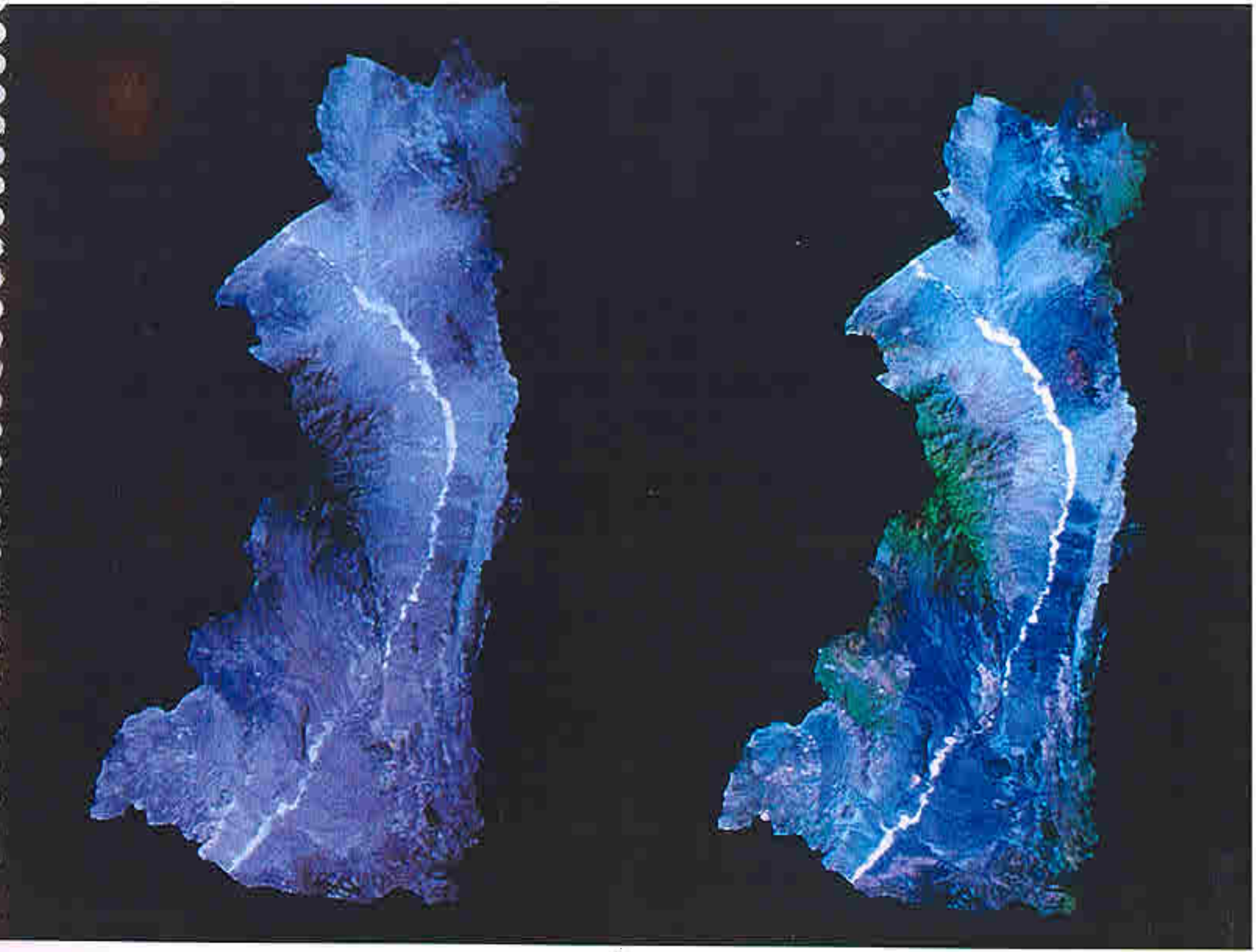

HYDROLOGY AND STEADY STATE GROUND-WATER MODEL OF PAHROC VALLEY, LINCOLN AND NYE COUNTIES, NEVADA

1993

Las Vegas
Valley
Water
District

COOPERATIVE WATER PROJECT
Water for Nevada's Future
Report No. 10
Hydrographic Basin 208

HYDROLOGY AND STEADY STATE GROUND-WATER MODEL OF PAHROC VALLEY, LINCOLN AND NYE COUNTIES, NEVADA

By

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The Earth Technology Corporation

1993

PREFACE

This report on the water resources and development potential of Pahroc Valley is one of a series of reports on hydrographic basins in southern and eastern Nevada, prepared by The Earth Technology Corporation for the Las Vegas Valley Water District as part of the District's Cooperative Water Project. The work was conducted between November and December, 1990. Thomas Buqo, Managing Senior Hydrogeologist, was the project manager and co-author of this report. Ouarda Drici, Senior Project Hydrogeologist, developed the ground-water flow model and co-authored the report. Chris Garey, Staff Geologist, performed detailed evaluations of the available data and prepared selected portions of the report. Quality assurance reviews and technical assistance were provided by Dr. Richard Bateman, Principal Hydrogeologist and Dr. James Tracy, a consultant to the Las Vegas Valley Water District. Information used in performing this work was provided by the Nevada State Engineer Office, the U.S. Geological Survey, Summit Engineering, Inc., and the U.S. Air Force. Additional information and technical assistance was provided by the staff of the Research Department of the Las Vegas Valley Water District, under the direction of Terry Katzer, Director.

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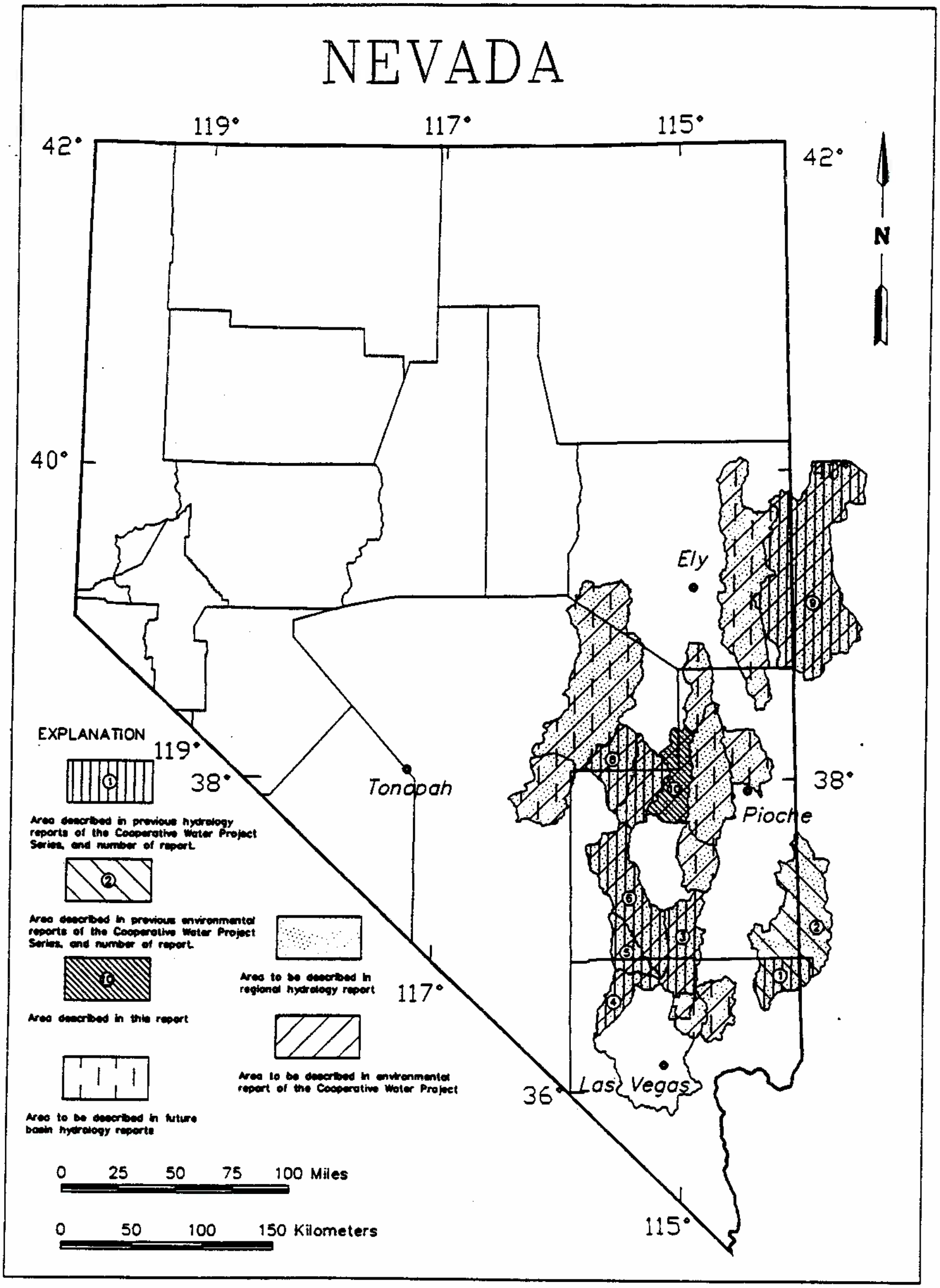


Areas described in previous reports of this series, the area described in this report and the areas to be described in future reports.

INTRODUCTION

In October 1989, the Las Vegas Valley Water District (District) filed seven applications to obtain ground-water rights from Pahroc Valley in Nye and Lincoln Counties, Nevada. In March 1990, The Earth Technology Corporation entered into an agreement with the District to provide hydrologic and geologic services in support of these water right filings. This report details the hydrologic assessment of Pahroc Valley that was conducted, and the steady-state ground-water flow model developed to represent Pahroc's aquifer system.

BACKGROUND

Pahroc Valley is an arid basin located about 100 miles north of Las Vegas, Nevada (Figure 1). Pahroc Valley is totally uninhabited, but there have been a few water wells drilled in the center of the valley, presumably into the alluvium only. On the basis of the geology of the basin and the hydrogeology of neighboring basins, it is assumed, however, that the regional carbonate aquifer underlies Pahroc Valley.

The District plans to develop the water resources of Pahroc Valley through the installation of a well field and distribution system that will convey the water to users in metropolitan areas of Clark County. Preliminary plans call for the drilling of water wells at seven locations; final optimized wellfield designs will be developed in subsequent phases of the development program and will be based upon detailed planning and environmental studies.

To assist its efforts in formulating final plans for developing the water resources of Pahroc Valley, the District developed a numerical model of the steady state ground-water flow regime of the valley. A numerical model is a computer code which translates the mechanics of ground-water flow through the earth through a series of mathematical equations. By coupling the available information on Pahroc Valley (and similar valleys in Nevada) with the predictive capabilities of a regional, transient ground-water model, it is possible to predict the response of the ground water to the proposed water withdrawals by the District.

The development of a regional ground-water flow model, which includes Pahroc Valley, serves two important purposes. First, it is a useful planning tool in developing well field designs by allowing water supply design experts to simulate the efficiency of different design alternatives; secondly, it allows planners to simulate the potential effects of the water withdrawals, if any, on neighboring water users, or the environment.

Both beneficial and negative impacts may result from ground-water withdrawals from the valley-fill deposits and/or the regional carbonate aquifer in the arid basins of Nevada. The benefits derived from the application of currently unused ground water to beneficial use is, of course, the primary positive impact. The economic impact of large-scale ground-water development programs, such as that proposed by the District, is likely to be appreciable and the project is likely to result in significant short-term and long-term economic benefits. The proposed program will require the cooperative efforts of large teams of scientists, engineers, and water

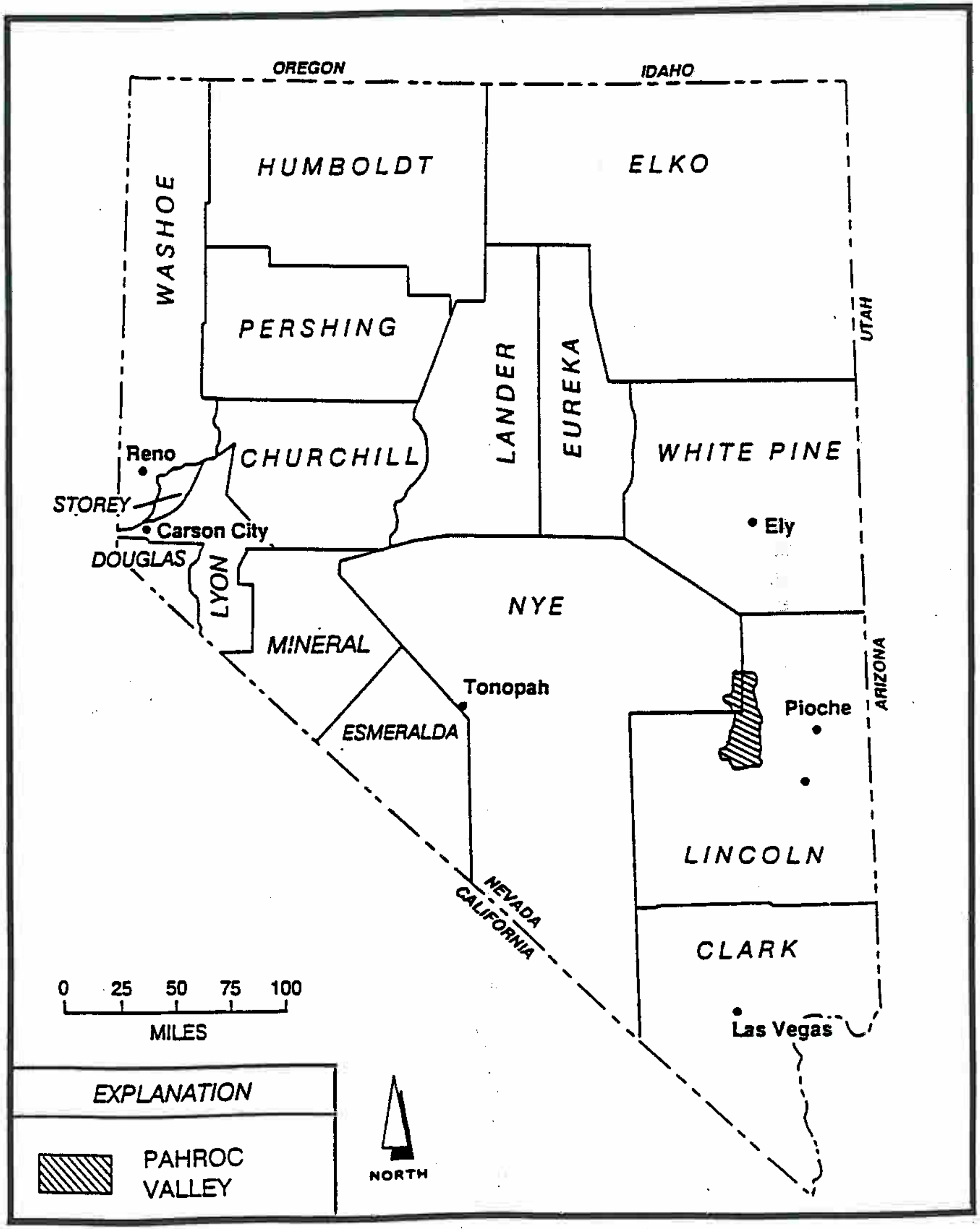


Figure 1.--Location of Pahroc Valley.

planners, and the services of the water well and construction industries. The cost of developing the ground-water resources in Pahroc Valley has not been established.

Beside the favorable economic impacts expected to result from the proposed development of ground water in Pahroc Valley, negative impacts can occur. The primary negative impact of ground-water withdrawals is the lowering of ground-water levels in the vicinity of the production wells; this lowering of water levels is commonly referred to as drawdown. If the drawdown near a pumping well, or a wellfield, is significant, then the direction and rate of ground-water flow can be altered and may result in:

- Increased pumping lifts and costs;
- Reductions in spring-flow rates;
- Reductions in surface-water flows; and
- Degradation of water quality.

The magnitude and significance of these impacts depends largely upon the overall hydrologic setting of the basin where the withdrawals occur. In remote, undeveloped or underdeveloped basins with no surface water or large springs (such as Pahroc Valley), the drawdown that will result from ground-water development may not result in significant adverse impacts within the valley. In other instances, the presence of sensitive environments in a valley may be adversely impacted as a result of the same amount of drawdown. Examples of sensitive environments in Nevada include: 1) wetland areas that provide valuable habitat for many types of wildlife; 2) surface water flows and their associated riparian habitats; 3) springs that either support wildlife or have been developed for ranching, mining, quasi-municipal, or domestic uses; and 4) areas where ground water provides the sole source of drinking water for a community.

Because many of the basins in central and southern Nevada are hydraulically linked, via the regional carbonate aquifer, the drawdown that results from the development of ground water in one valley can potentially impact the environment of another valley. Thus, the development of a numerical model of ground-water flow to simulate the impacts of pumping must take into account the environment in peripheral valleys as well as the valley actually being modelled. The District is in the process of preparing a computer model to evaluate these potential regional impacts.

Although there are no large springs or developed areas in Pahroc Valley, the valley is in direct hydraulic communication with adjacent valleys. Withdrawing water from Pahroc Valley could potentially impact adjacent basins. Ten miles north of Pahroc Valley, in the southern part of White River Valley, is located the Wayne Kirch Wildlife Management Area. Ten miles south of Pahroc Valley, in the northern part of Pahranagat Valley, is located the Key Pittman State Wildlife Management Area. Both of these areas are sensitive wetlands, and modelling Pahroc Valley's hydrogeology will aid in predicting the effects of withdrawing water in Pahroc Valley upon these areas. The meager discharge of ground water at springs in Pahroc Valley also provides water for wildlife.

The use of numerical methods to simulate water withdrawals in Pahroc Valley provides a tool for predicting the effects that would be expected to result from the proposed District development plan. Recently, the U.S. Geological Survey (USGS) has reported the findings of a cooperative study of the water resources potential of the carbonate aquifer conducted in cooperation with the U.S. Bureau of Reclamation, state and local agencies, including the District (Dettinger, 1989). This report recommends the effective use of computer models for predicting the site-specific effects of water withdrawals from the carbonate aquifer. The report concluded that increased confidence in such predictions can be achieved through a staged approach to development coupled with adequate monitoring and interpretation. The development of a computer model of the steady-state ground-water flow regime in Pahroc Valley performed as part of this investigation represents one of the first steps in implementing such a staged approach.

The steady-state ground-water model, described in this report, provides a preliminary representation of the aquifer system based upon the information available at this time. As additional data becomes available through District efforts, the model of the ground-water flow regime in Pahroc Valley can be updated accordingly to provide a more refined representation of the hydrologic system.

PURPOSE AND SCOPE

The purpose of this project was twofold: 1) to define the hydrologic conditions of Pahroc Valley, and 2) to develop a calibrated steady-state ground-water flow model of the valley. The specific objectives of these investigations were to:

- Collect land use data in the valley;
- Compile and review published reports and unpublished data on the basin;
- Interpret the available data and determine the characteristics of the basin; and
- Prepare a computer model to simulate steady-state ground-water flow in the basin.

To achieve these objectives, a detailed investigation of the hydrologic conditions of Pahroc Valley was conducted. The scope of work included a review of all available published and unpublished data, the evaluation of the occurrence and movement of ground water and water chemistry, and the development of conceptual and steady-state numerical models of the hydrogeologic regime of the valley. The basin characterization information and steady-state flow model discussed in this report will be used by the District to develop a transient regional model including Pahroc Valley's ground-water regime.

LOCATION AND PHYSIOGRAPHIC SETTING

Pahroc Valley is within the Great Basin Physiographic Region as defined by Fenneman (1931). Figure 2 shows the topographic expression of the valley and the basin boundaries as defined by the Nevada State Engineer. The valley is located between the Seaman Range to the west, the

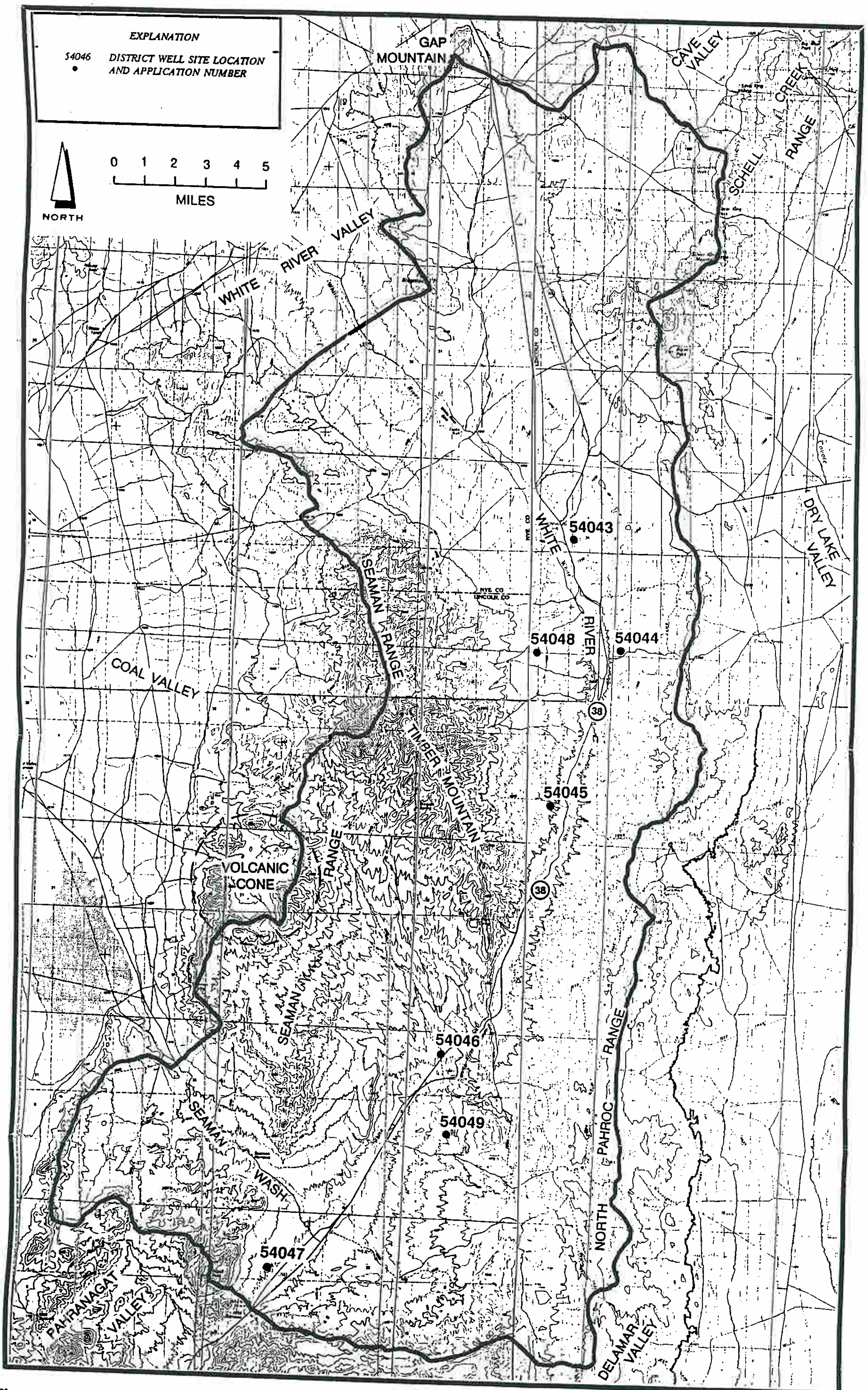


Figure 2. Physiography and location of Pahroc Valley. Base maps are 1:100,000 scale maps for the Wilson Creek Range, Quinn Canyon Range, Timpahute Range, and Caliente.

