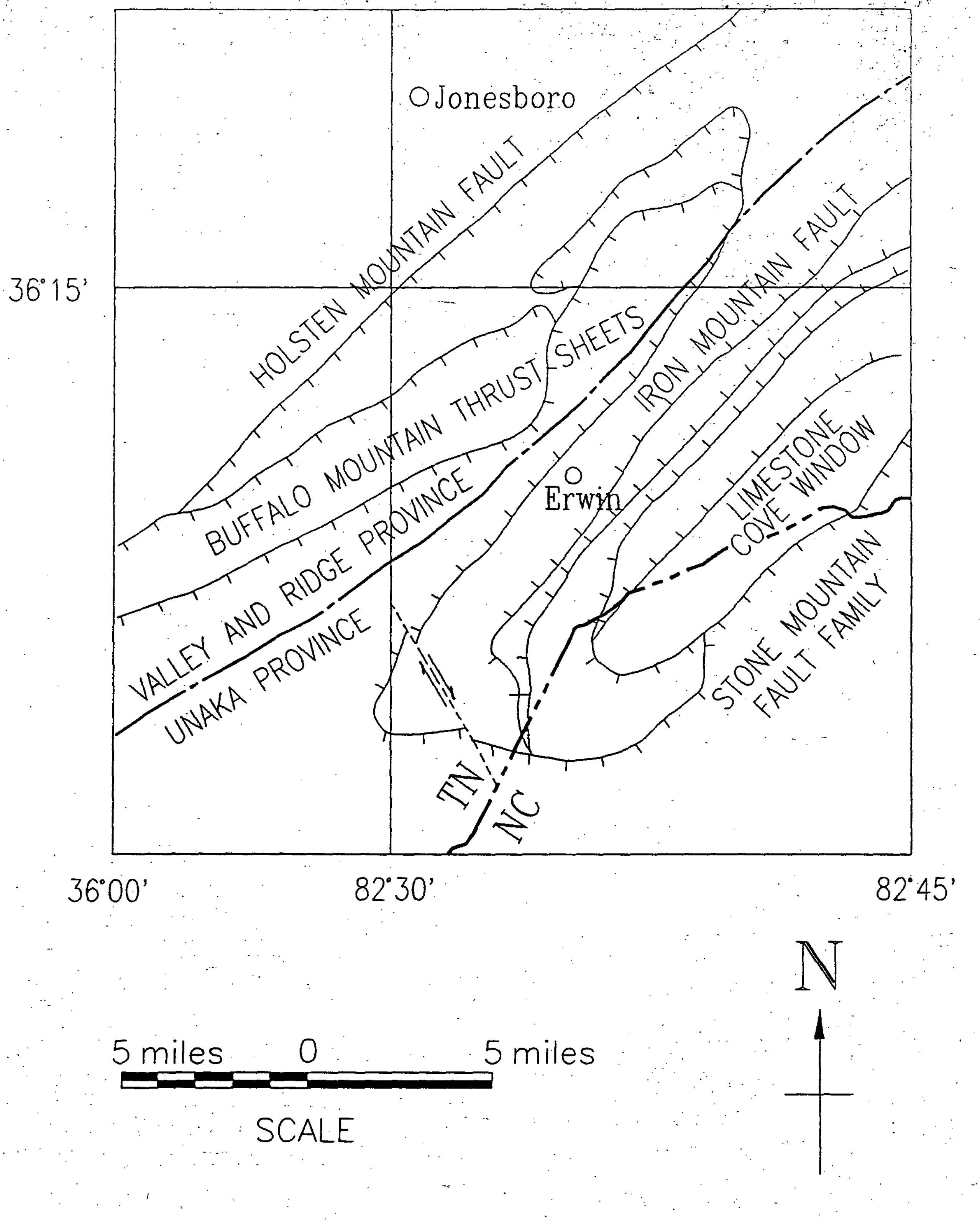
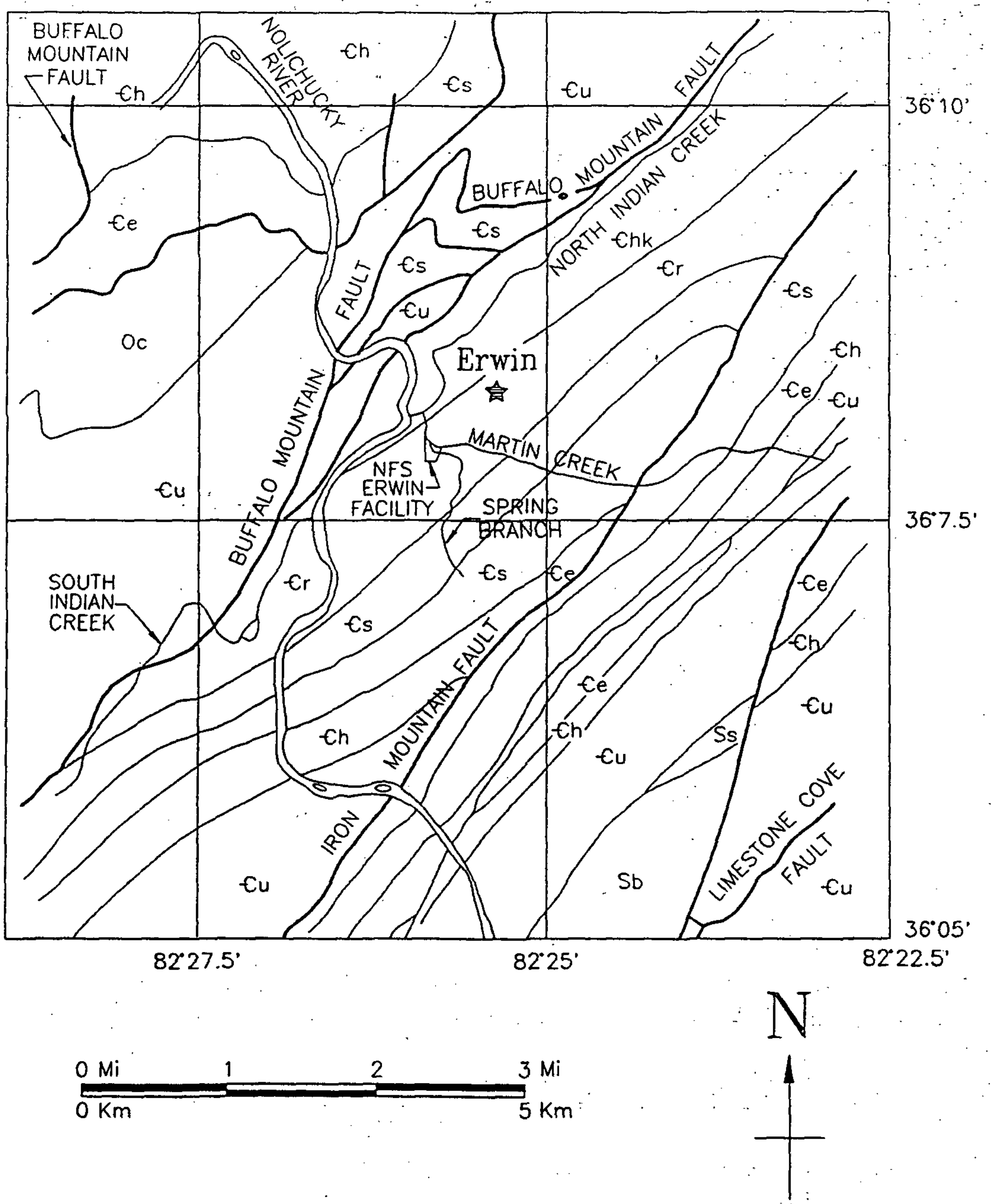


Figure 5–1
Location of Physiographic and Geologic Provinces and Major Structural Features, (modified after King and Ferguson, 1960)

Figure 5-2 Geology of the Erwin Region



PRECAMBRIAN	(pꞒ)	CAMBRIAN	(Ꞓ)
OCOEE GROUP	Oc	HONAKER DOLOMITE	Ꞓhk
SANDSUCK SHALE	Ss	ROME FORMATION	Ꞓr
SNOWBIRD FORMATION	Sb	SHADY DOLOMITE	Ꞓs
CONTACT	———	ERWIN FORMATION	Ꞓe
FAULT	———	HAMPTON FORMATION	Ꞓh
		UNICOI FORMATION	Ꞓu

SOURCE: Modified after J. Rodgers, Compiler; Geologic Map of East Tennessee; Open File Sheet 199, Tennessee Division of Geology; Knoxville, Tennessee.

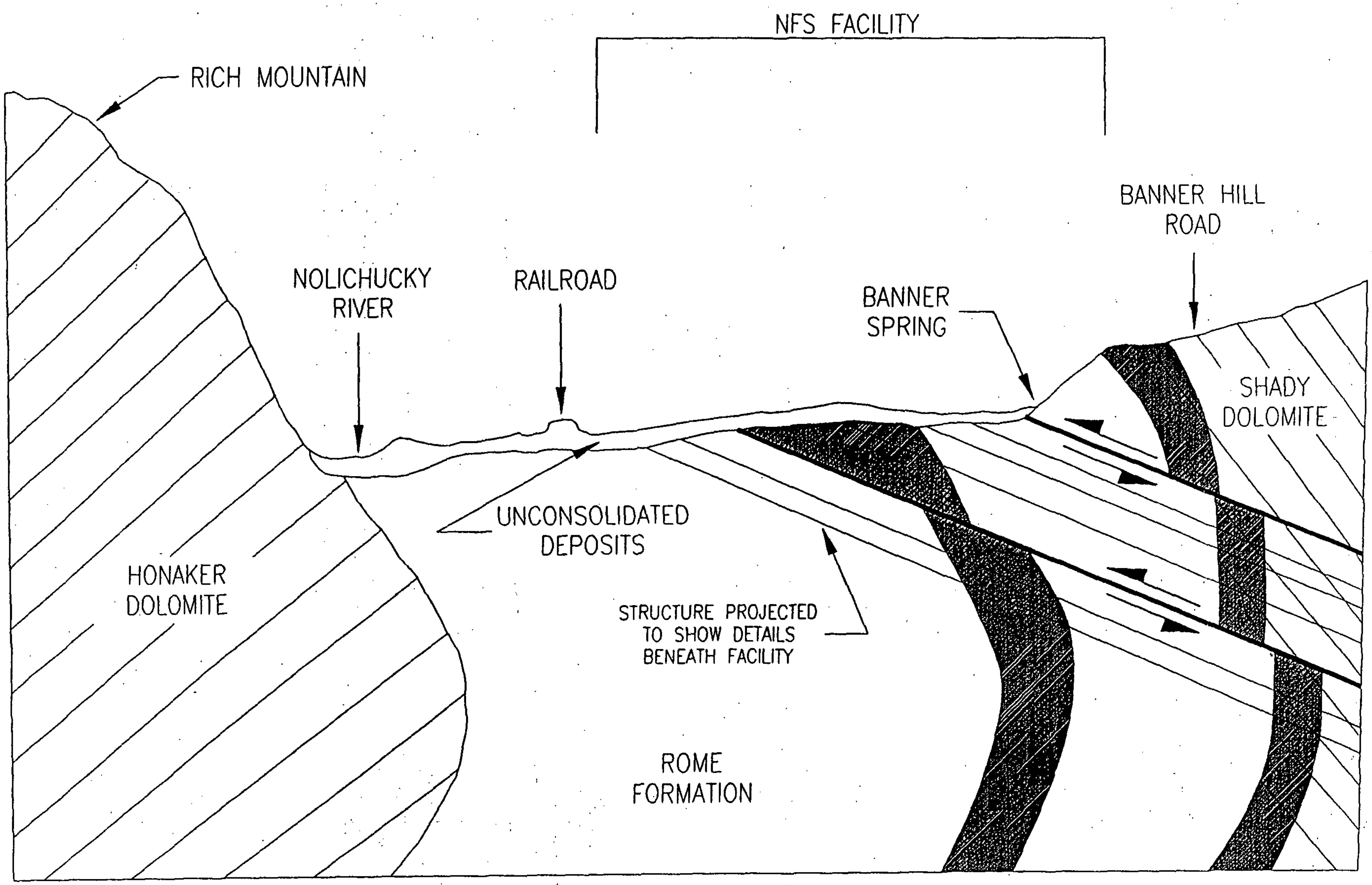
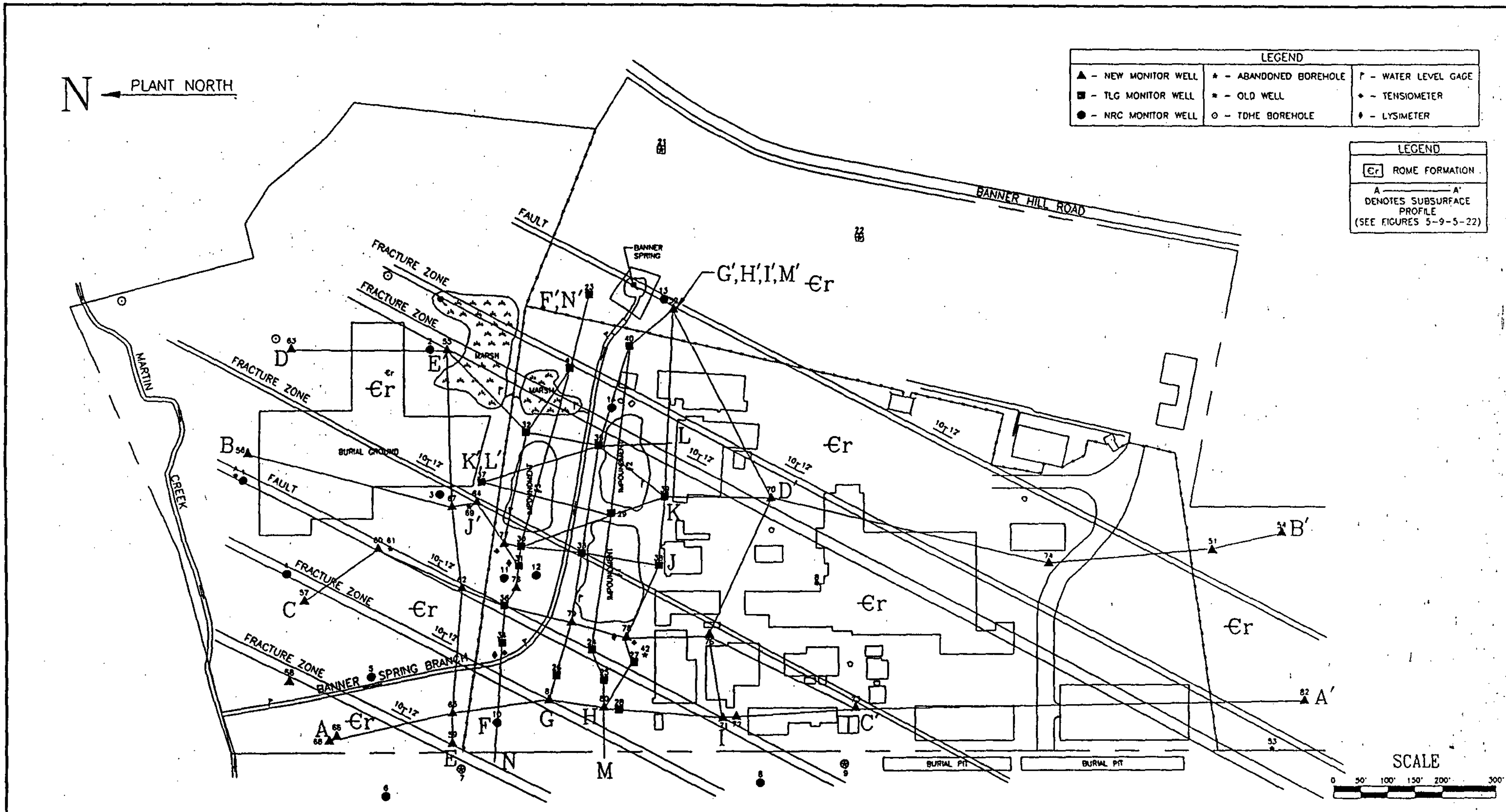


Figure 5–3
Generalized Subsurface Profile

NOT TO SCALE



A	10-13-89	ORIGINAL DRAWING	CWT	SJT	JRW
REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.

SCALE	DRAWN BY	DESIGNED BY
SHOWN	CHARLES W. TALLMAN	ECOTEK

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FIGURE 5-4 – SUBSURFACE GEOLOGY AND LOCATIONS OF SUBSURFACE PROFILES

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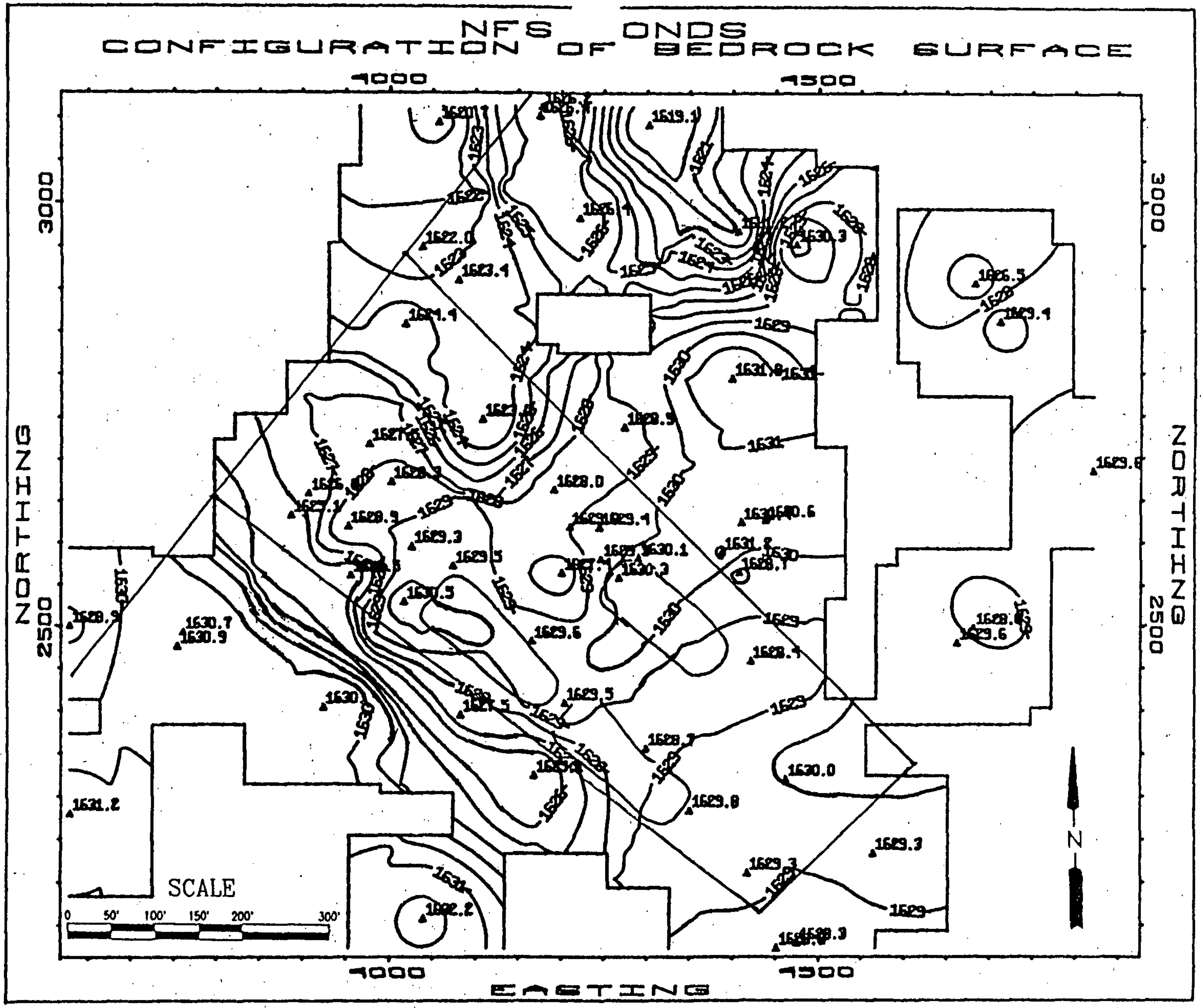


EXPLANATION

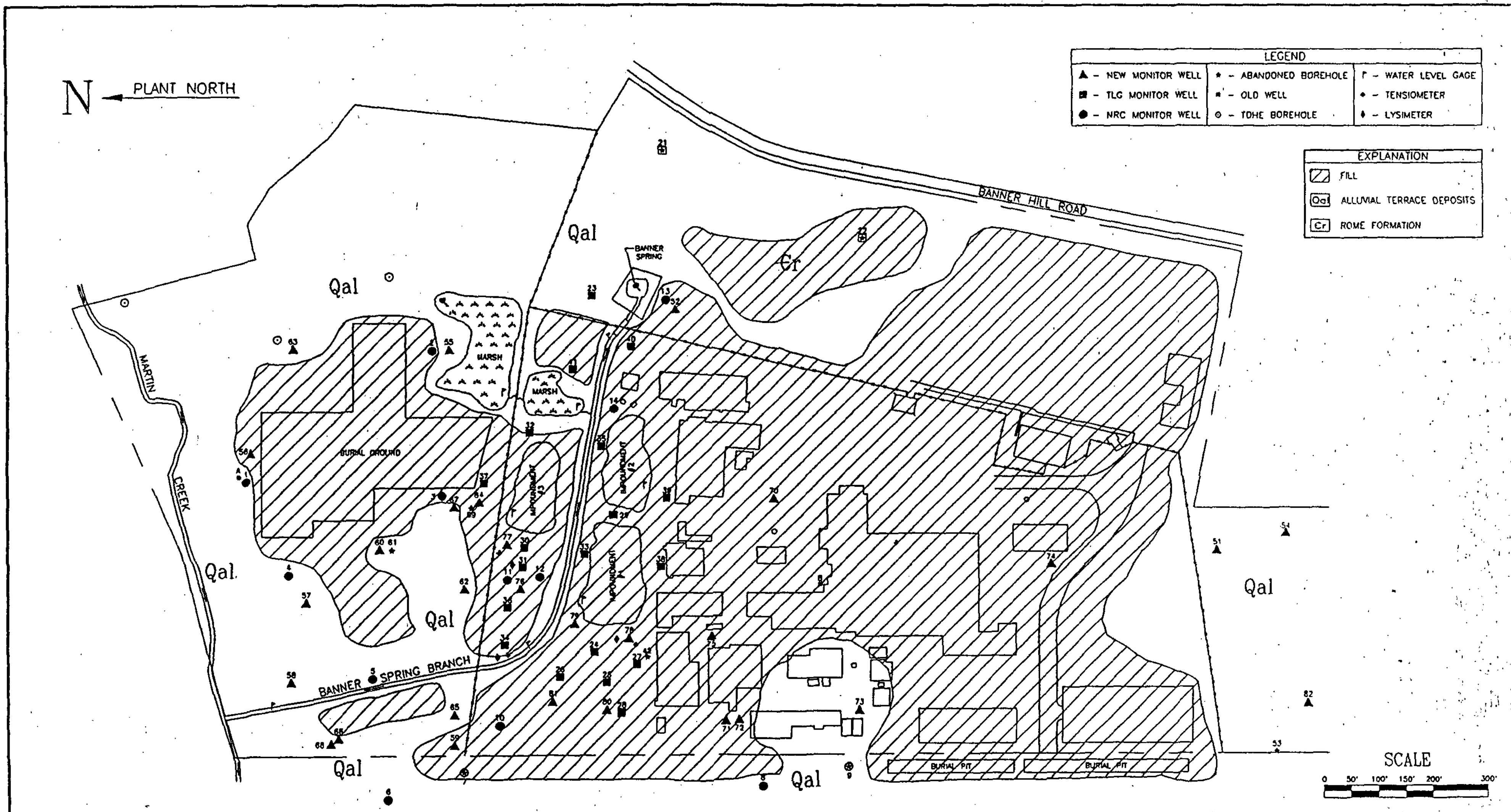
—— 1631 ——
Bedrock Contour

Shows altitude of bedrock surface. Contour interval 2 feet. Datum is mean sea level.

▲1628.0 Well location. Number is elevation of bedrock surface.

Area of low confidence based on lack of control points

Figure 5-5 Configuration of Bedrock Surface



A	10-13-89	ORIGINAL DRAWING	PSC	SJT	JRW
REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.

SCALE	DRAWN BY	DESIGNED BY
SHOWN	PAT CHAPPELL	ECOTEK

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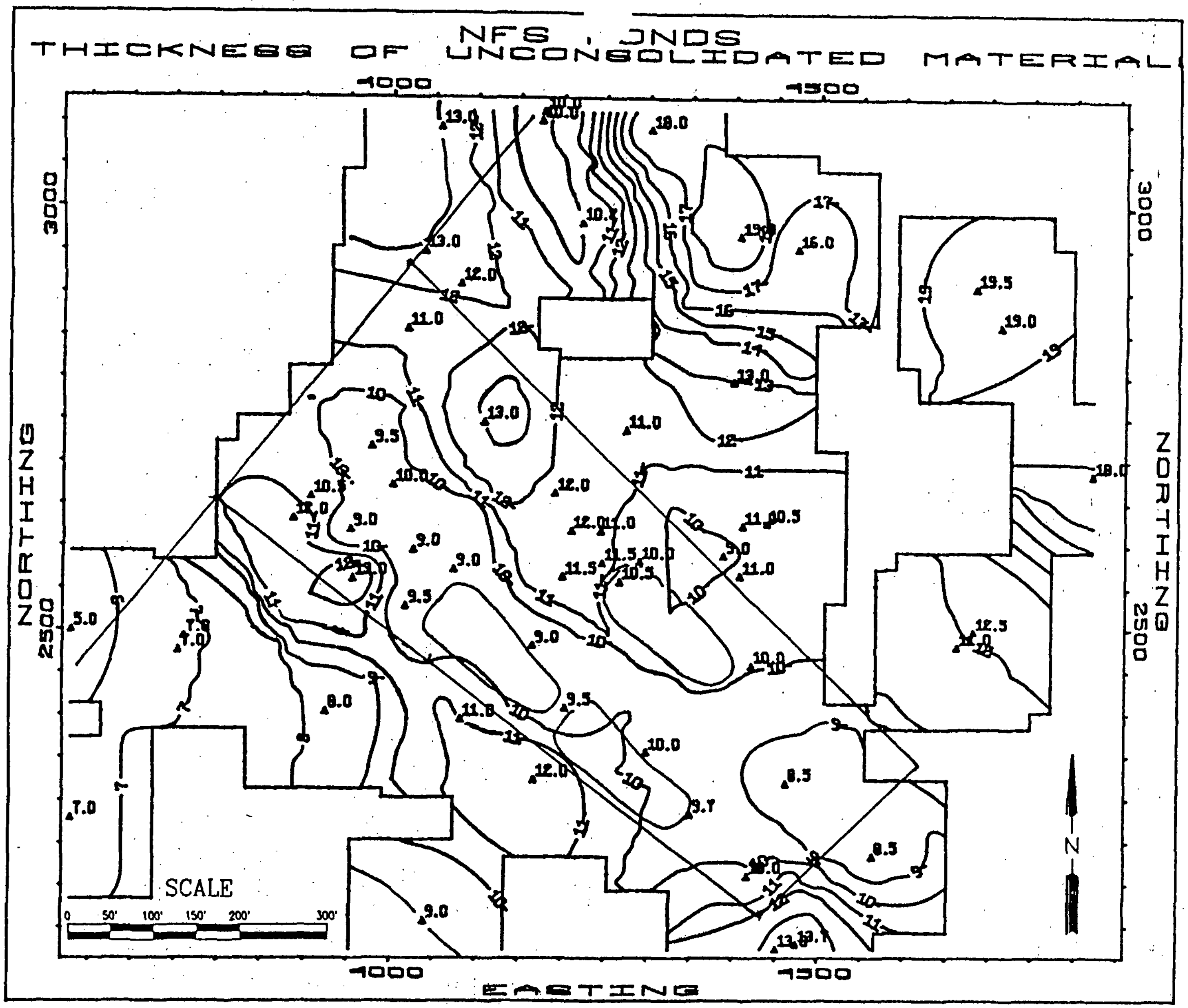
FIGURE 5-6
SURFICIAL GEOLOGY

DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
7-14-89	NFS-PONDS	NFOC0061	1 OF 1	A



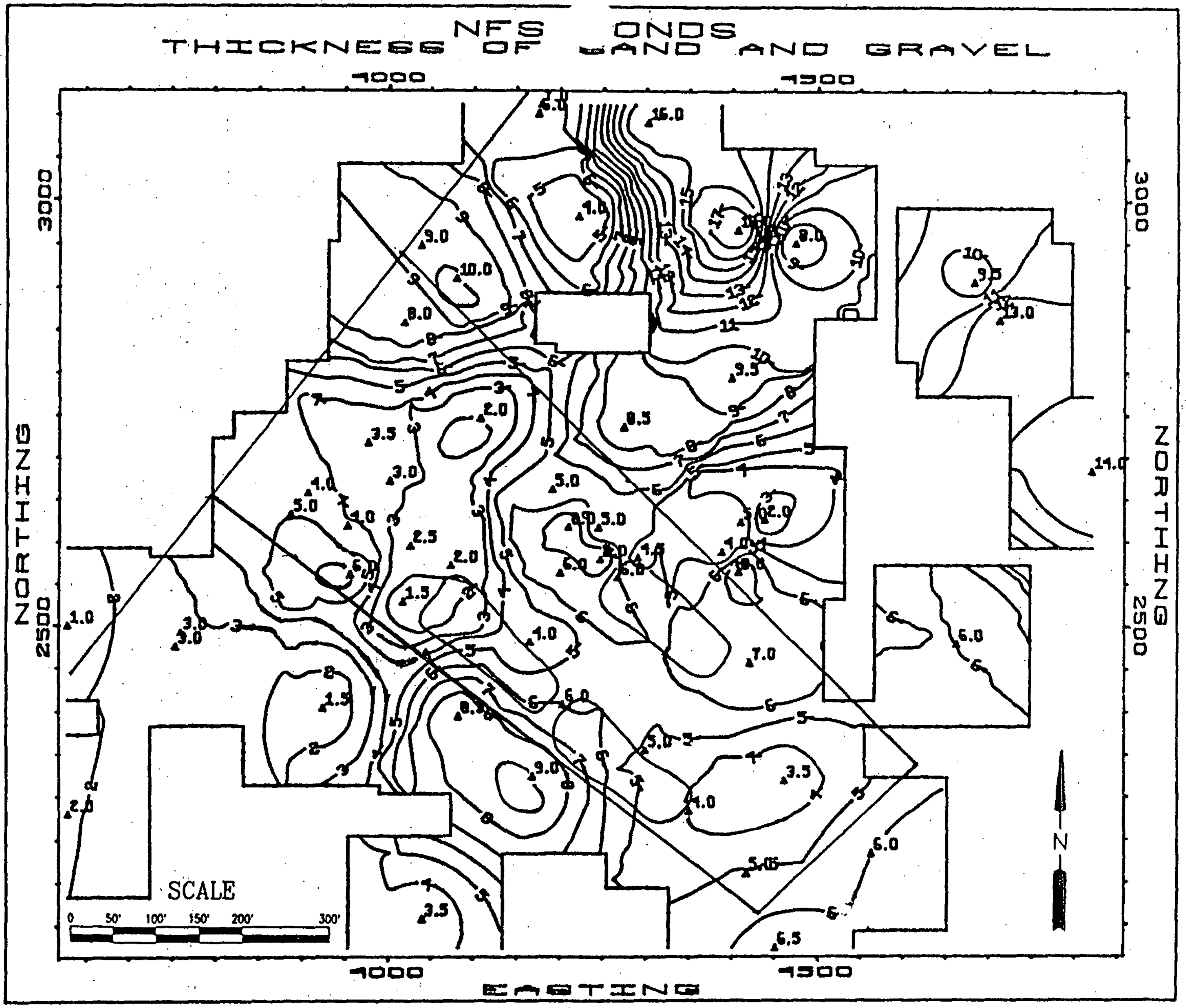
EXPLANATION

—— 10 ——
Line of equal soil thickness.
Contour Interval 1 foot.

▲9.0 Well location. Number is thickness of soil material.

Area of low confidence based on lack of control points

Figure 5-7 Thickness of Unconsolidated Materials



EXPLANATION

— 10 — Line of equal sand and gravel thickness. Contour interval 1 foot.

▲2 Well location. Number is thickness of sand and gravel.

Area of low confidence based on lack of control points

Figure 5-8 Thickness of Sand and Gravel

Figure 5-9 - Subsurface Profile A-A'

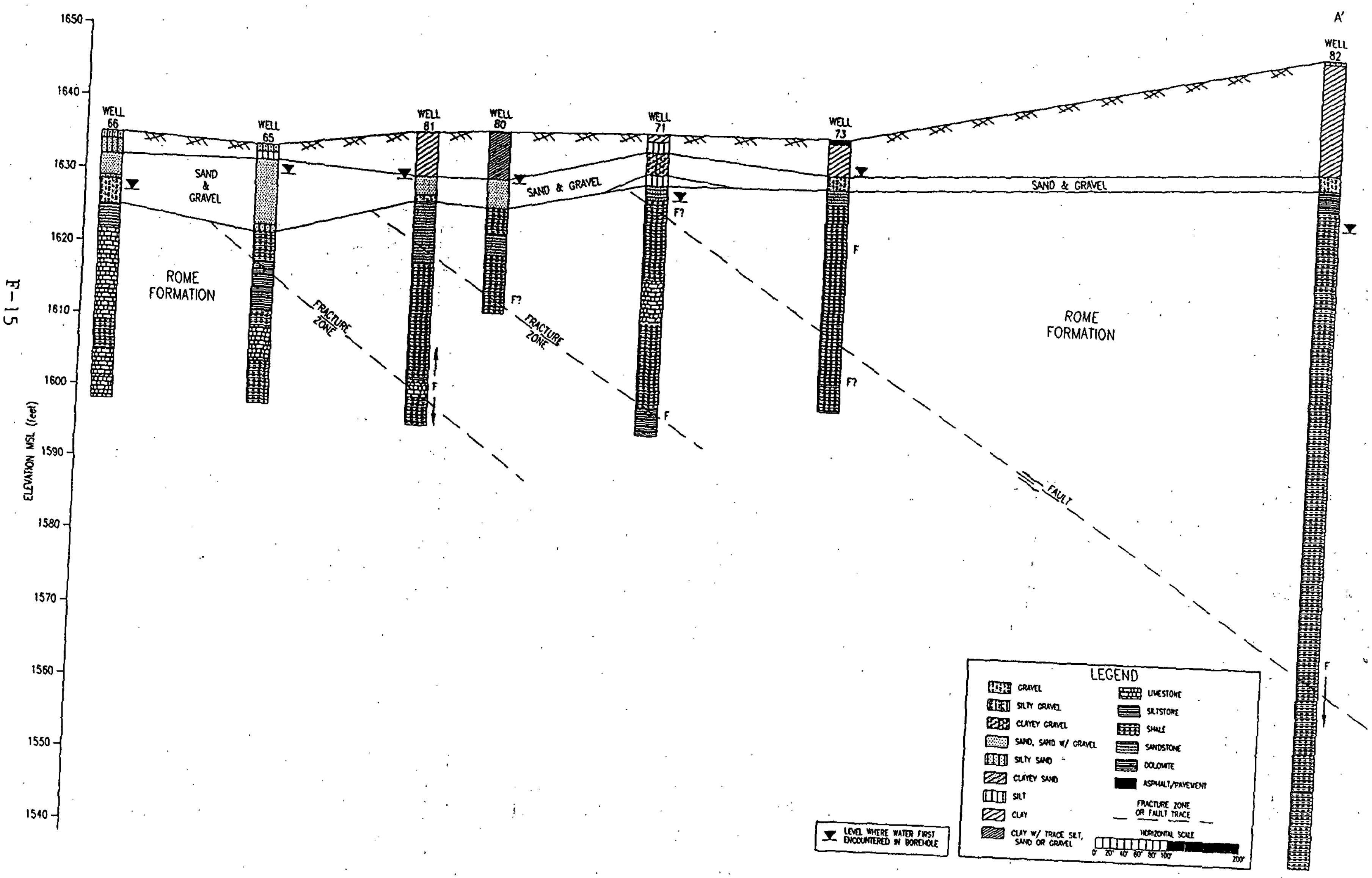


Figure 5-10 – Subsurface Profile B-B'

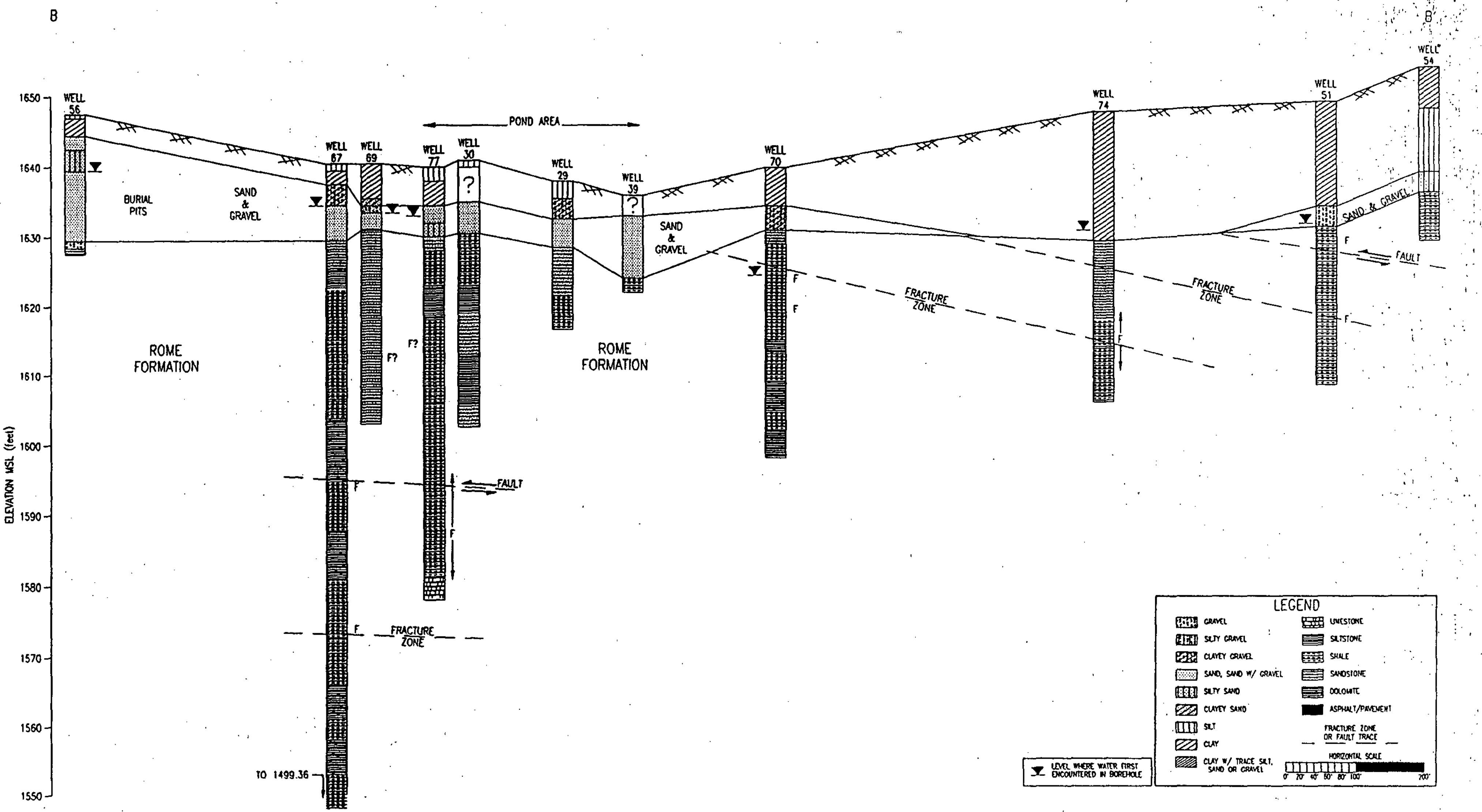


Figure 5-11 - Subsurface Profile C-C'

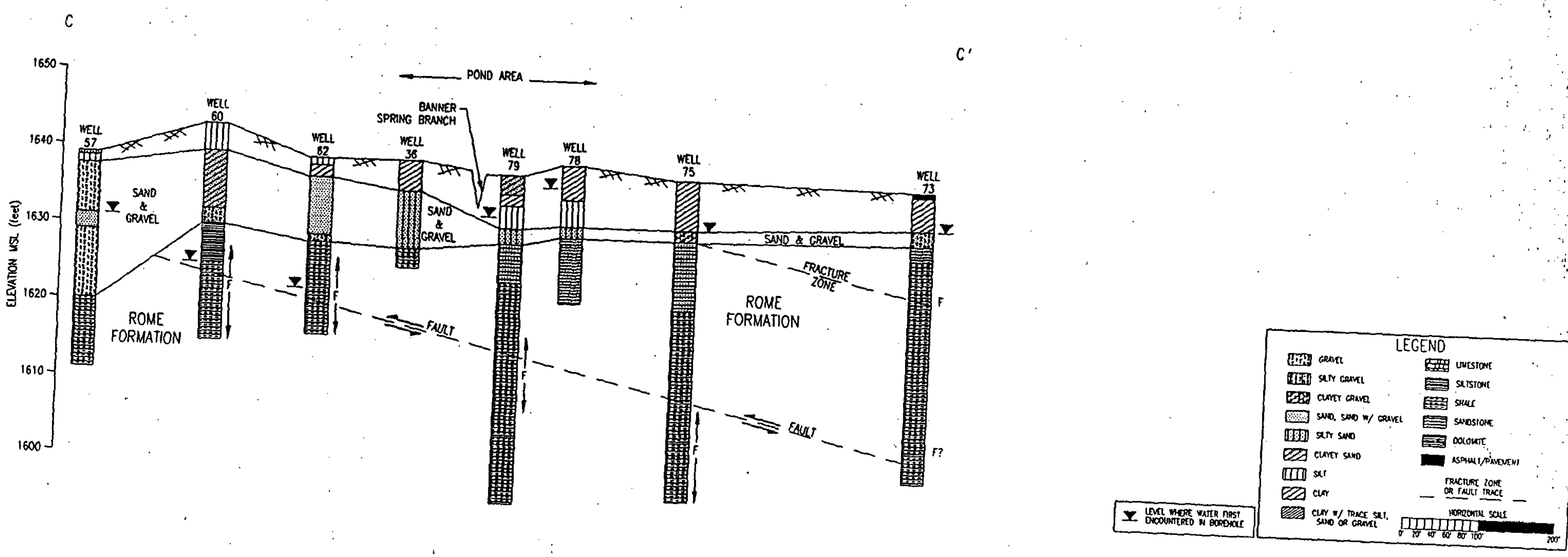


Figure 5-12 – Subsurface Profile D-D'

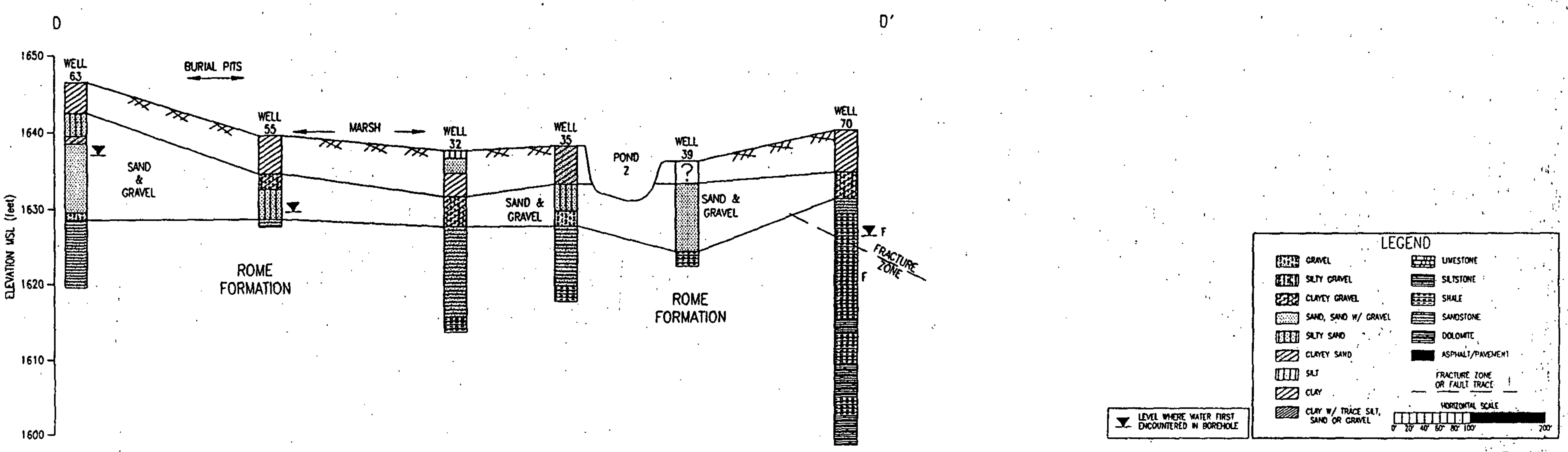


Figure 5-13 - Subsurface Profile E-E'

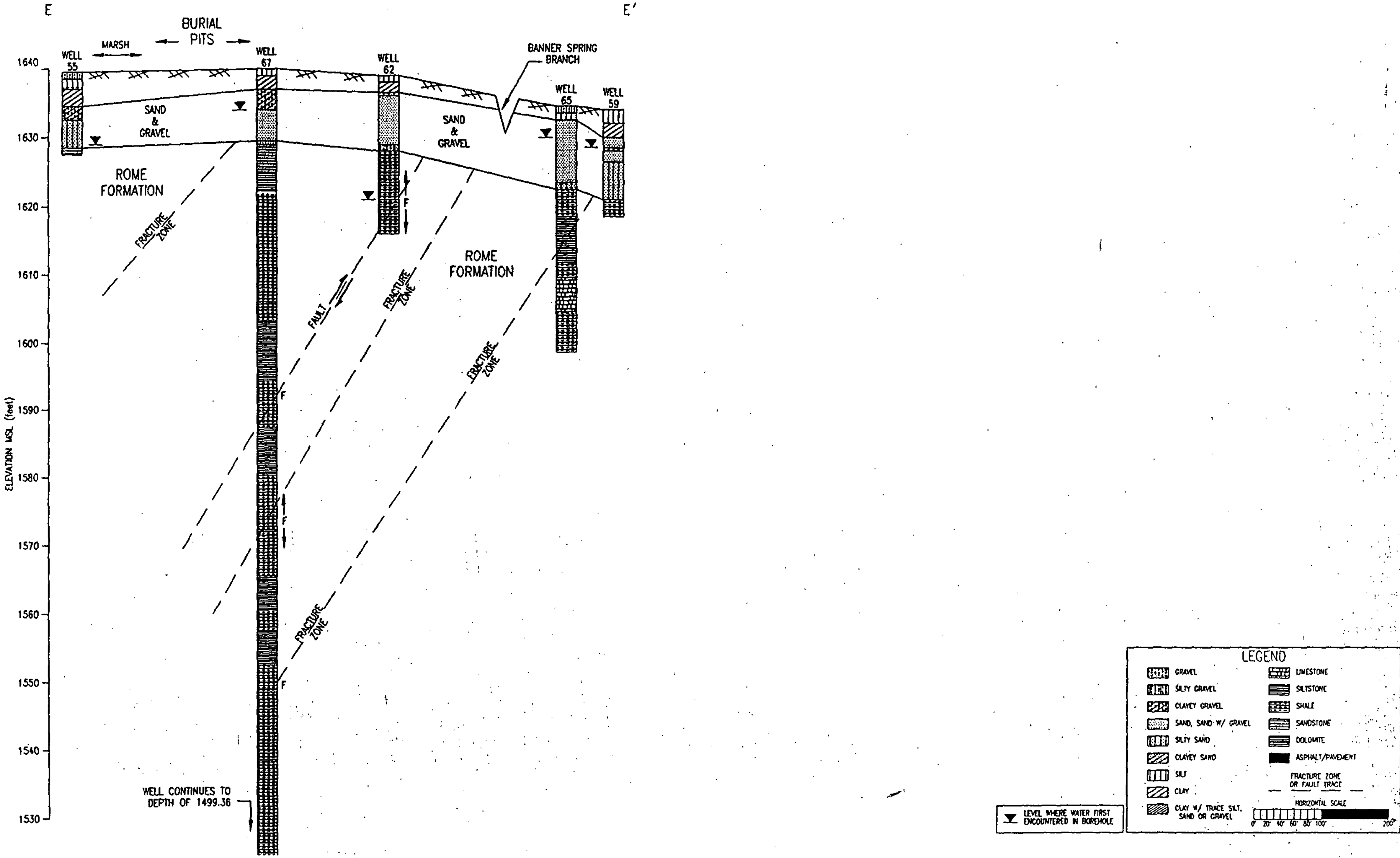


Figure 5–14 – Subsurface Profile F–F'

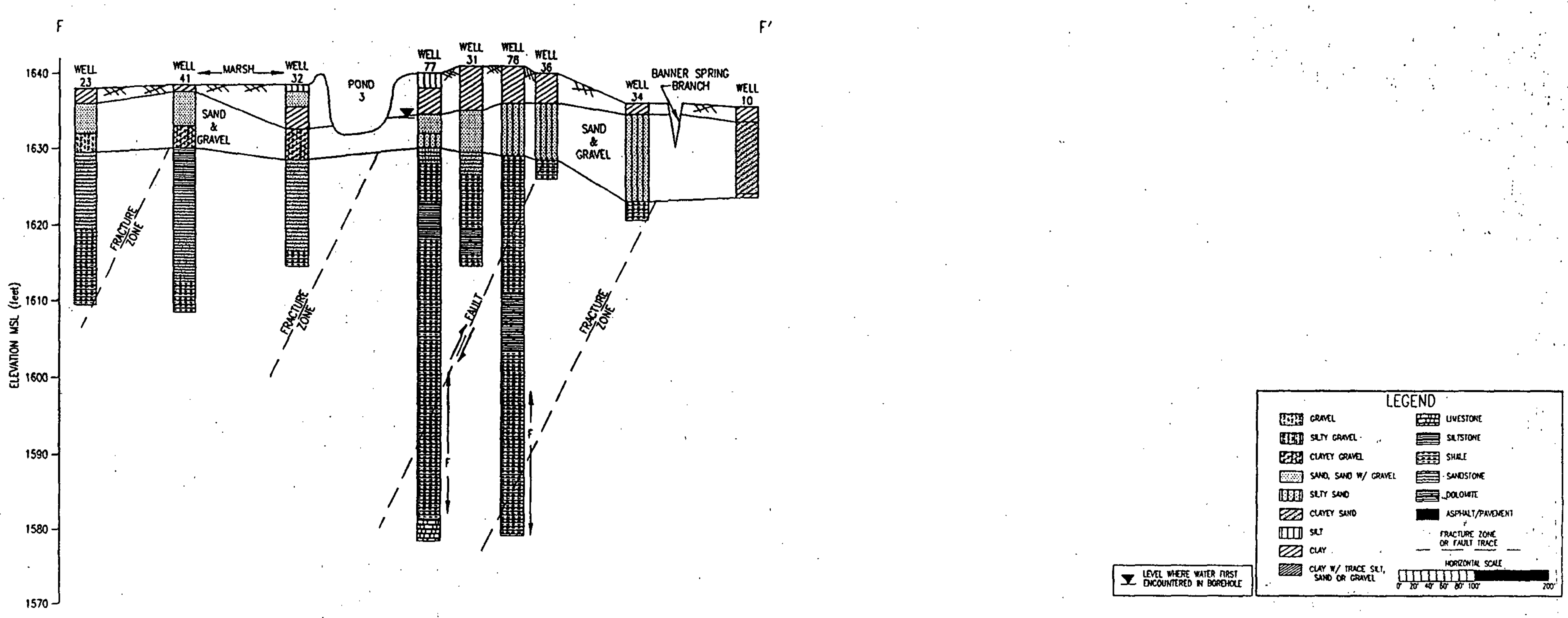


Figure 5–15 – Subsurface Profile G–G′

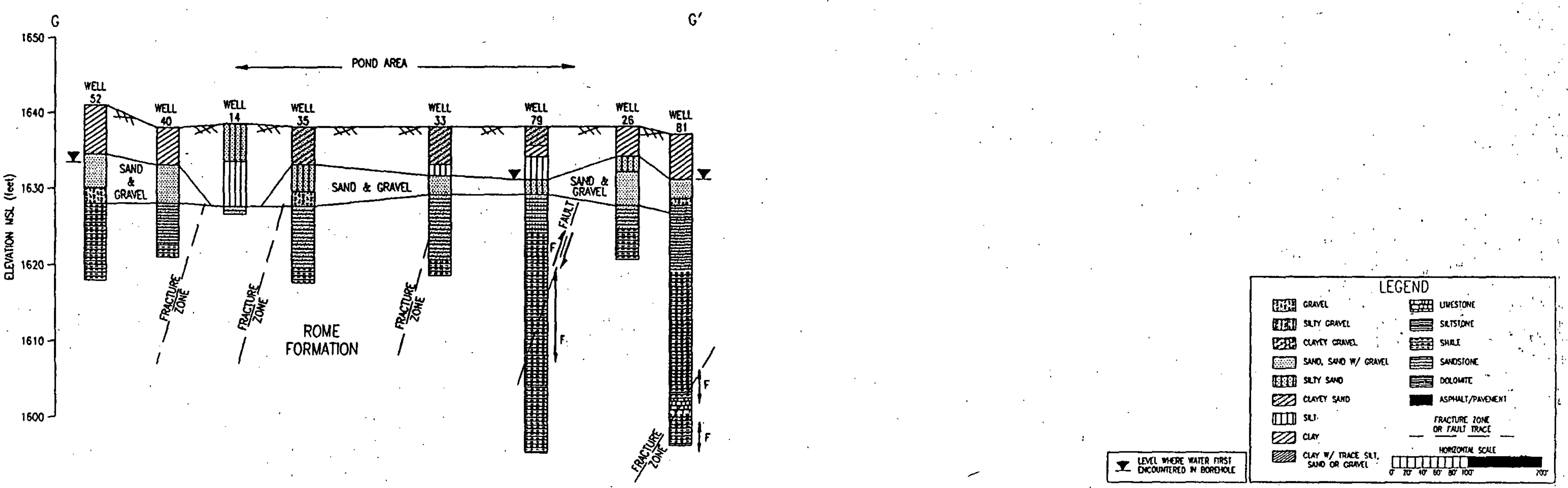


Figure 5–16 – Subsurface Profile H–H′

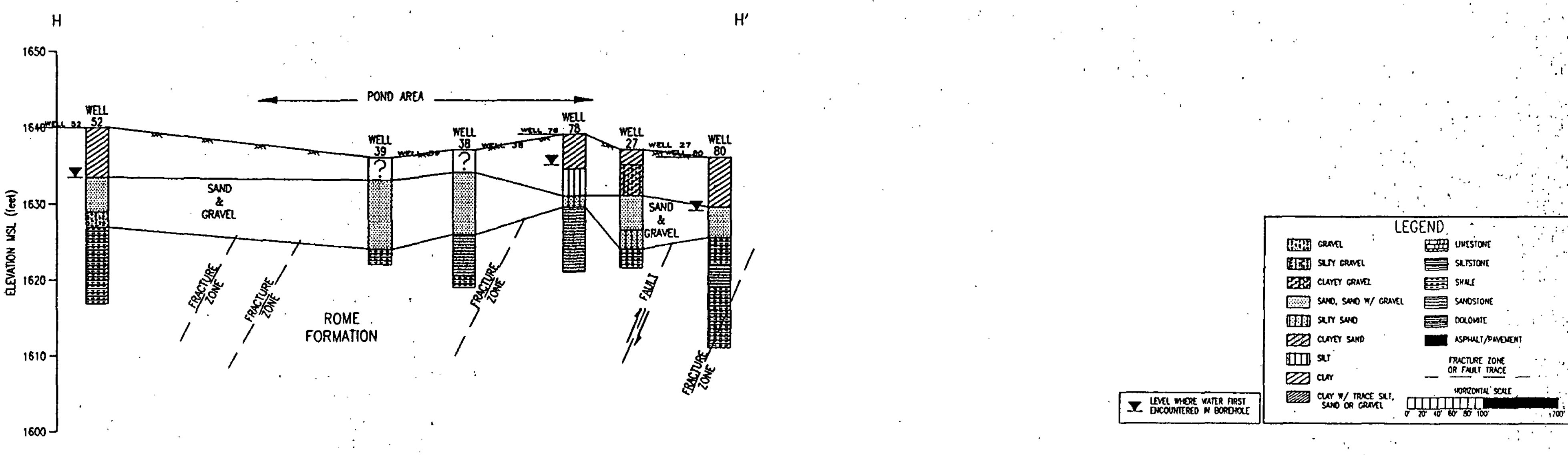


Figure 5-17 – Subsurface Profile I-I'

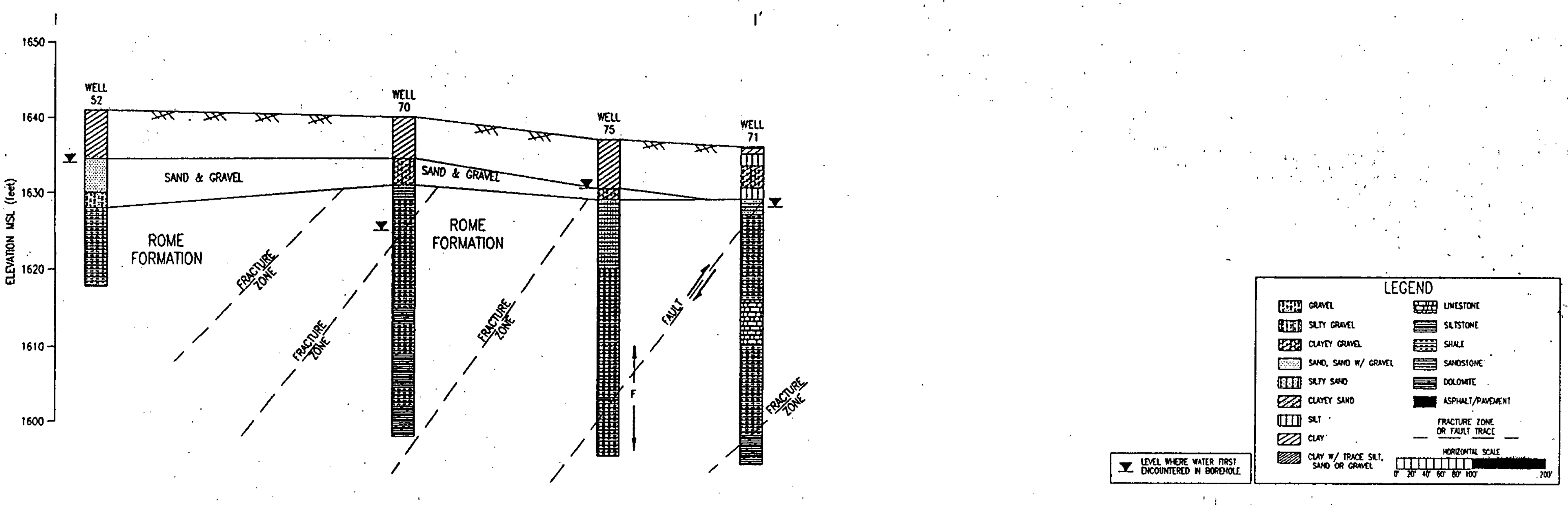


Figure 5-18 – Hydrogeologic Profile J-J'

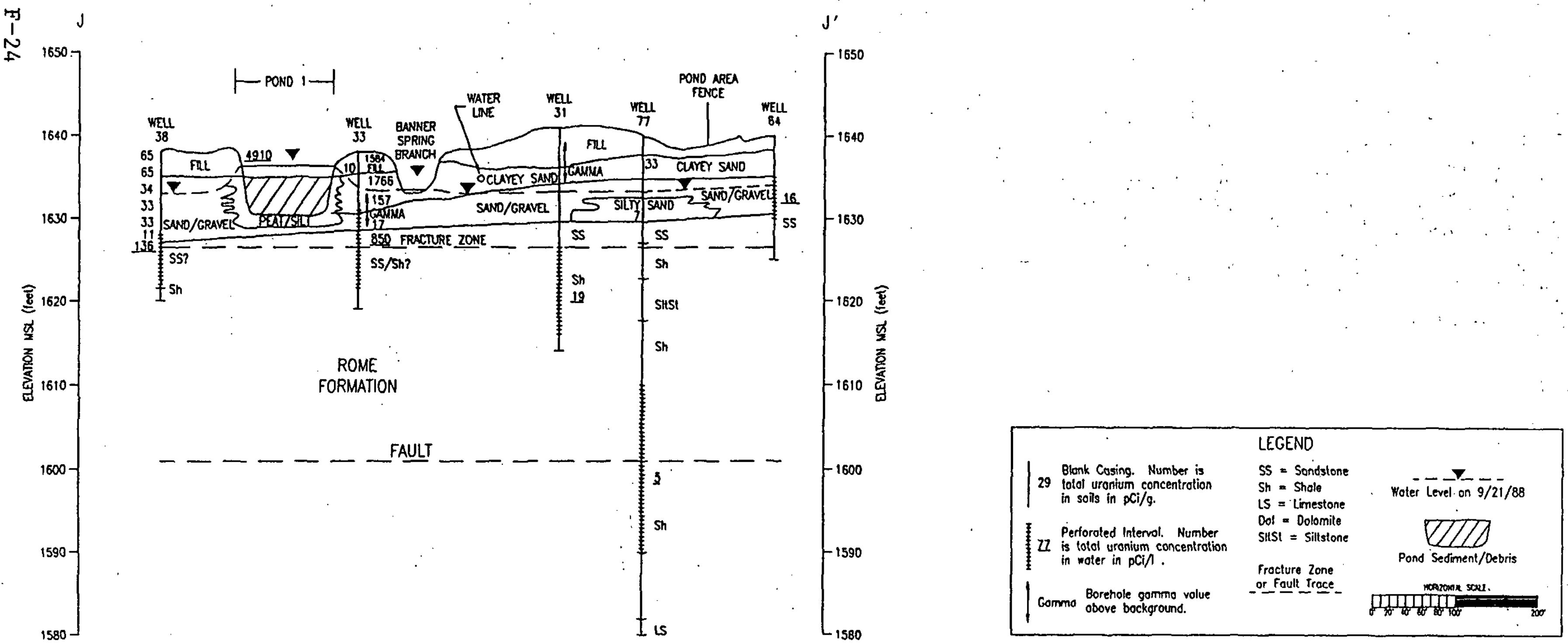


Figure 5-19 - Hydrogeologic Profile K-K'

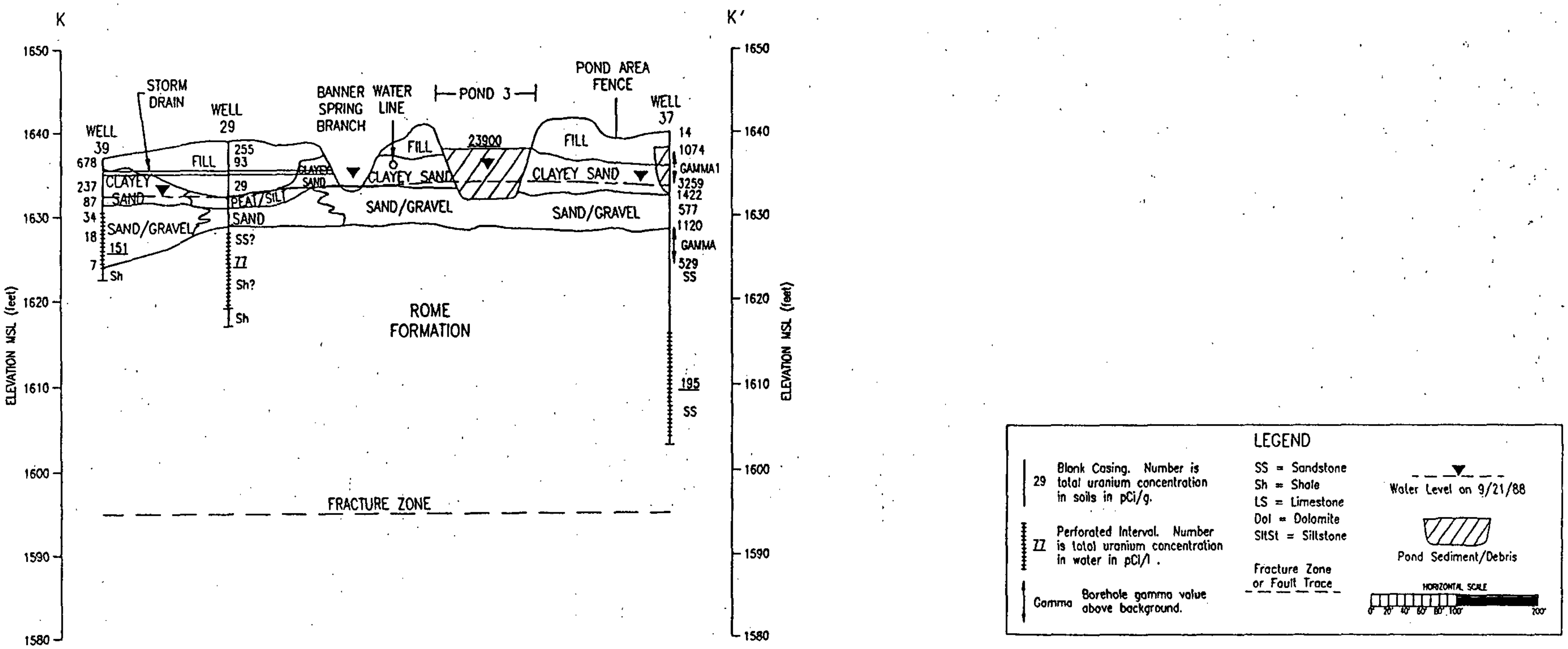


Figure 5-20 – Hydrogeologic Profile L-L'

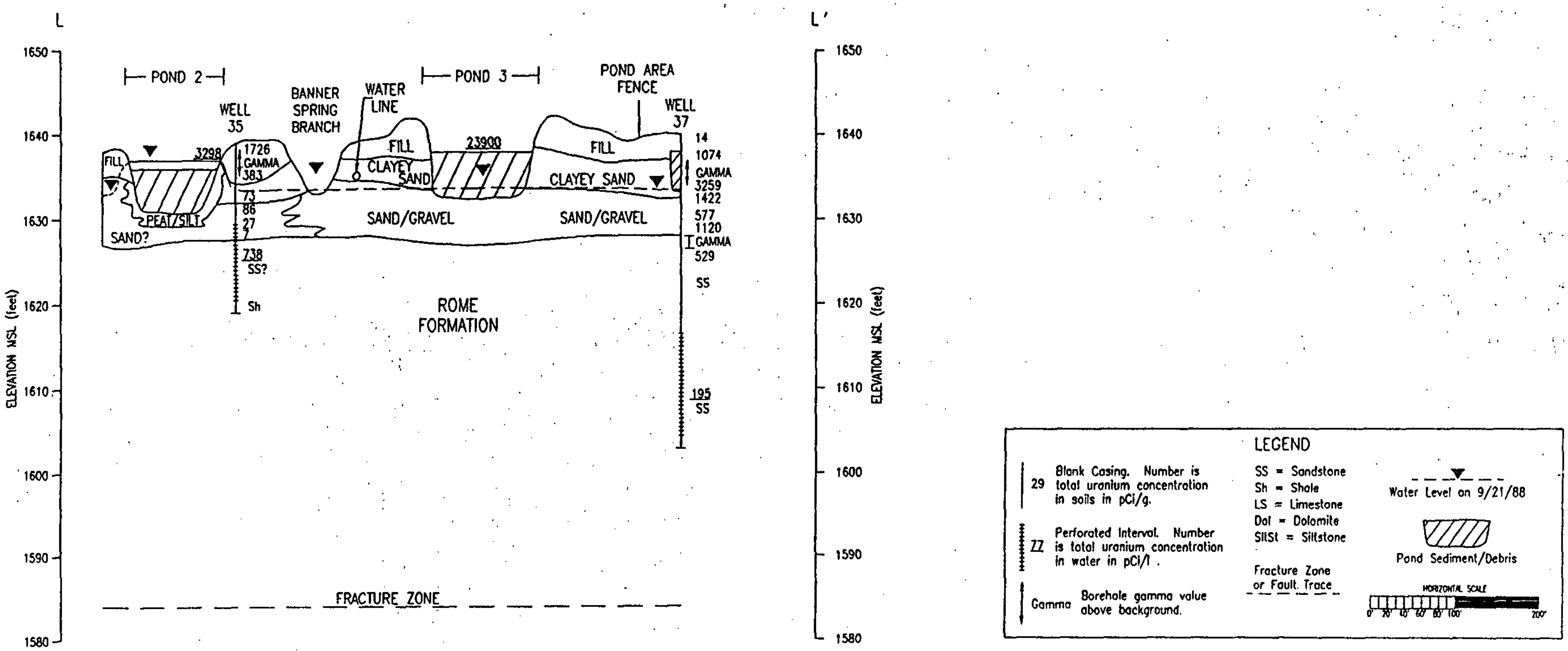


Figure 5-21 – Hydrogeologic Profile M–M'

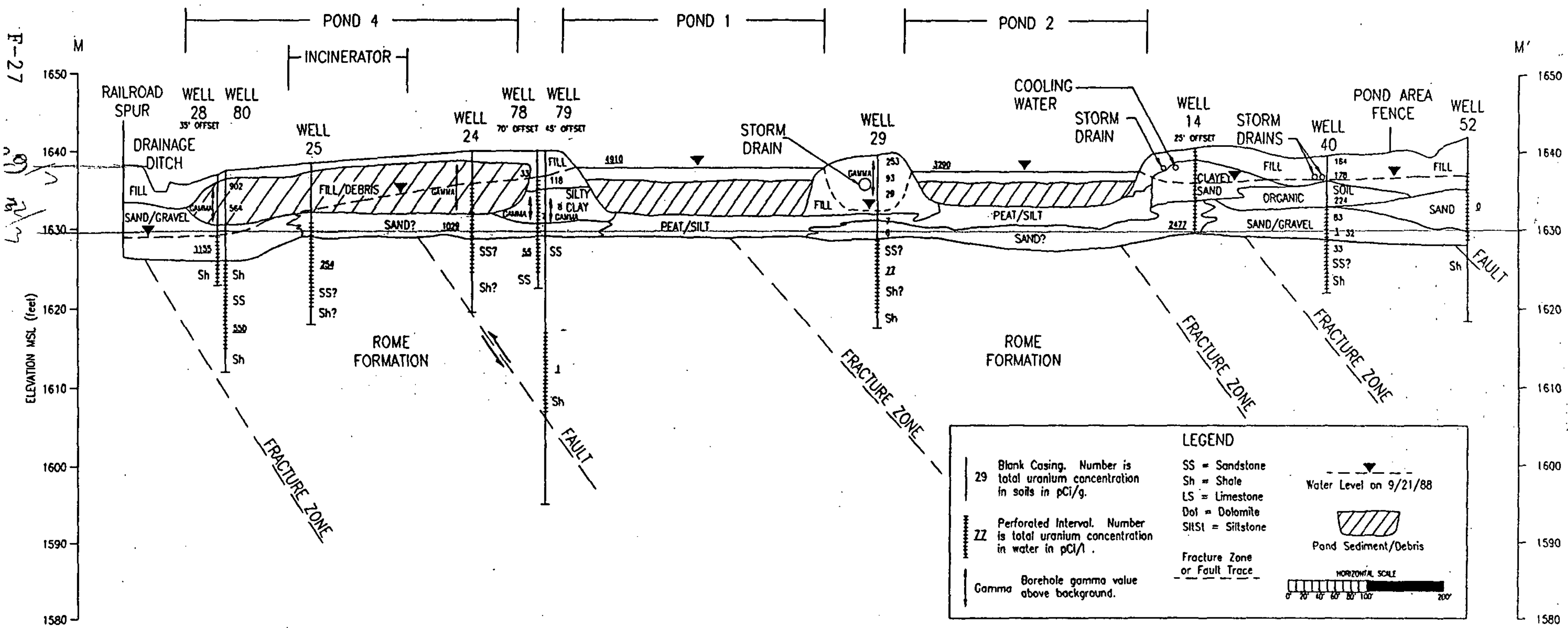
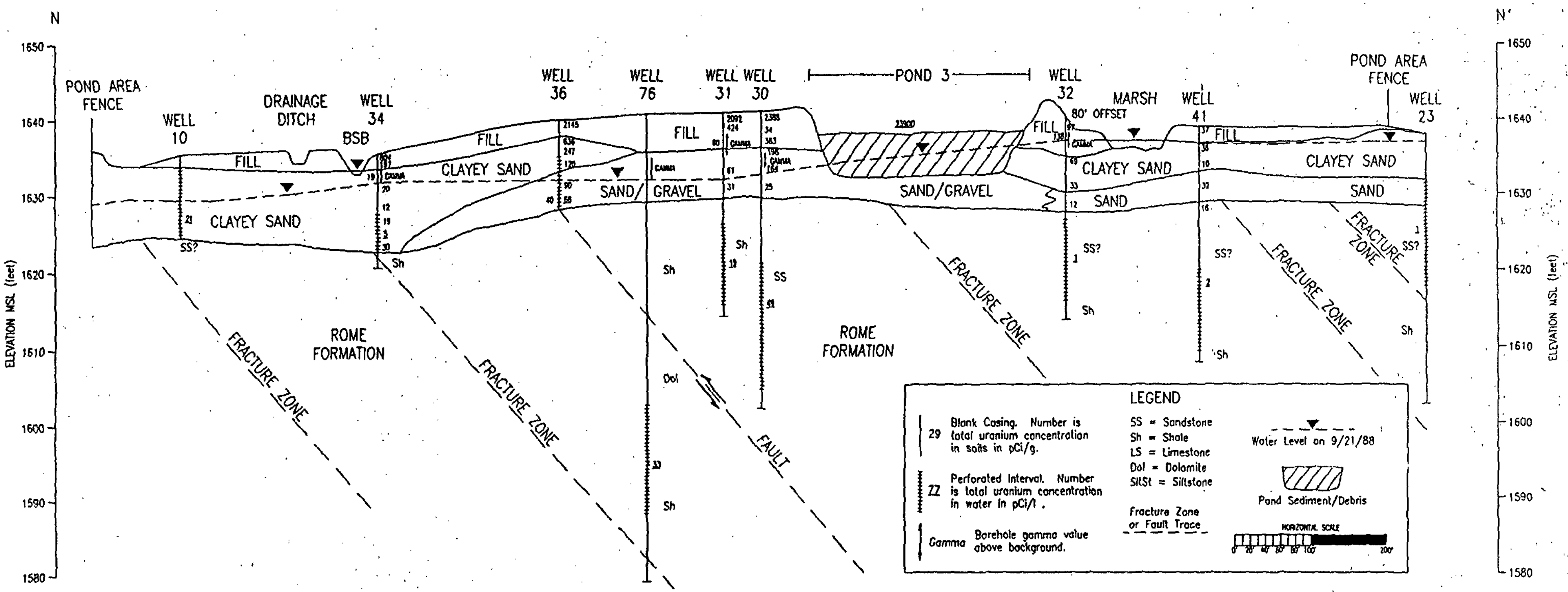
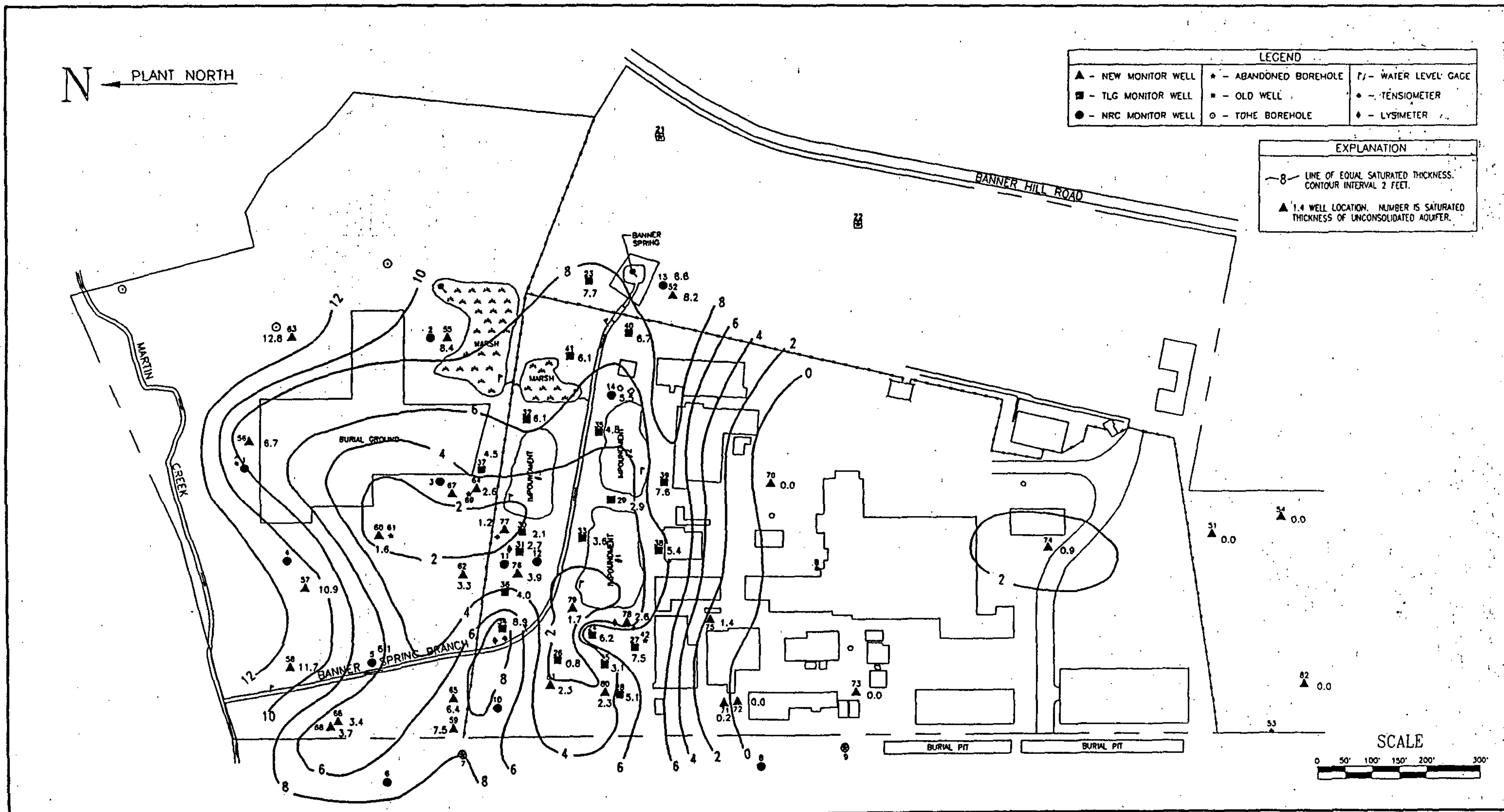


Figure 5-22 – Hydrogeologic Profile N-N′





A	10-13-89	ORIGINAL DRAWING	CWT	SJT	JRW		
REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.		

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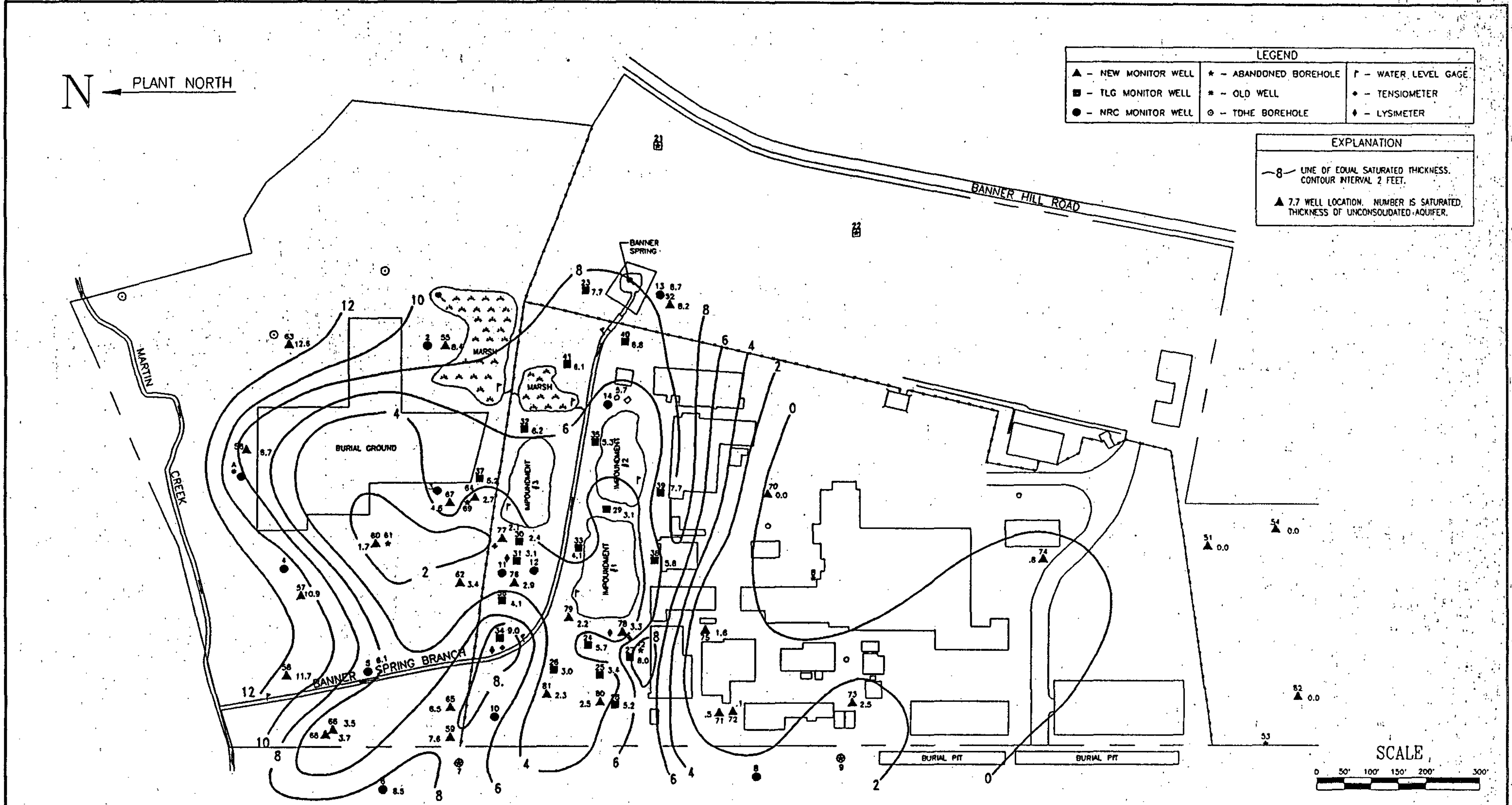
FIGURE 6-1 – SATURATED THICKNESS OF UNCONSOLIDATED AQUIFER (7/1/88)

SCALE	DRAWN BY	DESIGNED BY	DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
SHOWN	CHARLES W. TALLMAN	ECOTEK	7-18-89	NFS-PONDS	NFOC021	1 OF 1	A



F-30

A	10-13-89	ORIGINAL DRAWING	CWT	SJT	JRW
REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.

