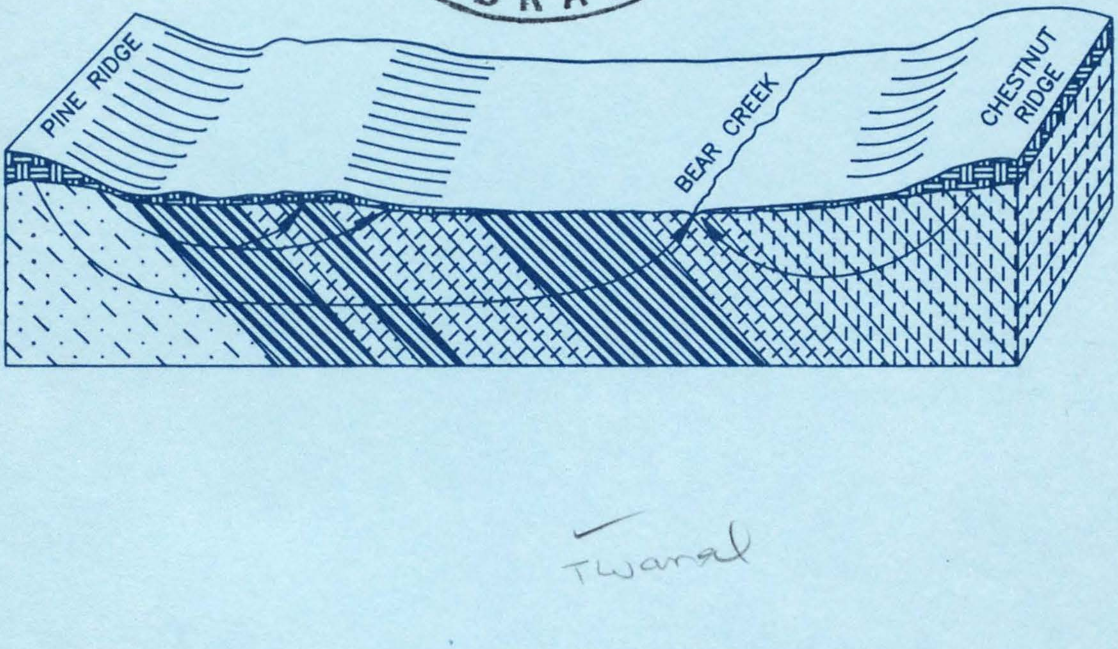
PRELIMINARY EVALUATION OF GROUND-WATER FLOW IN BEAR CREEK VALLEY, THE OAK RIDGE RESERVATION, TENNESSEE



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U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 88-4010

Prepared in cooperation with the
U.S. DEPARTMENT OF ENERGY

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By Zelda Chapman Bailey

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Nashville, Tennessee
1988

DEPARTMENT OF THE INTERIOR
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CONTENTS

ILLUSTRATIONS

TABLE

CONVERSION FACTORS

Factors for converting the inch-pound units to International System of Units (SI) are shown to four significant digits.

Multiply	*By*	*To obtain*
inch (in.)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
foot per day (ft/d)	0.3048	meter per day (m/d)
inch per year (in/yr)	2.54	centimeter per year (cm/a)

Sea level: In this report "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) – a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called "Mean Sea Level of 1929."

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ABSTRACT

Bear Creek Valley has several hazardous-waste disposal sites where contaminants are leaching into ground and surface water. The ground-water flow system and hydrologic boundaries, and therefore, the potential migration of contaminants, are poorly understood.

The study area is underlain by rocks of Cambrian age that dip about 45 degrees southeast. Bear Creek Valley is underlain primarily by calcareous shale that contains limestone units. Pine Ridge, on the north side of the valley, is underlain by interbedded sandstone, siltstone, and shale. Chestnut Ridge, on the south side, is underlain by massive, siliceous dolomite.

The bedrock is generally overlain by regolith, which is composed of soil and weathered rock, to a maximum thickness of about 80 feet. Observed hydraulic conductivities for the regolith range from 0.01 to 13 feet per day, and for the bedrock, from 0.001 to 11 feet per day. Ground-water flow is probably toward streams and is preferential along strike because of an areal anisotropy in hydraulic conductivity. Annual precipitation averages 55 inches, but the rates of recharge to the regolith and bedrock are unknown.

A finite-difference cross-sectional ground-water flow model was used to test the conceptualized flow system and to help identify areas where additional data are needed. The preliminary model shows a regional flow pattern of recharge at both ridges, flow toward the valley, and upward flow in the valley bottom that discharges into Bear Creek. Final model values of hydraulic conductivity in the bedrock ranged from 0.01 to 0.1 foot per day. These conductivity values reflect an areal anisotropy ratio of 1:5. Mean annual recharge simulated by the model was 10 inches per year.

INTRODUCTION

Bear Creek Valley, located within the Oak Ridge Reservation, Tennessee, contains the Y-12 Plant, a nuclear production facility. Several disposal sites containing hazardous wastes are located in and around the plant. The largest disposal areas are the S-3 ponds, New Hope Pond, Bear Creek burial grounds, and the oil landfarm (fig. 1). Oils, uranium, solvents, heavy metals, and nitric-acid waste have been disposed in these areas.