North Pahroc Range to the east, Schell Creek Range to the northeast, Pahranagat Valley to the south, and White River Valley to the north and northwest.

Pahroc Valley is approximately 43 miles along its central axis, 13 miles wide, and covers 508 square miles (Scott, et al., 1971). The valley floor is a segment of a large topographic trough that includes, from north to south, Jakes, White River, Pahroc, Pahranagat, Coyote Spring, and Moapa Valleys. The present day lowland of Pahroc Valley is the former flood plain of the White River, which forms the topographic axis of the valley. This presently dry streambed is now called White River (or Pahranagat Wash) on topographic maps of the area. White River slopes southward through Pahroc Valley from the lower end of White River Valley. By the time the White River reaches Pahranagat Valley, the elevation has dropped 970 feet, to 4,100 feet.

The valley floor ranges in elevation from 6,050 feet above mean sea level (AMSL) on the alluvial fans to 3,085 feet AMSL at the south end of the valley where the White River enters Pahranagat Valley. The valley floor averages about 5,000 feet AMSL overall in elevation. On the west, Pahroc Valley is bounded by the Seaman Range, which rises to a maximum elevation of 8,605 feet AMSL. On the east, Pahroc Valley is bounded by the North Pahroc Range, which rises to an elevation of 6,915 feet AMSL. On the northeastern boundary, the elevation rises to 7,850 feet AMSL in the Schell Creek Range.

The physiography of Pahroc Valley is similar to that of adjacent valleys in southern Nevada; mountains rise on the east and west. Alluvial fans radiate from the major mountain watersheds, forming a somewhat continuous bajada. On the valley floor, the major feature is the White River, a partially incised ephemeral stream.

AVAILABILITY OF DATA

Pahroc Valley is located in a remote and unpopulated portion of Nye and Lincoln Counties, and the limited development that occurred to date in the valley has resulted in a relative scarcity of valley-specific data. Regional data from adjacent valleys are however available to supplement the existing valley-specific data.

Some well data are available for a total of 7 known wells in Pahroc Valley. The locations of these wells are shown in Figure 3. As shown, the distribution of data points in the valley, although not ideal; does provide for coverage of a significant area. All other available well information is provided in Table 1. Appendix A provides an explanation of the well location designations used in Table 1 and throughout this report. The existing water level data in Pahroc Valley are limited to the location and depth to water for four wells: well Nos. 2, 3, 4 and 7 (USGS Nevada District Well Schedules; Eakin, 1963). No water level datum is available for well No. 1, and wells No. 5 and 6 are dry.

The site-specific data is supplemented by regional data. Previous investigations in neighboring valleys have generated a data base of regional information which can used to help formulate a round-water model for Pahroc Valley. These data provide specific measures or estimates of the ground-water conditions at selected points in time and values for key hydrologic parameters. Several of the wells in adjacent valleys that were drilled as part of the Air Force's MX investigations extend through the valley-fill into the underlying carbonate rocks. Summary information of selected wells for which data were available is listed in Table 1, with individual well numbers keyed into Figure 3.

The primary source of data for Pahroc Valley is a reconnaissance report authored by Eakin (1963). Investigators of the regional flow system and adjacent valleys have included Eakin (1963 and 1964); Winograd and Thordarson (1975); Guth (1980); Ertec Western (1981); Thomas, et al. (1986); Thomas (1988); Kirk and Campana (1988); and Dettinger (1989). The sources of recent data available for Pahroc Valley include: 1) details on water well construction from Well Drillers Reports filed with the Nevada State Engineer Office; 2) water level, spring discharge, and water chemistry data and the results of aquifer tests from the USGS databases; and 3) the results of aquifer tests and exploratory drilling into the carbonate aquifer by the Air Force during 1980 and 1981.

Other available data included technical reports of the Nevada Department of Conservation and Natural Resources, USGS Professional Papers, Water-Supply Papers, and Open-File Reports, and cooperative reports on the regional carbonate aquifer study conducted in 1988. Characterizations of the regional setting, particularly those by Eakin (1963), Kirk and Campana (1988), and the recent publications by the USGS, provide important, and accepted regional interpretations that are also of considerable use in evaluating Pahroc Valley.

Information on the status of water rights in Pahroc Valley was made available by Summit Engineering Corporation (SEC) in the form of water right abstracts. According to SEC, these abstracts were based upon a thorough compilation and review of the public documents available from the Nevada State Engineer Office, the regulatory authority governing water rights in Nevada.

The conceptual and numerical models of Pahroc Valley, discussed later in the report, are based on the available site-specific and regional data discussed in the previous paragraphs, the observations made during reconnaissance trips to the valley, and the knowledge of the overall regional ground-water setting.

METHODS

Standard approaches and procedures were used in assessing the water resources potential and developing a steady-state numerical model of the ground-water system of Pahroc Valley. In this section, the methods and procedures that were used are identified and discussed, along with a brief introduction to the selected numerical modelling code.

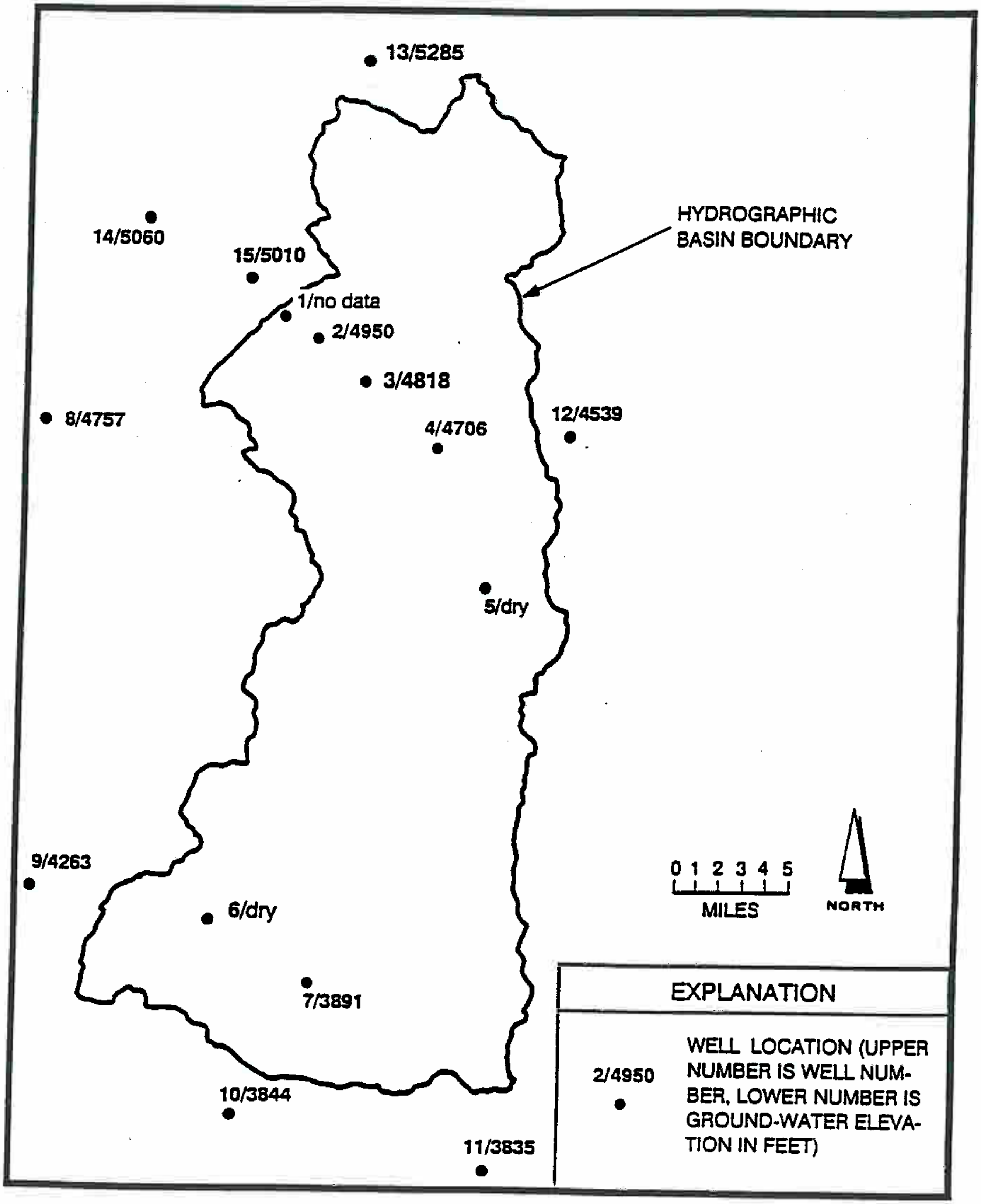


Figure 3.--Existing wells in Pahroc Valley and adjacent valleys.

Table 1.--Water level data for Pahroc Valley and adjacent valleys.

Site No.	Location Lat.	Long.	T	R	S	Drill Date	Surface Elev.	Well Depth	Water Depth	Water Elev.	Source Unit	Data Source	Basin No.	Site Name
1*	381001	1150613	4N	61E	27dddc 1	—	5070	—	ND	—	—	1	208	Griswald
2	380914	1150441	4N	61E	36c 1	—	5040	—	90	4950	—	1	208	BLM - White River Well #1
3	380736	1150235	3N	62E	17b 1	—	5036	—	216.5	4817.5	—	2	208	BLM - Eaplin
4	380505	1145935	3N	62E	35bbb 1	—	4957	315	250.6	4706.4	—	1	208	BLM - White River Well #2
5*			2N	63E	31b1	—	—	800	DRY	—	—	2	208	BLM
6*			2S	60E	1d1	—	—	302	DRY	—	—	2	208	Unnamed
7	374525	1150618	2S	61E	23d 1	—	4255	480	363.7	3891	—	1	208	Stewart
8			3N	59E	10bd	1980	5560	1835	803	4757	—	4	171	U.S. Air Force
9			1S	59E	34cb	1980	5125	1445	862	4263	—	4	171	U.S. Air Force
10	374058	1151135	3S	60E	13a1	—	4057	479	212.8	3844.2	—	3	209	Stewart Brothers
11	373803	1150505	4S	61E	1aa1	—	4520	>700	685.35	3834.65	—	3	209	Unnamed
12			3N	63E	27ca	1980	5390	2395	851	4539	C	4	181	U.S. Air Force
13			6N	62E	31ad	1971	5430	250	14.5	5285	—	4	207	Max Riggs
14			4N	60E	2aa	1949	5130	403	70.0	5060	—	3	207	Stewart
15	373614	115083701	4N	61E	16d	—	5094	—	84.0	5010	—	3, 4	207	Uhalde, John

* Not Used in Water Level

Data Source:
1 = USGS Nevada District Well Schedules
2 = Eakin (1963)
3 = U.S. Geological Survey Unpublished Data
4 = Bunch and Harrill, 1984

Data Collection and Compilation

Data from the USGS Water Resources Division's databases that included the most recent measurements available, were provided through the District along with well drillers reports, published reports, and maps. A literature search was conducted to identify and compile data from available published sources.

The locations and data sources were verified by comparing reported or entered data point locations and parameters with field observations and/or the published source of information. Spatial data sets (e.g., water levels, water chemistry, and water right locations), were plotted at uniform scales and annotated. The resulting maps were inspected for anomalous values and further verification was performed to resolve any anomalous data points.

Numerical Model Development

The model used to simulate the ground-water regime of Pahroc Valley is a computer code prepared by the USGS and referred to as MODFLOW (for "Modular Three-Dimensional Finite-Difference Ground-Water Flow Model"). The USGS has prepared comprehensive documentation for this code in one of their series of manuals on techniques of water-resources investigations (McDonald and Harbaugh, 1988). An overview of the code, a discussion of the general approach used in modelling, and the specifics of the model developed for the basin are detailed in the "Ground-Water Flow Model Development" section.

GENERAL HYDROGEOLOGIC FEATURES

The development of numerical simulations of the proposed District ground-water withdrawals in Pahroc Valley requires a thorough understanding of the hydrologic regime of the basin. The information that is available concerning the valley, and adjacent or similar areas, is used to develop a conceptual model of the source of water in the valley, its occurrence and flow in the subsurface, and the relationship between the valley and adjacent areas. In this section, the regional and valley-specific hydrologic conditions in Pahroc Valley are described and discussed.

REGIONAL AND BASIN HYDROGEOLOGIC FEATURES

Pahroc Valley is situated in the Alluvial Basins Ground-Water Region as defined by Heath (1984). Individual hydrographic basins in this region are characterized by alluvial basins that are underlain by bedrock, and are separated by the bedrock outcrops in the bounding mountain ranges, or, in some instances, by lower divides in alluvial terrain.

When ground-water flows from one basin to another, the basins are termed to be part of a flow system. The Pahroc Valley hydrographic basin is located in the Colorado River Flow System as defined by Harrill, et al (1988). This flow system comprises 35 individual hydrographic basins as shown in Figure 4; thus some part of the ground water under Pahroc Valley is believed to have originated as precipitation in upland areas more than a hundred miles to the north. This water, after being discharged from Pahroc Valley, ultimately reaches the Colorado River through a pathway combining ground-water, spring, and surface-water flows.

The general patterns of interbasin flow in the White River Flow System are shown in Figure 5. The overall component of regional ground-water flow is to the south. Within individual valleys in the flow system, recharge from the bounding mountain ranges results in a local flow component that generally coincides with the topography (i.e, from the mountains toward the axis of the valleys or toward playas with downward vertical hydraulic gradients).

Pahroc Valley receives an appreciable amount of subsurface underflow primarily through the rocks that occur at the southern end of White River Valley. This water flows under Pahroc Valley and discharges, through underflow, to Pahranagat Valley.

LITHOLOGIC AND HYDROLOGIC FEATURES

The hydrostratigraphic units present and their ability to store and transmit ground water are important considerations in developing both conceptual and numerical models of Pahroc Valley. The type, thickness and depth, and water-bearing properties of the geologic materials in the valley can be used to define the overall water resources potential. In this section, the geologic units present in Pahroc Valley and their hydraulic properties are described and discussed.

Hydrostratigraphy

The hydrostratigraphy of Pahroc Valley has been well defined. Based upon the work of Winograd and Thordarson (1975), and Ertec Western (1981), six consolidated rock hydrostratigraphic units in the valley comprising fourteen stratigraphic units were defined. These units, in descending order, include: 1) Muddy Creek Formation (aquitard); 2) Tertiary volcanic rocks (aquitard); 3) Bird Spring Formation, Monte Cristo Limestone, Sultan Limestone, Lone Mountain Dolomite, and Ely Springs Dolomite (all aquifers); 4) Eureka Quartzite (aquitard); 5) Pogonip Group and Middle and Upper Cambrian Limestone and Dolomite (aquifers); and 6) Chisolm and Pioche Shale, Prospect Mountain Quartzite, and Precambrian clastic rocks (all aquitards). For unconsolidated sediments, Eakin (1964) had previously identified two units that overlie this sequence, younger valley-fill and older valley-fill.

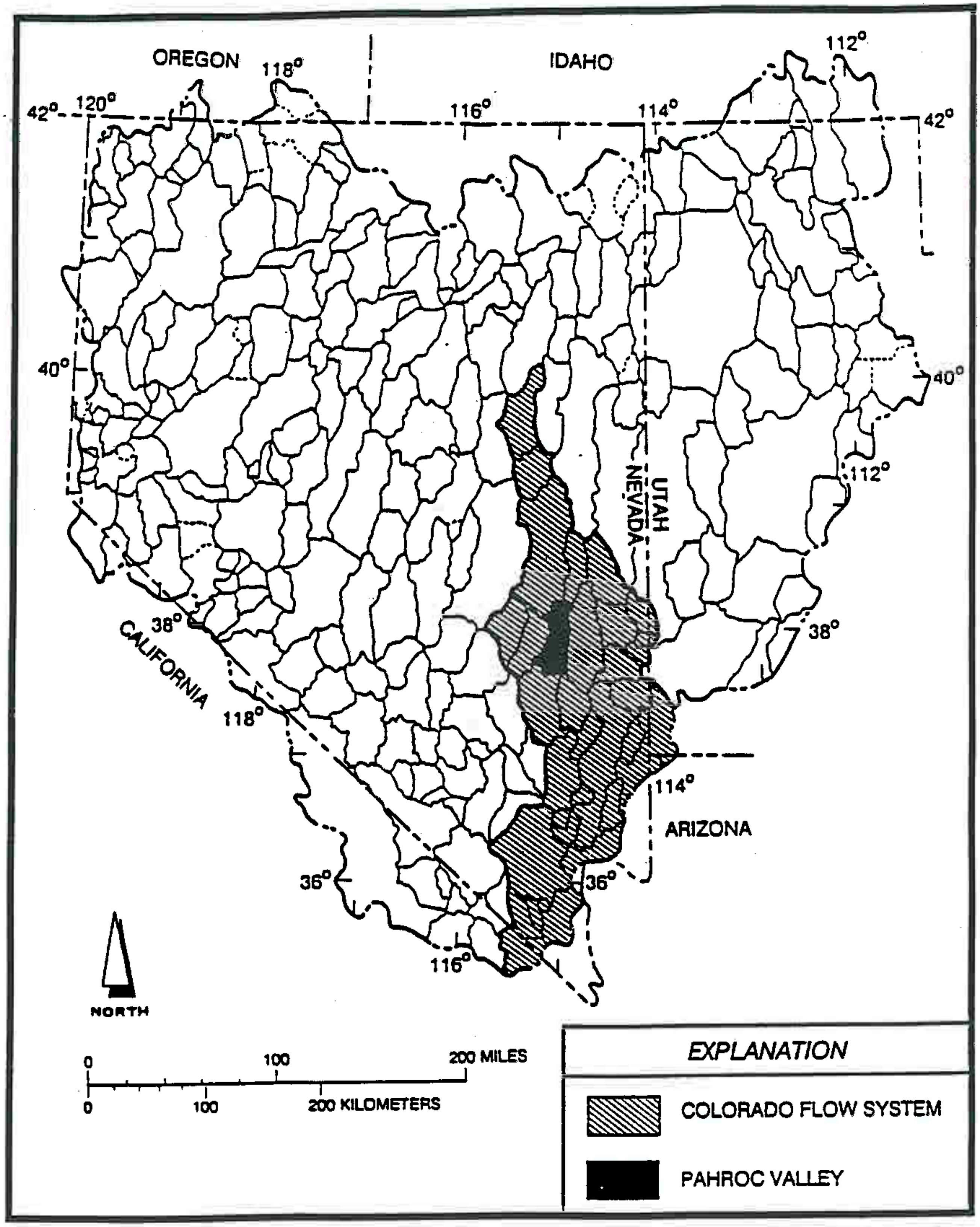


Figure 4.--Hydrographic basins in the Great Basin (adapted from Harrill, et.al. (1988).

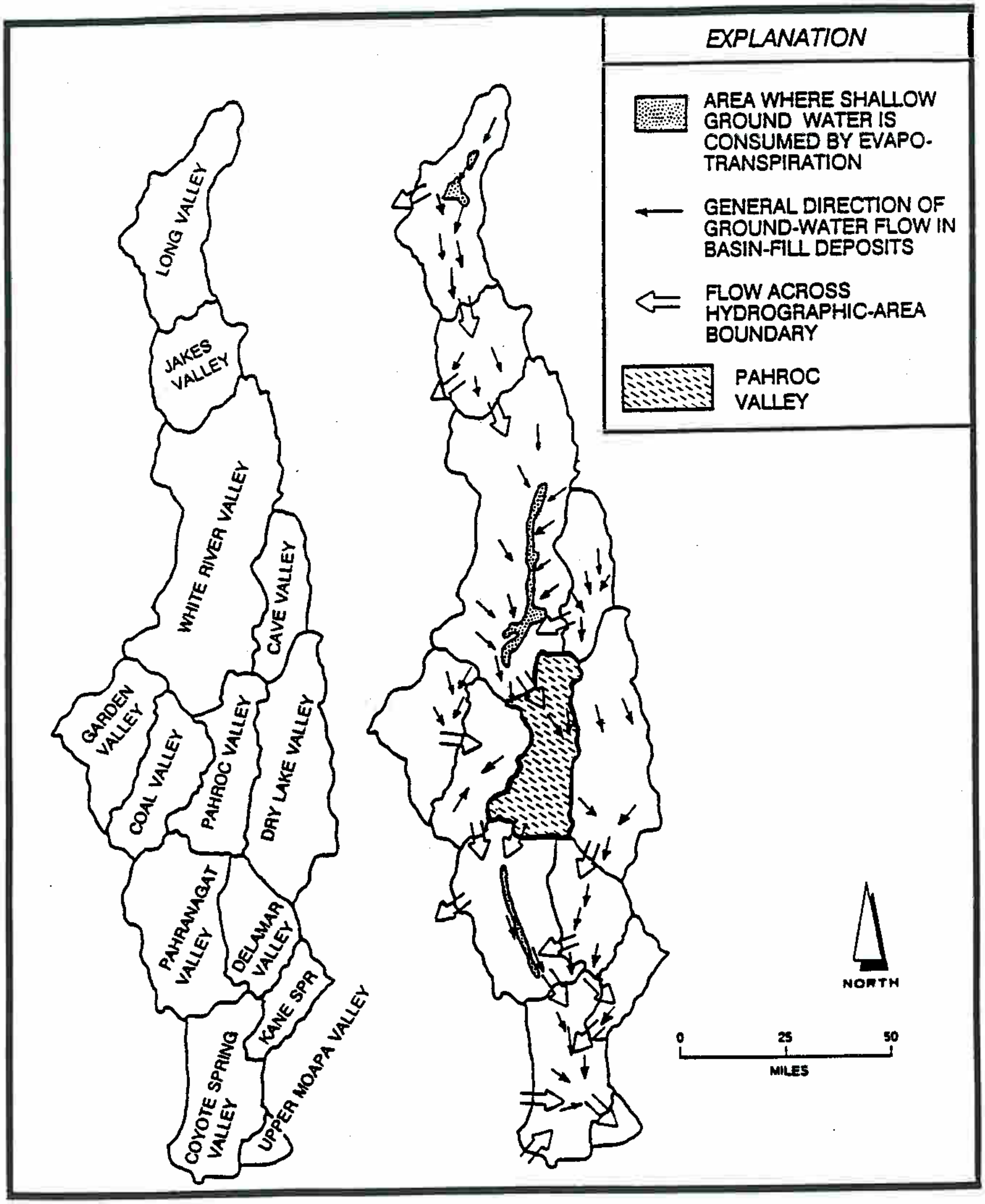


Figure 5.--General patterns of interbasin flow in the White River Flow System (adapted from Harrill, et.al (1988)).