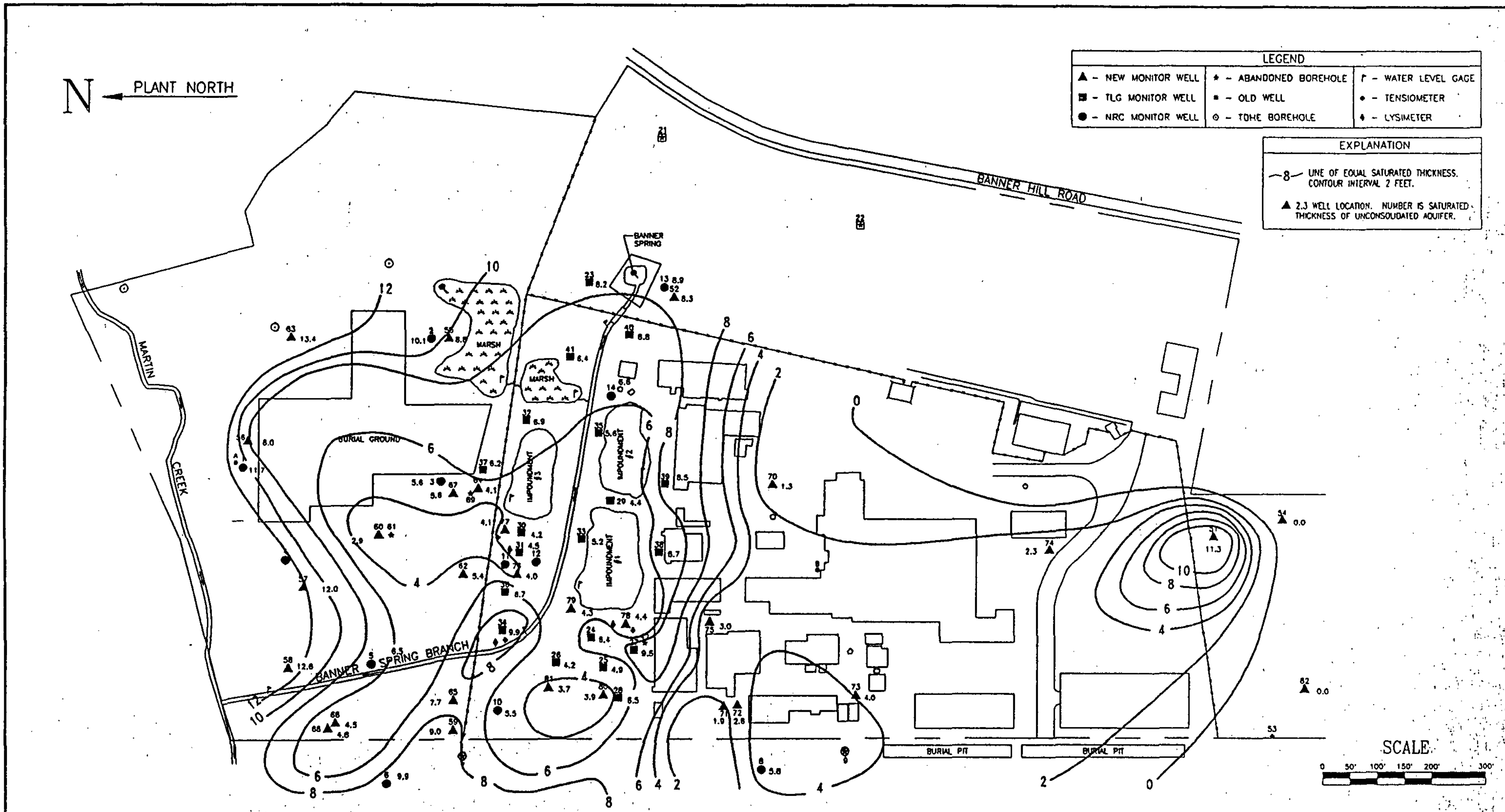
SCALE	DRAWN BY	DESIGNED BY
SHOWN	CHARLES W. TALLMAN	ECOTEK

EcoTek NFS

ECOTEK, INC.
NFS PONDS PROJECT
ERWIN, TENNESSEE

FIGURE 6-2 – SATURATED THICKNESS OF UNCONSOLIDATED AQUIFER (9/21/88)

DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
7-13-89	NFS-PONDS	NFOC022	1 OF 1	A



REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.
A	10-13-89	ORIGINAL DRAWING	CWT	SJT	JRW

SCALE	DRAWN BY	DESIGNED BY
SHOWN	CHARLES W. TALLMAN	ECOTEK

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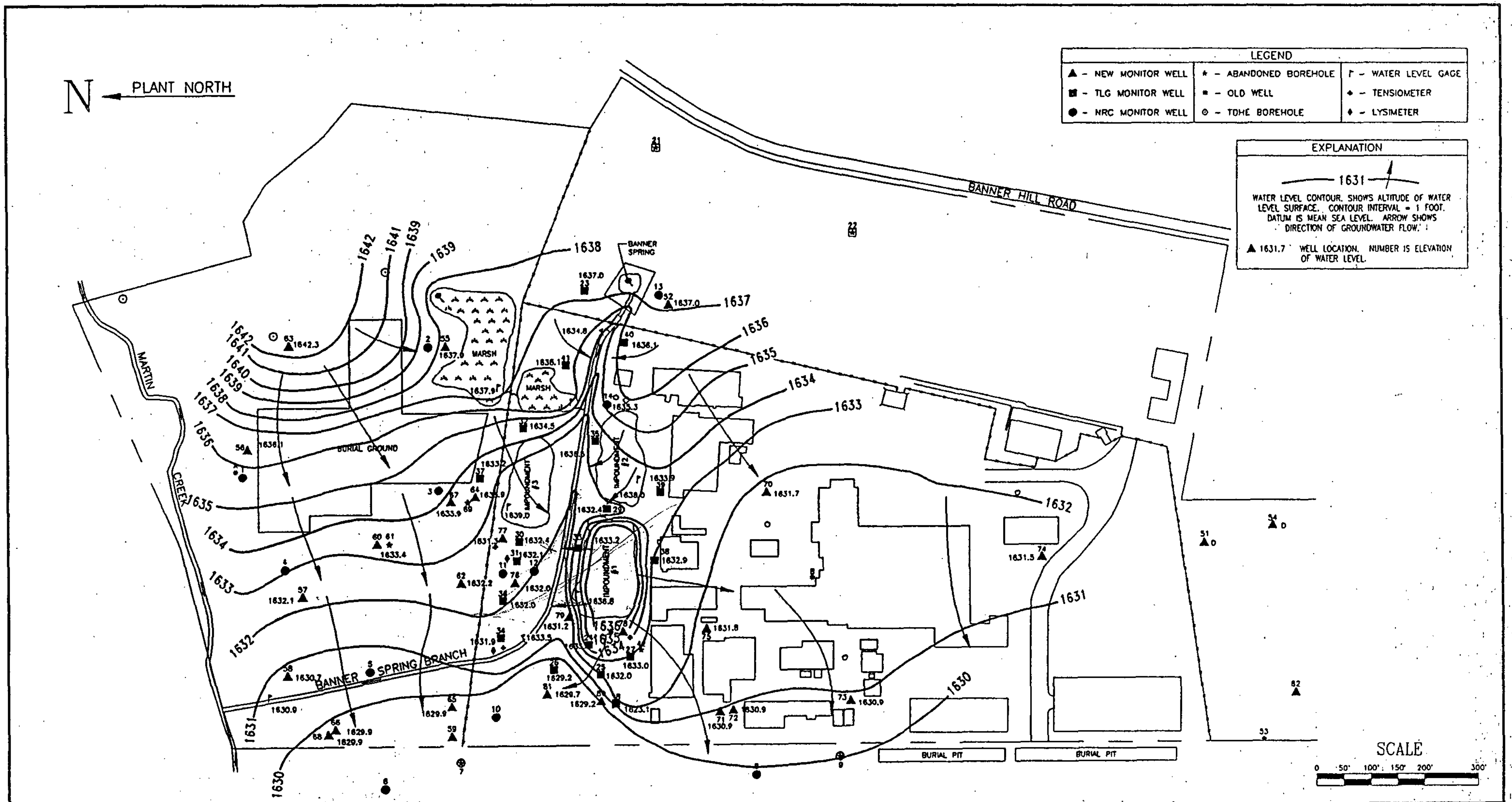
ECOTEK, INC.
NFS PONDS PROJECT
ERWIN, TENNESSEE

FIGURE 6-3 - SATURATED THICKNESS OF UNCONSOLIDATED AQUIFER (2/8/89)

DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
7-18-89	NFS-PONDS	NFOC023	1 OF 1	A



A	10-13-89	ORIGINAL DRAWING	CWT	SJT	JRW
REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.

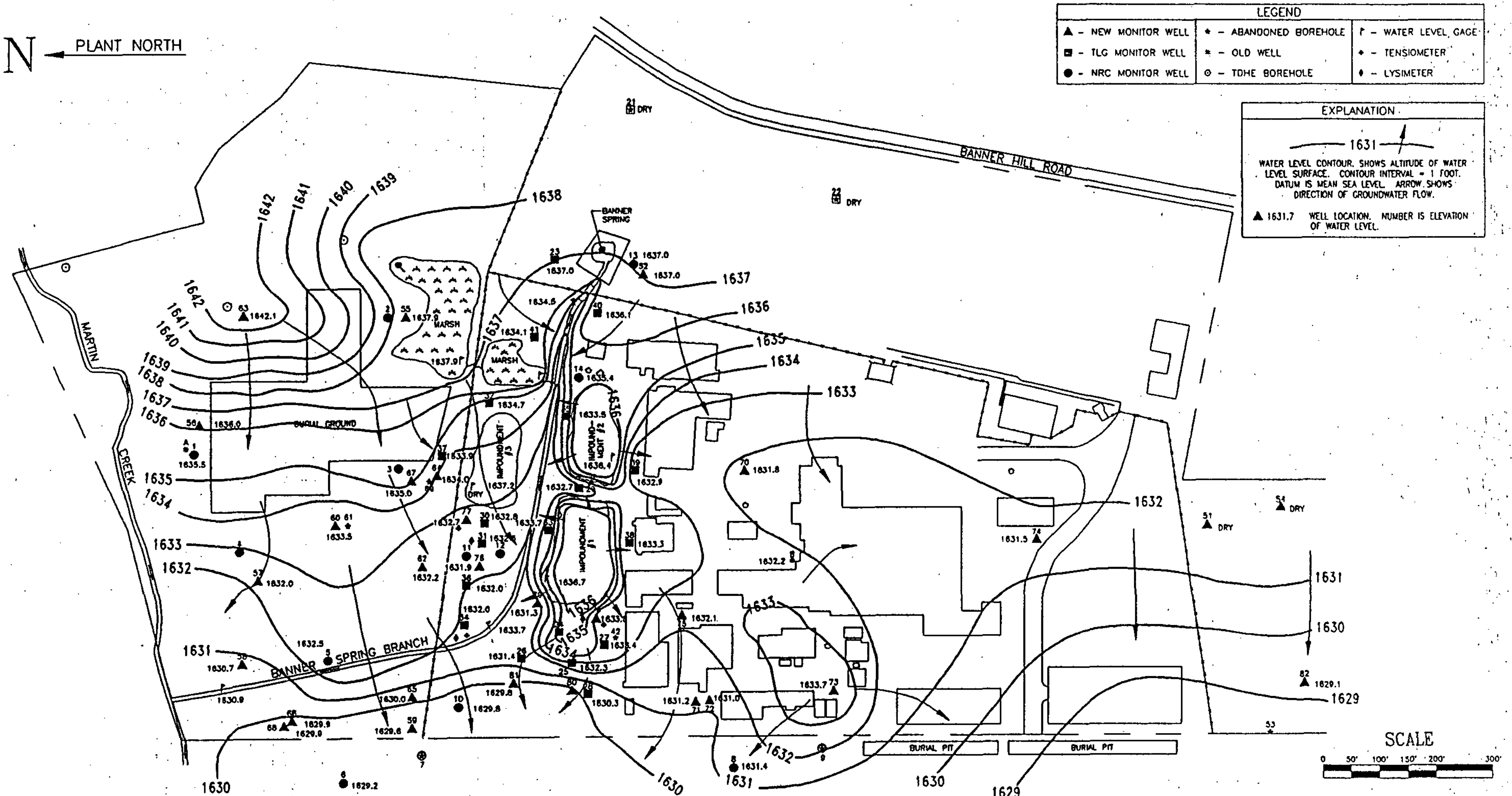
SCALE	DRAWN BY	DESIGNED BY
SHOWN	CHARLES W. TALLMAN	ECOTEK

EcoTek NFS

ECOTEK, INC.
NFS PONDS PROJECT
ERWIN, TENNESSEE

FIGURE 6-4 – WATER LEVEL ELEVATIONS (7/1/88)

DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
7-20-89	NFS-PONDS	NFOC024	1 OF 1	A



A	10-13-89	ORIGINAL DRAWING	CWT	SJT	JRW
REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.

SCALE	DRAWN BY	DESIGNED BY
SHOWN	CHARLES W. TALLMAN	ECOTEK

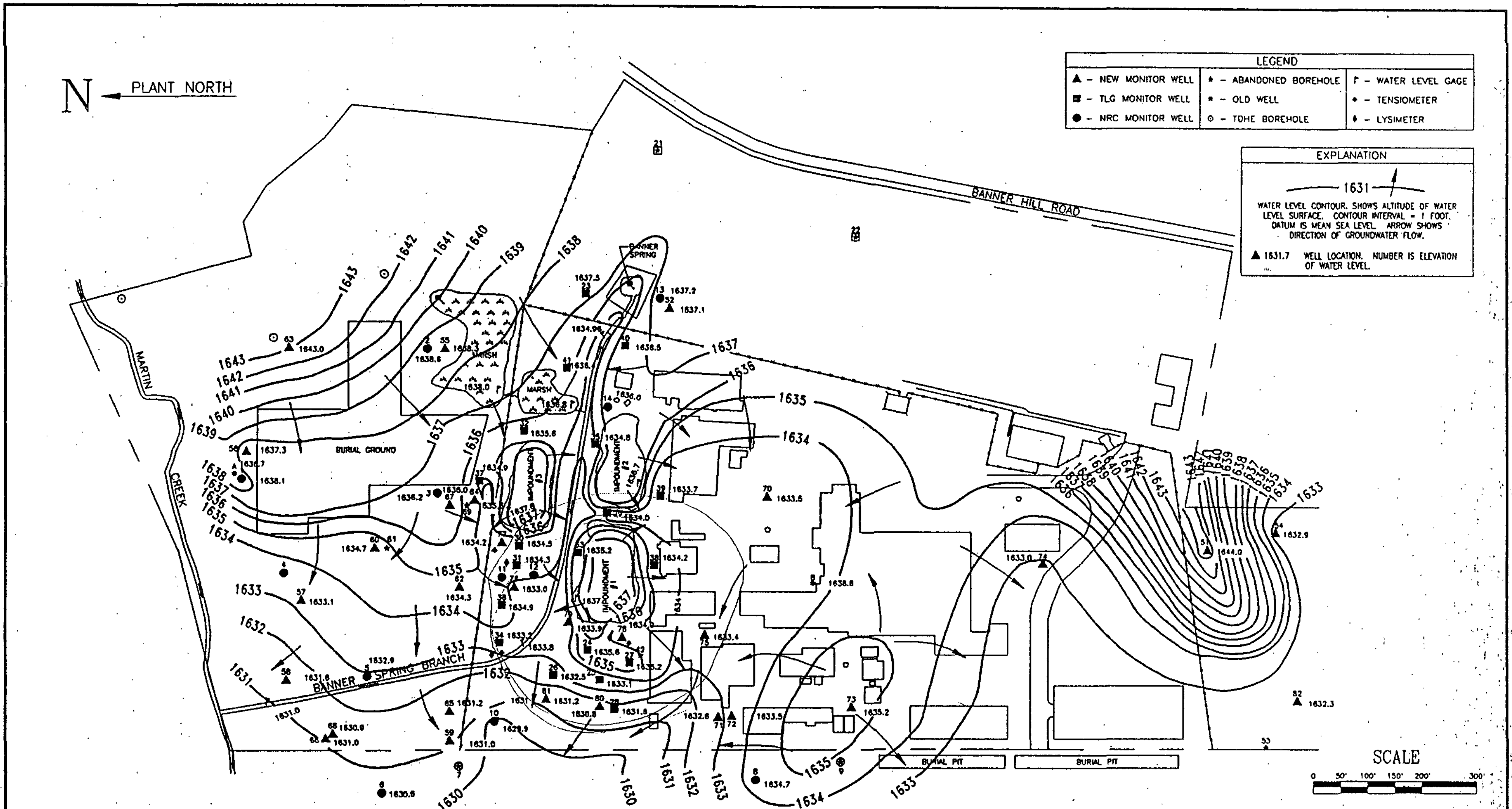
EcoTek NFS

ECOTEK, INC.
NFS PONDS PROJECT
ERWIN, TENNESSEE

FIGURE 6-5 - WATER LEVEL ELEVATIONS (9/21/88)

DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
7-18-89	NFS-PONDS	NFOC025	1 OF 1	A

F-22



A	10-13-89	ORIGINAL DRAWING	CWT	SJT	JRW
REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.

EcoTek NFS

ECOTEK, INC.
NFS PONDS PROJECT
ERWIN, TENNESSEE

FIGURE 6-6 – WATER LEVEL ELEVATIONS (2/8/89)

SCALE	DRAWN BY	DESIGNED BY		DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
SHOWN	CHARLES W. TALLMAN	ECOTEK		7-18-89	NFS-PONDS	NFOC026	1 OF 1	A

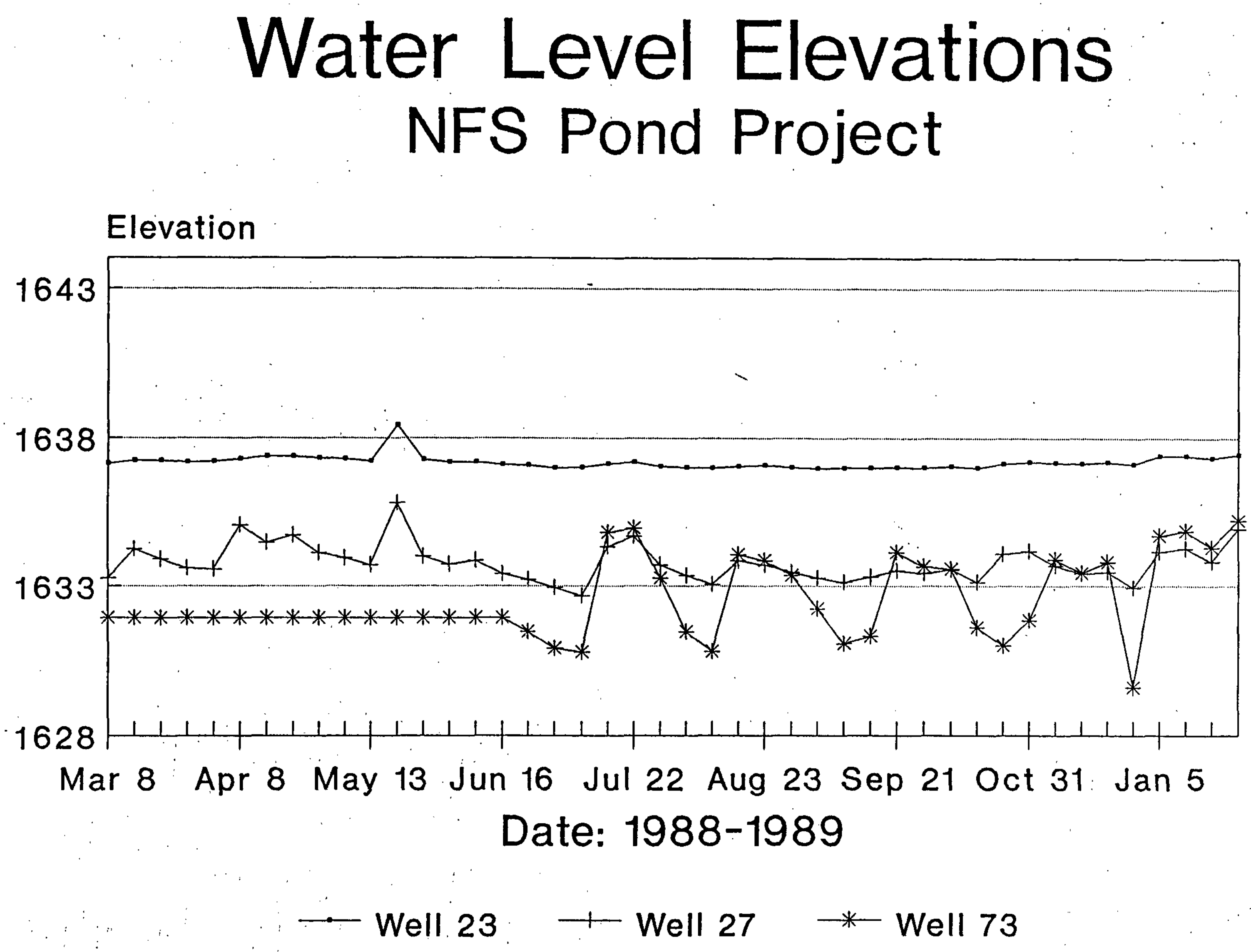


Figure 6-7

F-35

Water Level Elevations
NFS Ponds Project

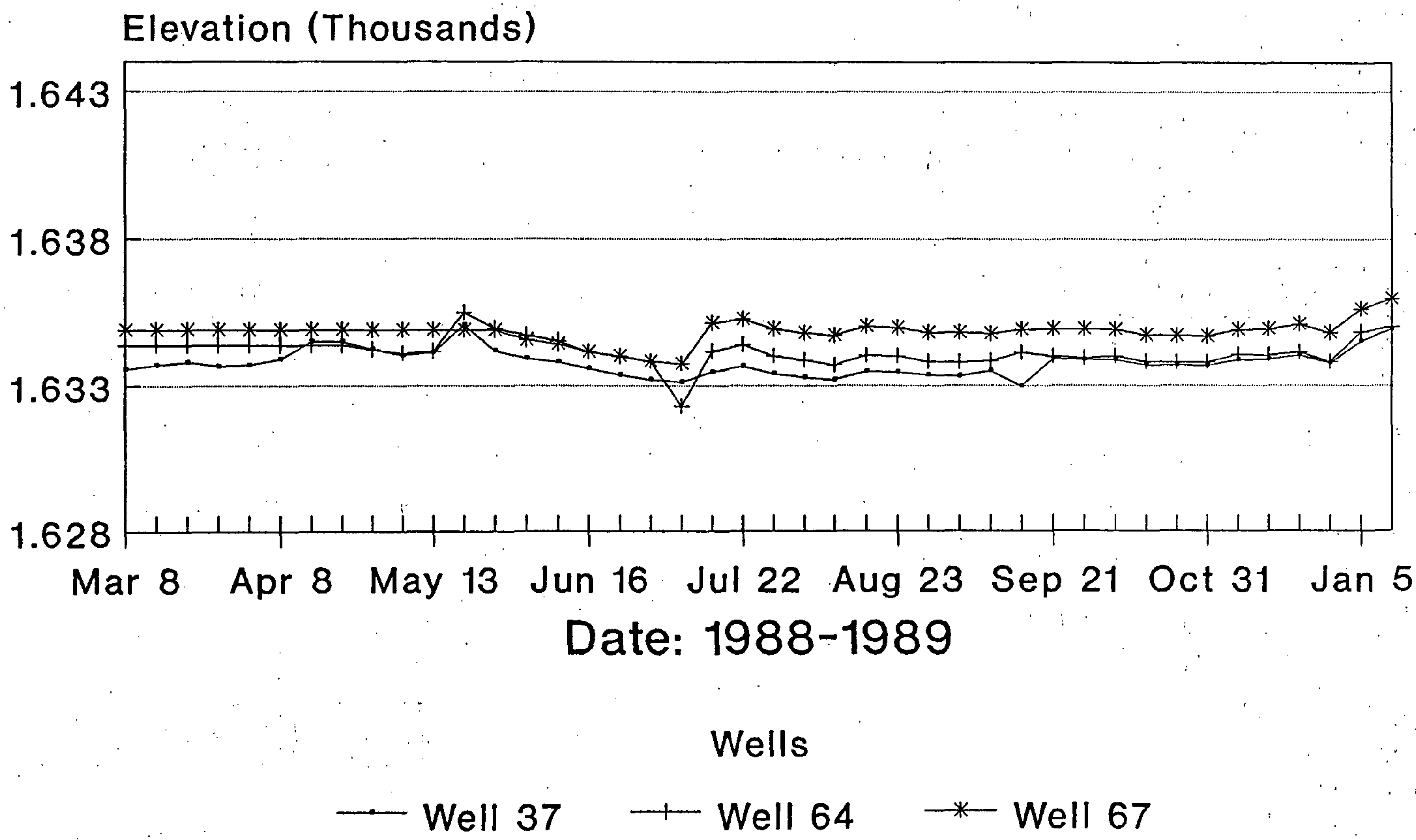


Figure 6-8

Figure 6-9
Generalized Well Completion

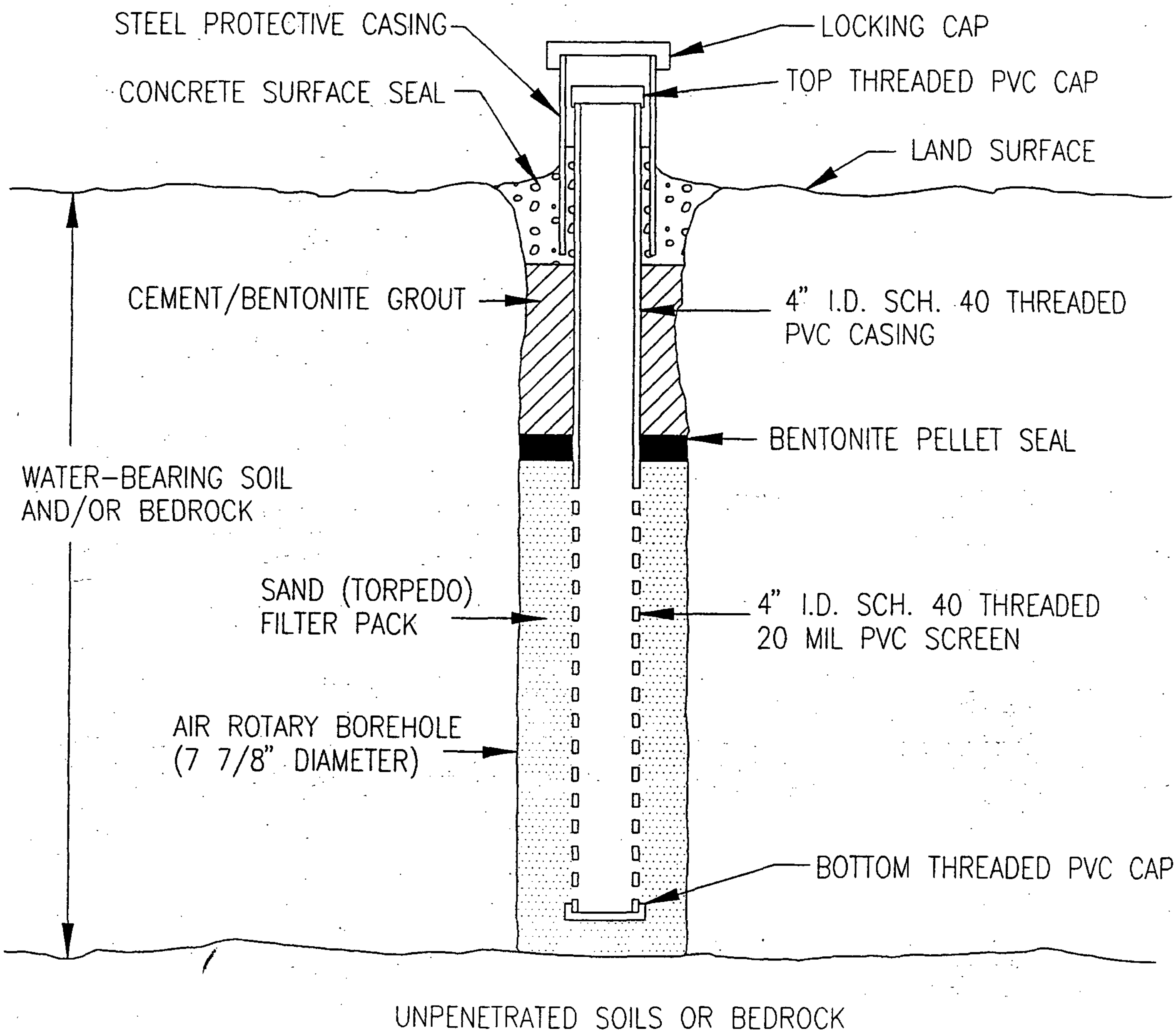


Figure 6-10
Aquifer Test Well Layout

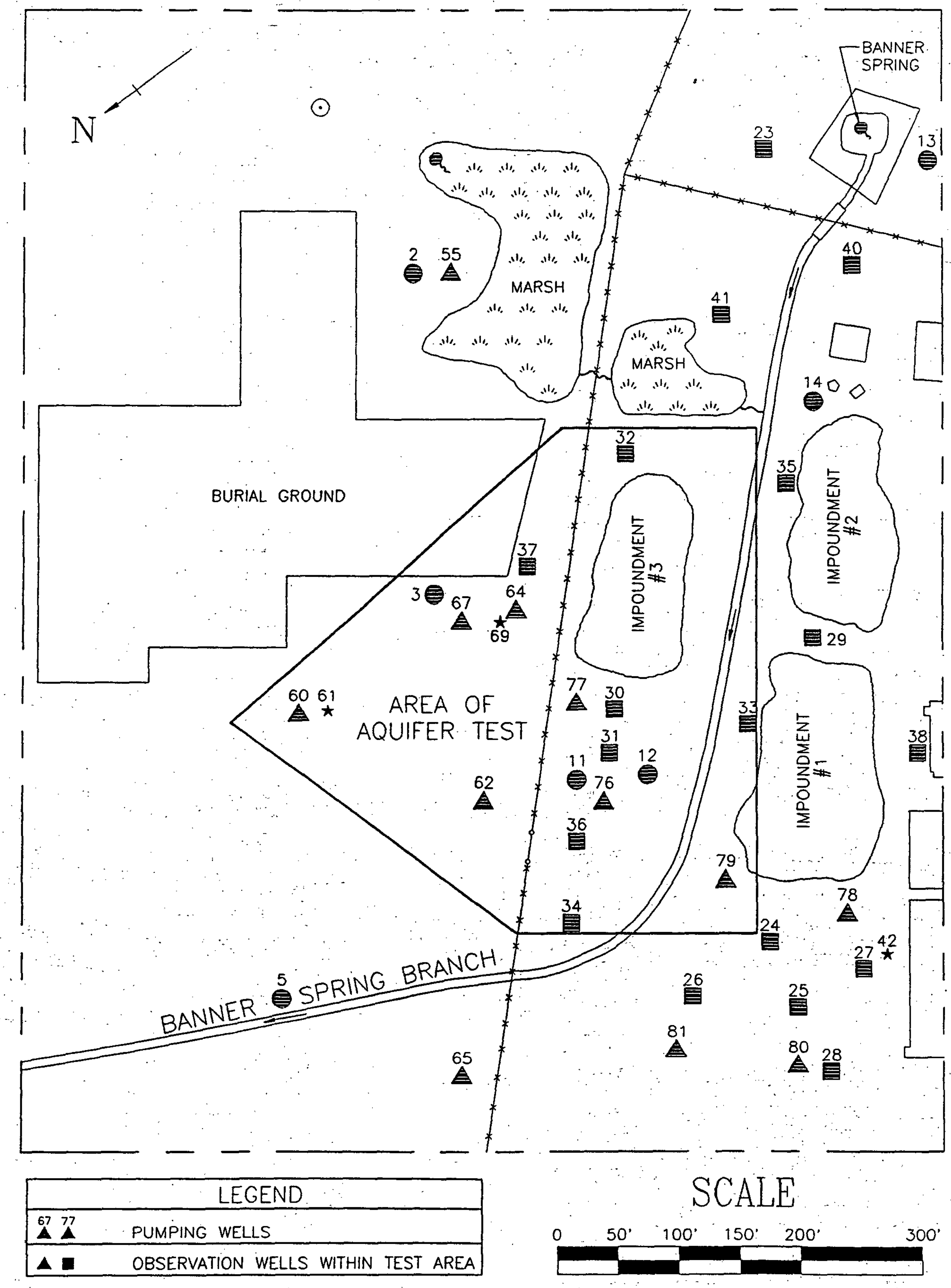


Figure 6-11
Hydrogeologic Section A-A′

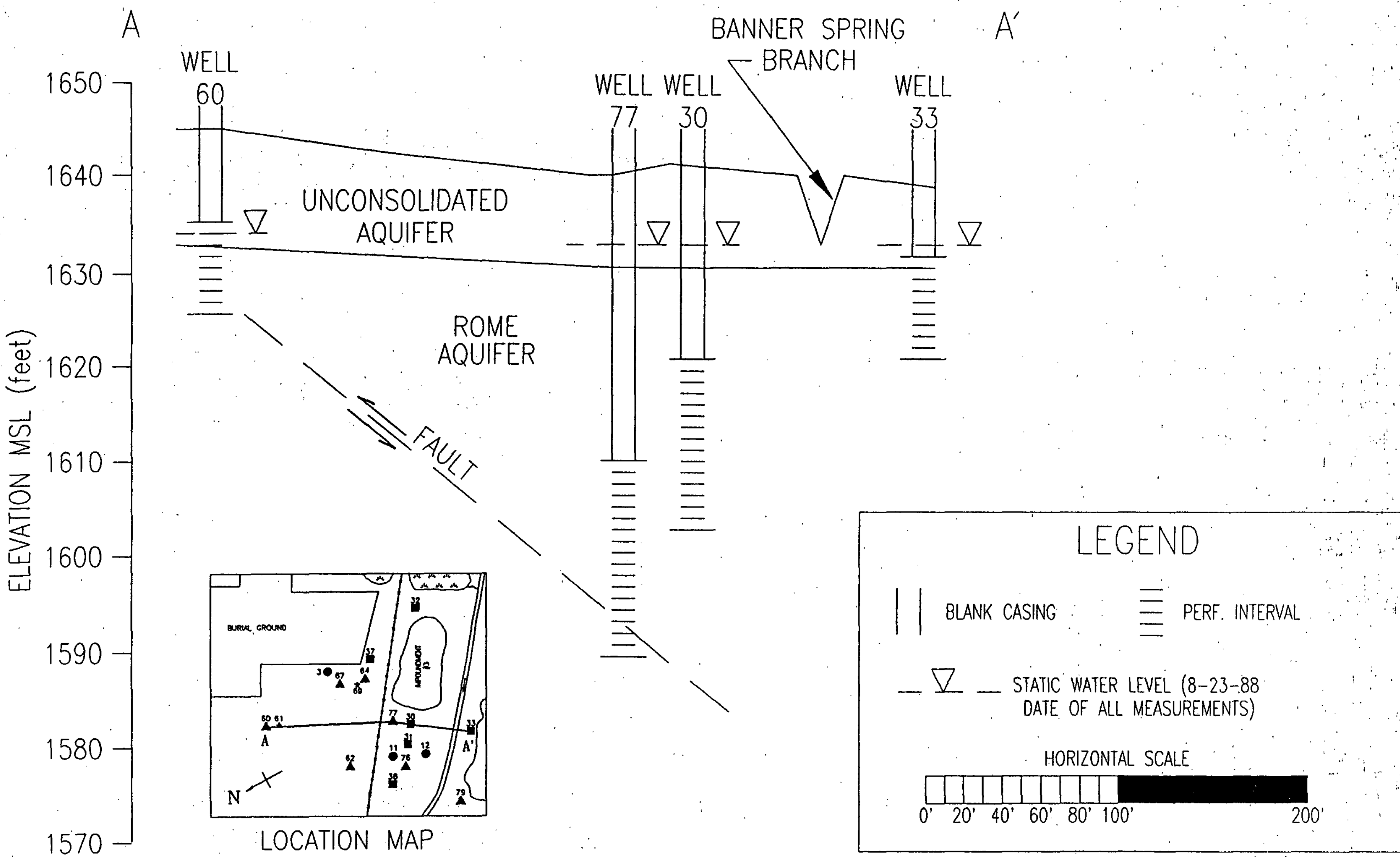


Figure 6-12
Hydrogeologic Section B-B′

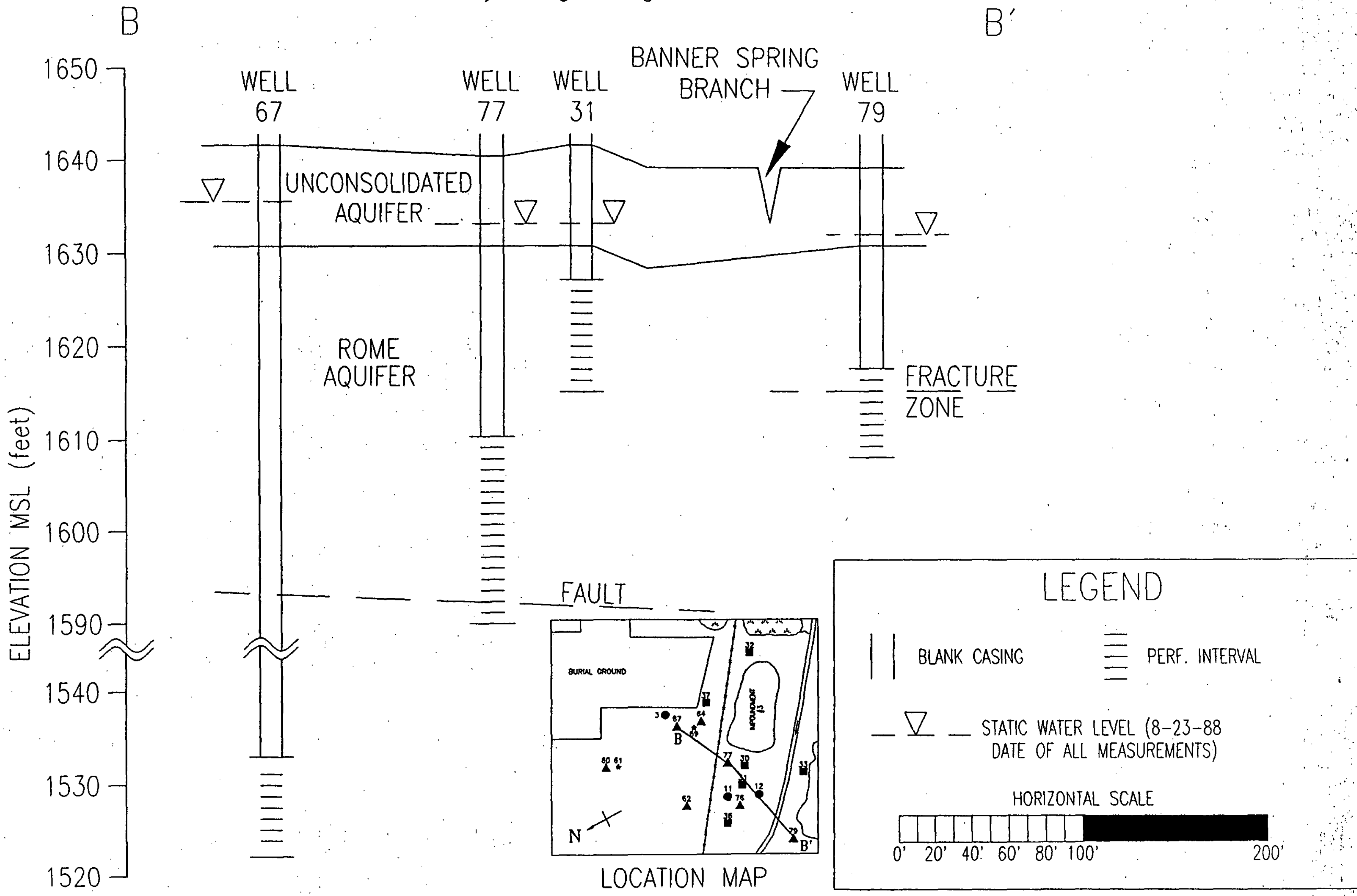
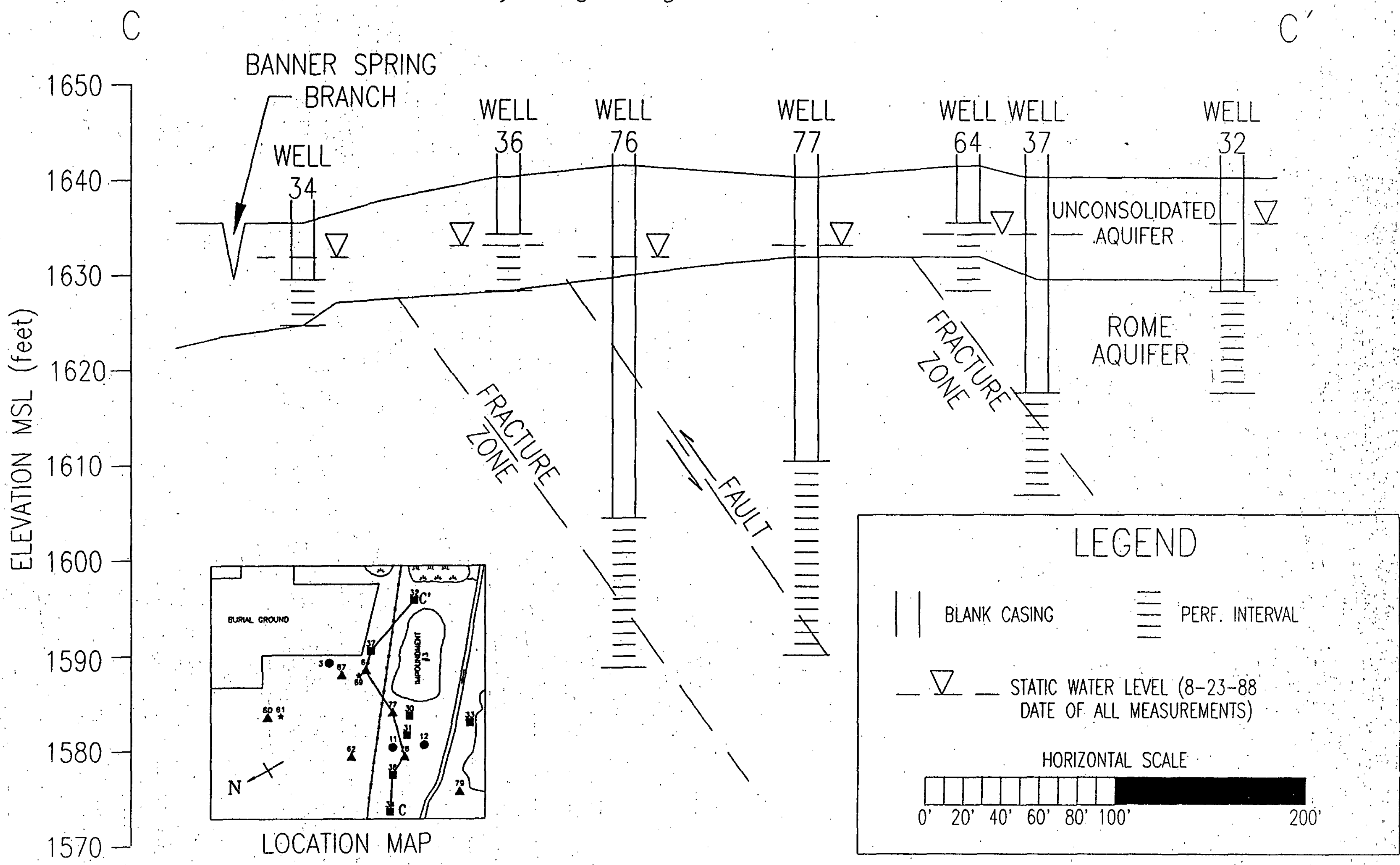
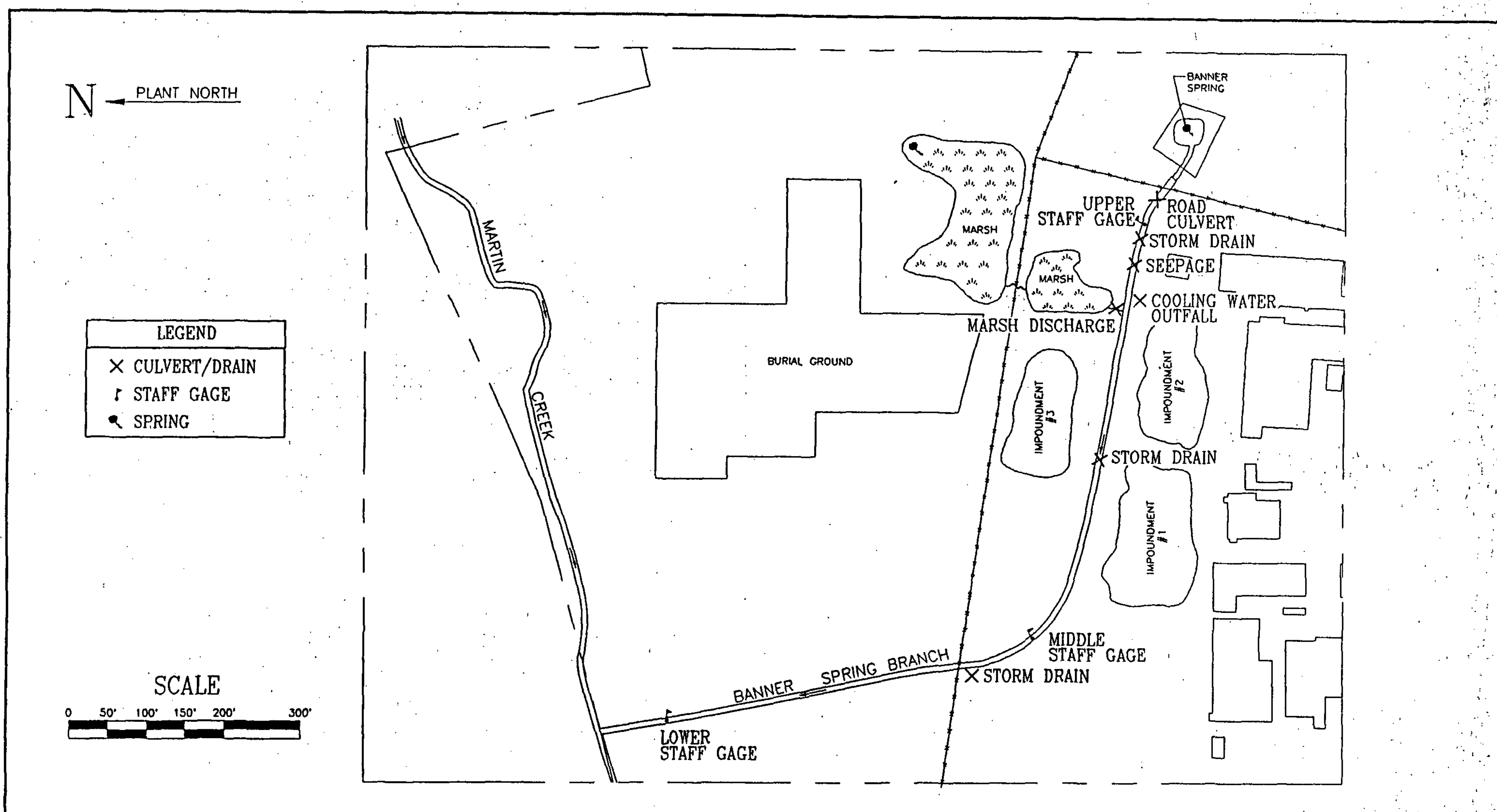


Figure 6-13
Hydrogeologic Section C-C′





REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.
A	10-13-89	ORIGINAL DRAWING	SJT	RAM	JRW

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FIGURE 6-14 – STREAMFLOW MEASUREMENT GAGE LOCATIONS

SCALE	DRAWN BY	DESIGNED BY		DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
SHOWN	STEVEN J. TYLER	ECOTEK		6-17-88	NFS-PONDS	NFOC037	1 OF 1	A

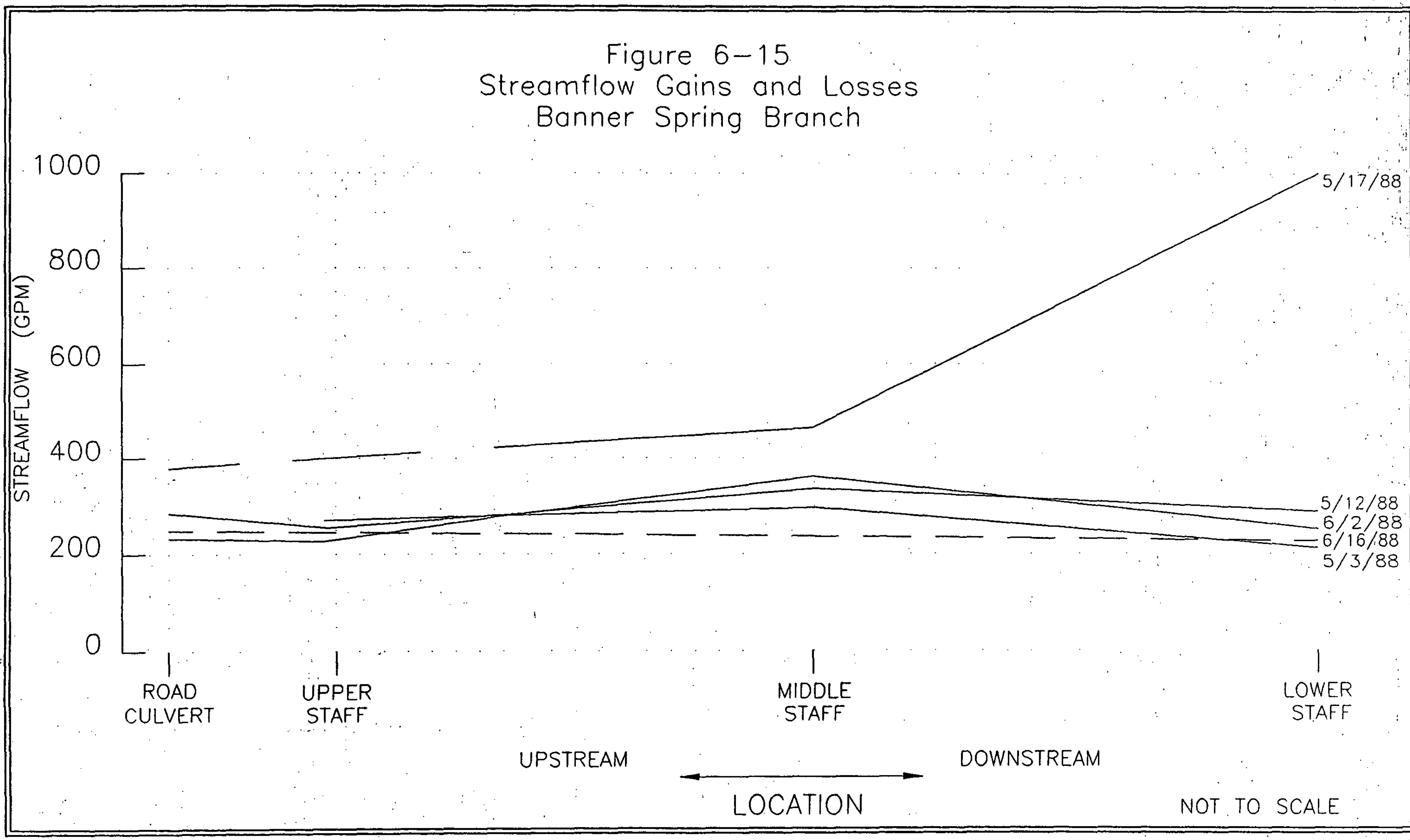


Figure 6-15
Streamflow Gains and Losses
Banner Spring Branch
1000
800
600
400
200
0
STREAMFLOW (GPM)
5/17/88
5/12/88
6/2/88
6/16/88
5/3/88
ROAD CULVERT
UPPER STAFF
MIDDLE STAFF
LOWER STAFF
UPSTREAM
DOWNSTREAM
LOCATION
NOT TO SCALE

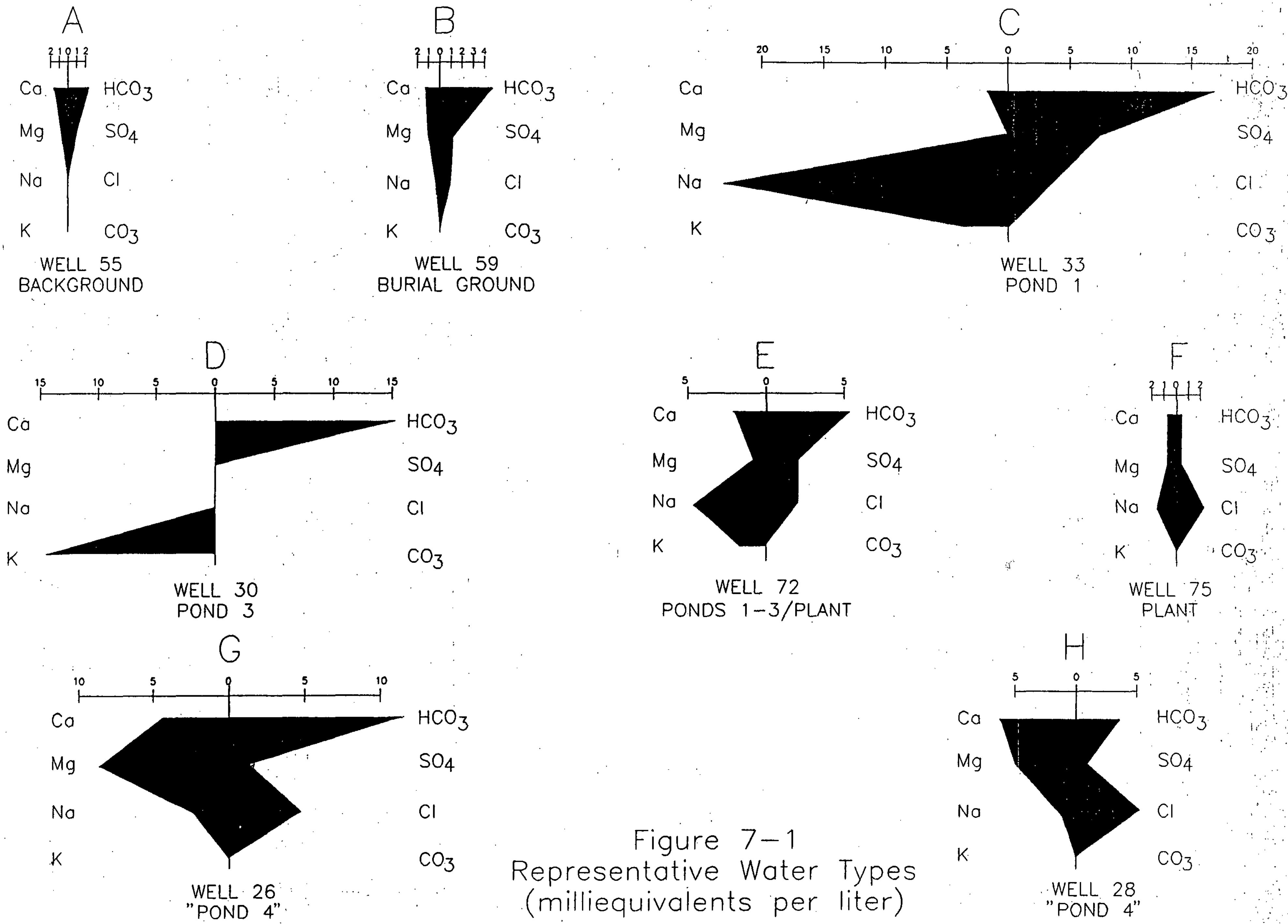
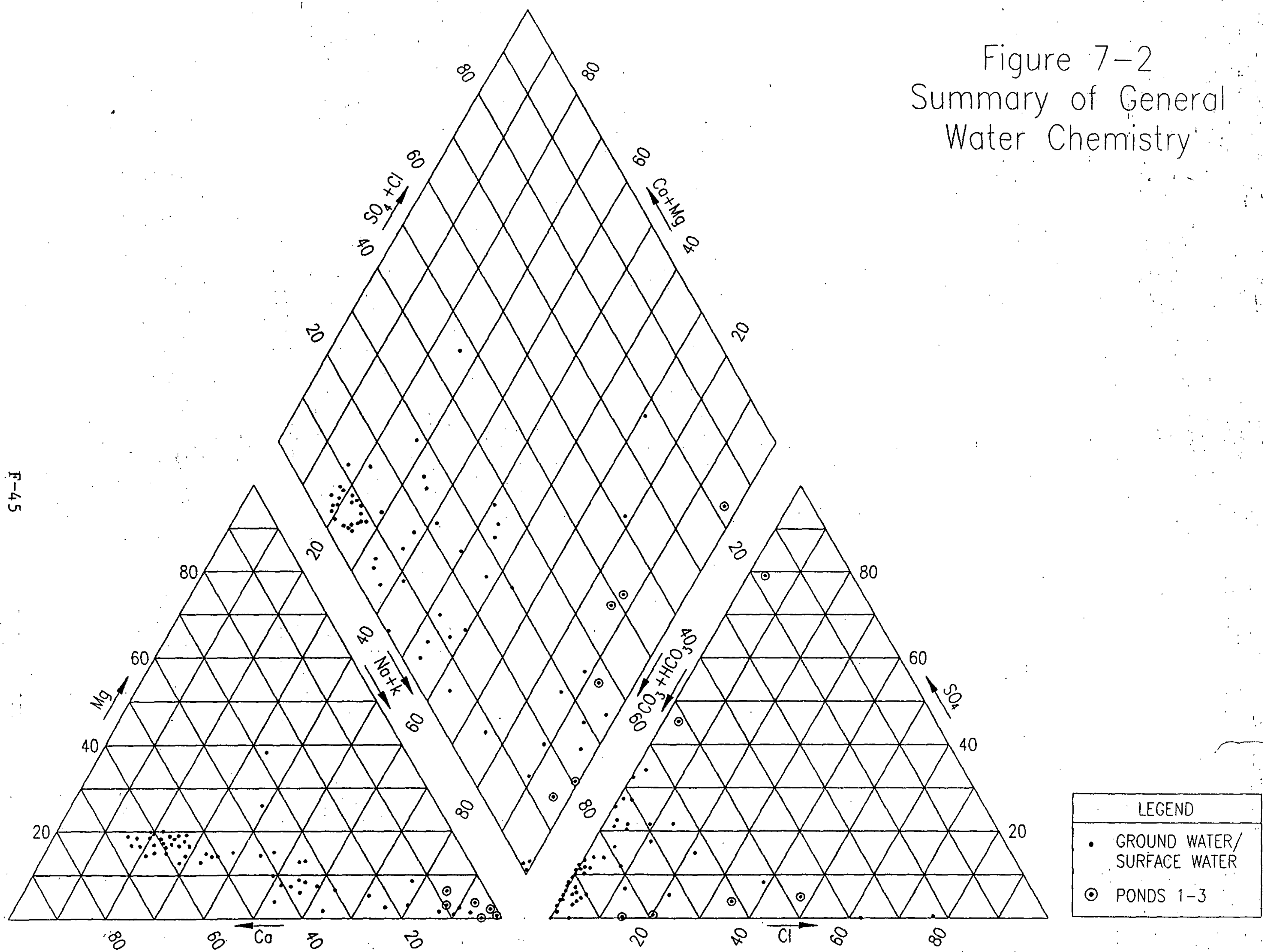
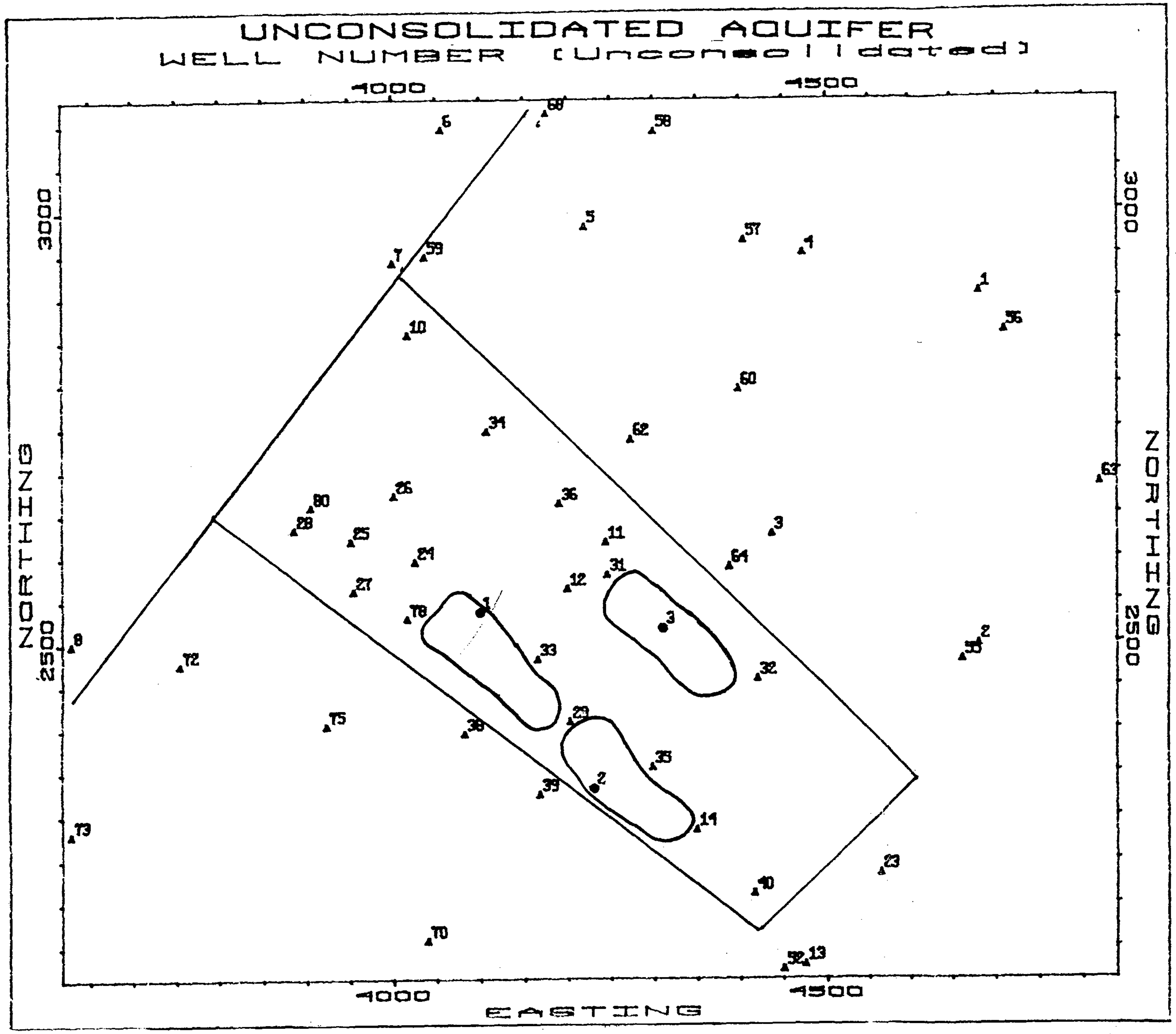
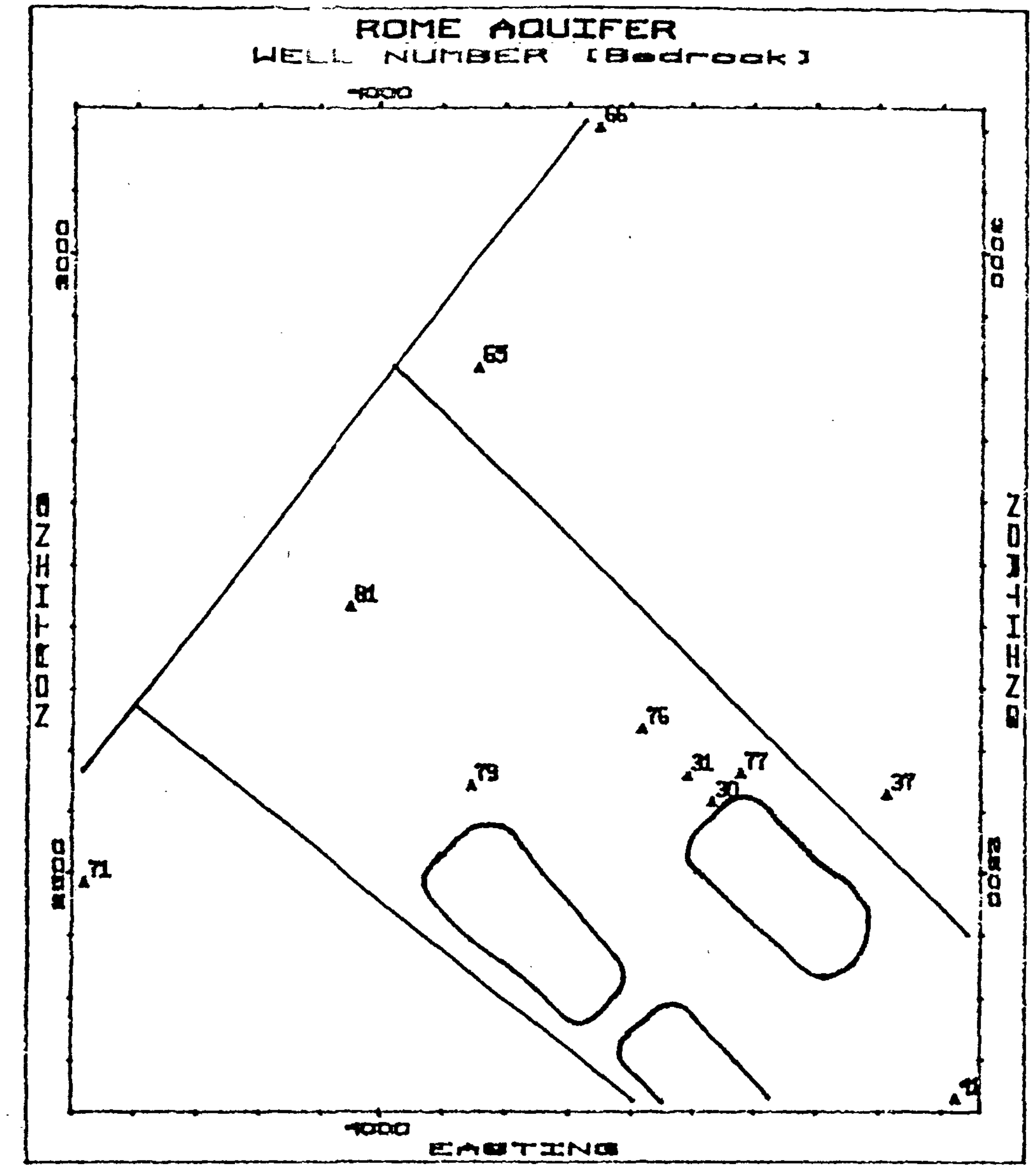


Figure 7-1
Representative Water Types
(milliequivalents per liter)

Figure 7-2
Summary of General
Water Chemistry







EXPLANATION

60 Well location and ID number.

1 Pond sample location and ID number.

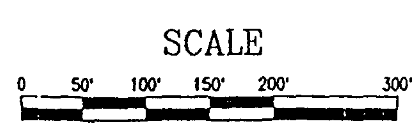
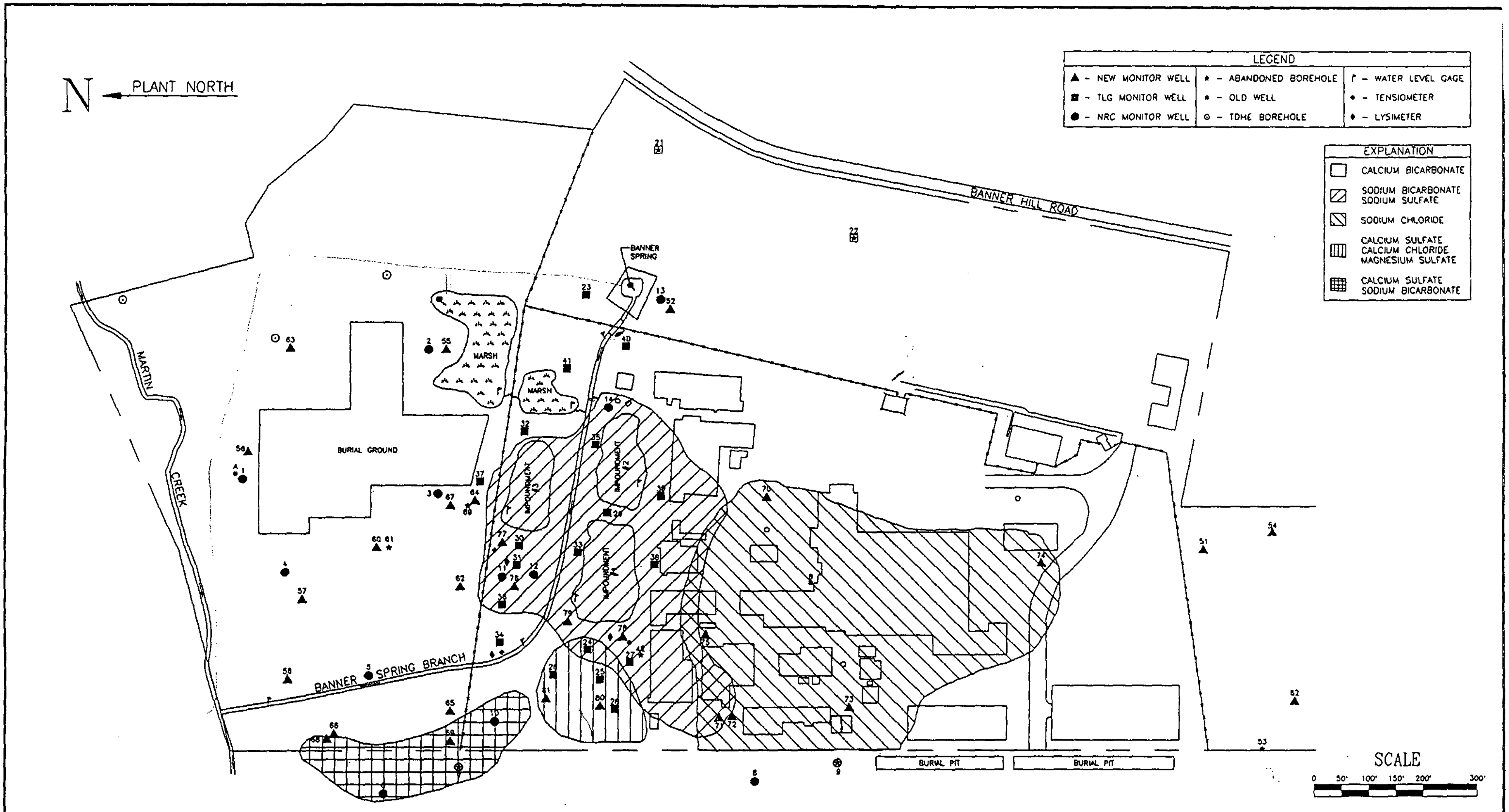


Figure 7-3 Well Locations



A	10-13-89	ORIGINAL DRAWING	PSC	SJT	JRW
REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.

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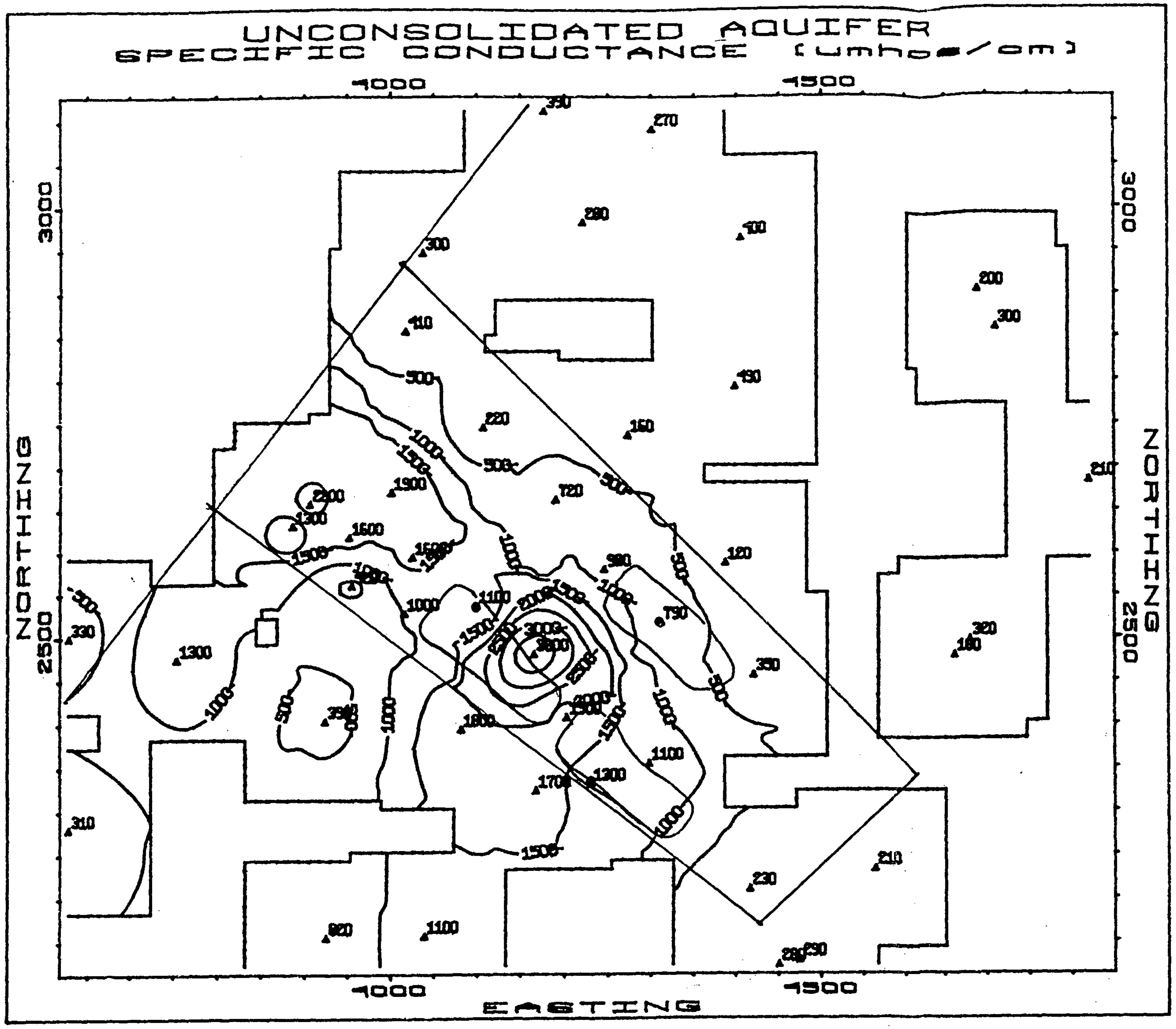
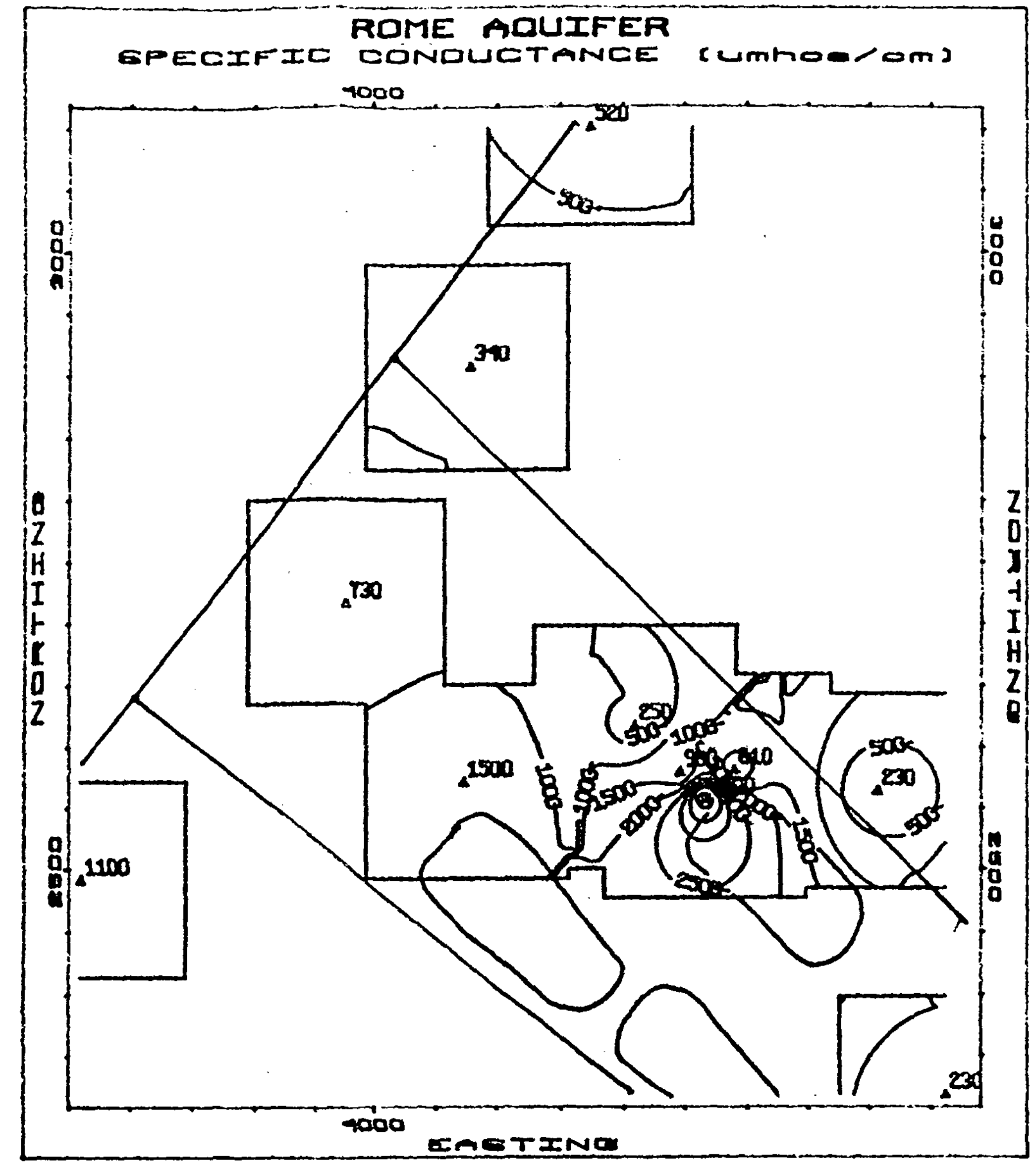
ERWIN, TENNESSEE

FIGURE 7-4 - ESTIMATED DISTRIBUTION OF GENERAL GROUNDWATER CHEMISTRY WATER TYPES

SCALE	DRAWN BY	DESIGNED BY	DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
SHOWN	PAT CHAPPELL	ECOTEK	7-12-89	NFS-PONDS	NFOC035	1 OF 1	A





SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

—— 1000 ——

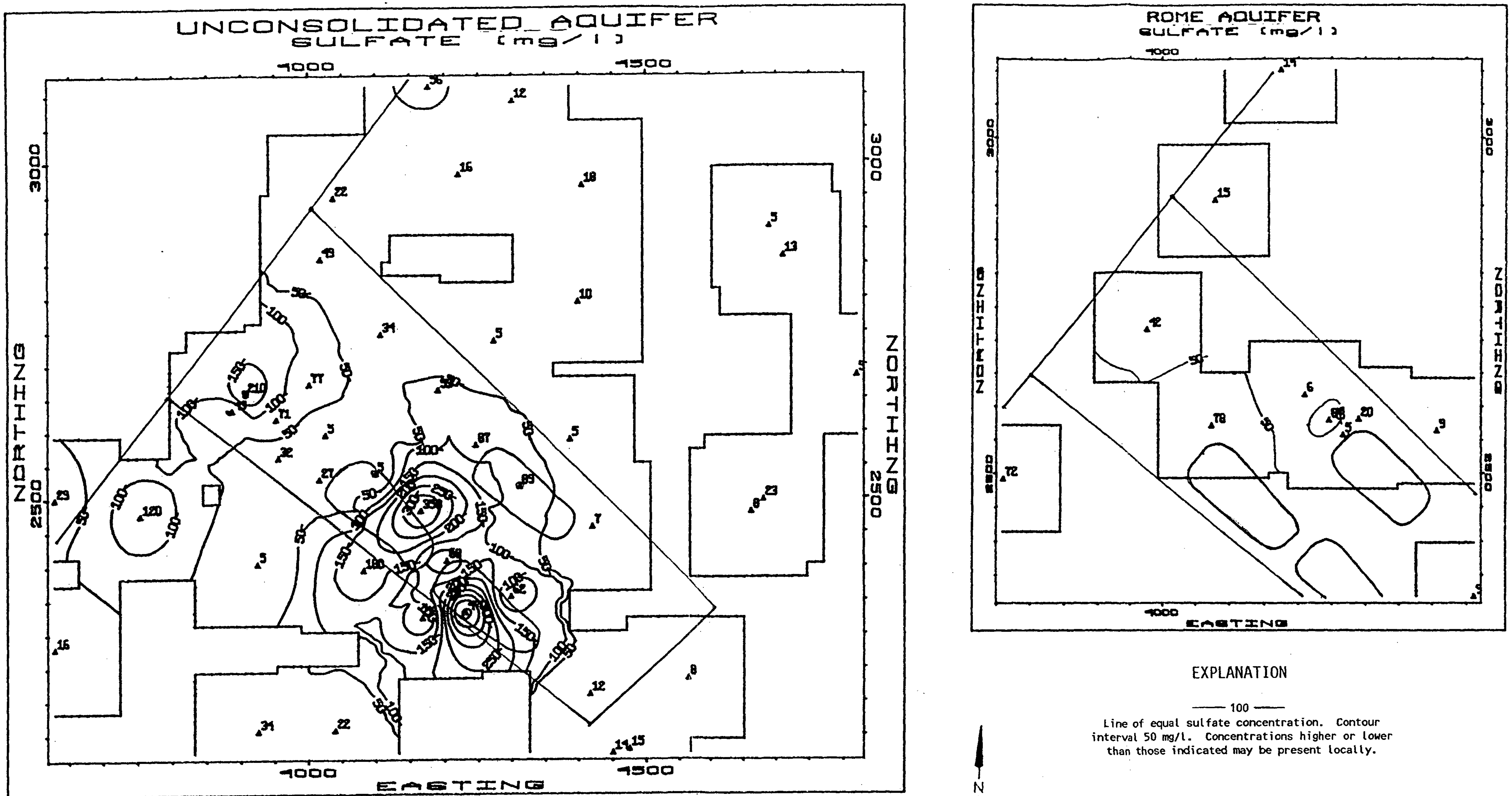
Line of equal specific conductance. Contour interval 500 micromhos per centimeter at 25° C. Conductance higher or lower than those indicted may be present locally.

Δ400.0 Well location. Number is concentration.

•1300 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-5 Specific Conductance of Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)



EXPLANATION

—— 100 ——

Line of equal sulfate concentration. Contour interval 50 mg/l. Concentrations higher or lower than those indicated may be present locally.

▲34 Well location. Number is concentration.

●89 Pond sample location. Number is concentration.