The purpose of this U.S. Geological Survey-U.S. Department of Energy cooperative study is to describe the ground-water flow system in Bear Creek Valley and vicinity. The determination of flow direction is critical because of the proximity of the plant to Reservation

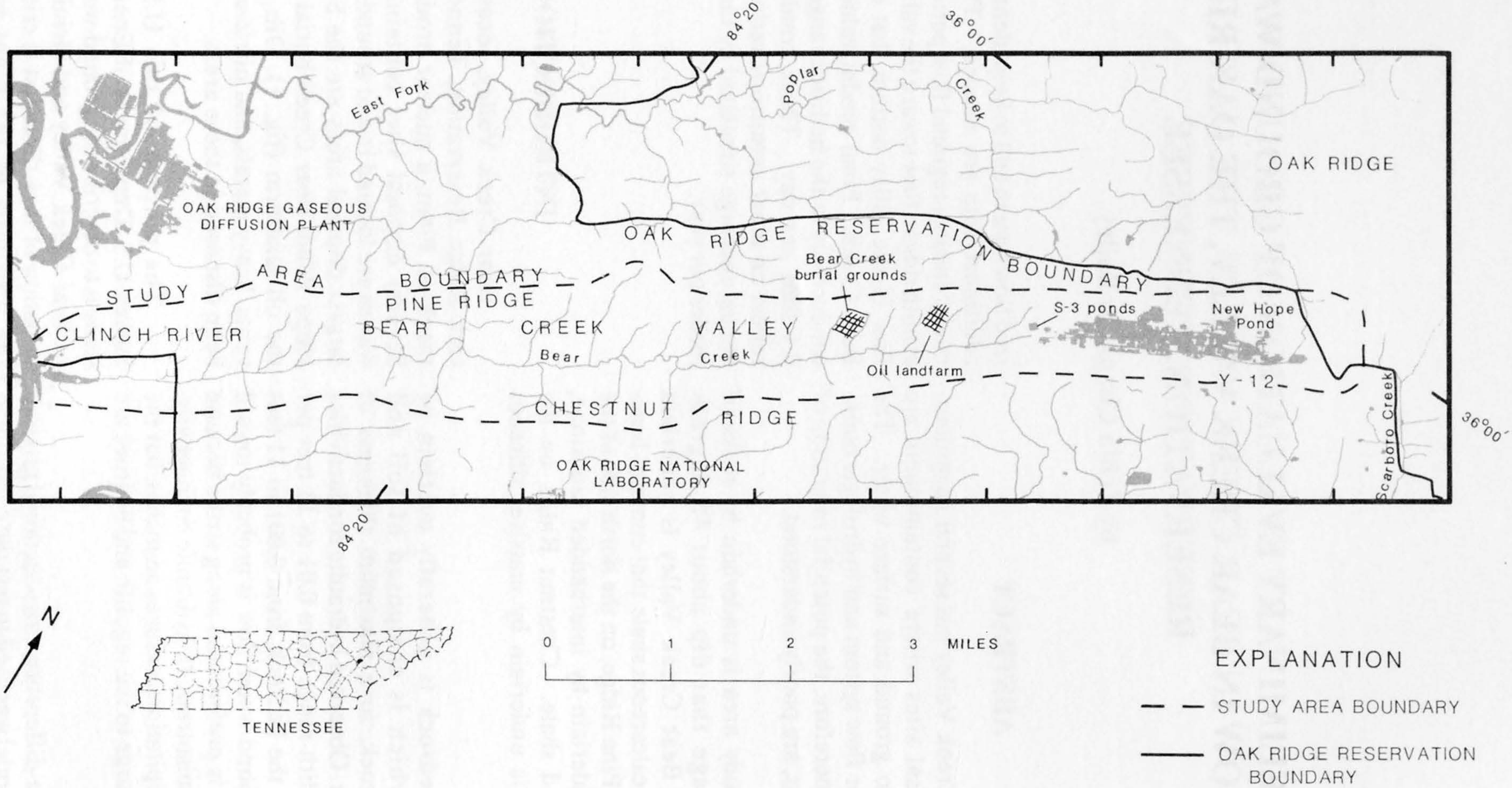


Figure 1.--Study area.

boundaries, and therefore, the potential for migration of contaminants off site.

The objectives of this preliminary analysis are to use available data to formulate a concept of the regional hydrology and ground-water flow and to identify the type and location of additional data needed to gain a more complete understanding of the ground-water flow system. The scope of this evaluation includes (1) the review and compilation of all available lithologic and hydrologic information, (2) the formulation of a preliminary concept of the ground-water flow system, and (3) the use of a digital cross-sectional ground-water flow model to test the concept.