Based upon these reports, a hydrostratigraphic column for Pahroc Valley was developed (Figure 6). This column includes the younger and older alluvium, and the six units identified above. Although a total of at least sixteen hydrostratigraphic units are known to be present, for the purpose of the conceptual model, only four distinct hydrostratigraphic units are defined. They consist of 1) the alluvial sediments (the younger and older valley-fill deposits); 2) the carbonate rocks of the Bird Spring Formation and other units above the Eureka Quartzite; 3) the Tertiary volcanics and 4) the Precambrian and Cambrian clastic aquitard. Figure 7 shows the distribution at the surface of each of the hydrostratigraphic units in Pahroc Valley.

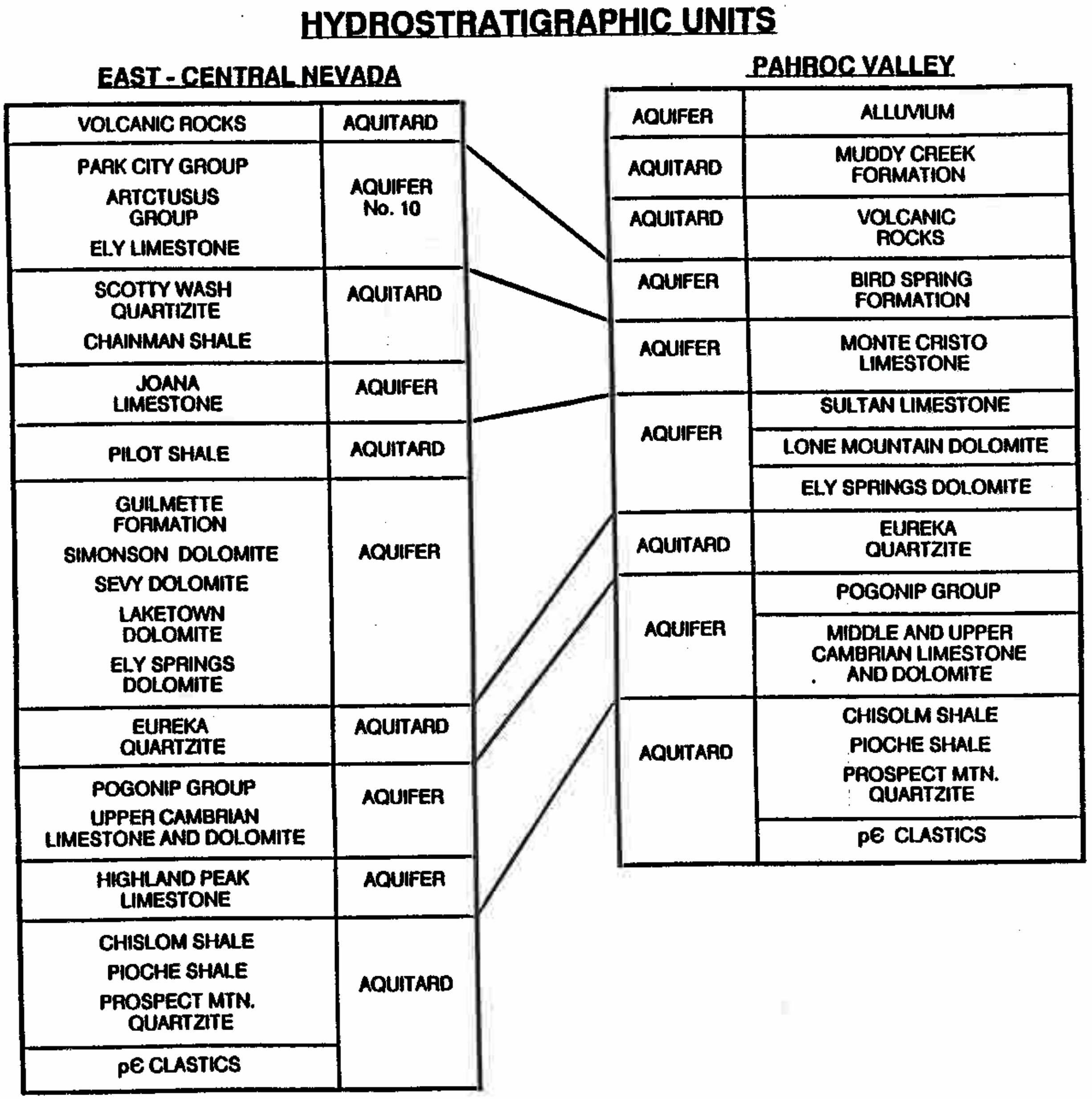
Cross-sections of the subsurface geologic conditions in Pahroc Valley were prepared at two scales to graphically exhibit the distribution of geologic units and structures. Regional cross-sections, illustrating the major features described in the discussion of structural features found later in this report, are shown in Figure 8; these regional cross-sections (A-A' and B-B') span the valley and provide a general indication of the subsurface conditions. Larger scale cross-sections were also prepared to illustrate the inferred geologic conditions in the immediate vicinity of the points of diversions listed on the District water right applications (see Figure 2). These localized cross-sections, are highly conceptualized, and are merely presented here to help the reader understand the geologic framework of the subject aquifer system.

Cross-section C-C' (Figure 9) runs south to north across very low-relief topography in the center of the valley. The elevation ranges from 4,920 feet where the White River crosses the southern part of the cross-section, to 5,500 feet in the middle of the cross-section. White River cuts across the cross-section at two locations.

Along the cross-section, only alluvium is exposed to the surface, though to the west, the Paleozoic carbonates are at the surface. The thickness of the alluvium along the section ranges from 100 to possibly as much as 1,000 feet, with a typical range of 200-400 feet. Buried beneath these Tertiary and Quaternary sands and gravels are small, isolated pockets of Cretaceous-Tertiary volcanics. The great bulk of the bedrock is comprised of Devonian- to Mississippian-aged carbonates. This sequence, which may be thousands of feet thick, is underlain by pre-Cambrian and Cambrian clastics.

The District has applied to drill four water wells near cross-section C-C'. Applications No. 54043 and 54044 are 1 and 2 miles east, respectively, of the line of section, and both will be completed in the alluvium. Applications No. 54045 and 54048 are both within one mile east of the cross-section, and the associated wells are expected to produce from the Paleozoic carbonate aquifer.

Cross-section D-D' (Figure 10) runs west to east from the Seaman Range, across Pahroc Valley, and into the northern extension of the North Pahroc Range. The elevation across the cross-section ranges from 7,380 feet at the apex of the Seaman Range to 4,890 feet along the channel of the White River in the center of the valley.



HYDROSTRATIGRAPHIC UNITS

EAST - CENTRAL NEVADA

VOLCANIC ROCKS	AQUITARD
PARK CITY GROUP ARTCTUSUS GROUP ELY LIMESTONE	AQUIFER No. 10
SCOTTY WASH QUARTIZITE CHAINMAN SHALE	AQUITARD
JOANA LIMESTONE	AQUIFER
PILOT SHALE	AQUITARD
GUILMETTE FORMATION SIMONSON DOLOMITE SEVY DOLOMITE LAKETOWN DOLOMITE ELY SPRINGS DOLOMITE	AQUIFER
EUREKA QUARTZITE	AQUITARD
POGONIP GROUP UPPER CAMBRIAN LIMESTONE AND DOLOMITE	AQUIFER
HIGHLAND PEAK LIMESTONE	AQUIFER
CHISLOM SHALE PIOCHE SHALE PROSPECT MTN. QUARTZITE	AQUITARD
pЄ CLASTICS	

PAHROC VALLEY

AQUIFER	ALLUVIUM
AQUITARD	MUDDY CREEK FORMATION
AQUITARD	VOLCANIC ROCKS
AQUIFER	BIRD SPRING FORMATION
AQUIFER	MONTE CRISTO LIMESTONE
AQUIFER	SULTAN LIMESTONE
	LONE MOUNTAIN DOLOMITE
	ELY SPRINGS DOLOMITE
AQUITARD	EUREKA QUARTZITE
AQUIFER	POGONIP GROUP
	MIDDLE AND UPPER CAMBRIAN LIMESTONE AND DOLOMITE
AQUITARD	CHISOLM SHALE PIOCHE SHALE PROSPECT MTN. QUARTZITE
	pЄ CLASTICS

Figure 6. Relationship between hydrostratigraphic units and lithostratigraphic units (adapted from Ertec Western, 1981).

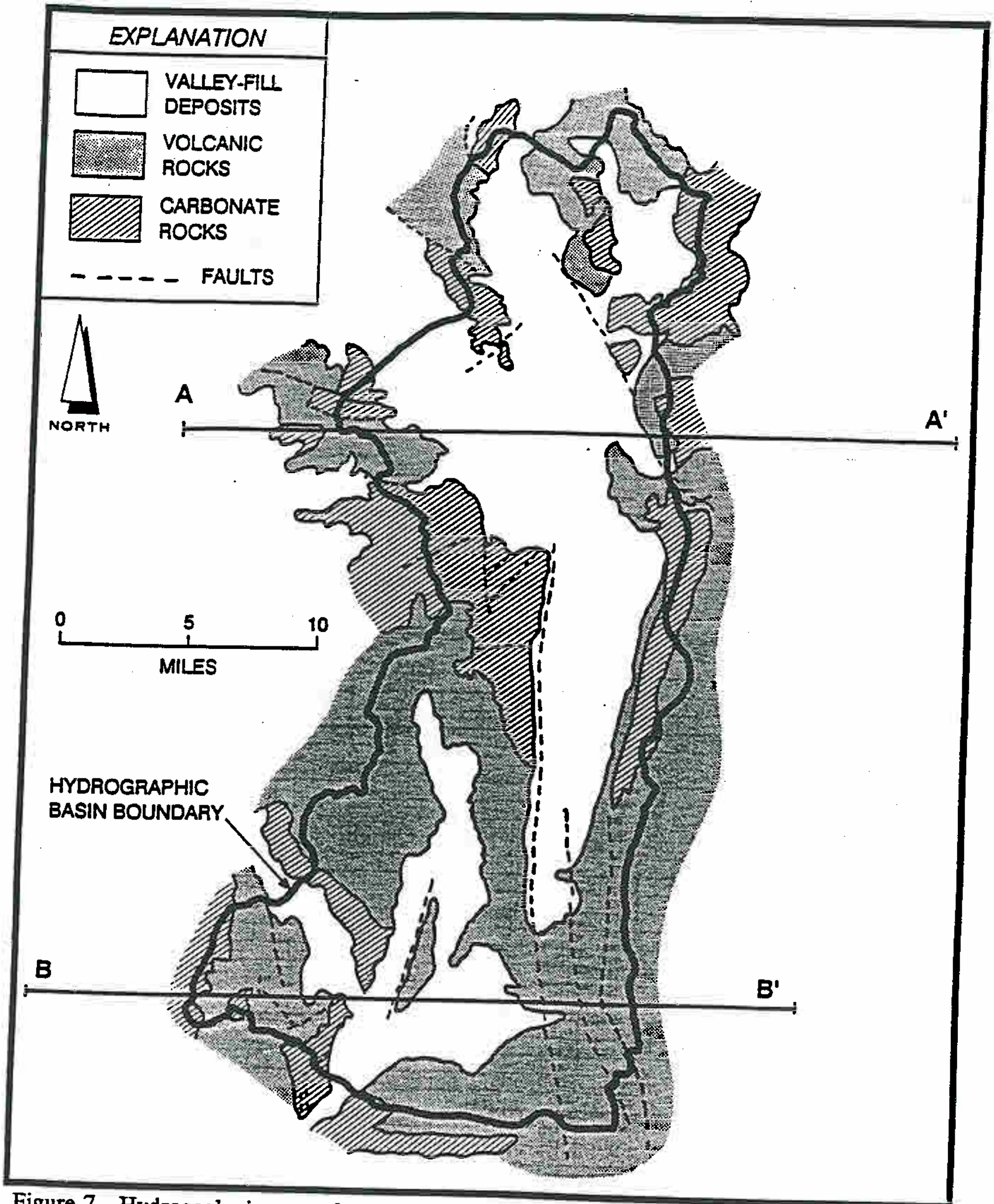


Figure 7.--Hydrogeologic map of Pahroc Valley (adapted from Tschanz and Pampeyan (1970) and Kleinhampl and Ziony (1984)).

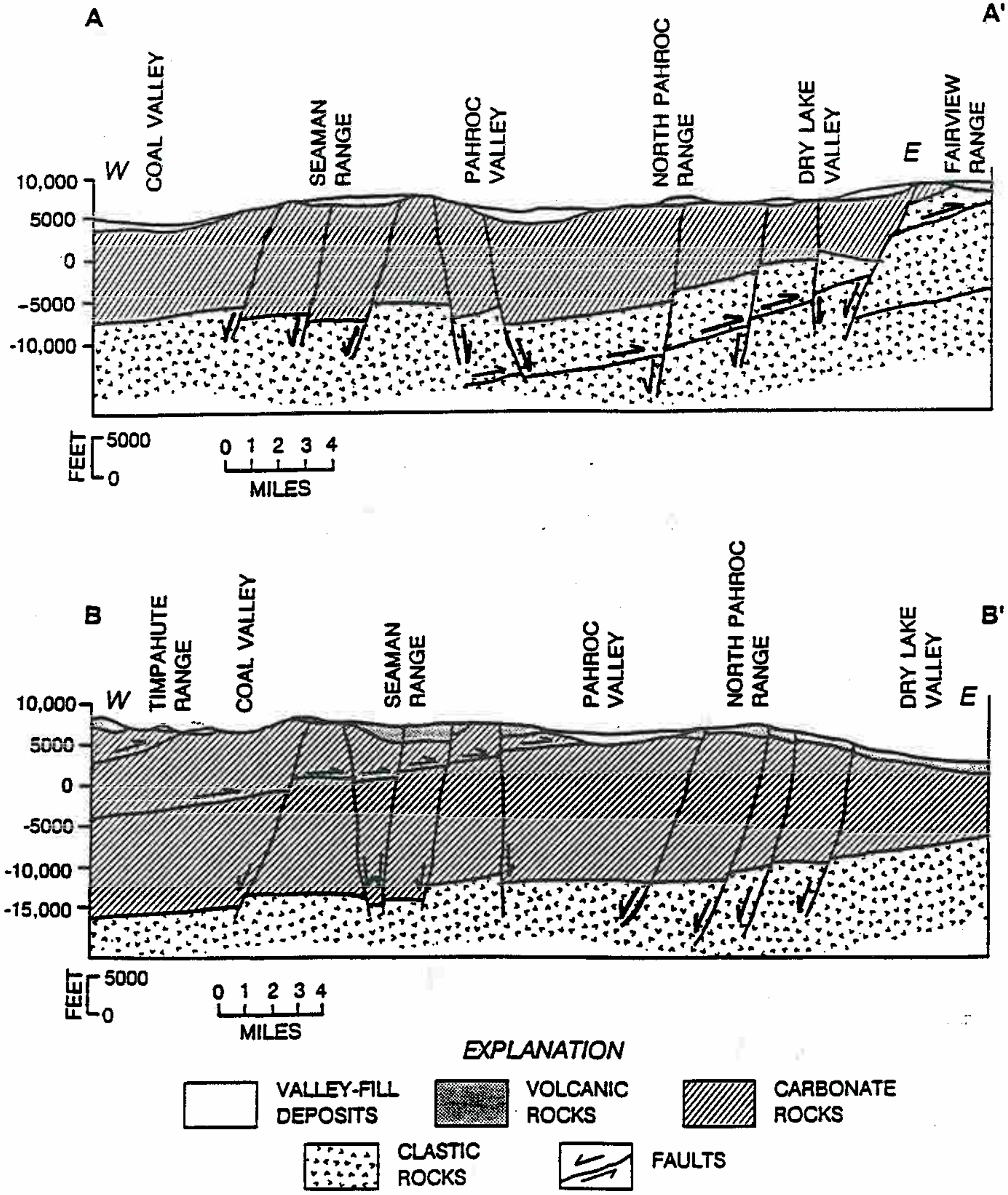


Figure 8.--Regional cross-sections through Pahroc Valley (adapted from Tschanz and Pampeyan (1970).

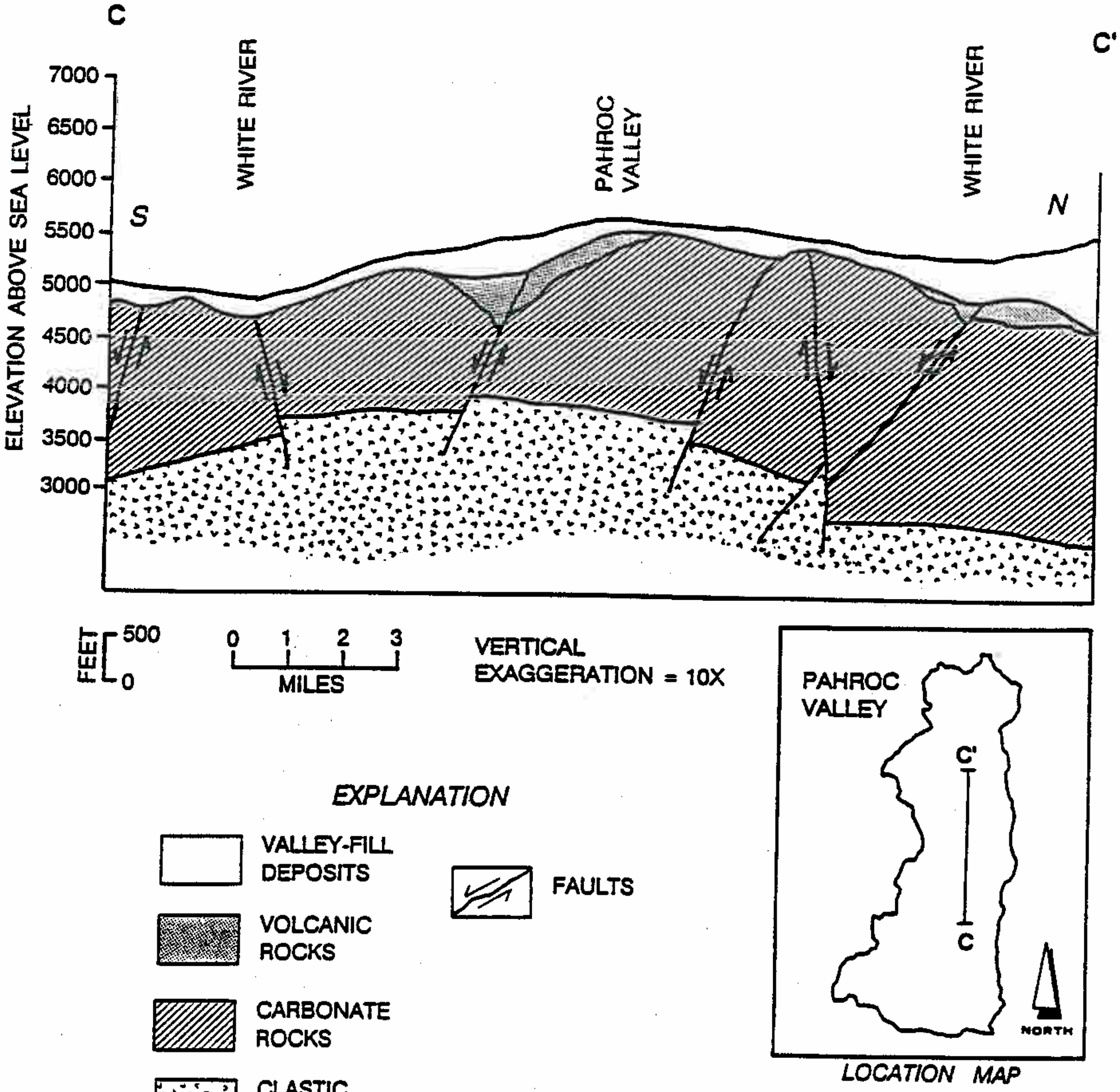


Figure 9.--Conceptual hydrogeologic cross-section C-C' through the proposed District well field.