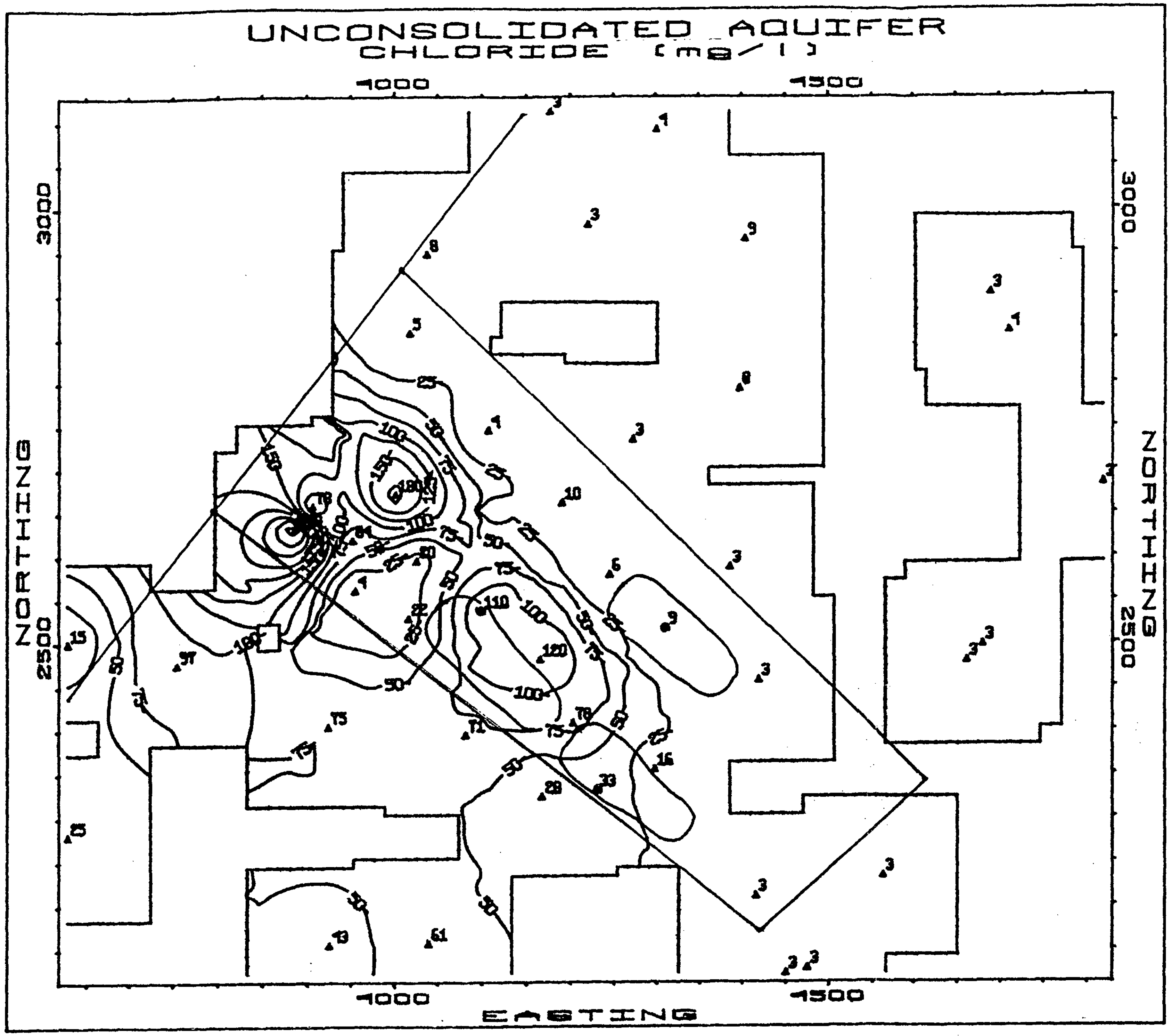
Area of low confidence based on lack of control points

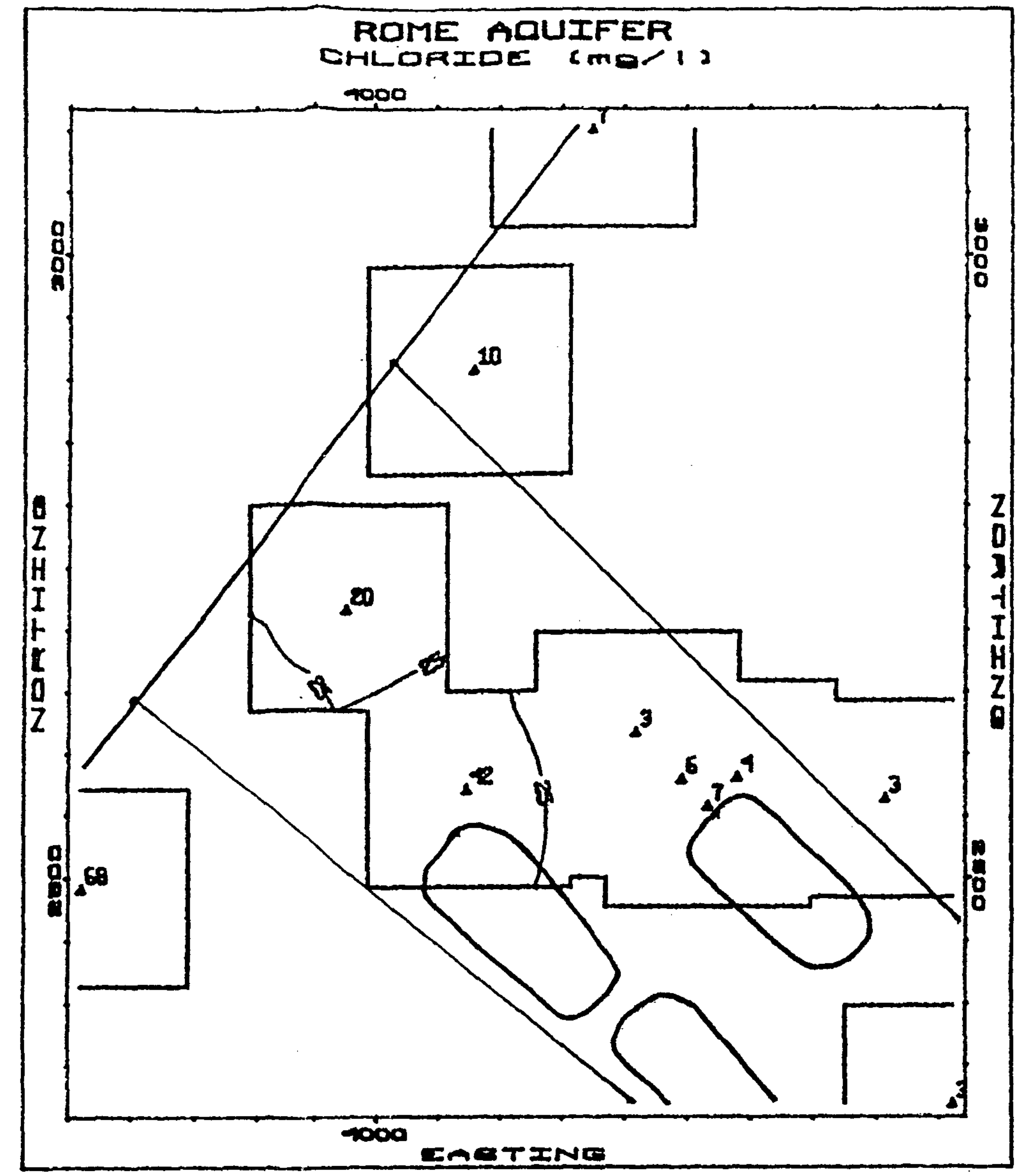
N

SCALE

0 50' 100' 150' 200' 300'

Figure 7-6 Concentration of Sulfate in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

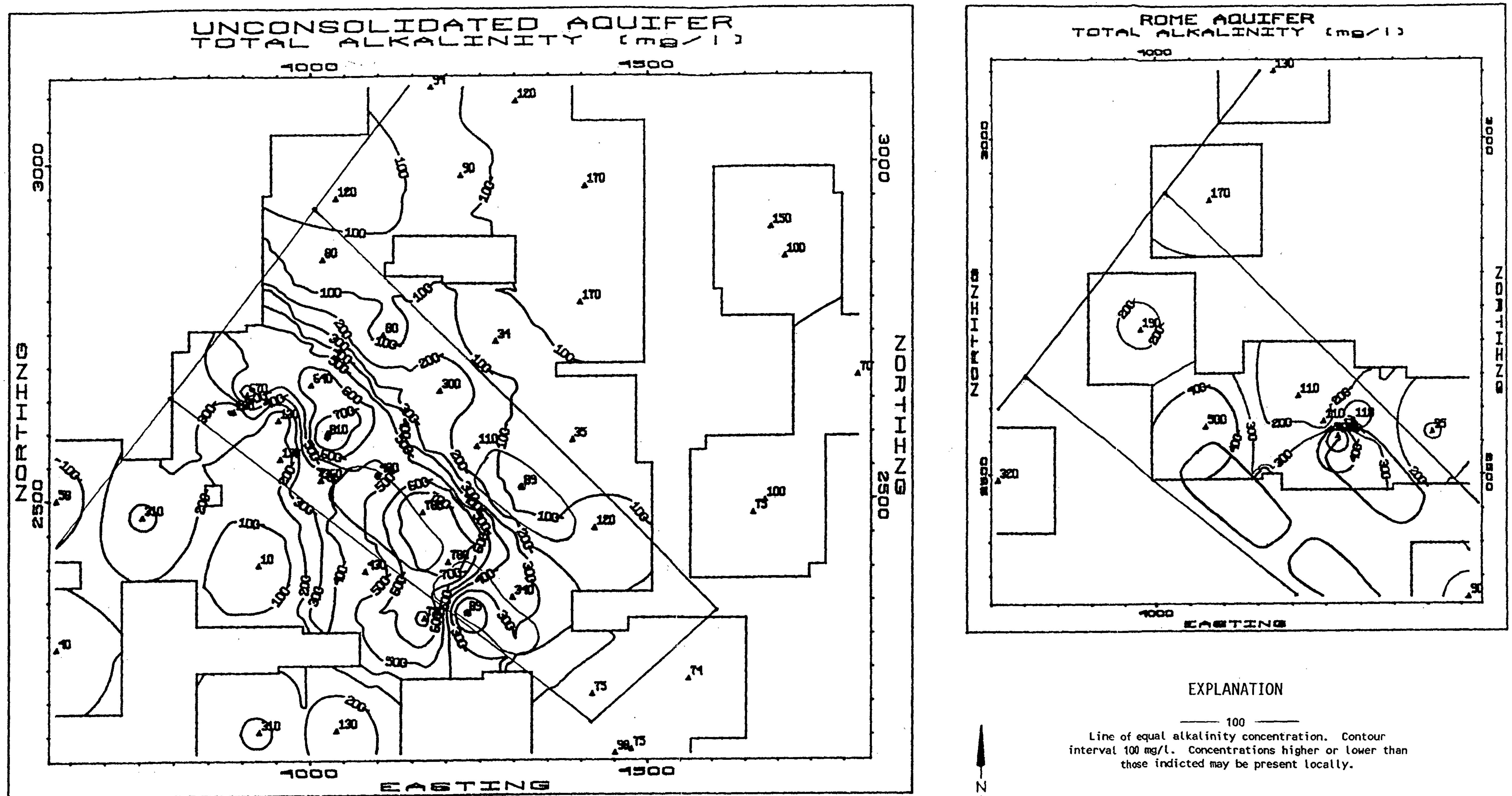
——— 100 ———
Line of equal chloride concentration. Contour interval 25 mg/l. Concentrations higher or lower than those indicated may be present locally.

▲10 Well location. Number is concentration. Value of 3 may indicate less than detection limit.

•9 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-7 Concentration of Chloride in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)



SCALE

0 50' 100' 150' 200' 300'

EXPLANATION

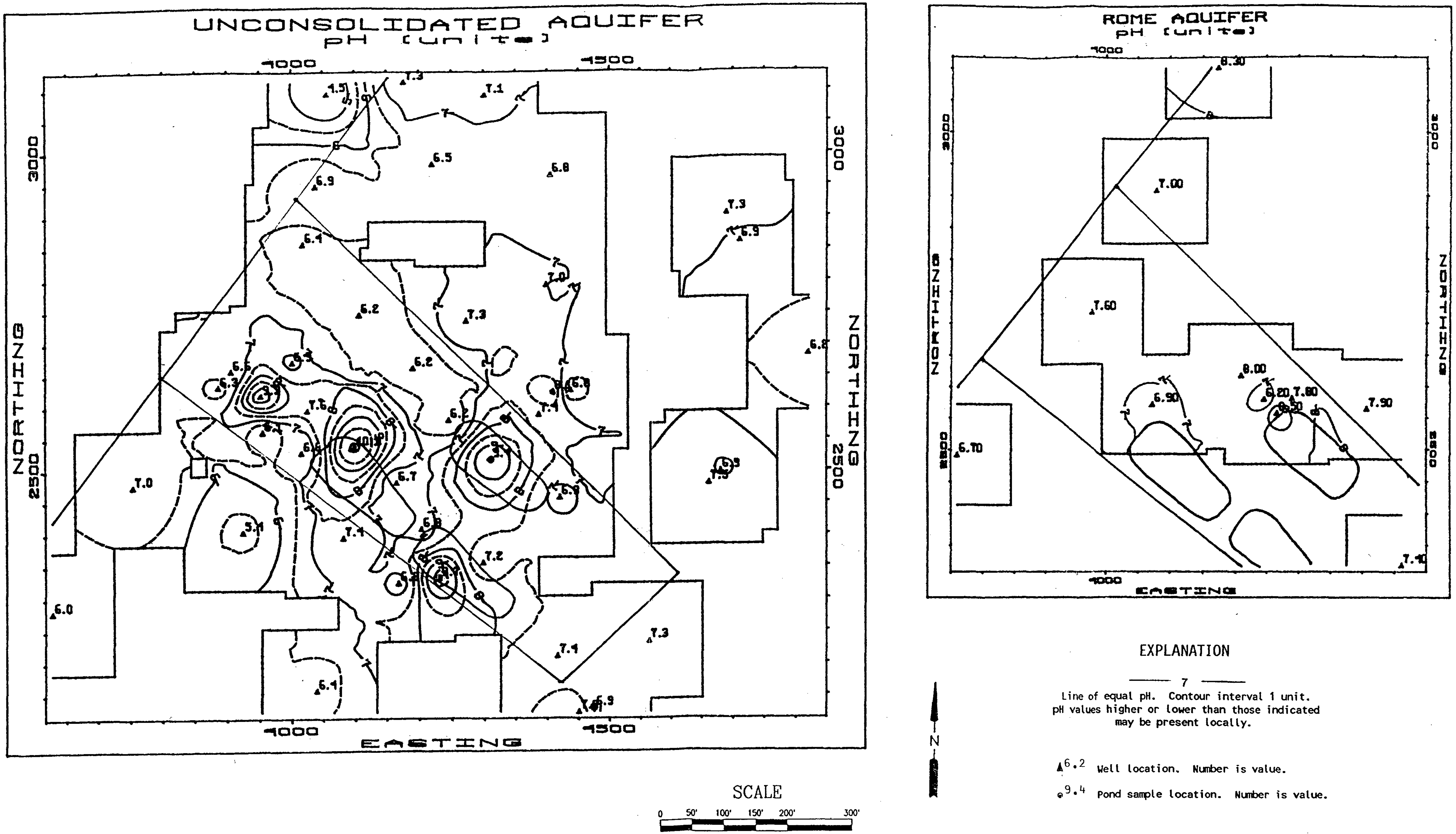
—— 100 ——
Line of equal alkalinity concentration. Contour interval 100 mg/l. Concentrations higher or lower than those indicted may be present locally.

▲110 Well location. Number is concentration.

●89 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-8 Concentration of Carbonate Alkalinity in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)



EXPLANATION

——— 7 ———

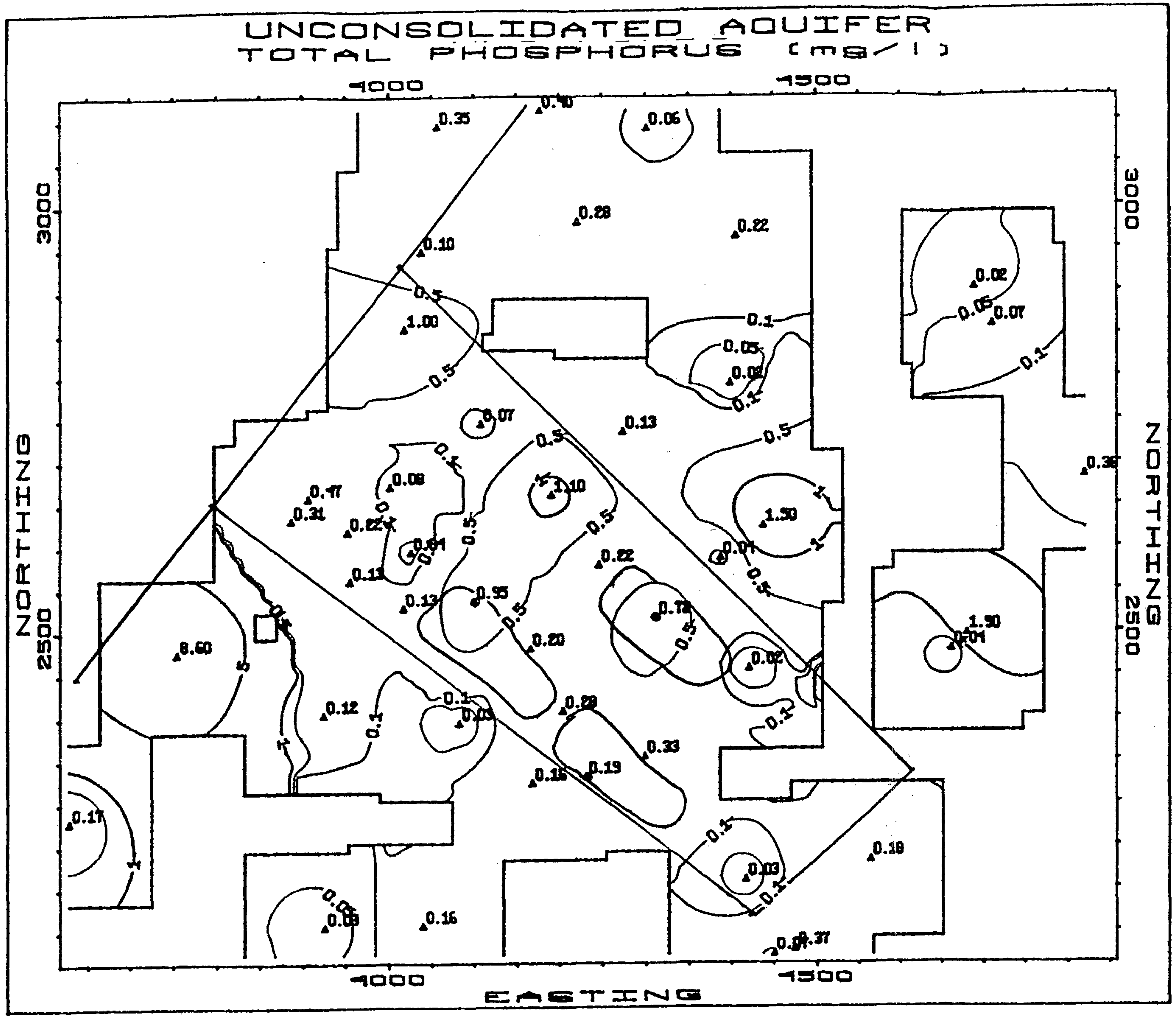
Line of equal pH. Contour interval 1 unit. pH values higher or lower than those indicated may be present locally.

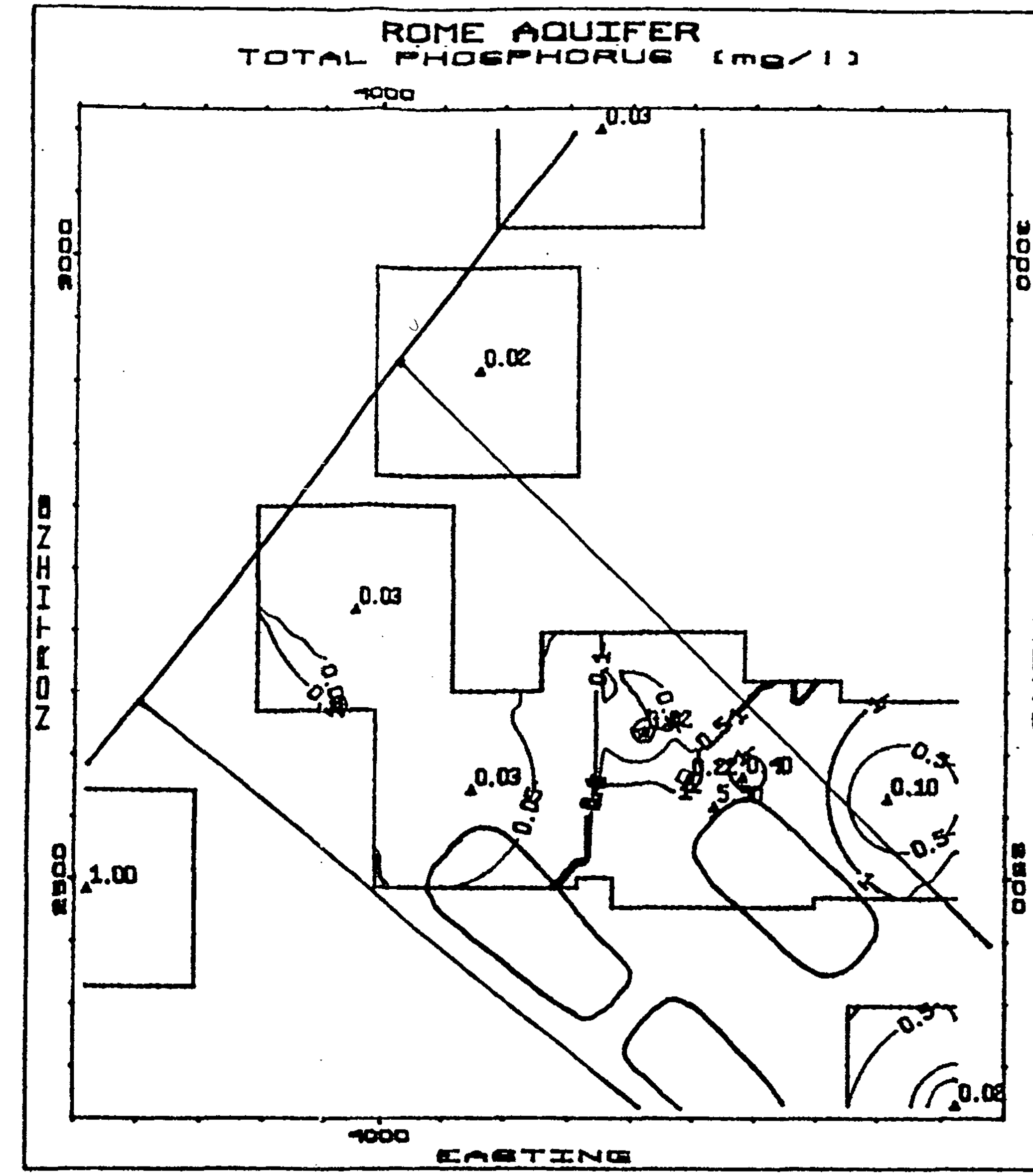
▲6.2 Well location. Number is value.

◦9.4 Pond sample location. Number is value.

Area of low confidence based on lack of control points

Figure 7-9 pH of Water from Wells in Unconsolidated and Rome Aquifers (July- August 1988)





SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

——— 1 ———

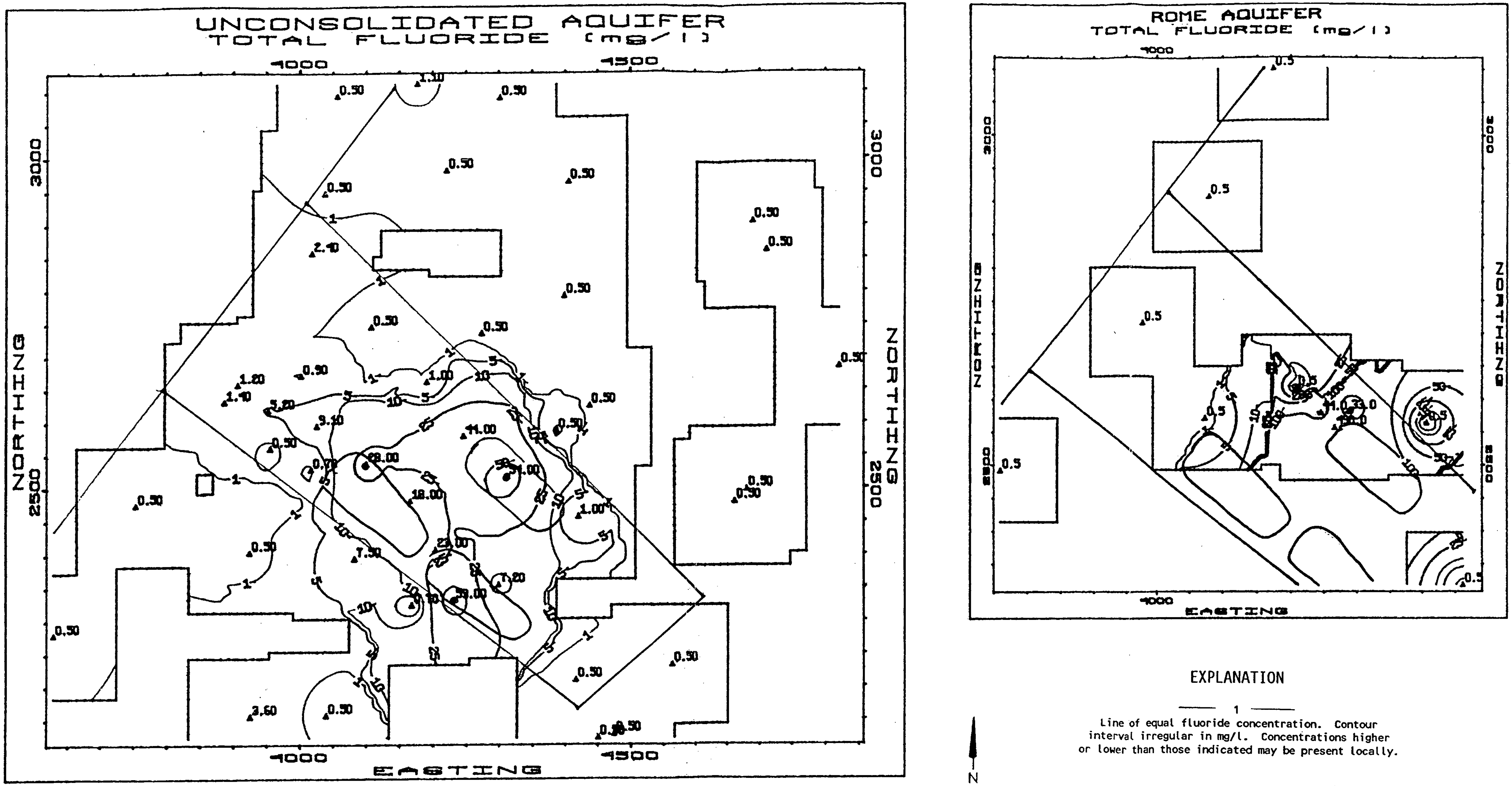
Line of equal phosphorus concentration. contour interval irregular in mg/l. Concentrations higher or lower than those indicated may be present locally.

▲0.16 Well location. Number is concentration.

●0.95 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-10 Concentration of Phosphorus in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)



SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

1

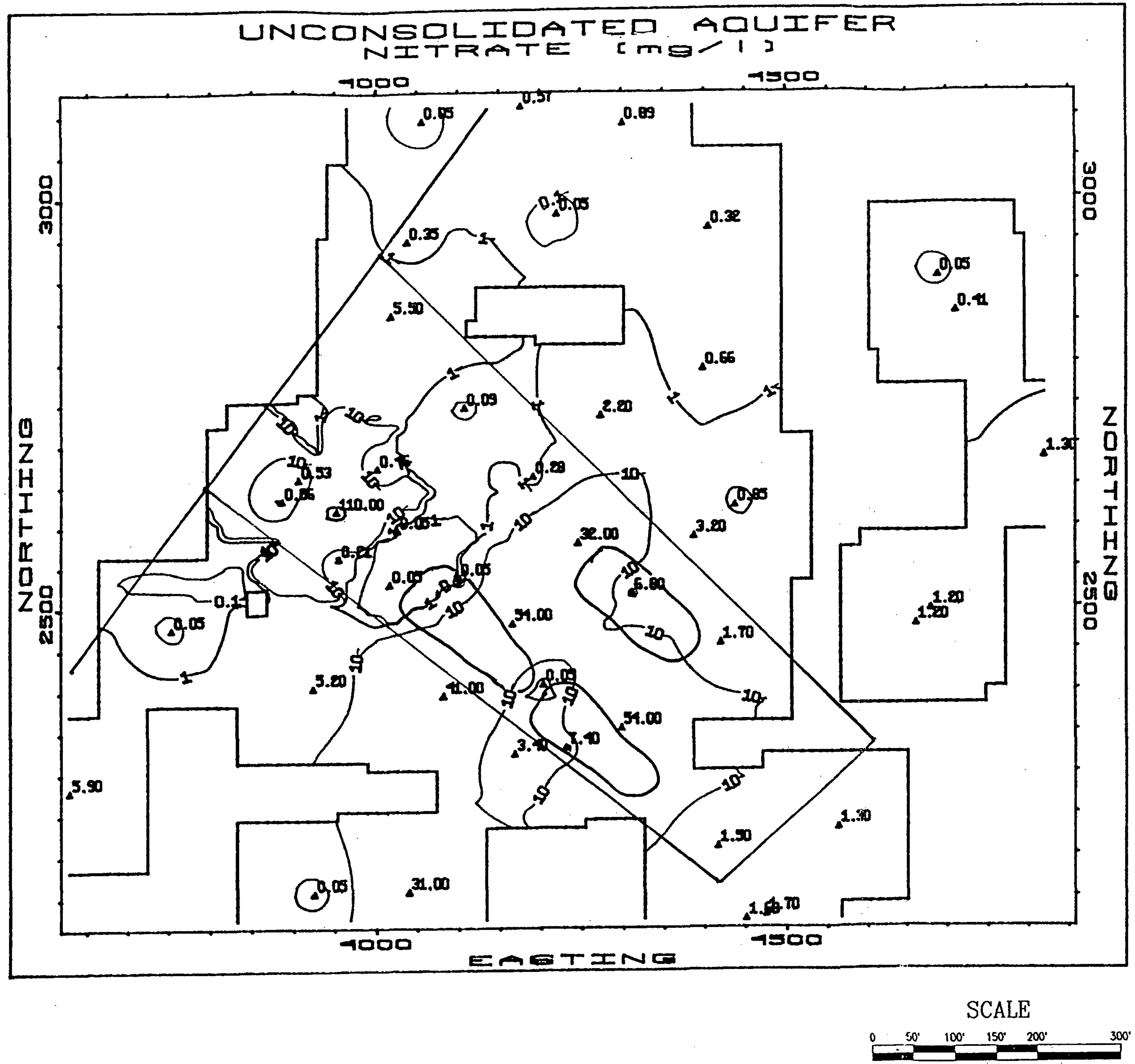
Line of equal fluoride concentration. Contour interval irregular in mg/l. Concentrations higher or lower than those indicated may be present locally.

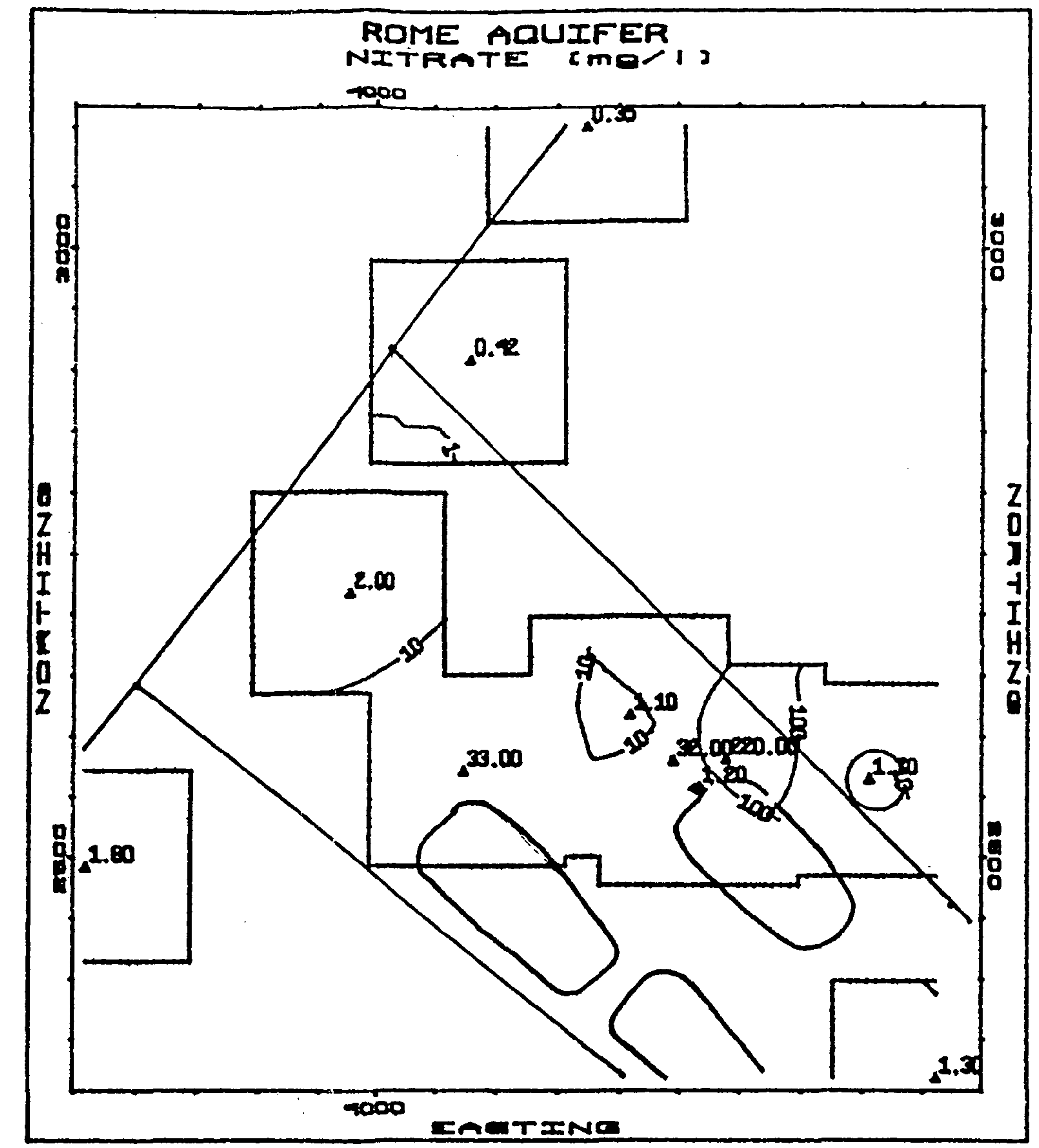
▲0.90 Well location. Number is concentration. Value of 0.50 may indicate less than detection limit.

•28.0 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-11 Concentration of Fluoride in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





EXPLANATION

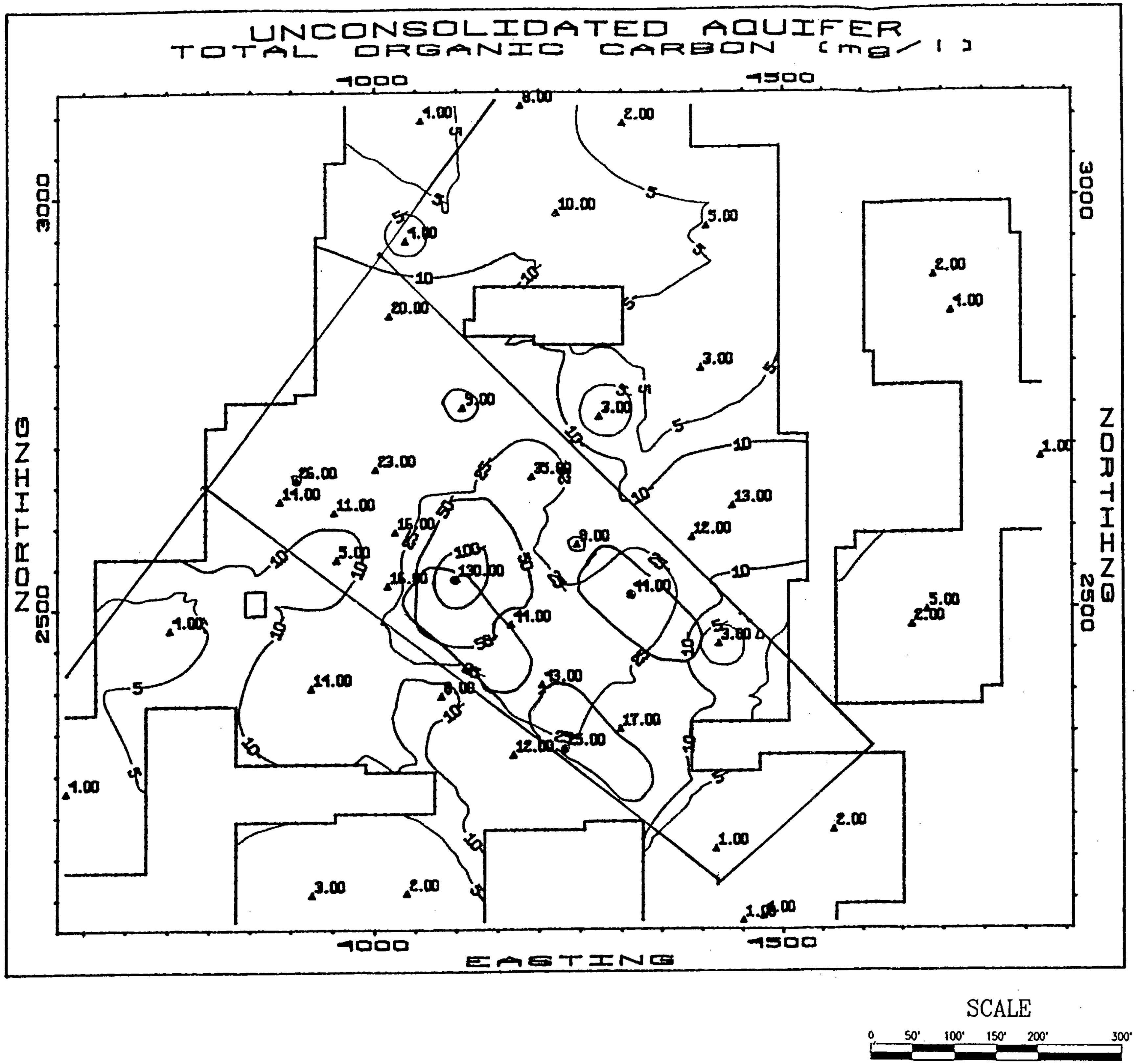
——— 1 ———
Line of equal nitrate concentration. Contour interval irregular in mg/l. Concentrations higher or lower than those indicated may be present locally.

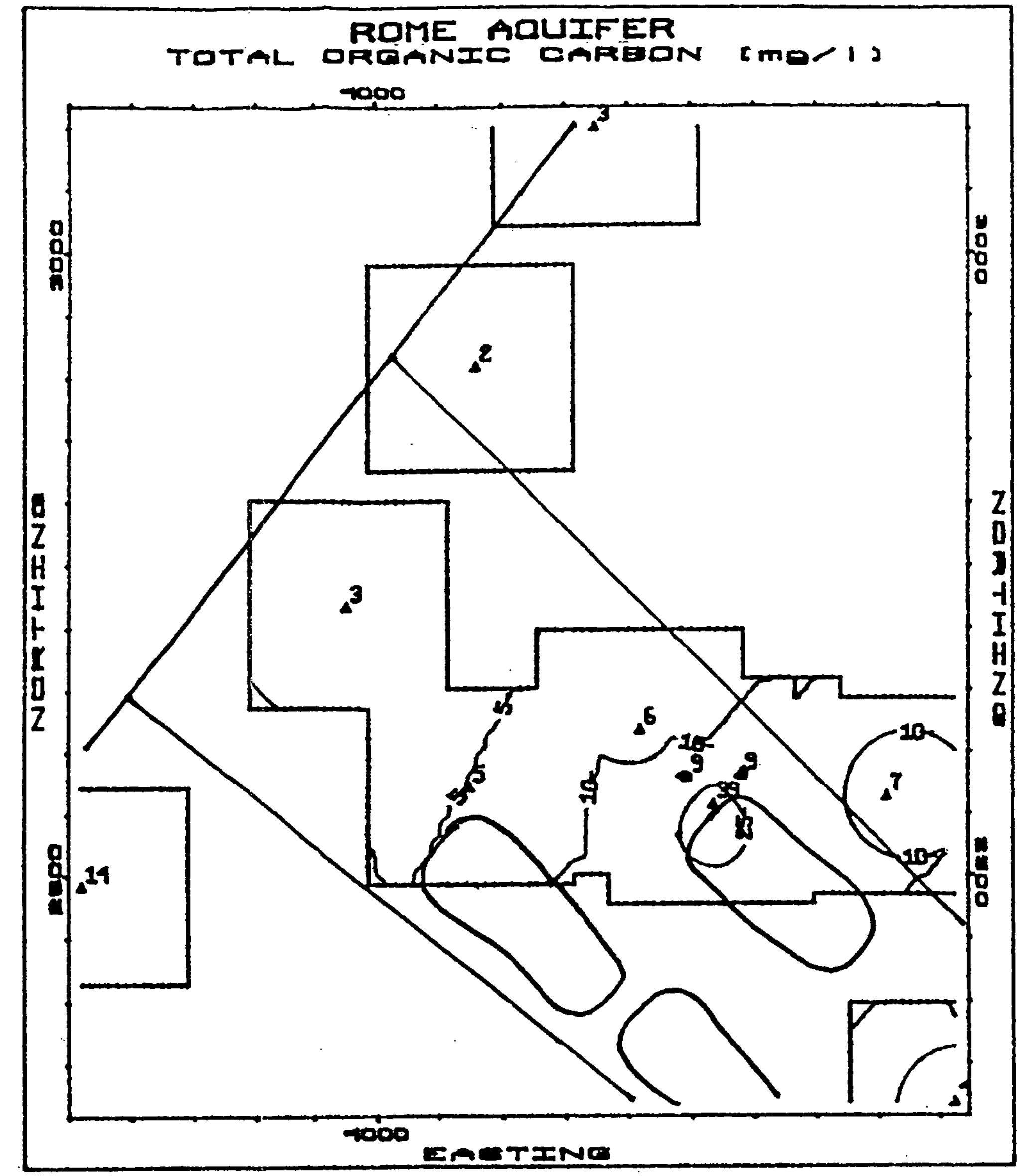
▲2.20 Well location. Number is concentration. Value of 0.05 may indicate less than detection limit.

•6.80 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-12 Concentrations of Nitrate in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





EXPLANATION

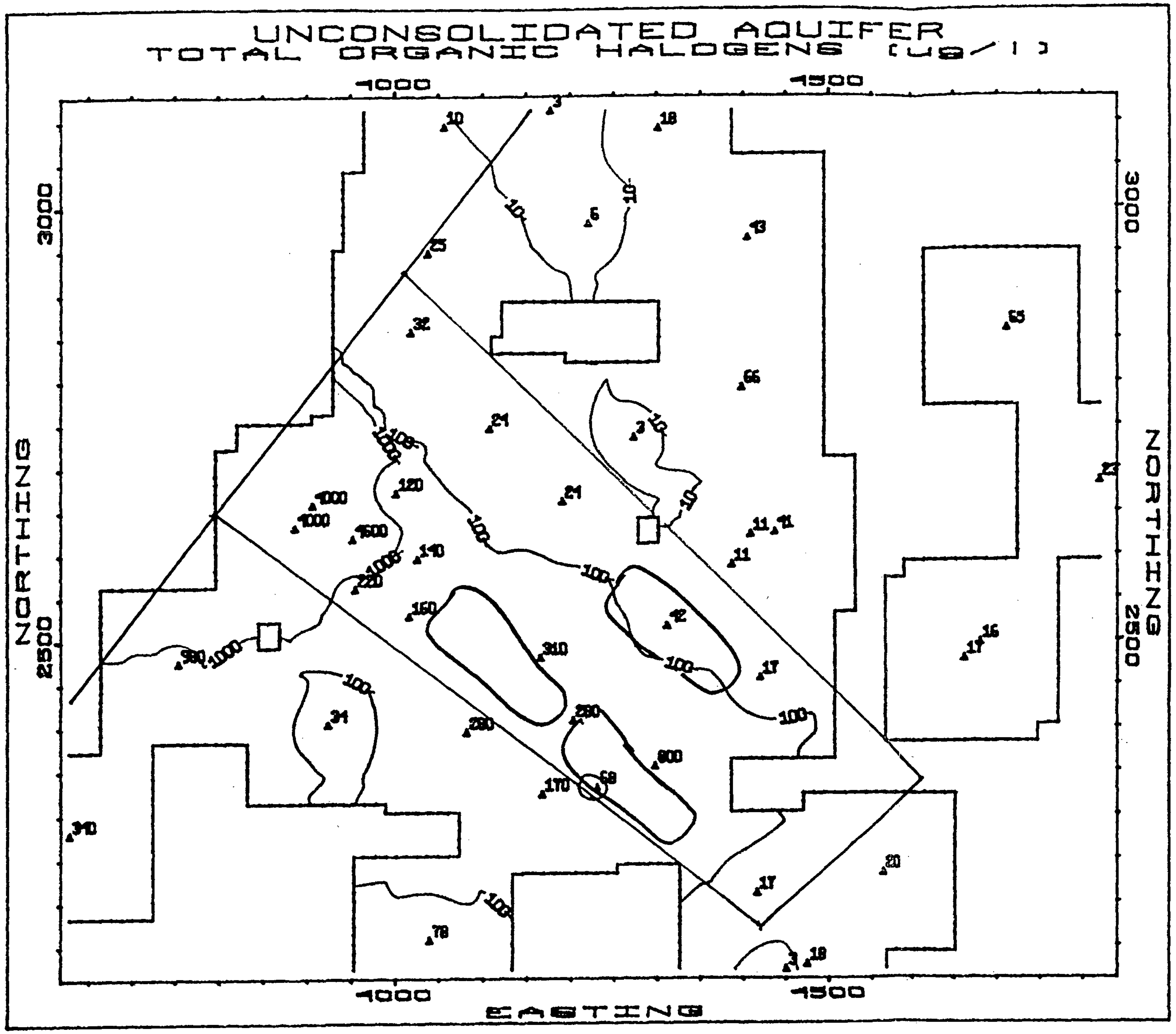
——— 10 ———
Line of equal total organic carbon concentration. Contour interval irregular in mg/l. Concentrations higher or lower than those indicated may be present locally.

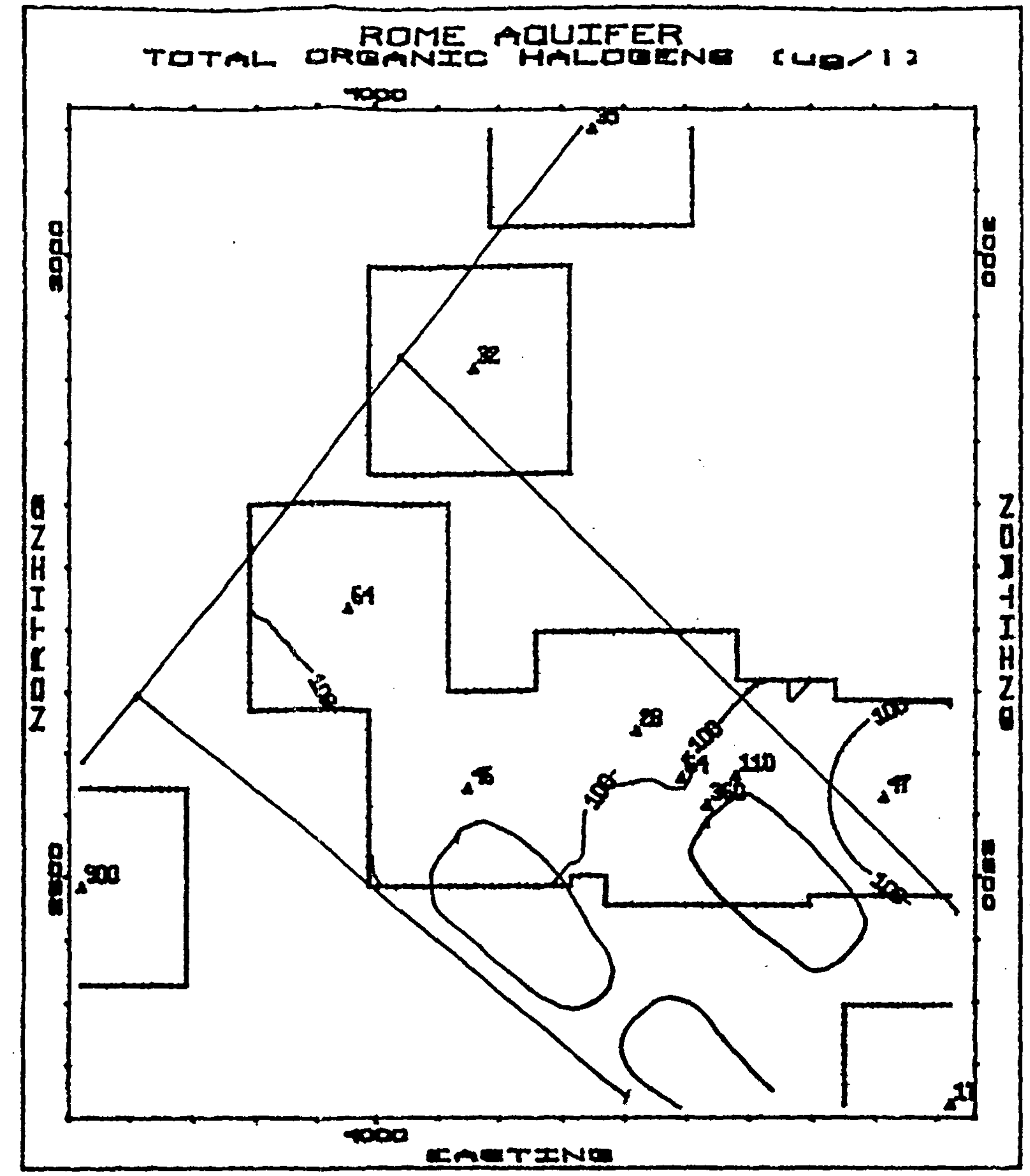
▲9.00 Well location. Number is concentration.

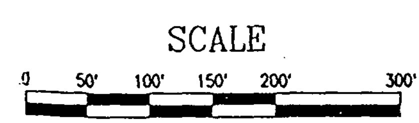
•44.00 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-13 Total Organic Carbon in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)







N

EXPLANATION

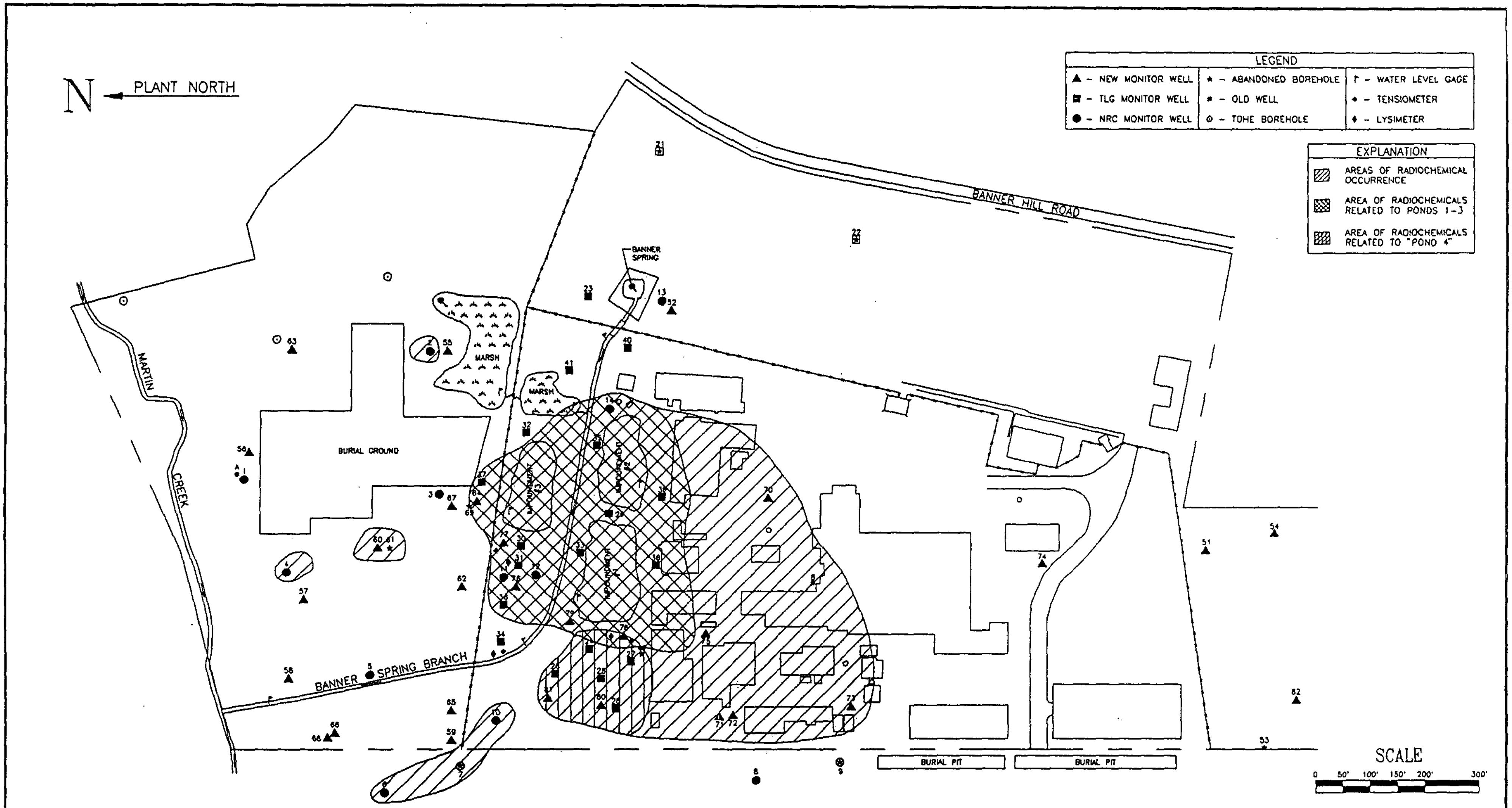
—— 100 ——
Line of equal total organic halogens. Contour interval irregular in ug/l. Concentrations higher or lower than those indicated may be present locally.

▲310 Well location. Number is concentration.

●68 Pond sample location. Number is concentration. Data for Pond 1 not available. Value of 3 may indicate less than detection limit.

Area of low confidence based on lack of control points

Figure 7-14 Total Organic Halogens in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)



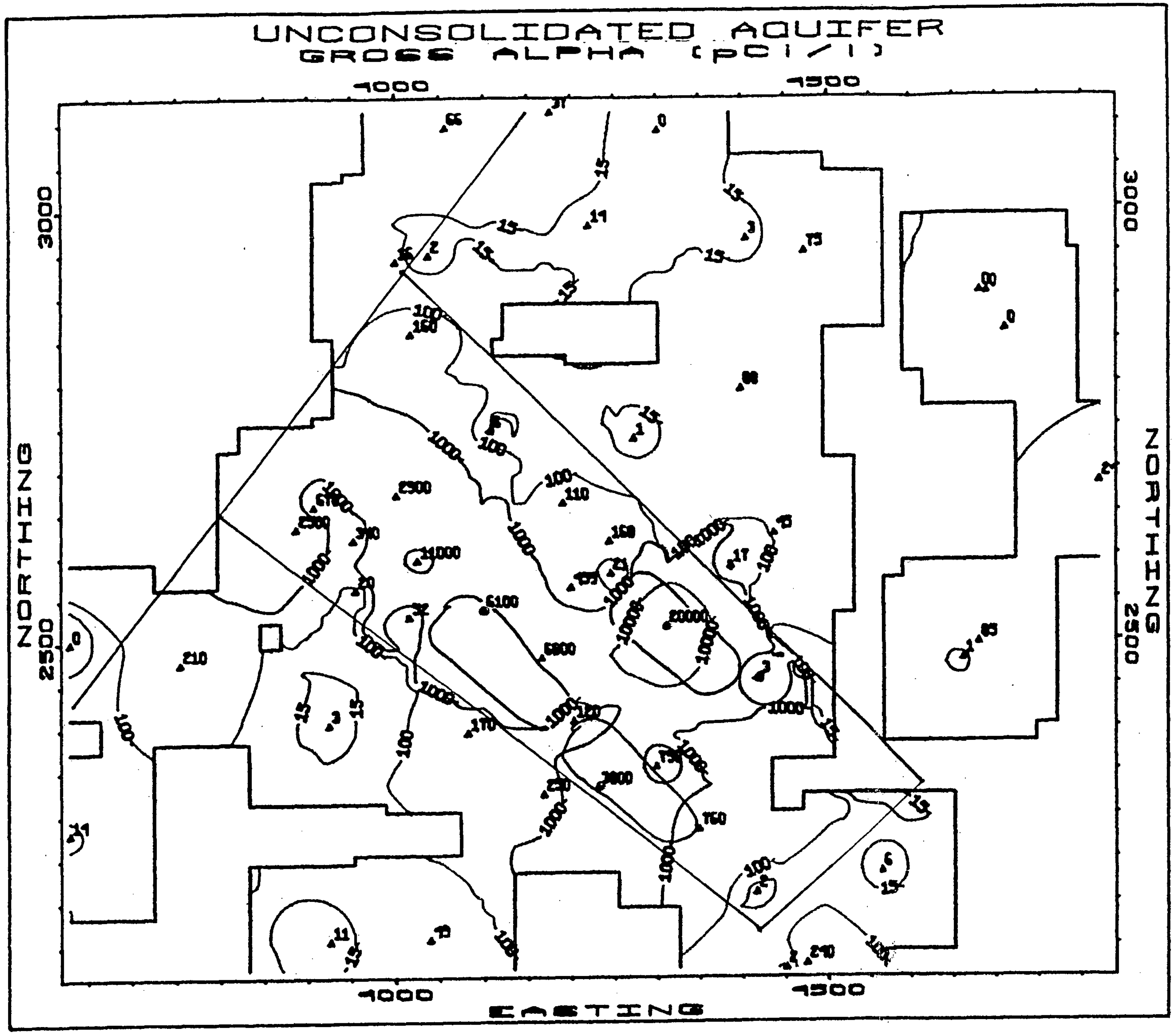
REV.	DATE	DESCRIPTION	BY	CHK'D	APPV.
A	10-13-89	ORIGINAL DRAWING	PSC	SJT	JRW

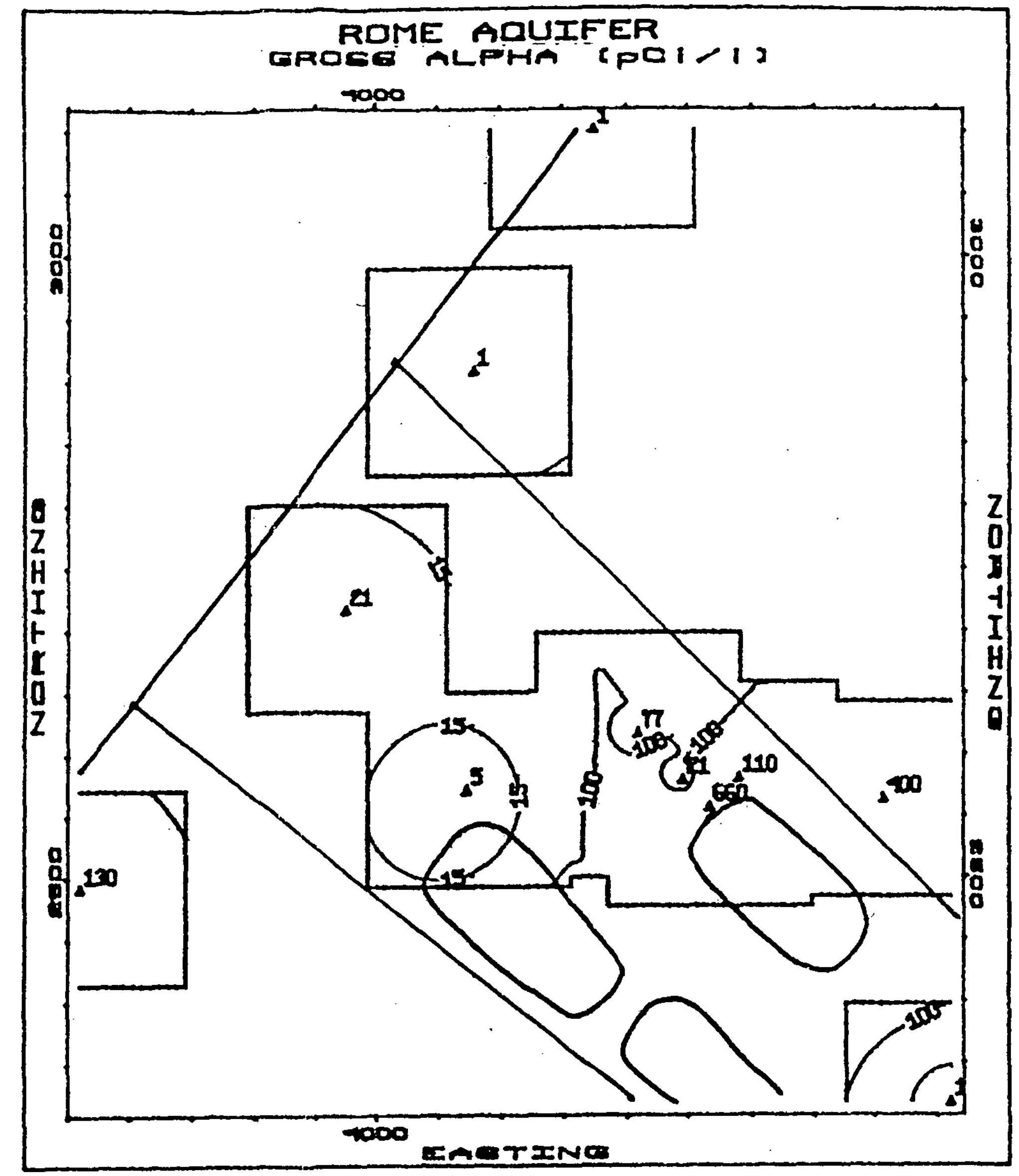
EcoTek NFS

ECOTEK, INC.
NFS PONDS PROJECT
ERWIN, TENNESSEE

FIGURE 7-15 – ESTIMATED DISTRIBUTION OF RADIOCHEMICALS IN GROUNDWATER

SCALE	DRAWN BY	DESIGNED BY	DATE	JOB NO.	DRAWING NO.	SHEET NO.	REVISION
SHOWN	PAT CHAPPELL	ECOTEK	7-12-89	NFS-PONDS	NFOC036	1 OF 1	A





SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

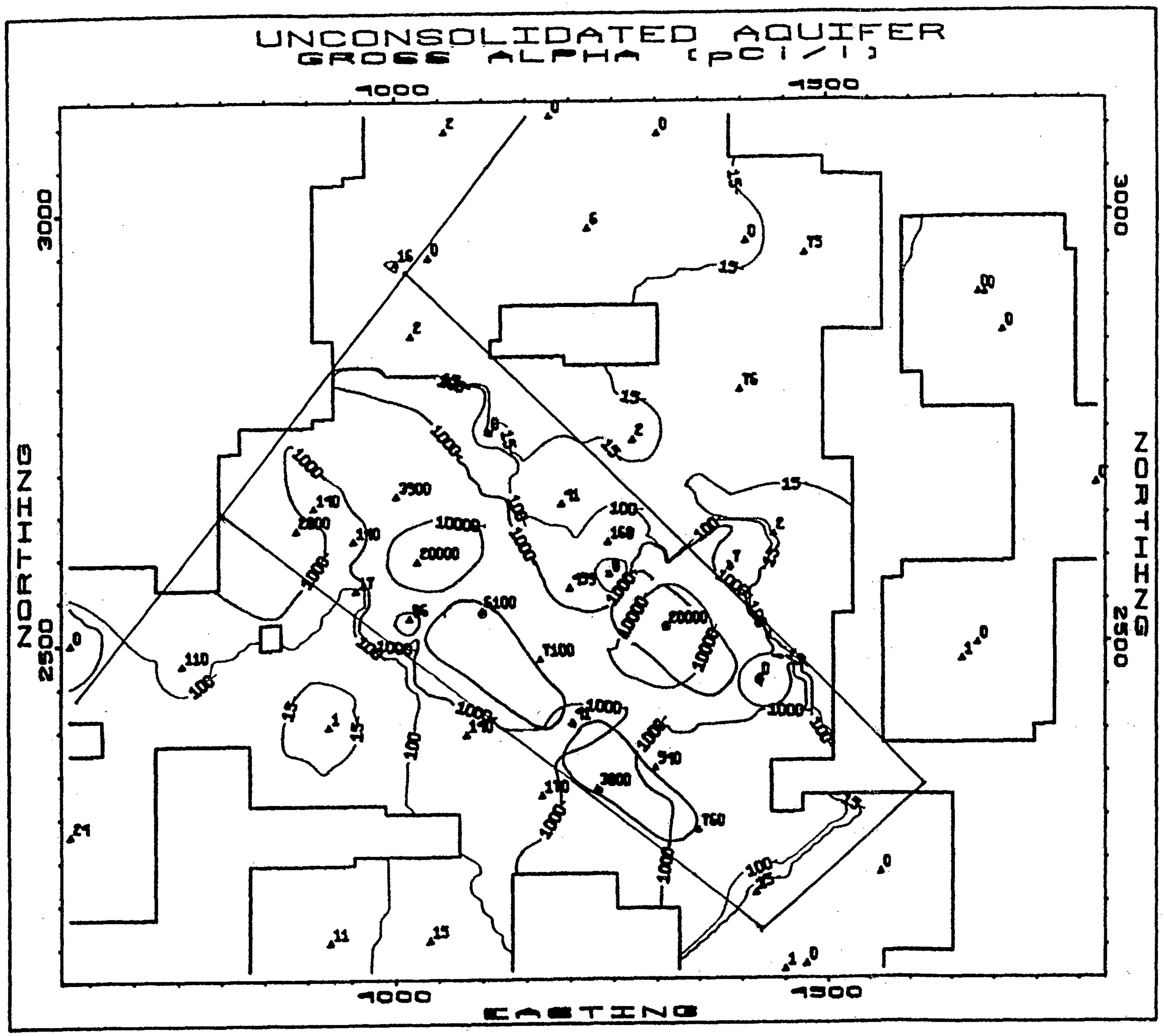
—— 100 ——
Line of equal gross alpha concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

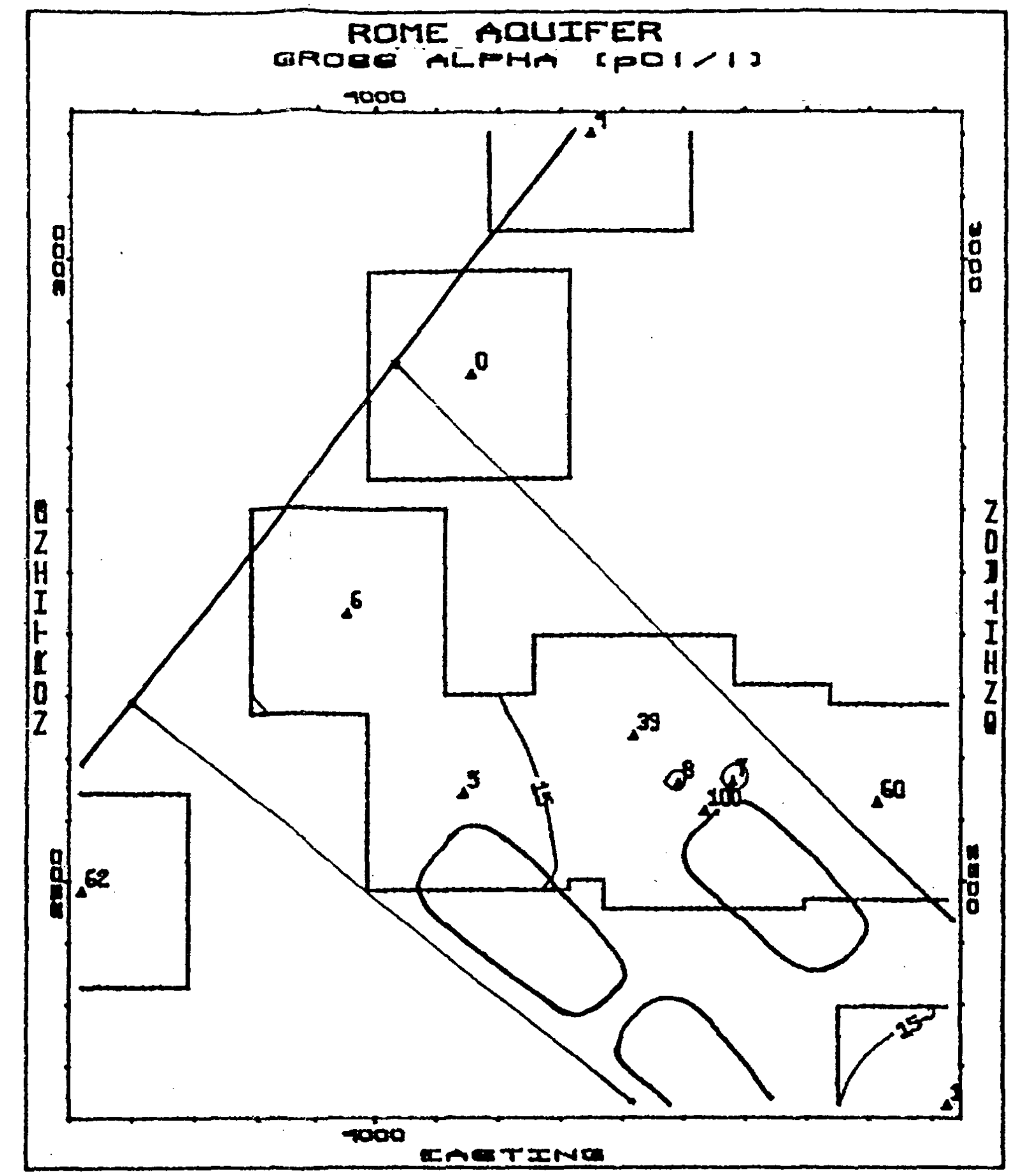
▲17 Well location. Number is concentration. Value of zero may indicate less than detection limit.

●6100 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-16 Gross Alpha in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





SCALE

0 50' 100' 150' 200' 300'

EXPLANATION

—— 100 ——
Line of equal gross alpha concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

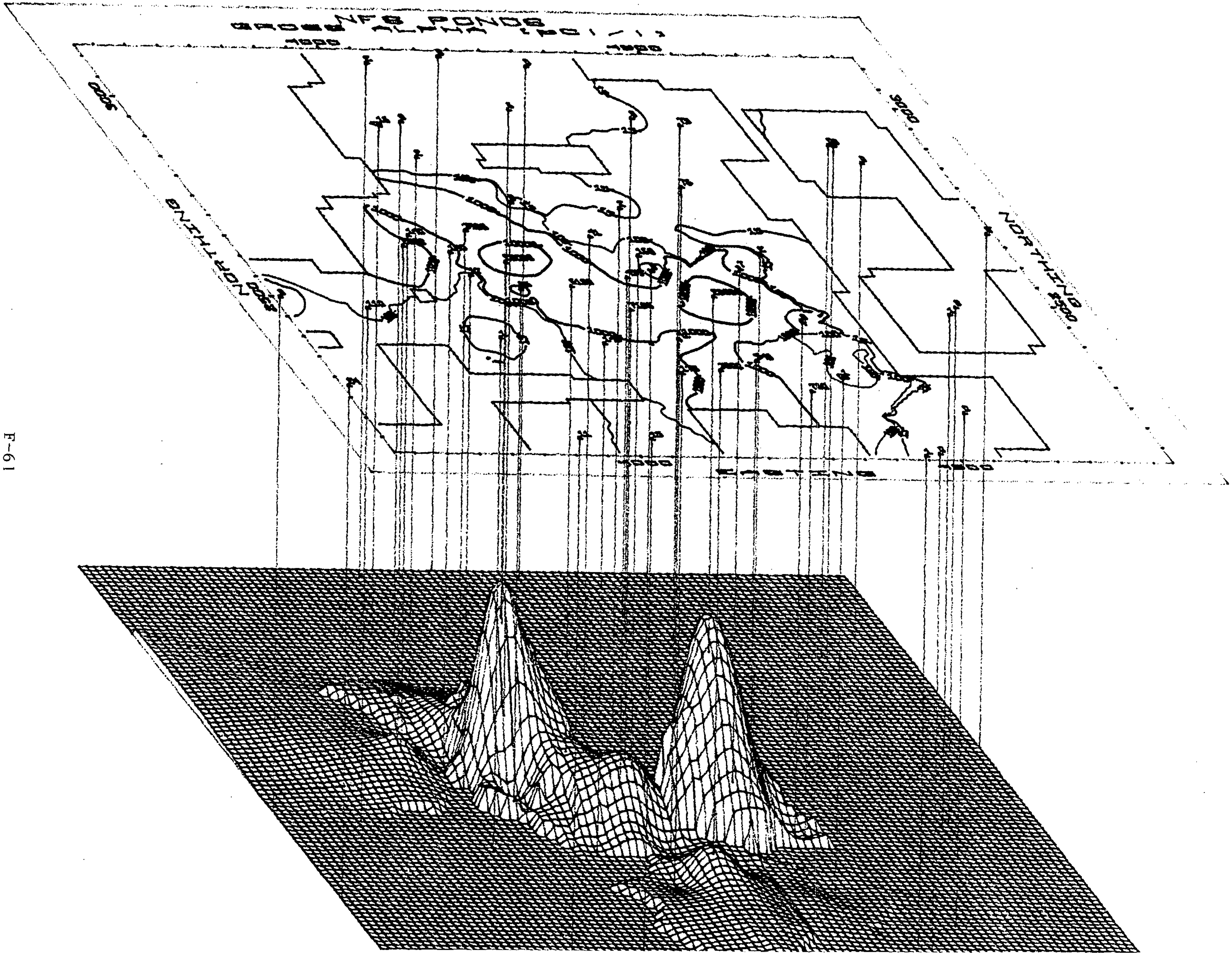
▲41 Well location. Number is concentration. Value of zero may indicate less than detection limit.

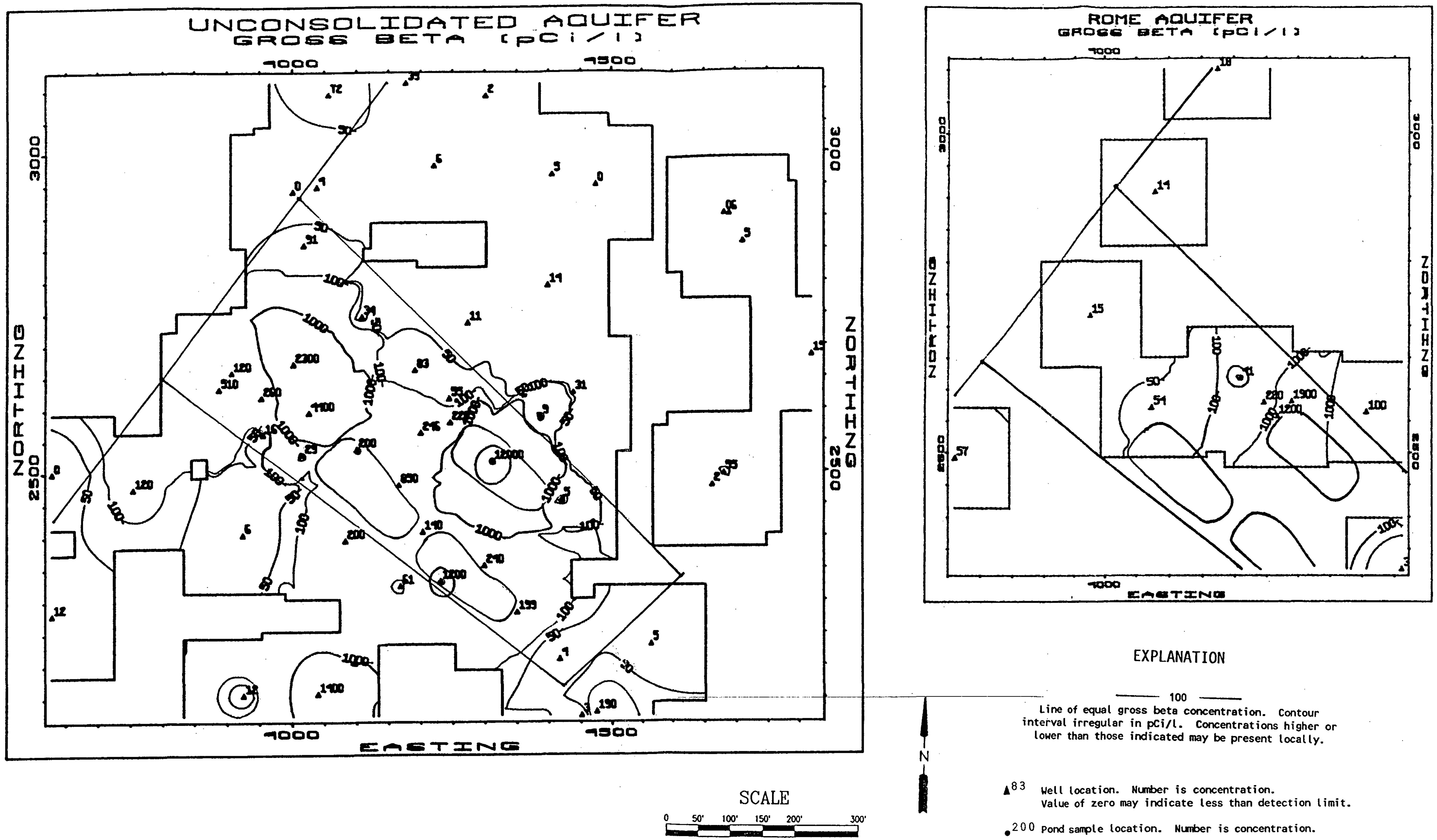
•6100 Pond sample location. Number is concentration. Values used were measured in July-August 1988.

Area of low confidence based on lack of control points

Figure 7-17 Gross Alpha in Water from Wells in Unconsolidated and Rome Aquifers (October 1988)

Figure 7-18 Distribution of Gross Alpha in Water from Wells in Unconsolidated Aquifer (October 1988)





EXPLANATION

——— 100 ———

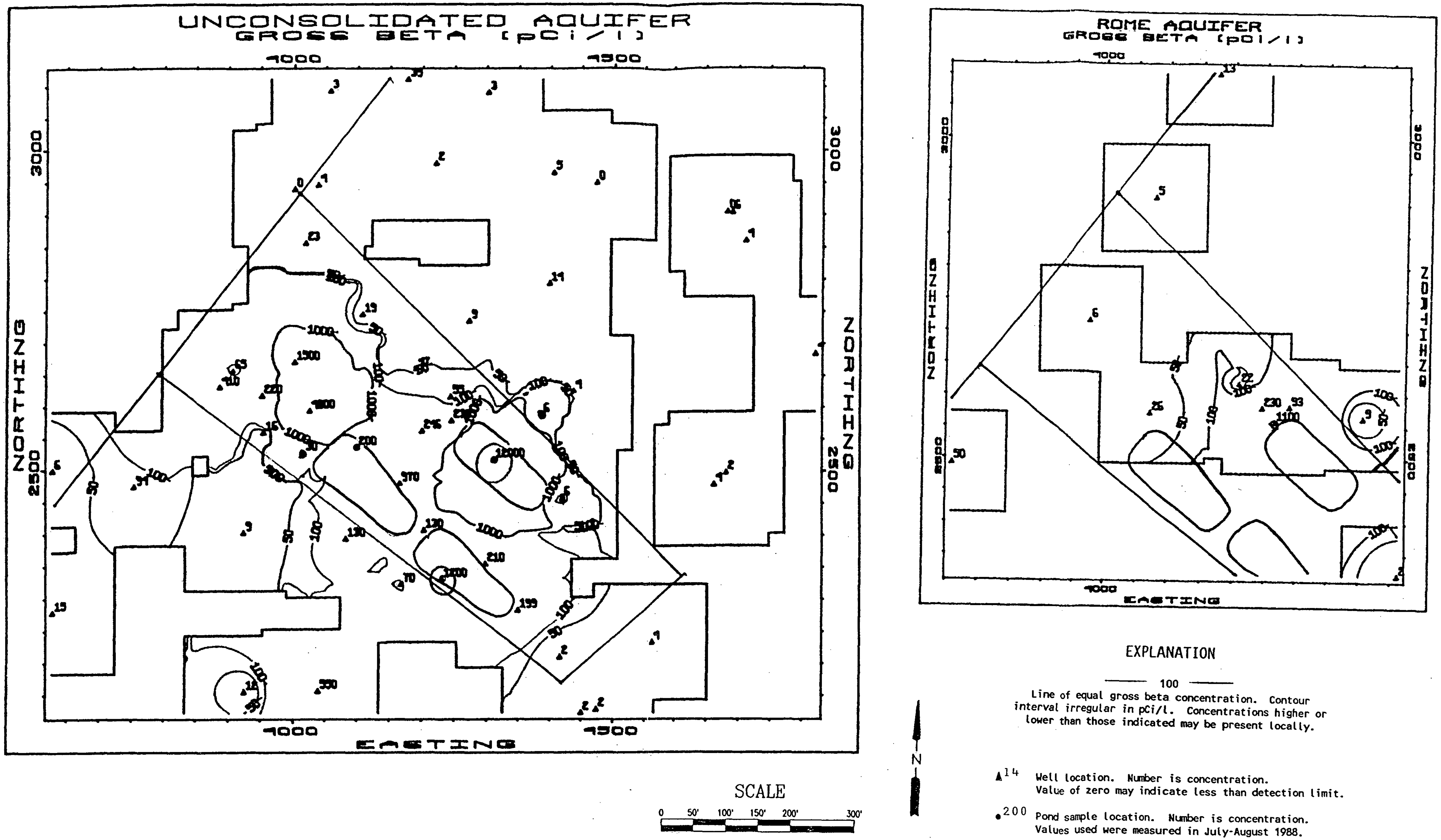
Line of equal gross beta concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

▲83 Well location. Number is concentration. Value of zero may indicate less than detection limit.