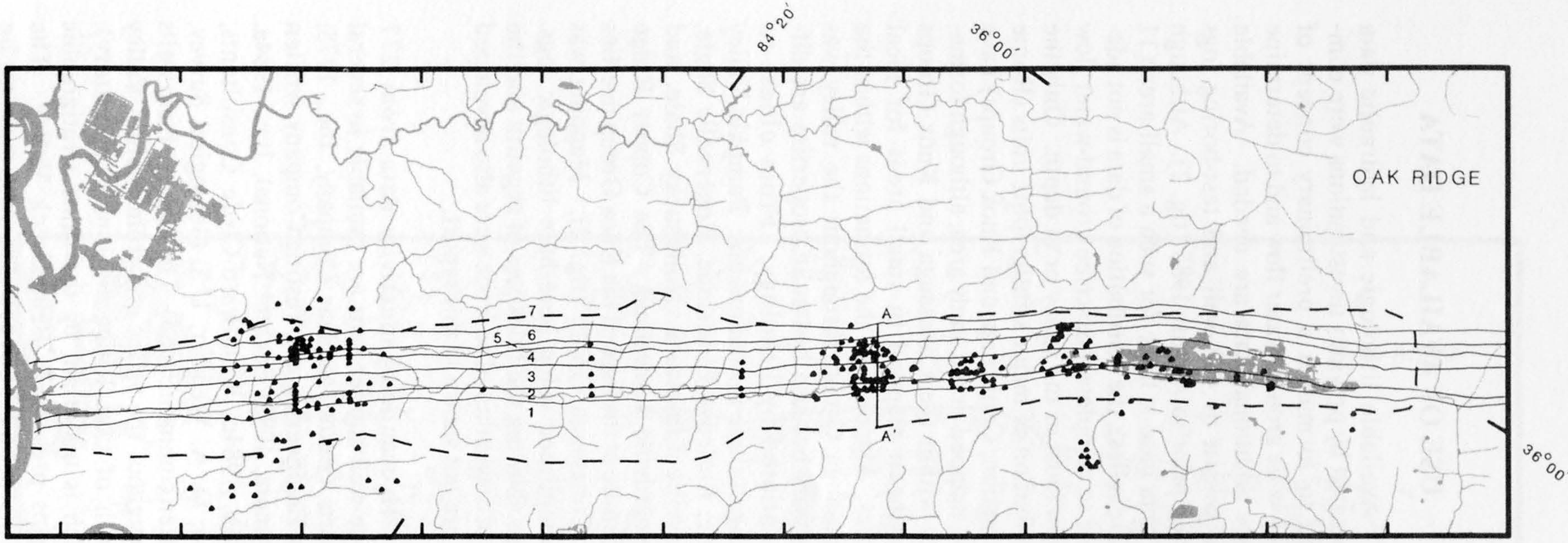
Bear Creek Valley and adjacent ridges are underlain by rocks of Cambrian age that strike north 56 degrees east (fig. 2). The dip of the rocks varies from 30 to 70 degrees to the southeast, but the average dip is about 45 degrees (fig. 3). Pine Ridge is underlain by interbedded sandstone, siltstone, and shale of the Rome Formation. Bear Creek Valley is underlain by calcareous shale and limestone of the Conasauga Group. Chestnut Ridge is underlain by massive, siliceous dolomite of the Knox Group and contains solution and karst features. The regolith, which consists of soil and weathered rock, ranges from 0 to 80 feet in thickness and overlies the bedrock except where rock crops out in stream channels.

Many site-specific studies have been conducted in Bear Creek Valley, but the information needs to be integrated into an area-wide interpretation of the ground-water flow system. More than 400 wells and test borings have been drilled for previous and ongoing studies. These wells and borings are clustered in hazardous-waste disposal areas, in contaminated areas, or in areas under investigation for future use. Because of a general lack of deep wells (greater than 100 feet deep), the deep ground-water flow system and its connection to the regolith and shallow bedrock system is poorly understood.

USE OF AVAILABLE DATA

Available lithologic and hydraulic data generated by previous investigations were compiled to formulate a preliminary concept of valley-wide ground-water flow and to determine where additional data are needed. Available data consist of 430 well and test-boring logs drilled prior to August 1985 (fig. 2). Although the data base is large for such a small area (11 square miles), the distribution of data is not adequate to completely describe ground-water flow within most of the valley or at depth. Only the distribution of major stratigraphic units (Rome Formation, Conasauga and Knox Groups) have been mapped in the study area, although formations within the Conasauga and Knox Groups have been mapped in small areas for local studies. Mapping of the formations within the Conasauga Group throughout the valley was necessary because hydraulic properties are differentiated by lithology. From oldest to youngest these formations are: Pumpkin Valley Shale, Rutledge Limestone, Rogersville Shale, Maryville Limestone, Nolichucky Shale, and Maynardville Limestone. The Copper Ridge Dolomite at the base of the Knox Group overlies the Conasauga Group (fig. 2). Mapping was accomplished using bore-hole lithologic logs. Maps showing the thickness of regolith and the top of unweathered bedrock were also developed but are not shown in this report.