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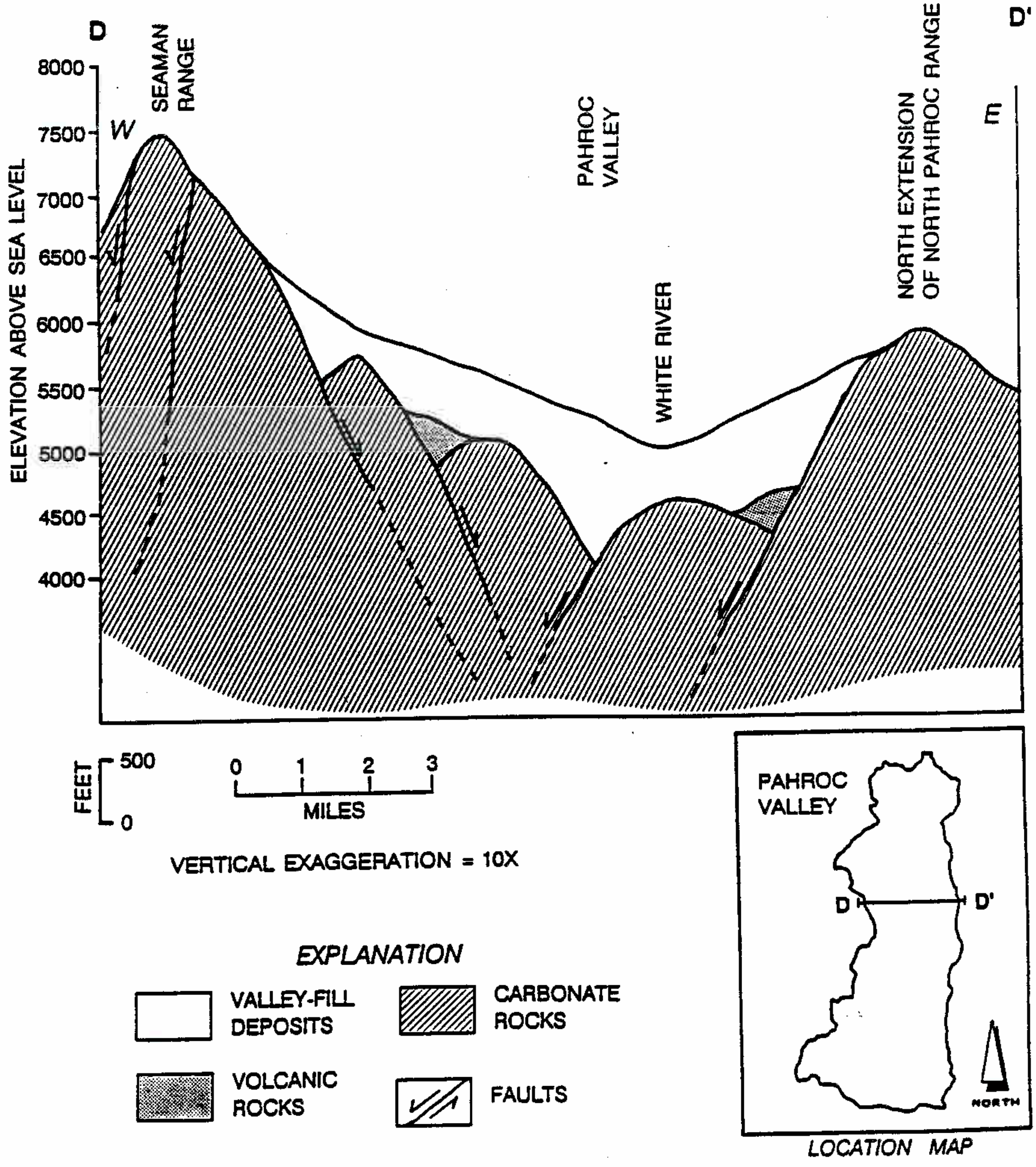


Figure 10.--Conceptual hydrogeologic cross-section D-D' through the proposed District well field.

On the west end of the cross-section, block-faulted Paleozoic carbonates of Devonian- and Mississippian-age are well-exposed in the Seaman Range. On the east end of the cross-section, Pennsylvania and Permian carbonates crop out in the North Pahroc Range. Between these two mountain ranges lies a broad, alluvium-filled valley. Small, isolated pockets of Cretaceous- to Tertiary-aged volcanics may be located along the block fault planes.

The alluvium in Pahroc Valley is Tertiary and Quaternary unconsolidated erosional debris from the surrounding Paleozoics carbonates and Cretaceous-Tertiary volcanics. This alluvium, mostly sand and gravel, is typically unsaturated near the surface below the White River channel.

The District has applied to drill three water wells in the vicinity of Cross-section D-D'. Applications No. 54043 and 54044 are each 2 miles north and south, respectively, of the section, and both wells will be completed in the alluvium. The well associated with District application No. 54048 will be completed in the carbonate aquifer, and is located about one mile south of the cross-section.

Cross-section E-E' (Figure 11) runs from the southwest to the northeast, across the southern end of Pahroc Basin. The section begins near the top of Fossil Ridge, just outside the hydrographic boundary, and bears northeast across Pahroc Valley into the Pahroc Range. The elevation across the section ranges from 6,560 feet at the crest of the Pahroc Range to 4,360 feet where White River has cut a channel through Pahroc Valley.

Fossil Ridge is composed of Ordovician- to Devonian-aged block-faulted carbonate strata and is a contrast to the Pahroc Range, which is comprised of block-faulted Tertiary volcanics. However, not far beneath these volcanics are Devonian- to Permian-aged carbonates, similarly disrupted.

The alluvial valley in the area of the cross-section is small by Nevada standards, and is made of erosional debris carried downslope from nearby carbonate and volcanic mountains. It is probably no deeper than 500 feet in most places, and is typified by sand, gravel, and boulders. Depth to the water table in the valley-fill is about 300 feet, leaving little saturated alluvium. However, the carbonate aquifer underlies the alluvium and small isolated pockets of Tertiary volcanic masses.

The District has applied to drill three water wells in the vicinity of Cross-section E-E'. Application No. 54046 is two miles northwest of the cross-section, while Application No. 54049, which is nearby, is on the line of the section. Application No. 54047 is on the line of section. All three wells associated with these applications will drill through valley-fill and probably Tertiary volcanics before reaching total depth in the carbonate aquifer.

Table 2 presents the available data on the hydraulic characteristics of rocks and unconsolidated sediments that are present. These parameters, and other features, are discussed for each modelled hydrostratigraphic unit in the following sections.

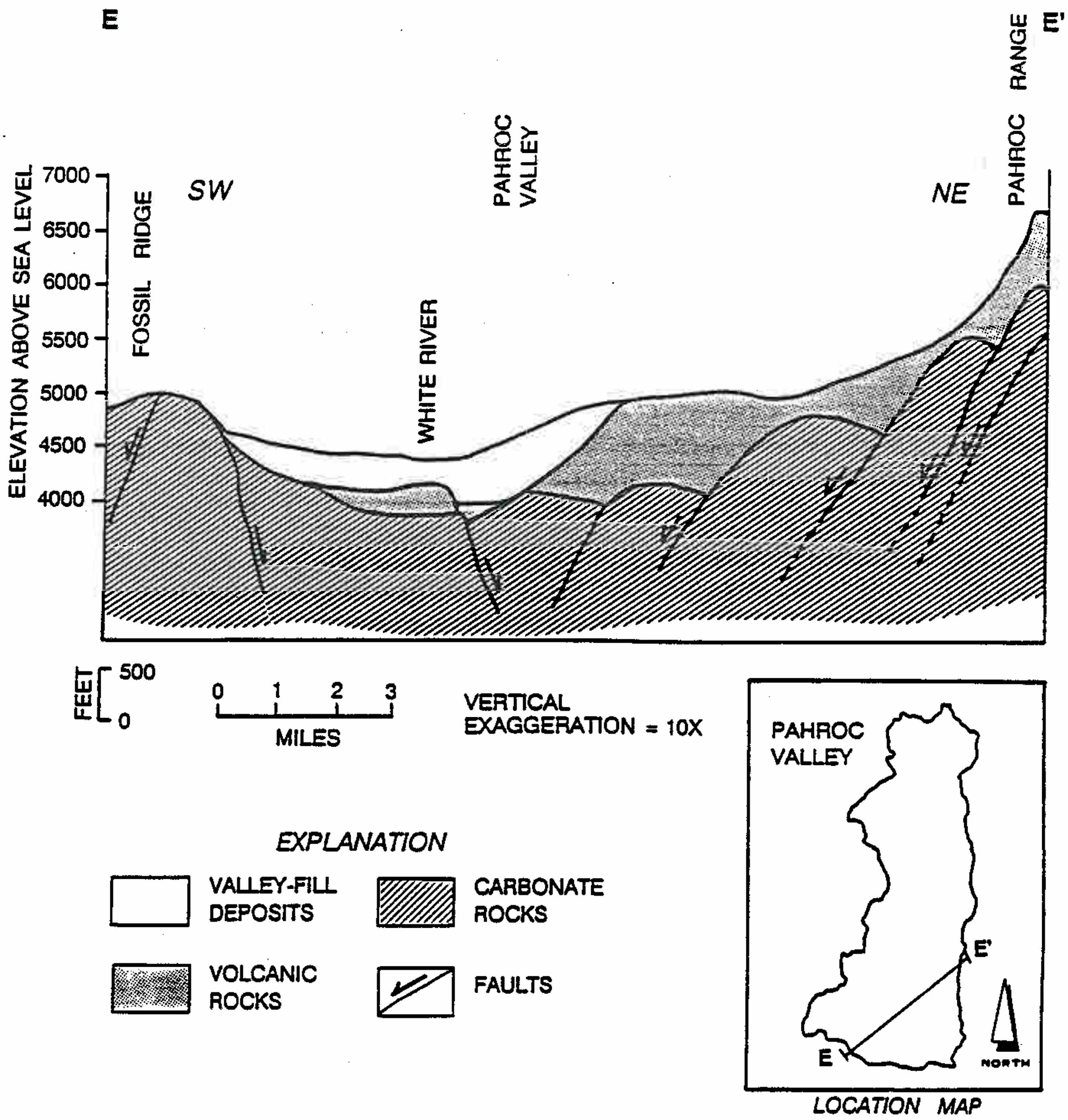


Figure 11.--Conceptual hydrogeologic cross-section E-E' through the proposed District well field.

Table 2.--Summary of transmissivity and hydraulic conductivity values in southern Nevada.

Transmissivity (ft^2/day)

Aquifer	Minimum	Maximum	Median	Number of Samples	Reference
Valley Fill	321	4,478	1,470	7	Winograd and Thordarson (1975)
	25,920	259,200	-	2	Burbey and Prudic (1985)
Tuff/Volcanic	6.7	9,090	281	5	Winograd and Thordarson (1975)
	259	-	-	1	Burbey and Prudic (1985)
Carbonate	174	11,496	1,470	11	Winograd and Thordarson (1975)
	11	250,000	2,100	31	Unpublished USGS Data
	86	43,200	4,320	5	Burbey and Prudic (1985)

Hydraulic Conductivity (ft/day)

Aquifer	Minimum	Maximum	Median	Number of Samples	Reference
Valley Fill	0.02	140	74[a]	7	Plume and Carlton (1988)
Carbonate	0.01	940	5.40	38	Unpublished USGS Data
	0.02	1.53	0.18	8	Winograd and Thordarson (1975)
Clastic	0.006	0.10	0.02	4	Unpublished USGS Data

[a] Average value for 18 tests in 14 basins

Valley-Fill Deposits

The valley-fill aquifer is composed of alluvial-fan, fluvial, fanglomerate, lake-bed, and mudflow deposits of Quaternary (Younger Alluvium) and Tertiary (Older Alluvium) age. The Older Alluvium is typically more consolidated than the Younger Alluvium, is more highly cemented, and, where saturated, exhibits lower hydraulic properties.

The grain size of these deposits decreases with distance from the source, and away from distributary channels on alluvial fans. Interbedding of fine and coarse-grained materials is common in the valley-fill deposits, which range from gravels and sand, in alluvial fans, to clay-sized material, in mudflows and playa deposits. Caliche deposits, which may impede the downward infiltration of water in the soil zone, may also be common in the valley-fill.

The younger and older alluvium are present throughout the valley floor in Pahroc Valley. Tschanze and Pampeyan (1970) indicate that Older Alluvium crops out along the center of the basin, with very minor amounts of the Older Alluvium being exposed only along the White River channel. Based upon the available information, the older alluvium is presumed to be similar, hydraulically, to the valley-fill sediments and, for the purposes of modelling, the older and younger valley-fill may be considered as one hydrostratigraphic unit. Eakin (1963) estimate the thickness of the valley fill to probably be "at least several hundred feet thick" or "exceed a thousand feet.

The flow of ground water through the valley-fill aquifer occurs primarily through the interstitial porosity. However, flow is controlled by the variations in the relative permeabilities of the interbedded materials. The fine-grained deposits of the Muddy Creek Formation and similar alluvial materials, although not tested in Pahroc Valley, can be expected to exhibit permeabilities several orders of magnitude smaller than sand and gravel. The interbedding of fine grained and coarse-grained sediments in the valley-fill deposits results in horizontal permeabilities that are considerably greater than vertical permeabilities.

On a regional basis, the transmissivity (a measure of the ability of an aquifer to transmit ground water) of the valley-fill ranges from about 321 to about 259,200 ft^2/day according to Burbey and Prudic (1985) and Winograd and Thordarson (1975). The transmissivity of the alluvium in a given valley or hydrologic setting is a function of both the permeability and the saturated thickness of the aquifer. Low values of transmissivity (less than 670 ft^2/day) generally indicate fair to poor well yield potential while high transmissivity wells (greater than 6,700 ft^2/day) may be capable of producing wells yields in the hundreds or even thousands of gallons per minute.

As with most of the undeveloped basins in Nye and Lincoln Counties, and elsewhere in Nevada, data on the transmissivity of the valley-fill aquifer in Pahroc Valley is not available. No tests have been conducted in Pahroc Valley. Ertec Western Inc. (1981) reported a transmissivity of only 120 ft^2/day for the valley-fill aquifer at (12S/63E-29db1) based upon an aquifer test at Air Force well CV-VF-1 in Coyote Spring Valley. In neighboring Dry Lake Valley aquifer tests in the alluvium yielded transmissivity values ranging from 15 ft ^{2}/day to 5,600 ft ^{2}/day (Bunch and Harrill, 1984).

Regionally, the hydraulic gradient (slope of the surface of the ground water) in the valley-fill aquifer is often less than 60 ft/mi, and is usually less than 30 ft/mi (Winograd and Thordarson, 1975). Because of the distribution of wells in Pahroc Valley, the calculation of gradients must be based upon widely separated wells and the inferred water surface between the wells. Based upon water level measurements taken at wells in and around Pahroc Valley, the gradient is about 35 ft/mi.

Consolidated Rock

The carbonate aquifer consists of thick sequences of Paleozoic limestones and dolomites. This unit comprises the numerous individual rock units that were previously discussed, and has an overall thickness of several thousand feet. Flow through the carbonate aquifer is believed to occur primarily through fractures, and is likely to be concentrated in areas of greater fracture frequency. Except in areas of structural or stratigraphic anomalies, the hydraulic gradient in this aquifer is likely to be low because of high transmissivity.

The movement of ground water across the contact between the valley-fill aquifer and the carbonate aquifer depends on the potentiometric heads (elevation of the water table or piezometric surface) in each aquifer. In areas where the head is higher in the valley-fill, the ground water is semi-perched and moves principally downward into the underlying carbonate, serving to recharge the regional carbonate aquifer. Where the head in the carbonate aquifer is higher than the valley-fill, ground water in the overlying alluvial material is derived through upward leakage of water from the carbonate rocks.

The carbonate aquifer underlies the alluvial deposits under most of Pahroc Valley. This aquifer, because the Chainman Shale and the Pilot Shale are almost totally absent in the central and southern portions of the valley, comprises three of the aquifers identified by Winograd and Thordarson (1975). In most of Pahroc Valley, these units form a continuous vertical sequence and, for the purposes of modelling, can be considered as a single hydrostratigraphic unit.

In the nearby valleys, the transmissivity of the carbonate aquifer has been found to range from 11 to 250,000 ft^2/day (Winograd and Thordarson (1975); Burbey and Prudic (1985); and unpublished USGS data), with values as high as several hundred thousand ft^2/day possible in fractured areas (Winograd, 1963; Winograd and Thordarson, 1975). Variations in structural setting, proximity to faults, mechanical rock properties, depositional environment, and aquifer thickness are the chief parameters that account for the large variations in the transmissivity of carbonates.

In general, it is inferred that the transmissivity of the carbonate aquifer in Pahroc Valley is variable with the highest transmissivities occurring in the vicinity of major structural elements such as north-south trending normal faults typical of the Great Basin. In these areas, dissolution of the carbonates results in high secondary porosities and very high transmissivities. In the relatively undisturbed areas between such structural features the transmissivities are probably appreciably lower because of the inferred lesser degree of development of secondary porosity.

The Tertiary volcanic rocks that crop out in the southern part of Pahroc Valley are believed to represent a partial hydraulic barrier between Pahranagat Valley and Pahroc Valley. These rocks consist of tuffs and other volcanoclastic rocks that generally form aquitards. Other Tertiary volcanic rocks, exposed further north in Pahroc Valley may be of consequence in the development of the ground-water flow model even though they are not widespread.

The clastic aquitard is composed of Precambrian and Cambrian siltstones, quartzites, shales and sandstones. Ground-water potentials are likely to be greatly affected by this unit because of the low transmissivity. In fact, recharge and discharge areas are often determined by the location and orientation of this unit. Ground water will tend to flow along the dip of this barrier rather than through it. The aggregate thickness of this unit is approximately 10,000 feet; however, local thickness varies with structure. With respect to ground water in Pahroc Valley, the clastic aquitard is of little significance because it is believed to occur at depths well below those considered economic for ground-water development.

The transmissivity of the clastic aquitard is low, estimated at approximately 135 ft^2/day or less, by Winograd and Thordarson, (1975). No tests of this unit have been conducted in Pahroc Valley.

Structural Features

Structures within Pahroc Valley are consistent with features typical of the Basin and Range Province (i.e., horst and graben structures oriented along north and northeast-trending normal faults). The Basin and Range is dominated by north-south trending fault scarps and lineaments that cut through the alluvium (Tschanz and Pampeyan, 1970). Several periods of regional tectonism have faulted, fractured, and displaced both bedrock and valley-fill materials. Compared to much of the region, Pahroc is tectonically intact, except for long north-south normal faults. The depths to the underlying clastic aquitard is unknown, as is the contact relationship between the clastic and carbonate sequences.

The most significant structural feature of Pahroc Valley from a hydrological aspect, besides the extensive block faulting, is a large Cretaceous-Tertiary volcanic cone which forms the core of the Seaman Range. This circular cone, which is partially obscured by younger volcanics and alluvium, appears to be about 6 miles in diameter at the surface. It is unbroken by faults, possibly enlarges at depth, and may be deep-rooted. Under these circumstances it would be a very effective hydrogeological barrier between Pahroc Valley and Coal Valley. This cone is unnamed, but is labelled on Figure 2. Other geologic features of lesser importance and which are volcanic in origin are Burnt Peak (a small cinder cone) and many widespread Tertiary flows of unknown proportions.

WATER RESOURCES APPRAISAL

To develop a steady-state ground-water flow model that is representative of Pahroc Valley's hydrologic system, it is necessary to define the magnitude of the water resources available in the basin and the basin's development history. Knowledge of the location and magnitude of planned future development need are necessary when using the regional transient model for predictive purposes. The following sections present the available information on the surface and ground-water resources of the valley.

SURFACE WATER

An accurate simulation of a hydrogeologic system requires an understanding of the surface water conditions and the significance of surface water in the overall water budget for a given hydrographic basin. This section describes the general conditions of the surface water regime of Pahroc Valley.

General Conditions

Surface water resources are meager in Pahroc Valley and limited to two main streams: White River, sometimes referred to as Pahranagat Wash; and Seaman Wash (Figure 2). Surface-water flow into Pahroc Valley occurs infrequently along White River, which drains White River Valley to the northwest and enters Pahroc Valley between Gap Mountain and the northern end of Seaman Range. Seaman Wash originates in the southern part of Seaman Range. The confluence of the two washes is located in the south-central part of Pahroc Valley.

Flow in the washes is ephemeral, occurring in response to the infrequent precipitation over the contributing hydrographic basins. No surface water measurements or estimates are available for either White River or Seaman Wash in Pahroc Valley. Scott, et al. (1971) give the quantity of this flow as "significant" but unknown. The infrequent inflows of surface water inflow into the valley are believed to be insignificant when compared to other components of the water budget for the valley. Surface water inflow may therefore be considered to be zero in the flow model of the valley.

Available Records

Primarily because there are no perennial surface water bodies in the valley, there are no available records on surface water flow.

Runoff

The quantity of runoff from the mountains bounding Pahroc Valley is not known, but Scott, et al. (1971) estimated the combined amount of runoff for Pahroc and Pahranagat valleys to be 1,800 acre-feet per year. Heavy runoff events may result in short-duration flows along reaches of Pahranagat Wash in the center of the valley; however, most runoff infiltrates along the upper portions of the alluvial fans, directly into open fractures in the consolidated rock areas, or into the coarse streambed deposits of the channels that drain the area. Much of this water also is transpired by vegetation or simply evaporates. Scott, et al. (1971) did not include runoff as a separate term in the water budget for Pahroc Valley, therefore, it need not be directly included in a ground-water model of the basin; however, that portion of the precipitation over the basin that does not runoff, but infiltrates through the unsaturated zone to recharge the aquifers, must be accounted for in the model. Since the quantity of recharge represents the total precipitation minus the runoff and losses to evaporation, soil moisture in the unsaturated zone, and consumption by plants, each of these factors is indirectly accounted for in the recharge estimate.

GROUND WATER

It is necessary to understand the conditions and characteristics of the ground water in Pahroc Valley to develop an accurate numerical simulation. This section discusses the ground water occurrence, source, movement, chemical quality, and budget for Pahroc Valley.

Occurrence

Ground water occurs at depths ranging from about 90 feet below land surface in well No. 2 in the vicinity of the northwestern end of Pahranagat Wash, to 364 feet below land surface at well No. 7 located near the southern end of the White River channel (see Table 1 and Figure 3). Because of a lack of data, however, the depth to the water table is not known for a very large portion of Pahroc Valley.

Figure 12 shows the regional potentiometric surfaces for Pahroc Valley based upon the water level data for the valley and vicinity, and an evaluation of potentiometric data for the entire Colorado River Flow System. As shown, the elevation of the water table ranges from about 5,100 feet AMSL, in northernmost part of the valley, to less than 3,900 feet AMSL at the south end of the valley where the ground-water discharges into Pahranagat Valley. All data used to define this potentiometric surface is believed to be from the alluvial aquifer.

No hydrographs (graphs showing the elevation of the water in a well at various points in time) were developed for wells in Pahroc Valley, due to the lack of temporal water level data. Temporal records of water levels for the wells in the basin are limited to 2 measurements at well No 4 (see Table 1 and Figure 3). The first measurement made in May 1963, is reported to be 4,704.2 feet (Eakin, 1963). The second measurement is reported to be 4,706.4 in March 1985 (Nevada District Well Schedules). Based on these two records, water levels in the vicinity of well No. 4 have remained stable over the 22-year period between 1963 and 1985. The 2-feet increase in the water level in the well is most probably due to seasonal variations and/or measurement errors. Considering the available data and the low level of development of the valley, it is reasonable to assume that the water levels in Pahroc have remained stable throughout the valley.