•200 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-19 Gross Beta in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)



EXPLANATION

100 — Line of equal gross beta concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

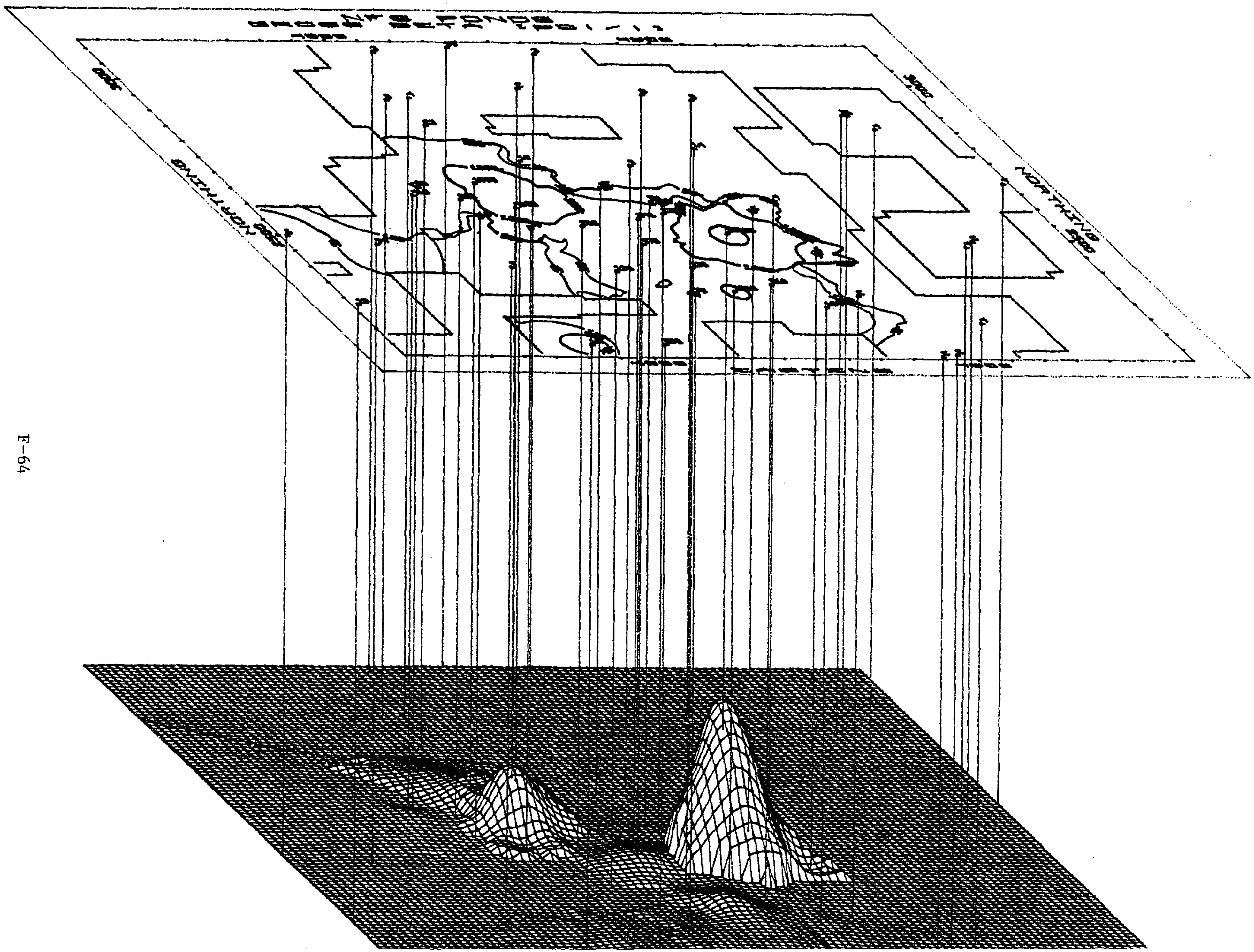
▲14 Well location. Number is concentration. Value of zero may indicate less than detection limit.

•200 Pond sample location. Number is concentration. Values used were measured in July-August 1988.

Area of low confidence based on lack of control points

Figure 7-20 Gross Beta in Water from Wells in Unconsolidated and Rome Aquifers (October 1988)

Figure 7-21 Distribution of Gross Beta in Water from Wells in Unconsolidated Aquifer (October 1988)



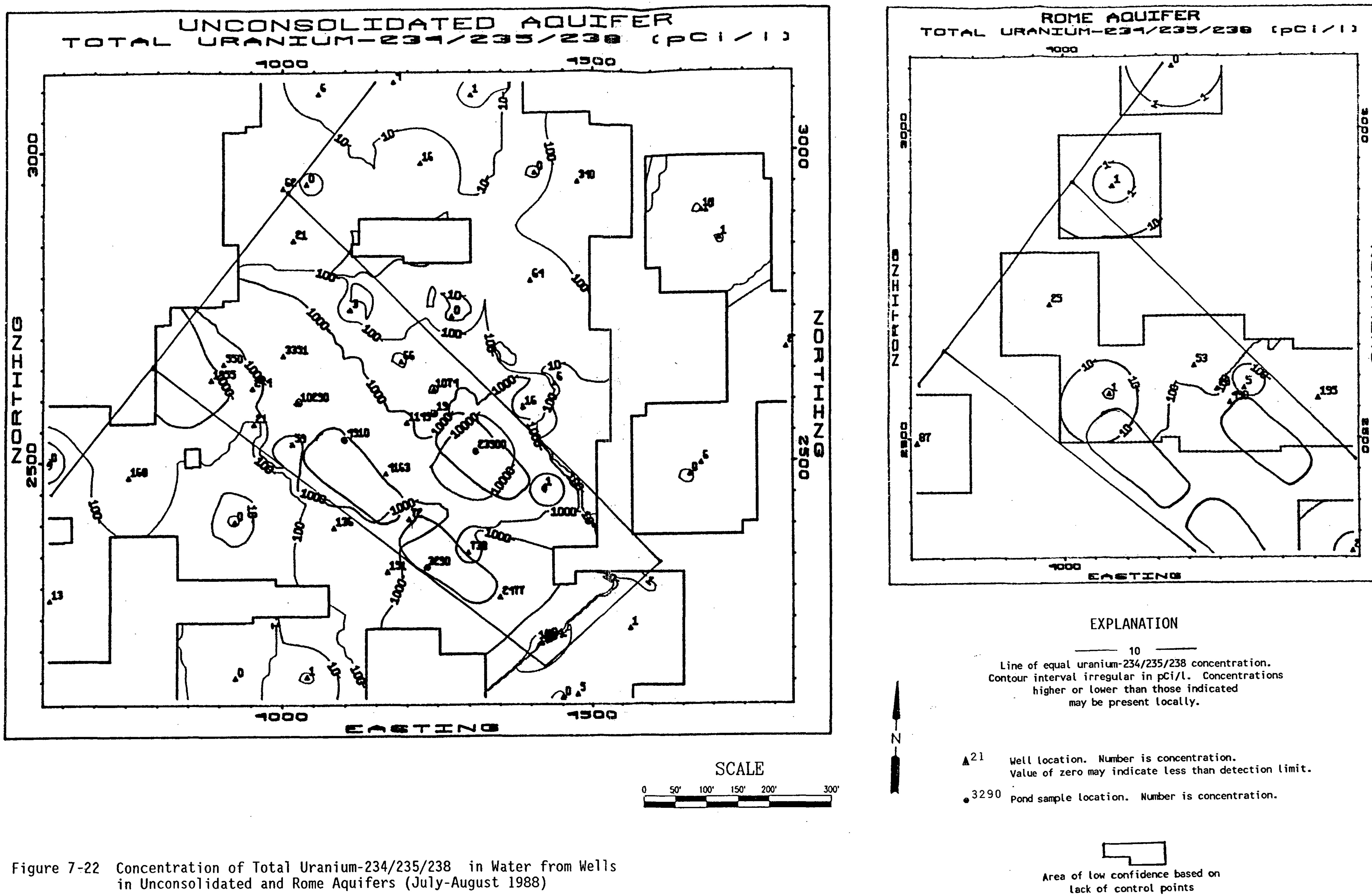
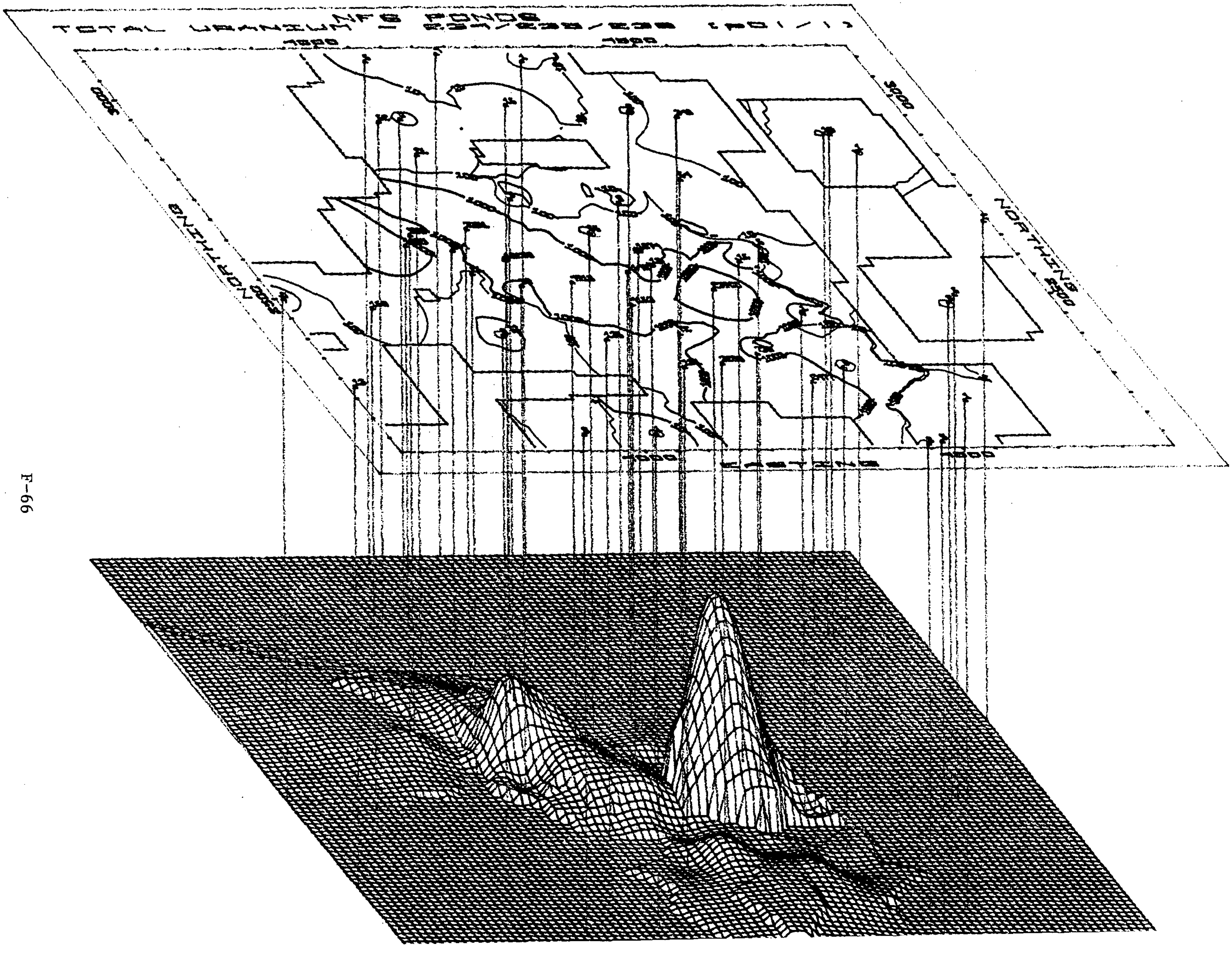
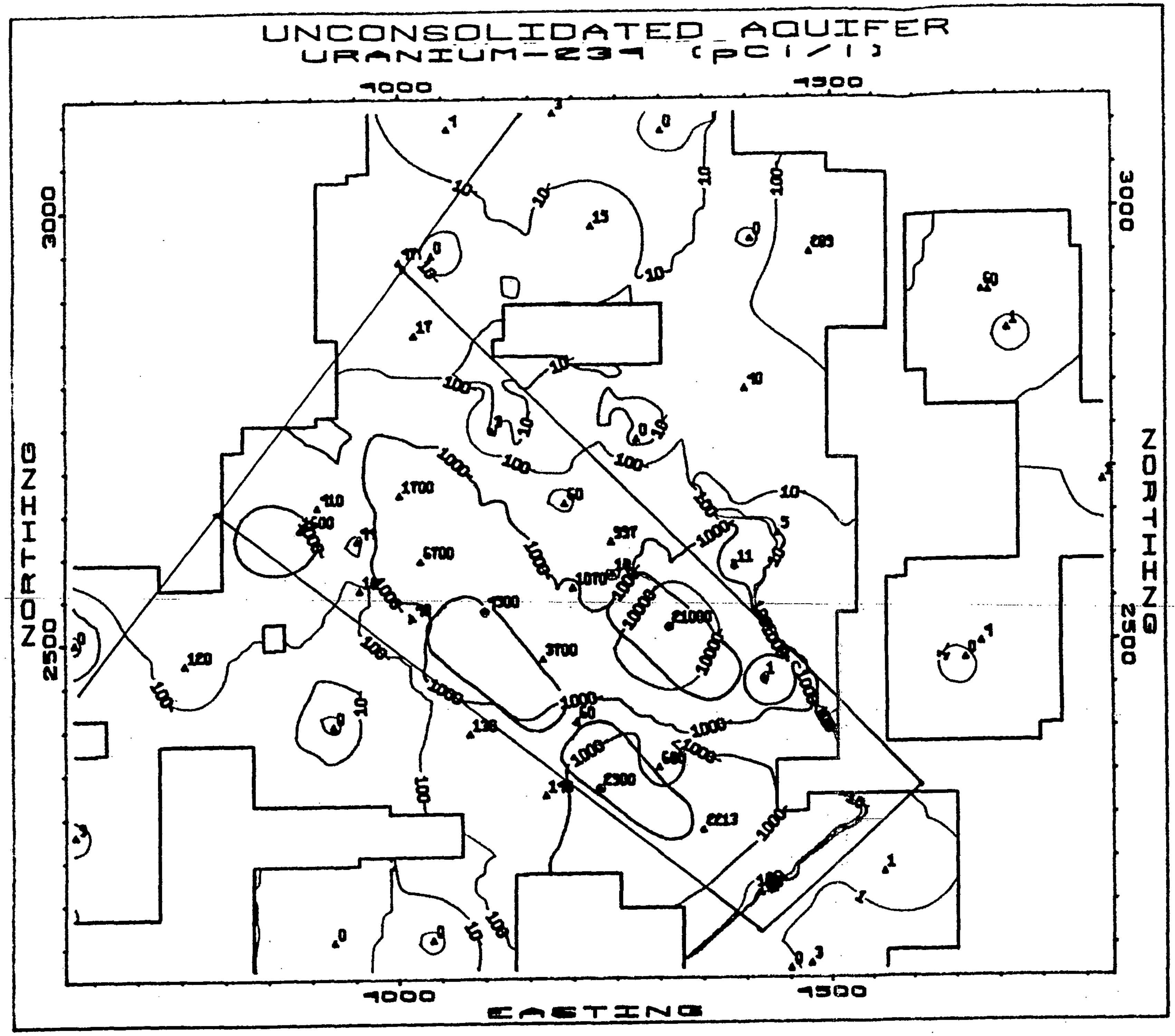
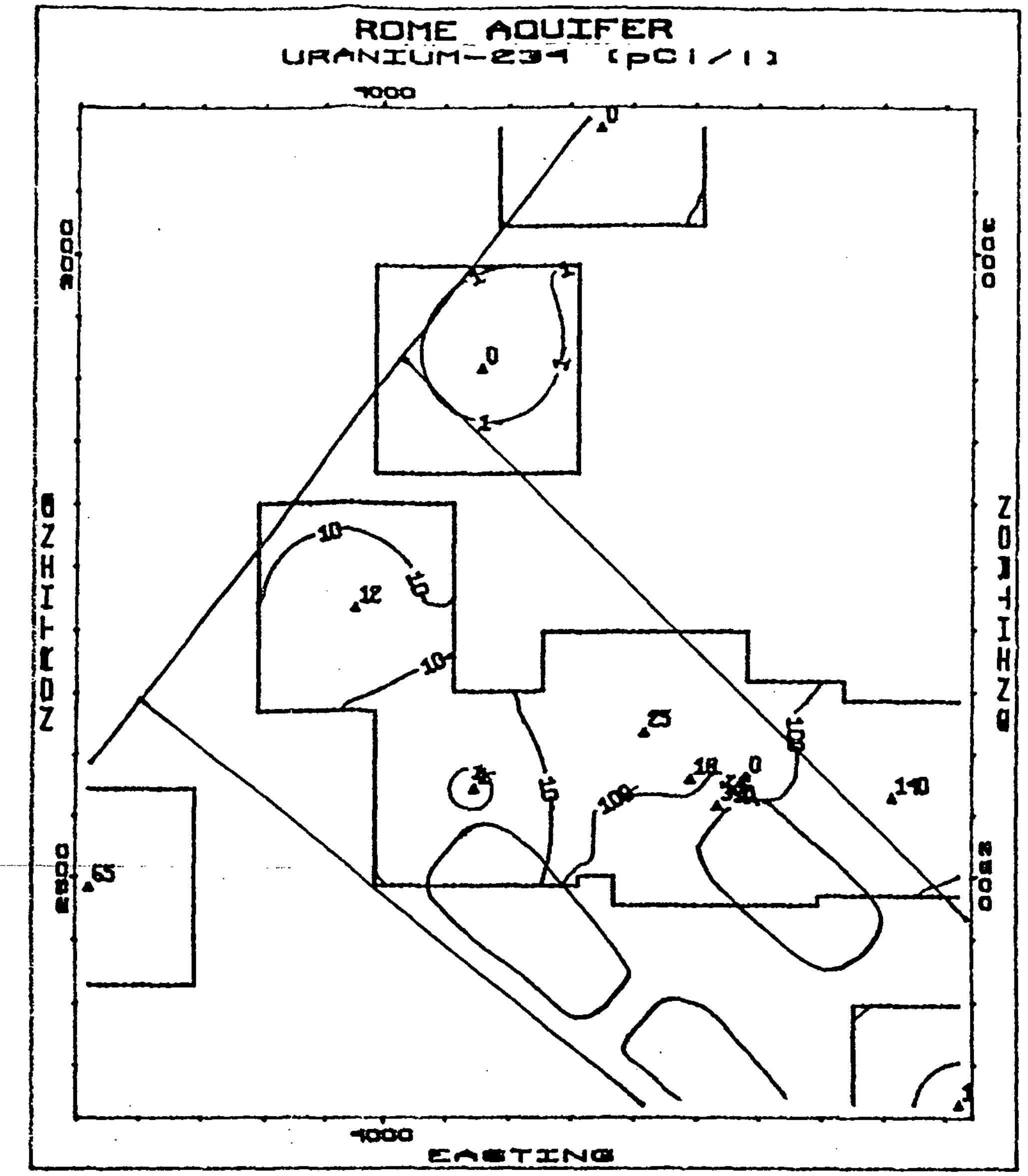


Figure 7-22 Concentration of Total Uranium-234/235/238 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)

Figure 7-23 Distribution of Total Uranium-234/235/238 in Water from Wells in Unconsolidated Aquifer (-August 1988)







SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

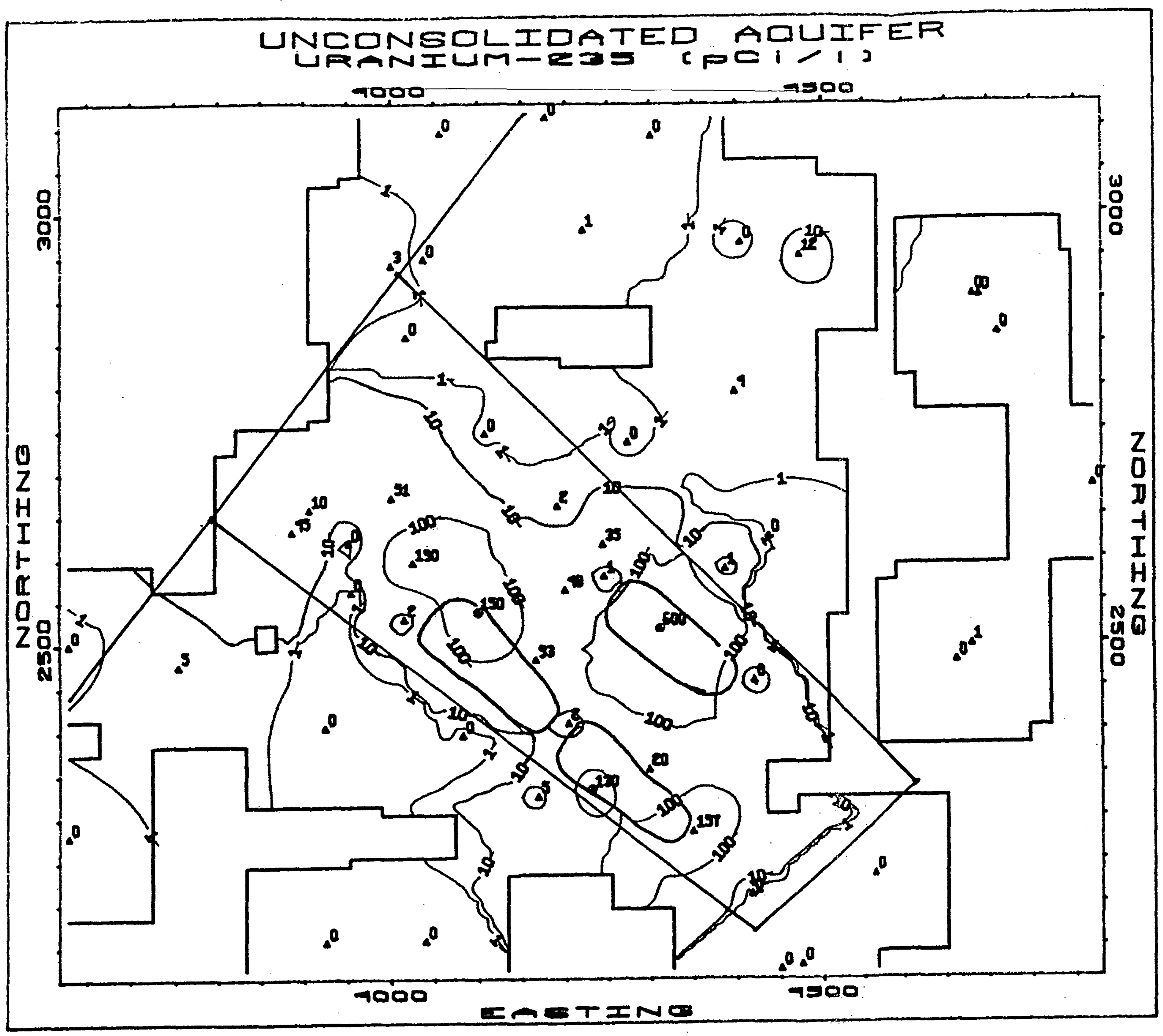
——— 10 ———
Line of equal uranium-234 concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

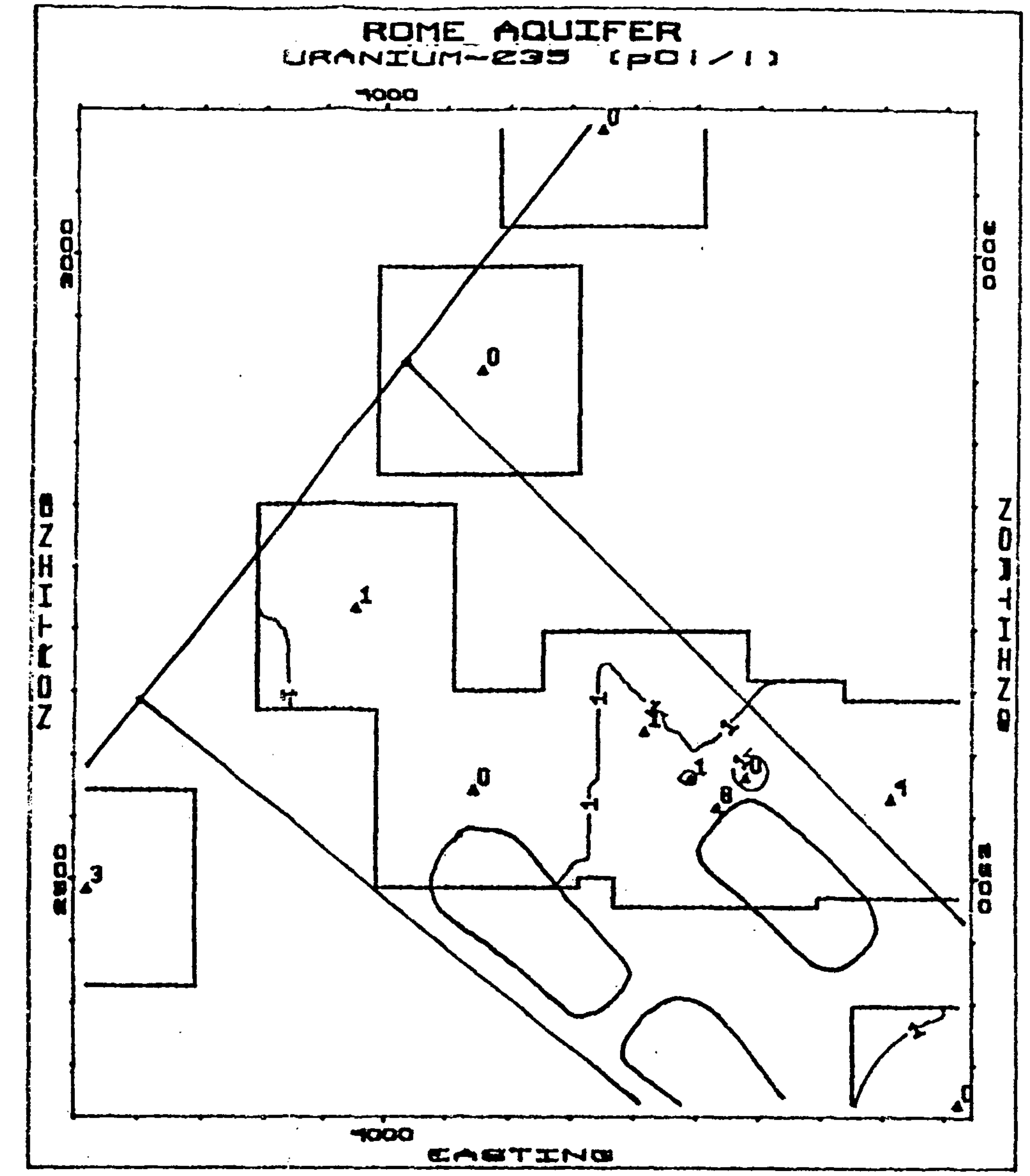
▲17 Well location. Number is concentration. Value of zero may indicate less than detection limit.

•2900 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7:24 Concentrations of Uranium-234 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

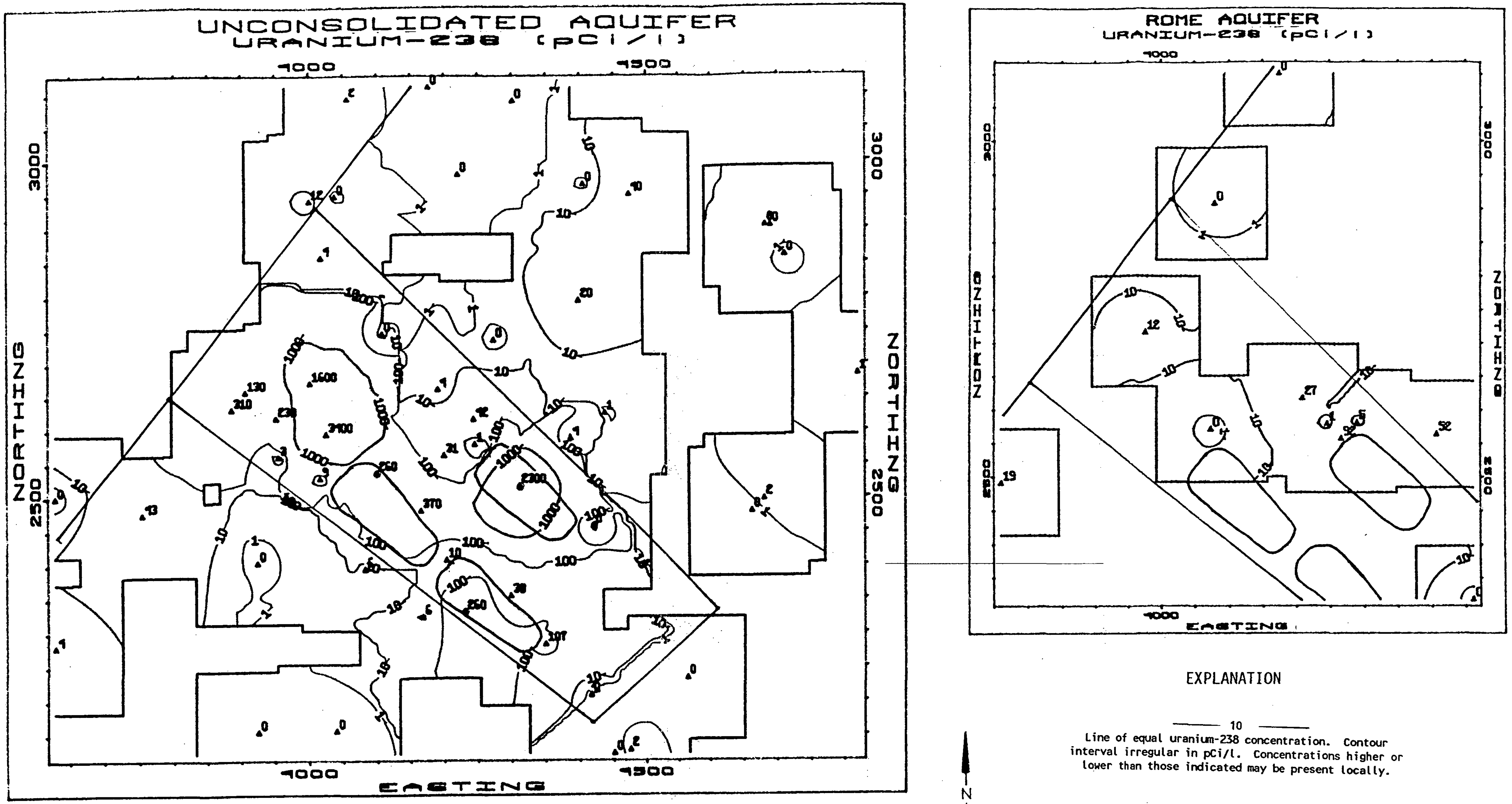
——— 10 ———
Line of equal uranium-235 concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

▲10 Well location. Number is concentration. Value of zero may indicate less than detection limit.

•130 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-25 Concentration of Uranium-235 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)



SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

——— 10 ———

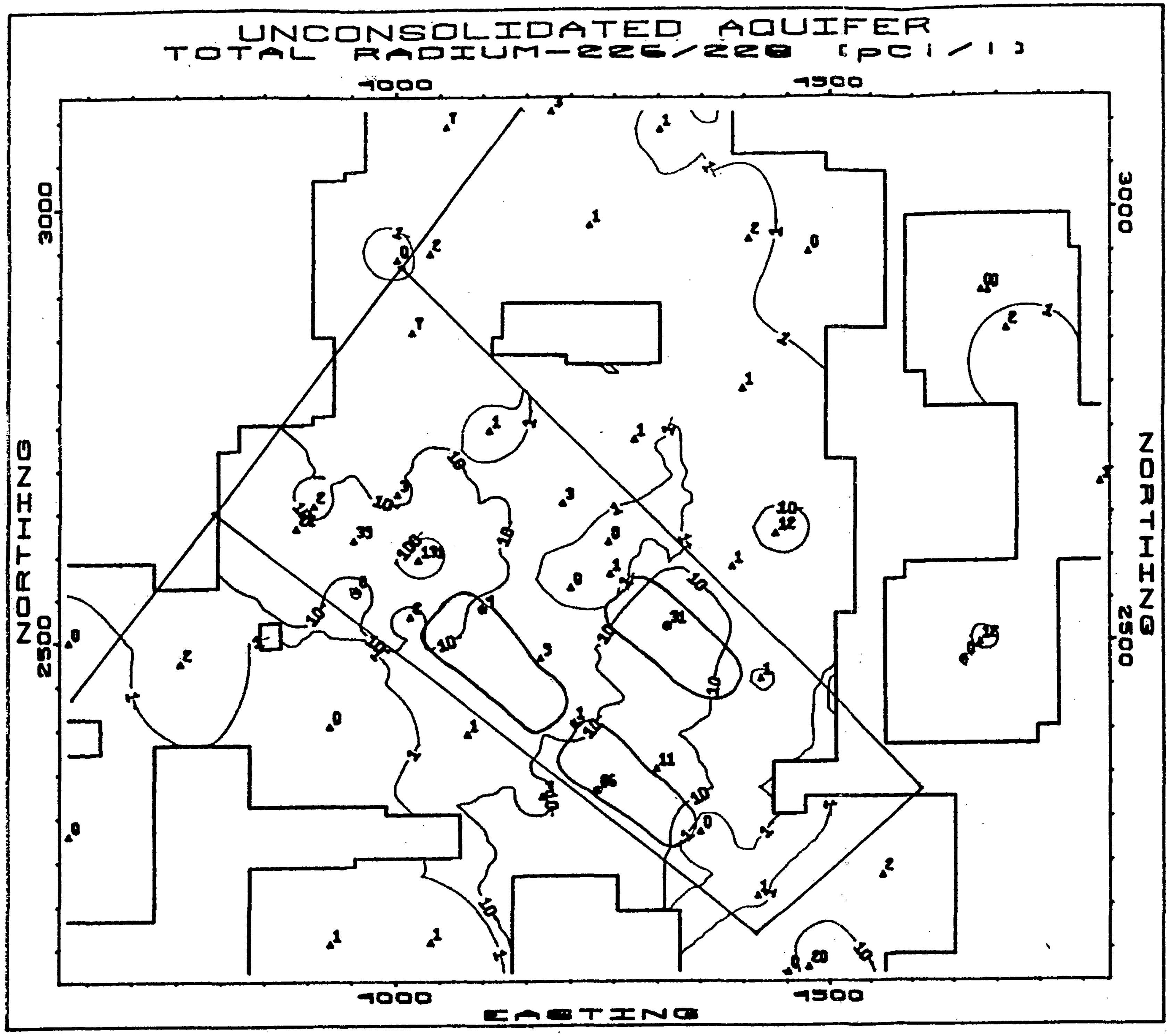
Line of equal uranium-238 concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

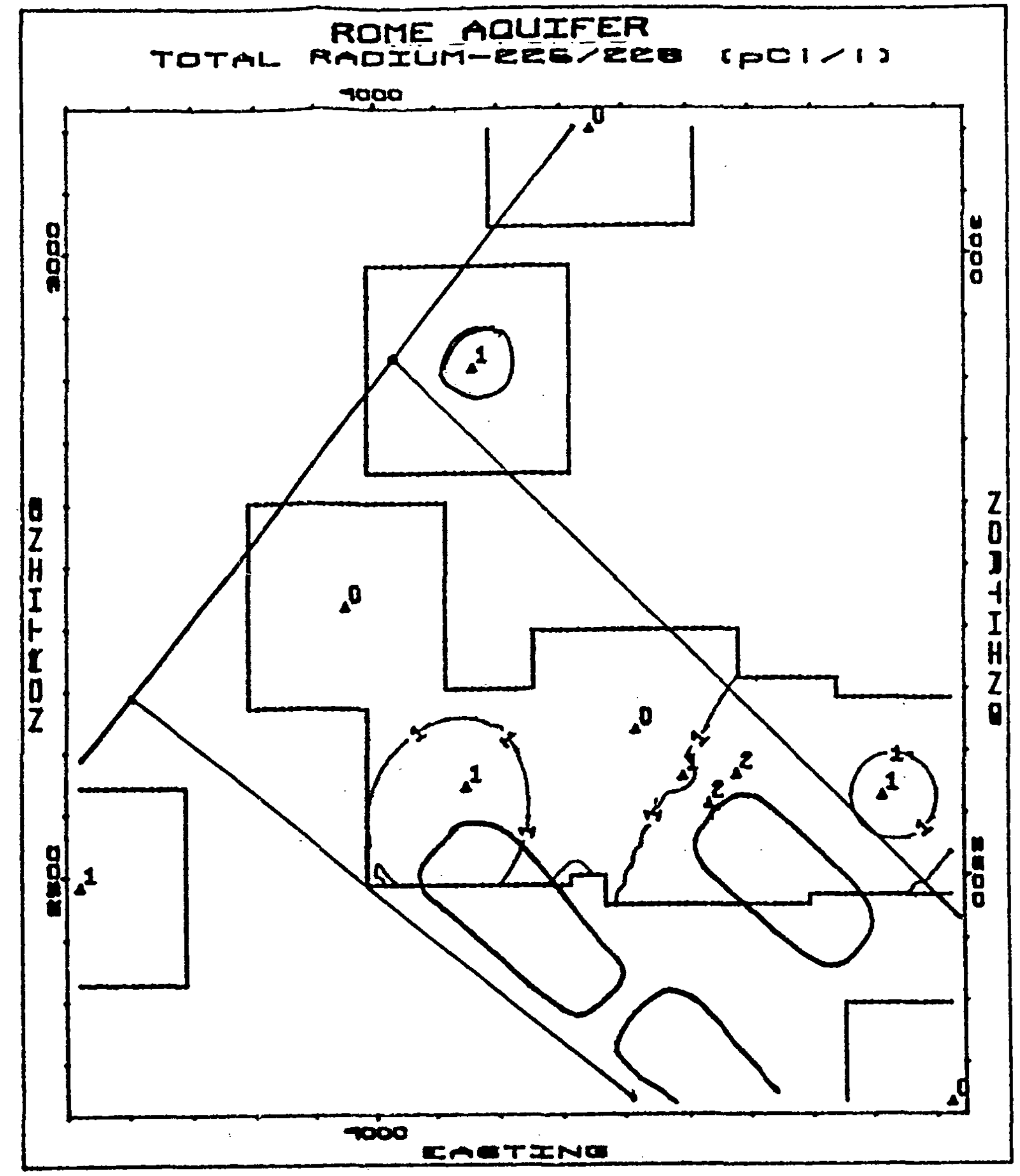
▲4 Well location. Number is concentration. Value of zero may indicate less than detection limit.

•260 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-26 Concentration of Uranium-238 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

10 — Line of equal radium concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

▲3 Well location. Number is concentration. Value of zero may indicate less than detection limit.

●4 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-27 Concentration of Total Radium-226/228 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)

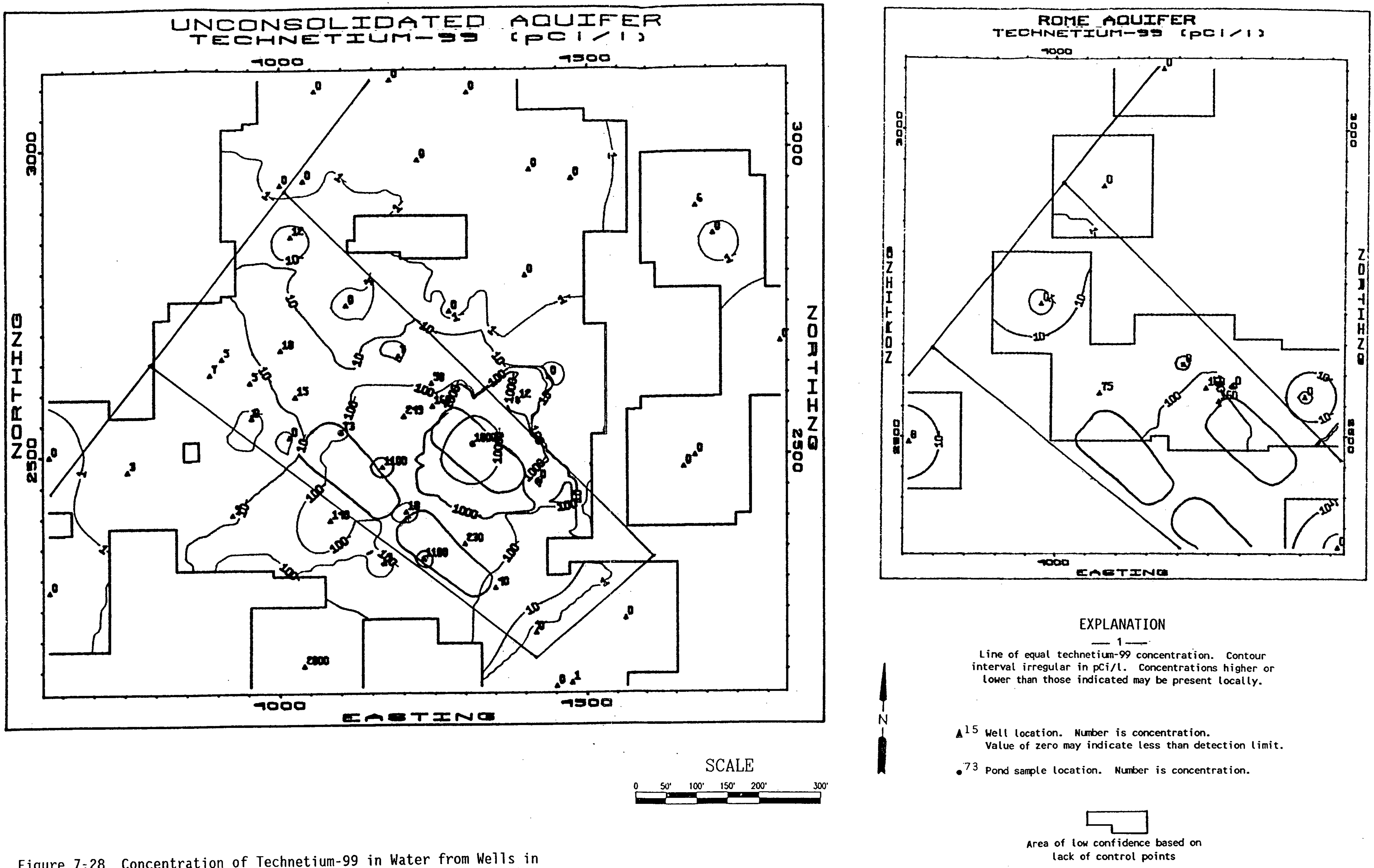
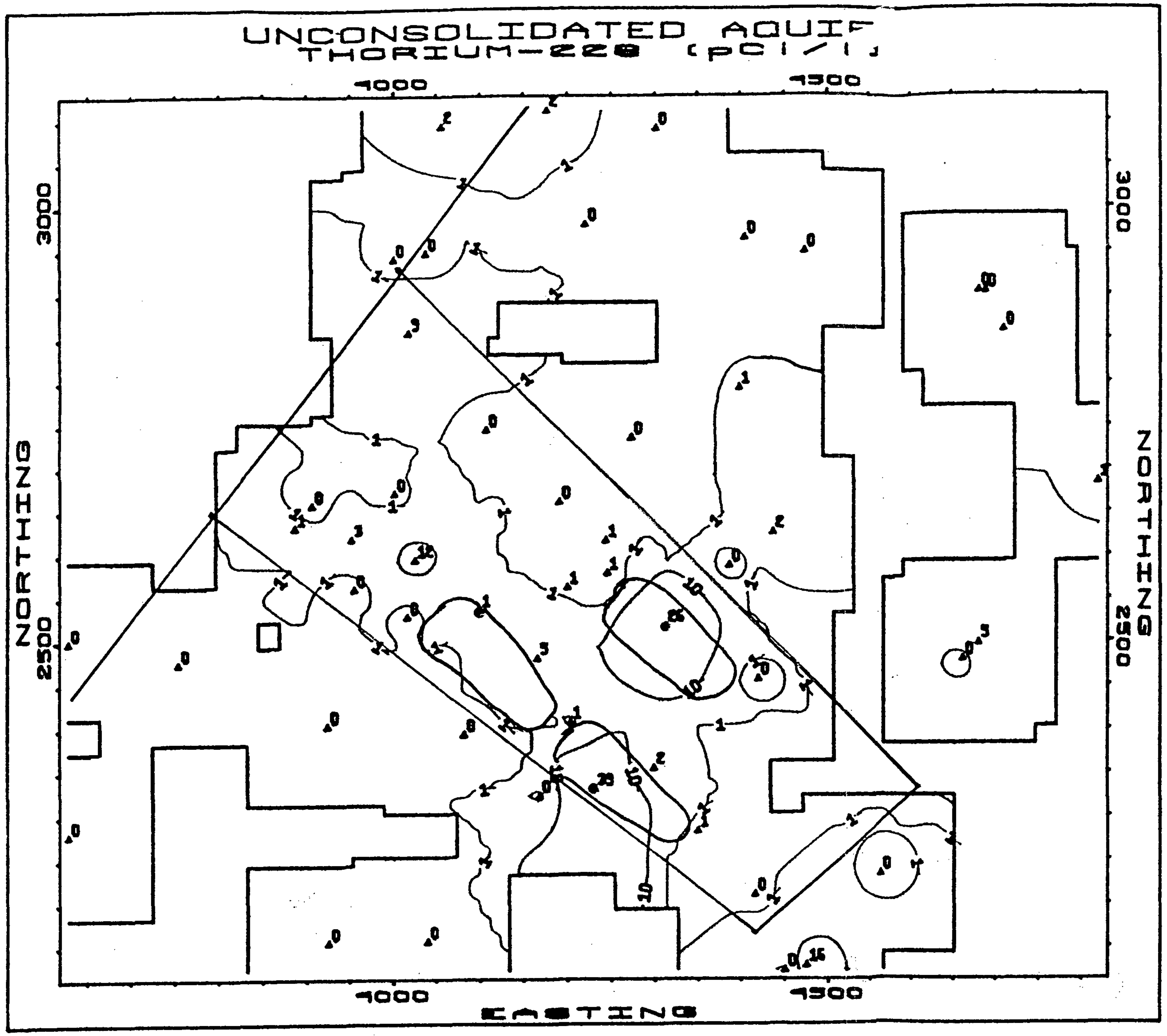
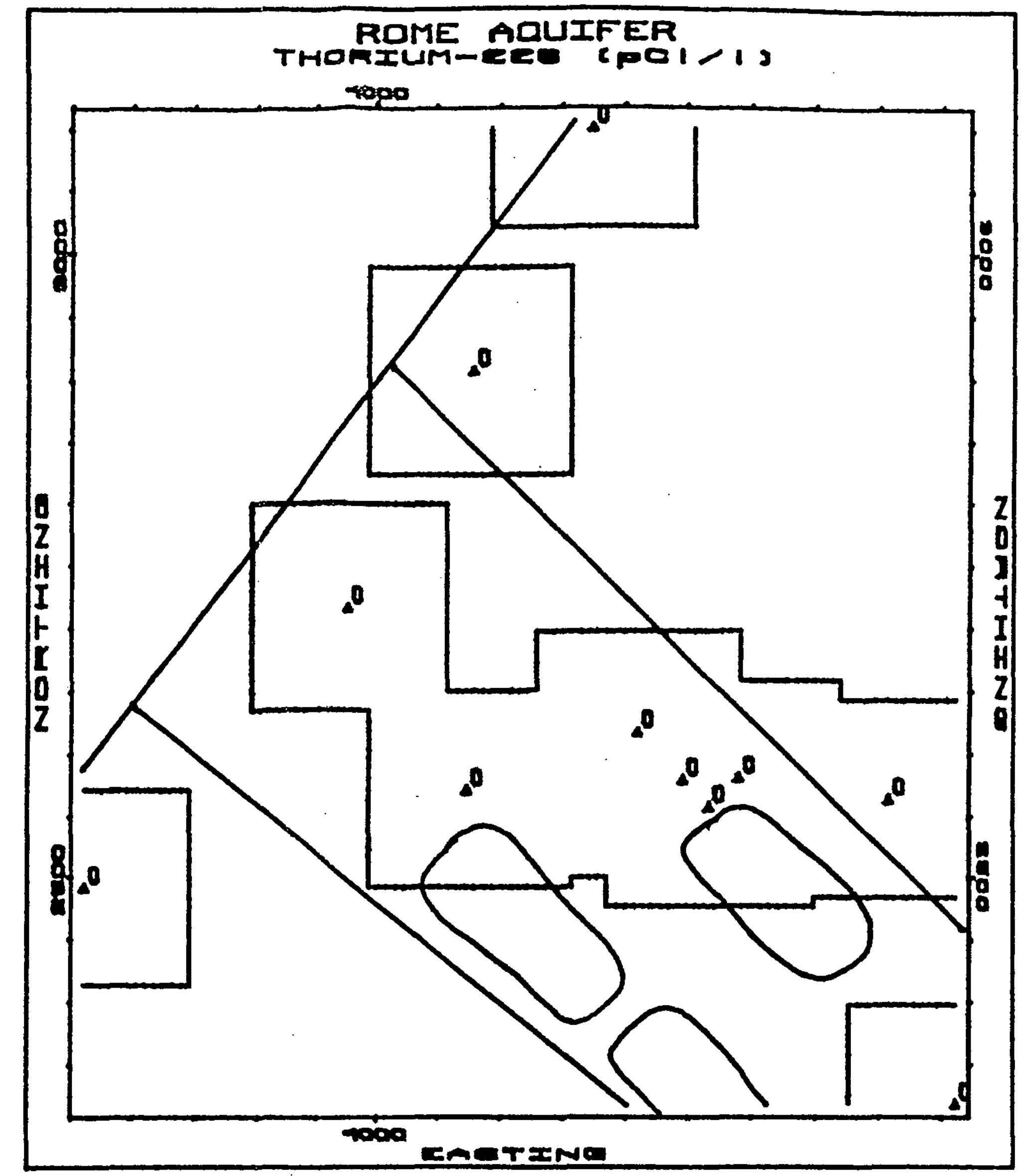


Figure 7.28 Concentration of Technetium-99 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





EXPLANATION

10

Line of equal thorium-228 concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

▲1 Well location. Number is concentration. Value of zero may indicate less than detection limit.

●1 Pond sample location. Number is concentration.

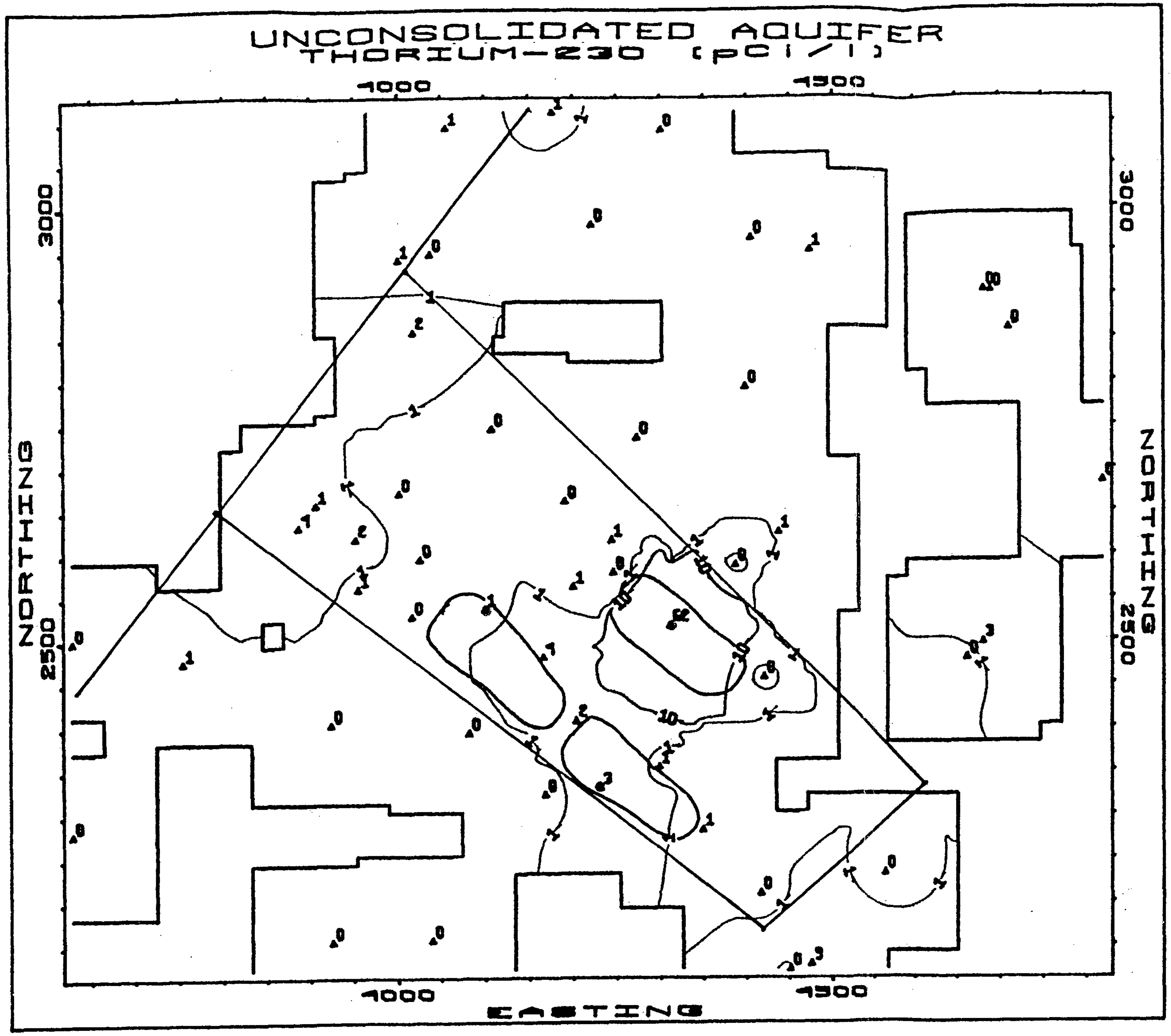
Area of low confidence based on lack of control points

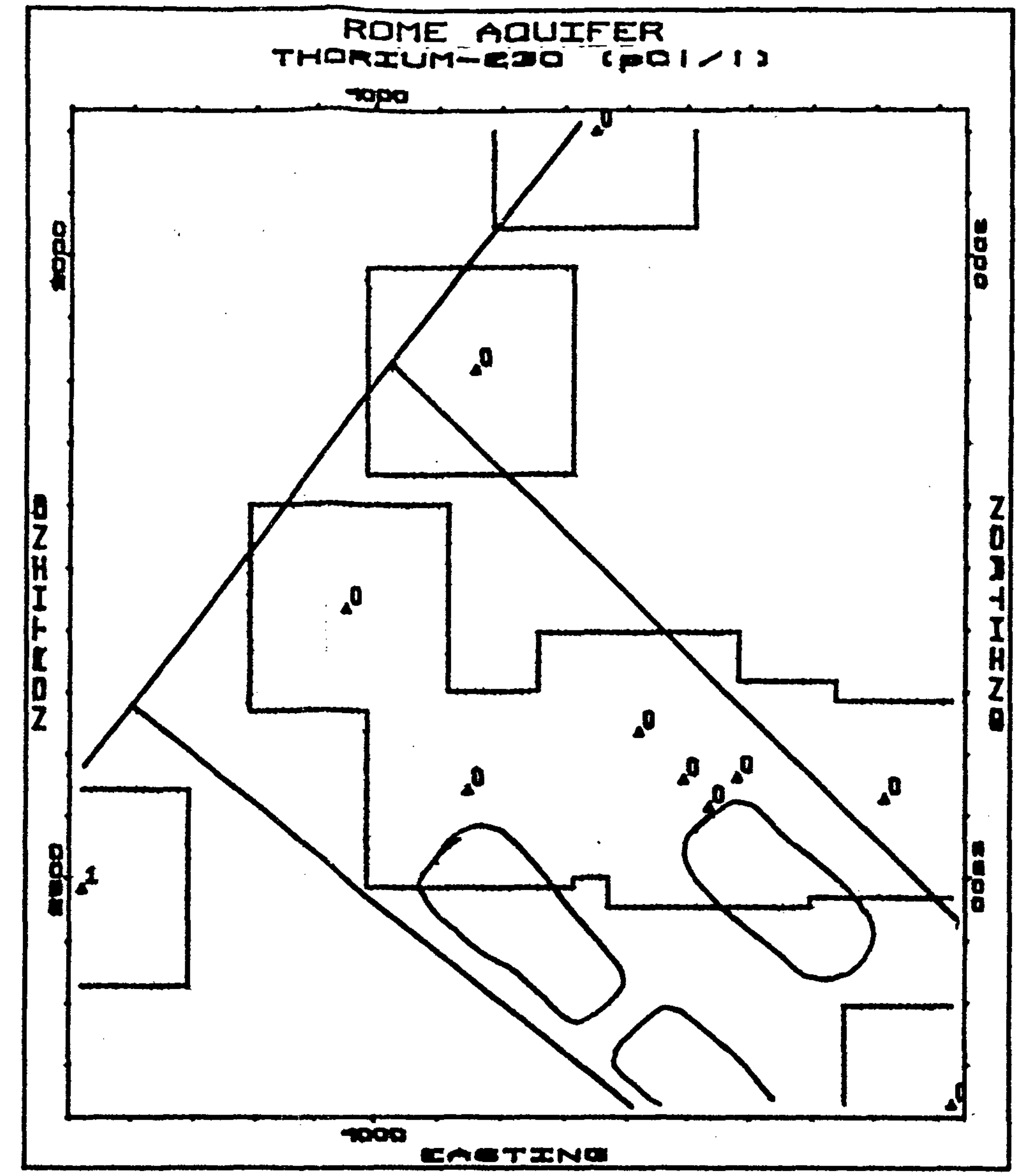
N

SCALE

0 50' 100' 150' 200' 300'

Figure 7-29 Concentration of Thorium-228 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

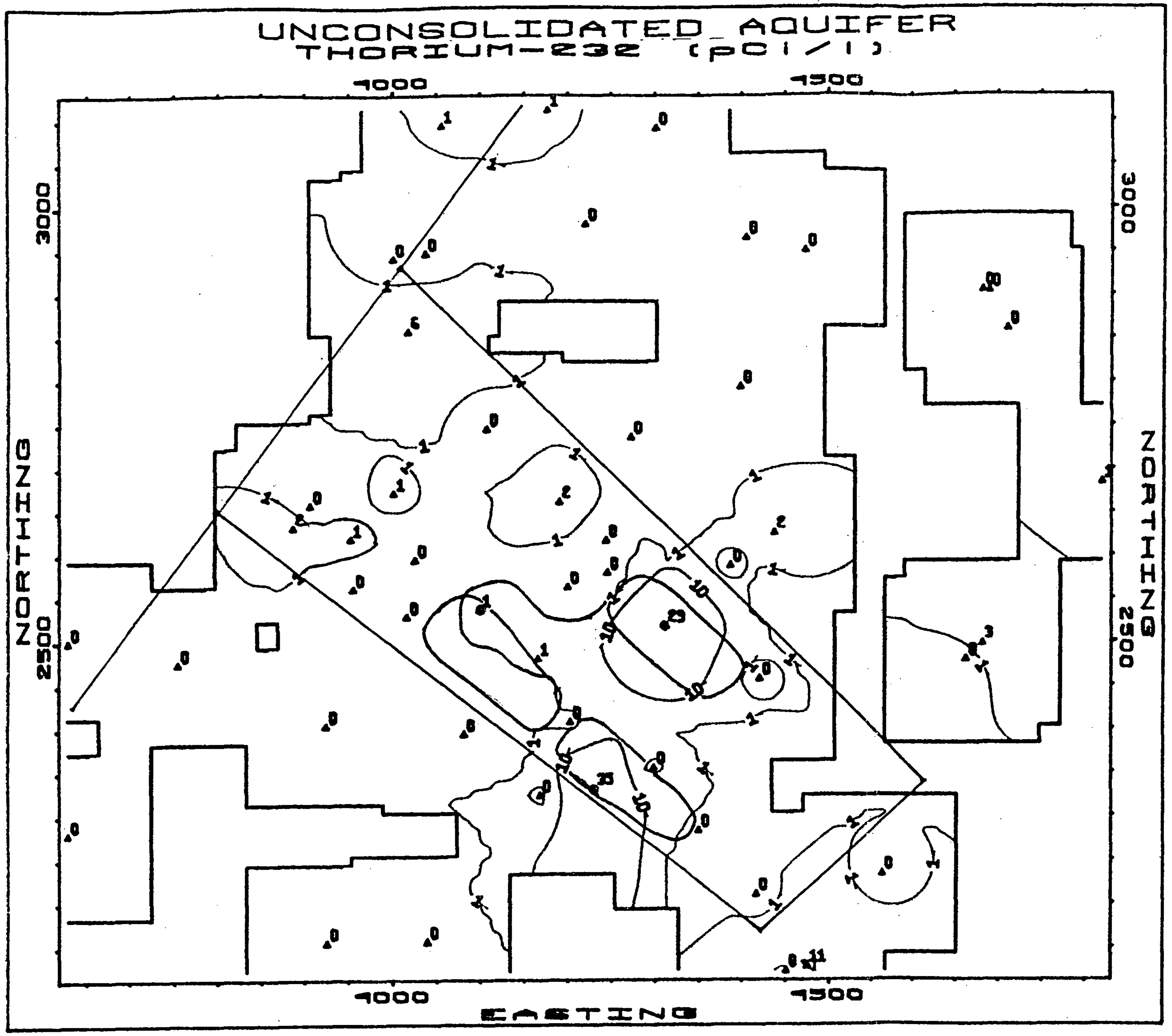
——— 10 ———
Line of equal thorium-230 concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

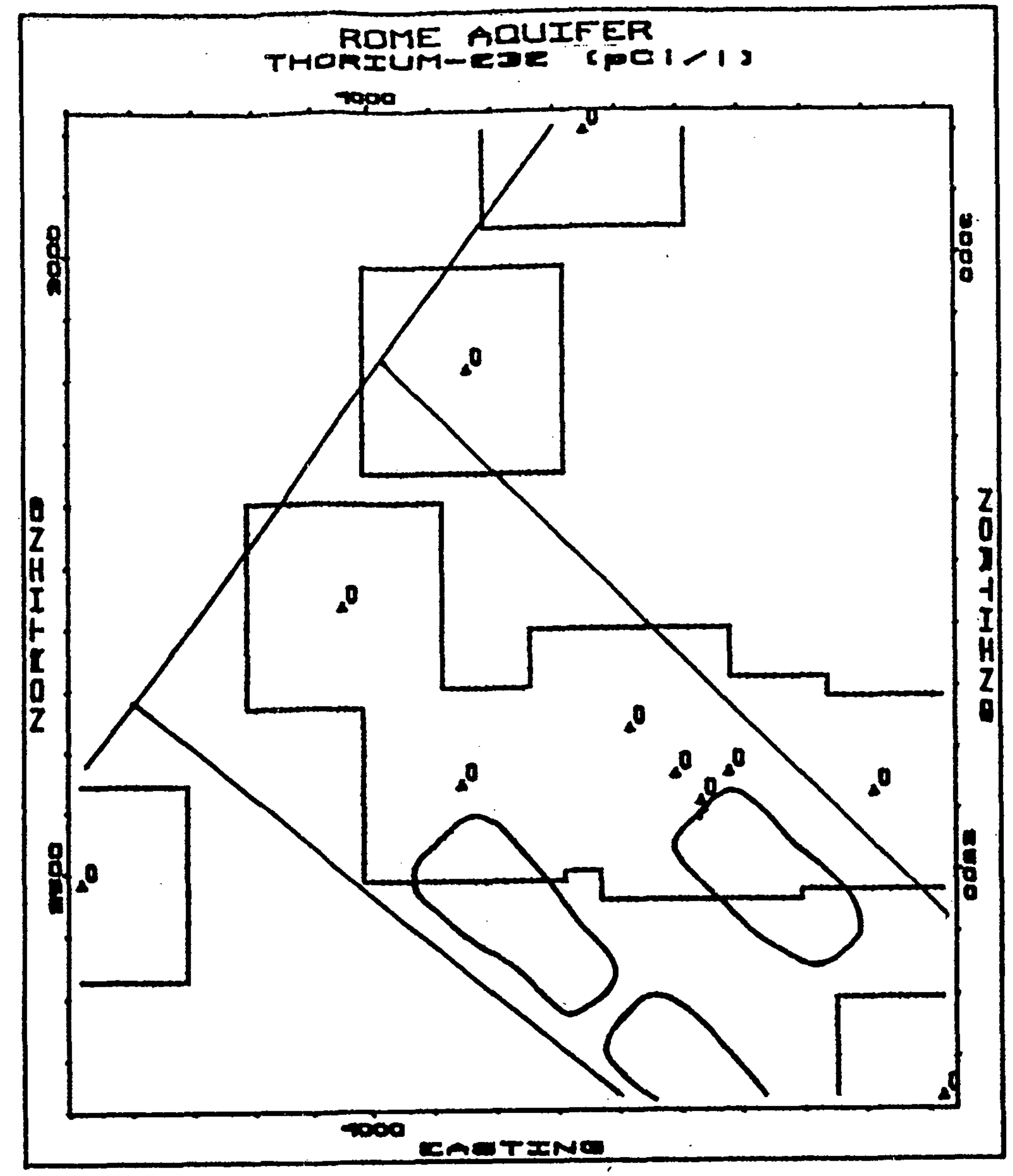
Δ 1 Well location. Number is concentration. Value of zero may indicate less than detection limit.

• 3 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-30 Concentration of Thorium-230 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

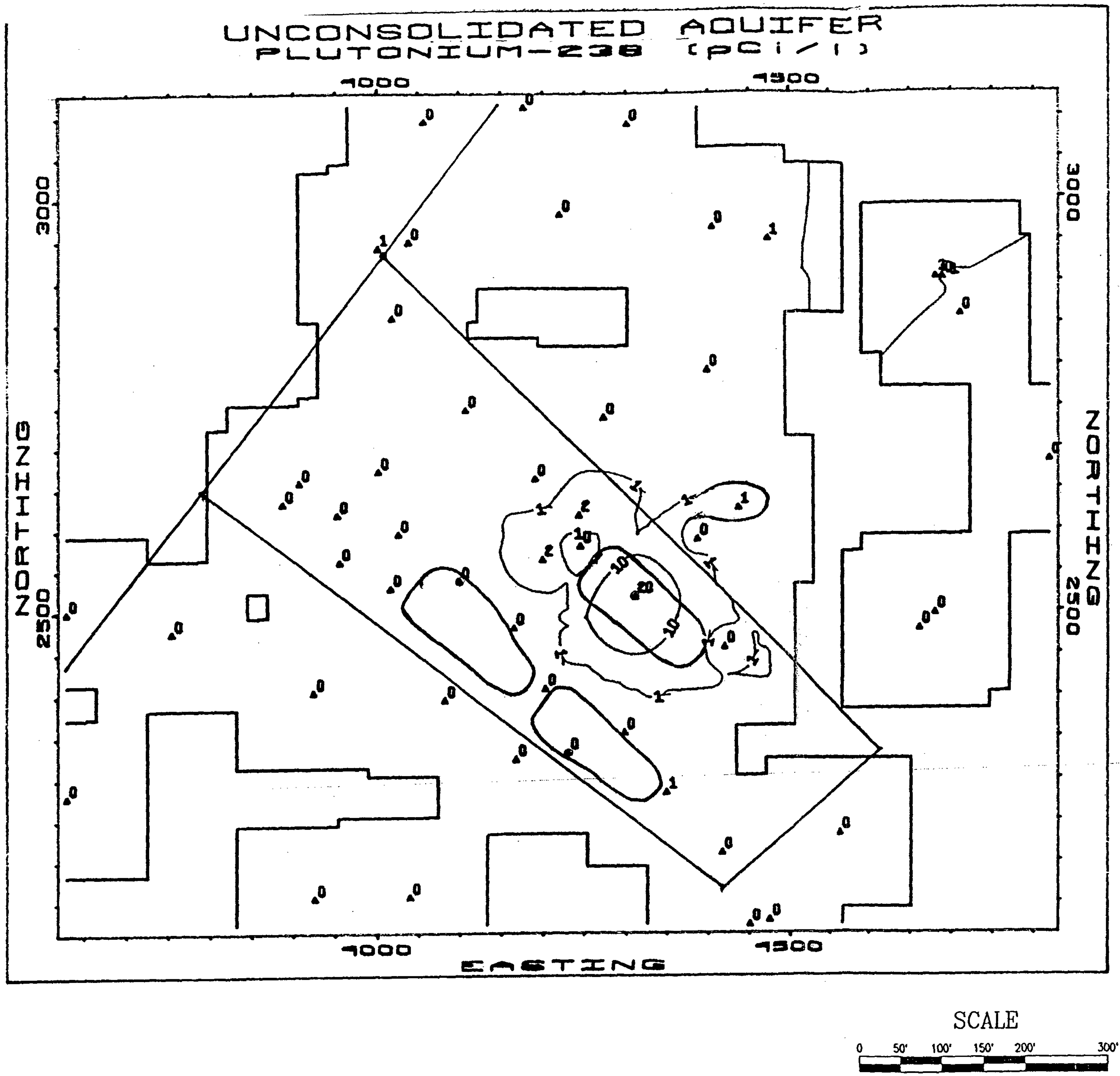
—— 10 ——
Line of equal thorium-232 concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

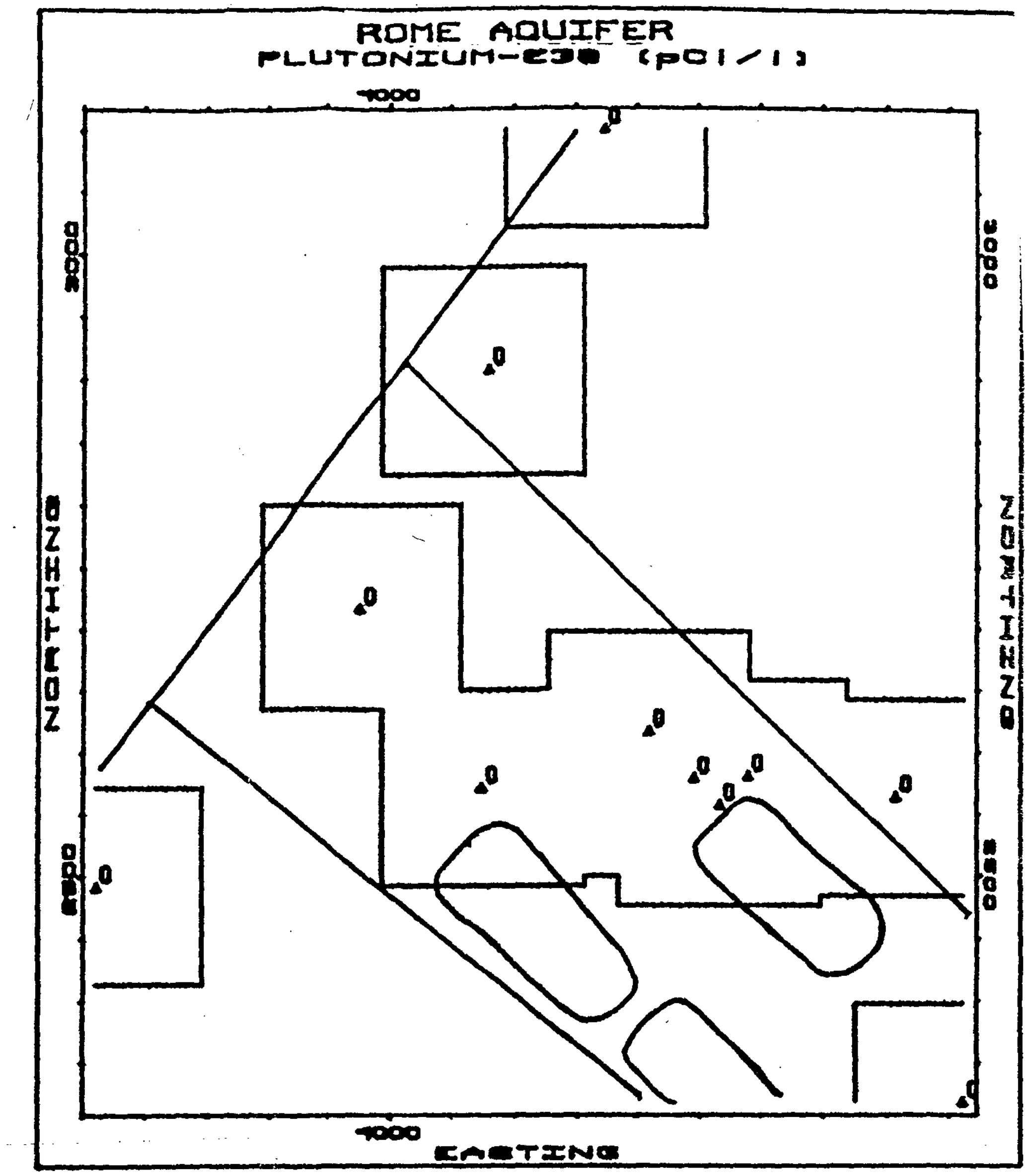
Δ^1 Well location. Number is concentration. Value of zero may indicate less than detection limit.

$\bullet^1$ Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-31 Concentration of Thorium-232 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





EXPLANATION

—— 1 —— Line of equal plutonium-238 concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

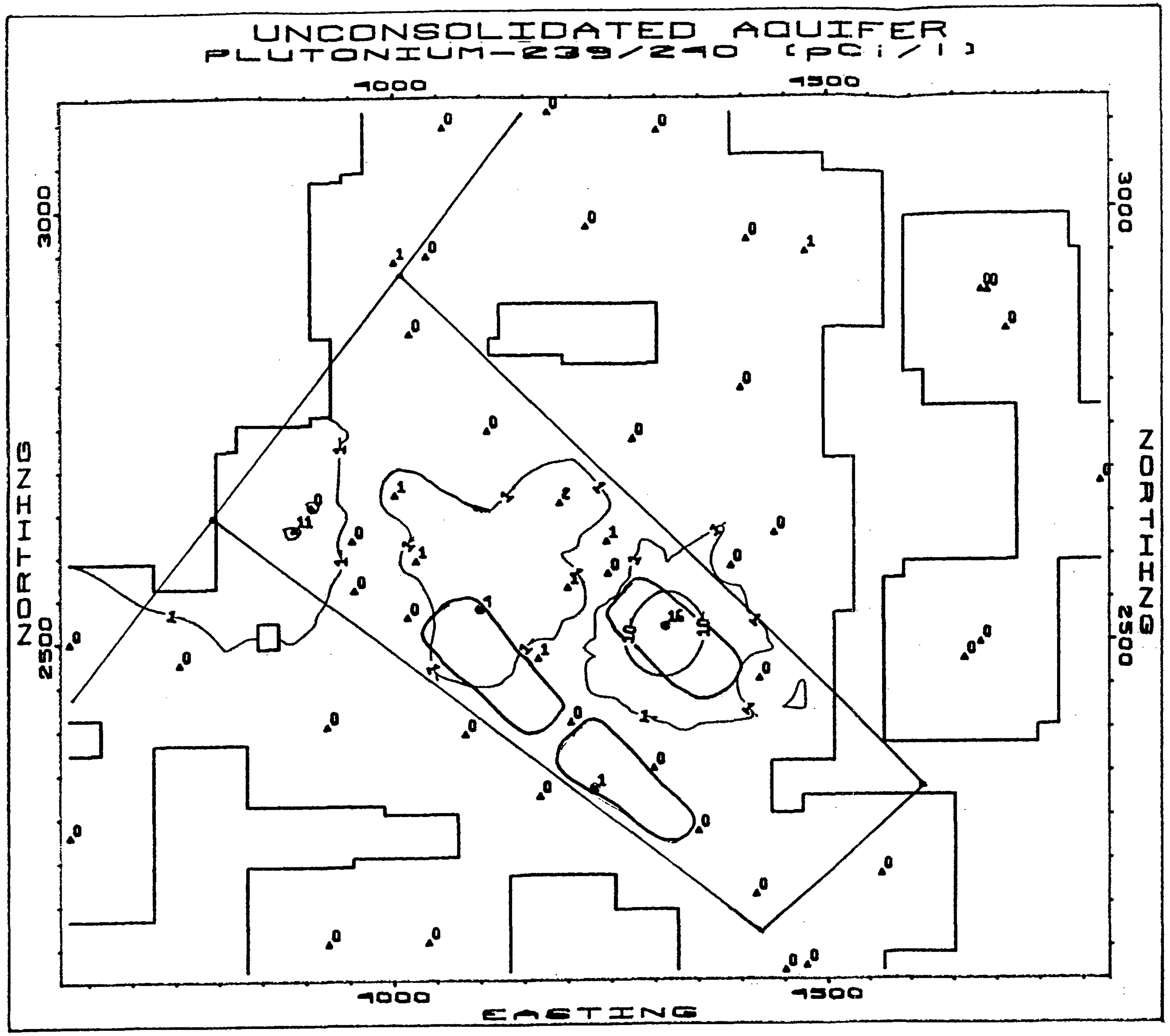
N

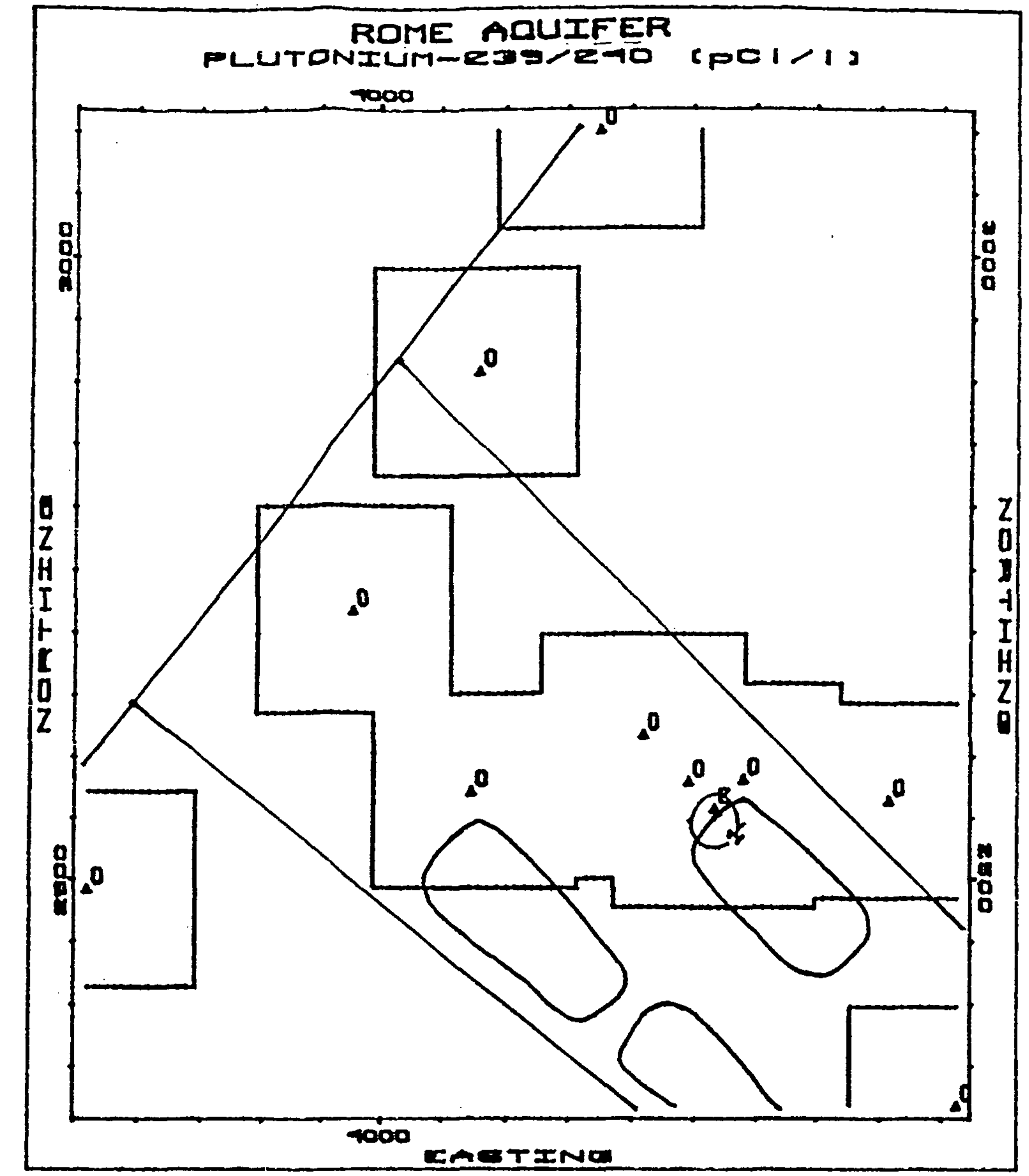
▲1 Well location. Number is concentration. Value of zero may indicate less than detection limit.

●0 Pond sample location. Number is concentration.

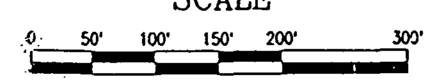
Area of low confidence based on lack of control points

Figure 7-32 Concentration of Plutonium-238 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)





SCALE



EXPLANATION

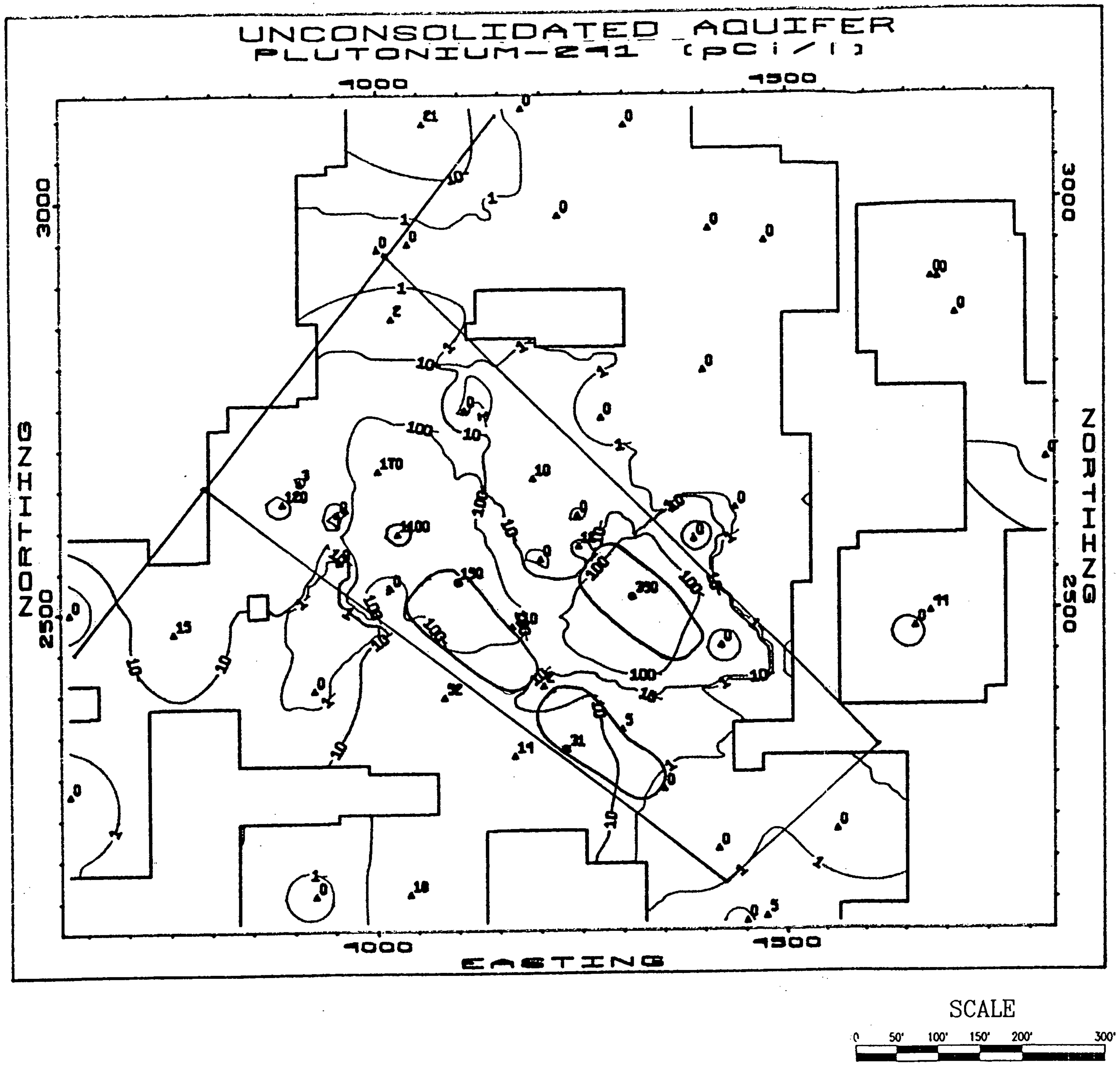
——— 1 ———
Line of equal plutonium-239/240 concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

▲2 Well location. Number is concentration. Value of zero may indicate less than detection limit.