Hydraulic-conductivity data from 277 single-well aquifer tests are available in several reports (Exxon Nuclear Company, Inc., 1975; Law Engineering and Testing Company, written commun., 1983; Bechtel National, Inc., 1984a, 1984b, 1984c; Woodward-Clyde Consultants, 1984; D. A. Webster, U.S. Geological Survey, written commun., 1985). The data are from wells throughout the valley and from Melton Valley (south of Oak Ridge National Laboratory), which is underlain by the same stratigraphic groups present in Bear Creek Valley. The regolith and bedrock are assumed to be



Base from Tennessee Valley Authority S-16A map, 1:24,000, revised in part in June 1974

84°20'

Geology from A. B. Hoos and Z. C. Bailey, U. S. Geological Survey, written commun., 1985

EXPLANATION

1	KNOX GROUP	Copper Ridge Dolomite		CAMBRIAN
2	CONASAUGA GROUP	Maynardville Limestone		
3		Nolichucky Shale		
4		Maryville Limestone		
5		Rogersville Shale and Rutledge Limestone		
6		Pumpkin Valley Shale		
7		Rome Formation		

APPROXIMATE GEOLOGICAL CONTACT

WELL OR TEST BORING

A —— A' LINE OF CROSS SECTION

VALLEY BOUNDARY--Study Area

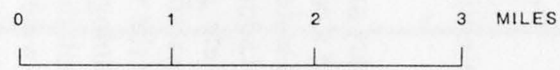


Figure 2.--Bedrock geology of Bear Creek Valley and locations of wells and test borings.

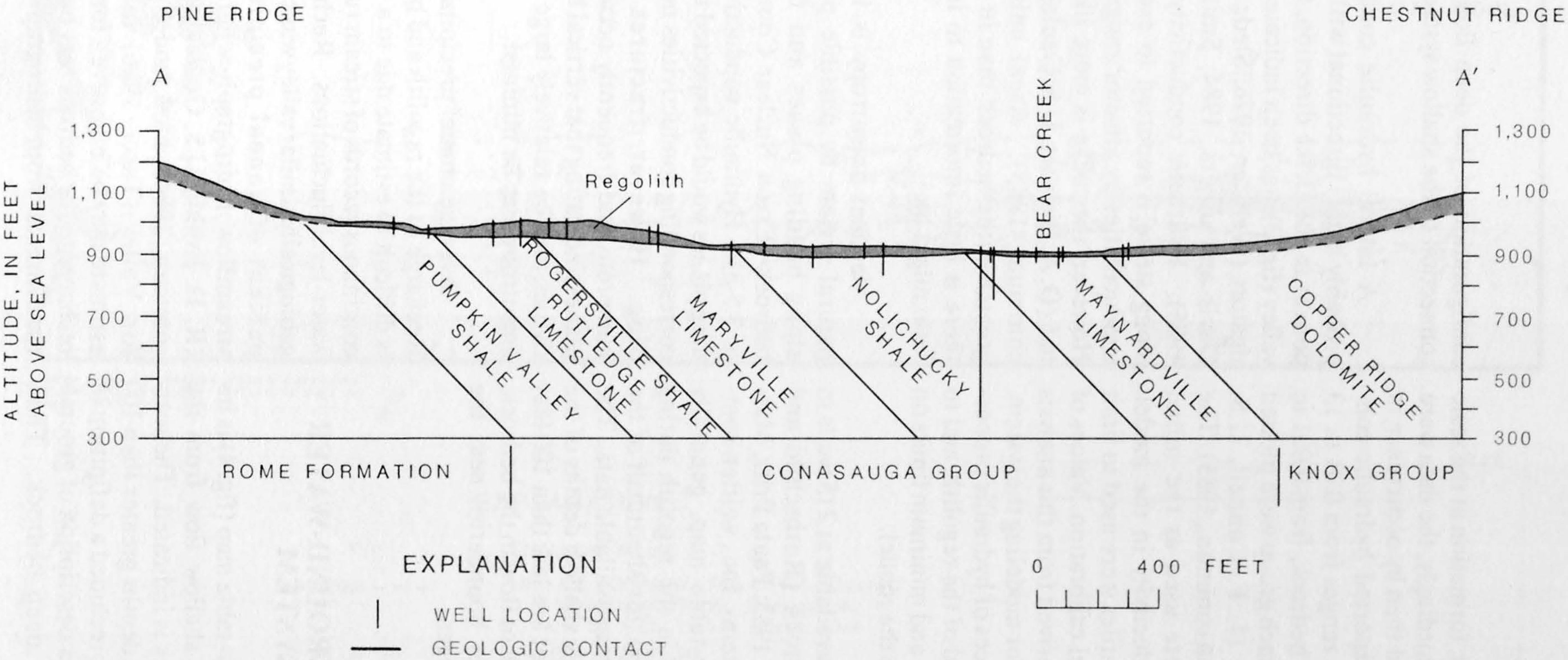


Figure 3.--Hydrologic section through Bear Creek burial grounds.

homogeneous within each formation at the scale of this investigation. Accordingly, the data were grouped by formation and then by occurrence in bedrock or regolith. Reported hydraulic conductivity for the regolith ranges from 0.01 to 13 feet per day, and for the bedrock, from 0.001 to 11 feet per day. Data in each group were plotted on a probability curve (J. F. Connell, U.S. Geological Survey, written commun., 1985). The 50-percentile values were used as the initial values of hydraulic conductivity in the model, and the 10 and 90 percentiles were used to limit the changes during model calibration. Values of hydraulic conductivity derived from this analysis were used as a guideline for modeling the system, to show relative differences of hydraulic properties of the formations and of the regolith, and to set reasonable maximum and minimum limits on hydraulic conductivity in the model.