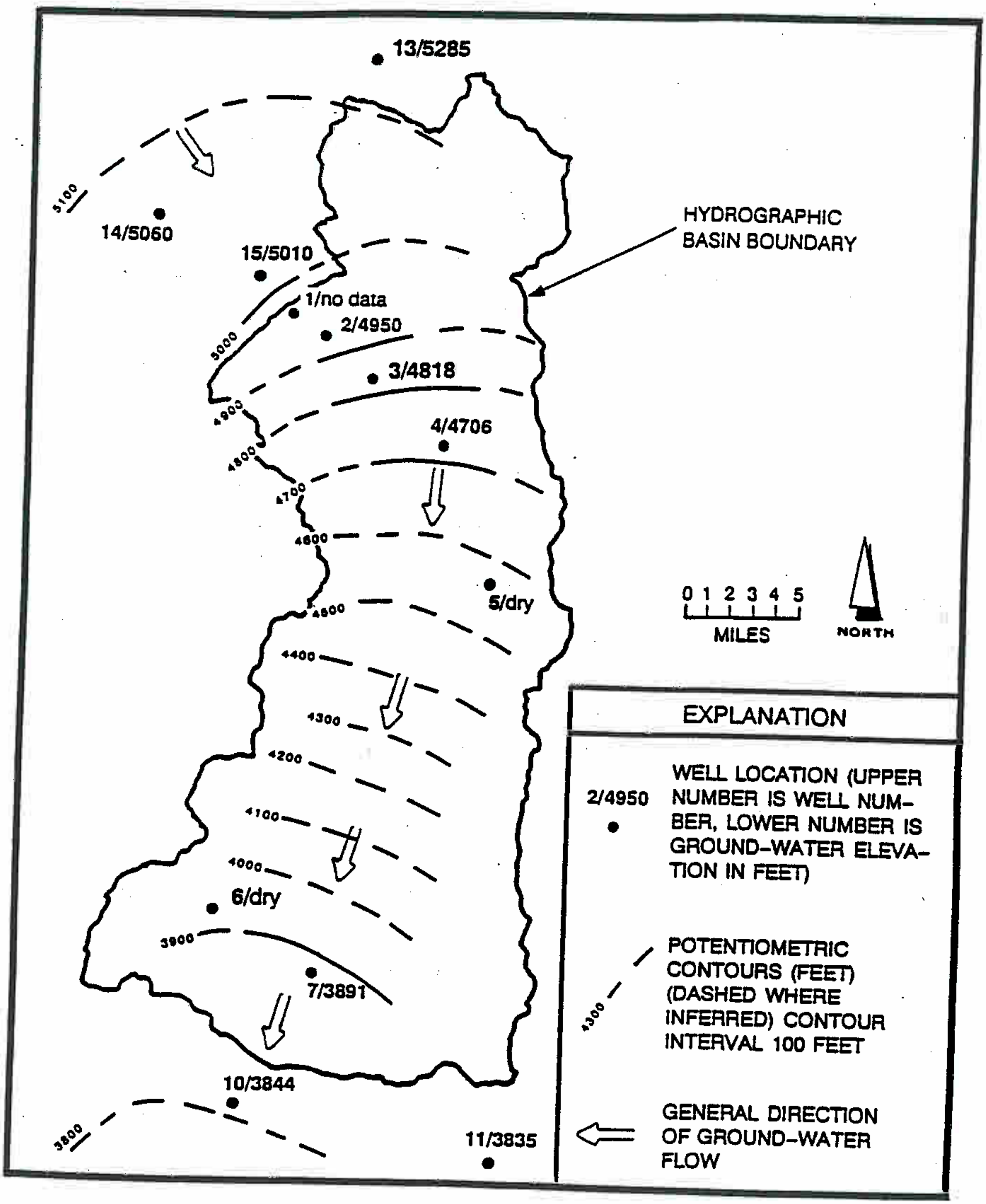


Figure 12.--Potentiometric surface for the alluvial aquifer of Pahroc Valley.

No head elevation data are available for the carbonate aquifer in Pahroc valley. The closest carbonate well is in Dry Lake Valley, very near the northeastern boundary of Pahroc Valley (Figure 8). The head elevation at this well is 4,540 feet (Bunch and Harrill, 1984)

Source

The source of ground water within Pahroc Valley is partly recharge from precipitation on the basin, but is mostly subsurface inflow of ground water from adjacent valleys (mainly White River Valley). Both of these sources must be accounted for in developing a flow model of the basin. A minor amount of subsurface inflow occurs at the boundary of Cave Valley, and possibly at other adjoining basins. These quantities of ground water are unknown, but are believed to be insignificant relative to other components of the water budget for the basin and, therefore, do not need to be included as discrete parameters in developing the model.

Movement

In general, ground water in the axial part of Pahroc Valley flows south from the area of White River Valley toward the discharge area of Pahranagat Valley. The hydraulic gradient in the alluvial aquifer remains relatively constant along the axis of the valley. The hydraulic gradient is about 35 feet per mile between well No. 2 in northern Pahroc Valley, and well No. 4 near the central part of the valley. It averages about 36 feet per mile from well No. 4 to well No. 7 in the southern part of the valley (see Figure 3). The hydraulic gradient in the alluvial aquifer may locally be steeper in the southern end of the basin in the areas where lower-transmissivity volcanic rocks lie across the ground-water flow path. The hydraulic gradient in the carbonate aquifer is expected to be generally similar to that of the alluvial aquifer because the potentiometric heads distribution is similar to that of the alluvial aquifer.

Chemical Water Quality

The chemical quality of the ground water in Nevada depends on its location. The chemical concentration in recharge areas is normally very low; however, the ground water comes into contact with soluble rock materials for long periods of time as it moves towards discharge areas where the chemical concentration is higher. The solubility, volume, distribution of rock materials, time of water contact with the rocks, temperature, and pressure in the ground-water system are factors that determine the extent to which the chemical constituents from the rock materials will be dissolved.

No chemical water quality data were available for Pahroc Valley. However, to provide a possible range of values for the water quality variables of interest, data from wells located near Pahroc Valley in adjacent valleys were selected and summarized in tabular form in Appendix B. The National Drinking Water Standards are presented in Appendix C. The chemical data in the vicinity of Pahroc Valley have been examined with reference to these standards, and it has been determined that the quality of the water falls well above the minimum standard. All concentrations reported by the USGS (unpublished data) and Bunch and Harrill (1984) for these three wells and seven springs shown on Figure 13 are below the maximum tolerable limits. The specific conductance and temperature of the water at selected locations in the vicinity of Pahroc are presented in Figure 13.

Budget

A ground-water budget consists of a complete accounting of all components of inflow and outflow for a hydrographic basin. The results of any model developed to simulate flow in a basin are dependent upon the accuracy of the budget. Table 3 summarizes the water budget for Pahroc Valley. The following sections present the current estimates for recharge and discharge for Pahroc Valley.

Estimated Average Annual Recharge

Recharge to a basin usually consists of several components: precipitation, subsurface inflow, and secondary recharge. Estimates for these elements for Pahroc Valley are provided in the following sections.

Precipitation

One source of recharge to the hydrologic system of Pahroc Valley is the infiltration of precipitation over the basin. No meteorological stations are located in Pahroc Valley and the characterization of precipitation over the area is inferred from recording stations located in adjacent valleys. The total precipitation over Pahroc Valley is 190,000 acre-feet per year (Scott, et al., 1971). The volume of recharge derived from precipitation is reported by these same authors to be 2,200 acre-feet per year, or about 1 percent of the precipitation. Harrill, et al. (1988) reported the recharge from precipitation in Pahroc Valley to be about also 2,200 acre-feet per year. Kirk and Campana (1988) used a recharge value of 2,000 acre-feet/year in their ground-water flow model.

The infiltration of precipitation does not occur evenly over a large area. Rather, as determined by Maxey and Eakin (1949) and Quiring (1965), the distribution of precipitation, and hence, infiltration and recharge, in the desert valleys of Nevada, is primarily a function of elevation and latitude.

Thus, for the purposes of developing a ground-water flow model of Pahroc Valley, recharge is distributed according to the zones summarized in Table 4.

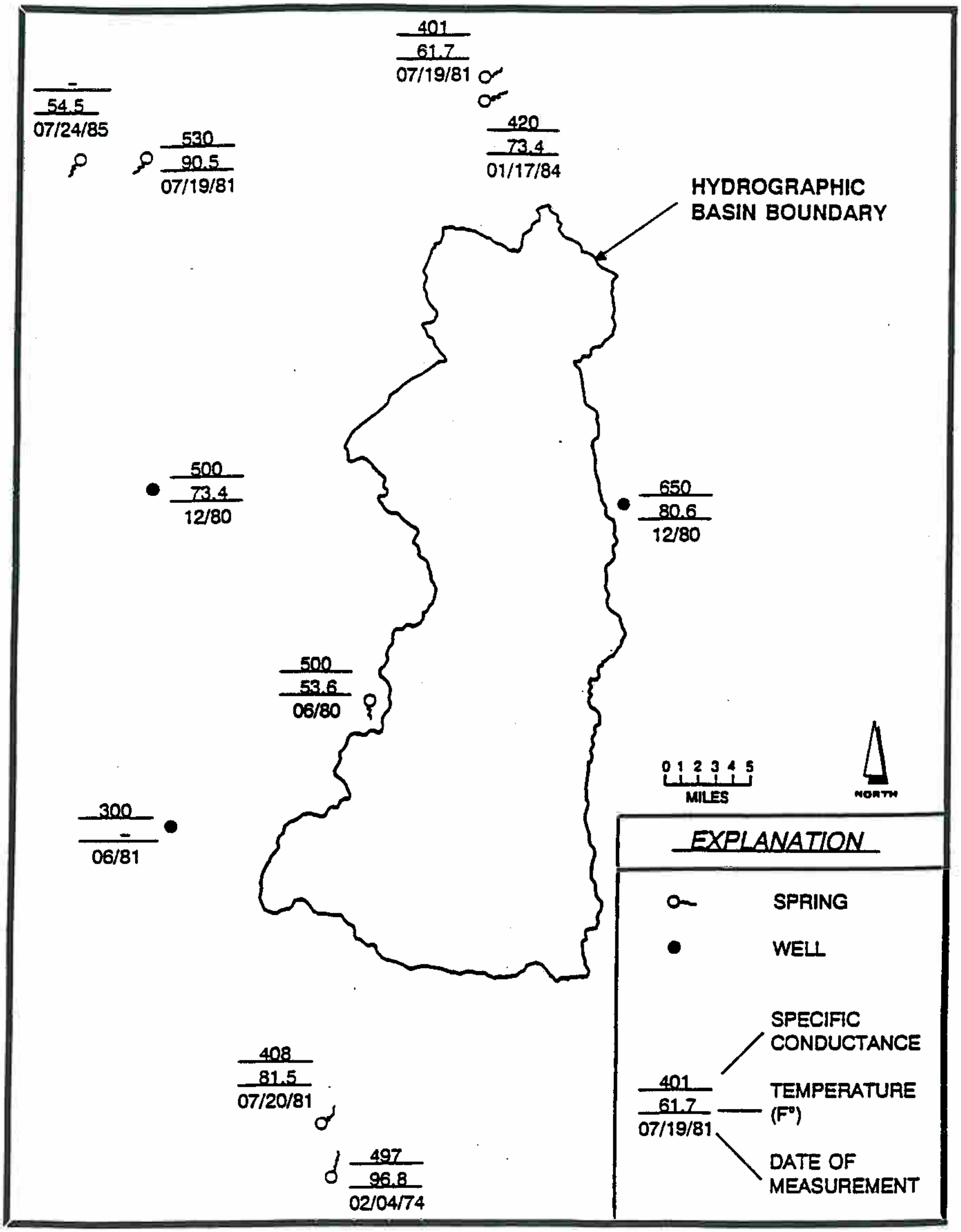


Figure 13.--Specific conductance and water temperature of wells and springs in vicinity of Pahroc Valley.

Table 3.--Ground-water budget for Pahroc Valley (stated in acre-feet per year).

		Published Value Acre-feet/year (rounded)
RECHARGE		
Precipitation (Recharge)		2,200
Subsurface Inflow		40,000
Subsurface Inflow (Dry Lake steady state model)		2,600
	TOTAL	45,000
DISCHARGE		
Evapotranspiration		Minor
Springs		Minor
Water Wells		Minor
Outflow		45,000
	TOTAL	45,000

Source: Scott et al. (1971), Summit Engineering Corp. (1990), The MARK Group (in press)

Table 4.--Recharge distribution zones for Pahroc Valley (Eakin, 1963).

ELEVATION Feet Above Sea Level	PRECIPITATION Inches/Year	APPROX. AREA Acres	PRECIPITATION Acre-feet/year (rounded)	RECHARGE RATE Percentage	RECHARGE FLUX Acre-feet/year (rounded)
8,000-9,000	+15	600	900	15	150
7,000-8,000	12-15	8,400	9,400	7	650
6,000-7,000	8-12	56,000	46,500	3	1,400
<6,000	<8	263,000	131,500	0	0
TOTAL	---	328,000	190,000	---	2,200

Subsurface Inflow

The inflow of ground water to Pahroc Valley from upgradient basins is appreciable. It represents the largest portion of the water budget for the valley. An estimated 40,000 acre-feet per year of ground water flows through the subsurface into Pahroc Valley (Scott, et al., 1971; and Harrill, et al., 1988). Most of this inflow is derived from White River Valley, with a possible minor contribution from Cave Valley. According to Harrill, et al. (1988) unknown, but probably small, quantities of inflow may also be contributed from the east, from Dry Lake Valley along the eastern part of Pahroc Valley, and according to a recent ground-water flow model of Dry Lake Valley (The MARK Group, in press), approximately 2,600 acre-ft/year of ground water from Dry Lake Valley flows into Pahroc Valley. As a result, the total subsurface inflow is increased to 42,600 acre-feet per year.

Secondary Recharge

Secondary recharge is usually estimated based on the type of usage of the ground water. Currently, the ground water withdrawn within Pahroc Valley is used for livestock watering only and therefore there is no secondary recharge.

Estimated Average Annual Discharge

Components of discharge include evapotranspiration, springs, well pumpage, and subsurface outflow. Estimates of the quantity of these components are included in the following sections.

Evapotranspiration (ET)

Because of the substantial depths to the water table, and the lack of significant spring discharge or streamflow in Pahroc Valley, ET is not a major source of ground-water discharge from the valley. Although Scott, et al. (1971) and Harrill, et al. (1988) reported ET from ground water to be zero, Eakin (1963) reported that, in Pahroc Valley, ET is "no more than a few tens or hundred acre-feet per year." The existing ET is limited to areas located near the few springs in the highlands. The evapotranspiration probably consumes most, if not all of, the water discharged through the springs. This minor amount of ET need not be accounted for in developing a flow model of the basin.

Springs

There are only two areas where a few springs exist in Pahroc Valley (Figure 14). Table 5 is a list of springs in the vicinity of Pahroc Valley hydrographic basin.

These springs are located in the relatively lower areas of Pahroc Valley, and are relatively small, meteoric springs (i.e., springs derived from local sources, usually snowmelt in the topographically higher portions of the mountains that bound the basin).

Table 5.--Springs in the vicinity of Pahroc Valley.

Site #	Location	Surface Elev.	Discharge GPM	Basin #	Data Source	Name
1	1N-62E-18cbb	6315	ND	208	1	Weepah Springs
2	1S-62E-3ba	5233	ND	208	1	White Rock Spring

1. USGS Topographic Maps
ND No Data Available

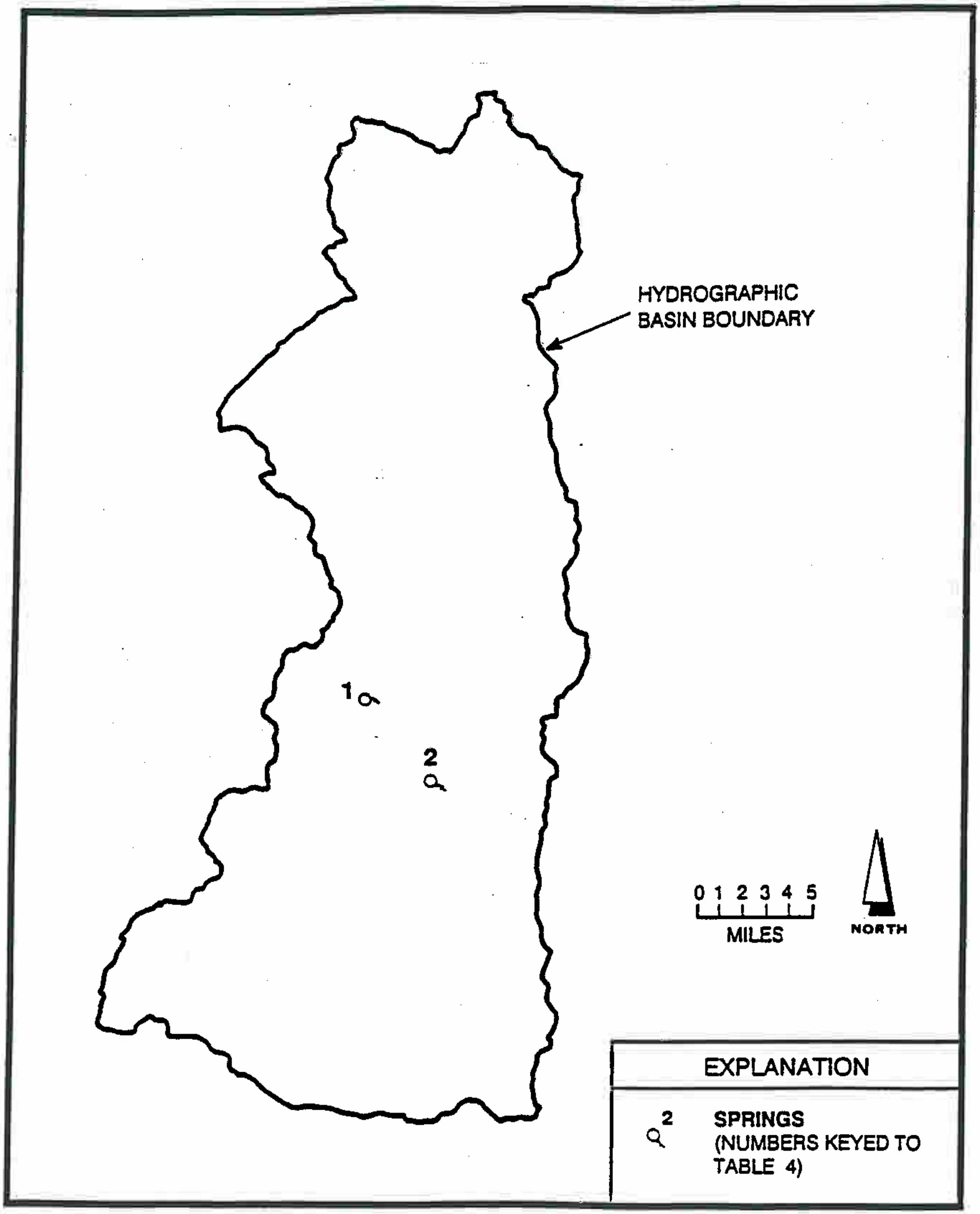


Figure 14.--Springs in Pahroc Valley.

The small volume of flow and localized nature of these springs indicates that the quantity of discharge associated with them is probably insignificant in terms of the overall water budget for Pahroc Valley, and, as a consequence, the presence of this minor spring discharge need not be simulated in a ground-water flow model of the valley. Ground water that flows through the aquifer system of Pahroc Valley is the principal source of ground water to Pahranagat Valley and its springs, perennial streams and lakes. Because the springs of Pahranagat Valley sustain a large wildlife refuge, the identification of the potential for impacting their discharges is an important factor in the ground-water flow model development.

Water Wells

Several water wells exist in Pahroc Valley; according to Eakin (1963) five of them were used for livestock. Based on information provided by SEC, only one of the 7 existing wells is permitted. Two other ground-water right permits have been issued at two locations that do not correspond to any of the other wells. The total ground-water usage in Pahroc Valley is estimated to be about 50 acre-feet per year, based on the consumptive use figures compiled by SEC. This amount of ground water is negligible compared to the total amount of ground water flowing through the valley's aquifer system. Therefore, the total pumpage within the Pahroc Valley hydrographic basin was set to zero in the steady-state model.

Outflow

Discharge through subsurface flow is along the southern boundary of Pahroc Valley into Pahranagat Valley (Scott, et al., 1971). Scott, et al. (1971) estimated the quantity of this outflow to be 42,000 acre-feet per year. However, taking into account the additional subsurface inflow from Dry Lake (The Mark Group, in press), the total subsurface outflow is between 42,000 and 45,000 acre-feet per year. The approximate location of this outflow is shown on Figure 5.

Total Discharge

Ground-water outflow from Pahroc Valley is between 42,000 and 45,000 acre-feet per year (Scott, et al., 1971 and The Mark Group, in press). Eakin (1963) estimated that the total evapotranspiration in Pahroc Valley is probably not more than a few tens or hundred acre-feet per year. No measurements of spring discharges are available in Pahroc Valley, but the total discharges are believed to be minimal. The ground-water discharge rate by wells is estimated to be about 50 acre-feet per year, based on the water-rights abstracts compiled by SEC. The total discharge from Pahroc Valley, based on these estimates of ground-water outflow, evapotranspiration, spring discharge rates and well discharge, is estimated to be between 42,000 and 45,000 acre-feet per year.

Perennial Yield

Scott, et al. (1971) define perennial yield as "the maximum amount of natural discharge that can be salvaged each year over the long term without depleting the ground-water reservoir." The perennial yield of Pahroc Valley is reported to be 21,000 acre-feet per year (Scott et al., 1971).

Storage

The quantity of ground water stored in the geologic units underlying Pahroc Valley is large; the amount of recoverable ground water in storage in the valley reservoir is estimated to average about 10 percent of the volume of the saturated valley-fill (Scott, et al., 1971). For Pahroc Valley, Scott, et al. (1971) estimated the quantity of recoverable ground water to be 1.3 million acre-feet in the upper 100 feet.

No estimates have been made of the amount of ground water that is stored in the carbonate aquifer in Pahroc Valley. Although the storage capacity of the carbonates is believed to be less than that of the valley-fill, the large saturated thickness and great areal extent of the carbonate aquifer suggests that the quantity of recoverable water from storage may be even greater than that expected from the valley-fill deposits.

Dettinger (1989) reported that the quantities of ground water in the regional carbonate aquifer are "enormous", and estimated that the total quantity of water stored in this regional aquifer south of Pioche and Tonopah is on the order of 800 million acre-feet. Adopting Dettinger's assumption of a total of one percent of the aquifer volume as being recoverable, then a rough estimate of the recoverable ground water in storage in Pahroc Valley can be made. Based upon this recovery factor, the areal extent of the carbonate aquifer underlying the valley (approximately 510 square miles), and an assumed saturated thickness of 2,000 feet (about the limit for economic well drilling), then the total recoverable ground-water storage in Pahroc Valley is estimated to be approximately 6.5 million acre-feet. However, the upper 100 feet of the rock aquifer probably contains about only 325,000 acre-feet of ground water.

INVENTORY OF WATER RIGHTS, PUMPAGE, AND LAND USE

An estimate of ground-water usage in a basin can be obtained from present water rights, pumpage, and application of pumped water to crops and other uses. These factors are examined in the following sections.