•4 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-33 Concentration of Plutonium-239/240 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)



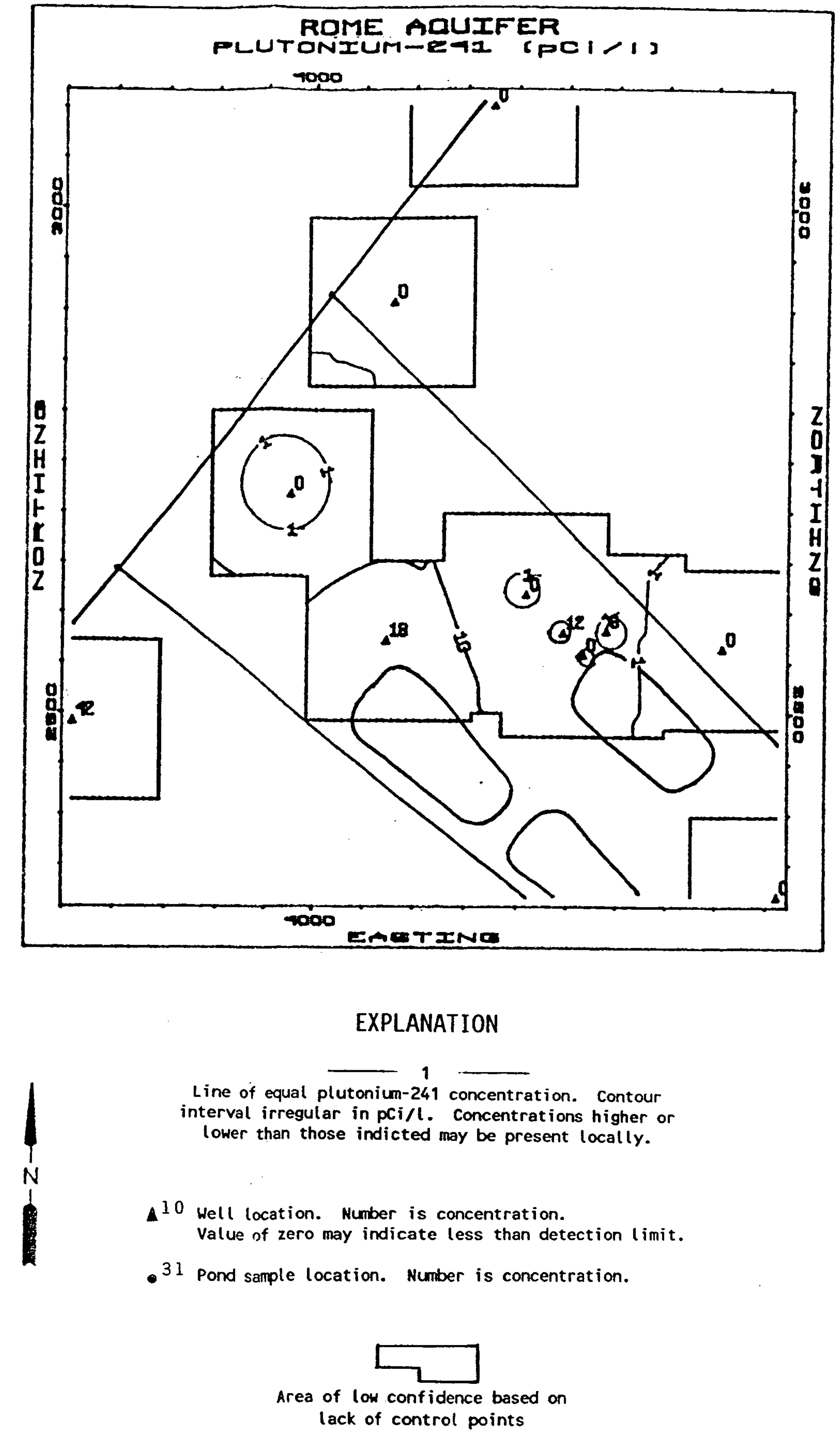
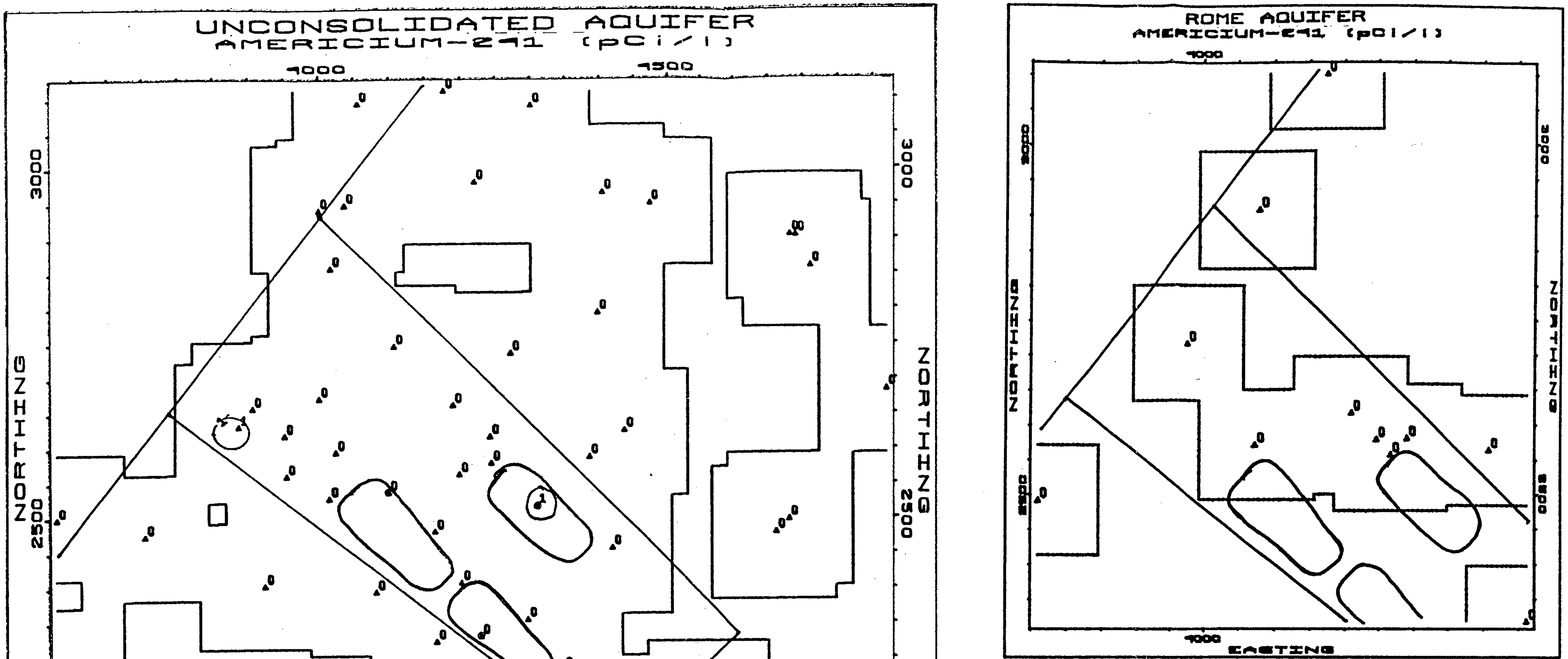


Figure 7-34 Concentration of Plutonium-241 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)



SCALE

0 50' 100' 150' 200' 300'

N

EXPLANATION

——— 1 ———
Line of equal americium-241 concentration. Contour interval irregular in pCi/l. Concentrations higher or lower than those indicated may be present locally.

▲0 Well location. Number is concentration. Value of zero may indicate less than detection limit.

●0 Pond sample location. Number is concentration.

Area of low confidence based on lack of control points

Figure 7-35 Concentration of Americium-241 in Water from Wells in Unconsolidated and Rome Aquifers (July-August 1988)

TABLES

Table 3-1 Volume of Solutions Discharged to Lagoons

Building	Process	Operating Years	Gallons/Day	
Bldg. 110A	H.E. U02 Production	1957 thru 1967	500	
Bldg. 110B	L.E. U02 Production	1957 thru 1967	800	
Bldg. 111	H.E. Uranium Scrap Recovery	1960 thru 1965	700	
Bldg. 111	Thorium Metal Production	1962 thru 1969	10,800	
Bldg. 301	L.E. U02 Production	1964 thru 1970	2,000	
Bldg. 233	H.E. Uranium Scrap Recovery	1962 to 1978*	2,600	
Bldg. 302	H.E. Fuel Manufacturing	1966 to 1978*	2,400	
Bldg. 303	H.E. Fuel Manufacturing	1970 to 1978*	2,400	

Note: * Discharge to the lagoons was discontinued in 1978

Source: Modified after NFS Lagoon Historical Data, August 30, 1985

Table 3-2 Chemical Storage and Usage at Nuclear Fuel Services, Inc. Erwin Facility (1984)

Type	Chemical	Average Annual Use	Max. Quantity Stored	Avg. Shipment Size	Approx. No. of Shipments/Yr.
Compressed Gas	Helium	22 cyl.	20	8	3
	Argon (Ar)	61 cyl.	20	9	7
	Oxygen	65 cyl.	12	6	10
	P-10 (90% Argon/10% Methane)	53 cyl.	8	5	10
	Acetylene	7 cyl.	5	2	4
	Nitrogen	1 cyl.	5	1	1
Liquified Gas	Carbon Dioxide	4.0 E 6 ft^3	48,000 ft^3	1.6 E 5 ft^3	25
	Argon	8.7 E 6 ft^3	450,000 ft^3	4.1 E 5 ft^3	21
	Hydrogen	10.4 E 6 ft^3	200,000 ft^3	1.8 E 5 ft^3	57
	Nitrogen	11.1 E 6 ft^3	400,000 ft^3	3.6 E 5 ft^3	31
Fuel	#2 Diesel Oil	199 gal.	10,000 gal.	66 gal.	3
	Natural Gas	4.5 E 4 ft^3			
	Lubricating Oils	1,000 gal.	500 gal.	100 gal.	10
	Gasoline	2,000 gal.	500 gal.	500 gal.	4
	Propane	20,000 gal.	5,000 gal.	2,000 gal.	10
Process Chemicals	67% Nitric Acid	43,000 gal.	5,000 gal.	3,600 gal.	12
	Tributyl Phosphate	594 gal.	500	198	3
	AMSCO 125	2,000 gal.	900	500	4
	Hydrochloric Acid	7,000 gal.	10,000 gal.	700 gal.	9
	Ammonium Hydroxide (25%)	4,000 gal.	4,000 gal.	700 gal.	6
	Sodium Hydroxide	1,700 gal.	1,000 gal.	425 gal.	4
	Acetone	700 gal.	275 gal.	175 gal.	4
	Hexanol	3,500 gal.	4,100 gal.	1,750 gal.	2
	Methyl Alcohol	2,700 gal.	400 gal.	385 gal.	7
	Detergent	2,000 lb.	1,000 lb.	1,000 lb.	2
	Sulfuric Acid	534 gal.	150 gal.	100 gal.	5
	Hydrogen Peroxide	11,500 gal.	2,000 gal.	1,500 gal.	8
Radioactive Chemicals	Low Enriched Uranium	16,500 kg.	50,000 kg.	1,400 kg.	12
	High Enriched Uranium		Refers to a Classified Product		
	Plutonium	0	0.350 kg.	0	0

Source: Nuclear Fuel Services, Inc. Environmental Report, July 27, 1984

Table 3-3
Annual Average and Quarterly Composite Groundwater Radioactivity from Well B in the Vicinity of 6000 Gallon Underground Holding Tanks (pCi/l or uCi/ml x 10^{-9})

		Type of Radiation				
Year	Quarters	Gross Alpha	Gross Beta	U-234	U-235	U-238
1979	3-4	-	-	289	10	6
1980	1-4	900	3473	40	6	7
1983	1-4	505	70	479	11	15
1984	1	188	28	102	2	0
1984	2	211	75	314	5	2
1984	3	226	51	185	7	2

Note: Analytical technique and MDA not available

Source: NFS Files, 1986

TABLE 4-1

WELL COMPLETION SUMMARY

Well No.	Coord X	Coord Y	Elevation of LSD (ft MSL)	Depth to Bedrock (ft)	Elevation of Bedrock (ft MSL)	Depth to Top of Wellscreen (ft)	Elevation of Top of Wellscreen (ft)	Depth to Base of Wellscreen (ft)	Elevation of Base of Wellscreen (ft)	Screen Length (ft)	Screen Diameter (in)	Wellscreen Materials	Depth to Top of Sandpack (ft)	Elevation of Top of Sandpack (ft)	Depth to Base of Sandpack (ft)	Elevation of Base of Sandpack (ft)	Thickness of Sandpack (ft)	Thickness of Bentonite Seal (ft)	Type of Monitoring Well
1	4681.52	2904.48	1647.95	21.5	1626.45	11.50	1636.45	21.50	1626.45	10.00	2.00	10-slot Sch 40 PVC	9.00	1638.95	21.50	1626.45	12.50	1.00	Unconsolidated
2	4680.37	2497.32	1641.08	12.5	1628.58						2.00	10-slot Sch 40 PVC							Unconsolidated
3	4437.51	2625.42	1641.10	10.5	1630.60						2.00	10-slot Sch 40 PVC							Unconsolidated
4	4472.99	2949.98	1642.31	16.0	1626.31						2.00	10-slot Sch 40 PVC							Unconsolidated
5	4220.29	2981.01	1636.61	10.2	1626.41	0.20	1636.41	10.20	1626.41	10.00	2.00	10-slot Sch 40 PVC	4.20	1632.41	10.20	1626.41	6.00	1.00	Unconsolidated
6	4056.03	3093.45	1633.70	13.0	1620.70						2.00	10-slot Sch 40 PVC							Unconsolidated
8	3628.25	2499.48	1638.41	9.5	1628.91	2.00	1636.41	8.90	1629.51	6.90	2.00	10-slot Sch 40 PVC	4.50	1633.91	9.50	1628.91	5.00	1.00	Unconsolidated
10	4017.63	2856.63	1635.36	11.0	1624.36	1.00	1634.36	11.00	1624.36	10.00	2.00	10-slot Sch 40 PVC	4.00	1631.36	11.00	1624.36	7.00		Unconsolidated
11	4244.06	2616.35	1640.42	11.0	1629.42	1.00	1639.42	11.00	1629.42	10.00	2.00	10-slot Sch 40 PVC	4.00	1636.42	11.00	1629.42	7.00	1.00	Unconsolidated
12	4199.78	2562.40	1638.86	11.5	1627.36	1.50	1637.36	11.50	1627.36	10.00	2.00	10-slot Sch 40 PVC	7.50	1631.36	11.50	1627.36	4.00	1.00	Unconsolidated
13	4474.92	2128.64	1641.98	13.7	1628.28	3.30	1638.68	13.30	1628.68	10.00	2.00	10-slot Sch 40 PVC	3.30	1638.68	13.70	1628.28	10.40	1.00	Unconsolidated
14	4349.31	2282.64	1639.47	9.7	1629.77	-0.50	1639.97	9.50	1629.97	10.00	2.00	10-slot Sch 40 PVC	3.70	1635.77	9.70	1629.77	6.00	1.00	Unconsolidated
21	4697.64	1942.43	1689.42	11.0	1678.42	7.50	1681.92	22.50	1666.92	15.00	4.00	10-slot Sch 40 PVC	5.50	1683.92	23.00	1666.42	17.50	1.00	Rome/Unconsolidated
22	4292.76	1680.63	1686.36	0.5	1685.86	14.00	1672.36	29.00	1657.36	15.00	4.00	10-slot Sch 40 PVC	13.00	1673.36	30.00	1656.36	17.00	1.50	Rome
23	4563.37	2232.62	1637.79	8.5	1629.29	5.50	1632.29	20.50	1617.29	15.00	4.00	10-slot Sch 40 PVC	4.50	1633.29	22.00	1615.79	17.50	1.50	Rome/Unconsolidated
24	4025.30	2594.33	1638.28	9.0	1629.28	3.00	1635.28	13.00	1625.28	10.00	4.00	10-slot Sch 40 PVC	2.50	1635.78	17.00	1621.28	14.50	1.50	Rome/Unconsolidated
25	3951.88	2618.02	1637.87	9.0	1628.87	7.00	1630.87	17.00	1620.87	10.00	4.00	10-slot Sch 40 PVC	6.00	1631.87	18.00	1619.87	12.00	1.50	Rome/Unconsolidated
26	4001.29	2671.11	1638.33	10.0	1628.33	8.00	1630.33	13.00	1625.33	5.00	4.00	10-slot Sch 40 PVC	7.00	1631.33	15.00	1623.33	8.00	1.50	Rome/Unconsolidated
27	3954.80	2559.91	1638.45	13.0	1625.45	7.50	1630.95	12.50	1625.95	5.00	4.00	10-slot Sch 40 PVC	6.00	1632.45	13.00	1625.45	7.00	1.50	Unconsolidated
28	3886.13	2631.16	1637.08	12.0	1625.08	7.50	1629.58	12.50	1624.58	5.00	4.00	10-slot Sch 40 PVC	6.00	1631.08	13.00	1624.08	7.00	2.00	Unconsolidated
29	4203.23	2407.18	1639.04	9.5	1629.54	9.00	1630.04	19.00	1620.04	10.00	4.00	10-slot Sch 40 PVC	8.00	1631.04	19.50	1619.54	11.50	2.00	Rome/Unconsolidated
30	4266.74	2556.87	1640.77	10.5	1630.27	20.50	1620.27	35.50	1605.27	15.00	4.00	10-slot Sch 40 PVC	18.50	1622.27	36.50	1604.27	18.00	2.00	Rome
31	4245.91	2578.92	1640.96	11.5	1629.46	14.00	1626.96	24.00	1616.96	10.00	4.00	10-slot Sch 40 PVC	13.00	1627.96	25.00	1615.96	12.00	2.00	Rome
32	4420.40	2456.65	1638.42	10.0	1628.42	11.00	1627.42	21.00	1617.42	10.00	4.00	10-slot Sch 40 PVC	10.00	1628.42	22.00	1616.42	12.00	2.00	Rome
33	4165.30	2480.35	1638.62	9.0	1629.62	7.00	1631.62	17.00	1621.62	10.00	4.00	10-slot Sch 40 PVC	6.00	1632.62	17.50	1621.12	11.50	1.00	Rome/Unconsolidated
34	4107.06	2745.25	1636.00	13.0	1623.00	7.50	1628.50	12.50	1623.50	5.00	4.00	10-slot Sch 40 PVC	6.00	1630.00	13.00	1623.00	7.00	1.00	Unconsolidated
35	4298.38	2354.23	1638.71	10.0	1628.71	8.00	1630.71	18.00	1620.71	10.00	4.00	10-slot Sch 40 PVC	7.00	1631.71	18.50	1620.21	11.50	1.50	Rome/Unconsolidated
36	4190.35	2661.35	1639.98	12.0	1627.98	5.50	1634.48	10.50	1629.48	5.00	4.00	10-slot Sch 40 PVC	4.50	1635.48	12.00	1627.98	7.50	0.50	Unconsolidated
37	4407.02	2563.53	1639.74	11.0	1628.74	23.50	1616.24	34.00	1605.74	10.50	4.00	10-slot Sch 40 PVC	22.00	1617.74	34.70	1605.04	12.70	1.50	Rome
38	4081.71	2393.48	1638.52	11.0	1627.52	10.00	1628.52	15.00	1623.52	5.00	4.00	10-slot Sch 40 PVC	9.50	1629.02	16.50	1622.02	7.00	1.00	Rome/Unconsolidated
39	4167.94	2322.81	1637.23	12.0	1625.23	7.00	1630.23	12.00	1625.23	5.00	4.00	10-slot Sch 40 PVC	5.50	1631.73	12.50	1624.73	7.00	1.00	Unconsolidated

TABLE 4-1
WELL COMPLETION SUMMARY

Well No.	Coord X	Coord Y	Elevation of LSD (ft MSL)	Depth to Bedrock (ft)	Elevation of Bedrock (ft MSL)	Depth to Top of Wellscreen (ft)	Elevation of Top of Wellscreen (ft)	Depth to Base of Wellscreen (ft)	Elevation of Base of Wellscreen (ft)	Screen Length (ft)	Screen Diameter (in)	Wellscreen Materials	Depth to Top of Sandpack (ft)	Elevation of Top of Sandpack (ft)	Depth to Base of Sandpack (ft)	Elevation of Base of Sandpack (ft)	Thickness of Sandpack (ft)	Thickness of Bentonite Seal (ft)	Type of Monitoring Well
40	4416.55	2209.70	1639.34	10.0	1629.34	5.00	1634.34	15.00	1624.34	10.00	4.00	10-slot Sch 40 PVC	4.00	1635.34	16.00	1623.34	12.00	1.00	Rome/Unconsolidated
41	4461.23	2318.64	1638.48	8.5	1629.98	18.50	1619.98	28.50	1609.98	10.00	4.00	10-slot Sch 40 PVC	17.50	1620.98	29.00	1609.48	11.50	1.00	Rome
51	3428.90	1578.51	1650.73	18.0	1632.73	8.00	1642.73	18.00	1632.73	10.00	4.00	20-slot Sch 40 PVC	5.00	1645.73	21.00	1629.73	16.00	2.00	Rome/Unconsolidated
52	4450.52	2123.00	1641.80	13.0	1628.80	4.00	1637.80	12.00	1629.80	8.00	4.00	20-slot Sch 40 PVC	4.00	1637.80	12.00	1629.80	8.00	2.00	Unconsolidated
54	3355.96	1449.99	1654.67	18.0	1636.67	13.00	1641.67	23.00	1631.67	10.00	4.00	20-slot Sch 40 PVC	11.00	1643.67	23.00	1631.67	12.00	2.00	Rome/Unconsolidated
55	4661.86	2478.95	1640.55	11.0	1629.55	5.50	1635.05	10.50	1630.05	5.00	4.00	20-slot Sch 40 PVC	4.00	1636.55	10.50	1630.05	6.50	2.00	Unconsolidated
56	4710.75	2860.01	1648.36	19.0	1629.36	6.50	1641.86	16.50	1631.86	10.00	4.00	20-slot Sch 40 PVC	3.50	1644.86	16.50	1631.86	13.00	2.00	Unconsolidated
57	4404.86	2965.38	1640.15	19.0	1621.15	9.00	1631.15	19.00	1621.15	10.00	4.00	20-slot Sch 40 PVC	7.00	1633.15	19.00	1621.15	12.00	2.00	Unconsolidated
58	4301.07	3090.95	1637.05	18.0	1619.05	8.50	1628.55	18.50	1618.55	10.00	4.00	20-slot Sch 40 PVC	5.00	1632.05	18.50	1618.55	13.50	1.50	Unconsolidated
59	4037.02	2946.77	1635.00	13.0	1622.00	7.50	1627.50	15.50	1619.50	8.00	4.00	20-slot Sch 40 PVC	4.50	1630.50	15.50	1619.50	11.00	2.00	Rome/Unconsolidated
60	4398.55	2793.04	1644.80	13.0	1631.80	10.00	1634.80	20.00	1624.80	10.00	4.00	20-slot Sch 40 PVC	8.00	1636.80	20.00	1624.80	12.00	1.50	Rome/Unconsolidated
62	4272.82	2735.53	1639.88	11.0	1628.88	8.00	1631.88	18.00	1621.88	10.00	4.00	20-slot Sch 40 PVC	6.00	1633.88	21.00	1618.88	15.00	2.00	Rome/Unconsolidated
63	4819.77	2683.45	1647.55	18.0	1629.55	9.00	1638.55	19.00	1628.55	10.00	4.00	20-slot Sch 40 PVC	7.00	1640.55	24.00	1623.55	17.00	2.00	Rome/Unconsolidated
64	4387.15	2587.32	1640.23	9.0	1631.23	5.00	1635.23	10.00	1630.23	5.00	4.00	20-slot Sch 40 PVC	3.50	1636.73	10.00	1630.23	6.50	2.00	Rome/Unconsolidated
65	4078.45	2908.31	1635.44	12.0	1623.44	23.00	1612.44	33.00	1602.44	10.00	4.00	20-slot Sch 40 PVC	19.00	1616.44	35.00	1600.44	16.00	1.50	Rome
66	4174.06	3100.99	1636.43	10.0	1626.43	18.00	1618.43	33.00	1603.43	15.00	4.00	20-slot Sch 40 PVC	13.00	1623.43	35.00	1601.43	22.00	3.00	Rome
67	4409.35	2622.51	1641.36	11.0	1630.36	100.00	1541.36	120.00	1521.36	20.00	4.00	20-slot Sch 40 PVC	85.00	1556.36	120.00	1521.36	35.00	4.00	Rome
68	4176.94	3111.69	1636.22	10.0	1626.22	4.50	1631.72	9.50	1626.72	5.00	4.00	20-slot Sch 40 PVC	3.50	1632.72	9.50	1626.72	6.00	2.00	Unconsolidated
70	4039.12	2156.70	1641.16	9.0	1632.16	12.00	1629.16	42.00	1599.16	30.00	4.00	20-slot Sch 40 PVC	6.20	1634.96	42.00	1599.16	35.80	3.70	Rome/Unconsolidated
71	3760.01	2491.59	1637.70	7.0	1630.70	20.00	1617.70	30.00	1607.70	10.00	4.00	20-slot Sch 40 PVC	10.00	1627.70	30.00	1607.70	20.00	3.50	Rome
72	3753.92	2474.50	1637.90	7.0	1630.90	4.00	1633.90	14.00	1623.90	10.00	4.00	20-slot Sch 40 PVC	3.00	1634.90	18.00	1619.90	15.00	2.00	Rome/Unconsolidated
73	3628.32	2278.95	1638.17	7.0	1631.17	1.50	1636.67	31.50	1606.67	30.00	4.00	20-slot Sch 40 PVC	2.00	1636.17	31.50	1606.67	29.50	1.00	Rome/Unconsolidated
74	3643.52	1843.18	1649.15	18.5	1630.65	9.00	1640.15	39.00	1610.15	30.00	4.00	20-slot Sch 40 PVC	5.00	1644.15	39.00	1610.15	34.00	2.50	Rome/Unconsolidated
75	3924.11	2403.24	1638.45	8.0	1630.45	0.00	1638.45	20.00	1618.45	20.00	4.00	20-slot Sch 40 PVC	5.00	1633.45	20.00	1618.45	15.00	2.00	Rome/Unconsolidated
76	4209.36	2616.97	1641.00	12.0	1629.00	37.50	1603.50	52.50	1588.50	15.00	4.00	20-slot Sch 40 PVC	28.50	1612.50	52.50	1588.50	24.00	2.50	Rome
77	4289.79	2580.41	1640.09	10.0	1630.09	30.00	1610.09	50.00	1590.09	20.00	4.00	20-slot Sch 40 PVC	14.50	1625.59	58.50	1581.59	44.00	4.50	Rome
78	4016.45	2528.05	1640.02	9.5	1630.52	4.00	1636.02	14.00	1626.02	10.00	4.00	20-slot Sch 40 PVC	2.00	1638.02	14.00	1626.02	12.00	1.50	Rome/Unconsolidated
79	4073.06	2570.86	1638.54	9.0	1629.54	20.50	1618.04	30.50	1608.04	10.00	4.00	20-slot Sch 40 PVC	5.00	1633.54	30.50	1608.04	25.50	2.00	Rome
80	3905.95	2657.29	1637.33	10.5	1626.83	11.00	1626.33	21.00	1616.33	10.00	4.00	20-slot Sch 40 PVC	5.00	1632.33	21.00	1616.33	16.00	1.00	Rome/Unconsolidated
81	3976.05	2716.48	1636.95	9.5	1627.45	31.00	1605.95	41.00	1595.95	10.00	4.00	20-slot Sch 40 PVC	20.00	1616.95	41.00	1595.95	21.00	4.00	Rome
82	3093.84	1596.14	1653.50	18.0	1635.50	62.00	1591.50	107.00	1546.50	45.00	4.00	20-slot Sch 40 PVC	52.00	1601.50	107.00	1546.50	55.00	1.00	Rome

Table 5-1 Generalized Section of Lower Paleozoic Formations in Northeastern Tennessee

Age	Group	Formation (Map Symbol)	Lithology	Thickness meters	Thickness feet
Lower Ordovician		Athens Shale Oa	Gray to black shale, calcareous below, sandy above	300-1500	1000-5000
		Knox Dolomite OCk	Gray to blue-gray limestone and dolomite, in part cherty; argillaceous seams in lower part	1200	4000
Upper Cambrian		Nolichucky Shale Cn	Green calcareous and dolomitic shale, and shaly dolomite	30	100
Middle Cambrian		Honaker Dolomite Chk	Gray to blue-gray dolomite and limestone, with many silty and shaly laminae	600	2000
		Rome Formation Cr	Red shale & siltstone, some green shale & dolomite; residual clay contains many manganese deposits	360-550	1200-1800
Lower Cambrian		Shady Dolomite Cs	Blue-gray, white & ribboned dolomite & limestone; residual clay contains many manganese deposits	270-360	900-1200
	Chilhowee Group	Erwin Formation Ce	White quartzite, greenish sandy shale and siltstone	360-460	1200-1500
		Hampton Formation Ch	Dark-greenish argillaceous shale, sandy shale & siltstone; some beds of arkosic quartzite	360-460	1200-1500
		Unicoi Formation Cu	Arkosic quartzite, conglomerate, arkosic sandy shale and siltstone; some beds of amygdaloidal basalt	600-1500	2000-5000

The Ocoee Group (Oc) conformably underlies the Chilhowee Group and it, as well as lowermost Chilhowee strata, is tentatively considered to be Precambrian age. The Sandsuck (Ss) and Snowbird (Sb) formations are members of the Ocoee Group, the Snowbird being the oldest and resting unconformably on Precambrian crystalline rocks. The correlation of Ocoee Group rocks in the Erwin area is uncertain with respect to similarly named units found further to the south.

Source: Modified after R. J. Ordway, Geology of the Buffalo Mountain-Cherokee Mountain Area, Northeastern Tennessee, Tennessee Department of Conservation and Commerce, Divisionof Geology, Report of Investigation No. 9, Nashville, Tennessee, 1959.

Table 6-1 Surveyed Wells and Springs Within a 5-mile Radius of the Nuclear Fuel Services, Inc. Erwin Facility

Spring or Well Number (w = well; s = spring)	Owner or Name of Spring or Well	Topographic Situation[a]	Altitude above Sea Level (ft)	Well Depth (ft)	Probable water-bearing beds		Yield (gallons per minute)	Use of Water Supply
					Character of Material	Geologic Horizon[b]		
1-w	Crystal Ice, Coal and Laundry Co.	V	1680	135	Dolomite	Chk	75	Industrial
2-s	Love Spring	V	1700		Dolomite	Cs	500	
3-w	Grady Ledford	V	1760	122	Sandstone	Ce	Not measured	Domestic
4-w	Sam Tipton	S	1720	80	Sandstone	Ce	Not measured	Domestic
5-s	E. L. Lewis	S	1920		Sandstone	Ce	5	Domestic
6-s	Unaka Springs	S	1720		Sandstone	Cu	Not measured	Domestic
7-s	Banner Hill Spring	V	1640		Shale	Cr	300	
8-s	Erwin Water Department	S	1730		Dolomite	Cs	640	Public
9-s	U.S. Dept. of the Interior Fish Hatchery	V	1760		Dolomite	Chk	916	Industrial
10-s	Erwin Water Department	S	1760		Dolomite	Chk	450	Public
11-w	Fess Radford	V	1340	30	Residual dolomite	Chk	Not measured	Domestic
12-s	Birchfield Spring	V	1650		Dolomite	Cs	2000	
13-w	Kelley Rice	V	1780	24	Residual dolomite	Cs	Not measured	Domestic
14-w	Charles Erwin	S	1900	323	Dolomite	Chk	Not measured	Domestic[c]
15-s	Yates Spring	V	1620		Sandstone	Cu	10	Domestic
16-w	W. B. Walker	V	1590	Not measured	Shale	Ch	3	Domestic

[a]Topographic Situation: V = Valley; S = Slope.
[b]Geologic Horizon: Chk = Honaker Dolomite, Cs = Shady Dolomite, Ce = Erwin Formation, Cu = Unicoi Formation, Cr = Rome Formation, Ch = Hampton Formation.
[c]Well supplies two houses.

Source: Nuclear Fuel Services, Inc., 1983

Table 6-2
Summary of Observed Groundwater Levels

Well No.	Minimum Measured Depth Below Ground Surface (ft)	Maximum Measured Depth Below Ground Surface (ft)	Measured Range of Groundwater Level Variation (ft)
1	8.42	12.30	3.88
2	2.25	2.92	0.67
3	4.51	6.82	2.31
4			0.00
5	3.46	4.37	0.91
6	2.46	4.69	2.23
8	2.46	8.35	5.89
10	4.25	5.97	1.72
13	4.70	5.78	1.08
14	3.43	4.24	0.81
23	-0.65	0.80	1.45
24	2.43	4.87	2.44
25	3.92	7.15	3.23
26	5.73	9.16	3.43
27	2.63	5.78	3.15
28	5.31	7.27	1.96
29	4.65	6.90	2.25
30	5.78	9.42	3.64
31	6.12	8.94	2.82
32	2.79	3.99	1.20
33	3.77	5.64	1.87
34	2.67	5.20	2.53
35	4.25	5.30	1.05
36	4.62	8.40	3.78
37	4.65	6.76	2.11
38	3.94	6.15	2.21
39	2.86	4.93	2.07
40	2.95	3.42	0.47
41	1.91	2.48	0.57
51	6.70	18.00	11.30
52	3.74	4.93	1.19
53	19.70	20.60	0.90
54	21.62	23.41	1.79
55	1.18	2.88	1.70
56	10.20	12.99	2.79
57	7.02	8.21	1.19
58	5.29	6.43	1.14
59	3.45	8.61	5.16
60	9.74	11.49	1.75
62	5.31	7.85	2.54
63	4.06	5.56	1.50
64	4.72	7.96	3.24
65	3.91	5.69	1.78
66	5.54	6.81	1.27
67	5.37	7.59	2.22
68	5.23	6.45	1.22
70	7.71	9.66	1.95
71	4.94	7.76	2.82
72	4.45	8.05	3.60
73	2.96	8.56	5.60
74	16.17	21.34	5.17
75	5.01	6.76	1.75
76	8.00	9.35	1.35
77	5.87	8.82	2.95
78	5.10	7.08	1.98
79	4.69	7.32	2.63
80	6.47	8.28	1.81
81	5.69	7.39	1.70
82	22.90	25.60	2.70
A	10.53	12.57	2.04

TABLE 6-3
WELL COMPLETION DATA

Well No.	Coordinates(ft) X	Coordinates(ft) Y	Aquifer Interval Screened	Surface Elevation (ft msl)	MP Elevation (ft msl)	Total Depth (ft)	Screen Interval Depth(ft)	Length Screen Interval(ft)	Depth Below M.P. to Water Level(ft)(8-23-88)	Static Water Level Elevation (ft msl)
30	3054266.738	652536.867	Rome	1640.77	1642.44	39.0	20.5-35.5	15.0	9.85	1632.59
31	3054245.909	652578.920	Rome	1640.96	1643.34	26.5	14.0-24.0	10.0	10.78	1632.56
32	3054420.403	652456.651	Rome	1638.42	1640.08	24.0	11.0-21.0	10.0	5.50	1634.58
36	3054190.353	652661.350	Uncon.	1639.98	1642.53	14.0	5.5-10.5	5.0	10.15	1632.38
37	3054407.022	652563.525	Rome	1639.74	1643.08	37.0	23.5-34.0	10.5	9.48	1633.60
60	3054398.554	652793.040	Rome, Uncon.	1644.80	1647.28	28.0	10.0-20.0	10.0	13.66	1633.62
62	3054272.821	652735.526	Rome, Uncon.	1639.88	1642.86	23.0	8.0-18.0	10.0	10.43	1632.43
64	3054387.151	652587.319	Uncon.	1640.23	1643.25	15.0	5.0-10.0	5.0	9.21	1634.04
67	3054409.345	652622.507	Rome	1641.36	1643.65	142.0	113.5-120.0	6.5	8.65	1635.00
76	3054209.359	652616.974	Rome	1641.00	1643.62	62.0	37.5-52.5	15.0	11.66	1631.96
77	3054289.791	652580.412	Rome	1640.09	1643.17	62.0	30.0-50.0	20.0	10.82	1632.35

TABLE 6-4: SUMMARY OF WELL 77 AQUIFER TEST ANALYSES (August 24-26, 1988)

Well No.(1)	Distance From Pumped Well(ft)	Theis (Hantush) T(2)	Theis (Hantush) S(3)	Theis (Hantush) r/B(4)	Jacob T	Jacob S	Residual Drawdown T	Distance Drawdown T	Distance Drawdown S	Estimated Aquifer Thickness(5) (ft)	Hydraulic Conductivity(6) (gpd/ft2)	Equivalent Permeability (md)(7)
30	33.0	2082	0.0490	0.100	1927	0.0350	2186			40	52.1	2863
31	43.9	1848	0.0031	0.100	2078	0.0019	1130			40	46.5	2538
32	179.9	15399	0.0044	0.050	17992	0.0034	10777			40	385.0	21154
36	128.2	11922	0.0170	0.000	12017	0.0140	12895			40	298.1	16379
37	118.4	9856	0.0051	0.075	9647	0.0043	10643			40	246.4	13538
60	238.8	13440	0.0068	0.000	13804	0.0055	13313			40	336.0	18462
62	156.0	14783	0.0061	0.150	14994	0.0049	11011			40	369.6	20308
64	97.6	4928	0.0051	0.200	5774	0.0033	4199			40	123.2	6769
67	126.8	14783	0.0130	0.000	15164	0.0110	15548			40	369.6	20308
76	88.4	21119	0.0170	0.100	21110	0.0140	21021			40	528.0	29011
77 Pumped Well		N/A(8)	N/A	N/A	1548	N/A	1022					2126
All Wells (1440 minutes)								1742	0.016			
Mean Values		11016	0.0127		10550	0.0097	9431			40	275.4	13951

(1) See Table 6-3 for well construction details.
(2) Transmissivity in gallons per day per foot (gpd/ft).
(3) Storage coefficient (non-dimensional).
(4) r= distance from pumped well, in feet; B= leakage factor, in feet; $r/B=\sqrt{r/(1/k'/b')}$.
(5) Aquifer thickness taken as interval from bedrock surface to bottom of Well 77.
(6) Based on transmissivity determined by Theis method except Well 77 which is based on Jacob method.
(7) One millidarcy (md) at 15.56°C(60°F)= 0.0182 gpd/ft2.
(8) Method not applicable to analysis.

TABLE 6-5: SUMMARY OF WELL 77 AQUIFER TEST ANALYSES (August 23-24, 1988)

Well No.(1)	Distance From Pumped Well(ft)	Theis (Hantush) T(2)	Theis (Hantush) S(3)	Residual Drawdown	Estimated Aquifer Thickness(4) (ft)	Hydraulic Conductivity(5) (gpd/ft2)
30	33.0	2460	0.0380	1942	40	61.5
31	43.9	1367	0.0020	2221	40	34.2
32	179.9	16773	0.0069	13389	40	419.3
36	128.2	15376	0.0018	18857	40	384.4
37	118.4	10250	0.0034	11315	40	256.3
60	238.8	18451	0.0031	16596	40	461.3
62	156.0	25449	0.0028	15490	40	636.2
64	97.6	4146	0.0042	4298	40	103.7
67	126.8	16401	0.0010	17001	40	410.0
76	88.4	26358	0.0081	20535	40	659.0
77 Pumped Well		N/A(6)	N/A	324	40	8.1
Mean Values		13703	0.0071	11088		312.2

(1) See Table 6-3 for well construction details.
(2) Transmissivity in gallons per day per foot (gpd/ft).
(3) Storage coefficient (non=dimensional).
(4) Aquifer thickness taken as interval from bedrock surface to bottom of Well 77.
(5) Based on transmissivity determined by Theis method except Well 77 which is based on residual drawdown method.
(6) Method not applicable to analysis.

TABLE 6-6: SUMMARY OF WELL 67 AQUIFER TEST
ANALYSES (May 25, 1988)

Well No.(1)	Distance From Pumped Well (ft)	Theis (Hantush) T(2)	Theis (Hantush) S(3)	Jacob T	Jacob S	Residual Drawdown	Estimated Aquifer Thickness(4) (ft)	Hydraulic Conductivity(5) (gpd/ft2)
37	59.0	6876	0.0055	6541	0.0076	5110	110	62.5
64	41.6	6032	0.0130	8388	0.0079	2948	110	54.8
67 Pumped Well		N/A(6)	N/A	N/A	N/A	4372	110	39.7

(1) See Table 6-3 for well construction details.
(2) Transmissivity in gallons per day per foot (gpd/ft).
(3) Storage coefficient (non-dimensional).
(4) Aquifer thickness taken as interval from bedrock surface to bottom of Well 67.
(5) Based on transmissivity determined by Theis method except Well 67 which is based on residual drawdown method.
(6) Method not applicable to analysis.

TABLE 6-7
SUMMARY OF WELL 77 DISTANCE-
DRAWDOWN ANALYSES (August 24-26, 1988)

Time Since Pumping Began (min)	Transmissivity (gpd/ft)	Storage Coefficient (units)
100	6079	0.0033
200	4546	0.0041
500	2702	0.0077
800	2213	0.0105
1000	1942	0.0118
1440	1742	0.0160

TABLE 6-8
RADII-OF-INFLUENCE RESULTING
FROM CONTINUOUSLY DEWATERING AN INDIVIDUAL
POND FOR DRAWDOWNS GREATER THAN ONE FOOT (Feet)

Time After Pumping Begins Days	Discharge Due to Pumping 10 gpm	25 gpm	50 gpm	100 gpm
15	16	285	780	1380
30	23	405	1105	1950
90	39	700	1915	3375
180	56	990	2710	4775
270	68	1210	3315	5850
360	79	1400	3830	6755

TABLE 6-9
WELL 77 SPECIFIC CAPACITY
(gpm/foot Drawdown)

Length of Pumping Period (hours)	Pumping Rate (gpm)							
	6.1[1]	12.6[1]	12.9[2]	16.4[1]	19.5[1]	28.0[1]	41.3[1]	43.9[1]
0.5	3.91[3]		3.33					
1.0		3.30[4]	2.89	3.44[3]				
1.5			2.67				3.14[3]	
2.0			2.50		2.70[4]			
3.0			2.20			1.50[4]		
3.5			2.13					1.40[4]
6.0			2.06					
12.0			1.42					
24.0			1.27					

(1) Step-drawdown tests (August 22 and 27, 1988)
(2) Long-term pumping test (August 24-26, 1988)
(3) Length of pumping period as shown, but only 0.5 hour at given pumping rate.
(4) Length of pumping period as shown, but only 1.0 hour at given pumping rate.

TABLE 6-10
SUMMARY OF SOIL PERMEABILITIES
DETERMINED BY WATER INJECTION TESTS

Well No.	Aquifer	Transmissivity (gpd/ft)	Coefficient of Permeability(k) (ft/day)	(cm/sec)
23	Rome	1425	9.7	3.4 E-3
37	Rome	713	3.5	1.2 E-3
39	Unconsolidated	59	1.0	3.7 E-4
52	Unconsolidated	792	13.0	4.5 E-3
55	Unconsolidated	1351	21.5	7.5 E-3
56	Unconsolidated	311	6.1	2.2 E-3
57	Unconsolidated	1031	12.7	4.4 E-3
58	Unconsolidated	497	5.5	1.9 E-3
59	Unconsolidated	783	10.3	3.6 E-3
60	Unconsolidated, Rome	900	13.8	4.8 E-3
62	Unconsolidated, Rome	431	5.5	1.9 E-3
63	Unconsolidated	1553	15.2	5.3 E-3
64	Unconsolidated	408	13.9	4.9 E-3
65	Rome	651	3.2	1.1 E-3
66	Rome	1575	8.0	2.8 E-3
67	Rome	5756	6.8	2.4 E-3
68	Unconsolidated	205	7.3	2.6 E-3
71	Rome	3326	18.8	6.6 E-3
72	Unconsolidated	133	2.4	8.4 E-4
73	Unconsolidated, Rome	998	5.9	2.1 E-3
79	Rome	3054	17.2	6.0 E-3
81	Rome	1088	4.3	1.5 E-3
82	Rome	5345	8.7	3.0 E-3

TABLE 6-11

BANNER SPRING BRANCH STREAMFLOW

Date of Measurements (in gallons/minute)

Location	5/3/88	5/12/88	5/17/88[1]	6/2/88	6/16/88
Road Culvert[4]	N/A[6]	282	360[2]	250	262
Upper Staff Gage	269	259	N/A[3]	241	N/A[6]
Middle Staff Gage[5]	281	324	435	329	N/A[6]
Lower Staff Gage	207	269	865	241	218

Notes:

(1) Measurements made following heavy rain.
(2) Measurement includes both spring discharge and overland runoff.
(3) No measurement possible due to backwater effects from downstream culvert.
(4) Measurements do not include upstream withdrawal for cooling water.
(5) Measurements include gains due to marsh tributary, seepage and Building 220 cooling water.
(6) No measurement made.

RAI 9

Attachment 2

1992/1993 Nuclear Fuel Services

Hydrogeologic Investigation and Monitoring Well Installation Program,

June 30, 1994

1992/1993 NUCLEAR FUEL SERVICES

HYDROGEOLOGIC INVESTIGATION AND

MONITORING WELL INSTALLATION PROGRAM

Volume I
Text

Prepared for

Nuclear Fuel Services, Inc.
1205 Banner Hill Road
Erwin, Tennessee 37650

Prepared by

EcoTek, Inc.
1219 Banner Hill Road
Erwin, Tennessee 37650

June 30, 1994

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1.0 INTRODUCTION

This report presents the planning, methods, and results of a drilling, monitoring well installation, and hydrogeologic characterization program conducted at Nuclear Fuel Services, Inc. (NFS) from November 30, 1992 to May 13, 1993. NFS is a nuclear fuel fabrication and uranium scrap recovery facility located in Erwin, Tennessee. The facility is licensed by the Nuclear Regulatory Commission (NRC) and is regulated by the Environmental Protection Agency (EPA) through a RCRA Hazardous and Solid Waste Amendments (HSWA) permit. EcoTek, Inc. (EcoTek) provided study objectives, technical oversight of field operations, and data interpretation for the characterization. Drilling services were subcontracted by EcoTek to Boyles Bros. Drilling Company, Murfreesboro, Tennessee.

The program was conducted for two purposes 1) to further characterize site hydrogeology and 2) to install groundwater monitoring wells in compliance with HSWA permit and NRC requirements. Several geologic studies have been conducted at NFS since 1986 (EcoTek 1989, TLG 1987). These studies have provided a hydrogeologic framework which the subject program builds upon.

1.1 Scope

The scope of the investigation included coring at nine locations to establish the elevation of the top of bedrock and to determine the nature of the shallow bedrock. Coreholes were hydraulically tested and geophysically logged to investigate the possibility of subsurface fractures and to provide further data for bedrock characterization.

In addition to coring, twenty-five monitoring wells and six piezometers were installed. The wells and piezometers were installed around and downgradient of the radioactive waste burial ground (EcoTek 1993a), the 6,000 gallon underground wastewater tanks (EcoTek 1993b), the soil excavation site on CSX property (SWMU 8) and the burial trenches on CSX property (SWMU 11) (EcoTek 1993c), and Building 234. Well and piezometer locations are shown on Figure 1-1. Most of the wells and piezometers were screened in the shallow alluvium, and a few were screened in shallow bedrock.

Other activities included slug testing new wells and rehabilitation of existing wells.

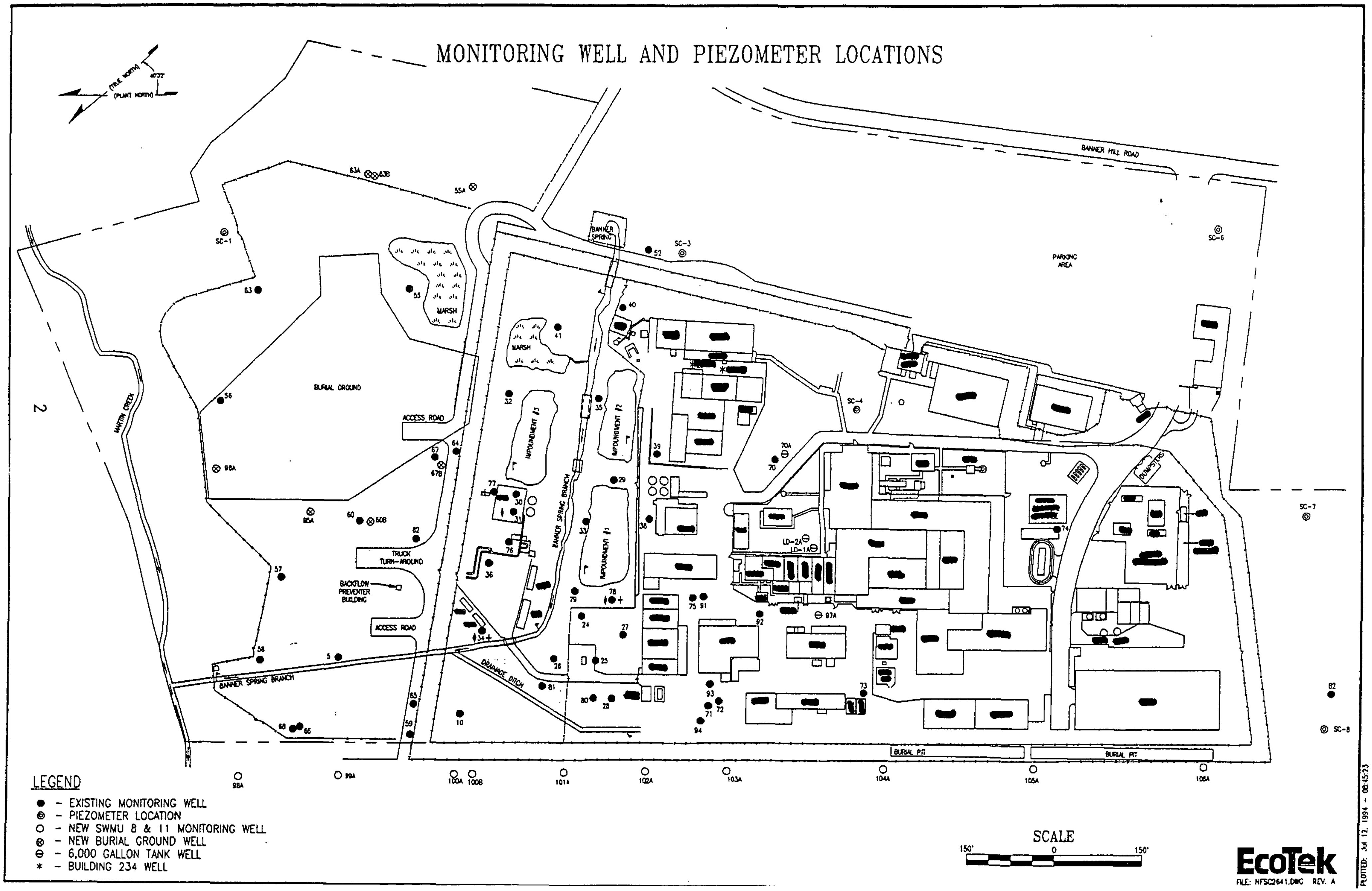
1.2 Objectives

The objectives of the drilling and well installation program were to:

(1) establish the elevation of the top of bedrock beneath the plant and the geologic nature of the bedrock, by:

- continuously coring nine locations;

Figure 1-1



MONITORING WELL AND PIEZOMETER LOCATIONS
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
PARKING AREA
BURIAL GROUND
MARSH
ACCESS ROAD
IMPOUNDMENT #1
IMPOUNDMENT #2
IMPOUNDMENT #3
BANNER SPRING BRANCH
BANNER SPRING
MARTIN CREEK
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
DRAINAGE DITCH
DUMPSTERS
BURIAL PIT
LEGEND
● - EXISTING MONITORING WELL
◎ - PIEZOMETER LOCATION
○ - NEW SWMU 8 & 11 MONITORING WELL
⊗ - NEW BURIAL GROUND WELL
⊖ - 6,000 GALLON TANK WELL
* - BUILDING 234 WELL
SCALE
150' 0 150'
EcoTek
FILE: NFSC2641.DWG REV. A
PLOTTED: Jul 12, 1994 - 08:45:23

- packer testing coreholes;

- geophysically logging coreholes;

(2) increase understanding of head relationships between hydrologic zones by the installation of well clusters and piezometers;

(3) increase the potentiometric database for the NFS site;

(4) improve the groundwater monitoring network;

(5) provide a means for detecting contaminant releases to groundwater from the burial ground, SWMUs 8 and 11, two 6,000 gallon underground wastewater tanks, and Building 234 by installing groundwater monitoring wells; and

(6) determine upgradient versus downgradient groundwater quality in the vicinity of the burial ground, SWMUs 8 and 11, the tanks, and Building 234.

1.3 Site Location

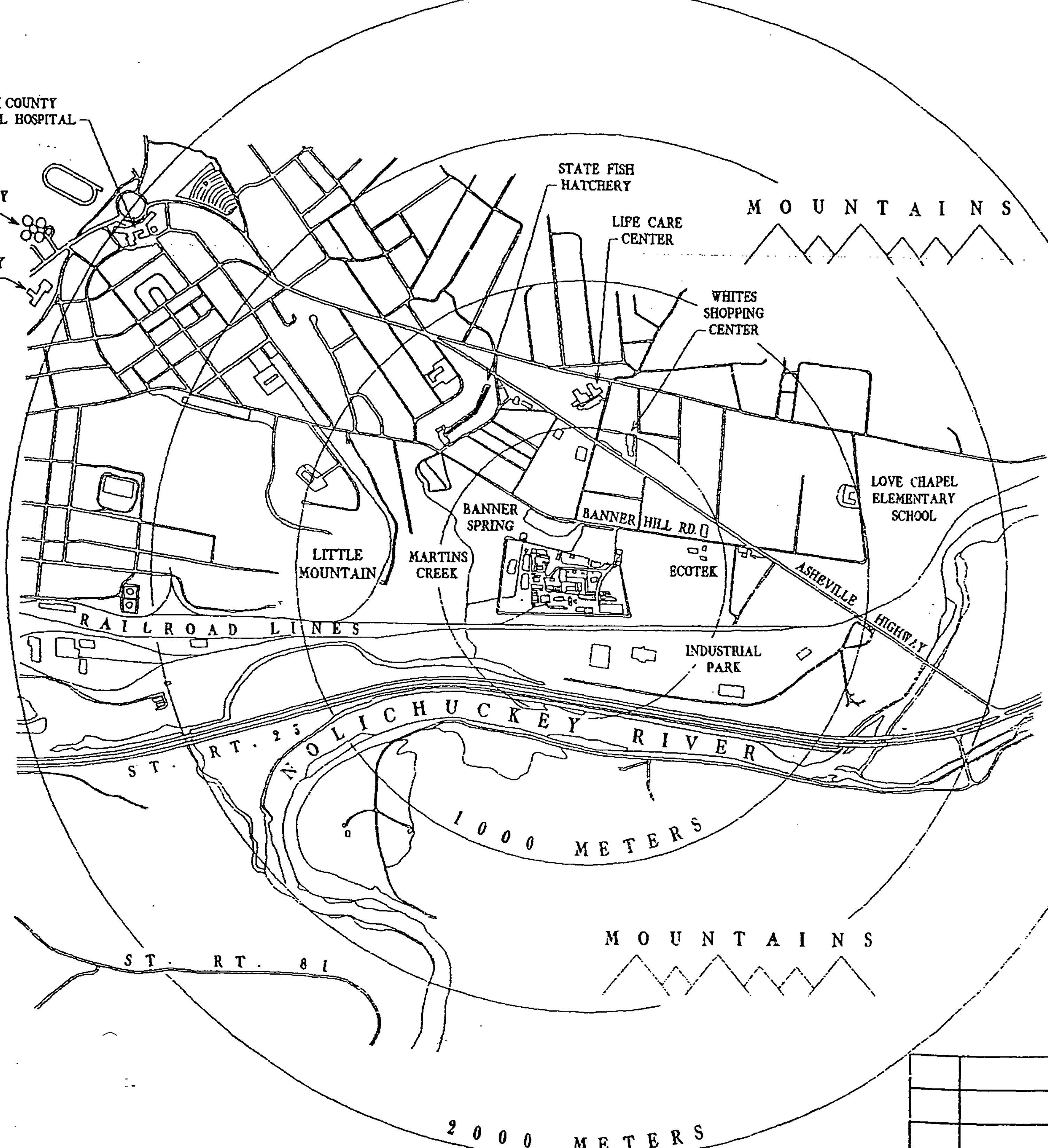
1.3.1 Site Description

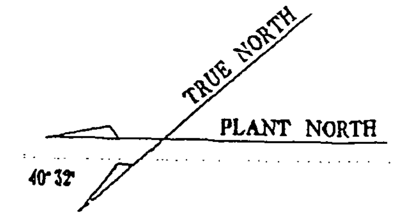
The NFS property encompasses 57.8 acres. The facility buildings, parking lots, and other structures occupy approximately 21 acres (Figure 1-2). The site is bordered on the south by Banner Hill Road and private residences, respectively. To the south and southwest, housing density is relatively low. The CSX Railroad right-of-way parallels the site boundary on the northwest. An industrial park is located to the northwest of the railroad. Martin Creek bounds the site to the northeast, with privately-owned, vacant, and low density residential land on the other side of the creek.

1.3.2 Regional Setting

NFS is located in northeast Tennessee within the city limits of the town of Erwin in Unicoi County. The facility lies in the alluvial valley of the Nolichucky River. Along much of the Nolichucky River, there is little clearly defined floodplain; but in the vicinity of Erwin, the confluence of the Nolichucky and the North and South Indian Creeks form a relatively broad alluvial valley bordered by the Unaka province to the southeast and the Valley and Ridge to the northwest. At the NFS facility, the valley is approximately 3,000 feet wide. The surrounding upland region is characterized by rugged mountains rising from 1650 feet above mean sea level (msl) to elevations of 3,500 to 5,000 feet msl within a few miles of the

FIGURE 1-2
NFS SITE LOCATION





UNCLASSIFIED

Reviewed By [signature] Date 10-15-90
AUTHORIZED CLASSIFIER
Nuclear Fuel Services, Inc.

BY	DATE	REVISION	LET

NUCLEAR FUEL SERVICES, INC.
ERWIN, TENNESSEE

NAME
NFS PLANT AND AREA MAP

MADE BY BILL HENSLEY	SCALE 1"-1500'	DATE 6-22-89	
TRACED BY DB			
CHECKED BY	DRAWING NO.	RMG-1272B	SHEET 2 OF 2
APPROVED BY J.A. LYLES			

plant.

Several geologic studies have been published on the area of northeast Tennessee, in which the NFS Erwin plant is located. These include: King and Ferguson 1960; Ordway 1959; Debuchananne and Richardson 1956; and Rogers 1953. These references have been used to establish the regional geologic setting of the facility.

Unicoi County lies entirely within the Blue Ridge physiographic province. Its southeast boundary follows the crest of Iron, Unaka, and Bald Mountains, and its northwest boundary follows the crest of Buffalo and other mountains. These mountains are underlain primarily by quartzite and other clastic rocks of Cambrian and pre-Cambrian age. They project 1,000 to 2,500 feet above the adjacent lowlands. The long valley between these two lines of mountains is underlain chiefly by the Honaker dolomite, Rome formation, and Shady dolomite, all of Cambrian age (DeBuchananne and Richardson 1956).

The NFS Erwin Plant lies just outside of the southwest corner of the Buffalo Mountain-Cherokee Mountain area mapped by Ordway in the late 1950's. The Buffalo Mountain-Cherokee Mountain area is underlain by Cambrian and Ordovician sedimentary rocks. These rocks were folded and thrust faulted during the Appalachian Orogeny (Ordway 1959). The area has been extensively mapped and the rock types in the valley and along the bordering ridges are known so that an adequate geologic setting for the NFS Erwin site can be described. According to Ordway, in this area, bedrock differences are reflected in the topography. The mountainous area consists mainly of sedimentary clastic rocks-pebble conglomerates, graywackes, sandstones, quartzites, siltstones, and shales-which have been thrust upon the younger rocks of the Valley and Ridge province.

The entire area along the Blue Ridge/Valley and Ridge transition is characterized by thrust faults and contemporaneous lesser faults such as strike slip faults. Rogers "Geologic Map of East Tennessee" depicts several fault contacts between the ridges on either side of the Nolichucky River Valley near Erwin. The Buffalo Mountain Fault is mapped just northwest of the NFS-Erwin site. No faults have been mapped through or adjacent to the plant site.

As previously discussed, mapped rock units in and along the valley occupied by the NFS facility include the Rome formation, Shady dolomite and Honaker dolomite, all of Cambrian age. The Rome is described by King and Ferguson as largely, red, maroon, or brown shale, mostly silty and well consolidated. Outcrops on and around the NFS plant site include silty competent shale, but also finer grained and softer, less competent beds of shale. The Shady consists largely of blue-gray and white dolomite, but includes small amounts of limestone and a few beds of shale. Outcrops of Shady around the NFS site include fine-grained, competent dolomite as well as weathered, soft and crumbly beds of shaley dolomite. The Honaker dolomite is described by Ordway as "dark-blue limestone with numerous distinct tan-brown silty laminae which show on weathered surfaces". Across the Nolichucky River northwest of NFS, there is a large quarry into blue-gray dolomite, mapped as Honaker by Rogers, 1953. Dr. Kenneth Hasson, Professor of Geology at East Tennessee State University, believes that this quarry outcrop is actually Shady dolomite (Hasson 1993). His explanation is that a large synclinal fold underlies the valley with the fold axis somewhere near the CSX rail line. Therefore, the Shady should be in contact with the Rome to the northwest and southeast of the axis. Hasson also believes that the contact between the Rome and Shady is an interfingering one. The theory is supported to some degree by the fact that interbeds of Rome shale are found with blue-gray to white dolomite, throughout the Erwin area. Hasson's theory is also based on years of field mapping in the NFS/Erwin area.

Valley floors within the Unaka province (NFS is located in a valley adjacent to the Unaka province) are cut mainly on the Shady dolomite and Rome formation. They are floor-like, mainly by contrast with the steeper mountains. They are complex in detail consisting of hills, ridges, sinks, and terraces, all more or less dissected by recent drainage. Their surfaces expose unweathered bedrock, residuum, and gravel deposits (King and Ferguson 1960).

All the valley floor surface has long been subject to weathering in a warm humid climate. This weathering has produced a blanket of residuum (weathered rock material) over the bedrock. The thickest and most extensive masses of residuum overlie the Shady dolomite. Residuum is thinner over the Rome formation as it contains greater thicknesses of poorly soluble shale beds (King and Ferguson 1960).

Wide areas of the bedrock and residuum of the valley floors are covered by rudely stratified deposits of gravel, made up of water-rounded pebbles, cobbles, and boulders of sandstone and quartzite. These deposits were derived from the Chilhowee group (lower Cambrian quartzite, shales, and sandstones) in the adjacent mountains and were brought to their present position by streams. Where best preserved and least dissected, they form steep fans or piedmont alluvial slopes along the mountain bases; and they flatten into gravel plains farther out in the valleys. Gravels were laid down when more material was washed onto the valley floors from the adjacent mountains than streams could carry out of the region. The bases of the gravel deposits, as exposed in artificial openings, lie unconformably on the eroded surfaces of fresh bedrock, weathered bedrock or residuum (King and Ferguson 1960).

Alluvium also underlies the present floodplains. Like the earlier gravel deposits, it includes pebbles, cobbles, and boulders of quartzite, sandstone, and plutonic and metamorphic rocks, derived from the mountains. It also includes much sand from the same sources, and clay from the carbonate rocks and shale (King and Ferguson 1960).

2.0 FIELD INVESTIGATION

The field investigation consisted of:

- continuous coring at nine locations;
- geophysical logging of five coreholes;
- packer testing of five coreholes;
- six piezometer installations;
- two corehole abandonments;
- installation and development of twenty-five monitoring wells;
- slug testing twenty-four wells; and
- rehabilitation of twenty-two previously installed wells.

Three drilling rigs were used during the project, a track mounted Terramec 1000, a Mobile B-61, and a Mobile B-80. Each rig was capable of coring, augering and mud rotary drilling. Rigs were decontaminated with a high pressure hot water wash prior to their use on site. Each rig was then inspected to ensure that all soil, oil, grease, and hydraulic fluid had been removed. Downhole drilling and sampling equipment was decontaminated between every location with a high pressure hot water wash. Equipment blanks were obtained to determine the effectiveness of this process.

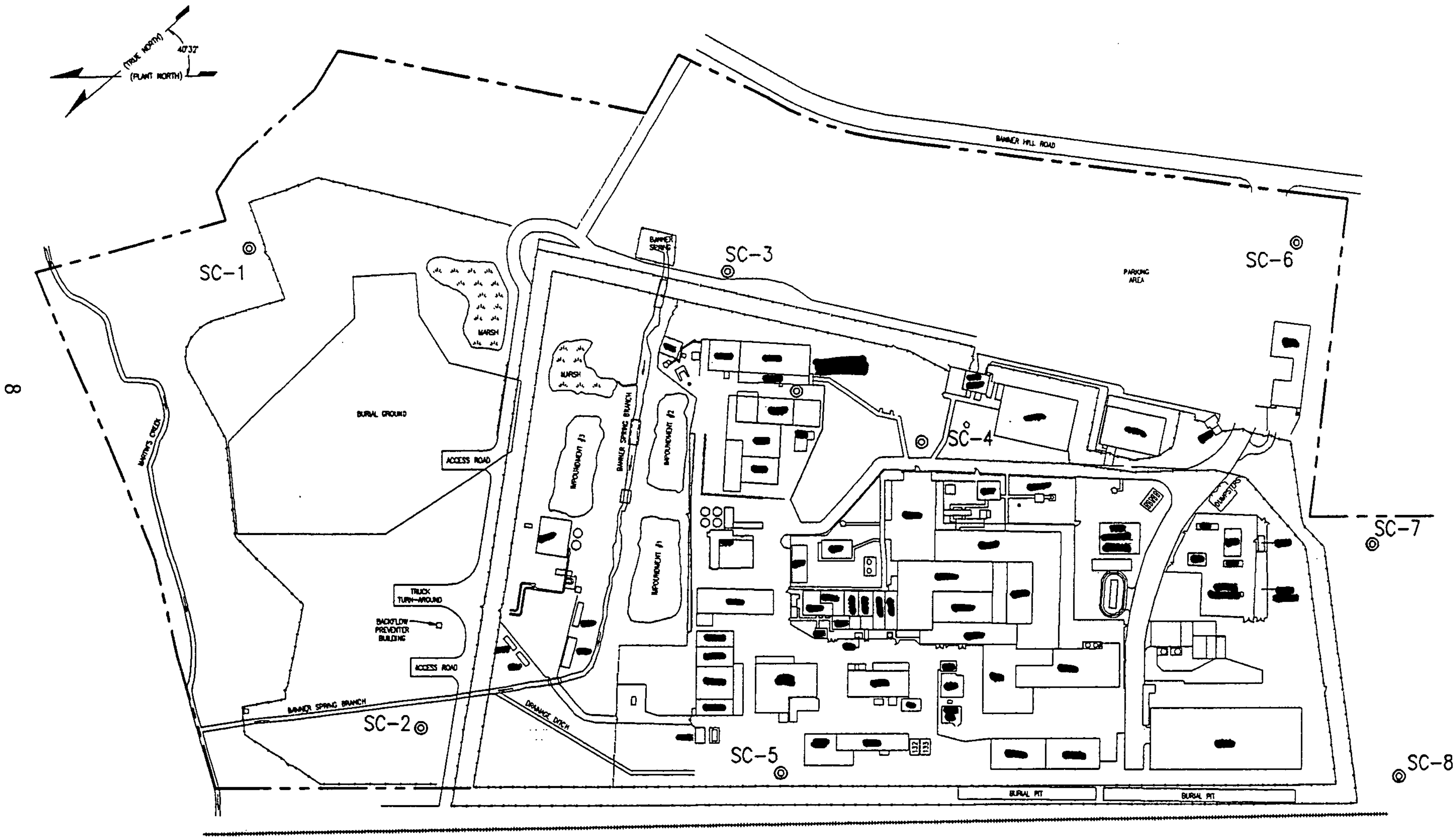
NFS approval was obtained prior to drilling at any location to ensure that underground utilities were not encountered. Cuttings were drummed in areas of potential contamination and at all borings located on the CSX right-of-way. A log of drill site activities was maintained daily by the field geologist. These records are included in Appendix A.

2.1 Coreholes for Site Characterization

Drilling locations were spread out across the plant site (Figure 2-1) and were chosen to provide transects for geologic cross sections perpendicular to strike, parallel to strike and

Figure 2-1

COREHOLE LOCATIONS



LEGEND

◎ COREHOLE LOCATION

SC-1 COREHOLE NUMBER

SCALE

250' 0 250'

EcoTek

oblique to strike. Coreholes were drilled sixty to eighty feet into the subsurface. Once coring was complete at SC-1, SC-3, SC-6, SC-7, and SC-8, packer testing was conducted to determine hydraulic conductivity of the geologic material. Details of the procedure used for packer testing and results are provided in section 2.3.1. Lithologic correlation and porosity estimations were supplemented at these locations by running a suite of borehole geophysical logs. After hydraulic testing and logging were complete, piezometers were installed in SC-1, SC-3, SC-4, SC-6, SC-7, and SC-8. Three coreholes,(SC-2, SC-5, and 234-1) were abandoned. SC-2 was abandoned because of difficult drilling conditions. SC-5 was drilled in an area where contamination was previously indicated, therefore, the corehole was abandoned to prevent potential contamination of deeper formation materials. Corehole 234-1 was abandoned because the geologic material encountered was nearly impermeable making it unsuitable as a well location.

A mud rotary coring system with a retrievable inner barrel was used for coring. To enhance core recovery in soft sediment, a split tube was used as the inner barrel. A face discharge bit and soft sediment shoe were used for drilling unconsolidated material and shale. Dolomite bedrock was drilled with an impregnated bit and a rock shoe. Clear Mud™, an inert polymer, was used to maintain borehole stability and hold the core together at locations where no groundwater contamination was suspected. Bentonite powder was used at all other locations to maintain borehole stability. After coring through the unconsolidated material and cobble zone, four-inch temporary casing was set in each hole to prevent caving as coring continued into the bedrock.

Prior to coring, drill rod length and mud pan height were measured. Mud pan height was subtracted from the drill rod length to establish a mark representing ground surface that was visible on the drill rod. Depth to be drilled was then measured and marked on the drill rod so that cored depths remained accurate. Core was described and boxed on site by a field geologist under the supervision of a Tennessee Registered Professional Geologist (RPG). A field geologic log was prepared for each corehole. These logs were combined with geophysical logs and piezometer construction information to form composite geologic logs. The composite logs are included in Appendix B. Composite logs were not created for two of the coreholes that were not geophysically logged. The field geologic logs for these two holes (SC-2 and SC-5) are included in Appendix C.

2.1.1 Geophysical Logging

Geophysical logging was conducted by Geological Logging Systems a division of Marshall Miller & Associates. Coreholes SC-1, SC-3, SC-6, SC-7 and SC-8 were logged to attempt to define zones of high porosity (fractures, etc.) and to augment core logs for determining lithologies through intervals where core recovery was incomplete. Logs run included gamma, neutron, spontaneous potential, resistivity (long & short normal, single point, and lateral), caliper, temperature, sonic, and compensated density (gamma-gamma). Following are brief summaries of these logging methods condensed from Keys, 1989.

Gamma

Gamma logs are used for lithologic determinations and for stratigraphic correlation by providing a record of the naturally occurring radiation in the borehole. Potassium-40 and daughter products of the uranium and thorium decay series are the most significant naturally occurring gamma-emitting radioisotopes in water-bearing rocks. A small percentage (0.012%) of the potassium in feldspar and mica that decompose to clay is potassium-40. Uranium and thorium are concentrated in clay by adsorption and ion exchange. Therefore, clay and shale tend to be more radioactive than quartz sand and carbonate rocks. Limestone and dolomite are generally less radioactive than shale.

Neutron

Neutron logs are primarily used for moisture content and porosity determinations and have also been shown to be beneficial for lithologic determinations. Neutron logs record the neutron interactions in the vicinity of the borehole. Most of these interactions are related to the amount of hydrogen present, which, in ground water investigations is a function of the water content of the rocks. Some anomalously large apparent porosities may be interpreted from shale and clay because of bound water; therefore, neutron logs should be interpreted with other logs.

Sonic

Sonic logs are records of the travel time of an acoustic wave from one or more transmitters to the receiver in the logging probe. The travel time is related to the matrix mineralogy and porosity of the rocks. Acoustic velocity increases with rock hardness and cementing. Solution openings and fractures may cause cycle skips in the sonic log. If cycle skips occur, caliper logs can be used to identify these potential openings in the rock.

Caliper

Caliper logs provide a continuous record of borehole diameter and are beneficial for identifying secondary porosity. Borehole diameter may vary as a result of drilling impact and changes in lithology. Boreholes drilled in hard rocks such as limestone and dolomite have a smaller diameter than adjoining shale. Thin beds have an irregular trace. Secondary porosity created by fractures and solution cavities are prominent on a caliper log.

Spontaneous-Potential

Spontaneous-Potential logs are useful for determinations of lithology, bed thickness and salinity of formation water. These logs record potentials or voltages that develop at the contacts between shale or clay beds. Spontaneous potential is a function of chemical activities of borehole fluids and fluids in adjacent rocks, temperature, and the type and quantity of the clay present. Porosity and permeability are not directly related to spontaneous potential.

Resistivity

Single-point resistivity (single point, long and short normal) measures resistance in ohms, between an electrode in the well and an electrode at the land surface or between two electrodes in the well. These logs measure apparent resistivity and they need to be corrected for borehole diameter, mudcake thickness, and borehole fluid. Single-point logs are excellent for lithologic correlation and for determining water quality. Saturated silt, clay and shale have low resistivities. Sand and gravel saturated with fresh water have high to moderate resistivities. High resistivities are seen from sandstone and limestone saturated with fresh water.

Compensated Density (Gamma-Gamma)

Gamma-gamma logs are records of the radiation received at a detector from a gamma source in the probe, after it is attenuated and scattered in the borehole and surrounding rocks. Gamma-gamma logs are used in lithology determinations and to determine bulk density, porosity, and moisture content.

Temperature

Temperature logs are useful for determining movement of water in the borehole and for locating discrete intervals where water enters or exits the borehole. Therefore, these logs can provide valuable information on fracture locations.

2.1.2 Piezometer Installations

Piezometers were installed in six of the nine coreholes for the purpose of obtaining water level data in locations where potentiometric data were sparse. Piezometers were screened across the water table or in the bedrock, depending upon the particular data needs. Based on the selected screen interval, the portion of the corehole below the interval to be screened was backfilled with granular bentonite or a combination of sand and bentonite. Screens were placed at the base of coreholes SC-1 and SC-4; and therefore, no back plugging was necessary.

Piezometers were constructed of one-inch diameter PVC casing with slotted PVC screen. Prior to placement in the corehole, casing and screen were decontaminated with a high pressure hot water wash and casing length was measured to within 0.01 foot and recorded. Sand pack material was placed from the bottom of the corehole to a minimum height of two feet above the screen. A minimum of two feet of bentonite pellets were placed above the sand pack. Bentonite pellets were allowed to hydrate for at least eight hours prior to placement of annular grout. Sand and bentonite pellets were installed by pouring into the annular space. The final depths of all annular materials were measured to within 0.10 foot with a weighted tape. Measurements of all annular materials for each piezometer were recorded on a monitoring well diagram.

The remaining annulus of each piezometer was grouted with a cement/bentonite slurry consisting of portland cement with three to six percent (by volume) bentonite. The grout mix was verified to weigh between 12 and 14 pounds/gallon, using a mud scale, prior to pumping it into the annular space. Construction details for piezometers are listed in Table 2-1.

2.1.3 Corehole Abandonment

Three coreholes, SC-2, SC-5, and 234-1, were abandoned after coring was complete. During drilling of SC-2, no core was recovered from 18-38 feet and drilling fluid loss was substantial. Repeated attempts to install temporary casing through the poor circulation zone were unsuccessful. Large cobbles/boulders encountered above 18 feet consistently caved into the borehole and the hardness of this material prevented successful drilling of the casing through it. After attempts to install casing were ceased, coring resumed to establish the depth of competent bedrock. Bedrock (apparently dolomite based on no reaction to HCl) was encountered at approximately 38 feet, and the corehole was advanced to 42 feet. Because of the inability to install temporary casing and the difficulty in maintaining circulation, the corehole was abandoned by grouting from the bottom up with a cement/bentonite grout.

SC-5 was cored in an area where groundwater contamination had been previously detected. The corehole was advanced to a depth of 60 feet to verify the top of bedrock and to characterize the upper bedrock. A piezometer was not installed at SC-5 because the installation of permanent surface casing would have been required to prevent cross contamination from the alluvium into the bedrock and this was not included in the project scope. Consequently, the corehole was abandoned by grouting.

Table 2-1

PIEZOMETER
CONSTRUCTION DETAILS

Well No.	Ground Surface Elevation (ft msl)	Total Depth Drilled	Total Depth of Installed Well	Screen Slot Size	Depth of Screened Zone	Depth to Top of Sand Pack	Depth to Top of Bentonite Pellets	Well Head Type
SC-1	1648.97	80.00	77.80	.010	72.65-77.65	69.50	67.50	Above Ground
SC-3	1643.19	78.60	59.54	.010	49.65-59.43	45.35	35.83	Above Ground
SC-4	1646.10	60.00	60.00	.010	55.00-60.00	52.50	50.20	Flush Mount
SC-6	1661.86	79.00	30.38	.010	20.49-30.27	17.42	11.35	Flush Mount
SC-7	1653.33	77.00	28.73	.010	18.60-28.60	15.90	14.00	Above Ground
SC-8	1651.68	77.00	34.90	.010	19.79-29.56	17.29	14.75	Above Ground

*All depths in feet

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Location 234-1 was originally intended to be used for a monitoring well after coring. During coring, a nearly impermeable clay was encountered and the hole was deemed unsuitable for a well installation. Consequently, the hole was abandoned.

Coreholes were abandoned by pumping a quantity of cement/bentonite grout equal to one borehole volume through a tremie pipe from the bottom of the hole. The slurry (grout) was verified to weigh between 12 and 14 pounds/gallon. If after 24 hours of curing, the grout level was below land surface, additional grouting was conducted until cured grout was level with the ground surface.

2.2 Monitoring Well Installations

Twenty-one alluvial wells were drilled to depths from twelve to twenty-six feet. These wells were screened to accommodate seasonal fluctuations in the water table. Four wells were drilled into the bedrock to depths of thirty-two to forty-one feet. The bedrock wells were screened to allow monitoring of the shallow bedrock and to provide head measurements adjacent to water table wells. Figure 1-1 shows new piezometer and well locations. During drilling for the well installations, geologic information was gathered from split spoon samples and cuttings, and geologic logs were created. As each monitoring well was installed, a well construction diagram was prepared. These diagrams were brought in from the field and combined to form well logs. The well logs are included in Appendix D.

Several references were consulted during the planning and conduct of the monitoring well installation program to ensure compliance with the intent of regulatory guidance. These documents included the Technical Enforcement Guidance Document (EPA 1986), Region IV Standard Operating Procedures and Quality Assurance Manual (EPA 1991a), and Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells (EPA 1991b).

2.2.1 Alluvial Wells

A variety of methods were used in drilling the boreholes for monitoring well installations. Hollow stem augering is the simplest and least expensive method for installing shallow wells. For this reason, initial efforts focused on augering. After a few attempts, it was learned that the augers would not advance into the cobble/boulder zone and in most cases, therefore, would not provide a deep enough hole for the well installation. Wells 99A and 63A were installed through 6 1/4-inch inner diameter (I.D.) hollow stem augers. It was determined after installing the first two wells, that the amount of annular space between the 4-inch casing and the 6 1/4-inch I.D. auger made installation of annular materials difficult. A change was made to 8 1/4-inch I.D. augers. Two wells, Well 101A and Well LD-2A, were successfully installed using 8 1/4-inch I.D. augers. As previously stated, augering was not successful in most cases. A drill through casing driver system (trade name ODEX) was used for several well installations replacing the auger method. ODEX involved the use of an air percussion hammer that advanced threaded steel casing as it progressed down hole. When the desired depth was achieved, the bit was tripped out and the well was installed through the casing. As annular materials were installed, the casing was backed out. The method was very successful with the only limitation being that the system utilized 6" diameter casing and the annular space was very small making it difficult to install annular materials. Wells 70A, 97A, 98A, 102A, 103A, 104A, and 105A were installed through the 6-inch ODEX system. Wells LD-1A, 55A, and 96A were installed using a combination of 8 1/4-inch hollow stem auger and 6-inch ODEX.

To overcome the limitations of the 6-inch ODEX system, EcoTek requested that the drilling contractor provide an 8-inch I.D. system. The system was promptly delivered and Wells 63B, 95A, 100A, 106A, 107A, 234-2, and 234-3 were installed using the larger ODEX. Drilling methods, borehole diameters and total depths are listed for each well and corehole in Table 2-2.

At each borehole, split spoon samples were collected at intervals of five feet and continuously through the screened zone, in most cases. In some instances, geologic conditions (such as when cobbles were encountered) prevented split spoon samples from being obtained through the zone to be screened. If split spoon samples were not obtainable, drill cuttings were collected at intervals of one to two feet. Cuttings and split spoon samples were logged and representative samples were archived in sealed glass jars.

Alluvial monitoring wells were constructed of four-inch diameter schedule 40 PVC casing with slotted PVC screen. Screen lengths for alluvial wells were ten feet. Screens were set so that at least two and no more than four feet of screen extended above the water table. Water level depth was obtained from existing, similarly screened wells within 100 feet of the new well. When these data did not exist, depth to the water table was determined in the field by leaving the hollow stem augers or ODEX in the hole and taking a water level measurement after twelve hours. Prior to placement in the borehole, well casing and screen were decontaminated with a high pressure hot water wash and casing length was measured to within 0.01 foot and recorded.