Water levels were available at 215 wells in both regolith and bedrock (Rothschild and others, 1984; McCauley, 1985; Paula Pritz, Martin Marietta Energy Systems, Inc., written commun., 1985). A water-table map, generally representing conditions in the regolith during mid-October 1984 (fig. 4), for about half of the valley was constructed from available data. The distribution and generally shallow depths of the bedrock wells (70 percent are less than 100 feet deep) limit the definition of flow in the bedrock, particularly at the valley boundaries near the Clinch River and the ridges.

CONCEPTUAL GROUND-WATER FLOW SYSTEM

Although the water-table map (fig. 4) is incomplete, a pattern of shallow flow from the ridges toward Bear Creek is indicated. The scarcity of wells screened at depths greater than 100 feet below land surface precluded a definition of hydraulic potential and a description of ground-water flow within the deep bedrock. Thus, configuration of the deep flow system, and its connection to the shallow system, is uncertain.

A lateral hydraulic conductivity tensor, probably highly directional with the major component in the strike direction, that is, down the valley (fig. 2), has been indicated by other investigators (Webster, 1976; Sledz and Huff, 1981; Davis and others, 1984; Smith and Vaughn, 1985). Hydraulic conductivity in the regolith along strike is reported to exceed cross-valley conductivities by a factor ranging from 3 to 20. However, the range is more likely to be from 2 to 5 (D. A. Webster, U.S. Geological Survey, oral commun., 1985). Areal anisotropy may be greater in the bedrock than in the regolith, but there is little information to indicate what the ratio might be.

Vertical anisotropy is indicated in the natural system by possible preferential flow along bedding planes and fractures in the bedrock (Exxon Nuclear Company, Inc., 1975, p. 3.5-3). Hydraulic conductivities along bedding planes would be expected to be greater than corresponding conductivities normal to the bedding. However, fractures and joints are numerous and frequently occur across bedding planes, indicating that vertical hydraulic conductivities may be relatively large and that vertical anisotropy may be minimal.

Average annual precipitation is 55 inches. Recharge to the regolith and bedrock, however, is difficult to estimate due to a lack of long-term continuous records of stream runoff and ground-water-level fluctuations. Recharge in a nearby, geologically similar valley was calculated to be 25 percent of annual precipitation by using streamflow hydrograph-separation techniques (R. D. Evaldi, U.S. Geological Survey, written commun., 1984). Flow modeling in nearby Melton Valley (Tucci, 1986) indicates that this estimate may be high, even for the regolith, and recharge to the bedrock may be much lower than the estimates from hydrograph-separation.