PRESENT DEVELOPMENT

The level of development of water resources in a basin can be illustrated by the water right allocations and the current ground-water pumpage within that basin. In Pahroc Valley, little ground water has been pumped historically, and little is presently being used. The Nevada State

Engineer has however allocated several water-right permits in the basin. The only water right applications that have not yet been acted upon by the Nevada State Engineer are those filed by the District in October of 1989. The status of water rights in Pahroc Valley is summarized in the following sections.

Water Right Status

Based on information supplied by SEC, the State Engineer has allocated a total of 13 water-right permits in Pahroc Valley for both surface and ground water. An additional seven applications are currently pending. Table 6 summarizes the current ground-water rights that have been granted and the water appropriation applications that have been filed for Pahroc Valley water, including the District's recent filings.

Ten surface-water permits exist in Pahroc Valley. Their locations are mostly on White River and the numerous ephemeral streams on the flanks of the mountains. All of them are for stockwatering usage. Their total consumptive use value is 64 acre-feet per year.

According to the Summit Engineering water-right abstract, the ground-water permits are for stockwatering use. The reconnaissance trip to Pahroc Valley confirmed this fact. No land uses other than livestock watering were observed. The observed stock consists mainly of cattle and a few horses. The water-right abstract shows that 50 acre-feet per year of ground water (consumptive use) have been allocated. However, only one of the existing locations coincides with a known existing well, well No. 7 (see Figure 3), which suggests that the actual ground-water discharge from wells is much less than 50 acre-feet per year. These minor discharges were neglected in the steady-state model.

There are currently 7 applications for ground-water appropriations that have been filed with the Nevada State Engineer by the District.

In summary, about 64 acre-feet per year of surface water rights and a total of 50 acre-feet per year of water rights have been permitted in Pahroc Valley. The annual duty on the proposed District wells will be determined by the Nevada State Engineer.

Pumpage

The abstract provided by SEC showed the current total permitted pumpage in the basin to be 50 acre-feet per year. The wells in Pahroc Valley are currently used for stockwatering and grazing. Based on data collected during the reconnaissance trip to the valley the actual pumpage is much less than 50 acre-feet per year and is considered to be minor.

Table 6.--Current water appropriations in Pahroc Valley.

WATER BASIN 208
PAHROC VALLEY
SURFACE PERMITS AND APPLICATIONS
OTHER USES

APPLICATION/CERTIFICATE PERMIT/PROOF	DATE OF PRIORITY	POINT OF 1/4 1/4	DIVERSION SECTION	TOWNSHIP	RANGE	DIVERSION RATE	CONSUMPTION AC.FT./YR.	ALLOCATED DUTY AC.FT./YR.	USE	ACAD BLOCK	PLACE OF USE	NOTES
2429 NONE	01/01/04					5.0000	22.40	22.40	STOCKWATER	SURF_OTM	ALONG WHITE RIVER BETWEEN NE 14/5/60, SE 7/3/62	PROOF 02429. SEE POU POO
2822 213	11/10/13	NW NW	10	1S	62E	0.0250	0.00	0.00	STOCKWATER	SURF_OTM	NW NW 10/1/62	NO DUTY GIVEN
4666 1575	11/01/17	NE SE	5	1W	62E	0.0008	0.56	0.56	STOCKWATER	SURF_OTM	NW SE 5/1/62	
5970 932	02/02/20	NW NW	5	3S	63E	0.0100	0.56	0.56	STOCKWATER	SURF_OTM	NW NW 5/3/63	
6497 1020	06/22/21	NE NW	24	2S	62E	0.0150	10.75	10.75	STOCKWATER	SURF_OTM	NONE GIVEN	
7057 1216	02/26/24	SE SW	36	4W	61E	0.0250	19.04	19.04	STOCKWATER	SURF_OTM	SE SW 36/4/61	
9574 2206	03/18/32	NE NW	1	2S	61E	0.0060	4.48	4.48	STOCKWATER	SURF_OTM	NE NW 1/2/61	
11308 3187	06/06/45	SE SW	24	2S	62E	0.0022	2.24	2.24	STOCKWATER	SURF_OTM	SE SW 24/2/62	
12510 4389	06/18/48	SW NW	29	2S	63E	0.0016	1.12	1.12	STOCKWATER	SURF_OTM	SW NW 29/2/63	
52774 NONE	12/13/88	NW SE	30	2S	61E	0.1000	2.24	2.24	STOCKWATER	SURF_OTM	NW SE 30/2/61	
TOTAL							63.39	63.39				

WATER BASIN 208
PAHROC VALLEY
GROUND-WATER PERMITS AND APPLICATIONS
OTHER USES

APPLICATION/CERTIFICATE PERMIT/PROOF	DATE OF PRIORITY	POINT OF 1/4 1/4	DIVERSION SECTION	TOWNSHIP	RANGE	DIVERSION RATE	CONSUMPTION AC.FT./YR.	ALLOCATED DUTY AC.FT./YR.	USE	ACAD BLOCK	PLACE OF USE	NOTES
2418 NONE	01/01/30	NW SW	8	3W	62E	0.0200	15.68	15.68	STOCKWATER	WELL_OTM	NW SW 8/3/62	PROOF 02418
13173 NONE	11/23/90	NW SW	8	3W	62E	0.1000	17.92	17.92	STOCKWATER	WELL_OTM	NW SW 8/3/62	
54291 NONE	01/01/90	NW SE	23	2S	61E	0.0500	15.68	15.68	STOCKWATER	WELL_OTM	NONE GIVEN	
TOTAL							49.28	49.28				

Table 6.--Current water appropriations in Pahroc Valley (continued).

WATER BASIN 208
PAHROC VALLEY
UNDERGROUND APPLICATIONS
LAS VEGAS VALLEY WATER DISTRICT

APPLICATION/CERTIFICATE PERMIT/PROOF		DATE OF PRIORITY	POINT OF 1/4 1/4	DIVERSION SECTION	TOWNSHIP	RANGE	DIVERSION RATE	CONSUMPTION AC.FT./YR.	ALLOCATED DUTY AC.FT./YR.	USE	ACAD BLOCK	PLACE OF USE	NOTES
54043	NONE	10/17/89	NE SE	35	3W	62E	6.0000	0.00	0.00	MUNICIPAL & DOMESTIC	WELL_LVP	NONE	
54044	NONE	10/17/89	SW NE	19	2W	63E	6.0000	0.00	0.00	MUNICIPAL & DOMESTIC	WELL_LVP	NONE	
54045	NONE	10/17/89	SE NW	14	1W	62E	10.0000	0.00	0.00	MUNICIPAL & DOMESTIC	WELL_LVP	NONE	
54046	NONE	10/17/89	NW SE	29	1S	62E	10.0000	0.00	0.00	MUNICIPAL & DOMESTIC	WELL_LVP	NONE	
54047	NONE	10/17/89	NW SW	33	2S	61E	10.0000	0.00	0.00	MUNICIPAL & DOMESTIC	WELL_LVP	NONE	
54048	NONE	10/17/89	SE NE	22	2W	62E	10.0000	0.00	0.00	MUNICIPAL & DOMESTIC	WELL_LVP	NONE	
54049	NONE	10/17/89	NE NE	8	2S	62E	10.0000	0.00	0.00	MUNICIPAL & DOMESTIC	WELL_LVP	NONE	
TOTAL								0.00	0.00				

Land Use

Most of the land in Pahroc Valley is public-domain land administered by the Bureau of Land Management. Some areas along the White River channel are used for livestock range. No evidence of other land use was observed during reconnaissance trips to the valley between 1990 and 1992.

FUTURE DEVELOPMENT

Other than the District's plans for ground-water withdrawal, there is no known other development planned in Pahroc Valley at this time.

STEADY-STATE MODEL DEVELOPMENT

In previous sections, the conceptual model of the hydrologic system of Pahroc Valley was described. This section presents all the steps taken to construct the numerical steady-state model based on the conceptual model. It includes descriptions of the modelling approach, the model set-up and assumptions, the initial parameter estimates and the steady-state calibration procedure. The resulting steady-state model along with an evaluation of the accuracy of the hydrologic database and model code used are also presented in this section.

MODELLING APPROACH

The selected model, MODFLOW is a ground-water flow model capable of simulating ground-water regime in basins such as Pahroc Valley, through a block-centered finite-difference approach. This approach basically consists of the solution of partial differential equations that describe ground-water flow in two-or-three dimensions. A full treatment of the mathematics of the model can be found in the MODFLOW documentation (McDonald and Harbaugh, 1988) and concise summary descriptions of the development and use of numerical modelling can be found in Mercer and Faust (1980a, 1980b, and 1980c) and Faust and Mercer (1980a and 1980b).

The first step in developing a numerical flow model using MODFLOW is the formulation of a conceptual hydrogeologic model of the area to be mathematically represented by the model. This conceptual model is based upon the available hydrologic data, inferences based on observations of analogous hydrologic settings, and assumed conditions, or expected ranges of conditions for parameters that have not been measured and are not readily estimated. The conceptual model of the hydrologic regime, water resources potential, and present status of ground-water development in Pahroc Valley, key elements in formulating a numerical model of the basin, were described and discussed in preceding sections of this report.

Following, or concurrent with the development of the conceptual model, the development of the mathematical representation of the hydrologic system is initiated. First a grid system is overlain on a map of the area to be modelled as shown diagrammatically in Figure 15. This grid system can comprise either a single layer or multiple layers, as shown in Figure 16, if a 3-dimensional simulation is desired. The grid system represents a convention whereby each cell in the model can be uniquely identified by grid row, column, and layer designations (Figure 17).

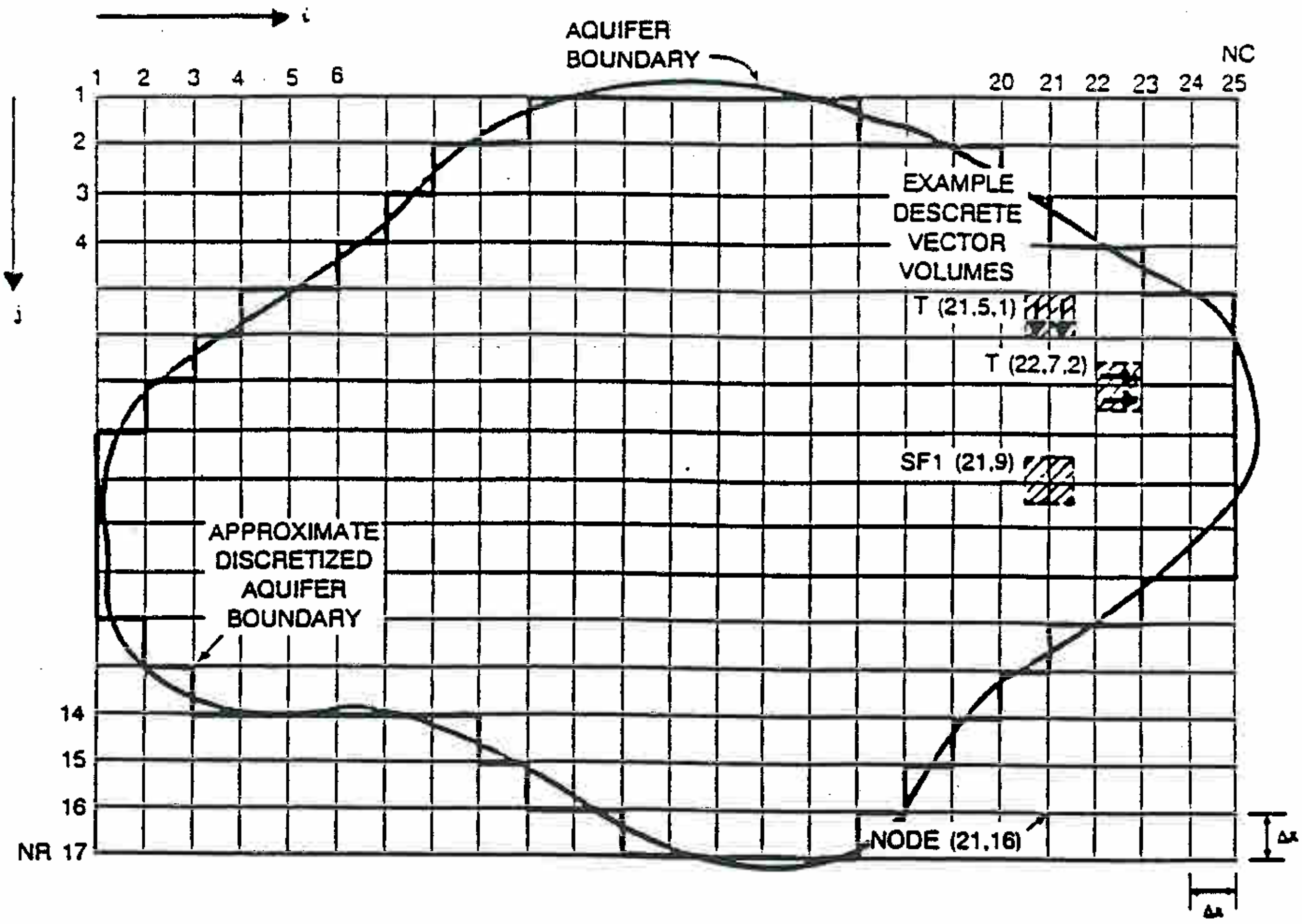
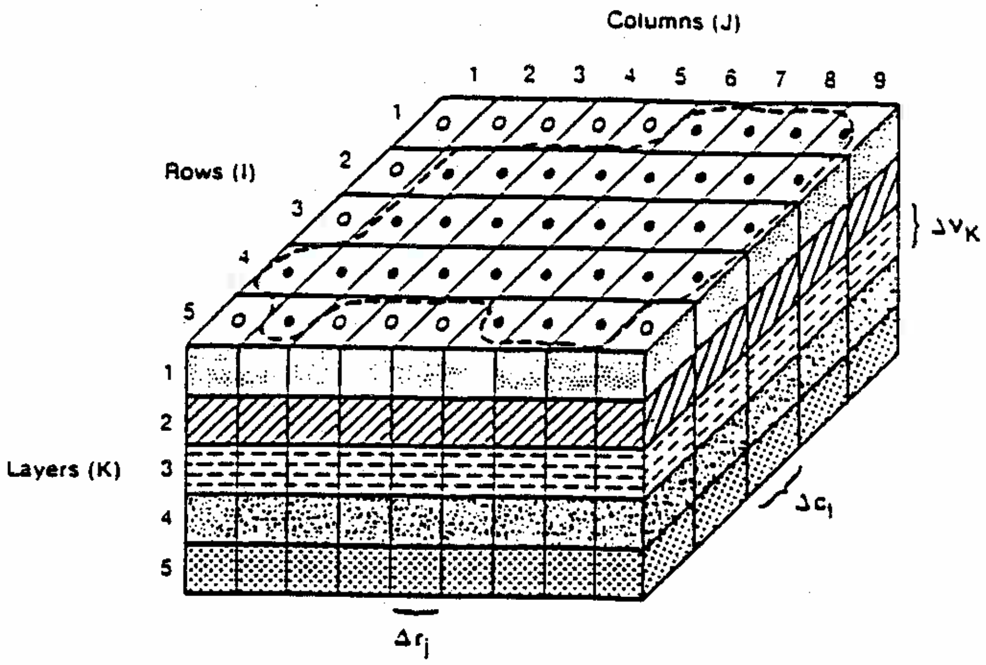


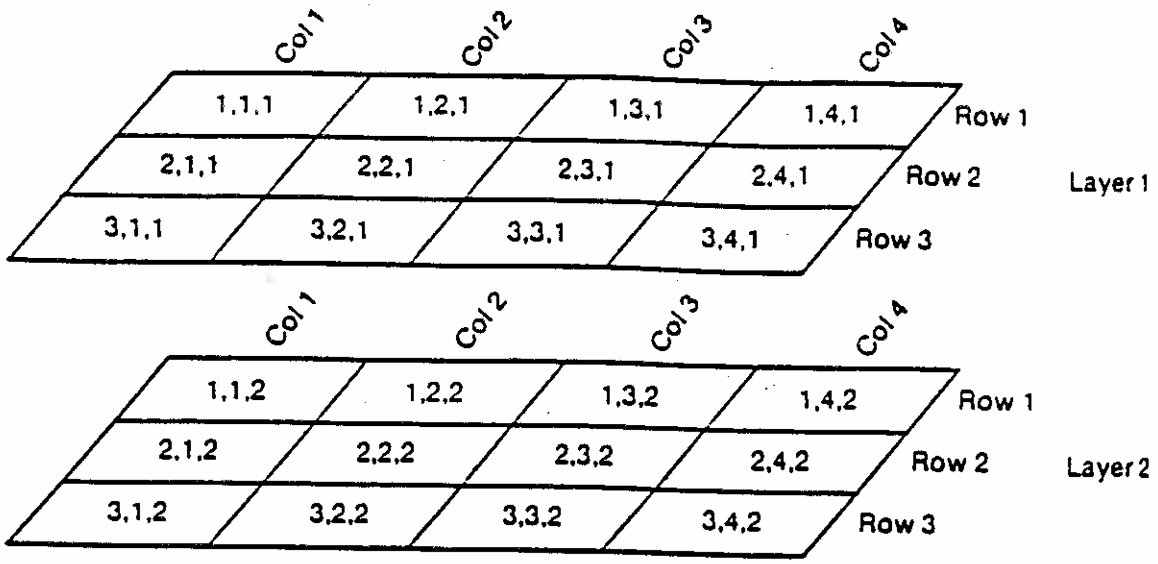
Figure 15.--Example of finite-difference grid overlain on an aquifer system (from Prickett and Lonnquist (1971)).



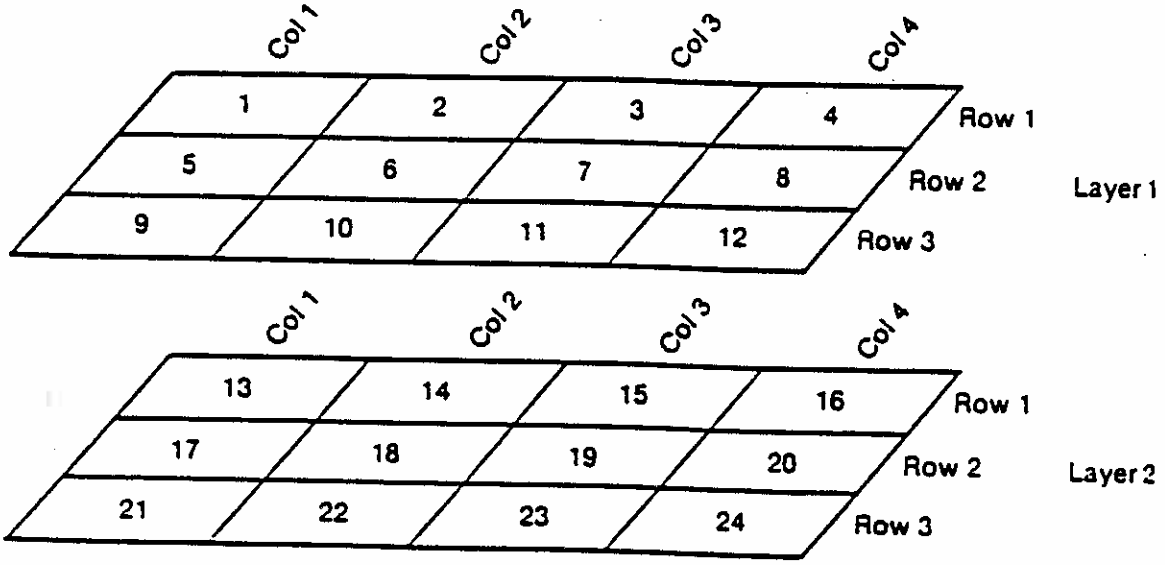
Explanation

----	Aquifer Boundary
●	Active Cell
o	Inactive Cell
Δr_J	Dimension of Cell Along the Row Direction. Subscript (J) Indicates the Number of the Column
Δc_I	Dimension of Cell Along the Column Direction. Subscript (I) Indicates the Number of the Row
Δv_K	Dimension of the Cell Along the Vertical Direction. Subscript (K) Indicates the Number of the Layer

Figure 16.--A hypothetical, multi-layered aquifer system represented by a three-dimensional grid (from McDonald and Harbaugh (1988)).



(a) Cell Numbering With 3 Indices



(b) Cell Numbering With 1 Index

Figure 17.--Three indices and single index cell designation schemes (from McDonald and Harbaugh (1988)).

Next, the input parameters required by the model are provided for each cell. For example, the areas of the grid that are outside the boundary of the basin can be set as inactive and cells that occur along the boundary of the area being modelled can be set to represent no-flow boundaries, general-head, constant-head, or variable-head cells, as shown in Figure 18. Codes or values for other hydrologic or model parameters are then input; Figure 19 shows the hypothetical configuration of recharge for a typical model. As shown on this figure, recharge can be simulated at any number of cells within a model. The ability to input areally (and vertically) distributed data into MODFLOW allows the modeler to develop a model that is consistent with the conditions that are known or inferred to be present in the subject area.

MODFLOW contains discrete modules designed to simulate a number of hydrologic conditions. Conditions that can be modelled using MODFLOW include confined, unconfined, and semi-confined hydraulic conditions, the discharge of water through evapotranspiration by plants, drains, wells, and streams, and the boundary conditions identified above. Sophisticated algorithms in the MODFLOW code also allow the simulation of phenomena that occur when an aquifer is stressed, including reductions in evapotranspiration rates and well yields in response to a lowering of the head in aquifer. Codes specifying the modules to be used and data values for each input grid to the model, e.g., transmissivity, recharge, and water well information are input for each desired feature. A complete list of the MODFLOW options and data requirements is provided in Table 7.

MODEL SET-UP/ASSUMPTIONS

A three-dimensional finite-difference grid system comprising 2 layers was overlain on a map of Pahroc Valley, including the hydrologic boundary of the basin. The grid boundary was then designed to approximate the boundaries of the valley. A one-mile grid spacing was selected for use in all of the models, per discussions with the District. The one-mile grid spacing resulted in a 45 rows by 23 columns grid for Pahroc Valley. An areal view of the resulting grid system is shown on Figure 20. Additional model set-up input data are provided on Table 7.

The top layer (or layer 1) was designed to represent all of the saturated valley-fill present in the valley, and similar thicknesses of saturated carbonate or volcanic rocks present within the same horizon. The bottom layer (or layer 2) was designed to represent mostly the deeper saturated carbonate rocks and the saturated volcanic rocks where present at similar elevations.

Although the top layer is under unconfined conditions, both layers were modelled as being confined because the additional data required to model unconfined conditions (i.e. hydraulic conductivities and elevation of aquifer bottom) were not available. This assumption will not affect the steady-state model as the saturated thicknesses and therefore transmissivities remain constant under such time-independent conditions. Although not exactly representative of real conditions, this assumption should not introduce significant errors in the transient modelling results either, as long as the drawdowns caused by pumping remain small relative to the saturated thickness of the top layer. Actually, drawdowns observed in a confined aquifer are similar to those observed in an unconfined aquifer if the induced drawdowns are less than 20% of the saturated thickness.