Sand pack size was determined based on results of sieve analyses of representative samples of the formation material in the screened zones using a method described in Groundwater and Wells (Driscoll 1986). Samples were not collected and analyzed from each borehole, but a representative group was tested. The grain size in the saturated alluvium was consistent enough across the plant site to apply the results of the analyses to all of the wells, with the exception of

Table 2-2

Monitoring Well/Corehole Drilling Method Descriptions

Well Number	Drilling Method	Depth Drilled (ft)	Nominal Borehole Diameter (in)
55A	8 1/4" ID Hollow Stem Auger 6" ID ODEX	0–4 4–15	12 5/8 8
60B	8" ID Driven Steel Casing 6" ID ODEX	0–23.73 23.73–35.5	9 5/16 8
63A	6 1/4" ID Hollow Stem Auger	0–14.60	10 5/8
63B	8" ID ODEX	0–25.40	9 5/16
67B	8" ID Driven Steel Casing 6" ID ODEX	0–19.73 19.73–32.20	9 5/16 8
70A	6" ID ODEX	0–16.17	8
95A	8" ID ODEX	0–16.90	9 5/16
96A	8 1/4" ID Hollow Stem Auger 6" ID ODEX	0–17.10 17.10–18.40	12 5/8 8
97A	6" ID ODEX	0–15.90	8
98A	6" ID ODEX	0–24.60	8
99A	6 1/4" ID Hollow Stem Auger	0–21.00	10 5/8
100A	8" ID ODEX	0–23.20	9 5/16
100B	8" ID Driven Steel Casing 7 3/4" Air Rotary (Roller Cone)	0–30.00 30.00–40.55	9 5/16 7 3/4–7 7/8
101A	8 1/4" ID Hollow Stem Auger	0–20.04	12 5/8
102A	6" ID ODEX	0–24.40	8
103A	6" ID ODEX	0–20.04	8
104A	6" ID ODEX	0–24.25	8
105A	6" ID ODEX	0–23.40	8
106A	8" ID ODEX	0–24.20	9 5/16
107A	8" ID ODEX	0–25.00	9 5/16
107B	8" ID Driven Steel Casing 7 3/4" Air Rotary (Roller Cone)	0–26.09 26.09–40.26	9 5/16 7 3/4–7 7/8
LD–1A	8 1/4" ID Hollow Stem Auger 6" ID ODEX	0–14.50 14.50–17.00	12 5/8 8
LD–2A	8 1/4" ID Hollow Stem Auger	0–13.00	12 5/8
234–1	HX Core Barrel	0–34.00	3.65
234–2	8" ID ODEX	0–22.00	9 5/16
234–3	8" ID ODEX	0–15.00	9 5/16
SC–1	HX Core Barrel	0–80.00	3.65
SC–2	HX Core Barrel	Abandoned	3.65
SC–3	HX Core Barrel	0–79.00	3.65
SC–4	HX Core Barrel	0–60.00	3.65
SC–5	HX Core Barrel	Abandoned	3.65
SC–6	HX Core Barrel	0–79.00	3.65
SC–7	HX Core Barrel	0–80.00	3.65
SC–8	HX Core Barrel	0–77.00	3.65

a few borings that had a distinctly finer grained formation material in the screened zone. The filter sand size was chosen by multiplying the 70% retained grain size by a conservative factor of four to obtain the 70% retained of the theoretical filter material. Using semi-log graph paper, a curve was drawn through the calculated 70% retained point so that the uniformity coefficient of the curve was between 1.5 and 2.5 (uniformity coefficient equals 40% retained divided by 90% retained). The filter sand provided by Boyles Bros. (Bonsal medium) was near enough in size to the theoretical curve to warrant its use in most of the installations. A screen slot size of 0.015 was then chosen based on the 90% retained sand pack size. In the few wells screened in finer grained formation material, a .010 slot screen was used with the same medium filter sand. Appendix E contains the sieve analysis data.

Sand pack material was placed from the bottom of the borehole to a height approximately two feet above the screen. Approximately one foot of fine sand was placed above the sand pack, and two feet of bentonite pellets were placed above the fine sand. Bentonite pellets were allowed to hydrate a minimum of eight hours prior to placement of annular grout. Sand pack, fine sand, and bentonite pellets were installed by pouring into the annular space. The final depths of all annular materials were measured to within 0.10 foot with a weighted tape. Measurements of all annular materials for each well were recorded on a monitoring well diagram.

Wells were then grouted with a cement/bentonite slurry consisting of portland cement with three to six percent (by volume) bentonite. The grout was verified to weigh 12 to 14 pounds/gallon prior to installation into the annular space. Alluvial well specifications are documented in Table 2-3.

2.2.2 Bedrock Wells

Four wells were installed into the bedrock during the project. To avoid the possibility of spreading contamination vertically from the alluvium into the bedrock, permanent steel casing was seated into the bedrock and grouted in place before advancing each hole for the well installation. The casing used was 8 5/8-inch outer diameter (O.D.) Schedule 40 carbon steel. Ideally, permanent casing should be installed through a borehole large enough to allow for complete annular grouting providing a grout bond around and under the casing. Geologic conditions at the NFS site precluded maintaining a large diameter open borehole through the unconsolidated alluvium. Therefore, a system was devised to drive the casing into place. This was accomplished by fabricating a drive shoe that could be welded onto a section of casing five feet in length and then, using the air percussion hammer, the section of casing was driven into the ground in the same manner as the ODEX system.

Table 2-3

ALLUVIAL WELL
CONSTRUCTION DETAILS

Well No.	Ground Surface Elevation (ft msl)	Total Depth Drilled	Total Depth of Installed Well	Screen Slot Size	Depth of Screened Zone	Depth to Top of Sand Pack	Depth to Top of Fine Sand	Depth to Top of Bentonite Pellets	Well Head Type
55A	1641.49	16.00	14.27	0.015	1.41-11.41	1.10	NA	0.00	Above Ground
63A	1643.26	14.60	12.96	0.015	2.60-12.59	1.20	NA	0.00	Above Ground
70A	1641.82	16.17	16.01	0.015	5.65-15.64	4.25	3.10	0.00	Above Ground
95A	1643.76	18.20	16.62	0.015	6.25-16.25	4.20	3.00	1.00	Above Ground
96A	1647.00	18.40	18.24	0.015	6.27-16.25	3.20	NA	0.00	Above Ground
97A	1638.52	15.90	15.83	0.015	3.00-12.96	1.40	NA	0.60	Flush Mount
98A	1642.27	24.60	22.70	0.015	9.85-19.83	7.10	7.10	5.10	Flush Mount
99A	1642.03	21.00	19.72	0.015	9.33-19.35	7.30	6.50	3.00	Flush Mount
100A	1642.72	23.20	23.09	0.015	10.26-20.24	8.60	5.00	2.40	Flush Mount
101A	1642.84	20.04	19.89	0.015	9.54-19.52	8.00	6.90	3.70	Flush Mount
102A	1643.25	24.40	24.17	0.015	11.56-21.54	7.44	NA	2.70	Flush Mount
103A	1643.92	24.04	23.71	0.015	10.86-20.86	8.80	7.30	4.90	Flush Mount
104A	1645.44	24.25	23.57	0.015	10.83-20.82	8.25	7.40	4.75	Flush Mount
105A	1647.77	23.40	22.29	0.010	11.94-21.92	9.08	8.17	5.75	Flush Mount
106A	1650.63	24.20	23.83	0.015	13.47-23.46	11.58	10.60	8.40	Flush Mount
107A	1649.20	25.00	23.67	0.015	10.08-20.80	8.33	7.00	5.00	Above Ground
LD-1A	1638.90	17.00	16.70	0.010	6.34-16.33	3.50	2.50	1.50	Flush Mount
LD-2A	1639.91	13.00	13.00	0.010	2.63-12.63	1.10	NA	0.74	Flush Mount
234-2	1638.52	22.00	15.30	0.015	2.50-12.50	2.50	1.50	0.50	Flush Mount
234-3	1638.33	15.00	12.20	0.015	2.20-12.20	2.20	1.50	0.50	Flush Mount

NA = Fine sand seal not installed due to shallow depth of top of screen

* All depths in feet

As each length of casing was advanced, an additional section was welded on to create a string of casing, until total depth was reached (3 to 4 feet into competent bedrock). The bit used cut a 9 5/8-inch diameter hole which theoretically provided a 1/2-inch annular space. In reality, this annulus was not open and was filled with disturbed material.

Upon reaching total depth, the casing was lifted approximately one foot off of the bottom of the hole. A header equipped with a pressure gauge and ball valve was welded to the top of the casing. A cement/bentonite slurry consisting of 5% by volume bentonite, with a weight of 12 to 14 pounds/gallon was pumped through the header until the casing was full. This was verified by calculating the inside volume of the casing. When the casing was full of grout, a volume of water equal to 75% of the casing volume was pumped through the header, under pressure, to displace 75% of the grout. This would leave a substantial grout plug in the bottom of the casing and force some of the grout into the annular space, displacing the disturbed material. The pressure gauge was used to indicate that the grout was indeed being displaced by the water and that the pressure allowed the water to keep the grout from flowing back in. The following day, the valve was removed and a weighted tape was lowered through the port in the header to verify the existence of a grout plug. After the grout had cured for 24 hours, the header was removed and a 7 3/4-inch rotary bit was used to drill through the grout plug and into the bedrock to a depth adequate to install a monitoring well so that its five feet of screen was completely within bedrock. The top of the screen was set so that the annular seal would be inside the 8-inch steel casing.

In three of the four bedrock well installations, the grouting of the steel casing went as planned. In grouting the casing at Well 100B, no grout plug was left at the bottom. The tagged depth to grout was several inches below the bottom of the casing. An additional quantity of grout was added to bring the level up into the casing before proceeding.

At Wells 100B and 107B, air rotary methods were used to advance the borehole below the steel casing into bedrock to install the well. At Wells 60B and 67B, six inch ODEX was used inside the eight inch permanent casing to advance the boring into bedrock.

Originally, steel surface casing was planned for the installation of Well 63B. Upon drilling the borehole for 63B, it was discovered that the unconsolidated overburden was thicker in that area of the site (east) and that 63B could be installed at a similar horizon to the other B wells without penetrating bedrock. Therefore, Well 63B is actually, a deep alluvial well rather than a bedrock well although it shares a similar horizon with shallow bedrock wells and its head is used with other bedrock heads for mapping groundwater flow from that horizon. Bedrock well construction details, including Well 63B, are listed in Table 2-4.

Table 2-4
BEDROCK WELL

CONSTRUCTION DETAILS

Well No.	Ground Surface Elevation (ft/msl)	Total Depth Drilled	Total Depth of Installed Well	Screen Slot Size	Depth of Screened Zone	Depth to Top of Sand Pack	Depth to Top of Fine Sand	Depth to Top of Bentonite Pellets	Well Head Type	Total Depth of 8" Casing
60B	1644.42	36.00	34.06	0.015	26.19–31.19	23.82	22.77	20.40	Above Ground	21.81
63B	1643.44	25.50	25.40	0.015	20.03–25.03	18.10	17.12	14.82	Above Ground	NA
67B	1640.48	32.20	31.95	0.015	24.10–29.10	21.70	21.05	19.10	Above Ground	19.73
100B	1642.79	40.55	40.55	0.015	35.18–40.18	32.70	31.90	29.90	Flush Mount	30.00
107B	1649.52	40.25	38.16	0.015	30.21–35.31	28.00	27.00	24.17	Above Ground	26.09

* All depths in feet

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2.3 Hydraulic Testing

2.3.1 Packer Testing

Packer tests were conducted on coreholes SC-1, SC-3, SC-6, SC-7, and SC-8 to determine hydraulic conductivity of tested intervals. Intervals to be tested were selected based on zones that might represent both high and low hydraulic conductivity. Zones of potential high conductivity were crumbly shale and zones thought to contain soil filled fractures (some of these were later determined to be boulders in a sandy/clayey matrix). Clayey shale zones and competent dolomite zones were selected as intervals of potential low hydraulic conductivity.

A double packer assembly was placed in the corehole to isolate the selected interval. Once the assembly was placed, the packers were pressurized to seal off the interval to be tested. Water was then pumped into the interval at the desired pressure by means of a header and a bypass valve. Test pressure was determined by the "two-thirds" rule which limits the test pressure (in psi) to two-thirds the depth of the test interval. Three pressure steps were used to test each interval starting with a low pressure and building to a pressure nearly equal to 2/3 of the depth. Each step lasted a minimum of five minutes. Elapsed time, flow rate, and pressure were recorded during pumping. Appendix F contains packer test field measurements. Hydraulic conductivity for each tested interval was calculated using the following equation:

$$K = C_p \frac{Q}{H} when (L \geq 10r)$$

Where:

$$C_p = \frac{1}{2\pi L} \times \ln \frac{L}{r}$$

Q	=	constant rate of flow into the hole (ft^3/day)
H (gravity)	=	depth to water table + height of water swivel above ground surface
H (pressure)	=	PSI of water flowing into the formation x 2.31 feet/PSI
H	=	H (gravity) + H (pressure)

L	=	length of the portion of the hole tested (ft)
r	=	radius of the hole tested (ft)

The results of the packer testing are discussed in Section 4.0. The calculations are provided in Appendix G.

2.3.2 Slug Tests

Slug tests were conducted to obtain hydraulic conductivity estimates at all new well locations. This method of testing was selected for several reasons: 1) slug tests can be conducted with minimal resources, 2) a short period of time is required to conduct the test, and 3) disposal of potentially contaminated discharge water is not a concern.

Equipment and procedures used to perform the slug tests were selected based on the requirements of the Bouwer-Rice analytical method (Bouwer 1976) and physical requirements due to the relation of the water table and screened zone. The Bouwer-Rice method requires an instantaneous introduction (or removal) of a known volume of water to or from a well. Most tested wells were installed with a portion of the screen above the water table to allow for seasonal fluctuations. A falling head test, in which an instantaneous head rise is induced through displacement by a solid cylinder, causes water to flow out into the unsaturated zone surrounding the upper screen. This results in anomalously high hydraulic conductivity values. Therefore, in cases where the screen straddled the water table, a rising head test was used by inducing an instantaneous drop in head within the well using a bailing device.

2.3.2.1 Calculation of Induced Head Change

The bailer used to induce an instantaneous head change in tested wells, was 3.5 inches in diameter and 3.0 feet in length. The calculated volume of the bailer was 0.212 cubic feet. Upon removal, this created a drop in head of 2.34 feet inside a monitoring well 4.0 inches in diameter.

2.3.2.2 Field Testing Procedure

A field testing procedure was developed for slug testing that provided the parameters necessary to use the Bouwer-Rice analysis method and to meet site requirements. The slug test procedure was conducted as follows: 1) the static water level was obtained using an electric well sounding tape and this datum was recorded; 2) a pressure transducer was inserted and secured 1.0 foot from the bottom of the well; 3) the bailer was inserted into the well just below the water table surface and allowed to fill, causing a positive head change in the well casing; 4) the water level inside the well was allowed to return to static condition, determined by measuring the water level with the well sounding tape; 5) the reference level for the probe was set at zero; and 6) the bailer was quickly removed inducing an instantaneous drop in head, and the data logger was simultaneously started to record water level recovery on a logarithmic cycle. The measurement interval started with hundredths of minutes and increased to a maximum of one every two minutes. When the water level returned to static or near static conditions (+/- 10%), the test was terminated. Appendix H contains the slug test data.

2.3.2.3 Data Analysis

The Bouwer-Rice method was used to estimate hydraulic conductivity for the wells tested. This method is applicable to fully or partially penetrating wells in unconfined aquifers and assumes negligible drawdown of the water table in the vicinity of the well and no flow above the water table. The Bouwer-Rice equation for estimating hydraulic conductivity is:

$$K=\frac{r_c^2\ln\left(\frac{R_e}{r_w}\right)}{2L_e}\ \frac{1}{t}\ \ln\frac{y_0}{y_t}$$

where

where	R_e	=	effective radial distance over which the head difference y is dissipated;
	r_c	=	radius of the section where the water level is rising;
	r_w	=	radial distance between well center and undisturbed aquifer (r_c plus thickness of the sand pack or developed zone outside the well casing);
	L_e	=	height of screened section through which groundwater enters;
	y	=	the head in the well;

y_o = y at time zero;

y_t = y at time t;

t = time since y_o.

An empirical equation is used that relates R_e to the geometry of the boundary conditions of the system:

$$\ln\frac{R_e}{r_w} = \frac{1}{\dfrac{1.1}{\ln\left(\dfrac{L_w}{r_w}\right)} + \dfrac{A+B\ln\left[\dfrac{(H-L_w)}{r_w}\right]}{\left(\dfrac{L_e}{r_w}\right)}}$$

where A and B are dimensionless parameters found by comparing their relationship to L_e/r_w on a graph of curves provided by Bouwer-Rice. The observed values of y are plotted against t on semilog paper (y on the log scale). Appendix I contains semi-log data plots and calculations used to estimate hydraulic conductivity. The slug test results are discussed in Section 4.0

2.4 Monitoring Well Development

After installation, each monitoring well was developed to optimize its effectiveness for groundwater monitoring. Well development is the process in which the fine particulate matter surrounding the well bore is drawn into the well and purged. Well development on this project was accomplished to satisfy three objectives: 1) pull fines from the filter material and borehole wall into the well for purging; 2) remove all fluids introduced during drilling until purged water was representative of natural formation water; and 3) maximize the yield of each well.

2.4.1 Well Development Method

Well development began by mechanical bailing to remove sand and sediment from the bottom of each well. Bailing continued until the sand content was less than 0.5% by volume measured on a sand gauge. Each well was then surged with a surge block. A well development rig provided by the subcontractor was used for surging. Drill rods were attached to the surge block and lowered into the well via a cable attached to a winch on the development rig. The winch was used to raise and lower the surge block forcing water through the sand pack into the aquifer and pulling water from the aquifer through the sand pack into the well. This process stabilized the filter pack by breaking sand bridges, graded the filter pack sand into a fining outward (radially) condition, and pulled fine particles into the well. The wells were surged and bailed, alternately. Bailing removed sand and sediment pulled into the well during surging. This process was continued until the well water was free of sand, and pH, temperature, and conductivity had stabilized.

After development of several monitoring wells by surging and bailing (Wells 55A, 63A, 96A, 98A, 99A, and 101A), the use of the surge block was discontinued. The remaining wells were developed by bailing and pumping because it was determined that the objectives could be met more efficiently by pumping rather than surging and bailing. The bailer used to develop the wells was 3 inches in diameter. The size and capacity of the bailer provided limited surging action, thus stabilizing the filter pack. Wells were bailed, then pumped with a centrifugal pump. The intake of the pump was placed at the bottom of the well to remove material pulled into the well by development. The wells were pumped at a high rate (typically 10 to 12 gallons per minute). Some wells produced enough water to be pumped continuously while others could be pumped for only a few minutes before well capacity was exceeded. Purged water was contained in 55 gallon drums. The amount of water purged ranged from 200 to 1000 gallons per well.

A static water level reading was taken at each well before development began. This datum was used to calculate the volume of water in the well casing. The number of well casing volumes purged from the well was logged on a well development record along with sand content, pH, temperature, conductivity, and observed turbidity. Table 2-5 provides well development results. Appendix J contains the well development records.

2.4.2 Well Development Results

Most of the wells were developed until pH, temperature, and conductivity stabilized, and pumped water was free of solids. Several wells did not produce clear water after considerable development (Wells 99A, 101A, and 107B). Well 99A was developed using a combination of surging and bailing. The well was slow to recover after bailing. Well 99A was installed through hollow stem augers and drill cuttings from the auger flights may have dropped off the flights and mixed with the filter pack during installation, clogging the well screen, and reducing its effectiveness. Well 101A was also installed through hollow stem

Table 2-5

Well Development Results

Well Number	Final pH	Final Temperature (C)	Final Conductivity (uS)	Turbidity (Observed)	Total Volume Purged (Gal)
55A	6.02	9.0	186	Low	90
60B	6.90	14.2	372	Low	860
63A	6.95	9.5	279	Low	90
63B	6.99	13.7	311	Low	770
67B	7.03	14.7	375	Low	890
70A	6.98	18.2	330	Low	340
95A	6.89	13.3	317	Low	715
96A	6.85	11.9	236	Low	225
97A	6.60	13.4	619	Low	205
98A	7.09	15.5	646	Low	106
99A	7.09	15.5	646	Moderate	79
100A	6.89	14.7	707	Low	450
100B	6.93	14.4	672	Low	935
101A	6.82	13.0	491	Low	160
102A	6.85	15.2	320	Low	262
103A	7.20	15.3	342	Low	350
104A	7.09	13.5	320	Low	230
105A	7.00	14.9	470	Low	225
106A	6.84	13.9	461	Low	130
107A	7.02	14.1	422	Low	320
107B	7.02	14.4	412	Moderate	420
LD-1A	7.00	13.9	393	Low	210
LD-2A	6.79	11.4	493	Low	251

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augers and displayed the same characteristics as Well 99A.

All bedrock wells produced enough water to be pumped continuously at 10 to 12 gallons per minute facilitating rapid development. Well 107B was the only bedrock well that did not produce clear water. Problems with mud suspending in the borehole were encountered during drilling of 107B. The mud was allowed to settle overnight before installation of the filter pack. Some of the mud may have remained suspended and mixed with the filter pack during installation causing the turbidity in the purged water.

During development of Well 96A an excessive amount of sand was removed from the well (~ 5 gallons). The sand was clean, white, and very well sorted (similar to fine filter pack material). It is thought that the driller may have inadvertently poured a bag of fine sand into the annulus as filter material. Nonetheless, the well was successfully developed until the sand content in the purged water was less than 0.5% by volume.

Final water quality readings (pH, temperature, and conductivity) taken during the course of development ranged from 6.02 to 7.20 for pH; 9.0° C (degrees celsius) to 18.2° C for temperature; and 186 μS (micro secants) to 707 μS for conductivity. Development of all project wells occurred over several months. Ambient air temperature was variable during this time and may have affected groundwater temperature measurements. The range of temperature values, therefore, is potentially less than the results indicate.

2.5 Well Head Completion

Following final annular grouting, each well was completed to increase its extended service. Two methods of well completions were used; above ground and flush mount. Above ground completions consisted of placing a six-inch square protective steel casing with a hinged locking cap around the PVC casing stickup (2.5 feet above grade). The protective steel casing was seated at least 18 inches into the well annulus. Two weep holes ¼-inch in diameter were drilled into the protective casing to prevent standing water problems. A four feet x four feet x six inch square concrete pad was constructed around each well. The pad was peaked to prevent rain water from collecting around the well casing. Four, three inch diameter guard posts were installed outside the corners of the pad. The five feet long posts were installed with two feet below ground surface in a concrete footing. Concrete was placed inside each guard post for additional strength and rounded off at the top. Each above ground completion was equipped with a metal tag to facilitate field identification.

Flush mount completions were installed by excavating a 12-inch diameter space to a depth of two feet around the well casing. The PVC well casing was then cut off approximately 0.20 feet below land surface. An eight inch diameter steel sleeve with a water tight, rubber sealed cover was set over the PVC casing into the excavation so that the closed cover was flush with the ground surface. The annulus between the 12-inch hole and the eight inch sleeve was filled with concrete. Signs were installed to identify the locations of flush mount wells installed on CSX railroad property. The signs were offset on the side of the road adjacent to where the well heads were installed. The CSX access road is constantly used by vehicles and is routinely graded to maintain road conditions. The road grader could potentially damage a well head, so these signs were placed as a preventive measure to alert the grader operator(s) of the well locations.

Field trials of the flush mount covers and sleeves indicated that the covers were not water tight. Rubber gaskets were fabricated to fit on the lip of the sleeve where the cover bolted into place. Further tests proved this was a successful method for achieving a water tight seal. All flush mount completions were fitted with rubber gaskets.

Piezometers were completed both above ground and with flush mounts using the methods described above with the following exceptions: 1) the protective casing was three inches square and 2) the concrete pad was three feet x three feet x six inches.

2.6 Pump Installation

All wells installed in the program were equipped with dedicated submersible bladder pumps to facilitate sampling and to ensure that groundwater is not altered by the collection process. Dedicated systems reduce the risk of inter-well contamination by eliminating the use of sampling equipment in two or more different wells. The bladder pumps, tubing and well caps were supplied by QED Environmental Systems, Inc. Two types of bladder pumps were used. Model p1101s, a low capacity PVC pump, was installed in the wells which demonstrated low yield during well development, and model p1500, a high capacity stainless steel pump, was installed in the wells demonstrating a moderate to high yield during development.

The pumps, teflon lined polyethylene tubing, well caps, and fittings were supplied via custom order by QED. Each bladder pump came certified from QED stating the pump would not adversely affect groundwater sample analysis. Appendix K contains copies of the pump certifications. Therefore, no decontamination of pumps or related material was needed. During the installation of the pumps, care was taken not to expose the pumps to any potential sources of contamination. Pumps remained sealed in plastic until ready for installation.

The depth of the pump intake was determined by the design of the well. If the well was equipped with a sump, the pump intake was set two and one-half feet from the bottom of the well. If the well did not have a sump, the pump intake was set one foot from the bottom of the well. In both cases, this positioned the pump opposite the bottom of the well screen.

The pumps were suspended inside each well by the discharge and air lines which were routed through the well cap. Two types of well caps were used. Each allowed for easy access to the discharge and air supply line and also allowed for water level measurements through a hole in the top of the cap. Caps used for above ground completions were PVC that slipped over the well casing. Caps used for flush mount completions had water tight seals to prevent the infiltration of surface water should the seal on the flush mount cover fail. Since flush mount covers can not be locked, the PVC well caps were equipped with a lockable friction plug, which prevents access to the air and discharge lines and also precludes rainwater or runoff from entering the well through these portals.

3.0 WELL REHABILITATION

An inspection of the existing monitoring wells at the NFS site in September 1992 indicated numerous rehabilitation requirements. As a part of the same project used to install the twenty-five new wells, twenty-two wells were rehabilitated to comply with EPA monitoring well standards. Six existing wells were identified for abandonment, however, no well abandonments were performed during this program.

The scope of rehabilitation varied from well to well. Corrective actions ranged from excavation of the grout around the well to the depth of the bentonite seal, re-grouting the borehole, installing protective casing, installing a four feet x four feet x one foot concrete pad, and four bumper posts (Well 52) to installing a five feet x four feet x one-half foot concrete pad (Well 62). Table 3-1 lists rehabilitation activities for each well.

Several unexpected conditions were encountered during the rehabilitation of the wells. Well 65 was completed in 1988 with a man-hole sewer cover serving as the flush cover and sleeve. During rehabilitation the cover was removed and the area around the well excavated to allow installation of a water tight flush cover and sleeve designed and labeled for monitoring wells.

Excavation around Well 35 unearthed a void around the well casing. Bentonite pellets were inadvertently poured around the well screen in an attempt to fill the void. The size of the cavity was estimated from measurements at the surface, and the volume of bentonite pellets poured in the cavity was known. From the well log and this information the amount of well screen covered by the bentonite was estimated as the uppermost two feet.

Where required, wells were rehabilitated by installing a six inch x six inch x five feet protective casing with hinged locking cap. These protective casings were set at least 18 inches into the well annulus. New pads were formed for wells that had no pad or a damaged pad. Pads were four feet x four feet x one-half foot, set into the ground to prevent undermining of the soil beneath the pad. The pads were peaked to prevent rainwater from collecting around the well

Table 3-1
WELL REHABILITATION

Well Number	Summary of Work
Well 5	Removed old protective casing, added new PVC stick-up, installed new 3 x 3 inch protective casing, concrete pad, and four bumper posts.
Well 32	Installed new protective casing, concrete pad, and four bumper posts.
Well 33	Cut off PVC stick-up below ground surface, installed new flush mount cover and sleeve (converted above ground completion to flush mount completion).
Well 34	Installed new protective casing and concrete pad.
Well 35	Installed new protective casing, backfilled borehole with bentonite pellets, and installed concrete pad.
Well 36	Installed new protective casing and concrete pad.
Well 39	Installed new protective casing and concrete pad.
Well 40	Installed new protective casing and concrete pad.
Well 41	Installed new protective casing, concrete pad, and four bumper posts.
Well 52	Removed old protective casing and bumper posts, backfilled borehole with bentonite, installed new protective casing, 4 feet x 4 feet x 1 feet concrete pad, and four bumper posts.
Well 55	Installed new concrete pad and four bumper posts.
Well 56	Installed new concrete pad and four bumper posts.
Well 57	Installed new concrete pad and four bumper posts.
Well 58	Installed new concrete pad and four bumper posts.
Well 62	Installed new 5 feet x 4 feet x 0.5 feet concrete pad.
Well 63	Installed new concrete pad and four bumper posts.
Well 65	Replaced old sewer cover and sleeve used for well head completion with water tight flush mount cover and sleeve.

Table 3-1 (continued)
WELL REHABILITATION

Well Number	Summary of Work
Well 67	Installed new concrete pad and four bumper posts.
Well 72	Installed new concrete pad.
Well 76	Installed new concrete pad and four bumper posts.
Well 82	Welded additional protective metal casing to original casing, fitted well with protective cap, installed new concrete pad and four bumper posts.
Well 94	Installed new concrete pad and four bumper posts.

casing. If the well was in a traffic location, guard posts were installed. Three inch diameter steel posts five feet in length, were set at the corners of the pads. The posts were set in a concrete footing at least two feet into the ground, and filled with concrete for additional strength.

Ongoing well rehabilitation affected the reference elevations of several wells for several months. To ensure continuity of the monthly potentiometric database, revised elevations were provided to NFS as the changes occurred. After all monitoring well installations and well rehabilitation activities were complete, a final survey was conducted. This survey included the land locations and surface elevations, relative to mean sea level, for each well. Land locations were surveyed using State of Tennessee northing and easting coordinates. Elevations were surveyed for top of protective casing, top of PVC casing, and land surface. The survey results are included in Table 3-2.

4.0 RESULTS

In the following sections the results of coring, geophysical logging, hydraulic testing, head measurements, and well installations are discussed. Included is an update of the site hydrogeology and findings not reported in previous site characterization studies.

4.1 Previous Studies

Previous studies (TLG 1987, EcoTek 1989) have included numerous borings and well installations. Prior to the subject report, 51 monitoring wells existed across the site. Boring logs for 54 boreholes were available to characterize the site geology. While all of these data were useful, they were not sufficient to provide the level of characterization needed to install groundwater monitoring networks around the Burial Ground, 6,000 gallon tanks, and SWMUs 8 and 11, as required by the NRC and EPA. Therefore, a limited geologic investigation was planned and conducted as a component of the recent well installation program.

4.2 Stratigraphy

Based on the findings of the geologic investigation and well installation program, the subsurface stratigraphy can be described as two general units, alluvium and bedrock. These two units are discussed in detail in the following sections.

4.2.1 Alluvium

An alluvial overburden of varying thickness was found to exist across the site. This overburden consists of two to four feet of a clay/silt rich, brown to dark brown, fine to medium sand. This material is very cohesive and extends to a depth of four to six feet (in some areas the upper alluvial layer is covered by fill material of varying thickness). Below the cohesive material is a zone of medium to coarse, light to medium gray, micaceous sand or orange to brown quartzitic

Table 3-2

MONITORING WELL SURVEY

WELL NO.	ELEVATION OF GROUND SURFACE	ELEVATION OF METAL CASING	ELEVATION OF PVC CASING	NORTHING COORDINATE	EASTING COORDINATE
5	1636.32	1639.12	*1639.06	652981.205	3054220.098
10	1635.50	1639.35	*1639.24	652856.305	3054017.969
24	1638.28	----	*1641.85	652594.330	3054025.300
25	1637.87	----	*1637.87	652618.020	3053951.880
26	1638.92	----	*1639.99	652671.008	3054001.125
27	1638.80	----	*1641.76	652559.903	3053954.815
28	1638.12	----	*1639.96	652630.903	3053885.862
29	1639.61	----	*1639.52	652406.715	3054203.003
30	1640.38	1640.38	*1640.25	652556.261	3054266.345
31	1640.55	1640.55	*1640.30	652578.446	3054245.840
32	1638.42	1640.38	*1640.18	652456.285	3054420.335
33	1639.02	1639.02	*1638.80	652479.872	3054165.106
34	1636.35	1639.37	*1639.25	652744.933	3054106.928
35	1638.97	1641.65	*1641.50	652353.942	3054298.123
36	1640.42	1643.42	*1643.63	652661.138	3054190.162
38	1638.64	----	*1641.00	652394.072	3054082.228
39	1637.37	1640.47	*1640.16	652322.453	3054167.434
40	1639.24	1641.94	*1642.16	652208.614	3054416.253
41	1638.65	1641.57	*1641.49	652317.841	3054460.583
52	1641.89	1644.99	*1644.98	652122.965	3054450.650
55	1640.42	1643.92	*1643.84	652478.794	3054661.522
56	1648.45	1651.95	*1651.81	652859.691	3054710.746
57	1640.20	*1642.55	1641.72	652965.759	3054405.027
58	1636.20	1639.50	*1639.34	653091.196	3054301.482
59	1636.15	1636.25	*1635.37	652947.436	3054036.982
60	1644.79	*1647.29	1646.72	652793.235	3054398.301
62	1639.86	1642.96	*1642.68	652735.927	3054272.716
63	1647.59	*1649.99	1648.97	652683.710	3054819.865
64	1641.89	1641.92	*1641.42	652587.549	3054386.843
65	1637.37	1637.37	*1636.72	652908.251	3054078.469
66	1636.51	1638.61	*1638.41	653100.988	3054174.408
67	1640.78	*1643.68	1643.19	652622.258	3054409.088
68	1636.06	*1638.56	1637.61	653111.714	3054177.259

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Table 3-2 (continued)

MONITORING WELL SURVEY

WELL NO.	ELEVATION OF GROUND SURFACE	ELEVATION OF METAL CASING	ELEVATION OF PVC CASING	NORTHING COORDINATE	EASTING COORDINATE
70	1641.31	*1643.88	1643.41	652156.687	3054038.762
71	1637.95	1640.65	*1640.26	652491.704	3053759.583
72	1638.19	*1640.89	1639.58	652474.402	3053753.965
73	1638.36	1638.39	*1638.07	652279.746	3053628.427
74	1649.46	*1651.91	1650.54	651843.763	3053642.664
75	1638.67	*1641.97	1640.90	652403.197	3053924.082
76	1640.53	1643.91	*1643.58	652616.475	3054209.093
77	1640.43	*1643.50	1642.95	652580.277	3054289.545
78	1640.17	*1643.96	1643.07	652527.927	3054016.450
79	1638.88	*1641.88	1641.48	652570.817	3054073.050
80	1637.37	1640.03	*1640.03	652657.317	3053905.895
81	1637.64	1639.34	*1639.04	652716.156	3053976.252
82	1653.73	1657.13	*1657.02	651596.819	3053093.010
91	1638.46	1641.66	*1641.44	652391.217	3053852.075
92	1638.71	1638.71	*1637.96	652334.343	3053852.075
93	1638.38	1638.38	*1638.03	652482.138	3053800.231
94	1637.80	*1640.60	1639.16	652528.910	3053760.161
55A	1641.49	1644.69	*1644.62	652272.778	3054729.740
60B	1644.42	1647.52	*1647.51	652783.245	3054388.823
63A	1643.26	1646.16	*1645.88	652508.988	3054977.285
63B	1643.44	1646.14	*1646.00	652499.371	3054969.643
67B	1640.48	1643.78	*1643.71	652638.597	3054394.326
70A	1641.82	1644.67	*1644.62	652139.900	3054045.536
95A	1643.76	1646.86	*1646.80	652860.441	3054433.149
96A	1647.00	1650.30	*1650.17	652941.854	3054607.646
97A	1638.52	1638.52	*1638.17	652262.799	3053779.718
98A	1642.27	1642.27	*1641.82	653216.576	3054151.025
99A	1642.03	1642.03	*1641.69	653112.972	3054073.956
100A	1642.72	1642.82	*1642.42	652934.255	3053930.138
100B	1642.79	1642.89	*1642.47	652924.455	3053922.754
101A	1642.84	1642.84	*1642.52	652794.572	3053830.678

Table 3-2 (continued)

MONITORING WELL SURVEY

WELL	ELEVATION OF GROUND SURFACE	ELEVATION OF METAL CASING	ELEVATION OF PVC CASING	NORTHING COORDINATE	EASTING COORDINATE
102A	1643.25	1643.25	*1642.93	652673.432	3053741.839
103A	1643.92	1643.92	*1643.61	652568.813	3053663.376
104A	1645.44	1645.44	*1645.01	652349.805	3053502.568
105A	1647.77	1647.77	*1646.85	652126.085	3053338.605
106A	1650.63	1650.83	*1650.43	651887.784	3053163.064
107A	1649.20	1652.00	*1651.76	651884.799	3053454.078
107B	1649.52	1652.62	*1652.67	651865.112	3053884.427
234-2	1638.52	1638.52	*1638.31	652114.124	3054225.994
234-3	1638.33	1638.33	*1638.24	652157.008	3054243.132
LD-1A	1638.90	1638.90	*1638.47	652197.828	3053115.946
LD-2A	1639.91	1639.91	*1639.59	652194.665	3053906.403
SC-1	1648.99	1651.95	*1651.97	652674.441	3054969.880
SC-2	1635.72	----	----	653002.278	3054115.492
SC-3	1643.19	1645.99	*1645.64	652060.198	3054389.876
SC-4	1646.10	1646.10	*1645.87	652025.702	3054042.663
SC-5	1638.49	----	----	652475.540	3053725.265
SC-6	1661.86	1661.86	*1661.75	651295.536	3053407.042
SC-7	1653.33	1656.43	*1656.17	651507.657	3053407.042
SC-8	1651.68	1654.68	*1654.63	651689.117	3053115.946

*Reference elevation for water level data sand. The sand extends to a depth of 10 to 15 feet. A sharp contact does not exist between the clayey unit and underlying sand, but rather the change is gradational to a coarser texture with depth. Underlying the sand is a bed of rounded pebbles coarsening with depth into cobbles and boulders.

The coarsest material (cobbles/boulders) lies directly on the bedrock surface. Thickness of the alluvium ranges from 0 feet, at an outcrop of shale (possible alluvial terrace) along the eastern plant perimeter road, to 29 feet at the northeast corner of the burial ground.

The cobble/boulder zone does not occupy a consistent horizon across the site and is not laterally continuous in every direction. The origin of this material is probably channel fill brought into the valley by the surrounding mountain streams (see Section 1.3.2) and therefore its continuity and thickness is variable across the portion of the floodplain occupied by the NFS site.

Figure 4-1 is a structure contour map of the cobble/boulder zone surface. It depicts a variable surface with a high elevation of 1,642 feet msl to a low of 1,620 feet msl. The cobble\boulder zone is highest in the southern corner of the site with a high feature extending to the approximate center of the site. A high also is evident northeast of the burial ground. Low elevations occur along the CSX railroad property and in the vicinity of boring 234-1. Cobbles are apparently non-existent near Building 234 and the shale outcrop below the contractors parking lot, around the Building 105 complex, along the northeastern reach of Banner Spring Branch, and in the vicinity of Wells 59 and 65 (northern corner of the fenced portion of the site). Table 4-1 lists the stratigraphic picks used to construct geologic structure maps of the NFS site.

Figure 4-2 is an isopach map of the cobble/boulder zone. Thicknesses range from 0 feet at locations described above to 16 feet at corehole SC-1, just east of the burial ground. The thickest sequences occur at the burial ground, between Wells 98A and 100A (northern site corner), and in an "M" shaped zone through the Pond 4 and 300-Area of the plant. Thin zones occur in the Building 120\131 area, the Ponds area, and in the vicinity of Building 350. At several locations where the cobble/boulder zone is non-existent, a thick bed occurs in the immediately adjacent vicinity. This may indicate the presence of buried scarps or ledges. On the cobble/boulder zone isopach map (Fig. 4-2) these zones are hachured.

Along the southeast boundary of the site, the cobble/boulder zone exists as a lens in the southern corner, pinches out moving to the northeast, then reappears and thickens to 16 feet in the east corner. Above the cobble/boulder zone, the finer grained overburden is clayey in the southern corner and becomes distinctly sandier moving northeast toward the east corner of the site.

Figure 4-1

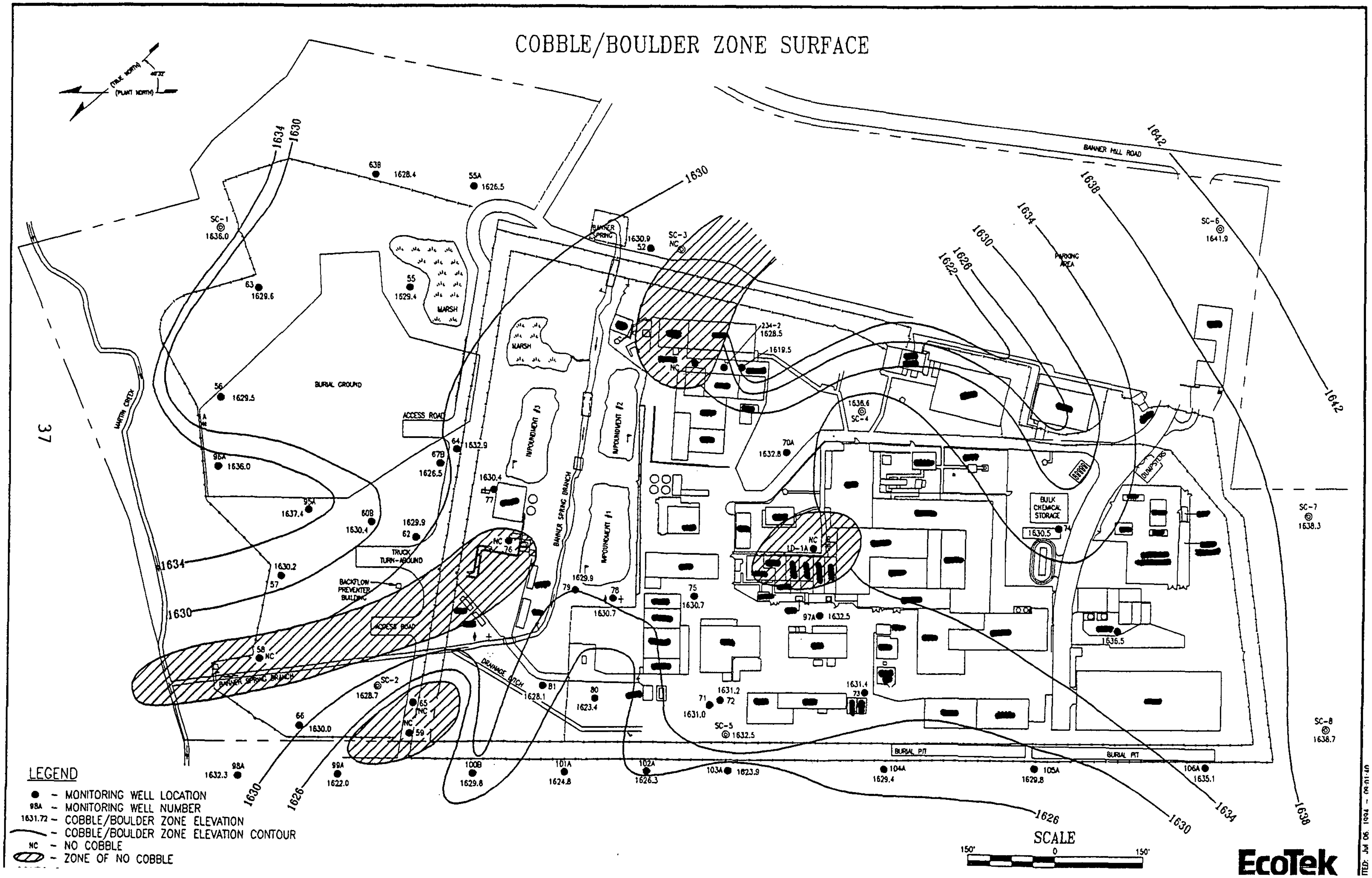

COBBLE/BOULDER ZONE SURFACE
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
BURIAL GROUND
ACCESS ROAD
MARSH
IMPOUNDMENT #3
IMPOUNDMENT #2
IMPOUNDMENT #1
BANNER SPRING BRANCH
BANNER SPRING
MARTIN CREEK
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
DRAINAGE DITCH
PARKING AREA
BULK CHEMICAL STORAGE
DUMPSTERS
BURIAL PIT
SC-1 1636.0
63B 1628.4
55A 1626.5
63 1629.6
55 1529.4
56 1629.5
96A 1636.0
95A 1637.4
60B 1630.4
62 1629.9
64 1632.9
67B 1626.5
77 1630.4
76 NC
57 1630.2
58 NC
SC-2 1628.7
65 NC
59 NC
66 1630.0
98A 1632.3
99A 1622.0
100B 1629.8
101A 1624.8
102A 1626.3
103A 1623.9
104A 1629.4
105A 1629.8
106A 1635.1
81 1628.1
80 1623.4
79 1629.9
78 1630.7
75 1630.7
97A 1632.5
71 1631.0
72 1631.2
73 1631.4
SC-5 1632.5
52 1630.9
SC-3 NC
234-2 1628.5
1619.5
SC-4 1638.6
70A 1632.8
LD-1A NC
74 1630.5
1636.5
SC-6 1641.9
SC-7 1638.3
SC-8 1638.7
1622
1626
1628
1630
1634
1638
1642
LEGEND
● - MONITORING WELL LOCATION
98A - MONITORING WELL NUMBER
1631.72 - COBBLE/BOULDER ZONE ELEVATION
COBBLE/BOULDER ZONE ELEVATION CONTOUR
NC - NO COBBLE
ZONE OF NO COBBLE
SCALE
150' 0 150'
EcoTek

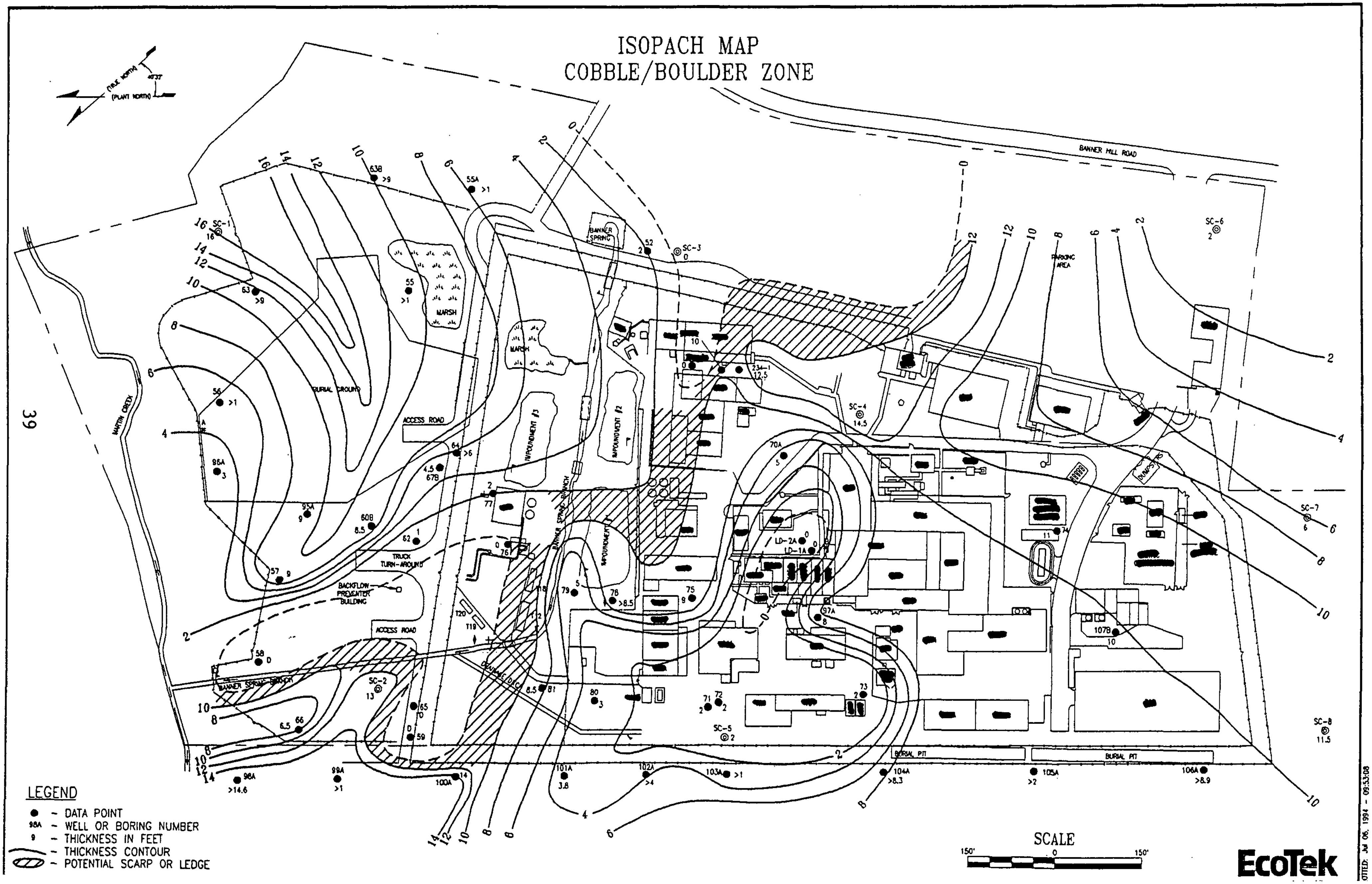
Table 4-1
Stratigraphic Picks

Well No.	Ground Elevation	Depth to Bedrock (ft)	Cobble Zone Thickness (ft)	Cobble\Boulder Elevation	Bedrock Elevation
52	1641.89	13	2	1630.89	1628.49
55	1640.42	>12	>1	1629.42	<1628.42
55A	1641.49	>16	>1	1626.49	<1625.49
56	1648.45	>20	>1	1629.45	<1628.45
57	1640.20	19	9	1630.20	1621.20
58	1636.20	18	0	NC	1618.20
59	1636.15	13	0	NC	1623.15
60B	1644.42	19	5	1630.42	1625.42
62	1639.86	11	1	1629.86	1628.86
63	1647.59	>27	>9	1629.59	<1620.59
63B	1643.44	23.5	8.5	1628.44	1619.94
64	1641.89	>15	>6	1632.89	<1626.89
65	1637.37	12	0	NC	1625.37
66	1636.51	13	6.5	1630.01	1623.51
67B	1640.48	18.5	4.5	1626.48	1621.98
70A	1641.82	14	5	1632.48	1627.82
71	1637.95	9	2	1630.95	1628.95
72	1638.19	9	2	1631.19	1629.19
73	1638.36	9	2	1631.36	1629.36
74	1649.46	30	11	1630.46	1619.46
75	1638.67	17	9	1630.67	1621.67
76	1640.53	12	0	NC	1628.53
77	1640.43	12	2	1630.43	1628.43
78	1640.17	>18	8.5	1630.67	<1622.17
79	1638.88	14	5	1629.88	1624.88
80	1637.37	17	3	1623.37	1620.37
81	1637.64	18	8.5	1628.14	1619.64
95A	1643.76	15	9	1637.76	1628.76
96A	1647.00	14	3	1636.00	1633.00
97A	1638.52	14	8	1632.52	1624.52
98A	1642.27	>24.6	>14.6	1632.27	<1617.67
99A	1642.03	>20	>1	1622.03	<1622.03
100B	1642.79	27	14	1629.79	1615.79
101A	1642.84	>21.8	>3.8	1624.84	<1621.04
102A	1643.25	>21	>4	1626.25	<1622.25
103A	1643.92	>20	>1	1623.92	<1623.92
104A	1645.44	>24.25	>8.25	1629.44	<1621.19
105A	1647.77	>20	>2	1629.77	<1627.77
106A	1650.63	>24	>8.9	1635.13	<1626.23
107B	1649.52	23	10	1636.52	1626.52
LD-1A	1638.90	>17	0	NC	<1621.90
LD-2A	1639.91	>13	0	NC	<1626.91
234-1	1639.00	32	12.5	1619.50	1607.00
234-2	1638.52	20	10	1628.52	1618.50
234-3	1638.33	12.5	0	NC	1625.80
SC-1	1648.99	29	16	1635.99	1619.99
SC-2	1635.72	20	13	1628.72	1615.72
SC-3	1643.19	6.5	0	NC	1636.69
SC-4	1646.10	24	14.5	1636.60	1622.10
SC-5	1638.49	10	4	1632.49	1628.49
SC-6	1661.86	22	2	1641.86	1639.86
SC-7	1653.33	21	6	1638.33	1632.33
SC-8	1651.68	24.5	11.5	1638.68	1627.18

All elevations referenced to mean sea level
NC – No Cobbles

B:\TABLES\GEOELEV.WK1

Figure 4-2


ISOPACH MAP
COBBLE/BOULDER ZONE
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
MARTIN CREEK
BANNER SPRING
MARSH
BURIAL GROUND
ACCESS ROAD
IMPOUNDMENT #3
IMPOUNDMENT #2
IMPOUNDMENT #1
BANNER SPRING BRANCH
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
DRAINAGE DITCH
PARKING AREA
DUMPSTERS
BURIAL PIT
LEGEND
● - DATA POINT
98A - WELL OR BORING NUMBER
9 - THICKNESS IN FEET
- THICKNESS CONTOUR
- POTENTIAL SCARP OR LEDGE
SCALE
150' 0 150'
EcoTek
OTTED: Jul 06, 1994 - 09:53:08

Through the middle of the long axis of the site, the cobble/boulder zone is continuous and ranges in thickness from five to 15 feet. The finer grained overburden consists of interbedded clay and sand, becoming sandier in a northeasterly direction.

The cobble/boulder layer is laterally continuous along the northwest boundary of the site but of unknown thickness until it disappears in the northern corner of the site. Rock fragments collected from drill cuttings in boreholes along this side consisted of both round quartz fragments (cobbles) and shards of sandstone (boulders). The remaining overburden above the cobble/boulder zone is clayier than along the southeastern site boundary. Clayey material extends from ground surface to as deep as 15 feet. Sandy material grades from dark yellowish orange to light olive gray moving in a northeasterly direction. Along the northeastern boundary of the site, the cobble/boulder zone varies from 18 feet thick in the east corner to 0 feet thick in the north corner.

Through the center of the short axis of the site, the cobble/boulder zone is variable. It is thick at corehole SC-4, pinches out to the northwest, is thick at corehole SC-5, and appears to be pinching out again to the northwest. Southwest of the plant the cobble/boulder zone is continuous in a northwest-southeast direction. It thickens to the northwest. The remaining overburden is mostly clayey to the southeast becoming interbedded clay overlying sand to the northwest. The clayey material is moderate yellowish brown, and dark yellowish orange to moderate yellowish orange. The underlying sand is moderate brown.

Underlying the northern quadrant of the plant is a consistent sand unit that is gray in color, mostly quartzitic, but with a high mica content (20-30%) and rich in heavy minerals (5-10%). This same gray sand can be seen along the present banks of the Nolichucky River. Underlying other parts of the site, the sand becomes more quartzitic, orange to brown in color, and less micaceous.

4.2.2 Bedrock

Bedrock is predominantly the red and tan shale of the Rome formation. This shale varies from competent, silty shale to soft shale with a clay-like consistency. Shale encountered during coring was easily broken and highly stratified (bedded), and fractures and joint sets were evident. Beds were variably dipping to contorted but mostly steeply dipping. Some soil filled fractures were encountered in the shallow bedrock. At several locations, the bedrock consisted of interbedded shale, dolomite, and mudstone, or just dolomite. Figure 2-1 depicts the eight corehole locations. At SC-1, SC-6, SC-7, and SC-8, the bedrock was all Rome formation shale. At SC-3, SC-4, and SC-5, the bedrock consisted of interbedded shale, mudstone, and dolomite. At one location, SC-2, a very soft zone of high permeability was encountered through which no recovery was obtained. Cobbles and boulders were encountered in this hole at a depth of 18 feet. No recovery was obtained from 18-38 feet except for some light gray, soft clay, perhaps dolomite or limestone residuum. Bedrock encountered at approximately 38 feet was blue-gray and competent and did not react to HCl (dolomite ?). Drilling fluid loss through the no recovery zone was substantial but not sudden or catastrophic, as is normally associated with drilling through large voids or fractures. No other fluid drilled holes exhibited such gross porosity. This particular corehole was along the northern end of the site near Martin Creek. Martin Creek is thought by some (Hasson 1993) to run along a strike slip fault (its course is unusually straight). Perhaps this zone of fluid loss is structurally associated with Martin Creek.

Limestone was encountered at other locations near SC-2 during previous investigations (Wells 58 and 66). Therefore the fluid loss may be related to limestone or dolomite dissolution. Based on the quantity of fluid loss, any potential zone of dissolution may be localized and not areally extensive.

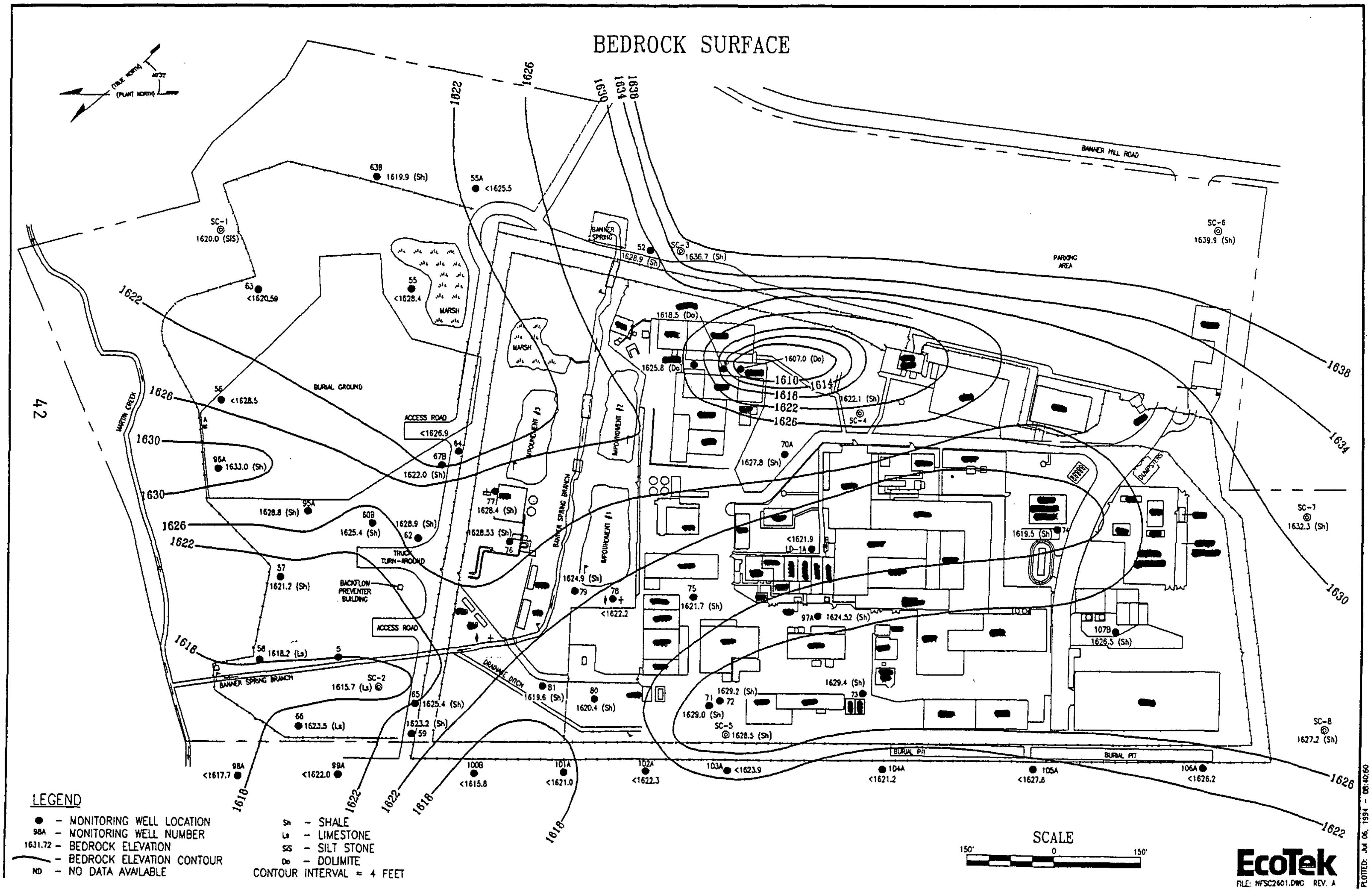
No previous investigation used coring to characterize the shallow subsurface. Previous investigators relied on rotary cuttings to determine where the bedrock surface lay. In many of the geologic logs, sandstone bedrock is described at shallow depths. The recent coreholes revealed that this sandstone is actually rounded boulders marking the base of the alluvium. A look at coarse material along the banks and point bars of the Nolichucky River confirms that boulders, several feet across, are common and frequently composed of quartzite, sandstone, and other terrigenous rocks.

Figure 4-3 is a structure contour map of the bedrock surface. It was developed using bedrock picks from the coreholes and well boreholes drilled during the subject investigation combined with picks from the 1988/1989 EcoTek investigation that encountered shale, dolomite, limestone, or mudstone.

Combining information from the current study with previous studies, there are 37 locations across the site where bedrock was encountered. Of the 37 locations, shale was encountered at the top of bedrock 30 times. At most locations, the shale was interbedded with dolomite, mudstone, or limestone.

The core retrieved during the subject investigation displayed mostly steeply dipping beds but included dips ranging from vertical to horizontal and sometimes contorted. The bedrock in this region of the southeast was severely folded and faulted during the Appalachian Orogeny prior to the erosional episode that formed the modern day alluvial valley. Therefore, variable dip angles and interbedded lithologies observed in the core are compatible with the geologic history of the area. As further evidence, outcrops on either side of the valley display nearly vertical dips. If a synclinal fold exists under the valley, as previously discussed (Section 1.3.2), dip angles across the valley would range from horizontal to vertical.

Figure 4-3



BEDROCK SURFACE
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
PARKING AREA
BANNER SPRING
MARSH
BURIAL GROUND
ACCESS ROAD
IMPOUNDMENT #3
IMPOUNDMENT #2
IMPOUNDMENT #1
BANNER SPRING BRANCH
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
DRAINAGE DITCH
MARTIN CREEK
DUMPSTERS
BURIAL PIT
SC-1 1620.0 (SiS)
63B 1619.9 (Sh)
55A <1625.5
SC-3 1636.7 (Sh)
52 1628.9 (Sh)
SC-6 1639.9 (Sh)
63 <1620.59
55 <1628.4
1618.5 (Do)
1607.0 (Do)
1625.8 (Do)
1622.1 (Sh)
SC-4
56 <1628.5
<1626.9
64
67B 1622.0 (Sh)
70A 1627.8 (Sh)
96A 1633.0 (Sh)
77 1628.4 (Sh)
95A 1628.8 (Sh)
60B 1625.4 (Sh)
1628.9 (Sh)
62
1628.53 (Sh)
76
<1621.9 LD-1A
1619.5 (Sh) 74
SC-7 1632.3 (Sh)
57 1621.2 (Sh)
1624.9 (Sh)
79
78 <1622.2
75 1621.7 (Sh)
97A 1624.52 (Sh)
107B 1626.5 (Sh)
58 1618.2 (Ls)
5
SC-2 1615.7 (Ls)
65 1625.4 (Sh)
81 1619.6 (Sh)
80 1620.4 (Sh)
1629.2 (Sh) 72
71 1629.0 (Sh)
1629.4 (Sh) 73
SC-5 1628.5 (Sh)
66 1623.5 (Ls)
1623.2 (Sh) 59
SC-8 1627.2 (Sh)
98A <1617.7
99A <1622.0
100B <1615.8
101A <1621.0
102A <1622.3
103A <1623.9
104A <1621.2
105A <1627.8
106A <1626.2
1610
1614
1618
1622
1626
1630
1634
1638
LEGEND
● - MONITORING WELL LOCATION
98A - MONITORING WELL NUMBER
1631.72 - BEDROCK ELEVATION
- BEDROCK ELEVATION CONTOUR
ND - NO DATA AVAILABLE
Sh - SHALE
Ls - LIMESTONE
SiS - SILT STONE
Do - DOLIMITE
CONTOUR INTERVAL = 4 FEET
SCALE
150' 0 150'
EcoTek
FILE: NFSC2601.DWG REV. A
PLOTTED: Jul 06, 1994 - 08:40:60

Examining Figure 4-3, a subsurface bedrock high is evident to the south in the parking lot vicinity at coreholes SC-3 and SC-6 (1636.2 and 1639.9 respectively). Corehole SC-3 is at the base of a bedrock cliff (exposed) which displays vertically dipping shale at an elevation of approximately 1650 feet msl.

Bedrock lows occur along the northeast reach of Banner Spring Branch, on CSX property just north of Pond 4, and at one corehole north of Building 234. At Building 234, three borings revealed a dramatic variation in bedrock elevation over a lateral distance of less than 100 feet (1610.1 to 1625.8). The bedrock encountered at these holes was apparently dolomite (did not react to HCl). The abrupt lateral elevation change may indicate a fault scarp, pinnacle erosion, or an alluvial terrace. At corehole 234-1, the bedrock was overlain by a thick, low permeability, gray clay. This may have been weathered dolomite and if so, the bedrock elevation differences are attributable to differential weathering (pinnacle erosion).

A long, linear, northeast/southwest trending trough is evident from Pond 4 to the Bulk Chemical Storage Area. A broad, east/west trending trough is evident around the southeast half of the burial ground. A local bedrock high exists at Well 95A in the northernmost portion of the burial ground.

4.2.3 Hydrogeologic Cross Sections

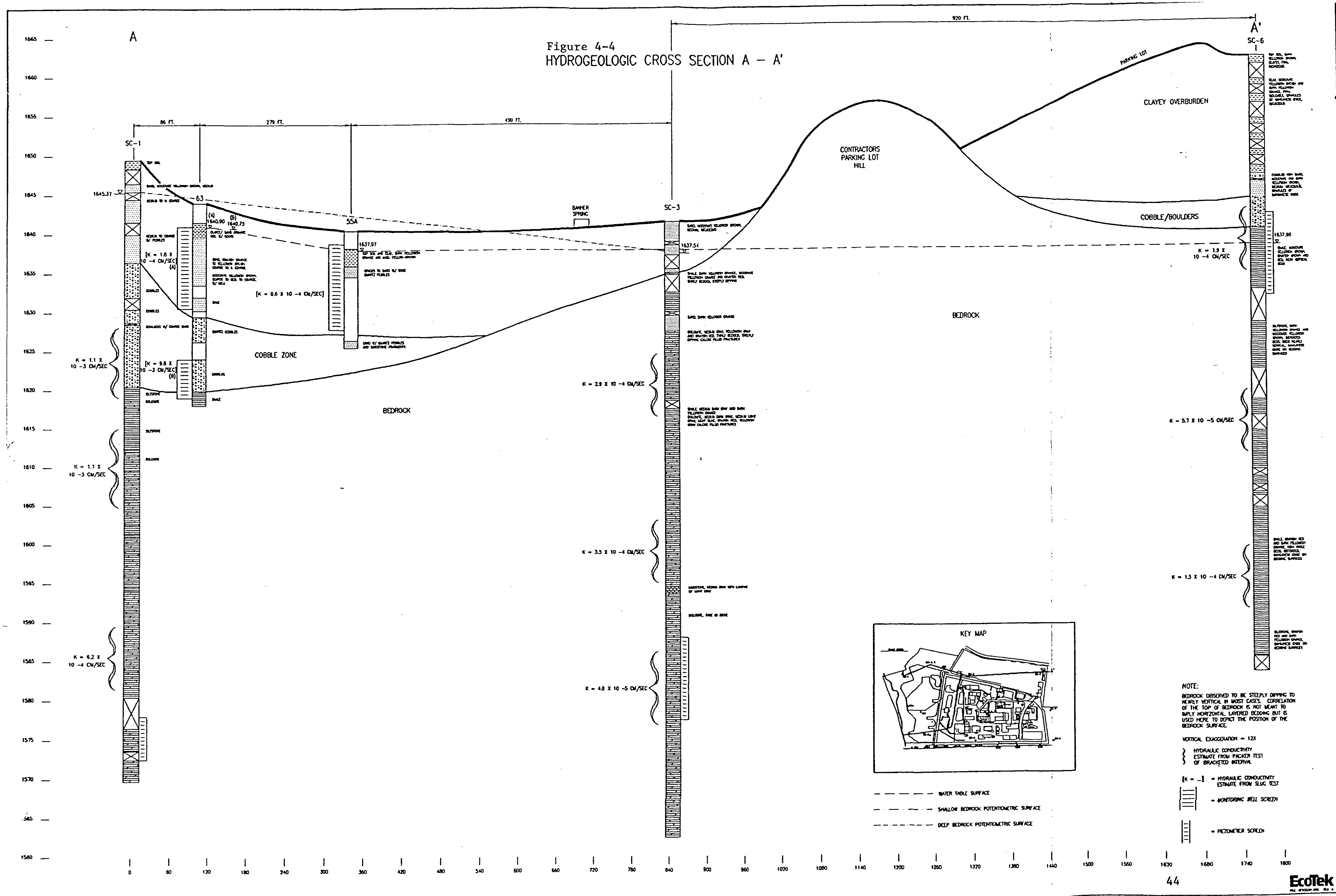
Several cross sections were developed using geologic data from the nine coreholes, the new monitoring wells, and some previously installed monitoring wells. These are included as Figures 4-4 through 4-10. Full size drawings of the cross sections are included in Appendix L. The following text sections describe each cross section.

<u>Section A - A'</u>

Section A-A' (Figure 4-4) is oriented parallel to strike (northeast-southwest). The section includes Corehole SC-1, Well cluster 63 A/B, Well 55A, Corehole SC-3, and Corehole SC-6. The northeasternmost corehole, SC-1, has a cobble/boulder zone thickness of 16 feet. This zone thins to the southwest and pinches out between Well 55A and Corehole SC-3. The cobble/boulder zone resumes southwest of the contractor's parking lot hill to a thickness of two feet at SC-6.

The uppermost bedrock at Corehole SC-1 is siltstone (mudstone) grading to shale and dolomite with depth. From SC-1 to SC-3, the bedrock surface rises 16.7 feet. Bedrock at SC-3 is predominantly dolomite. From northwest to southwest, the bedrock surface gradually rises, cropping out and forming the contractors parking lot hill. Southwest of the hill, the bedrock slopes down again and levels to elevation 1,639.86 at SC-6.

Figure 4-4
HYDROGEOLOGIC CROSS SECTION A – A'



August 1993 water levels were used on all of the cross sections. The water table surface elevation depicted on Figure 4-4 is 1,640.90 at Well 63A. The water table slopes toward Well 55A and drops 2.93 feet over that distance. Between Well 55A and SC-6, the water table surface shows no significant change because most of the section line is perpendicular to groundwater flow. The Zone 3 potentiometric surface appears to be higher than the water table surface between SC-1 and SC-3. This may indicate recharge to Zone 3 from upgradient sources and an upward hydraulic gradient from Zone 3 to Zones 1 and 2.

Section B - B'

Section B-B' (Figure 4-5) is also oriented parallel to strike (northeast to southwest). This section includes Well 95A, Well cluster 60, Well cluster 67 (which includes Wells 64, 67B and 67), Well 70A, and coreholes SC-4, and SC-7. The surface of the cobble/boulder zone is fairly uniform across this section, however, its thickness is variable from approximately five to 15 feet.

Most of the section line is perpendicular to groundwater flow and therefore the water table surface appears flat. The Zone 3 potentiometric surface is depicted on this section by using the head at corehole SC-4 with the head from deep Well 67. The section is not large enough to draw in the screen for Well 67 but the head is posted. Apparently, the Zone 3 potentiometric surface is higher than the water table indicating the potential for upward flow from deep to shallow. The screen for Well 64 is depicted on the column for Well 67B to demonstrate the water table at this location. Wells 64, 67B, and 67 are close enough together to be considered a three well cluster.

Hydraulic conductivity was estimated in SC-7 by packer tests. Results for this corehole indicate hydraulic conductivity decreases slightly with depth. Slug tests were conducted in Wells 60, 60B, 64, 67B, 70A, and 95A. Hydraulic conductivity also decreases with depth in these wells.

Section C - C'

Section C-C' (Figure 4-6) is oriented parallel to strike (northeast to southwest). Wells 98A, 99A, 100A, 100B, 101A, 102A, 103A, 104A, 105A, 106A, and corehole SC-8 are included in this section. The cobble/boulder zone was encountered everywhere except at 98A and 99A, and slopes gently northeast. Bedrock (shale) was encountered only in Well 100B and Corehole SC-8. The surface of the bedrock rises to the southwest.

Hydraulic conductivity decreases with depth in Corehole SC-8 and at Well cluster 100. The water table surface exists in the sandy overburden material and intersects the cobble/boulder zone at 106A and SC-8. At Well cluster 100, the water table is higher than the Zone 2 head indicating a downward flow potential

Figure 4-5
HYDROGEOLOGIC CROSS SECTION B – B'

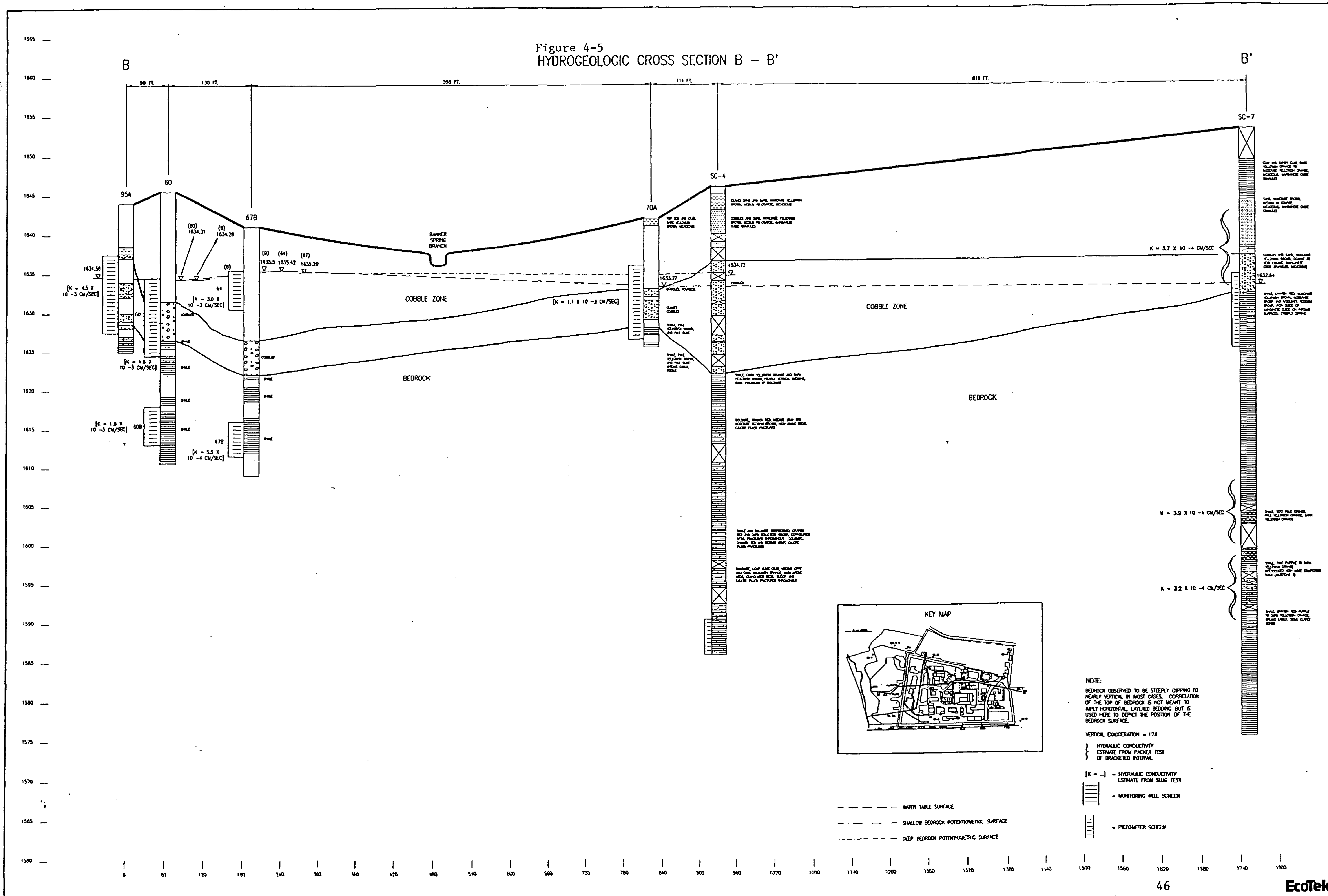
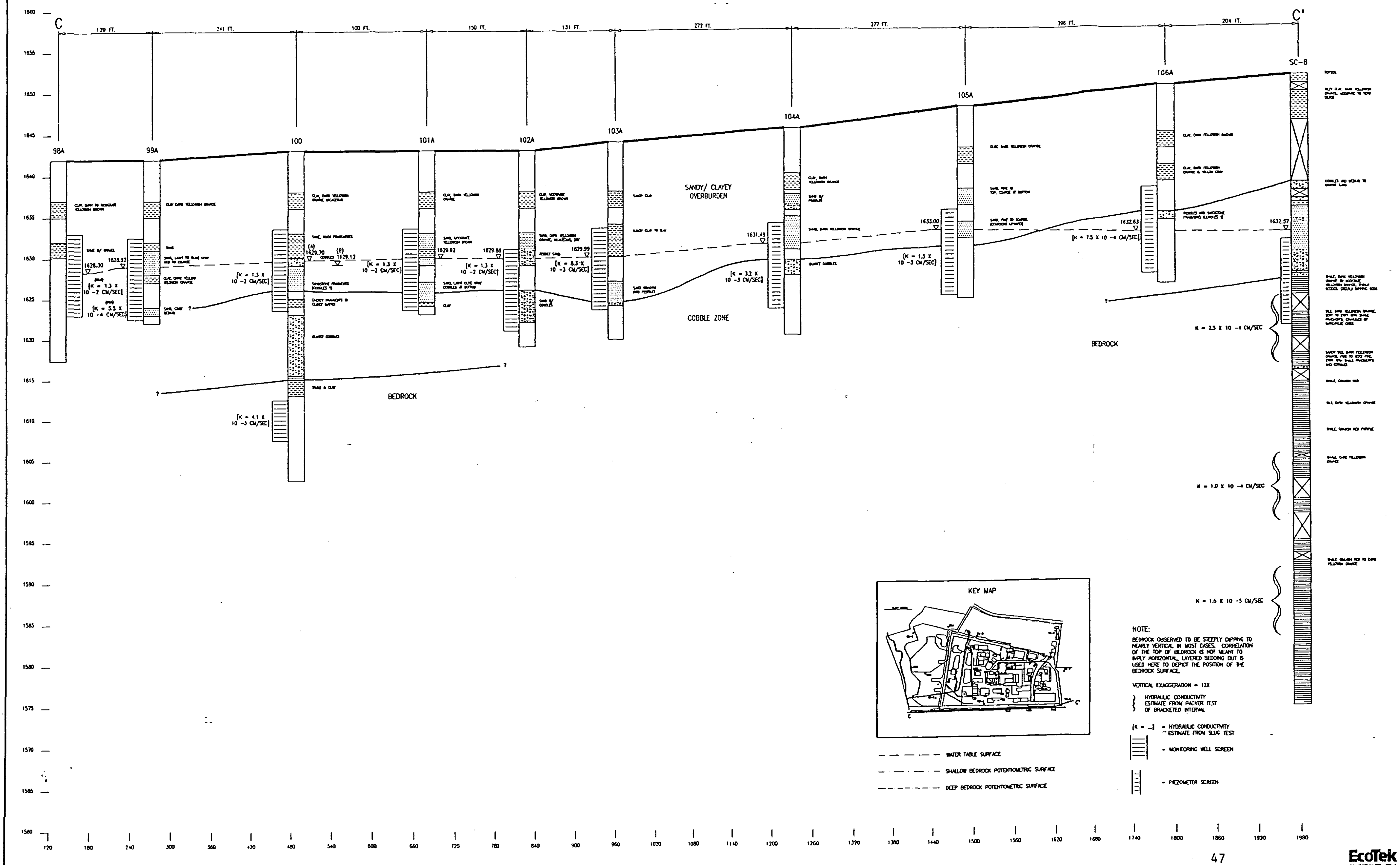


Figure 4-6
HYDROGEOLOGIC CROSS SECTION C – C'



from Zone 1 to Zone 2.

Section D - D'

Section D-D' (Figure 4-7) consists of Well 99A, Corehole SC-2, Well cluster 60, Well 63, and Corehole SC-1. This cross section is oriented approximately perpendicular to strike (northwest to southeast). Well 99A is the northwestern-most well depicted in this section. The cobble/boulder zone was encountered at all locations except 99A. Its thickness ranges from 16 feet at SC-1 to approximately seven feet at SC-2. A very soft zone of high permeability was encountered at the base of the cobble/boulder zone at SC-2. No recovery was obtained except for some light gray, soft clay, perhaps dolomite or limestone residuum.

A subtle bedrock knob is apparent at Well cluster 60. Bedrock lithology encountered along the section is interbedded shale, siltstone, and dolomite.

Hydraulic conductivity from slug tests conducted at Well 60 and Well 60B indicate a high K value in the cobble/boulder zone and a somewhat lower K in the shallow bedrock. At SC-1, K values found in cobbles and an intermediate depth shale/dolomite zone were higher than the deeper dolomite zone.

Section E - E'

Section E-E' (Figure 4-8) is also oriented perpendicular to strike (northwest to southeast). This section consists of two shallow wells (103A and LD-2A) and two coreholes, SC-5, and SC-4. The cobble/boulder zone is not laterally continuous across this section pinching out in the middle. The bedrock surface slopes gently (0.61 feet of change) to the northwest. Bedrock encountered at the two coreholes consists of shale interbedded with dolomite.

The cross section is perpendicular to groundwater flow. The water table surface slopes to the northwest with 3.34 feet of change over 446 lateral feet, demonstrating a shallow gradient of .007 ft/ft between LD-2A and 103A.

Section F - F'

Section F-F' (Figure 4-9) is oriented perpendicular to strike and groundwater flow, and consists of three coreholes, SC-8, SC-7, and SC-6. The cobble/boulder zone is laterally continuous across the section and slopes toward the northwest from SC-6 to SC-8. Between SC-7 and SC-8 the cobble/boulder zone surface is nearly uniform. Bedrock consists of shale with some siltstone interbeds in all three coreholes. The bedrock surface slopes toward the northwest dropping 10.18 feet from SC-6 to SC-8.

Hydraulic conductivity estimates from packer tests decreased with depth in SC-8 and SC-7. SC-6 displayed relatively high hydraulic conductivity in the deeper bedrock zone at a soft interval. Hydraulic conductivity in the deeper bedrock was higher than that in the middle of the corehole.

Section G - G'

Section G-G' (Figure 4-10) consists of Corehole SC-8, Well cluster 107, Corehole SC-4, and Corehole SC-3. The section is oblique to strike and groundwater flow (east to west). The cobble/boulder zone is laterally continuous across most of the section but pinches out between SC-4 and SC-3. The zone is thickest at SC-8 (14 feet), thins to 11.5 feet at Well cluster 107 and then thickens again to 14 feet at SC-4. The bedrock surface varies slightly between SC-8 and 107 A/B before dipping at SC-4. Between SC-4 and SC-3 the bedrock surface rises approximately 12 feet.

The potentiometric surface depicted to the east on the cross section is the water table surface. At well cluster 107, the water table is higher than the Zone 2 head indicating the potential for downward flow from Zone 1 to Zone 2. The potentiometric surface of Zone 3 is depicted on the west end of the section. It slopes in the same direction as the water table.

Packer tests were conducted at SC-8 and SC-3 to estimate the hydraulic conductivity of selected intervals in the bedrock. At these locations, hydraulic conductivity decreased with depth.

4.2.4 Geophysical Log Interpretation

As described in Section 2.1.1, geophysical logging was conducted at five coreholes (SC-1, SC-3, SC-6, SC-7, and SC-8). The purpose of the logging was to : (1) complement the physical data collected during coring and to fill in any data gaps through zones of no core recovery, and (2) investigate the possibility of fractures in the subsurface. For this purpose, several gross porosity type logs were run, including neutron, gamma-gamma, sonic, and caliper. With these, standard borehole logs such as natural gamma, spontaneous potential, and resistivity (long and short normal, single point, fluid resistivity) were also run. The tool containing the sonic, caliper, and gamma-gamma probes malfunctioned during borehole logging of SC-8, and consequently those logs are not available for that corehole. An explanation of the interpretation of the logs for each corehole follows. The geophysical logs for each hole are included in Appendix M.