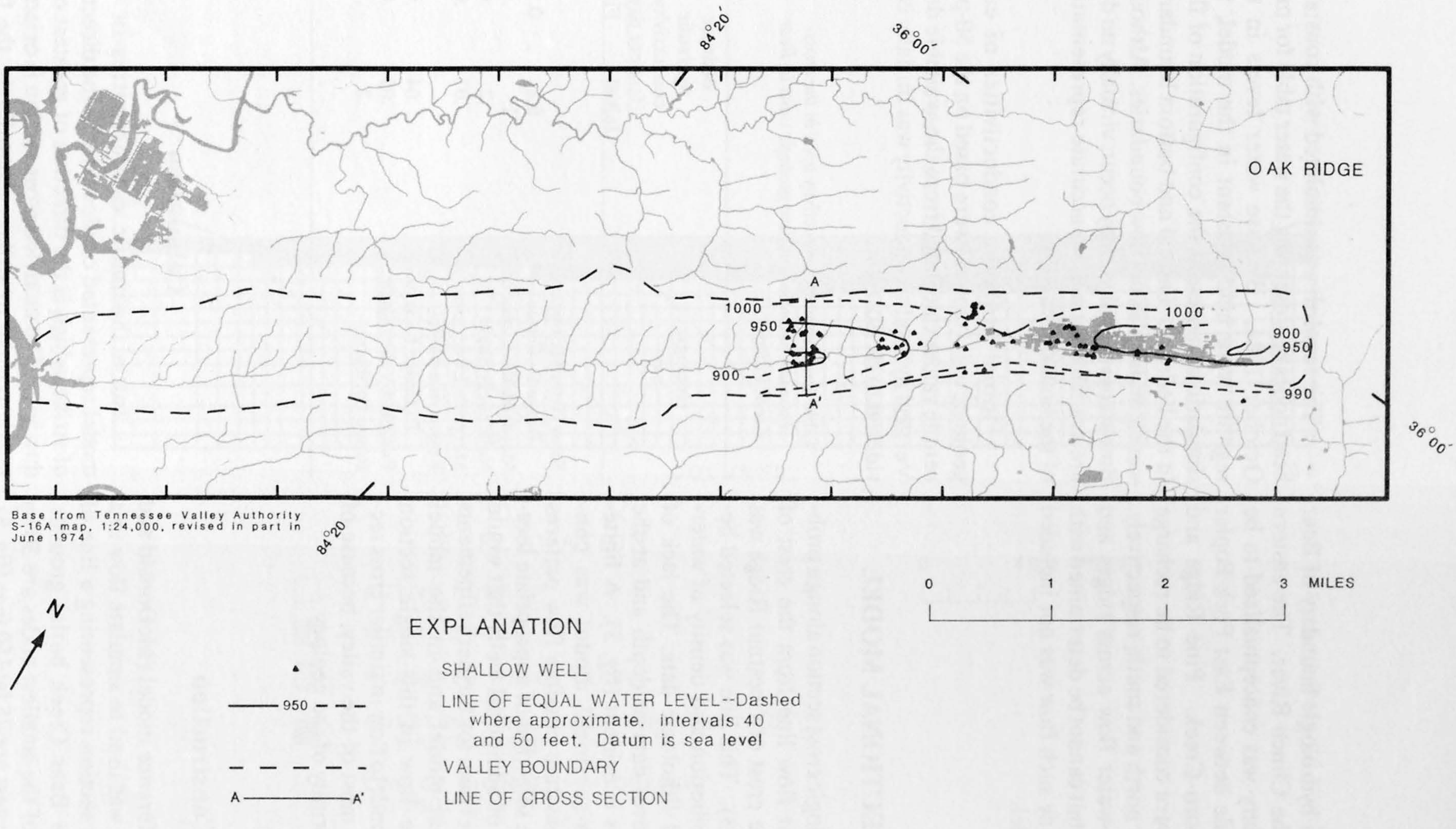


Figure 4.--Water-table configuration for the eastern half of Bear Creek Valley, October 1984.

The western hydrologic boundary of Bear Creek Valley is the Clinch River. The eastern hydrologic boundary was conceptualized to be the drainage divide between East Fork Poplar Creek and Scarboro Creek. Pine Ridge and Chestnut Ridge were considered to be recharge boundaries to the north and south, respectively. Regional ground-water flow across ridges and valleys is possible but cannot be determined with available data. Any such flow was not included in the digital model.

CROSS-SECTIONAL MODEL

A hydrogeologic cross section along a probable ground-water flow line from the crest of Pine Ridge to the crest of Chestnut Ridge was constructed (fig. 3). This line was selected because of the distribution and density of water-level (fig. 4) and lithologic data. The lack of adequate water-level data at depth and at the lateral boundaries is evident (fig. 3). A finite-difference cross-sectional model was constructed to demonstrate possible flow patterns and to help in the selection of appropriate locations and depths of additional wells that would provide water-level data for further refinements in the conceptual model and in the model calibration. The flow in this single section probably corresponds to flow in similar cross sections throughout most of the valley, because of the relative uniformity of the geology.

Construction

A finite-difference model (McDonald and Harbaugh, 1984) was used to simulate flow in a 1-foot wide cross section representing a line of flow through the Bear Creek burial grounds. The dimensions of the smallest nodes are 50 by 50 feet and the largest are 75 by 150 feet (fig. 5).

The regolith was simulated with constant-head nodes representing the water table for mid-October 1984. Because water levels in the regolith were held constant in the model, the simulations represent the configuration of flow in the bedrock. Lateral and bottom boundaries were simulated as no-flow boundaries. Although flow across the ridges may occur, virtually no data are available for a more accurate representation of the boundaries.

Initial hydraulic conductivities of each geologic unit (table 1) were based on the 50-percentile values calculated from the available data. Vertical hydraulic conductivity was initially considered to be isotropic.

Table 1.--*Hydraulic conductivity used in the cross-sectional model to simulate geologic units in Bear Creek Valley*

Geologic unit	Bedrock hydraulic conductivity (feet per day)	
	Initial	Final
Knox Group (Copper Ridge Dolomite)	0.2	0.1
Maynardville Limestone	1.	.1
Nolichucky Shale	.2	.04
Maryville Limestone	.07	.01
Rogersville Shale/ Rutledge Limestone	.04	.008
Pumpkin Valley Shale	.05	.01
Rome Formation	.2	.1

Calibration

Initial hydraulic conductivities in the model represented conductivity in the direction of strike, which is the direction of greatest conductivity. The modeled cross section is oriented nearly normal to strike. Accordingly, the flow