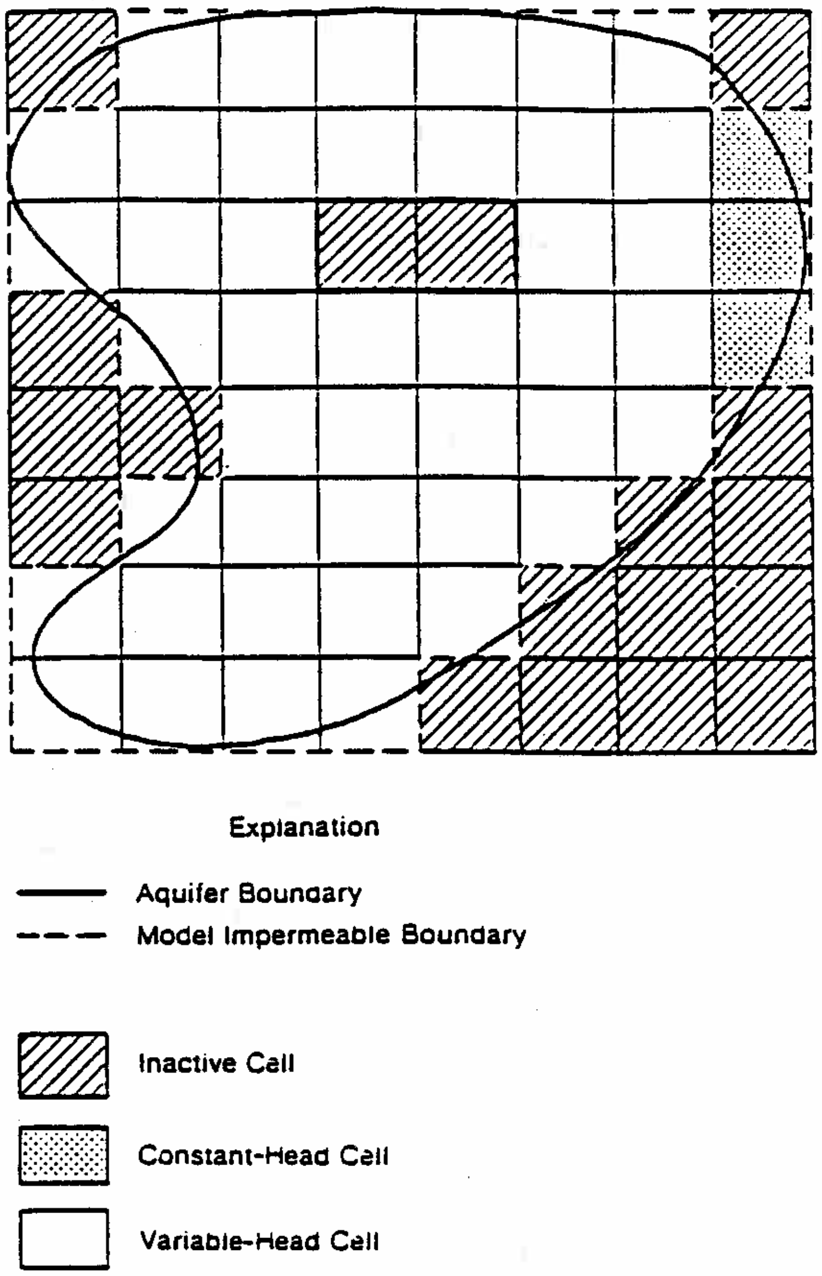


Figure 18.--Example of boundaries and cell designation for a simple model (from McDonald and Harbaugh (1988)).

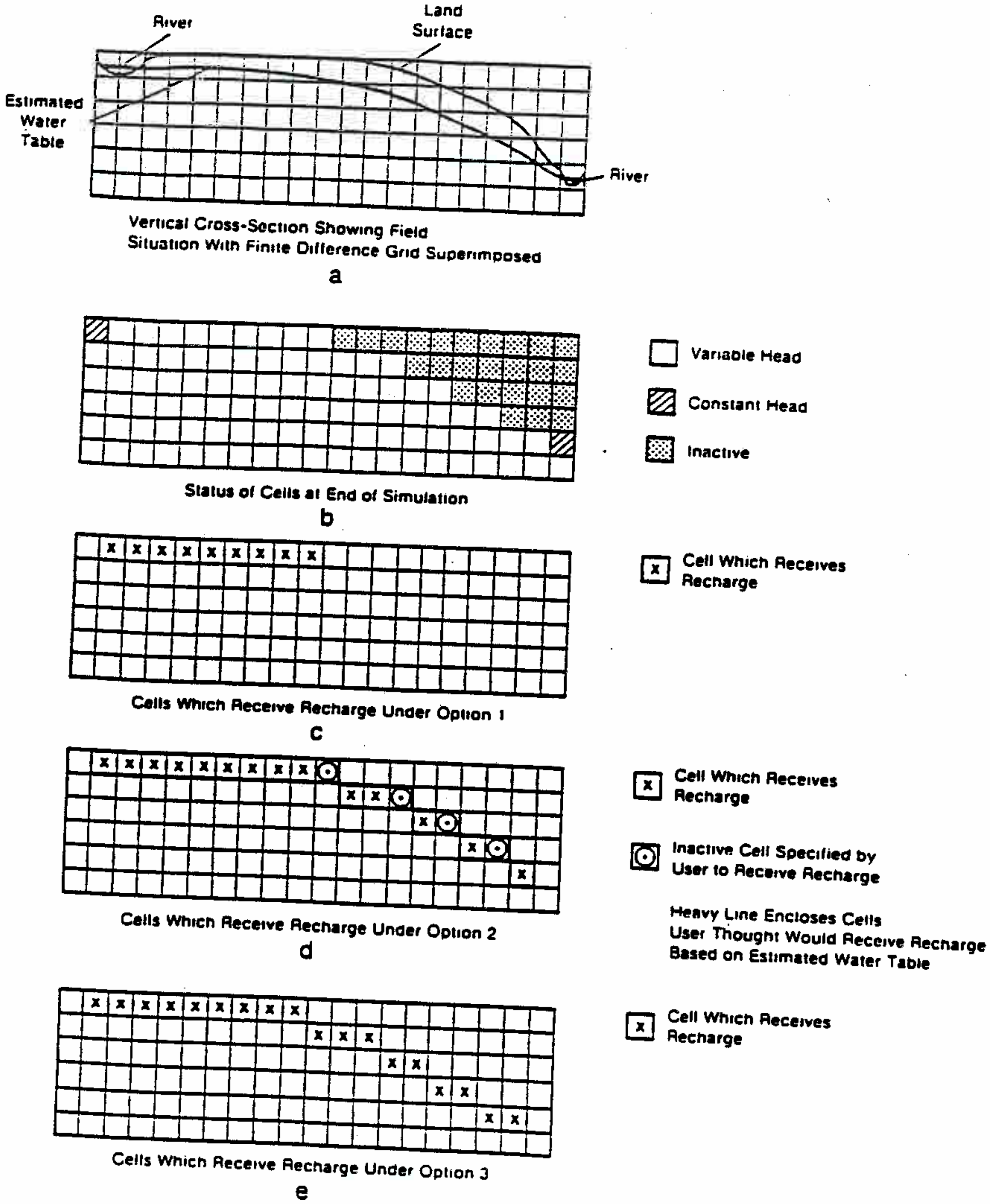


Figure 19.--Hypothetical examples showing variable recharge distributions (from McDonald and Harbaugh (1988)).

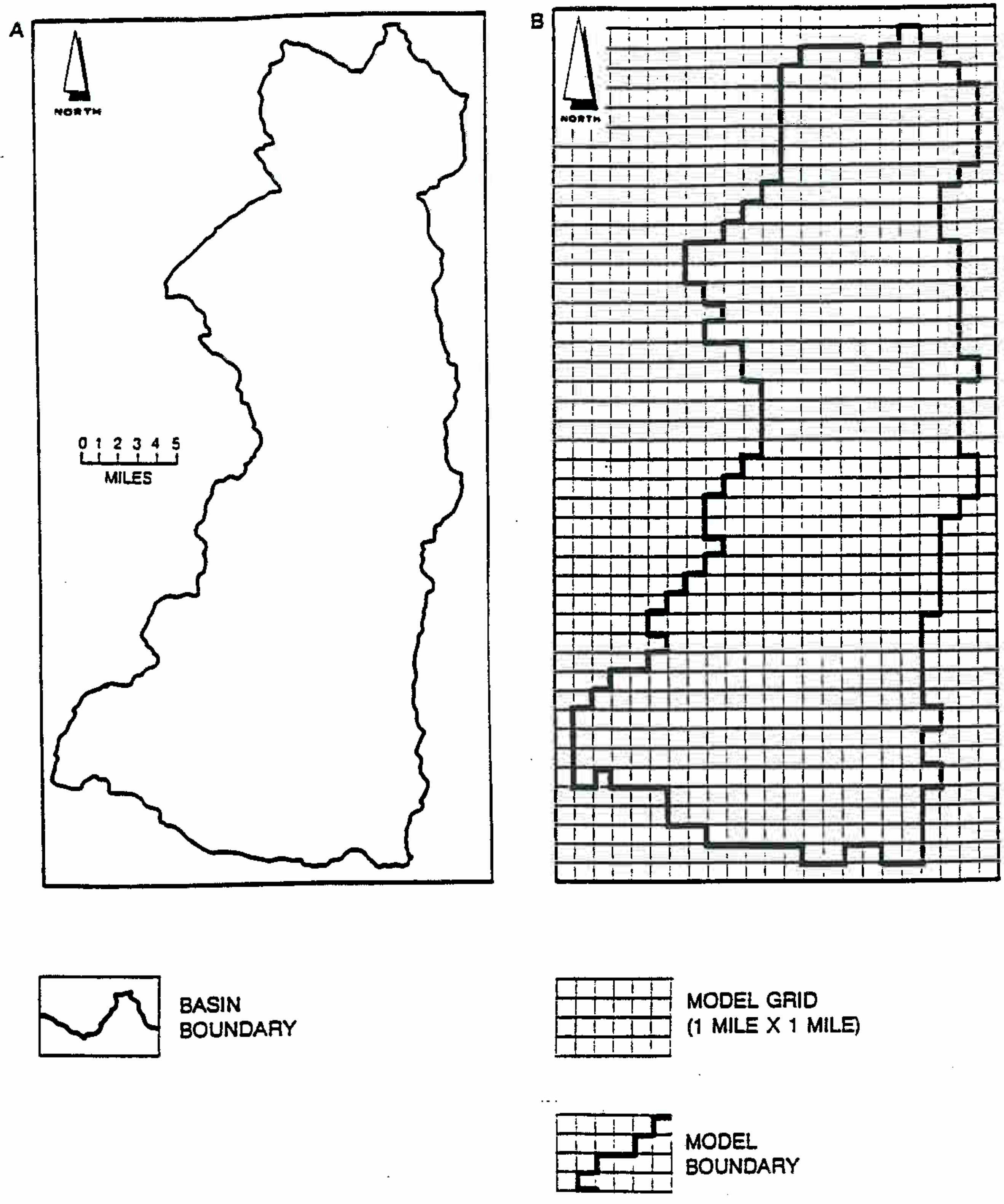


Figure 20.--Basin boundary and model grid for Pahroc Valley.

Table 7.--MODFLOW data parameters and values used for Pahroc Valley.

MODFLOW MODULE	DATA OR PARAMETER	VALUE FOR PAHROC VALLEY
BASIC PACKAGE INPUT	NUMBER LAYERS	2
	NUMBER ROWS	45
	NUMBER COLUMNS	23
	NUMBER STRESS PERIODS	1
	TIME UNIT	DAYS
	HEAD VALUES FOR INACTIVE CELLS	0
	INITIAL HEAD - TRANSIENT RUNS	NOT USED
	STRESS PERIOD LENGTH	0.00839 DAYS
BLOCK-CENTERED FLOW PACKAGE	LAYER TYPE	CONFINED
	ANISOTROPY FACTOR	ONE
	CELL DIMENSIONS	5,280' x 5,280'
	STORAGE COEFFICIENT	NOT USED
	TRANSMISSIVITY FOR CONF. LAYERS	SEE FIGURE 22(1)
	HYDRAULIC CONDUCTIVITY FOR UNCONF. LAYERS	NOT USED
	ELEVATION OF AQUIFER BOTTOM	NOT USED
	VERTICAL CONDUCTANCE OF CONF. LAYER	10^{-4} DAY^{-1}
	SECONDARY STORAGE COEFFICIENCY	NOT USED
	TOP OF AQUIFER	NOT USED
RIVER PACKAGE	NUMBER OF RIVER REACHES ACTIVE (MAX)	NOT USED
	NUMBER LAYERS	NOT USED
	NUMBER ROWS	NOT USED
	NUMBER COLUMN	NOT USED
	STAGE	NOT USED
	CONDUCTANCE	NOT USED
	ELEVATION OF RIVER-BED BOTTOM	NOT USED
RECHARGE PACKAGE	LAYER NUMBER	1 (UPPER)
	ROW NUMBER	VARIABLE
	COLUMN NUMBER	VARIABLE
	QUANTITY	VARIABLE

Table 7.--MODFLOW data parameters and values used for Pahroc Valley (Continued).

MODFLOW MODULE	DATA OR PARAMETER	VALUE FOR PAHROC VALLEY
WELL PACKAGE	NUMBER WELLS (MAX)	NOT USED
	WELL LOCATION	NOT USED
	Q	NOT USED
DRAIN PACKAGE	NUMBER DRAINS (MAX)	NOT USED
	DRAIN LOCATION	NOT USED
	Q	NOT USED
	ELEVATION OF DRAIN	NOT USED
	HYDRAULIC CONDUCTANCE OF INTERFACE	NOT USED
EVAPOTRANSPIRATION PACKAGE	ELEVATION OF ET SURFACE	NOT USED
	MAXIMUM ET RATE	NOT USED
	ET EXTINCTION DEPTH	NOT USED
	LAYER INDICATOR	NOT USED
GENERAL HEAD BOUNDARY PACKAGE	NUMBER GENERAL HEAD BOUNDARY CELLS (MAX)	SEE FIGURE 23
	LAYER NUMBER	VARIABLE
	ROW NUMBER	VARIABLE
	COLUMN NUMBER	VARIABLE
	BOUNDARY HEAD	SEE FIGURES 12 & 22 (1)
	CONDUCTANCE	DERIVED FROM FIGURES 12, 22 & 23 (1)
STRONGLY IMPLICIT PROCEDURE PACKAGE	NUMBER ITERATIONS (MAX)	150
	NUMBER ITERATION PARAMETERS	5
	ACCELERATION PARAMETER	1.0
	HEAD CHANGE CRITERION	0.01
	ITERATION PARAMETER SEED	DEFAULT
SLICE-SUCCESSIVE OVER-RELAXATION PACKAGE	NUMBER ITERATIONS (MAX)	NOT USED
	ACCELERATION PARAMETERS	NOT USED
	HEAD CHANGE CRITERION	NOT USED

---

(1) These figures reflect final variable distributions.

INITIAL PARAMETER ESTIMATES

Following the finite-difference grid setup, preparation of data grids representing each of the MODFLOW input parameter requirements was initiated. Data grids were prepared for recharge, transmissivity and boundary conditions. Additional parameter and option data used in the development of the Pahroc Valley ground-water flow model are identified in Table 7.

Recharge Distribution

The recharge grid is set up to represent primary and secondary recharge areal distributions over the modelled area. The recharge grid was set-up to account for primary recharge and secondary recharge if any.

Primary

Primary recharge in Pahroc Valley is limited to the infiltration of rainfall over the valley and seepage of water into streambeds during the infrequent ephemeral flows that occur in the drainages. There are no streamflow records available for Pahroc Valley, however, it is believed that, because of the low precipitation rate and frequency and the depth to water over most of the valley floor, little recharge occurs along the drainages.

The recharge derived from precipitation, as discussed in the Budget section, amounts to about 2,200 acre-feet per year, and is distributed as a function of elevation. In developing the numerical model of the valley, recharge was distributed according to the elevation as shown graphically in Figure 21; the resulting configuration of model cells that receive recharge is also shown on the same figure.

Secondary

Because of the lack of land and water users in Pahroc Valley, secondary recharge is considered negligible at present. Only in the areas immediately downgradient of the few existing springs and a few small seeps could any secondary recharge occur. However, because of the slight discharge from these areas and the evapotranspiration losses, it is likely that none of this discharge recharges the aquifer system.

Historically, none of the land in Pahroc Valley has been irrigated, according to information made available by the Nevada State Engineer. An inspection of the valley during the reconnaissance of Pahroc Valley, conducted as part of this investigation, confirmed that the area is not irrigated.

Because of the limited number of wells and their type of usage, secondary recharge in Pahroc Valley is considered negligible or nonexistent; therefore, no secondary recharge was accounted for in the steady-state ground-water flow model of the valley.

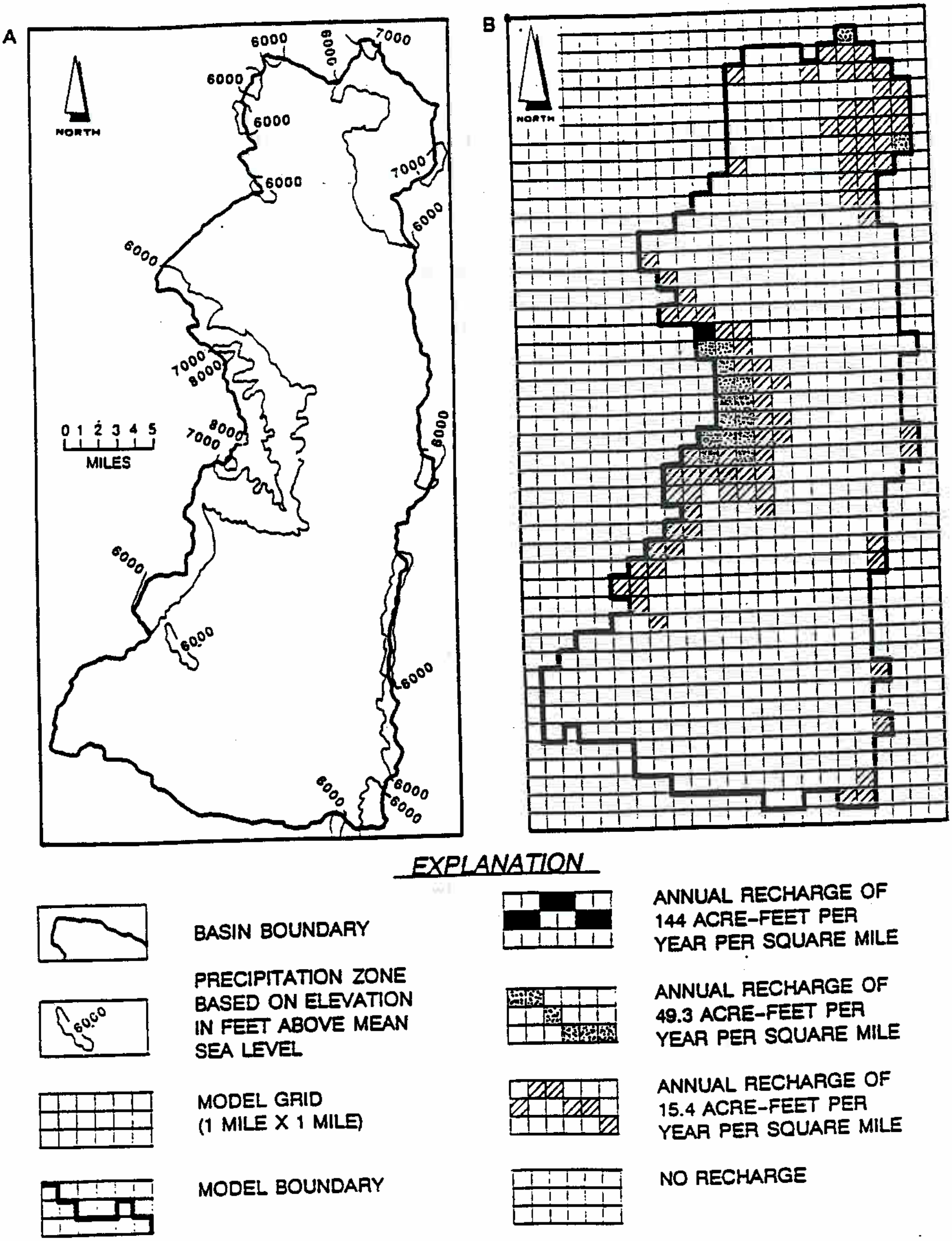


Figure 21.--Primary recharge zones in Pahroc Valley.

Hydraulic Characteristics

In developing a numerical model of a hydrographic basin, either measured or assumed values must initially be used to represent the hydraulic characteristics of the media being modelled. In this section, the initial estimates of the required parameters are presented.

Transmissivity

The initial transmissivity distributions were assumed to be uniform for both layers. The initial values were based on average transmissivity values observed for the valley-fill and the carbonate aquifers regionally. In performing steady-state simulations for model calibration, these values were adjusted. The adjustments that were made, and the results, are presented in the Model Calibration and Modelling Results sections of this report.

Vertical Leakance

The carbonate aquifer may be in a semi-confined state in areas where volcanic rocks are present. However, there are no water level data available for the carbonate aquifer within Pahroc Valley to define the hydraulic relationship between the alluvial and carbonate aquifers, and hence estimate the leakance term. As a result, a single value of 1.0×10^{-4} per day was estimated for the leakance, based on the average hydraulic conductivities and thicknesses of the two layers.

Storage Coefficients and Specific Yields

The assignment of values for storage coefficients or specific yield (collecting term storativity), although not a required parameter for steady-state simulations, is required for any transient simulations used to predict the performance of a pumping well or well field. Therefore, a discussion of this hydraulic characteristic is warranted.

Valley-specific data on the storativity of the aquifers in Pahroc Valley are lacking, but assumptions can be made on the basis of data available from other valleys in Nevada. For the valley-fill aquifer, the storativity generally ranges from .001 to .3. The lower value is typically measured at wells where semi-confined conditions exist, e.g. in the vicinity of playas and lacustrine deposits such as the Muddy Creek formation where fine-grained, but laterally discontinuous sediments overlie or are interbedded with more coarse-grained sediments. The higher value is more indicative of unconsolidated coarse-grained alluvial deposits that are well sorted, i.e. with minimal variations in grain size.