Figure 4-7
HYDROGEOLOGIC CROSS SECTION D – D'

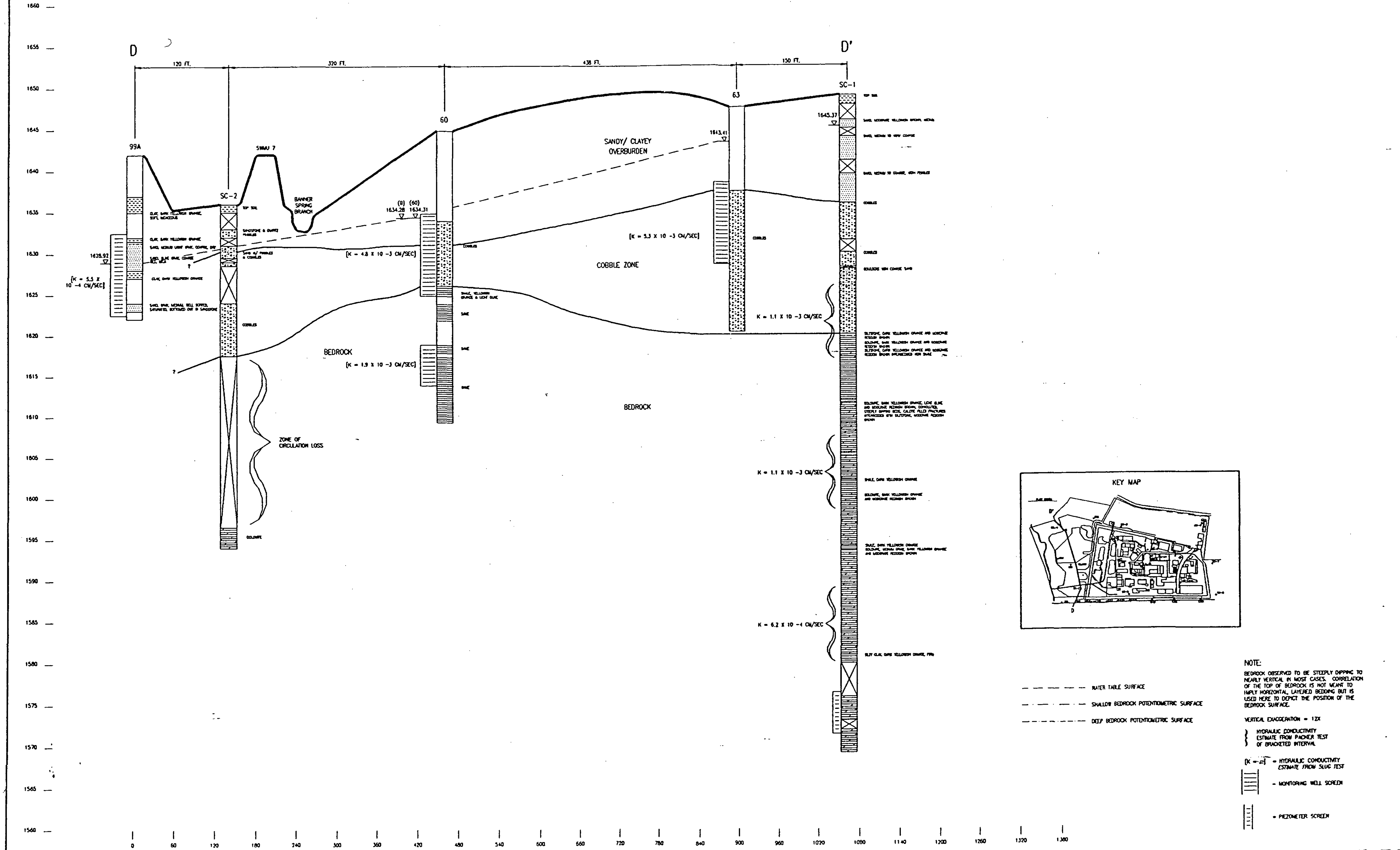


Figure 4-8
HYDROGEOLOGIC CROSS SECTION E – E'

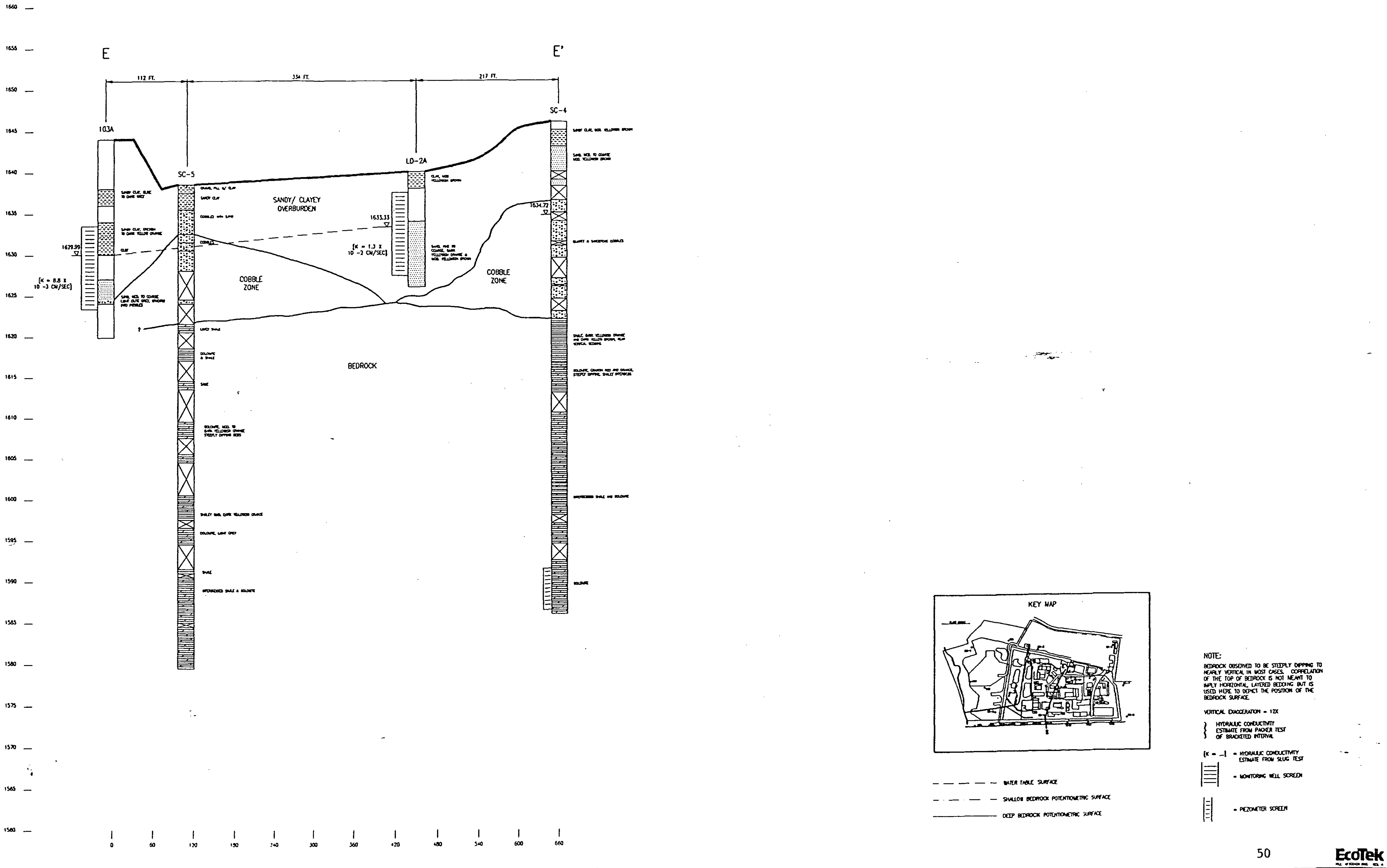
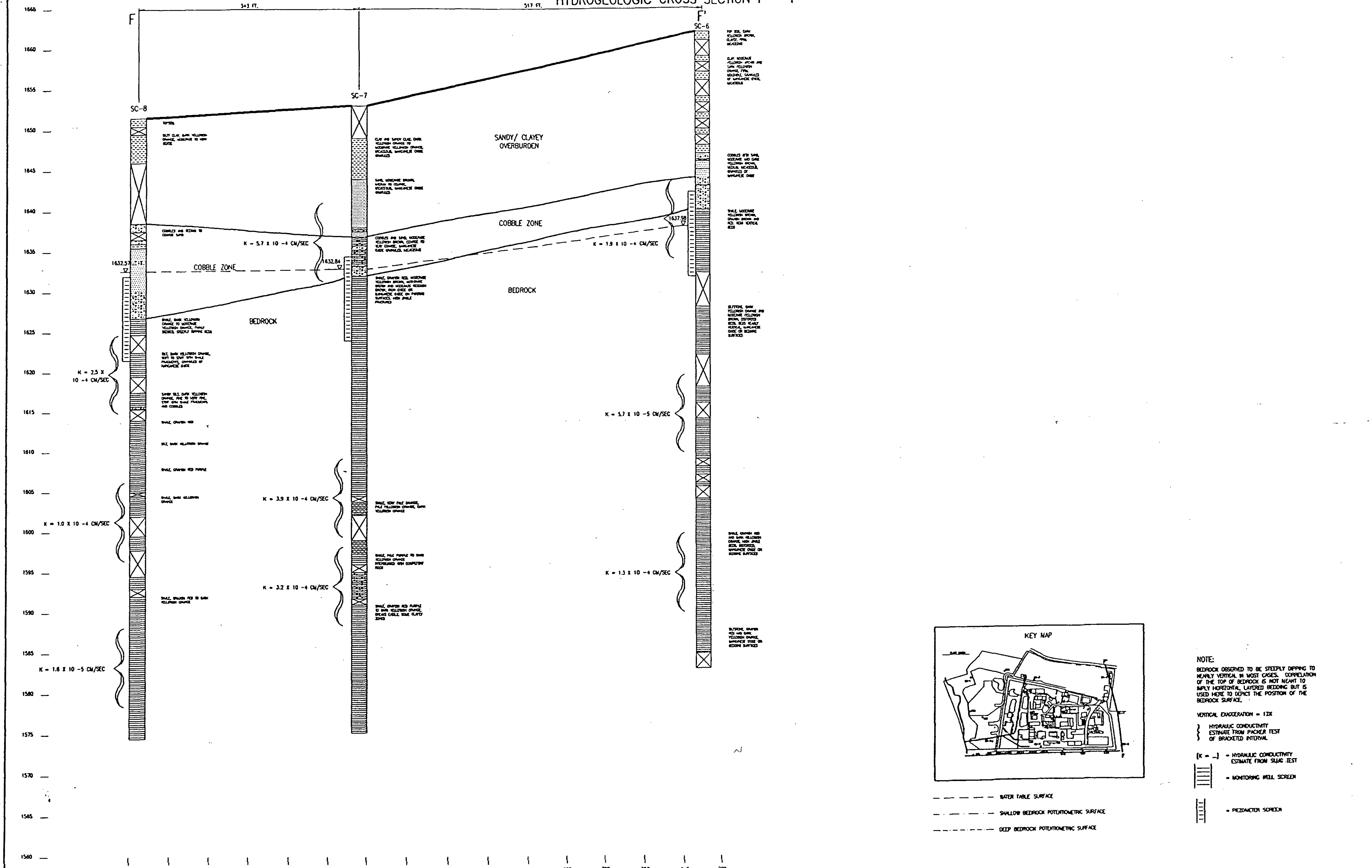


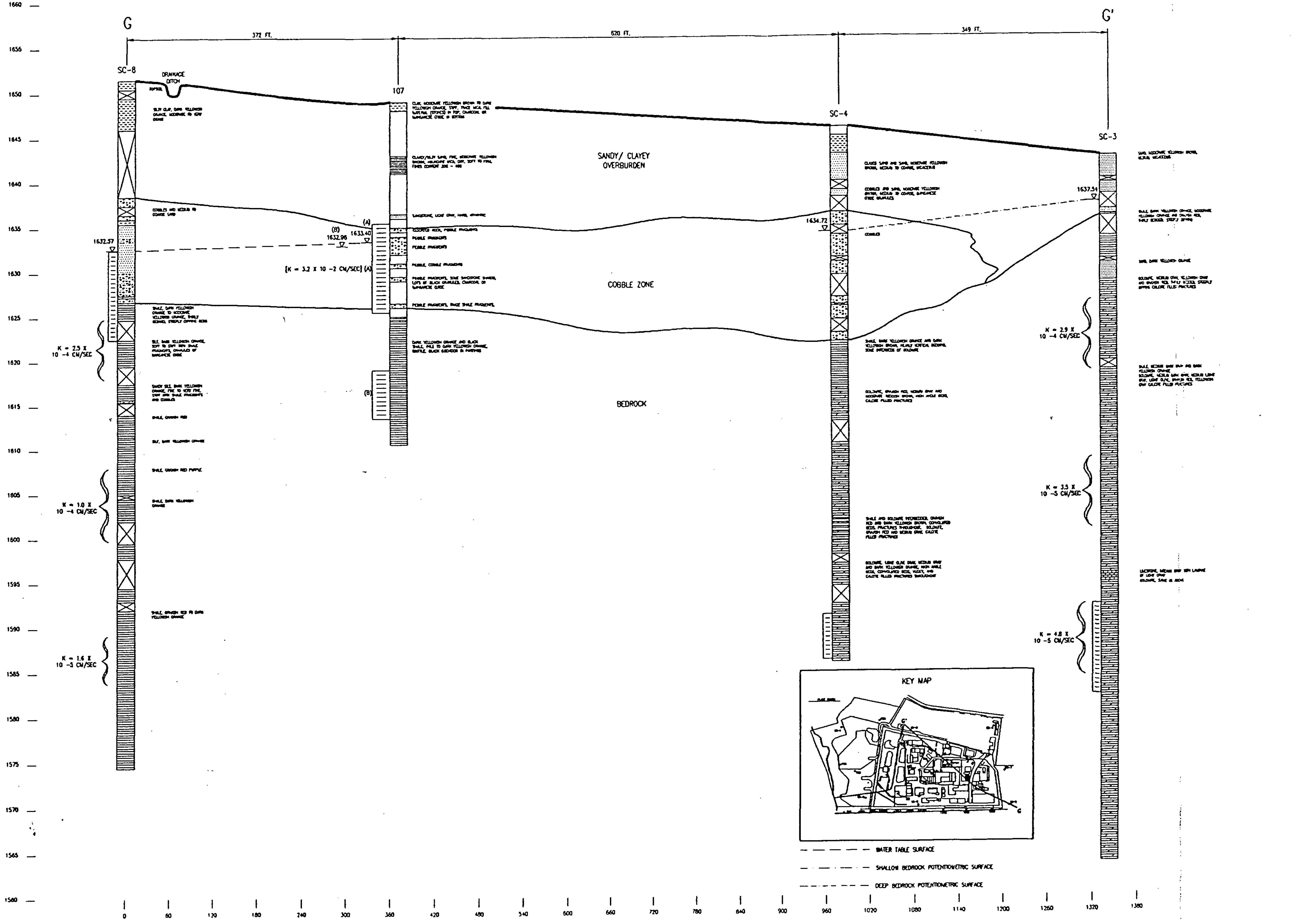
Figure 4-9

HYDROGEOLOGIC CROSS SECTION F – F'



EcoTek

Figure 4-10
HYDROGEOLOGIC CROSS SECTION G – G'



NOTE:
BEDROCK OBSERVED TO BE STEEPLY DIPPING TO NEARLY VERTICAL IN MOST CASES. CORRELATION OF THE TOP OF BEDROCK IS NOT MEANT TO IMPLY HORIZONTAL, LAYERED BEDDING BUT IS USED HERE TO DEPICT THE POSITION OF THE BEDROCK SURFACE.

VERTICAL EXAGGERATION = 12X

} HYDRAULIC CONDUCTIVITY ESTIMATE FROM PACKER TEST OF BRACKETED INTERVAL

[K = _] = HYDRAULIC CONDUCTIVITY ESTIMATE FROM SLUG TEST

= MONITORING WELL SCREEN

= PIEZOMETER SCREEN

EcoTek

SC-1

A distinct zone of high porosity is evident on the neutron log from a depth of 20 to 27 feet. This is within the cobble/boulder zone encountered during coring. The zone is also evident by its high resistivity. The borehole diameter through the cobble zone is variable indicating unstable borehole walls.

Within the bedrock, four distinct "kicks" are evident on the neutron log at depths of 38 to 41 feet, 45 to 47 feet, 50 to 53 feet, and 60 to 64 feet. These kicks or zones of increased porosity are verified on the resistivity logs, sonic log, and compensated density log. There is no change in borehole diameter through these depth intervals. Two of these depths were packer tested (38-41 and 60-63). The results indicate a hydraulic conductivity of 1.1×10^{-3} cm/sec (3.12 ft/day) for the shallower depth and 6.2×10^{-4} cm/sec (1.76 ft/day) for the deeper. Although the bedrock observed during coring appeared to be of lower hydraulic conductivity than the packer test results indicate, the values are not as high as would be expected for open fracture or void zones. Perhaps the neutron and resistivity highs are indicative of fractures filled with looser, more conductive material than the surrounding rock.

A washout is apparent in the borehole diameter at a depth of 71 to 72 feet. It is not manifested in the neutron or resistivity logs, but is evident in the sonic and compensated density logs. This depth interval was not packer tested.

SC-3

No cobble/boulder zone was encountered in Corehole SC-3. The interval from 14 to 23 feet displays a pronounced neutron signature like the cobble/boulder zone in SC-1. The interval was logged as dolomite. Just below this first dolomite zone is a thin zone of low neutron activity from 23 to 25 feet. This zone is verified by the resistivity, compensated density, sonic, and gamma logs. It was described during coring as shale. Surprisingly, the caliper log indicates a slight increase in borehole diameter (from 4 to 5 inches) through the shale. This is probably related to the poorly competent nature of the shale in relation to the dolomite.

Below the thin shale bed, the remainder of the corehole was described as dolomite and the core recovery was excellent. Within the dolomite, some variation is evident in porosity. There are ten distinct high neutron activity kicks from 29 feet to total depth (79 feet). These are also manifested on the resistivity, compensated density and sonic logs. The caliper log indicates no variation in borehole diameter throughout the dolomite.

Three intervals were packer tested in SC-3. The tested intervals all included apparent zones of high porosity. The hydraulic conductivity estimates ranges from 3.5 x 10^{-5} cm/sec (0.1 ft/day) to 2.9 x 10^{-4} cm/sec (0.8 ft/day). These numbers are relatively low when compared to the hydraulic conductivity of the overburden. If the high neutron and resistivity zones are evidence of fractures, the fractures are filled with material that reduces their conductivity. The temperature log displays no significant difference through the zones of high neutron activity.

SC-6

Corehole SC-6 was drilled through predominantly shale and siltstone bedrock. Consequently, the geophysical logs for the hole do not reveal much variation.

Neutron activity varies over a range of about 300 API as opposed to SC-1 and SC-3, which display a range of over 2,000 API. The gamma log displays an especially low attenuation through the cobble/boulder zone with a corresponding high compensated density.

One distinct low density reading corresponds to a two-foot thick bed of siltstone bordered above and below by no recovery intervals of three to four feet. Zones of relatively higher neutron activity tend to correspond with shale beds or no recovery zones. The shale encountered in SC-6 was mostly soft, weathered, thinly bedded, and poorly competent and sometimes difficult to recover in comparison with the more competent and massive beds of siltstone.

Three zones were packer tested within SC-6, 19.5 to 28 feet, 42.5 to 51 feet, and 62.5 to 71 feet. Hydraulic conductivity estimates were 1.9 x 10^{-4} cm/sec (0.54 ft/day), 5.7 x 10^{-5} cm/sec (0.16 ft/day), and 1.3 x 10^{-4} cm/sec (0.36 ft/day), respectively. The middle interval is siltstone and the upper and lower intervals are shale.

From 28 to 36 feet, the caliper log indicates that the borehole diameter is variable. This zone was logged as interbedded siltstone and shale. From 58 to 59 feet, the borehole diameter increases from four to six inches. The temperature log indicates a perturbation at the same depth but appears to be a tool adjustment, not a groundwater temperature change.

SC-7

Almost all of the bedrock encountered in SC-7 was described as shale. Consequently, the logs display little variation through the bedrock. The cobble/boulder zone (12-21 feet) is distinct on the neutron and resistivity logs. A packer test was conducted opposite the cobble/boulder zone yielding an estimate of hydraulic conductivity of 5.7 x 10^{-4} cm/sec (1.6 ft/day). This value seems low based on the visual log and high neutron activity and resistivity encountered in the interval.

The caliper log depicts an irregular borehole diameter through several depth intervals. The soft, poorly competent nature of the shale would tend to create such irregularities.

Two other intervals packer tested were 45 to 54 feet and 55 to 64 feet. Hydraulic conductivity estimates from these zones were 3.9 x 10^{-4} cm/sec (1.1 ft/day) and 3.2 x 10^{-4} cm/sec (0.91 ft/day).

To accommodate the resistivity logs, water was added to the corehole almost continuously to keep the hole full. Consequently, the temperature log is not valid.

SC-8

A limited suite of logs was run in Corehole SC-8 due to borehole instability and tool problems. No caliper, compensated density or sonic logs are available for interpretation.

Like SC-7, the bedrock encountered in SC-8 was predominantly shale. Consequently, the logs show little variation. One exception is a high neutron activity/high resistivity interval from 25 to 28 feet. This corresponds to shale just below the bottom of the temporary steel surface casing (installed through the cobble/boulder zone to enhance borehole stability). It is probably a washed out zone caused by the intersection of the casing bottom and soft shale. Unfortunately, no caliper log exists to confirm this.

Curiously, the cobble/boulder zone is not distinguishable on the geophysical logs although it was observed in the core. This is probably because the zone is mostly unsaturated at SC-8 and may have more interstitial clay than at SC-6 and SC-7.

Packer tests were conducted at intervals of 27-36 feet, 46-55 feet, and 60.5 to 69.5 feet. Hydraulic conductivity estimates from these intervals are 2.5 x 10^{-4} cm/sec (0.71 ft/day), 1.0 x 10^{-4} cm/sec (0.28 ft/day), and 1.6 x 10^{-5} cm/sec (0.045 ft/day), respectively. The shallowest zone includes part of the interval displaying the high neutron reading, but the corresponding hydraulic conductivity is not indicative of a very porous zone.

4.2.4.1 Conclusions of Geophysical Logging

The objective of the geophysical logging was to investigate the possibility of highly porous zones in the subsurface that might not be evident from a visual inspection of the core and to provide data through intervals where core recovery was poor. In both cases, the logging was successful in that it provided some data that the core did not. Much of the subsurface explored was revealed to be surprisingly predictable and consistent, especially at Coreholes SC-6, SC-7, and SC-8. At these locations, the geophysical logs do not provide much extra to the story because the visual description tells all. At Coreholes SC-1 and SC-3, the geophysics were very useful and revealed certain significant features.

Because of the variably dipping nature of the bedrock, it was not expected that the geophysical logs or the lithologic logs would be correlatable from hole to hole. It was hoped, however, that any fracturing or faulting encountered might be traceable from hole to hole. An interval between elevations 1,606 to 1,586 msl does seem to correlate between Coreholes SC-1 and SC-3. The interval is characterized by high neutron activity and high fluid resistivity, both potential indicators of gross porosity (fracturing). The two holes are generally along the same line of strike which increases the potential for similarities, structural or lithologic.

The geophysical logs for Coreholes SC-1, SC-3, SC-6, SC-7, and SC-8 are included as Appendix L.

4.3 Groundwater

Groundwater occurs beneath the site in both the unconsolidated alluvium and the bedrock. There is no evidence of any laterally continuous hydraulic separation (aquitard) between the alluvium and bedrock and in the strictest sense; therefore, they together comprise one aquifer. Because of the variably and mostly steeply dipping nature of the bedrock, the vertical extent of the aquifer could be many hundreds of feet. At the NFS site, groundwater monitoring wells and piezometers are screened in three distinct zones within the aquifer. From shallowest to deepest, these are: 1) across the water table which occurs in the alluvium; 2) the deep alluvium and shallow bedrock; several wells are completed with 5 feet screen lengths completely in the shallow bedrock; and a few are screened at a similar depth below the water table surface, but completely in alluvium at points where the alluvium is particularly thick e.g. 63B and 3) in the intermediate depth bedrock, from 50 to 120 feet below the land surface.

4.3.1 Alluvium

The water table is found in the alluvium from 0 depth where it intersects the land surface to 14 feet in the western corner of the plant. The alluvium is characterized by fining upward, unconsolidated sediments. The hydraulic conductivity, therefore, increases with depth. Based on slug tests of the new alluvial wells, the range of hydraulic conductivity is from 0.51 ft/day to 114.0 ft/day and averages 22.6 ft/day (Table 4-2). Hydraulic conductivity estimates for

Table 4-2

SLUG TEST RESULTS

EcoTek 1992/1993

Zone 1

Well No.	K (cm\sec.)	K (ft\day)
55A	1.14E-03	3.23
63A	1.80E-04	0.51
70A	1.12E-03	3.18
95A	3.37E-03	9.50
96A	8.67E-03	24.60
97A	4.60E-03	13.02
98A	2.49E-02	70.61
99A	5.49E-04	1.56
100A	1.34E-02	38.02
101A	1.37E-03	3.88
102A	1.41E-02	40.10
103A	9.53E-03	27.00
104A	3.20E-03	9.08
105A	1.28E-03	3.64
106A	7.45E-04	2.11
107A	4.05E-02	114.00
LD-1A	4.04E-04	1.15
LD-2A	1.29E-02	36.57

Zone 2

Well No.	K (cm\sec.)	K (ft\day)
60B	1.82E-03	5.14
63B	9.76E-03	27.64
67B	2.39E-03	6.78
100B	4.14E-03	11.75

OHM-1990

Zone 1

Well No.	K (cm\sec.)	K (ft\day)
91	1.49E-03	4.21
92	1.19E-03	3.36
94	1.70E-03	4.81

EcoTek 1989

Zone 1

Well No.	K (cm\sec.)	K (ft\day)
52	4.54E-03	13.00
55	7.53E-03	21.50
56	2.15E-03	6.10
57	4.43E-03	12.70
58	1.91E-03	5.50
59	3.61E-03	10.30
60	4.82E-03	13.80
62	1.94E-03	5.50
63	5.33E-03	15.20
64	4.86E-03	13.90
68	2.57E-03	7.30
72	8.43E-04	2.40
73	9.92E-04	2.80

Zone 2

65	7.21E-04	2.10
66	1.99E-03	5.70
71	3.92E-03	11.20
79	4.67E-03	12.80
81	2.25E-03	6.40

Zone 3

67	1.16E-02	33.00
82	1.72E-03	4.90

TLG-1987

Zone 1

Well No.	K (cm\sec.)	K (ft\day)
29	6.90E-04	1.95
31	1.40E-03	3.23
33	3.22E-04	0.91
36	1.31E-03	3.71
39	3.66E-04	1.00

Zone 2

30	9.45E-05	0.27

B:\TABLES\SLUGKVAL.WK1

Zone 1 are posted on a site map as Figure 4-11. In most cases, the water table occurs in the coarser grained alluvial material; and therefore, the range of hydraulic conductivity is indicative of the sandy to cobbly material and not the entire alluvium.

During the coring program, selected intervals were packer tested to investigate zones of high and low hydraulic conductivity in the bedrock. A shallow interval was selected in two of the coreholes (SC-1 and SC-7) that was thought to be highly fractured sandstone bedrock. As the coring progressed, it was realized that the sandstone was actually a boulder zone with cobbles and boulders in a sandy/clayey matrix that resembled fractured rock when first encountered.

Packer tests in the cobble/boulder zone yielded hydraulic conductivity estimates of 1.6 and 3.1 ft/day. As a validation of the packer testing, the falling head was measured at the cessation of inflow for each interval. The falling head data were analyzed using slug test methods. The results provided K estimates of 2.0 and 4.5 ft/day (Table 4-3).

Figures 4-12 through 4-14 are maps of the water table surface (Zone 1) using October, November, and December 1993 data. Table 4-4 contains fourth quarter 1993 potentiometric data used to contour the water table and potentiometric surfaces. Groundwater flow in Zone 1 is variable but generally to the northwest as it leaves the site. Zone 1 groundwater is unconfined and the Zone 1 surface is therefore the water table. The water table ranges from 1643 to 1628 feet msl from east to west across the site.

Several distinct features are evident in the water table surface that cause flow to be locally divergent. These features are difficult to interpret and consequently are portrayed differently in some months in an effort to provide the most technically sound depiction.

In October, a groundwater mound is evident around Pond 1 and Pond 4. Pond 1 is the likely cause of this mound providing local increased recharge to the water table. Flow is radial from this feature.

In November, two closed contour mounds are evident in the Ponds vicinity. One is located downgradient of Pond 3 and the other is focused on Pond 1 and Pond 4, as in October. A smaller closed contour mound is evident in the SWMU 14 vicinity.

In December, one closed contour covers the area depicted as two mounds in November (Pond 1 and Pond 4, and SWMU 14). Instead of a closed contour downgradient of Pond 3, a nose or ridge is evident there in December. Wells 73 and 74 were added to the data base in December (they were not previously used because of excessive screen lengths; recent observations indicate that these wells

Figure 4-1

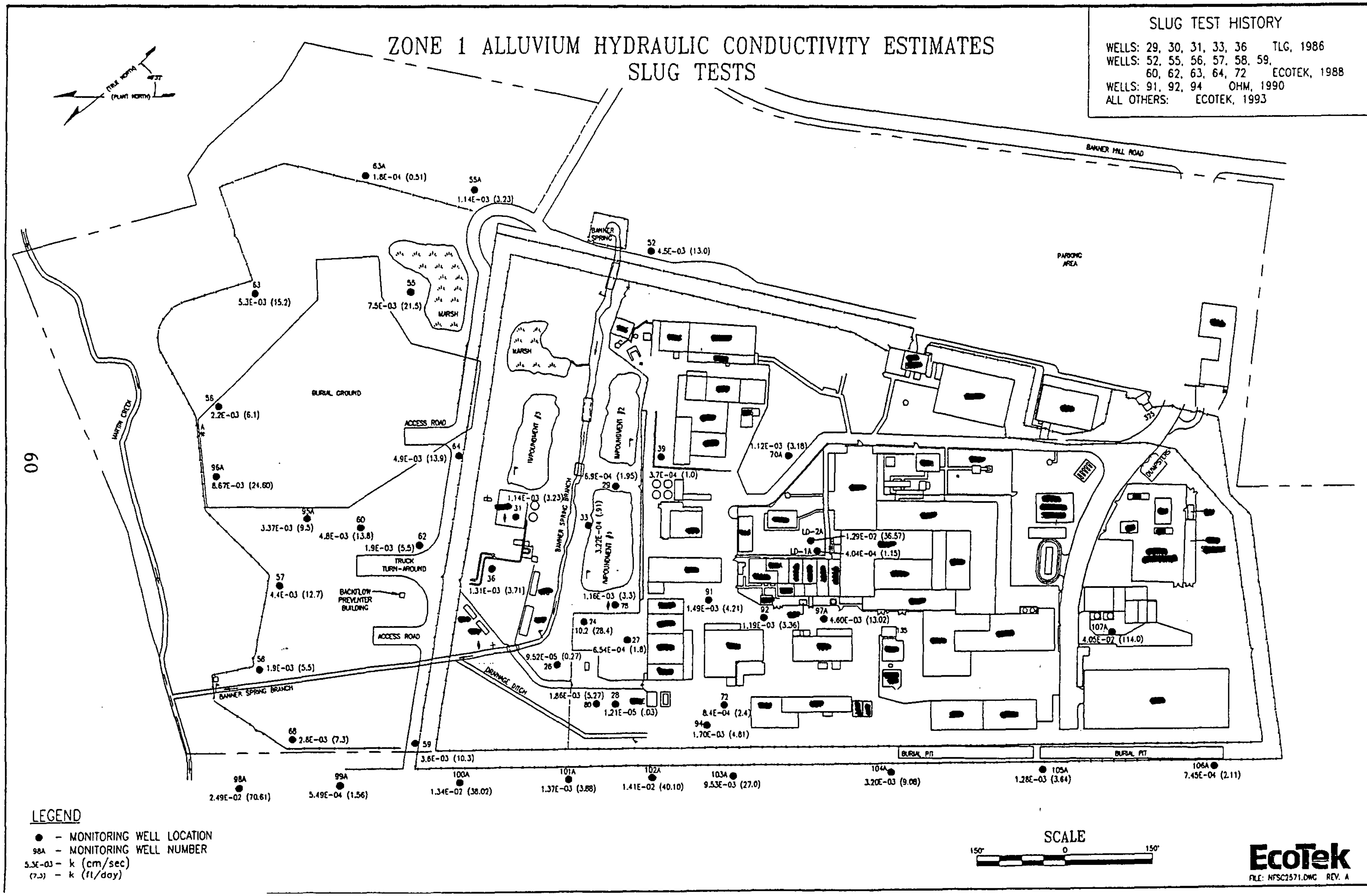

ZONE 1 ALLUVIUM HYDRAULIC CONDUCTIVITY ESTIMATES
SLUG TESTS
SLUG TEST HISTORY
WELLS: 29, 30, 31, 33, 36 TLG, 1986
WELLS: 52, 55, 56, 57, 58, 59, 60, 62, 63, 64, 72 ECOTEK, 1988
WELLS: 91, 92, 94 OHM, 1990
ALL OTHERS: ECOTEK, 1993
BANNER HILL ROAD
PARKING AREA
63A 1.8E-04 (0.51)
55A 1.14E-03 (3.23)
52 4.5E-03 (13.0)
63 5.3E-03 (15.2)
55 7.5E-03 (21.5)
MARSH
BURIAL GROUND
56 2.2E-03 (6.1)
ACCESS ROAD
64 4.9E-03 (13.9)
96A 8.67E-03 (24.60)
95A 3.37E-03 (9.5)
60 4.8E-03 (13.8)
62 1.9E-03 (5.5)
TRUCK TURN-AROUND
57 4.4E-03 (12.7)
BACKFLOW PREVENTER BUILDING
ACCESS ROAD
58 1.9E-03 (5.5)
BANNER SPRING BRANCH
68 2.8E-03 (7.3)
59 3.6E-03 (10.3)
MARTIN CREEK
IMPOUNDMENT #3
IMPOUNDMENT #2
IMPOUNDMENT #1
BANNER SPRING BRANCH
BANNER SPRING
31 1.14E-03 (3.23)
36 1.31E-03 (3.71)
29 6.9E-04 (1.95)
39 3.7E-04 (1.0)
33 3.22E-04 (.91)
1.16E-03 (3.3) 75
74 10.2 (28.4)
27 6.54E-04 (1.8)
9.52E-05 (0.27) 26
DRAINAGE DITCH
1.86E-03 (5.27) 80
28 1.21E-05 (.03)
1.12E-03 (3.18) 70A
LD-2A 1.29E-02 (36.57)
LD-1A 4.04E-04 (1.15)
91 1.49E-03 (4.21)
92 1.19E-03 (3.36)
97A 4.60E-03 (13.02)
72 8.4E-04 (2.4)
94 1.70E-03 (4.81)
107A 4.05E-02 (114.0)
DUMPSTERS
BURIAL PIT
BURIAL PIT
98A 2.49E-02 (70.61)
99A 5.49E-04 (1.56)
100A 1.34E-02 (38.02)
101A 1.37E-03 (3.88)
102A 1.41E-02 (40.10)
103A 9.53E-03 (27.0)
104A 3.20E-03 (9.08)
105A 1.28E-03 (3.64)
106A 7.45E-04 (2.11)
LEGEND
● - MONITORING WELL LOCATION
98A - MONITORING WELL NUMBER
5.3E-03 - k (cm/sec)
(7.3) - k (ft/day)
SCALE
150' 0 150'
EcoTek
FILE: NFSC2571.DWG REV. A

Table 4-3

Corehole Packer Test Results

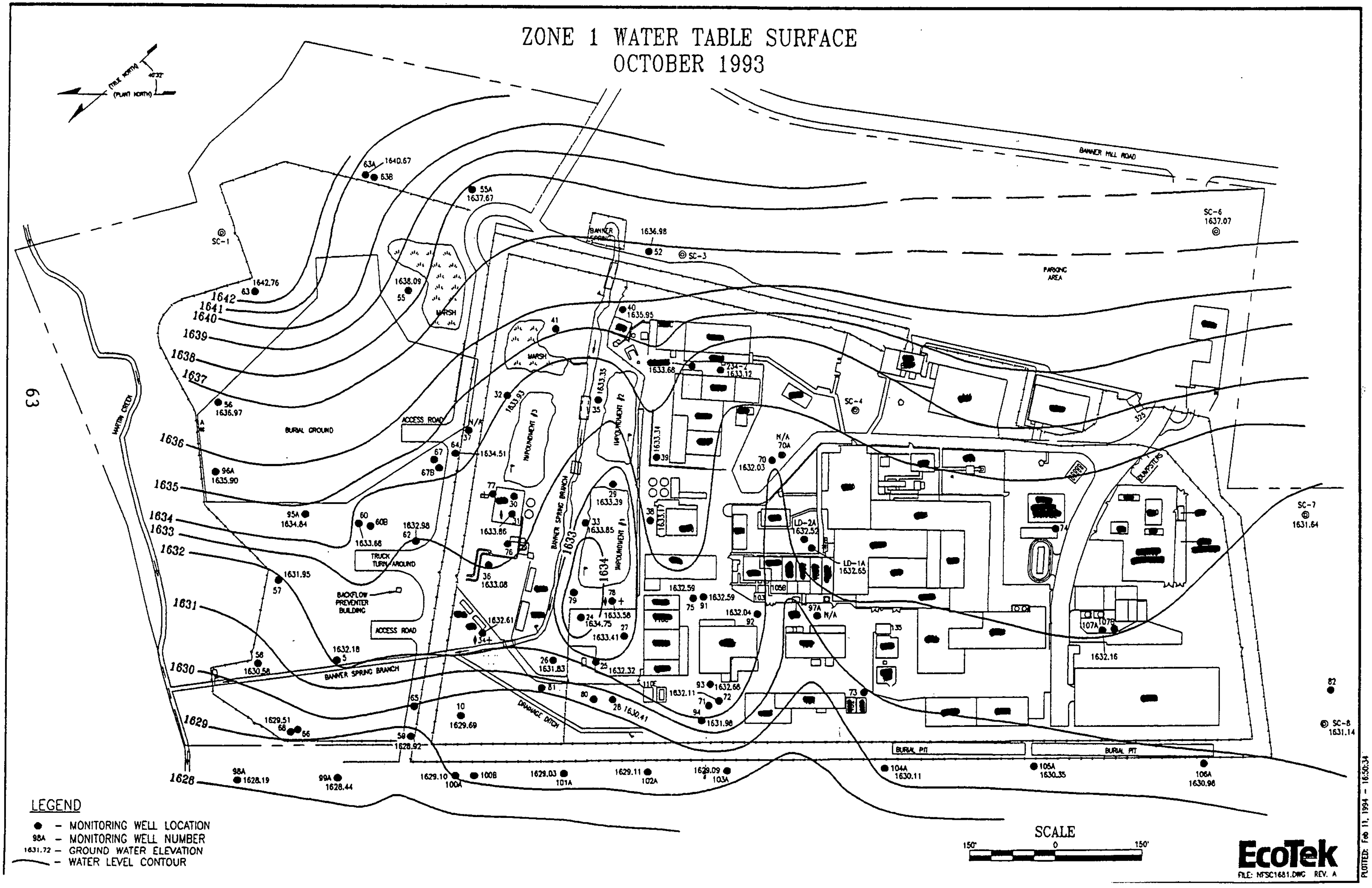
Location	Interval in Ft. Below Ground Level	Water Pressure at Swivel (psi)	K Ft/Day	K Cm/Sec	Falling Head Results K Ft/Day	Falling Head Results K Cm/Sec	Average K per Zone (From Packer Test Data) Ft/Day	Average K per Zone (From Packer Test Data) Cm/Sec
SC-1	22-31 ft.	5	1.8	6.3E-04				
		10	4	1.4E-03				
		15	3.7	1.3E-03	4.47	1.6E-03	3.1	1.1E-03
SC-1	35-44 ft.	10	3.7	1.3E-03				
		20	3.1	1.1E-03				
		30	2.6	9.1E-04	0.26	9.0E-05	3.1	1.1E-03
SC-1	61-69 ft.	20	1.9	6.7E-04				
		30	1.6	5.6E-04				
		40	1.7	6.1E-04	4.23	1.5E-03	1.8	6.2E-04
SC-3	17.5-26.5 ft.	10	0.82	2.9E-04				
		20	0.79	2.8E-04	1.04	3.7E-04	0.82	2.9E-04
SC-3	34.5-43.5 ft.	10	0.04	1.4E-05				
		20	0.12	4.2E-05				
		30	0.14	4.8E-05	0.22	7.6E-05	0.1	3.5E-05
SC-3	51-60 ft.	20	0.14	4.8E-05				
		30	0.14	4.8E-05				
		40	0.14	4.8E-05	0.68	2.4E-04	0.14	4.8E-05
SC-6	19.5-28 ft.	20	0.62	2.2E-04				
		10	0.48	1.7E-04	0.27	9.5E-05	0.54	1.9E-04
SC-6	42.5-51 ft.	25	0.14	4.9E-05				
		34	0.18	6.4E-05	0.086	3.0E-05	0.16	5.7E-05
SC-6	62.5-71 ft.	20	0.25	8.8E-05				
		40	0.48	1.7E-04	1.04	3.7E-04	0.37	1.3E-04
SC-7	12.5-21.5 ft.	10	1.9	6.7E-04				
		15	1.3	4.7E-04	1.99	7.0E-04	1.6	5.7E-04
SC-7	45-54 ft.	10	0.54	1.9E-04				
		20	1.1	4.0E-04				
		30	1.6	5.8E-04	1.12	4.0E-04	1.1	3.9E-04

Table 4-3 (continued)
Corehole Packer Test Results

Location	Interval in Ft. Below Ground Level	Water Pressure at Swivel (psi)	K		Falling Head Results K		Average K per Zone (From Packer Test Data)	
			Ft/Day	Cm/Sec	Ft/Day	Cm/Sec	Ft/Day	Cm/Sec
SC-7	55-64 ft.	10	0.51	1.8E-04				
		15	0.99	3.5E-04				
		20	1.2	4.3E-04	1.5	5.2E-04	0.91	3.2E-04
SC-8	27-36 ft.	5	0.71	2.5E-04	0.19	6.7E-05	0.71	2.5E-04
SC-8	46-55 ft.	10	0.43	1.5E-04				
		15	0.21	7.3E-05				
		20	0.25	8.8E-05	0.22	7.6E-05	0.28	1.0E-04
SC-8	60.5-69.5 ft.	20	0.01	3.5E-06				
		30	0.05	1.9E-05				
		40	0.08	2.7E-05	0.17	6.1E-05	0.05	1.6E-05

B:\TABLES\PACKER.WK1

Figure 4-12



63

Figure 4-13

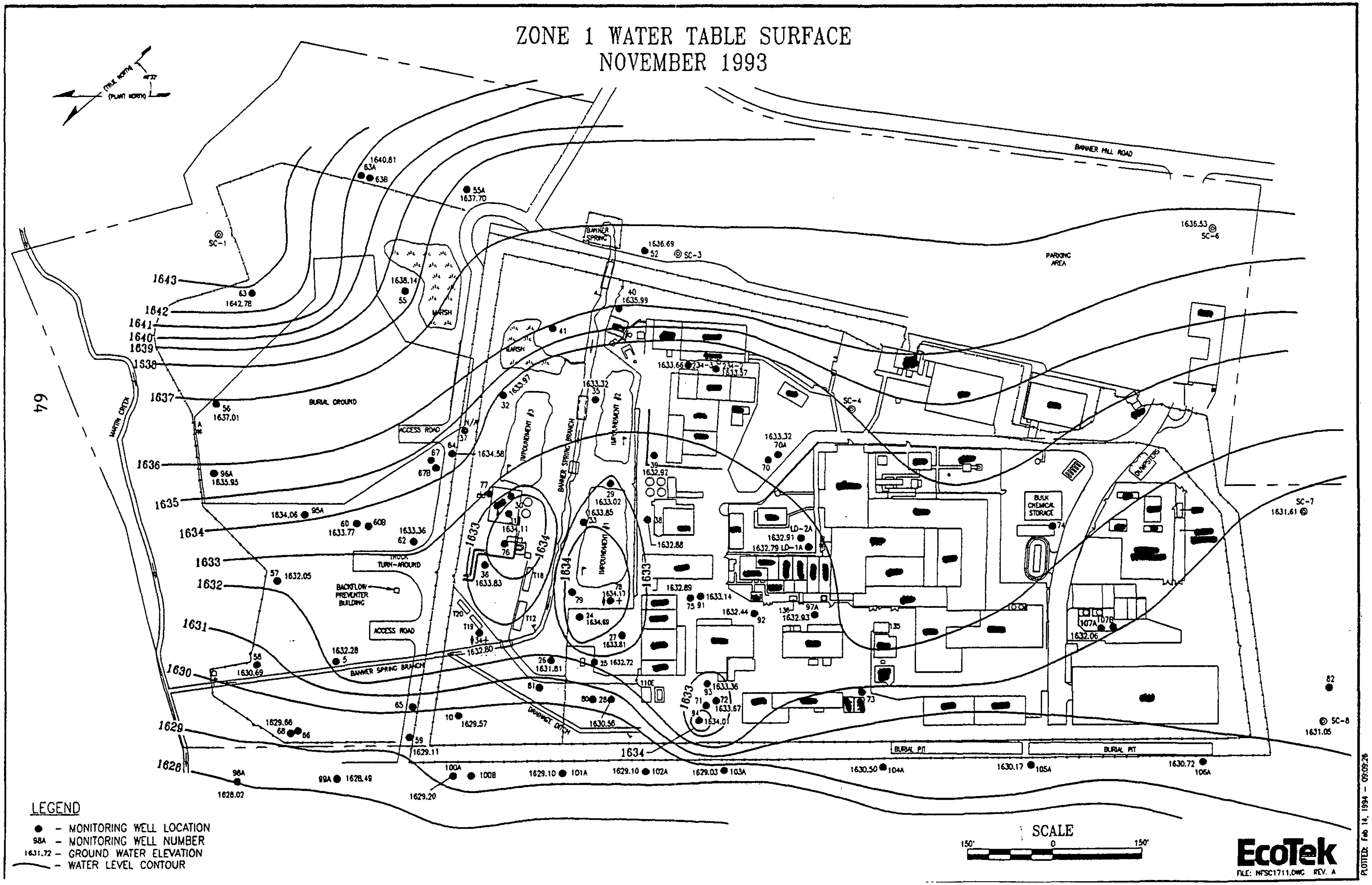

ZONE 1 WATER TABLE SURFACE
NOVEMBER 1993
(TRUE NORTH)
(PLANT NORTH)
BANNER MILL ROAD
PARKING AREA
BANNER SPRING
BURIAL GROUND
ACCESS ROAD
MARSH
IMPOUNDMENT #2
IMPOUNDMENT #1
BANNER SPRING BRANCH
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
BULK CHEMICAL STORAGE
DUMPSTERS
DRAINAGE DITCH
BURIAL PIT
MARTIN CREEK
64
1643
1642
1641
1640
1639
1638
1637
1636
1635
1634
1633
1632
1631
1630
1629
1628
LEGEND
● – MONITORING WELL LOCATION
98A – MONITORING WELL NUMBER
1631.72 – GROUND WATER ELEVATION
WATER LEVEL CONTOUR
SCALE
150'
0
150'
EcoTek
FILE: NFSC1711.DWG REV. A
PLOTTED: Feb 14, 1994 – 09:09:26

Figure 4-14

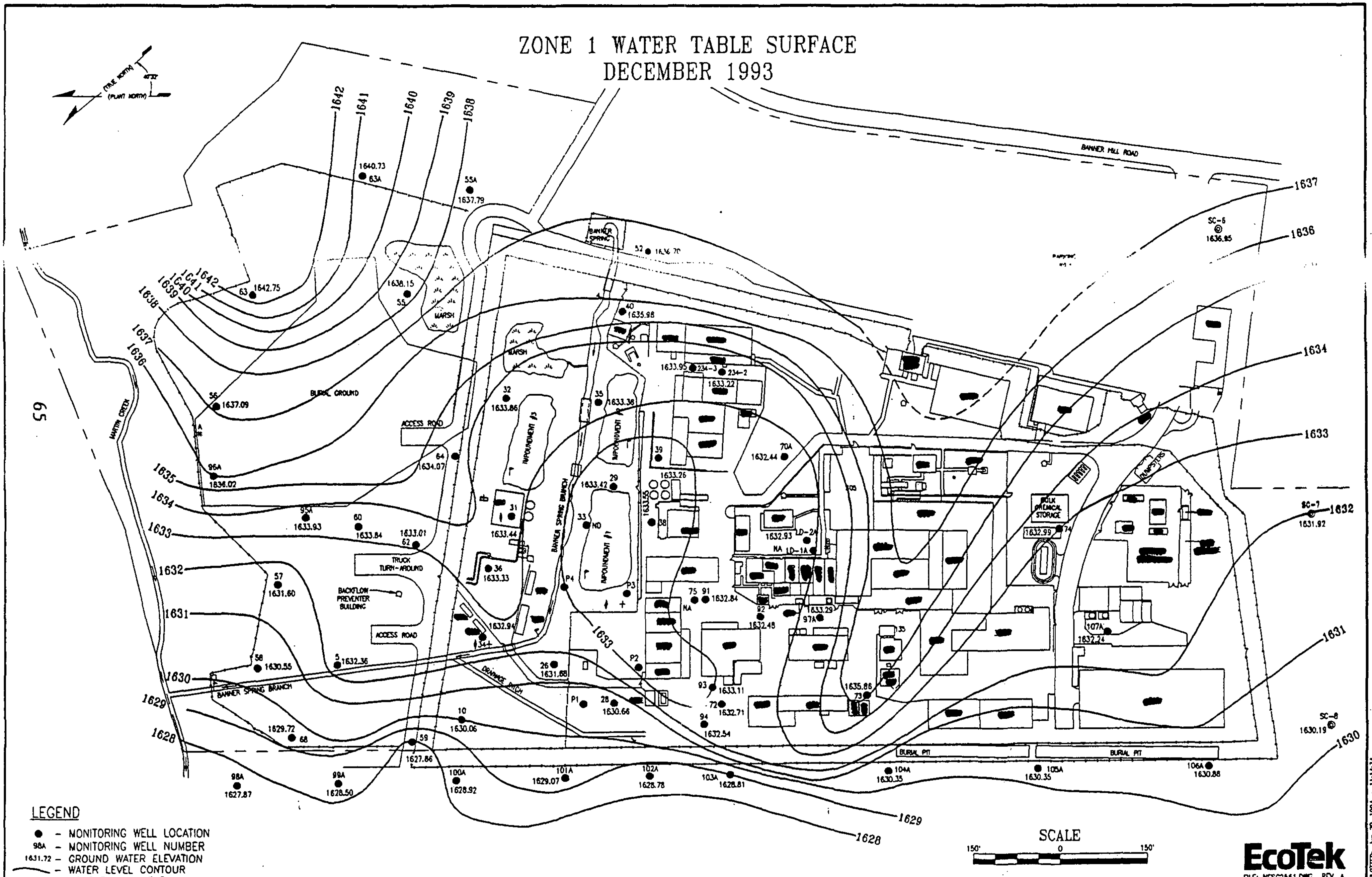

ZONE 1 WATER TABLE SURFACE
DECEMBER 1993
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
BANNER SPRING
BURIAL GROUND
ACCESS ROAD
MARSH
IMPOUNDMENT #1
IMPOUNDMENT #3
BANNER SPRING BRANCH
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
DRAINAGE DITCH
BULK CHEMICAL STORAGE
DUMPSTERS
BURIAL PIT
MARTIN CREEK
65
1642
1641
1640
1639
1638
1637
1636
1635
1634
1633
1632
1631
1630
1629
1628
LEGEND
● - MONITORING WELL LOCATION
98A - MONITORING WELL NUMBER
1631.72 - GROUND WATER ELEVATION
WATER LEVEL CONTOUR
NO DATA AVAILABLE
SCALE
150' 0 150'
EcoTek
FILE: NFSC2561.DWG REV. A
PLOTTED: Jun 20, 1994 - 11:14:34

Table 4-4

October 1993 Potentiometric Data

Zone 1		Zone 2		Zone 3	
Well Number	Elevation (ft msl)	Well Number	Elevation (ft msl)	Well Number	Elevation (ft msl)
5	1632.18	30	1633.83	67	1635.17
10	1629.69	41	1635.98	82	1628.12
24	1634.75	60B	1633.71	SC−1	1644.62
25	1632.32	63B	1640.39	SC−3	1637.34
26	1631.83	65	1629.80	SC−4	1633.32
27	1633.41	66	1629.76		
28	1630.41	67B	1634.94		
29	1633.39	71	1631.64		
31	1633.86	76	1632.69		
32	1633.93	77	1633.68		
33	1633.85	79	1632.11		
34	1632.61	81	1629.91		
35	1633.35	100B	1628.47		
36	1633.08	107B	1631.82		
38	1633.17				
39	1633.34				
40	1635.95				
52	1636.68				
55	1638.09				
55A	1637.67				
56	1636.97				
57	1631.95				
58	1630.58				
59	1628.92				
60	1633.68				
62	1632.98				
63	1642.76				
63A	1640.67				
64	1634.51				
68	1629.51				
70A	NA				
72	1632.11				
75	1632.59				
78	1633.58				
80	NA				
91	1632.37				
92	1632.04				
93	1632.68				
94	1631.98				
95A	1634.84				
96A	1635.90				
97A	NA				
98A	1628.19				
99A	1628.44				
100A	1629.10				
101A	1639.03				
102A	1629.11				
103A	1629.09				
104A	1630.11				
105A	1630.35				
106A	1630.98				
107A	1632.16				
LD−1A	1632.65				
LD−2A	1632.52				
234−2	1633.12				
234−3	1633.68				
SC−6	1637.07				
SC−7	1631.64				
SC−8	1631.14				

NA = Data not available

Table 4-4 (continued)

November 1993 Potentiometric Data

Zone 1		Zone 2		Zone 3	
Well Number	Elevation (ft msl)	Well Number	Elevation (ft msl)	Well Number	Elevation (ft msl)
5	1632.28	30	1633.83	67	1635.23
10	1629.57	41	1636.11	82	1629.43
24	1634.69	60B	1633.79	SC−1	1644.59
25	1632.72	63B	1640.40	SC−3	1637.34
26	1631.81	65	1630.02	SC−4	1632.99
27	1633.81	66	1629.83		
28	1630.58	67B	1634.98		
29	1633.02	71	1634.94		
31	1634.11	76	1632.81		
32	1633.97	77	1633.70		
33	1633.85	79	1632.06		
34	1632.80	81	1630.10		
35	1633.32	100B	1628.54		
36	1633.83	107B	1631.78		
38	1632.88				
39	1632.92				
40	1635.99				
52	1636.69				
55	1638.14				
55A	1637.79				
56	1637.01				
57	1632.05				
58	1630.69				
59	1629.11				
60	1633.77				
62	1633.36				
63	1642.78				
63A	1640.81				
64	1634.58				
68	1629.66				
70A	1633.32				
72	1633.67				
75	1632.89				
78	1634.17				
80	1629.73				
91	1632.92				
92	1632.44				
93	1633.36				
94	1634.01				
95A	1634.06				
96A	1635.95				
97A	1632.93				
98A	1628.02				
99A	1628.49				
100A	1629.20				
101A	1629.10				
102A	1629.10				
103A	1629.03				
104A	1630.50				
105A	1630.17				
106A	1630.72				
107A	1632.06				
LD−1A	1632.79				
LD−2A	1632.91				
234−2	1633.57				
234−3	1633.66				
SC−6	1636.53				
SC−7	1631.61				
SC−8	1631.05				

NA = Data not available

B:\TABLES\NOVWLDAT.WK1

Table 4-4 (contineud)

December 1993 Potentiometric Data

Zone 1 Well Number	Zone 1 Elevation (ft msl)	Zone 2 Well Number	Zone 2 Elevation (ft msl)	Zone 3 Well Number	Zone 3 Elevation (ft msl)
5	1632.36	30	1633.80	67	1635.26
10	1630.06	41	1636.08	82	1629.55
24	NA	60B	1633.87	SC-1	1644.51
25	NA	63B	1640.40	SC-3	1637.34
26	1631.68	65	1630.47	SC-4	1633.57
27	NA	66	1629.66		
28	1630.66	67B	1634.97		
29	1633.42	71	1631.92		
31	1633.44	76	1632.86		
32	1633.86	77	1634.38		
33	NA	79	1632.66		
34	1632.94	81	NA		
35	1633.38	100B	1628.32		
36	1633.33	107B	1631.97		
38	1633.35				
39	1633.26				
40	1635.98				
52	1636.70				
55	1638.15				
55A	1637.79				
56	1637.09				
57	1631.60				
58	1630.55				
59	1627.86				
60	1633.84				
62	1633.01				
63	1642.75				
63A	1640.73				
64	1634.07				
68	1629.72				
70A	1632.44				
72	1632.71				
73	1634.99				
74	1632.99				
75	1632.82				
78	NA				
80	NA				
91	1632.84				
92	1632.48				
93	1633.11				
94	1632.54				
95A	1633.93				
96A	1636.02				
97A	1633.29				
98A	1627.87				
99A	1628.50				
100A	1628.92				
101A	1629.07				
102A	1628.78				
103A	1628.81				
104A	1630.35				
105A	1630.35				
106A	1630.88				
107A	1632.24				
LD-1A	1632.52				
LD-2A	1632.93				
234-2	1633.22				
234-3	1633.95				
SC-6	1636.95				
SC-7	1631.92				
SC-8	1630.19				

NA = Data not available

B:\TABLES\DECWLDAT.WK1

closely reflect the water table surface in spite of their respective screen lengths). Adding these two points causes a well defined north/south trending ridge in the Building 130/131/134 area of the plant.

Based on the three months described above, the hydraulic gradient of the water table ranges from 0.003 ft/ft to 0.027 ft/ft. Using an average K of 22.6 ft/day, an average hydraulic gradient of 0.019 ft/ft and a porosity of 0.30, the groundwater velocity in the alluvium can be estimated as 1.43 ft/day or 526 ft/year.

4.3.2 Bedrock

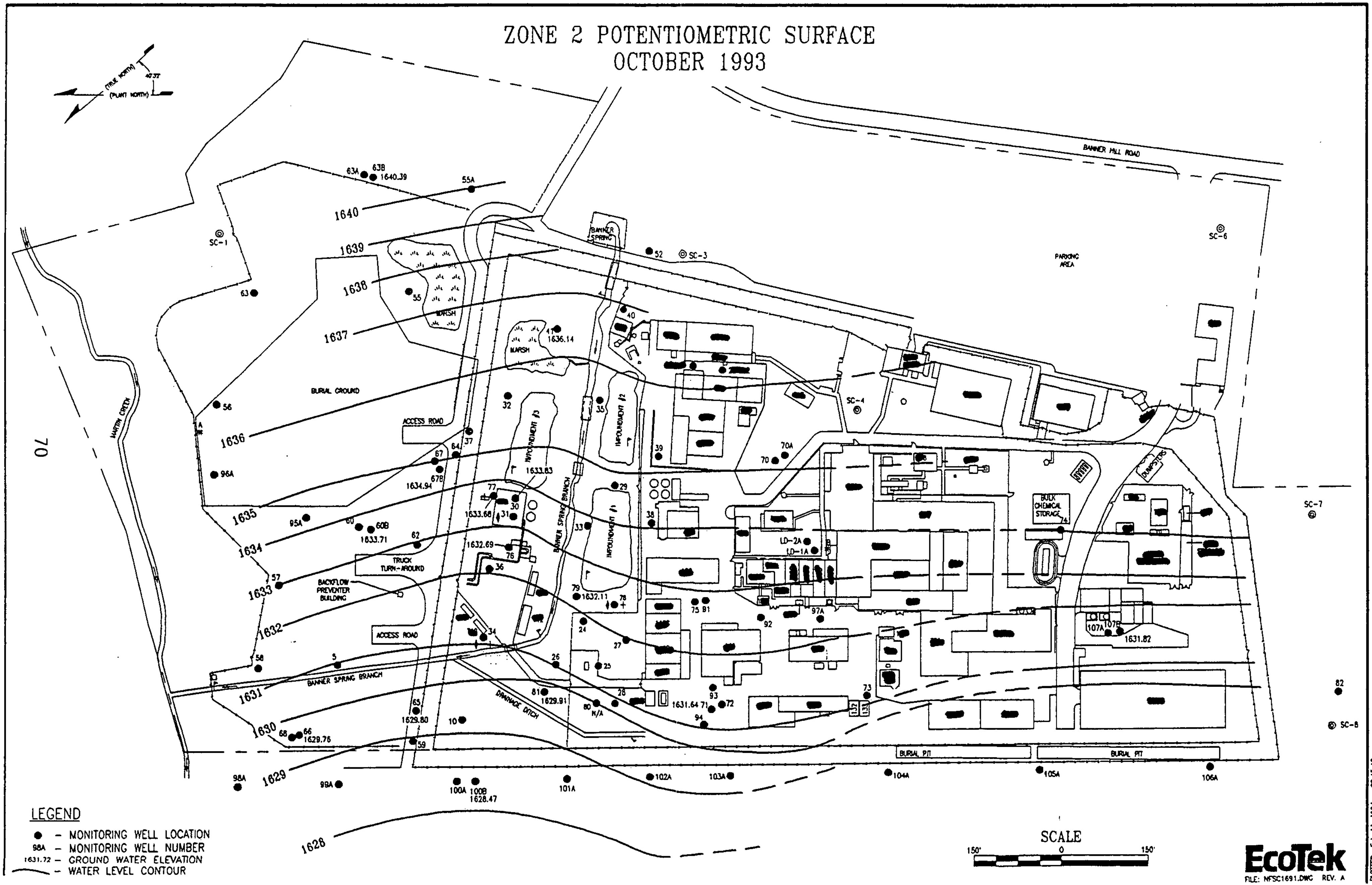
With the exception of the contractors' parking lot, which sits atop a bedrock knob, the bedrock beneath the NFS site is completely saturated. Coring across the site revealed no competent, laterally continuous aquitard separating the bedrock from the alluvium. The groundwater in the bedrock is therefore considered to be unconfined. The potentiometric surface of the deeper bedrock groundwater (Zone 3) indicates that some of the recharge to the zone may be from upgradient sources causing an upward flow potential at certain locations.

Bedrock observed down to depths of 80 feet was variably (from horizontal to vertical), but mostly steeply dipping, sometimes contorted, and usually very thinly bedded. The shale units were frequently soft and crumbly and easily broke along bedding planes or laminae. The softness of the shale material probably precludes the possibility of large open fractures. However, the number of partings along bedding combined with the crumbly nature of the material and its steep attitude probably result in a flow regime that more closely resembles a porous medium than a fracture-dominated medium. A similar scenario is described by Rovey and Cherkauer in "Ground Water", January/February 1994 (Rovey, 1994).

A different situation was observed where dolomite was encountered. For the most part, the dolomite was competent, hard, fine grained rock. Some calcite filled openings were observed, but these were small and random and not likely oriented so that they formed large tubes or openings. Fractures or faults within the dolomite would have more potential than in the shale to stand open (following dissolution) and act as conduits for flow. At one location (SC-2), a zone of lost circulation was encountered that bottomed out in apparent dolomite bedrock (no reaction to HCl).

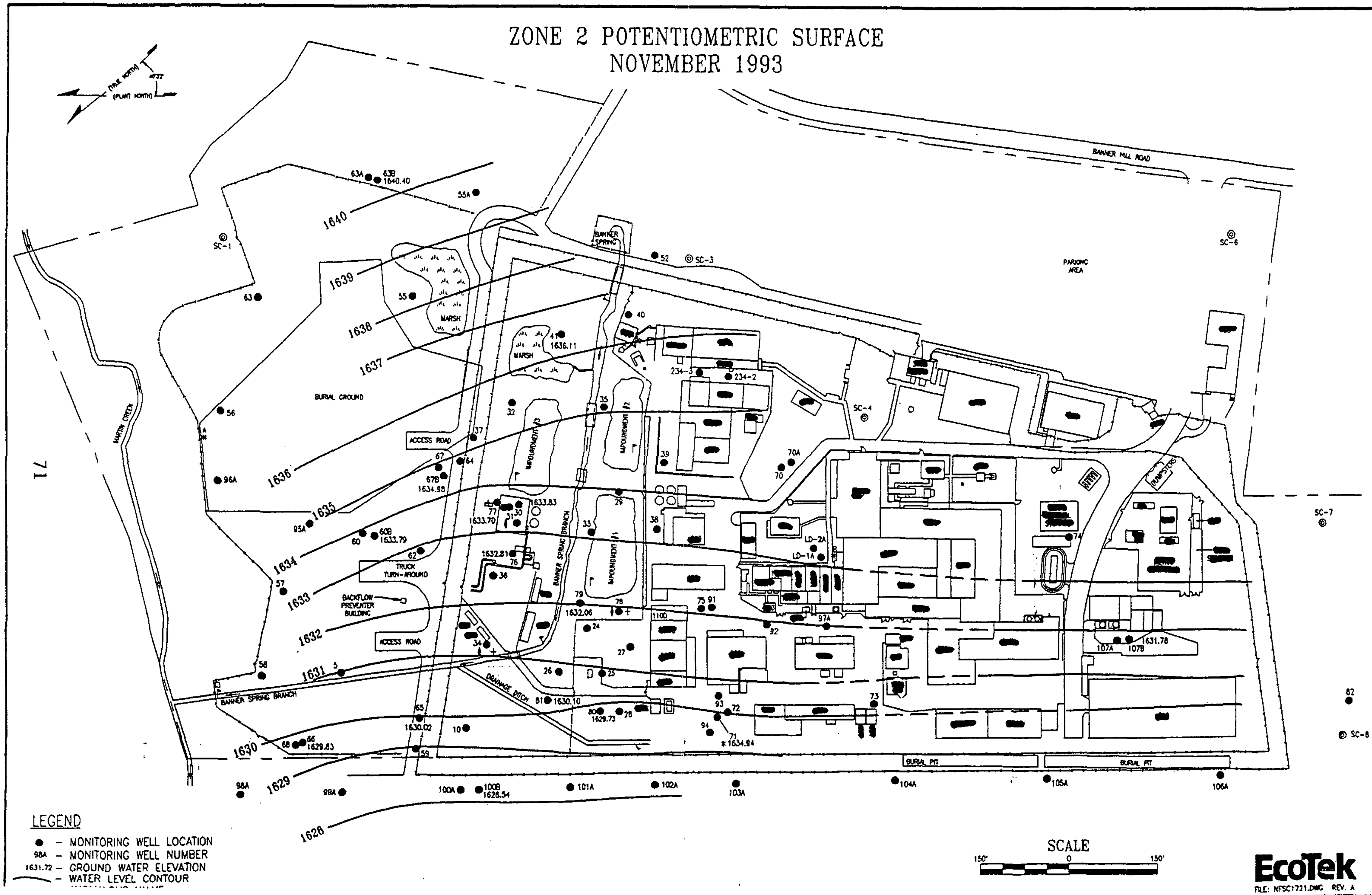
Head measurements from wells in the upper bedrock tend to uphold the porous flow theory. The data are easily mappable and create a surface that is smooth, mimics the water table, and implies a unidirectional flow toward the Nolichucky River (Figures 4-15 through 4-17). In a fracture flow regime, one would expect to see markedly different heads from similar horizons within the bedrock because some wells might penetrate fractures and others not. Also, one might expect an

Figure 4-15



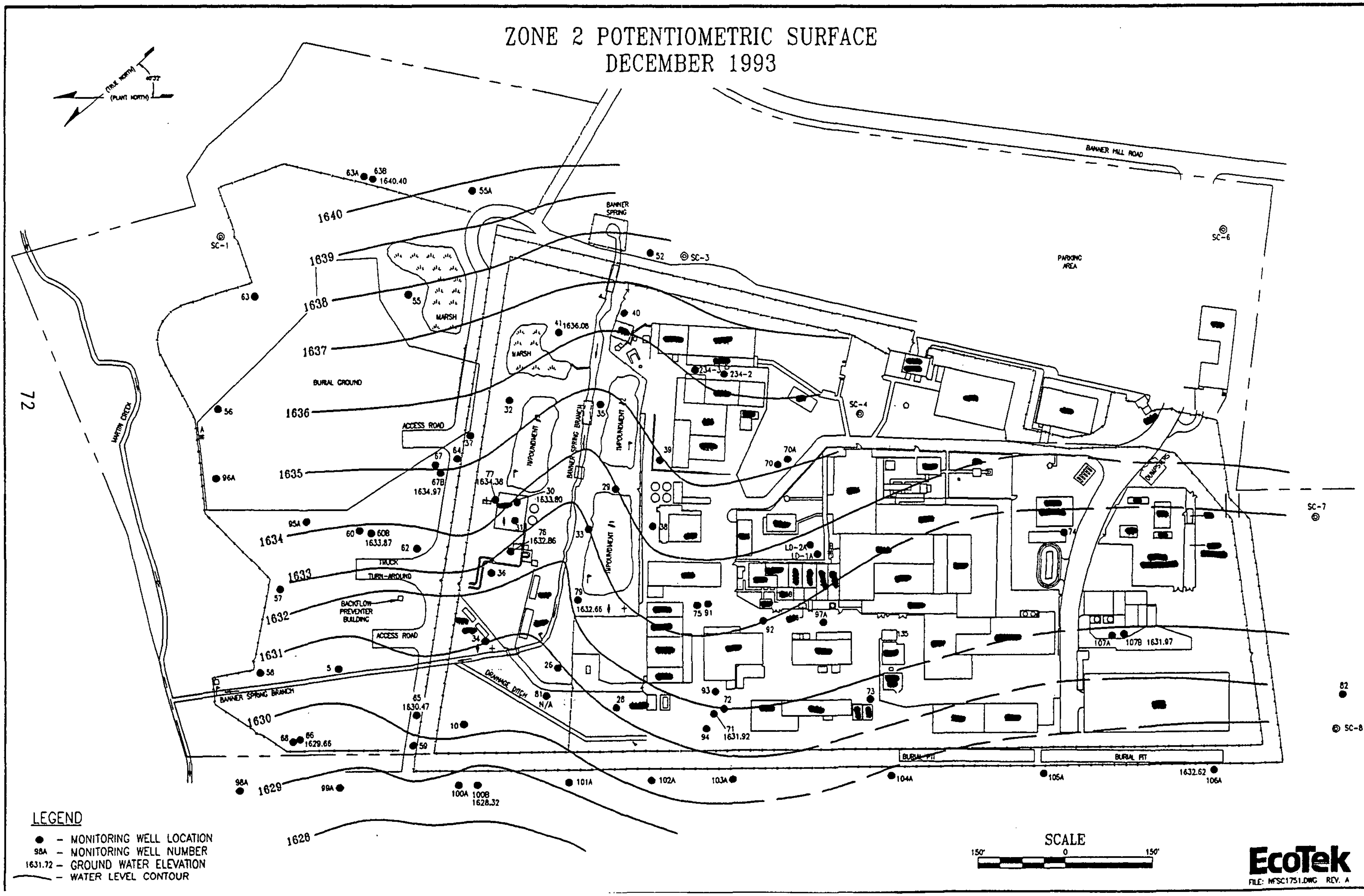
ZONE 2 POTENTIOMETRIC SURFACE
OCTOBER 1993
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
PARKING AREA
BANNER SPRING
MARSH
BURIAL GROUND
ACCESS ROAD
IMPOUNDMENT #3
IMPOUNDMENT #2
IMPOUNDMENT #1
BANNER SPRING BRANCH
MARTIN CREEK
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
BULK CHEMICAL STORAGE
DUMPSTERS
DRAINAGE DITCH
BURIAL PIT
BURIAL PIT
1640
1639
1638
1637
1636
1635
1634
1633
1632
1631
1630
1629
1628
63A
63B 1640.39
55A
SC-1
SC-3
SC-4
SC-6
SC-7
SC-8
52
63
55
47 1636.14
40
56
32
35
37
64
67
67B
1634.94
1633.83
77
1633.68
30
31
29
39
70
70A
38
33
95A
60
60B
1633.71
62
1632.69
76
36
57
LD-2A
LD-1A
74
79 1632.11
78
75 B1
97A
92
107A
107B
1631.82
24
27
34
58
5
26
25
81
1629.91
80 N/A
28
1631.64 71
72
93
94
73
65
1629.80
10
68
66
1629.76
59
98A
99A
100A
100B
1628.47
101A
102A
103A
104A
105A
106A
82
70
LEGEND
● - MONITORING WELL LOCATION
98A - MONITORING WELL NUMBER
1631.72 - GROUND WATER ELEVATION
- WATER LEVEL CONTOUR
SCALE
150'
0
150'
EcoTek
FILE: NFSC1691.DWG REV. A
PLOTTED: Feb 14, 1994 - 08:45:48

Figure 4-16



ZONE 2 POTENTIOMETRIC SURFACE
NOVEMBER 1993

Figure 4-17



ZONE 2 POTENTIOMETRIC SURFACE
DECEMBER 1993
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
BANNER SPRING
PARKING AREA
MARSH
BURIAL GROUND
ACCESS ROAD
IMPOUNDMENT
BANNER SPRING BRANCH
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
DRAINAGE DITCH
MARTIN CREEK
BURIAL PIT
DUMPSTERS
1640
1639
1638
1637
1636
1635
1634
1633
1632
1631
1630
1629
1628
63A 63B 1640.40
41 1636.08
77 1634.38
67B 1634.97
30 1633.80
60 60B 1633.87
76 1632.86
79 1632.66
65 1630.47
68 66 1629.66
100A 100B 1628.32
71 1631.92
107A 107B 1631.97
1632.62 106A
SC-1
SC-3
SC-4
SC-6
SC-7
SC-8
LEGEND
MONITORING WELL LOCATION
98A - MONITORING WELL NUMBER
1631.72 - GROUND WATER ELEVATION
WATER LEVEL CONTOUR
SCALE
150' 0 150'
EcoTek
FILE: NFSC1751.DWG REV. A
PLOTTED: Feb 11, 1994 - 11:00:42

occasional dry well where a screen was placed in very competent non-fractured rock. These possibilities have not been observed at the NFS site. Slug tests and packer tests have been performed on wells and boreholes in the shallow bedrock. Slug test results indicate a range of hydraulic conductivity from 5.14 ft/day to 11.75 ft/day with an average of 7.89 ft/day. Previous studies reported a range for the same interval from 3.12 to 18.8 ft/day with an average of 9.2 ft/day (EcoTek, 1989). The high end of this range (18.8) is from a well (71) with a sand pack of 20+ feet in length, and therefore may not be representative. Hydraulic conductivity estimates for Zone 2 are posted on a site map as Figure 4-18.

Packer testing of the shallow bedrock (to 50 feet) yielded a range of hydraulic conductivity from 0.10 to 3.1 ft/day with an average of 1.0 ft/day. As a check of the validity of the packer testing, the falling head was measured through time at the cessation of inflow for each packed off interval. These data were analyzed using slug test methods. The results provided a range of K from .09 to 0.26 ft/day with an average of 0.2 ft/day. These values are approximately an order of magnitude lower than the inflow test results and both are significantly lower than the slug test results.

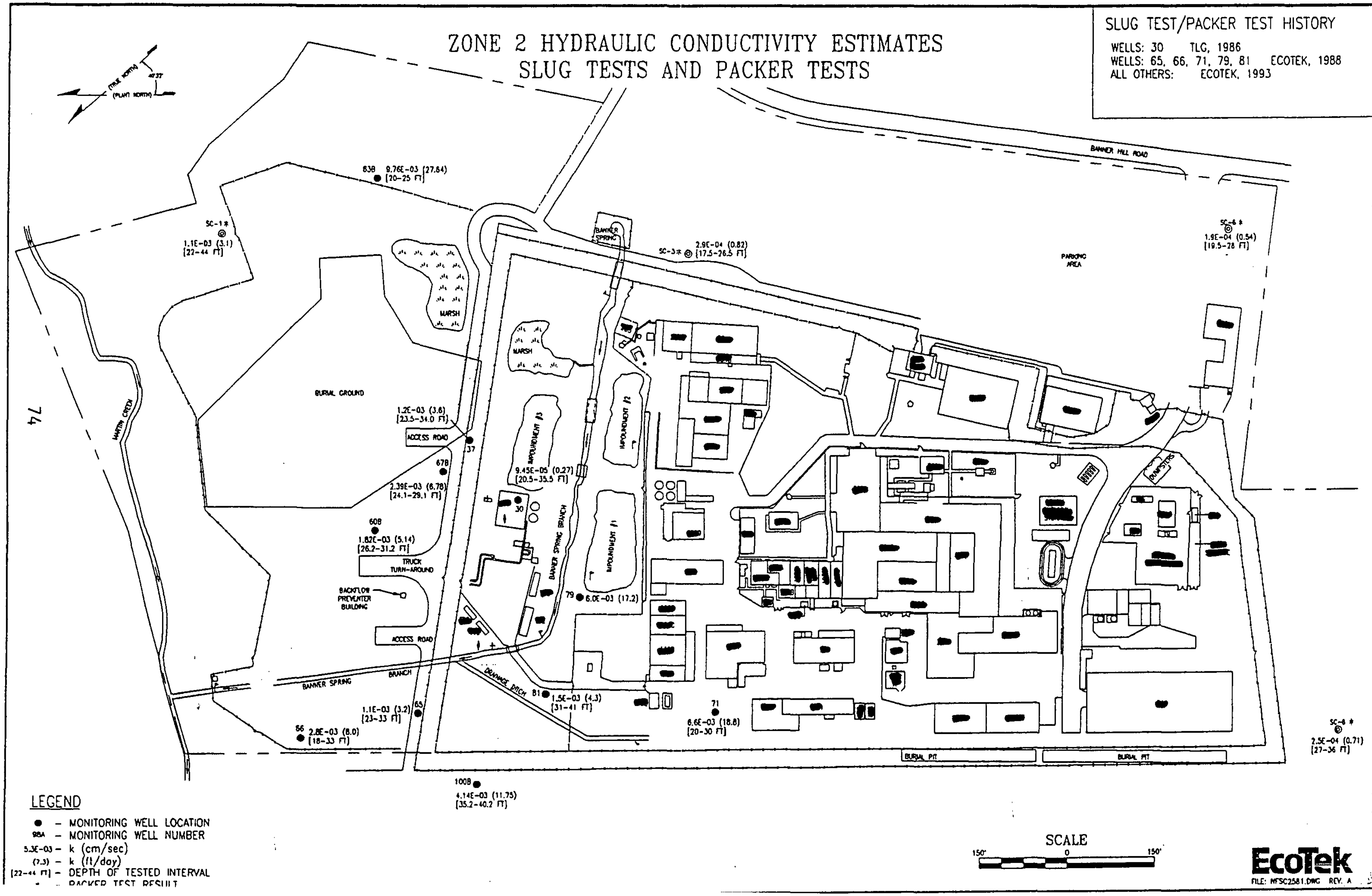
Shallow bedrock intervals that were packer tested were selected (in some cases) based on their apparent low permeability. Well screens, on the other hand, were placed for groundwater monitoring purposes with little attention given to the conductivity of the screened interval. This should explain the difference between the packer test results and the slug test results. The conclusion then is that the shallow bedrock displays variable hydraulic conductivity, as low as 0.1 ft/day in competent dolomite and as high as 11.75 ft/day in weathered shale.

One occurrence of significantly higher hydraulic conductivity was observed in the shallow bedrock during the coring program. At corehole SC-2, drilling fluid loss occurred through a zone from 18 to 38 feet below land surface where no geologic material was recovered. The core pipe was able to advance with no effort by the drill rig, only by gravity. This implies the existence of a void or fracture. The drilling fluid loss was not catastrophic, which may indicate that the void encountered was areally limited. One would expect to see a sudden loss of drill fluid if a large cavity were encountered, but the occurrence at SC-2 was a slow, easily observed migration of the drill fluid down the annular space.

Heads measured in wells near the location of SC-2 are not unusual, nor do the wells exhibit unusually high hydraulic conductivity. Previous drilling near SC-2 (Wells 58 and 66) did encounter limestone. Unfortunately, drilling difficulties at SC-2 precluded the installation of a piezometer and the hole was abandoned.

Figures 4-15 through 4-17 are maps of the potentiometric surface of the shallow bedrock groundwater (Zone 2) constructed using October, November, and

Figure 4-18



ZONE 2 HYDRAULIC CONDUCTIVITY ESTIMATES
SLUG TESTS AND PACKER TESTS
SLUG TEST/PACKER TEST HISTORY
WELLS: 30 TLG, 1986
WELLS: 65, 66, 71, 79, 81 ECOTEK, 1988
ALL OTHERS: ECOTEK, 1993
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
PARKING AREA
63B 9.76E-03 (27.64) [20-25 FT]
SC-1 * 1.1E-03 (3.1) [22-44 FT]
SC-3 * 2.9E-04 (0.82) [17.5-26.5 FT]
SC-6 * 1.9E-04 (0.54) [19.5-28 FT]
SC-8 * 2.5E-04 (0.71) [27-36 FT]
BANNER SPRING
MARSH
MARSH
BURIAL GROUND
MARTIN CREEK
74
1.2E-03 (3.6) [23.5-34.0 FT]
ACCESS ROAD
37
67B 2.39E-03 (6.78) [24.1-29.1 FT]
IMPOUNDMENT #3
9.45E-05 (0.27) [20.5-35.5 FT]
IMPOUNDMENT #2
IMPOUNDMENT #1
30
60B 1.82E-03 (5.14) [26.2-31.2 FT]
TRUCK TURN-AROUND
BANNER SPRING BRANCH
79 6.0E-03 (17.2)
BACKFLOW PREVENTER BUILDING
ACCESS ROAD
DUMPSTERS
BANNER SPRING BRANCH
DRAINAGE DITCH
81 1.5E-03 (4.3) [31-41 FT]
71 6.6E-03 (18.8) [20-30 FT]
65 1.1E-03 (3.2) [23-33 FT]
66 2.8E-03 (8.0) [18-33 FT]
BURIAL PIT
BURIAL PIT
100B 4.14E-03 (11.75) [35.2-40.2 FT]
LEGEND
● – MONITORING WELL LOCATION
98A – MONITORING WELL NUMBER
5.3E-03 – k (cm/sec)
(7.3) – k (ft/day)
[22-44 FT] – DEPTH OF TESTED INTERVAL
* – PACKER TEST RESULT
SCALE
150' 0 150'
EcoTek
FILE: NFSC2581.DWG REV. A
PLOTTED: Jun 16, 1994 - 13:57:56

December 1993 head data. The surface ranges from elevation 1,641 to 1,629 feet msl. The direction of flow is toward the Nolichucky River (north northwest). A relic of the Ponds mounding is evident in this depiction of a deeper groundwater surface. The horizontal hydraulic gradient averages approximately 0.017 ft/ft. Using an average hydraulic conductivity of 7.89 ft/day, an average gradient of 0.017 ft/ft and a porosity estimate of 0.15 for porous but fine grained bedrock, the groundwater velocity in Zone 2 is estimated to be 0.89 ft/day. Using packer test results, the groundwater velocity at some locations in the shallow bedrock would be considerably lower. The velocity calculated using the slug tests is thought to be on the high end of the range.