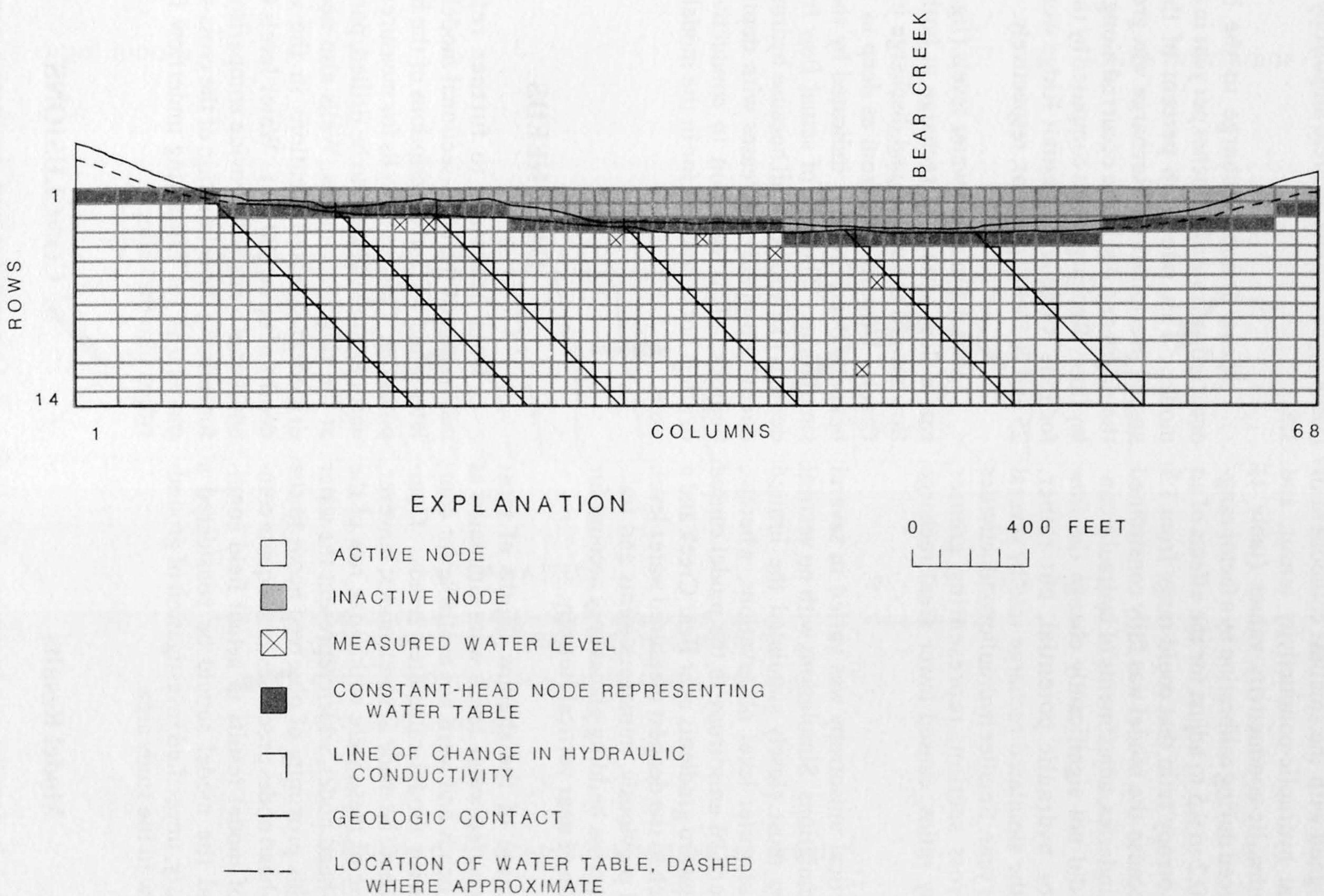


Figure 5.--Finite-difference grid for cross-sectional model.

path is aligned with the smallest component of the lateral hydraulic-conductivity tensor, and initial hydraulic-conductivity values (table 1) were reduced during calibration by a factor ranging from 0.2 to 0.5 to adjust for the effects of an areal anisotropy ratio that could range from 1:5 to 1:2. Because the model was fully constrained at the boundaries, adjustments of hydraulic conductivity did not significantly change the flow pattern or hydraulic potential, but rather, changed the simulated recharge rate by several inches per year. Smaller hydraulic conductivities in the cross section, representing greater anisotropy ratios, caused lower areal recharge rates.

Vertical anisotropy was varied in several model simulations. Simulations with no vertical anisotropy most closely simulated the limited number of water-level observations, whereas, greater vertical anisotropy in the model caused steeper upward gradients near Bear Creek and a poor match to the deepest measured water level. As noted previously, numerous joints and fractures that cross bedding planes may account for a condition of near vertical isotropy.

Because of the shallow depths of most wells, measured water levels were simulated as constant heads and were not available for comparison with model-calculated heads. Comparisons could be made at seven nodes; however, all but one of these were within one row of the constant-head nodes, which represent the water table. This proximity of observed heads to the constant-head nodes precludes an adequate comparison of model results to actual field conditions, and the model should be considered a preliminary, unverified investigation of ground-water flow in the study area.

Model Results

Final hydraulic conductivities for the bedrock ranged from 0.01 to 0.1 foot per day (table 1), and reflect an areal anisotropy ratio of 1:5.

Mean annual recharge to the bedrock occurred at a rate of 10 inches per year in the final model. This rate is 18 percent of the mean annual precipitation. Recharge was greatest at the ridges and discharge occurred along the valley floor. Recharge rates computed by the model for Pine Ridge and Chestnut Ridge were about 25 and 20 inches per year, respectively.

Model-simulated water levels (fig. 6) indicate a flow pattern of recharge at both ridges, flow toward the valley, and discharge into Bear Creek. Upward flow from as deep as 500 feet beneath Bear Creek is indicated by the model simulations. The rate of actual flow from that depth is likely to be small because hydraulic conductivity probably decreases with depth in the bedrock. This variation in conductivity with depth is not accounted for in the model simulations.