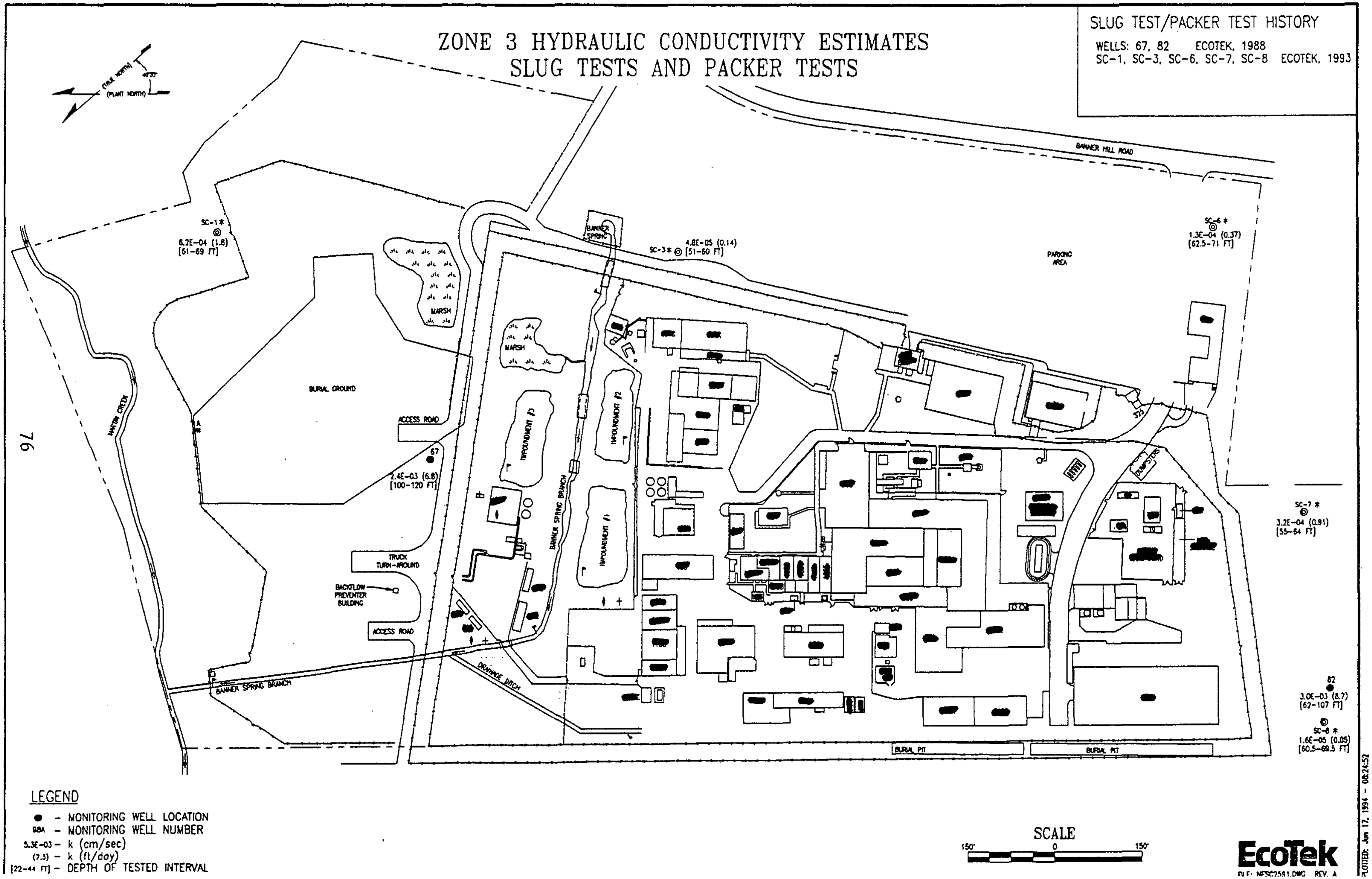
Several wells and piezometers are screened more deeply in the bedrock at depths ranging from 50 to 120 feet (Zone 3). This represents a relatively large range of depths compared to the other zones, but for the purpose of distinction, the five wells screened in this depth range are called Zone 3 wells. The deepest of these wells is Well 67 screened from 113.5 to 120 feet. During air rotary drilling of this well, airlifting produced a reported sustained yield of 300 gpm from the interval between 60 and 120 feet. This seems to indicate the presence of a fracture or other source of high yield. A slug test performed on the finished well yielded a hydraulic conductivity estimate of 6.8 ft/day, which by comparison, is on the low end of the range for the alluvium. A pumping test conducted at the well in May 1988, yielded an estimate of hydraulic conductivity of 5.3 ft/day using the recovery method of analysis. One would have to conclude then that the zone that produced the high yield is above the screen zone and below 60 feet.

Another Zone 3 well is Well 82 which is screened from 60 to 100 feet deep. It was installed as a water supply well although it has never been used in that capacity. Well 82 will reportedly yield 50 gpm (EcoTek 1989).

Three piezometers were installed in Zone 3 during the subject investigation. These are equipped with screens five feet in length and are screened between 55 and 80 feet. Five of the seven coreholes recently completed were packer tested to investigate potential zones of high and low hydraulic conductivity in the bedrock. Packer test results in Zone 3 provided estimates of hydraulic conductivity ranging from 4.5×10^{-2} to 1.8 ft/day. This range includes intervals that were competent rock, intervals with fractures or vugs, and intervals in which drilling fluid loss was experienced. As a check of the validity of packer testing, the falling head was measured after the cessation of inflow for each interval. These results provided a range of K from 0.17 to 4.23 ft/day. Hydraulic conductivity estimates for Zone 3 are posted on a site map included as Figure 4-19.

Figures 4-20 through 4-22 are depictions of the Zone 3 potentiometric surface based on five data points using October, November, and December 1993 data. Using this limited data base, a northwest direction of groundwater flow is

Figure 4-19



ZONE 3 HYDRAULIC CONDUCTIVITY ESTIMATES
SLUG TESTS AND PACKER TESTS
SLUG TEST/PACKER TEST HISTORY
WELLS: 67, 82 ECOTEK, 1988
SC-1, SC-3, SC-6, SC-7, SC-8 ECOTEK, 1993
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
SC-1
6.2E-04 (1.8)
[51-69 FT]
SC-3
4.8E-05 (0.14)
[51-60 FT]
SC-6
1.3E-04 (0.37)
[62.5-71 FT]
PARKING AREA
BANNER SPRING
MARSH
BURIAL GROUND
ACCESS ROAD
MARTIN CREEK
67
2.4E-03 (6.8)
[100-120 FT]
IMPOUNDMENT #3
IMPOUNDMENT #2
IMPOUNDMENT #1
BANNER SPRING BRANCH
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
DRAINAGE DITCH
DUMPSTERS
SC-7
3.2E-04 (0.91)
[55-64 FT]
82
3.0E-03 (8.7)
[62-107 FT]
SC-8
1.6E-05 (0.05)
[60.5-69.5 FT]
BURIAL PIT
BURIAL PIT
LEGEND
● - MONITORING WELL LOCATION
98A - MONITORING WELL NUMBER
5.3E-03 - k (cm/sec)
(7.3) - k (ft/day)
[22-44 FT] - DEPTH OF TESTED INTERVAL
SCALE
150' 0 150'
EcoTek
PLOTTED: Jun 17, 1994 - 08:24:52

Figure 4-20

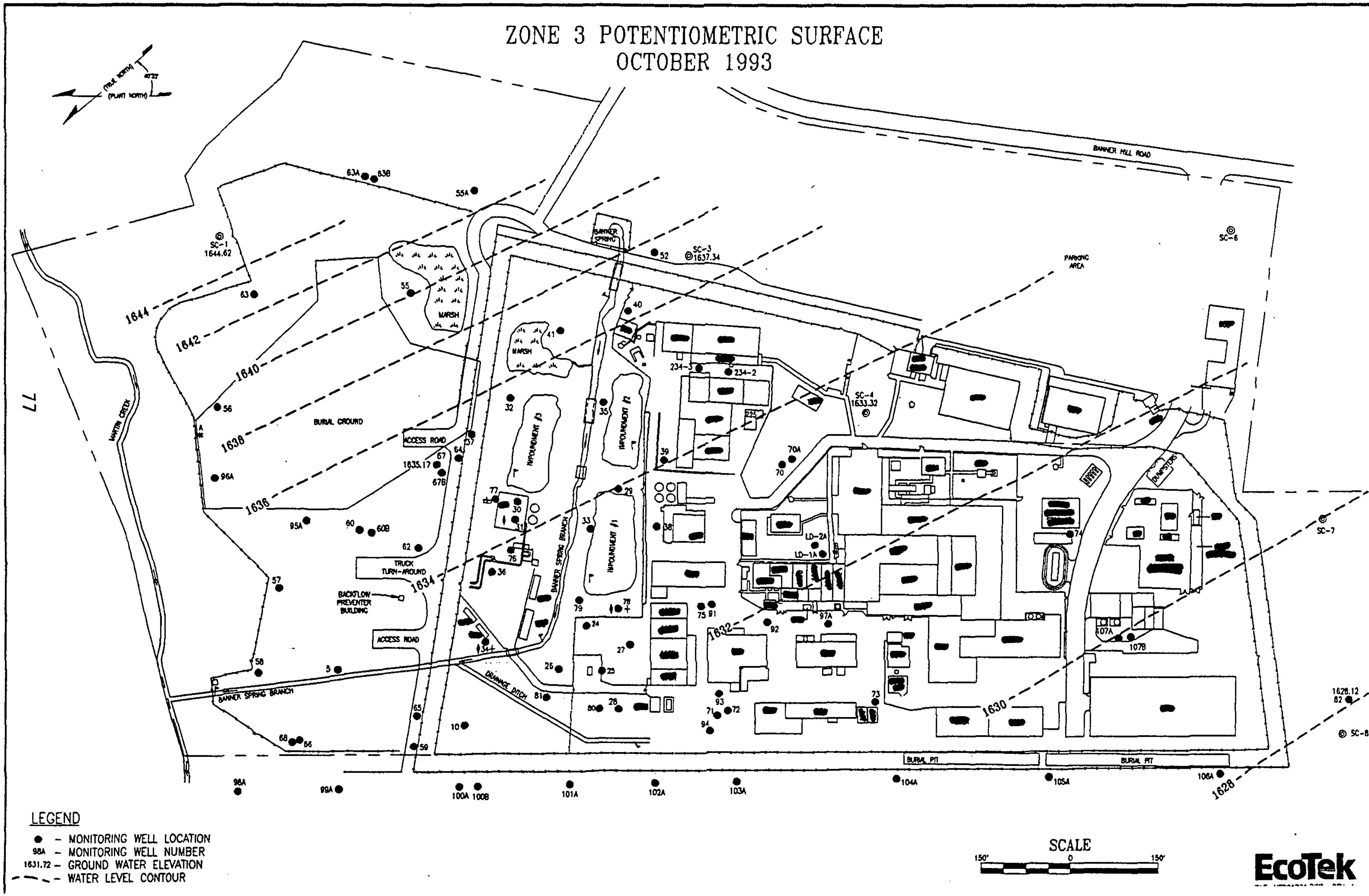

ZONE 3 POTENTIOMETRIC SURFACE
OCTOBER 1993
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
PARKING AREA
BANNER SPRING
MARSH
BURIAL GROUND
ACCESS ROAD
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
IMPOUNDMENT #1
IMPOUNDMENT #2
IMPOUNDMENT #3
BANNER SPRING BRANCH
DRAINAGE DITCH
MARTIN CREEK
BURIAL PIT
77
SC-1
1644.62
SC-3
1637.34
SC-4
1633.32
SC-6
SC-7
SC-8
1635.17
1628.12
1644
1642
1640
1638
1636
1634
1632
1630
1628
LEGEND
● – MONITORING WELL LOCATION
98A – MONITORING WELL NUMBER
1631.72 – GROUND WATER ELEVATION
– – WATER LEVEL CONTOUR
SCALE
150'
0
150'
EcoTek

Figure 4-21

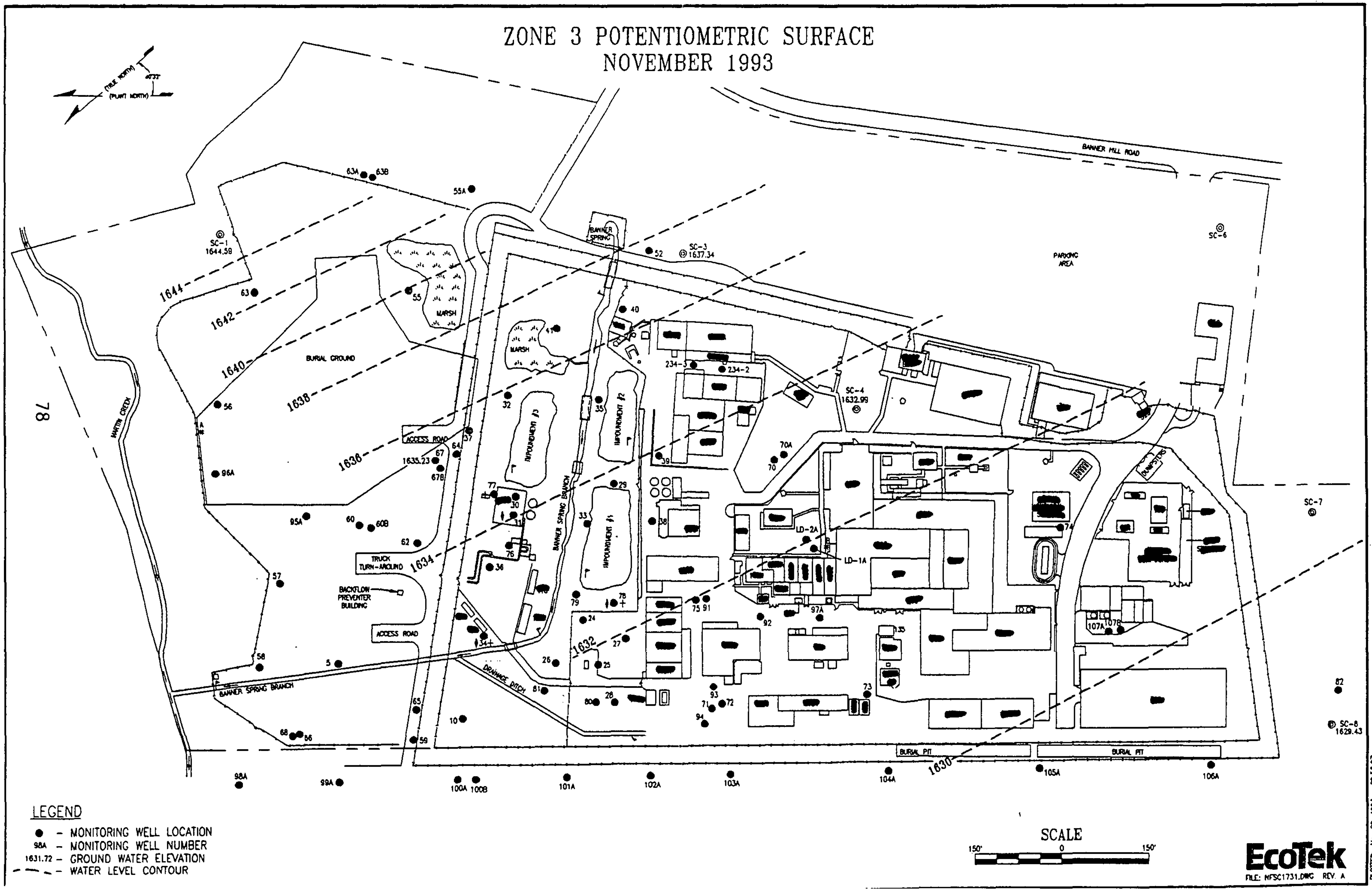
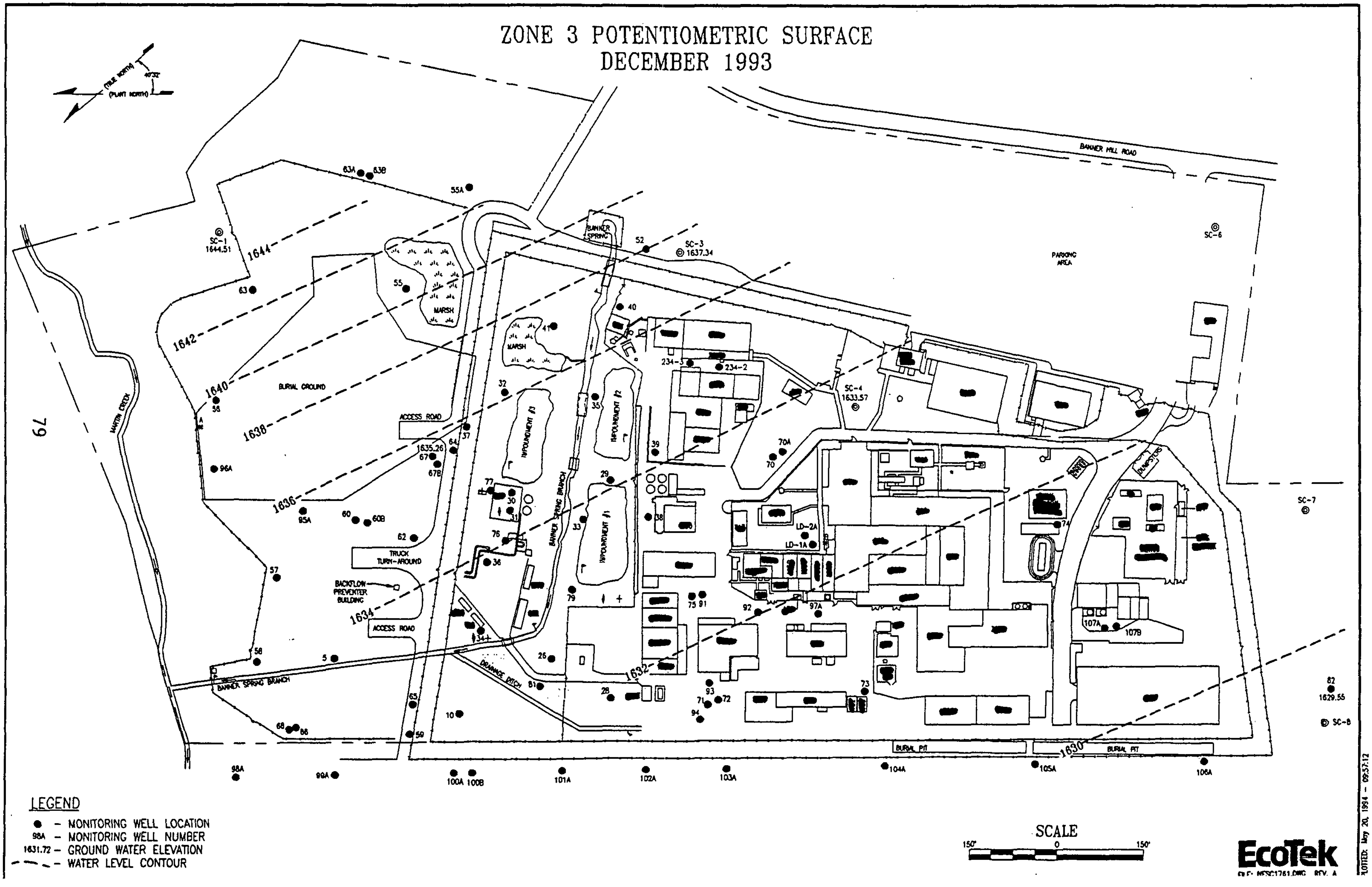

ZONE 3 POTENTIOMETRIC SURFACE
NOVEMBER 1993
(TRUE NORTH)
(PLANT NORTH)
BANNER MILL ROAD
PARKING AREA
BANNER SPRING
BURIAL GROUND
MARSH
IMPOUNDMENT #1
IMPOUNDMENT #2
IMPOUNDMENT #3
BANNER SPRING BRANCH
ACCESS ROAD
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
DRAINAGE DITCH
MARTIN CREEK
BURIAL PIT
SC-1 1644.58
SC-3 1637.34
SC-4 1632.99
SC-6
SC-7
SC-8 1629.43
1635.23
1644
1642
1640
1638
1636
1634
1632
1630
LEGEND
● - MONITORING WELL LOCATION
98A - MONITORING WELL NUMBER
1631.72 - GROUND WATER ELEVATION
WATER LEVEL CONTOUR
SCALE
150' 0 150'
EcoTek
FILE: NFSC1731.DWG REV. A
PLOTTED: May 20, 1994 - 09:56:07

Figure 4-22


ZONE 3 POTENTIOMETRIC SURFACE
DECEMBER 1993
(TRUE NORTH)
(PLANT NORTH)
BANNER HILL ROAD
PARKING AREA
BANNER SPRING
SC-1
1644.51
SC-3
1637.34
SC-4
1633.57
SC-6
SC-7
SC-8
82
1629.55
1635.26
1644
1642
1640
1638
1636
1634
1632
1630
MARSH
BURIAL GROUND
ACCESS ROAD
TRUCK TURN-AROUND
BACKFLOW PREVENTER BUILDING
IMPOUNDMENT #1
IMPOUNDMENT #2
IMPOUNDMENT #3
BANNER SPRING BRANCH
DRAINAGE DITCH
MARTIN CREEK
79
BURIAL PIT
LEGEND
● – MONITORING WELL LOCATION
98A – MONITORING WELL NUMBER
1631.72 – GROUND WATER ELEVATION
– – WATER LEVEL CONTOUR
SCALE
150'
0
150'
EcoTek

evident. The range of elevation is from 1644 to 1630 feet msl. Equipotential lines are dashed to signify the uncertainty associated with the contouring.

The apparent horizontal hydraulic gradient in Zone 3 is 0.01 ft/ft. Using the high end estimate for hydraulic conductivity of 4.23 ft/day, a gradient of 0.01 and an effective porosity of 0.15. The estimated groundwater velocity is 0.28 ft/day or 102.9 ft/year.

4.3.3 Vertical Head Relationships

Several Zone 1/Zone 2 well clusters exist at the NFS site. These are useful for comparing heads to estimate vertical flow potential. Table 4-5 contains October, November, and December heads and calculated vertical gradients for eight Zone 1/Zone 2 well clusters and one Zone2/Zone 3 well cluster. At three of the Zone 1/Zone 2 clusters there is a consistent upward vertical gradient from Zone 2 to Zone 1 for the three months reported. These clusters are all in the northeast section of the site near the burial ground and the northeast reach of Banner Spring Branch.

There is also a consistent upward vertical gradient from Zone 3 to Zone 2 at the one well cluster (Wells 64, 67B, and 67) available for observation. This cluster is also in the northeast section of the site.

The presence of an upward hydraulic gradient may indicate that the deeper groundwater is recharged from upgradient sources at a higher elevation causing a potentiometric surface that is higher than that in the overlying layers. An example of this can be seen on Figure 4-4 where the Zone 3 potentiometric surface is considerably higher than the Zone 1 surface between piezometers SC-1 and piezometer SC-3.

A consistent upward flow potential from the deeper bedrock to the shallow zones could have significant impact on contaminant transport. If such an upward flow could be demonstrated across the site, the need to investigate groundwater contamination below the transition from downward to upward flow might be eliminated. For RCRA groundwater monitoring, this transition zone could potentially be considered the base of the uppermost aquifer.

4.4 Monitoring Well Network

Prior to this investigation, there were 51 active monitoring wells on the site. With the addition of 25 wells, the total is now 76. Additionally, six piezometers are now available to provide head measurements.

Of the 76 wells, 56 are screened across the water table or in the shallow alluvium(Zone

Table 4-5

Vertical Hydraulic Gradients

October 1993

Zone 1 to Zone 2

Well No.	h_1	l_1	Well No.	h_2	l_2	dh	dl	dh / dl
60	1633.68	1634.31	60B	1633.71	1615.73	−0.03	18.58	−0.002
63A	1640.67	1640.66	63B	1640.39	1620.73	0.28	19.93	0.014
100A	1629.10	1629.70	100B	1628.47	1605.21	0.63	24.49	0.026
107A	1632.16	1633.40	107B	1631.82	1616.76	0.34	16.64	0.020
72	1632.11	1628.90	71	1631.64	1612.95	0.47	15.95	0.029
68	1629.51	1629.88	66	1629.76	1611.01	−0.25	18.87	−0.013
59	1628.92	1628.63	65	1629.80	1609.37	−0.88	19.26	−0.046
64	1634.51	1635.12	67B	1634.94	1608.88	−0.43	26.24	−0.016

Zone 2 to Zone 3

Well No.	h_1	l_1	Well No.	h_2	l_2	dh	dl	dh / dl
67B	1634.94	1608.88	67	1635.17	1530.26	−0.23	78.62	−0.003

November 1993

Zone 1 to Zone 2

Well No.	h_1	l_1	Well No.	h_2	l_2	dh	dl	dh / dl
60	1633.77	1634.31	60B	1633.79	1615.73	−0.02	18.58	−0.001
63A	1640.81	1640.66	63B	1640.40	1620.73	0.41	19.93	0.021
100A	1629.20	1629.70	100B	1628.54	1605.21	0.66	24.49	0.027
107A	1632.06	1633.40	107B	1631.78	1616.76	0.28	16.64	0.017
72	1633.67	1628.90	71	1634.94	1612.95	−1.27	15.95	−0.080
68	1629.66	1629.88	66	1629.83	1611.01	−0.17	18.87	−0.009
59	1629.11	1628.63	65	1630.02	1609.37	−0.91	19.26	−0.047
64	1634.58	1635.12	67B	1634.98	1608.88	−0.4	26.24	−0.015

Zone 2 to Zone 3

Well No.	h_1	l_1	Well No.	h_2	l_2	dh	dl	dh / dl
67B	1634.98	1608.88	67	1635.23	1530.23	−0.25	78.65	−0.003

December 1993

Zone 1 to Zone 2

Well No.	h_1	l_1	Well No.	h_2	l_2	dh	dl	dh / dl
60	1633.84	1634.31	60B	1633.87	1615.73	−0.03	18.58	−0.002
63A	1640.73	1640.66	63B	1640.40	1620.73	0.33	19.93	0.017
100A	1628.92	1629.70	100B	1628.32	1605.21	0.6	24.49	0.024
107A	1632.24	1633.40	107B	1631.97	1616.76	0.27	16.64	0.016
72	1632.71	1628.90	71	1631.92	1612.95	0.79	15.95	0.050
68	1629.72	1629.88	66	1629.66	1611.01	0.06	18.87	0.003
59	1627.86	1628.63	65	1630.47	1609.37	−2.61	19.26	−0.136
64	1634.07	1635.12	67B	1634.97	1608.88	−0.9	26.24	−0.034

Zone 2 to Zone 3

Well No.	h_1	l_1	Well No.	h_2	l_2	dh	dl	dh / dl
67	1634.97	1608.88	67B	1635.26	1530.23	−0.29	78.65	−0.004

Notes

h	=	hydraulic head
l	=	screen midpoint elevation
dh	=	difference in head, well to well
dl	=	length of vertical flow path (screen midpoint to screen midpoint or water table to screen midpoint)
dh / dl	=	vertical hydraulic gradient
h_1 and h_2	=	water elevations from fourth quarter 1993 data

1), 14 are screened in Zone 2, and two are screened in Zone 3. Three of the four remaining wells have unacceptably long screens (70, 73, 74) and one is in the microwave security zone (Zone 37) and is not useable. Table 4-6 lists all active wells by zone.

The monitoring well network at NFS now provides detection coverage downgradient of the burial ground and 6,000 gallon tanks. In addition, the entire downgradient site boundary is now equipped with shallow monitoring wells on approximately 200 feet centers. Three new upgradient wells have been installed to investigate background groundwater quality.

5.0 SUMMARY

From November 1992 through May 1993, a coring and monitoring well installation program was successfully executed. Twenty-five new monitoring wells were installed. As a result, the monitoring well networks at the radioactive waste burial ground and the 6,000 gallon underground wastewater tanks, were significantly improved. Additionally, monitoring wells installed along the downgradient site boundary provided for confirmatory sampling of SWMUs 8 and 11 as well as providing a downgradient network for the entire NFS site.

Nine locations were continuously cored through the overburden and into bedrock (as deep as 80 feet) to acquire information on the geology of the subsurface and its significance to groundwater movement. Geophysical logging and hydraulic testing provided valuable additional data.

Six coreholes were equipped with piezometers. Along with the twenty-five new monitoring wells, this added twenty-nine new measuring locations for site potentiometric data. All of the new wells were slug tested, and several subsurface intervals were packer tested during coring, to provide additional information on the hydraulic characteristics of the bedrock. The characterization activities suggest a hydrogeologic system that is both dynamic and complex.

Results indicate that, with a few exceptions, hydraulic conductivity decreases with depth. The most conductive zone is the sand and gravel alluvium. Shale and weathered dolomite and mudstone display moderate to low conductivity and competent bedrock generally displays low conductivity. Exceptions include Wells 67 and 82 and corehole SC-2 where high hydraulic conductivity was observed in the bedrock.

Based on detailed mapping, groundwater flow is predominantly to the north/northwest toward the Nolichucky River. In the alluvial zone, consistent evidence of mounding in the Ponds/Pond 4 vicinity exists. This causes locally complex flow patterns but does not seem to extend to the downgradient site boundary where groundwater flow becomes more uniformly north/northwest. Groundwater flow in Zone 2 (shallow bedrock) subtly mimics the flow in Zone 1. Zone 3 (deeper bedrock) flow is apparently more westerly but this supposition is based on a very limited data set.

Bedrock consists of predominantly shale with some dolomite, mudstone, and limestone. Shale

Table 4-6

MONITORING WELLS BY ZONE			
Zone 1		Zone 2	Zone 3
Well 5	Well 68	Well 30	Well 67
Well 10	Well 72	Well 41	Well 82
Well 24	Well 75	Well 60B	SC-1
Well 25	Well 78	Well 63B	SC-3
Well 26	Well 80	Well 65	SC-4
Well 27	Well 91	Well 67B	
Well 28	Well 92	Well 66	
Well 29	Well 93	Well 71	
Well 31	Well 94	Well 76	
Well 32	Well 95A	Well 77	
Well 33	Well 96A	Well 79	
Well 34	Well 97A	Well 81	
Well 35	Well 98A	Well 100B	
Well 36	Well 99A	Well 107B	
Well 38	Well 100A		
Well 39	Well 101A		
Well 40	Well 102A		
Well 52	Well 103A		
Well 55	Well 104A		
Well 55A	Well 105A		
Well 56	Well 106A		
Well 57	Well 107A		
Well 58	Well LD-1A		
Well 59	Well LD-2A		
Well 60	Well 234-2		
Well 62	Well 234-3		
Well 63	SC-6		
Well 63A	SC-7		
Well 70A	SC-8		
Well 64			

bedrock is thinly bedded, mostly steeply dipping, heavily jointed, and apparently fractured. These features produce a porous effect and groundwater flow in the bedrock seems to follow porous medium behavior rather than fracture dominated medium behavior. The bedrock surface exhibits at least one feature (trough) that could influence groundwater flow through the middle portion of the site.

Some evidence exists in the northern corner of the site, for limestone or dolomite dissolution features. The extent and impact are not currently known but future groundwater monitoring efforts in that area should consider the potential effects of secondary porosity in the subsurface.

Consistent evidence exists for an upward hydraulic gradient from Zone 2 to Zone 1 in the northeastern portion of the site (burial ground, northeast reach of Banner Spring Branch). This upward gradient is potentially beneficial to the site in that it may restrict the downward migration of groundwater contamination.

All of the new wells were installed according to regulatory guidance and are considered to be in compliance with RCRA standards. Twenty-two older wells were upgraded, in most cases by improving the above ground components of well completion. The successful completion of this comprehensive drilling, well installation, and field testing program, represents a step forward in improving both the understanding of the site hydrogeology and the groundwater monitoring capabilities at NFS.

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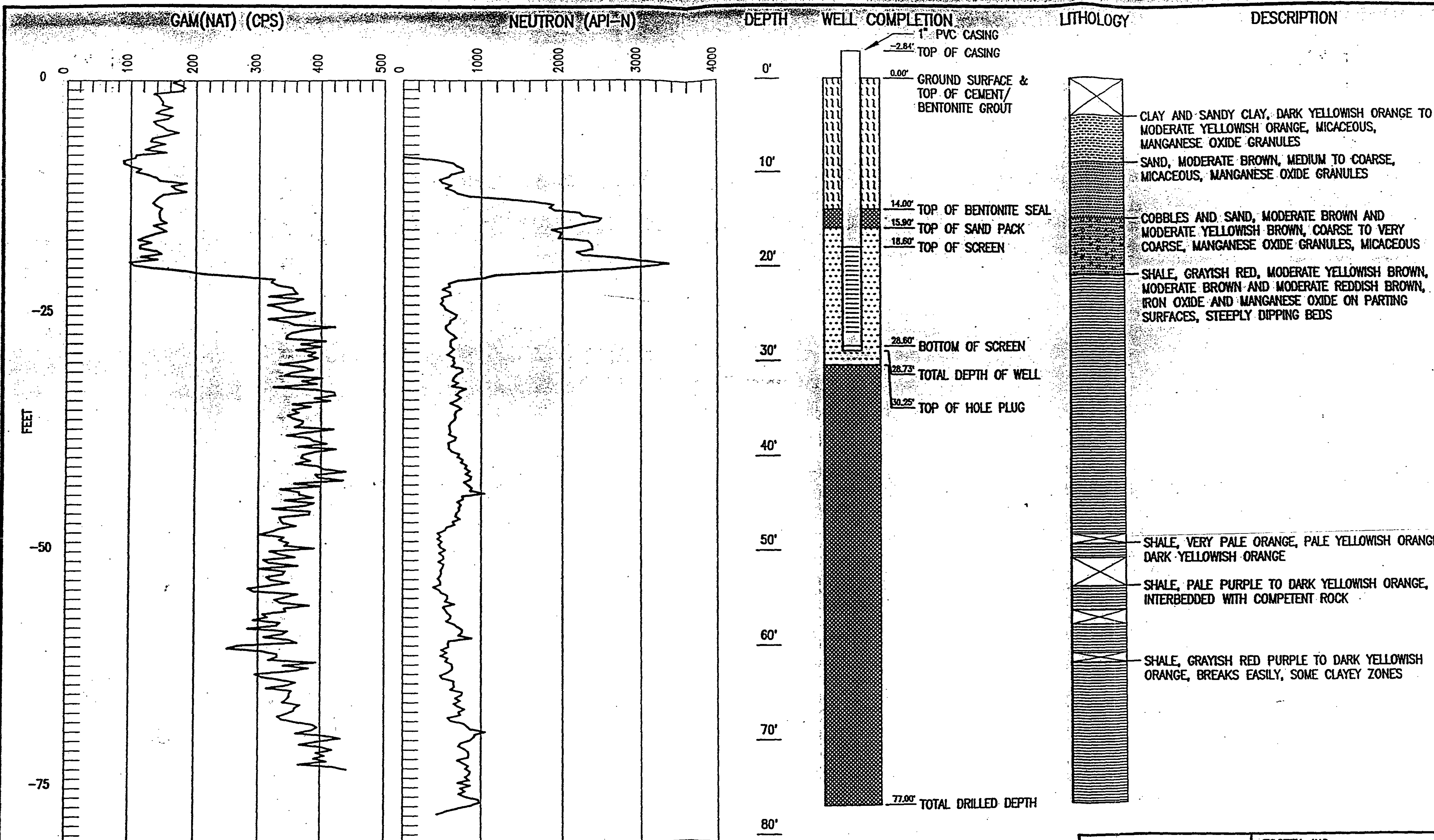
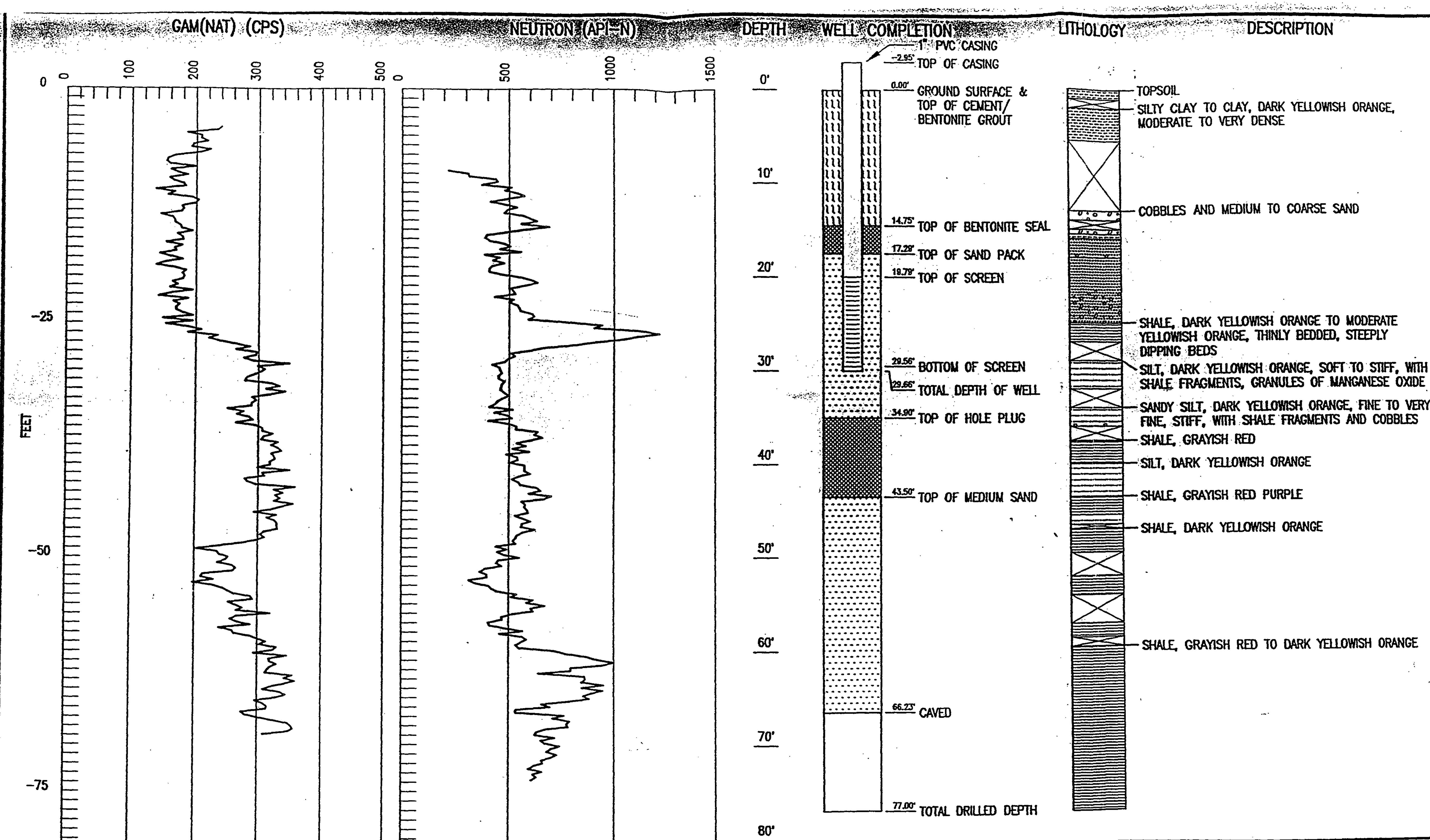


SC-7

EcoTek	ECOTEK, INC. 1219 BANNER HILL ROAD ERWIN, TENNESSEE 37650			
NFS 1992/1993 DRILLING PROGRAM				
VERT. SCALE	DATE	JOB NO.	DRAWING NO.	SHEET
1" = 10'-0"	6-11-93	NFS027	NFSG037	1 OF 1



SC-8

EcoTek

ECOTEK, INC.
1219 BANNER HILL ROAD
ERWIN, TENNESSEE 37650

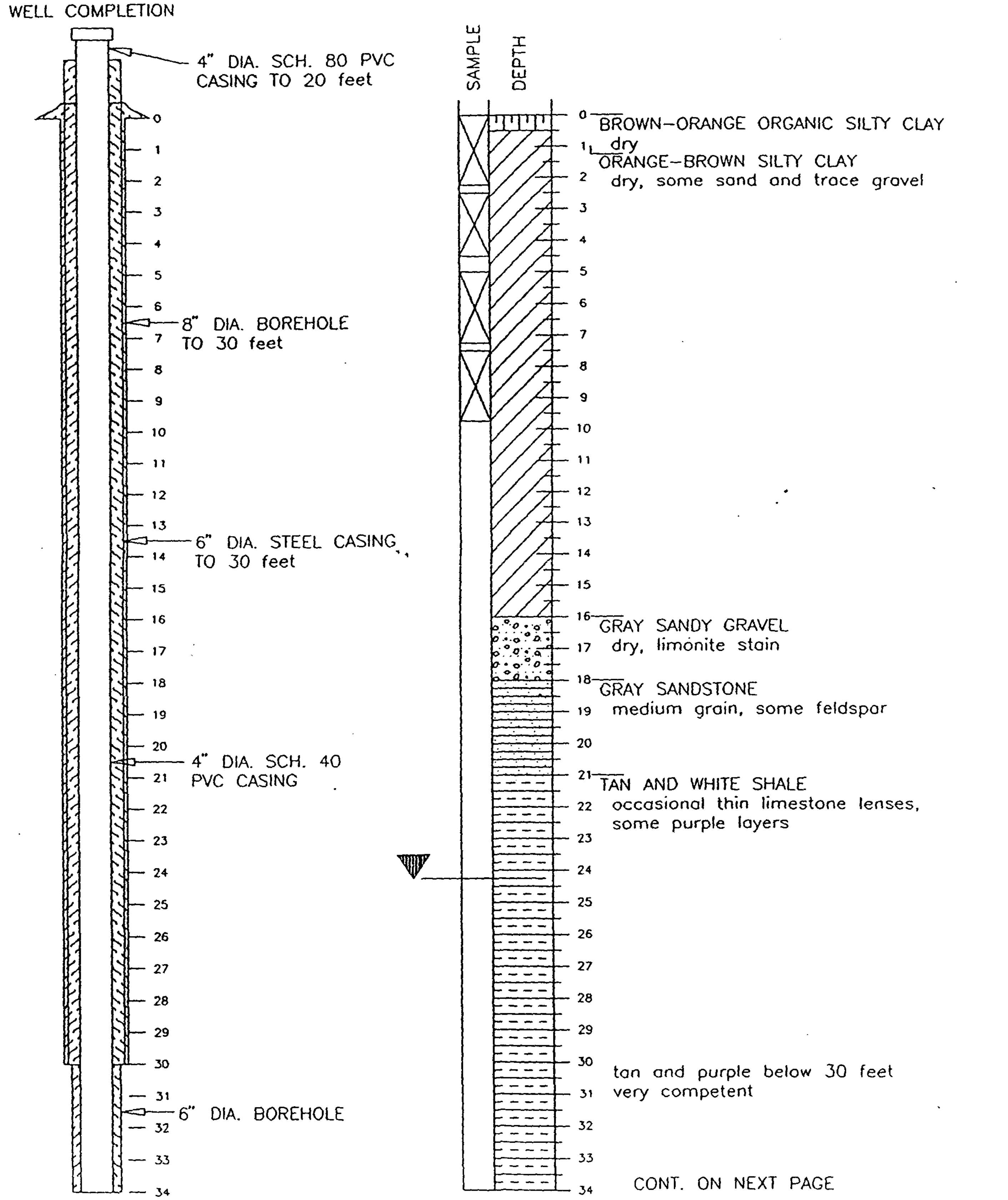
NFS 1992/1993 DRILLING PROGRAM

VERT. SCALE	DATE	JOB NO.	DRAWING NO.	SHEET
1" = 10'-0"	6-17-93	NFS027	NFSG038	1 OF 1

LOG OF BORING

Figure A-33a

Well Number	82	TOC Elevation	1657.12
Date	7/6-8/88	Ground Elevation	1653.50
Equipment	AIR ROTARY	Page Number	1 OF 4

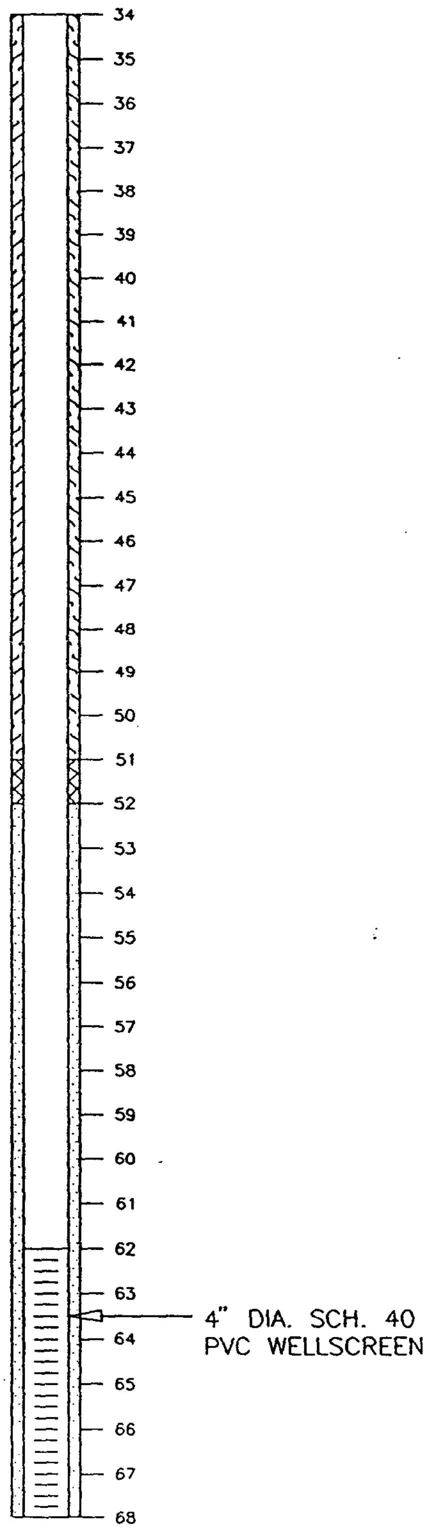


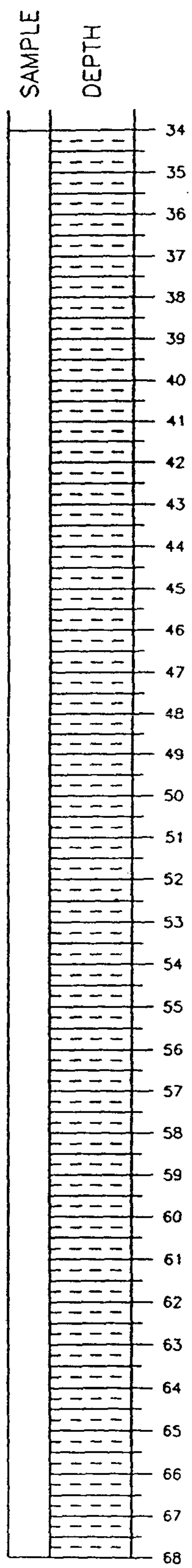
CONT. ON NEXT PAGE

LOG OF BORING

Figure A-33b

Well Number	82	TOC Elevation	1657.12
Date	7/6-8/88	Ground Elevation	1653.50
Equipment	AIR ROTARY	Page Number	2 OF 4





dark brown, gray and tan below 67 feet

CONT. ON NEXT PAGE

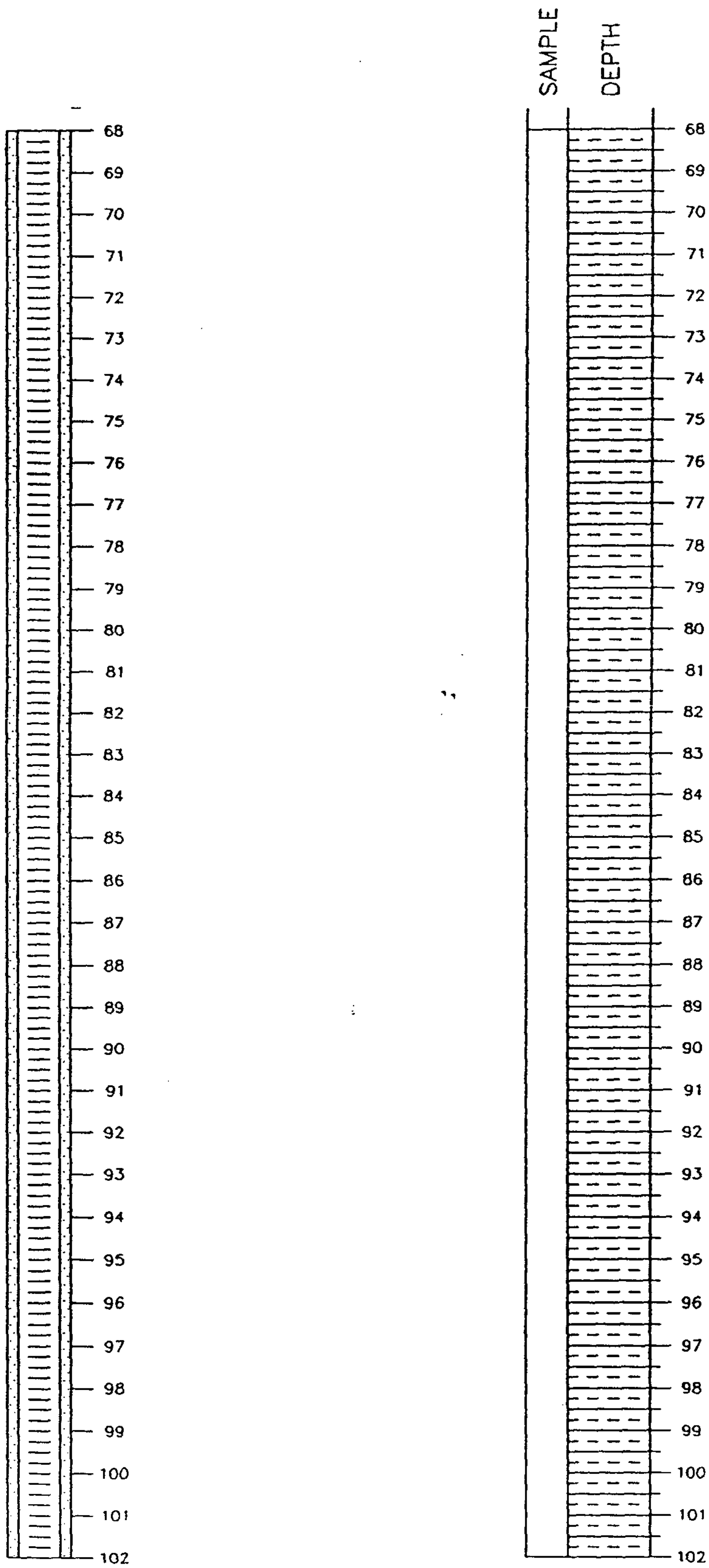
LOG OF BORING

Figure A-33c

Well Number 82
Date 7/6-8/88
Equipment AIR ROTARY

JRW

TOC Elevation 1657.12
Ground Elevation 1653.50
Page Number 3 OF 4



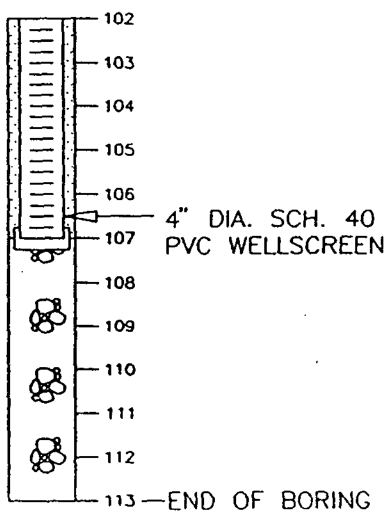
major fractures below 82 feet

CONT. ON NEXT PAGE

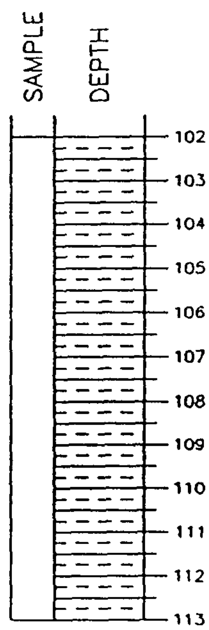
LOG OF BORING

Figure A-33d

Well Number	82	TOC Elevation	1657.12
Date	7/6-8/88	Ground Elevation	1653.50
Equipment	AIR ROTARY JRW	Page Number	4 OF 4



END OF BORING – 113 feet



JRW

TABLE K-5
ORGANIC CHEMISTRY
NFS PONDS PROJECT
(concentration in ug/l)

LOCATION/ WELL NO.	COORDINATES X	Y	DATE	TIME	STATUS	TOX	TETRA-CHLOROETHENE	TRICHLORO-ETHENE	TOTAL 1,2-DICHLOROETHENE	1,1- DI-CHLOROETHANE	VINYL CHLORIDE	TRIBUTYL PHOSPHATE	TRICHLORO-FLUOROMETHANE	NAPHTHALENE	DI-N-BUTYL PHTHALATE	BIS(2-ETHYHEXYL) PHTHALATE	DI-N-OCTYL PHTHALATE
24	3054025.300	652594.326	10/05/88	1645	UNFILTERED	58	12	7			69						
25	3053951.877	652618.016	10/05/88	1748	UNFILTERED	4300	4700	870	550		10						
26	3054110.288	652671.111	10/05/88	1825	UNFILTERED	170						(2) X					
27	3053954.802	652559.907	10/05/88	1710	UNFILTERED	190	49	39	40								
28	3053886.128	652631.164	10/05/88	1135	UNFILTERED	3300	4500	180	270			X					
29	3054203.228	652407.177	10/05/88	1410	UNFILTERED	540		11	580	32	1300	X					
30	3054266.738	652556.867	10/06/88	955	UNFILTERED	160			1400			X					
31	3054245.909	652578.920	10/06/88	925	UNFILTERED	55	12		[illegible]								
33	3054165.299	652480.345	10/05/88	1650	UNFILTERED	260	44		37								
35	3054298.377	652354.234	10/05/88	1330	UNFILTERED	550	770	32	72			X					
38	3054081.714	652393.476	10/06/88	1615	UNFILTERED	480	470	35	60								
39	3054167.943	652322.809	10/05/88	1945	UNFILTERED	530	75	30	8		82		7				
56	3054710.752	652860.009	10/04/88	925	UNFILTERED	(1) 65											
60	3054398.554	652793.040	10/04/88	1502	UNFILTERED	61	58	9	28								
70	3054039.124	652156.697	10/06/88	1745	UNFILTERED	67	130		16								
71	3053760.006	652491.586	10/06/88	1900	UNFILTERED	440	480	46	170								
72.	3053753.917	652474.503	10/06/88	1930	UNFILTERED	3500	3200	2200	5600		250	X		13	30	130	10
73	3053628.320	652278.954	10/06/88	1828	UNFILTERED	190	240		17			X	14				
77	3054289.791	652580.412	10/06/88	1055	UNFILTERED	74	26					X					
78	3054016.447	652528.046	10/06/88	1213	UNFILTERED	160			340		110	X					
80	3053905.954	652657.289	10/05/88	1930	UNFILTERED	4600	610	570	1200	7	110	X					
81	3053976.047	652716.483	10/05/88	1858	UNFILTERED	77	110		15								
82	3053093.840	651596.136	10/04/88	1740	UNFILTERED	BDL											
CT130	3053650.000	652300.000	10/06/88	2000	UNFILTERED	140							15				

Notes: (1) TOX measured on 7/28/33.
(2) X = parameter present, concentration not determined.

LOCATION/ WELL NO.	BROMACIL	PCB-(AROCLOR)-1254
24	X	
25	X	
26	X	
27	X	
28		
29		
30	X	
31	X	
33	X	
35		
38	X	
39	X	
56		
60		
70	X	
71	X	
72	X	X
73	X	
77	X	
78	X	
80	X	
81	X	
82		
CT130		

JP-W

TABLE K-4
WATER CHEMISTRY
NFS PONDS PROJECT
(mg/l, except where noted)

LOCATION(1) WELL NO.	X-COORD (Ft)	Y-COORD (Ft)	DATE	TIME	STATUS(2)	FIELD pH (units)	LAB pH (units)	FIELD TEMP (F)	FIELD COND (umhos/cm @ 25 C)	LAB COND (umhos/cm @ 25 C)	TOC(3)	TOX (ug/L)	NA	K	CA	MG	MN	FE	NH3	NO3	TKN	P	CL
77	3054289.791	652580.412	82588	130	Unfiltered		7.7			2700	9		15.0	200.0	28.0	6.90	0.033	1.20	110.0	140.00	140.0	0.33	15
77	3054289.791	652580.412	82588	530	Unfiltered		7.6			2300	9	98	16.0	150.0	25.0	6.10	0.036	0.38	95.0	110.00	99.0	0.33	13
77	3054289.791	652580.412	82588	1130	Unfiltered		7.6			2200	6	110	15.0	270.0	30.0	7.40	0.030	0.20	110.0	170.00	120.0	0.34	16
77	3054289.791	652580.412	82588	1700	Unfiltered		7.6			2500	6		16.0	180.0	27.0	6.70	0.037	0.42	100.0	120.00	100.0	0.33	14
77	3054289.791	652580.412	100688	1055	Filtered	7.3	7.3	65.0	512	610	8	74	21.0	41.0	10.0	3.00	0.045	0.03					4
78	3054016.447	652528.046	80588	935	Unfiltered	6.5	6.6	65.0	857	930	16	160	37.0	17.0	57.0	36.00	2.400	39.00	8.0	BDL	8.0	0.13	24
78	3054016.447	652528.046	100688	1213	Filtered	6.5	6.3	66.0	775	1000	14	160	39.0	23.0	55.0	40.00	2.100	35.00					22
79	3054073.064	652570.855	80588	910	Unfiltered	6.7	6.9	60.0	1386	1500	5	46	17.0	24.0	100.0	45.00	0.500	1.70	21.0	33.00	20.0	0.03	35
79	3054073.064	652570.855	100688	1250	Filtered	6.7	6.5	68.0	1168	1500	3	110	21.0	21.0	130.0	57.00	1.400	BDL	18.0	52.00	17.0		42
80	3053905.954	652657.289	80388	1550	Unfiltered	6.8	6.5	65.0	1315	1700	20	4000	52.0	40.0	95.0	39.00	1.700	12.00	24.0	0.51	25.0	0.47	100
80	3053905.954	652657.289	82888	1415	Unfiltered		6.6			1400	26		53.0	43.0	110.0	32.00	2.600	59.00	25.0	0.53	23.0	BDL	110
80	3053905.954	652657.289	100588	1930	Filtered	6.5	6.4	63.0	1821	2200	10	4600	58.0	45.0	200.0	45.00	2.500	0.37	26.0	3.00	27.0		78
81	3053976.047	652716.483	80588	1005	Unfiltered	7.5	7.6	60.0	430	500	3	64	10.0	2.0	40.0	18.00	0.093	0.19	0.2	2.00	BDL	0.03	16
81	3053976.047	652716.483	100588	1858	Filtered	7.5	7.4	60.0	509	730	2	77	13.0	2.6	53.0	22.00	0.150	BDL					20
81	3053976.047	652716.483	100588	1858	Filtered	7.5	7.4	60.0	509	650	3	87	12.0	2.5	54.0	23.00	0.150	BDL					18
82	3053093.840	651596.136	72888	1930	Unfiltered	7.6	8.2	62.0	59	64	2	BDL	1.6	1.6	3.1	4.30	0.130	2.20	BDL	0.96	BDL	0.04	BDL
82	3053093.840	651596.136	100488	1740	Filtered	6.8	6.9	61.0	79	86	2	BDL	1.1	1.4	4.3	4.70	BDL	BDL	BDL	1.00	BDL	0.07	BDL
A	3054689.484	652903.573	72788	1840	Unfiltered	7.4	7.3	61.0	291	200	2	BDL	2.3	3.2	30.0	11.00	0.240	12.00	3.4	BDL	3.0	BDL	BDL
B	3053925.000	652155.000	82888	1845	Unfiltered		7.4			820	3		22.0	5.5	120.0	14.00	1.800	0.32	BDL	BDL	BDL	0.03	43
BGSWP	3054506.467	652454.766	72088	1045	Unfiltered	6.8	6.2	75.0	169	150	8	8	1.1	2.3	20.0	8.40	0.160	2.30	BDL	BDL	BDL	0.05	BDL
BGSWP	3054506.467	652454.766	100388	1155	Unfiltered	6.8	6.9	64.5	176	250	10	5	1.3	5.4	19.0	8.90	0.120	1.90					BDL
BS	3054530.000	652135.000	72088	800	Unfiltered	7.9	7.2	58.0	195	170	BDL	22	1.4	2.1	19.0	10.00	BDL	BDL	BDL	1.80	BDL	0.03	BDL
BS	3054530.000	652135.000	72088	1105	Unfiltered	7.8	7.3	64.0	207	160	1	14	1.5	2.2	18.0	10.00	BDL	BDL	BDL	1.80	BDL	0.03	BDL
BS	3054530.000	652135.000	80288	1005	Unfiltered	7.8	8.3		194	190	BDL	13	1.4	2.3	19.0	10.00	BDL	BDL	BDL	1.90	BDL	0.04	BDL
BS	3054530.000	652135.000	100388	1059	Unfiltered	7.7	7.6	57.0	198	250	2	15	3.4	2.6	20.0	10.00	BDL	0.10					BDL
BSBL	3054282.637	653161.260	72088	1005	Unfiltered		7.6			170	2	10	2.1	2.4	21.0	10.00	0.030	0.23	BDL	1.70	BDL	0.04	BDL
BSBL	3054282.637	653161.260	72088	830	Unfiltered		7.5			180	2	8	2.2	2.5	21.0	10.00	0.031	0.19	BDL	1.70	BDL	0.04	BDL
BSBL	3054282.637	653161.260	100388	1111	Unfiltered	7.5	7.6	60.0	195	260	4	6	2.5	3.0	21.0	11.00	0.300	8.70					BDL

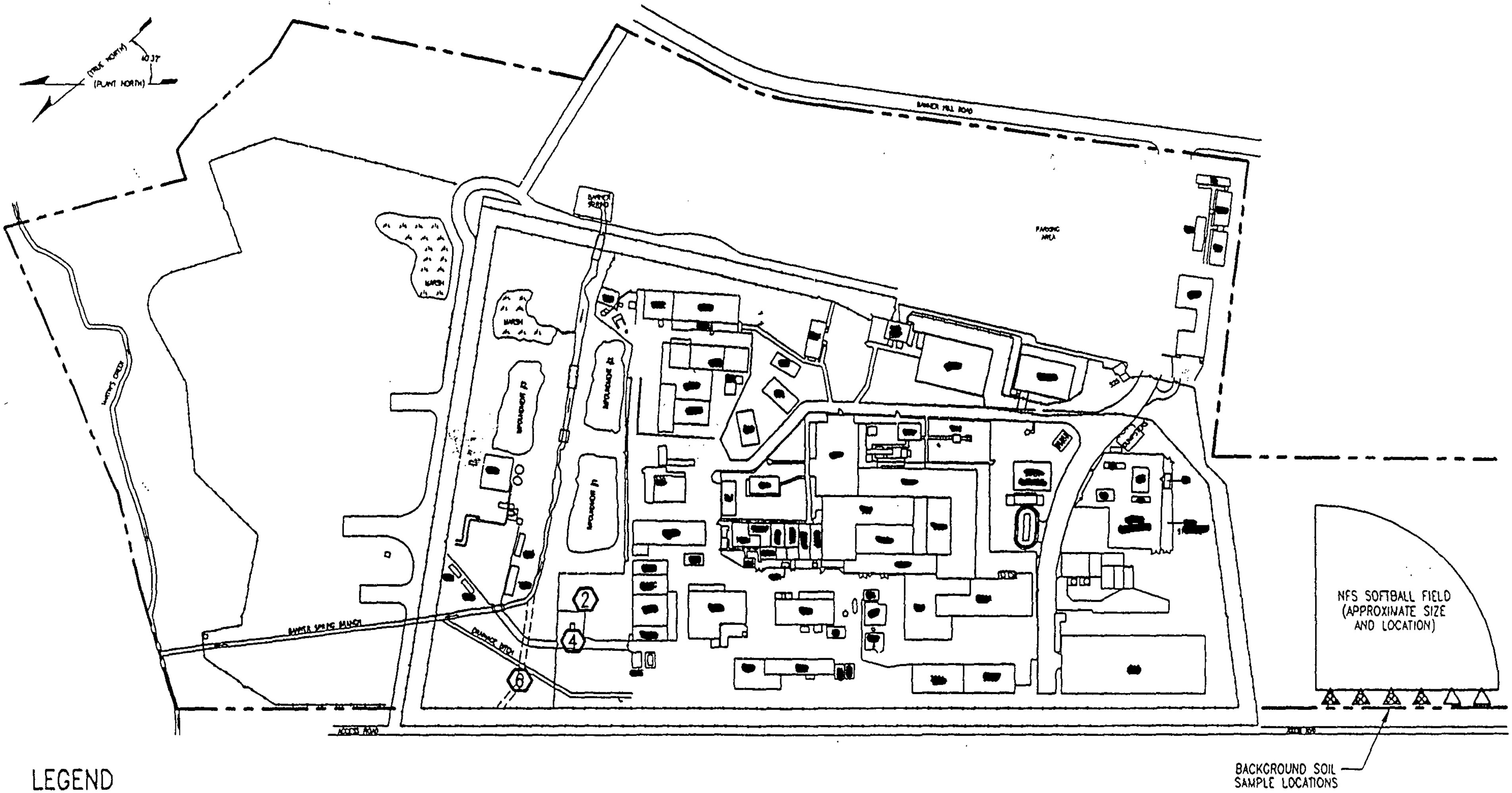
LOCATION(1) WELL NO.	CN	F	SO4	CO3	HCO3	ALK	TDS	TSS	AS	PB	BA	BE	CD	CR	CO	CU	HG	MO	NI	AG	V	SE	TL
77		23.0	32	BDL	180	150	850	BDL	BDL	BDL	0.51	BDL	BDL	BDL	0.009	BDL	0.0011	0.110	BDL	BDL	BDL	BDL	BDL
77		21.0	29	BDL	180	150	660	BDL	BDL	BDL	0.47	BDL	BDL	BDL	0.008	BDL	0.0011	0.094	BDL	BDL	BDL	BDL	BDL
77		25.0	30	BDL	210	170	910	BDL	BDL	BDL	0.54	BDL	BDL	BDL	0.007	BDL	0.0010	0.110	BDL	BDL	BDL	BDL	BDL
77		25.0	29	BDL	170	140	760	BDL	BDL	BDL	0.50	BDL	BDL	BDL	0.007	BDL	0.0011	0.100	BDL	BDL	BDL	BDL	BDL
77			20	BDL	130	110	160										BDL						
78	BDL	0.7	30	BDL	380	310	400		BDL	BDL	0.27	BDL	BDL	BDL	BDL	BDL	BDL	0.008	BDL	BDL	BDL	BDL	BDL
78			27	BDL	430	360	350										BDL						
79	0.026	BDL	60	BDL	400	330	650		BDL	BDL	0.12	BDL	BDL	BDL	BDL	BDL	0.0006	BDL	0.01	BDL	BDL	BDL	BDL
79			78	BDL	610	500	600										0.0002						
80	BDL	1.2	91	BDL	500	410	610		BDL	0.009	0.23	BDL	BDL	0.006	0.010	0.045	BDL	BDL	0.03	BDL	0.014	BDL	BDL
80		1.1	100	BDL	580	480	610		BDL	0.030	0.50	BDL	BDL	0.043	0.036	0.056	0.0003	0.026	0.06	BDL	0.081	BDL	BDL
80			210	BDL	810	670	980										BDL						
81	BDL	BDL	37	BDL	180	150	240		BDL	BDL	0.06	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
81			42	BDL	220	190	250										BDL						
81			40	BDL	200	170	240																
82	BDL	BDL	BDL	BDL	42	35	56		BDL	BDL	0.05	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
82	BDL	BDL	BDL	BDL	42	34	62										BDL						
A	BDL	BDL	BDL	BDL	180	150	130		BDL	BDL	0.12	BDL	BDL	BDL	BDL	BDL	BDL	BDL	0.01	BDL	BDL	BDL	BDL
B		3.6	34	BDL	370	310	420		BDL	0.008	0.27	BDL	BDL	BDL	0.008	0.038	BDL	BDL	BDL	BDL	BDL	BDL	BDL
BGSWP	BDL	BDL	7	BDL	88	73	100		BDL	BDL	0.08	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
BGSWP			9	BDL	130	110	100										BDL						
BS	BDL	BDL	9	BDL	100	84	100		BDL	BDL	0.07	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
BS	BDL	BDL	11	BDL	110	89	110		BDL	BDL	0.07	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
BS	BDL	BDL	13	BDL	100	88	130		BDL	BDL	0.09	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
BS			14	BDL	110	90	100										BDL						
BSBL	BDL	BDL	19	BDL	110	89	130		BDL	BDL	0.07	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
BSBL	BDL	BDL	18	BDL	110	94	130		BDL	BDL	0.07	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
BSBL			16	BDL	120	95	110										0.0007						

LOCATION(1) WELL NO.	ZN	SURFACTANTS	OIL AND GREASE
77	0.023		
77	0.029		
77	0.020		
77	0.026		
77			
78	BDL		
78			
79	BDL		
79			
80	0.050		
80	0.081	BDL	
80			
81	BDL		
81			
81			
82	0.006		
82			
A	0.099		
B	1.200		
BGSWP	BDL		
BGSWP			
BS	BDL		
BS	BDL		
BS	BDL		
BS			
BSBL	0.014		
BSBL	0.011		
BSBL			

K-337

FIGURE 2-2

BACKGROUND SOIL SAMPLE LOCATIONS



LEGEND

- (2) SWMU #2 - POND 4
- (4) SWMU #4 - YARD INCINERATOR
- (6) SWMU #6 - ABANDONED BANNER SPRING BRANCH CHANNEL
- ⊗ PHASE 2 BACKGROUND SOIL BORING SAMPLE
- △ PHASE 2 BACKGROUND SURFACE SOIL SAMPLE

SCALE

250' 0 250'

EcoTek

FILE: NFSC0721.DWG REV. B

Borehole aqueous sampling was conducted using the method described in Section 2.3.2.2. The proposed sampling method described in the Phase I Workplan was not effective. In addition, all borehole aqueous samples were filtered in the field due to the large amount of suspended solids.

During monitoring well sampling conducted on June 16 through June 23, 1993, the pH meter was calibrated once daily before use, but not at each well. The daily deviation during calibration was found to be negligible. The equipment calibration log states that the conductivity meter will be calibrated once daily. One of the Model M90 Corning meters would not calibrate conductivity on June 16, 1993. Purging efficiency was assessed with temperature and pH measurements; conductivity measurements were omitted on that day.

Trip blanks should accompany sample containers from the laboratory to the sample site and then from the site to the laboratory. For this investigation trip blanks were not provided by the laboratory; therefore, trip blanks were prepared with deionized water to accompany sample shipments from the sample site to the laboratory.

3.0 RESULTS

The results presented in this section identify nonradiological constituents detected at mean concentrations at or above health based action levels, and radiological contaminants detected at elevated levels (i.e., significantly above minimum detectable activities (MDAs). Appendix F includes a summary of all contaminants detected in each environmental medium.

3.1 Soil and Waste Materials

This section presents the results from analyses of samples collected from soil and waste materials in the Pond 4 area. Results from analysis of background soil are also included.

3.1.1 Background Soil

The background scope of analysis was based on contaminants detected in Pond 4 soil during Phase I of the investigation. Background soil samples were obtained from the NFS softball field (Figure 2-2).

Volatile Organic Compounds: Background soils were not analyzed for volatile organic compounds as part of this investigation.

Semivolatile Organic Compounds: No semivolatile organics were detected in background soil (Appendix F).

Metals: Appendix F presents the analytical results for metals in background soil. Beryllium and thallium results are presented below.

- Beryllium - detected at a mean concentration (0.92 mg/kg) above the health based action level of 0.2 mg/kg.

- Thallium - not detected although the practical quantitation limit was high (ranging from <97.9 mg/kg to <198 mg/kg) and was greater than the action level (6 mg/kg).

General Chemistry: TPHs and Aroclor-1254 were not detected in background soil samples (Appendix F).

Radionuclides: Background soil was not analyzed for radionuclides as part of this investigation. Background radiological data are available from the CSX Soil Investigation (EcoTek 1990) and are included in Appendix F. The background soil samples obtained during the CSX Investigation were also collected from the NFS softball field.

3.1.2 SWMUs 2, 4, and 6 Soil

Volatile Organic Compounds: No volatile organic compounds were detected in Pond 4 soil at concentrations above health based action levels (Appendix F).

Semi-Volatile Organic Compounds: The following semivolatile organic compounds were detected in Pond 4 soil at mean concentrations above health based action levels (Table 3-1):

- Benzo(a)anthracene - Benzo(a)anthracene was detected primarily in surface soil at a mean concentration (0.529 mg/kg) which exceeds the health based action level of 0.1 mg/kg.

- Chrysene - Chrysene was detected primarily in surface soil at a mean concentration (0.566 mg/kg) which exceeds the health based action level of 0.1 mg/kg.

- Benzo(b)fluoranthene - Benzo(b)fluoranthene was detected primarily in surface soil at a mean concentration (0.708mg/kg) which exceeds the health based action level of 0.1 mg/kg.

- Benzo(k)fluoranthene - Benzo(k)fluoranthene was detected primarily in surface soil at a mean concentration (0.401 mg/kg) which exceeds the health based action level of 0.1 mg/kg.

SWMUs 2, 4, and 6 – Analytical Results for Semi–Volatile Organics (Background Soil)

Client ID	Borehole/ Depth	Collection Date	Naphthalene (mg/kg)	2–Methyl–naphthalene (mg/kg)	Acenaphthylene (mg/kg)	Acenaphthene (mg/kg)	Fluorene (mg/kg)	Phenanthrene (mg/kg)	Anthracene (mg/kg)	Fluoranthene (mg/kg)	Pyrene (mg/kg)
02–S–155	B26/ 0–6"	8/16/93	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400
02–S–158/158D	B27/ 0–6"	8/16/93	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400
02–S–161	B28/ 0–6"	8/16/93	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390
02–S–164	B29/ 0–6"	8/16/93	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400
02–S–167	B30/ 0–6"	8/16/93	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390
02–S–168	B31/ 0–6"	8/16/93	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400
Mean			< 0.397	< 0.397	< 0.397	< 0.397	< 0.397	< 0.397	< 0.397	< 0.397	< 0.397
Standard Deviation			0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
No. of Observations			6	6	6	6	6	6	6	6	6
t–value			1.476	1.476	1.476	1.476	1.476	1.476	1.476	1.476	1.476
90% UCL			0.400	0.400	0.400	0.40	0.40	0.40	0.400	0.400	0.400
Action Level [1]			3000	ND	ND	5000	3000	ND	20000	3000	2000

NOTES:

- The contracted laboratory was EcoTek LSI, located in Atlanta, GA.
- Middle and lower background soils were not analyzed for polycyclic aromatic hydrocarbons (PAHs).
- Action Levels for chrysene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3–cd)–pyrene, and dibenzo(a,h)anthracene were based on IRIS toxicity data for benzo(a)pyrene.

[1] Action Levels were derived per EPA's RFI Guidance (May 1989) using toxicity data from IRIS (1993) and HEAST (1993).

< Less than detection limit

ND – No Data

SWMUs 2, 4, and 6 – Analytical Results for Semi–Volatile Organics (Background Soil)

Client ID	Borehole/ Depth	Collection Date	Benzo(a)–anthracene (mg/kg)	Chrysene (mg/kg)	Benzo(b)–fluoranthene (mg/kg)	Benzo(k)–fluoranthene (mg/kg)	Benzo(a) pyrene (mg/kg)	Indeno (1,2,3–cd)–pyrene (mg/kg)	Dibenzo(a,h) anthracene (mg/kg)	Benzo(g,h,i)–perylene (mg/kg)
02–S–155	B26/ 0–6"	8/16/93	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400
02–S–158/158D	B27/ 0–6"	8/16/93	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400
02–S–161	B28/ 0–6"	8/16/93	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390
02–S–164	B29/ 0–6"	8/16/93	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400
02–S–167	B30/ 0–6"	8/16/93	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390	< 0.390
02–S–168	B31/ 0–6"	8/16/93	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400	< 0.400
Mean			< 0.397	< 0.397	< 0.397	< 0.397	< 0.397	< 0.397	< 0.397	< 0.397
Standard Deviation			0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
No. of Observations			6	6	6	6	6	6	6	6
t–value			1.476	1.476	1.476	1.476	1.476	1.476	1.476	1.476
90% UCL			0.400	0.400	0.40	0.40	0.40	0.4	0.400	0.400
Action Level [1]			0.1	0.1	0.1	0.1	0.1	0.1	0.1	ND

NOTES:

- The contracted laboratory was EcoTek LSI, located in Atlanta, GA.
- Middle and lower background soils were not analyzed for polycyclic aromatic hydrocarbons (PAHs).
- Action Levels for chrysene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3–cd)–pyrene, and dibenzo(a,h)anthracene were based on IRIS toxicity data for benzo(a)pyrene.

[1] Action Levels were derived per EPA's RFI Guidance (May 1989) using toxicity data from IRIS (1993) and HEAST (1993).

< Less than detection limit

ND – No Data

SWMUs 2, 4, and 6 – Analytical Results for Metals (Background Soil)

Client ID	Borehole / Depth	Collection Date	Antimony (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)
02–S–155	B26 / 0–6"	8/16/93	2.1	9.5	199	1.1	< 0.24	26.5	9.8	2.7	22.9
02–S–156	B26 / 1'– 5'	8/17/93	2.6	8.0	97.9	0.61	< 0.24	24.4	8.9	5.8	14.7
02–S–157	B26/ 5'–16.8	8/17/93	3.9	7.1	169	1.3	< 0.24	23.9	18.0	3.2	12.6
02–S–158/158D	B27 / 0–6"	8/16/93	2.6	10.4	144	0.98	< 0.24	24.1	6.3	2.2	14.9
02–S–159	B27 / 1'– 5'	8/17/93	2.1	13.2	97.3	0.60	< 0.24	22.9	15.0	5.0	19.1
02–S–160	B27/ 5'–12.1	8/17/93	3.7	8.9	190	1.1	< 0.24	36.2	17.4	5.3	16.3
02–S–161	B28 / 0–6"	8/16/93	3.5	10.7	162.0	0.90	< 0.24	25.2	6.8	2.5	18.0
02–S–162	B28 / 1'– 5'	8/17/93	3.3	7.6	93.2	0.54	< 0.24	19.2	16.3	5.8	25.2
02–S–163	B28/ 5'–15.3	8/17/93	5.0	5.3	165	1.2	< 0.24	28.6	17.9	3.2	13.0
02–S–164	B29 / 0–6"	8/16/93	3.0	5.9	181	0.92	< 0.24	17.7	8.5	3.1	17.5
02–S–165	B29 / 1'– 5'	8/17/93	1.9	9.0	151	0.90	< 0.22	23.4	9.8	3.3	18.6
02–S–166	B29/ 5'–18.2	8/17/93	5.4	9.5	139	1.1	< 0.24	28.8	14.4	4.4	13.1
02–S–167	B30 / 0–6"	8/16/93	2.8	8.8	176	0.90	< 0.23	19.1	12.0	3.6	16.7
02–S–168	B31 / 0–6"	8/16/93	2.3	7.3	132.0	0.68	< 0.24	26.4	8.7	5.1	15.7
Mean			3.2	8.7	149.7	0.92	< 0.24	24.7	12.1	3.9	17.0
Standard Deviation			1.0	2.0	33.3	0.23	0.006	4.5	4.1	1.2	3.5
No. of Observations			14	14	14	14	14	14	14	14	14
t–value			1.350	1.350	1.350	1.350	1.350	1.350	1.350	1.350	1.350
90% Upper Conf. Limit			3.5	9.4	161.8	1.0	0.2	26.4	13.6	4.4	18.3
Action Level [1]			30	20	6000	0.2	40	400	ND	ND	500[I]

NOTES:

The contracted laboratory was EcoTek LSI, located in Atlanta, GA.
[1] Action Levels were derived per EPA's RFI Guidance (May 1989) using toxicity data from IRIS (1993) and HEAST (1993).
< Less than detection limit
[I] Interim action level based on IRIS contact Harlal Cloudhury (1992).
ND–No Data

SWMUs 2, 4, and 6 – Analytical Results for Metals (Background Soil)

Client ID	Borehole / Depth	Collection Date	Mercury (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Silver (mg/kg)	Thallium (mg/kg)	Tin (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)
02–S–155	B26 / 0–6"	8/16/93	< 0.080	9.6	10.6	< 0.36	< 196	< 1.7	46.2	41.3
02–S–156	B26 / 1'– 5'	8/17/93	0.13	9.2	10.9	< 0.36	< 194	5.6	38.5	37.2
02–S–157	B26/ 5'–16.8	8/17/93	< 0.087	17.7	13.5	< 0.36	< 97.9	9.9	76.0	42.7
02–S–158/158D	B27 / 0–6"	8/16/93	< 0.086	8.9	7.1	< 0.37	< 198	3.6	44.8	29.4
02–S–159	B27 / 1'– 5'	8/17/93	0.12	8.6	11.4	< 0.36	< 197	2.4	38.6	33.5
02–S–160	B27/ 5'–12.1	8/17/93	< 0.089	19.7	16.7	< 0.36	< 193	10.6	82.6	52.1
02–S–161	B28 / 0–6"	8/16/93	< 0.086	8.0	12.9	< 0.36	< 195	3.1	42.6	31.3
02–S–162	B28 / 1'– 5'	8/17/93	0.16	9.6	8.4	< 0.36	< 194	3.6	39.0	36.7
02–S–163	B28/ 5'–15.3	8/17/93	< 0.090	15.7	13.2	< 0.36	< 194.0	7.8	77.7	46.7
02–S–164	B29 / 0–6"	8/16/93	< 0.089	6.8	6.1	< 0.36	< 192	2.6	33.0	29.1
02–S–165	B29 / 1'– 5'	8/17/93	0.10	10.0	9.8	< 0.34	< 181	3.5	39.1	37.2
02–S–166	B29/ 5'–18.2	8/17/93	< 0.087	14.1	14.9	< 0.36	< 196	8.6	65.6	45.1
02–S–167	B30 / 0–6"	8/16/93	< 0.081	7.6	9.3	< 0.35	< 189	3.8	33.1	32.8
02–S–168	B31 / 0–6"	8/16/93	< 0.092	10.2	11.5	< 0.36	< 197	3.4	44.0	43.2
Mean			0.098	11.1	11.2	< 0.36	< 186.7	5.0	50.1	38.5
Standard Deviation			0.022	3.9	2.8	0.01	25.0	2.9	16.8	6.7
No. of Observations			14	14	14	14	14	14	14	14
t–value			1.350	1.350	1.350	1.350	1.350	1.350	1.350	1.350
90% Upper Conf. Limit			0.11	12.5	12.2	0.36	195.7	6.0	56.1	40.9
Action Level [1]			20	2000	400	400	6	50000	600	20000

NOTES:

The contracted laboratory was EcoTek LSI, located in Atlanta, GA.

[1] Action Levels were derived per EPA's RFI Guidance (May 1989) using toxicity data from IRIS (1993) and HEAST (1993).

< Less than detection limit

[I] Interim action level based on IRIS contact Harlal Cloudhury (1992).

ND–No Data

SWMUs 2, 4 and 6 – Analytical Results for TPH and Aroclor–1254 (Background Soil)

Client ID	Borehole / Depth	Collection Date	TPH (mg/kg)	Aroclor–1254 (mg/kg)
02–S–155	B26 / 0–6"	8/16/93	< 14.1	< 0.0503
02–S–158/158D	B27 / 0–6"	8/16/93	< 14.3	< 0.0505
02–S–161	B28 / 0–6"	8/16/93	< 14.4	< 0.0501
02–S–164	B29 / 0–6"	8/16/93	< 14.5	< 0.0491
02–S–167	B30 / 0–6"	8/16/93	< 14.4	< 0.0487
02–S–168	B31 / 0–6"	8/16/93	< 14.1	< 0.0504
Mean			< 14.3	< 0.0499
Standard Deviation			0.153	0.0007
No. of Observations			6	6
t–value			1.476	1.476
90% Upper Conf. Limit			14.4	0.0503
Action Level			250	10

NOTES:

- The contracted laboratory was EcoTek LSI, located in Atlanta, GA.
- Middle and lower background soils were not analyzed for total petroluem hydrocarbons (TPHs) and Arochlor–1254.
- Action Level for TPH is based on State of Tennessee soil cleanup level; Action level for Aroclor–1254 based on EPA spill cleanup level.

< Less than detection limit

ND No Data

C;\DATA\NFS027\DATA\S–BKGTPH.WK1

RAI 9

Attachment 3

Final Project Report Groundwater Flow and Constituent Transport Modeling

At The Nuclear Fuel Services Facility,

April 25, 1996