DATA NEEDS

Data necessary to further refine the calibration of the cross-sectional model include lateral and vertical descriptions of the hydraulic potential. Clusters of wells for measurements of vertical potential need to be drilled, particularly at the ridge boundaries. Wells also need to be drilled at selected locations in the valley to depths of up to 600 feet. Water levels from the additional wells will provide comparison points for refining the calibration of the cross-sectional model and for estimating underflow from the ridges into the valley.

CONCLUSIONS

Quantitative and qualitative concepts of the ground-water flow system in Bear Creek

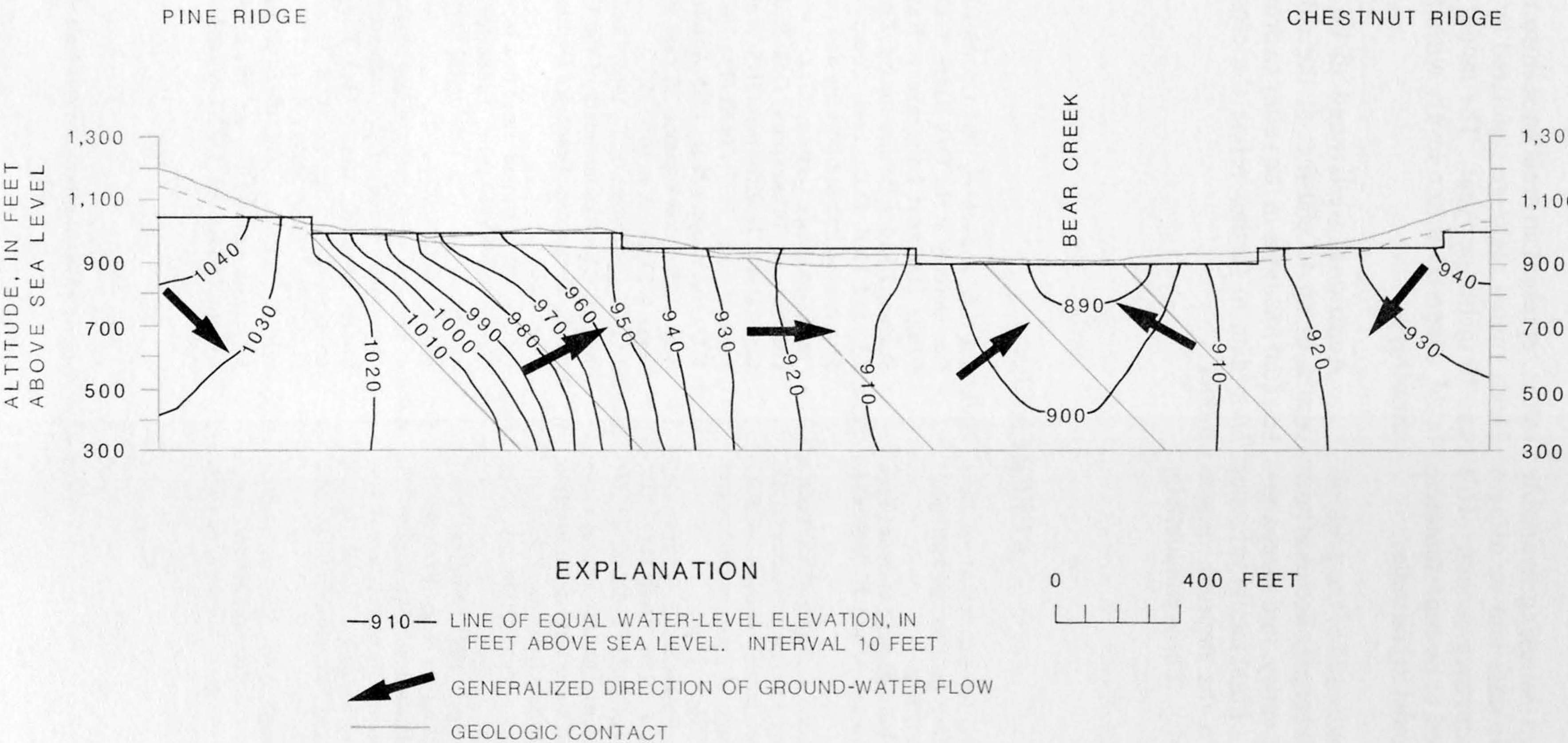


Figure 6.--Model-simulated water levels.

Valley were formulated by using available lithologic and hydrologic data and by using a cross-sectional finite-difference model. This cross section is considered to be representative of ground-water flow in most of the valley.

The flow pattern computed by the preliminary model indicates that recharge occurs at both ridges, flows toward the valley, and discharges upward into Bear Creek. Final model values of hydraulic conductivity in the bedrock ranged from 0.01 to 0.1 foot per day. These conductivity values represent an areal anisotropy ratio of 1:5. Mean annual recharge simulated by the model was 10 inches per year. The model best simulated observed water levels with no vertical anisotropy.

Additional wells need to be drilled to depths of up to 600 feet at the ridges and at selected locations in the valley to provide water-level data to further refine the cross-sectional model.

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Preliminary Evaluation of Ground-Water Flow in Bear Creek Valley, the Oak Ridge Reservation, Tennessee   USGS/WRIR 88-4010

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