Of special note are the variations in storativity that are often observed with time. In general, the storativity of both unconfined and semi-confined aquifers tends to increase as the duration of pumping increases. Short term (less than 10 days) aquifer tests often yield estimates of storativity of 0.1 or less while long term pumping tests indicate higher storativities. Such variations are believed to reflect the inhomogeneity of the sediments and the gradation of the response of an aquifer from semi-confined to unconfined during actual pumping.

With respect to the carbonate aquifer, a value of 0.01 is considered appropriate. This value is consistent with the recoverable yield estimate presented by Dettinger (1988). The storativity of the carbonate aquifers in Nevada is likely to exhibit a wide range of values however, reflecting the high degree of variability in aquifer mechanics related to the degree of fracturing, the fracture aperture widths, spacing, and continuity, the degree of confinement, and the extent to which secondary porosity has resulted through dissolution. Walton (1984) presents a summary of storativity values from published sources with a range of 0.1 to 0.24 for limestone aquifers and .000001 for fractured rock. Walton further notes that "gravity drainage of interstices is not instantaneous and the water-yielding capacity increases at a diminishing rate as the time of drainage increases, gradually approaching the specific yield."

Modeling of this phenomena is not considered conservative. The use of the recoverable yield estimate of 0.01 reported by Dettinger is considered appropriate for use as it is conservative in that it should tend to overestimate the drawdown resulting from large-scale water withdrawals over an extended pumping period.

Boundary Conditions

The types of boundary conditions used in the MODFLOW model of Pahroc Valley are shown in Figure 22. The boundary conditions were selected on the basis of reported or inferred hydrogeologic conditions. For the first layer, where outcrops of relatively impermeable rocks occur, a no-flow boundary condition was assigned to the grid cells representing the area. Similarly, model grid cells representing the area of the natural ground-water divide between Pahroc Valley and adjoining basins are assigned no-flow boundary conditions. For the second layer, general-head boundary conditions were assigned to all boundary cells based on the head distribution simulated by Prudic and Burbey (1985) which is based on Thomas et al. (1986). The head and initial conductance data necessary to define general-head boundary conditions were derived from head distributions and initial estimates of transmissivity. Initial conductances were calculated based on the initial transmissivity values, as specified in the MODFLOW user manual (McDonald and Harbaugh, 1988).

MODEL CALIBRATION

Model calibration is an iterative procedure that usually require numerous steps. Each step consists of three major sub-steps: 1) running the model with the current parameters to simulate a matrix of corresponding heads; 2) comparing the simulated heads with known heads; and 3) adjusting the most sensitive parameters to reduce the difference between the simulated and observed heads (Table 1). This step is repeated until the simulated heads match the observed heads. In addition, after a match is established between the heads, the simulated and observed basin water budgets are compared. If the two budgets do not match, the iterative procedure is continued until such a match occurs. The calibration of the steady-state model of Pahroc Valley primarily involved adjusting the grid-cell transmissivity values and the boundary conductances until the observed water levels and the flow budget matched.

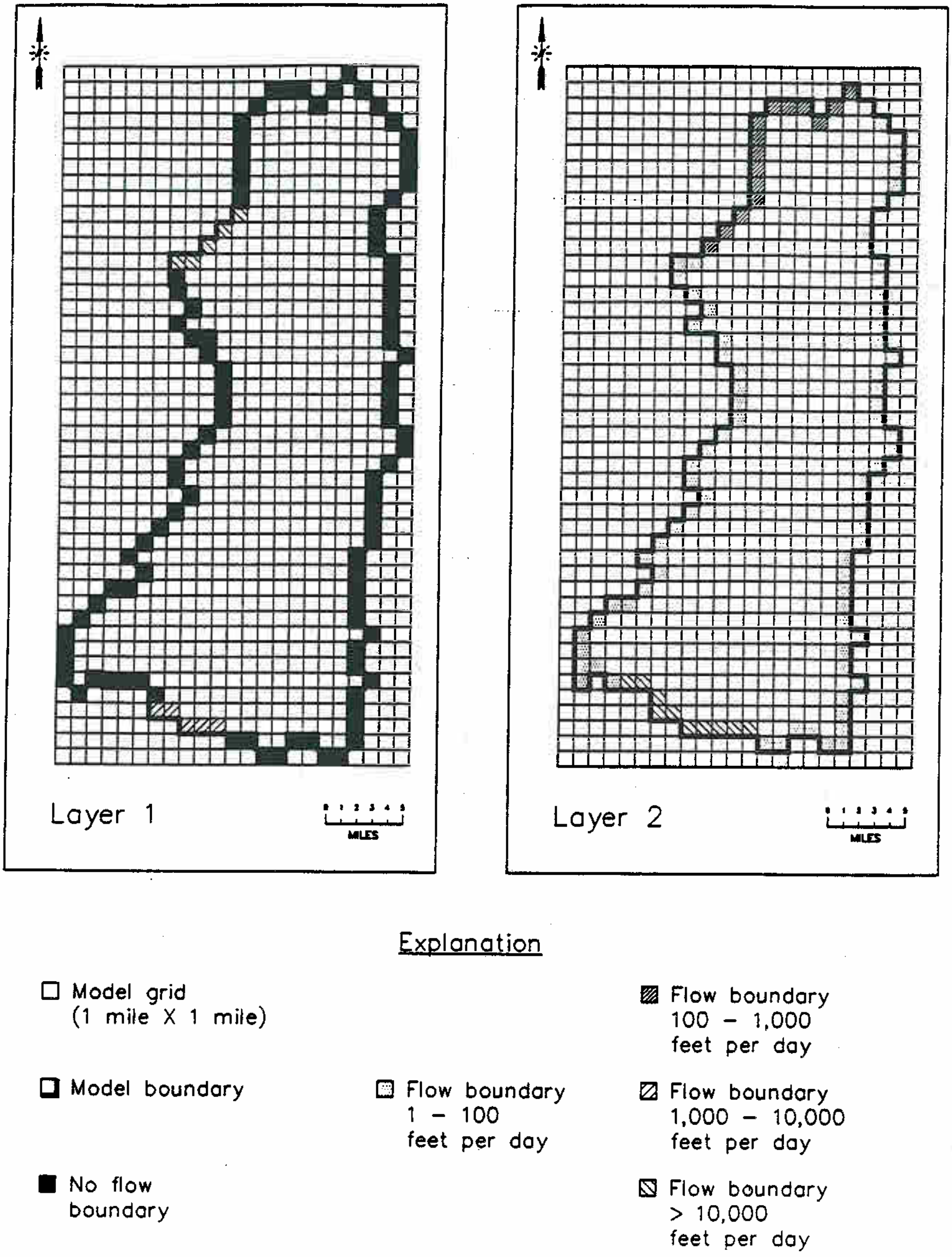


Figure 22.--Boundary conditions used in the model of Pahroc Valley.

Based on the results of the first simulation using uniform transmissivity distributions for the two layers, the transmissivity distributions were assigned based on the hydrogeology of the valley. Transmissivity zones were established for the two modelled layers to reflect the known or inferred hydrologic conditions in the valley. The grid cells representing the volcanic and carbonate rocks were assigned a low transmissivity value while those representing the alluvium were initially assigned a single higher transmissivity value. Subsequent simulations showed that the transmissivity of the alluvium should be higher in areas where the alluvium is thickest, and that the transmissivity of the carbonate aquifer is highly variable due to uneven thickness, the presence of volcanic rocks and that of fractures. Conductances were continually updated as the transmissivities were varied throughout the model calibration process.

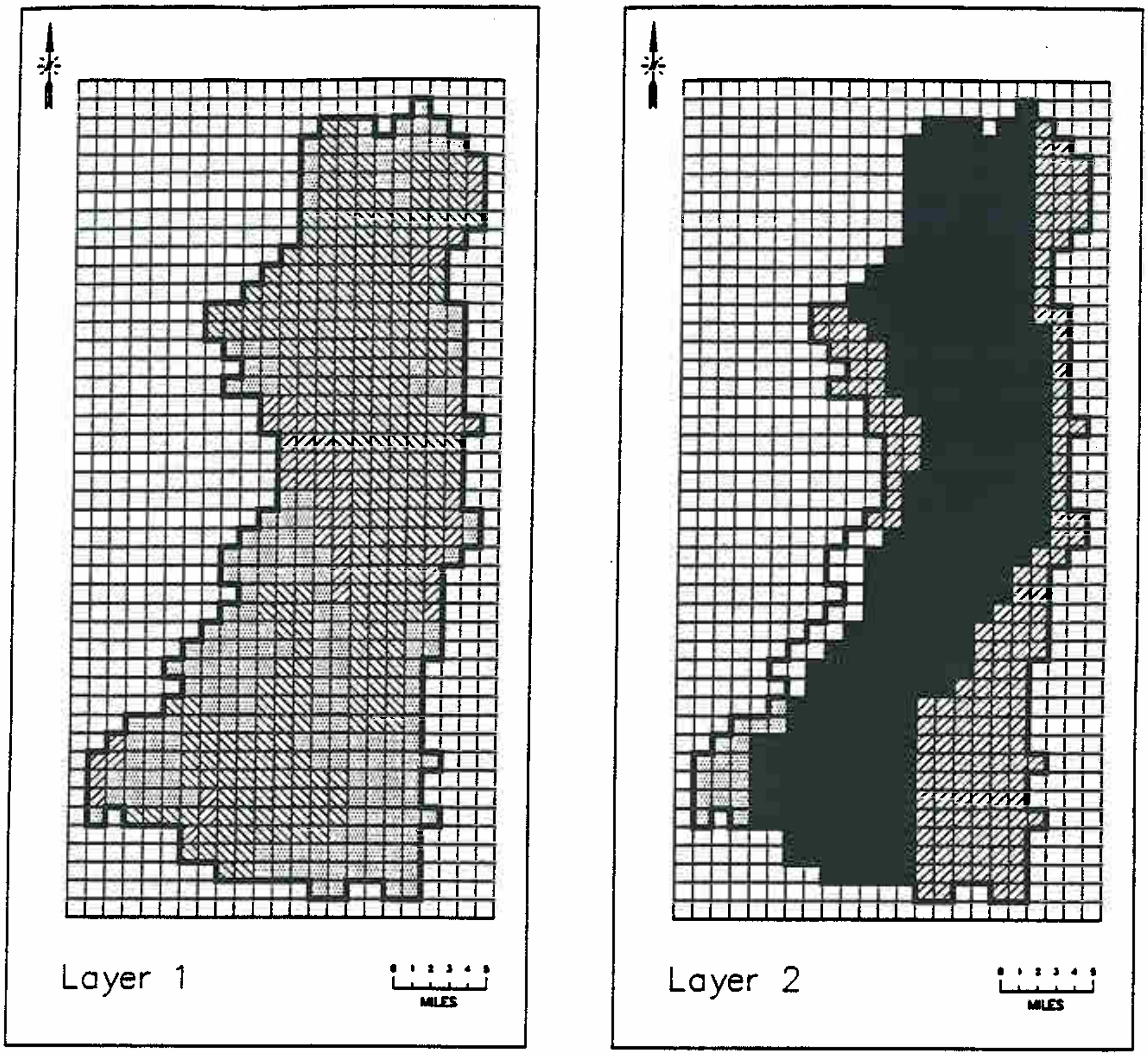
Additional simulations were then made to further calibrate the model. Following each simulation, the hydraulic heads simulated by the model were compared both to the interpreted potentiometric surface of the basin and the individual grid cells representing locations with measured water levels. The water budget for the basin was also compared with the flow balance calculated by MODFLOW at the end of the simulation.

MODEL RESULTS

The zones and associated values of transmissivity that provided the best correlation between the overall water surface, individual measured water levels, and the published estimates of subsurface recharge and discharge for Pahroc Valley, are shown in Figure 23. The transmissivity values fall within the range of published values for both the valley-fill and carbonate aquifers (see Table 2). The alluvial transmissivity falls near the middle of the values that resulted from the aquifer tests performed in Dry Lake Valley as part of the Air Force MX siting studies (Bunch and Harrill, 1984).

The calibrated steady-state potentiometric surfaces for both model layers are shown in Figure 24. The heads simulated by MODFLOW closely agree with the observed potentiometric surfaces for the area (Figure 12). Both the configuration and the slope of the simulated potentiometric surface coincide, with only minor differences, with the map based upon observed potentiometric levels (Figure 12).

The simulated quantity of ground-water discharge out of Pahroc Valley is about 44,000 acre-feet per year. This simulated discharge rate agrees within about 2 percent of the discharge estimate of 45,000 acre-feet per year. The comparison between the published and simulated ground-water budgets for Pahroc Valley is summarized in Table 8. Figure 25 shows the simulated interbasin-flow between Pahroc Valley and adjacent valleys.



Explanation

☐ Model grid
(1 mile X 1 mile)

▣ Model boundary

░ Transmissivity
Value of 10 square
feet per day

▨ Transmissivity
Value of 400 square
feet per day

▧ Transmissivity
Value of 2,500 square
feet per day

■ Transmissivity
Value of 20,000 square
feet per day

Figure 23.--Distribution of transmissivity values in the model of Pahroc Valley.

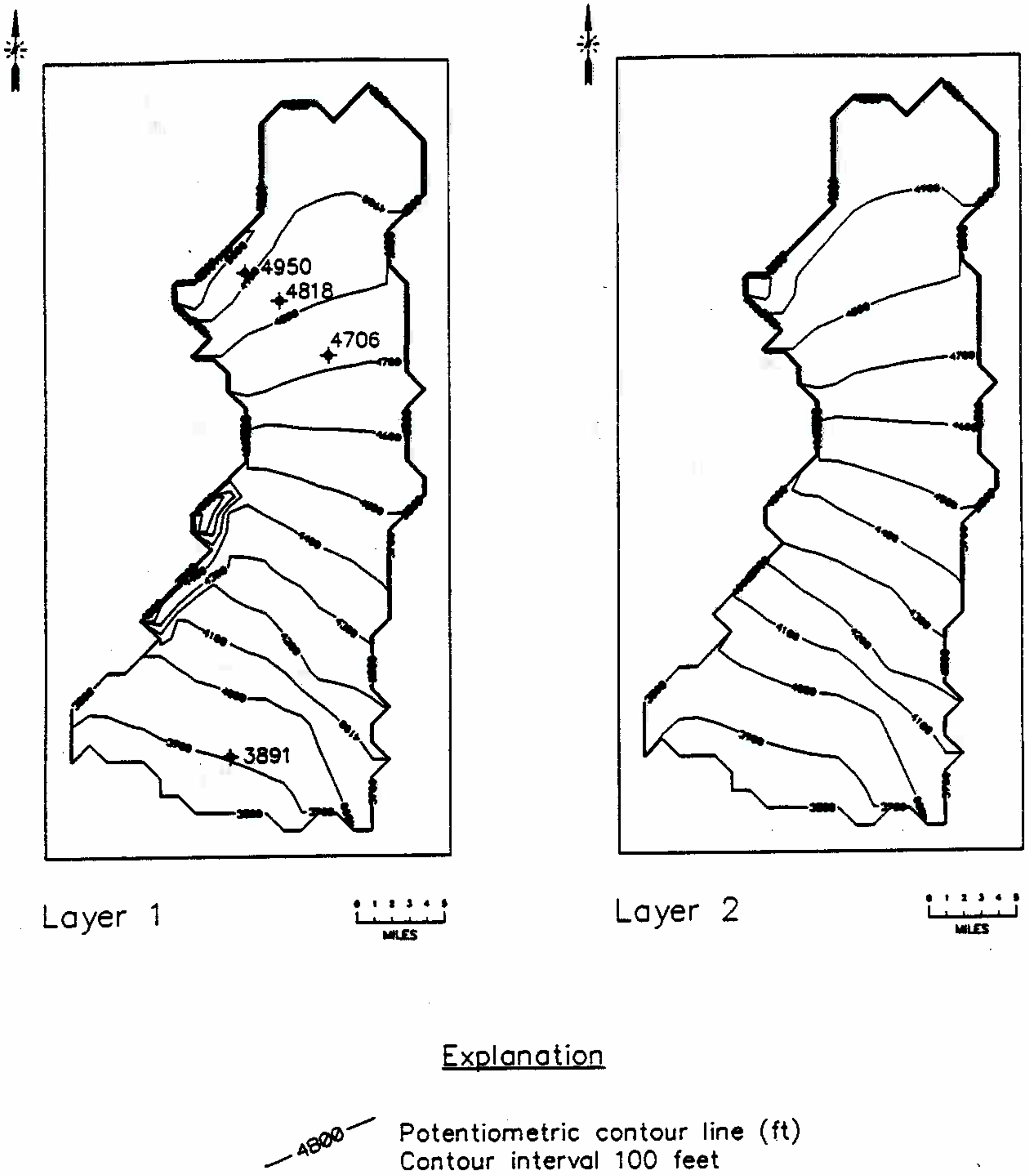


Figure 24.--Simulated steady-state potentiometric surfaces of Pahroc Valley.

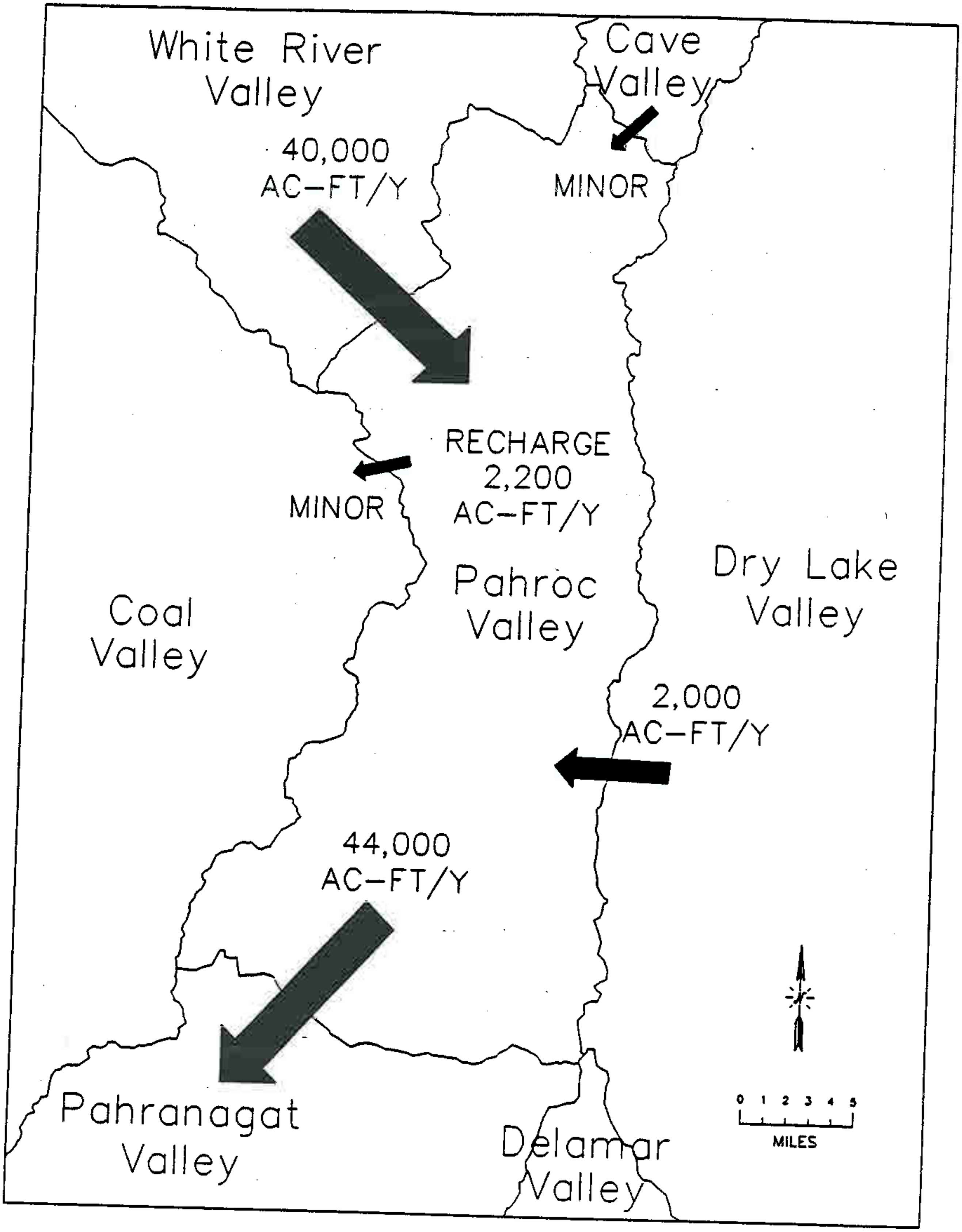


Figure 25.--Interbasin flow between Pahroc Valley and adjacent valleys.

Table 8.--Comparison between published and simulated ground-water budget for Pahroc Valley (stated in acre-feet per year (ac-ft/yr)).

	PUBLISHED VALUE	MODELLED VALUE FOR STEADY-STATE
RECHARGE		
Precipitation (Recharge)	2,200	2,200
Subsurface Inflow	40,000	40,000
Subsurface Inflow Modelled (Dry Lake steady-state model)	2,600	2,000
TOTAL	(rounded) 45,000	(rounded) 44,000
DISCHARGE		
Evapotranspiration	Minor	0
Springs	Minor	0
Water Wells	Minor	0
Outflow	45,000	44,000
TOTAL	45,000	44,000

Source: Scott, et al. (1970), Summit Engineering Corp. and The Mark Group (in press).

The model calibration is discussed further in Appendix D entitled Steady State Model Sensitivity. Because of the close agreement between the simulated water budget and heads and the existing data, the steady-state simulation presented above is considered a reasonably calibrated and accurate mathematical representation of the naturally occurring hydrologic system of Pahroc Valley. The level of calibration achieved further indicates that the assumptions used and values assigned to grid sets for key MODFLOW parameters result in a numerical model that can serve as the basis for simulating the performance and potential impacts of the proposed District water withdrawals in the basin.

The steady-state heads were compared with regional ground-water levels shown in Thomas et al. (1986). There are very few data points in the Pahroc Valley area, however the steady state heads fit within the regional head distribution found in Thomas et al. (1986).

ACCURACY OF HYDROLOGIC DATABASE AND MODEL CODE

The ability of numerical models to provide accurate representations of aquifer systems depends, to a large degree, on two factors: the hydrologic database and the type of model used. In this section, the overall data quality and the limitations of MODFLOW are discussed.

The key limitations of the hydrologic database are the number of data points and their spatial distribution. Water wells are installed to serve developed areas with basic water service and, as a consequence, often are not present in undeveloped areas. This is especially true in the remote areas of Nevada where development may be limited to a few geographic areas within a basin or may even be totally lacking. Thus, the areas of development may have numerous wells completed within relatively short distances of each other while in undeveloped areas it is not uncommon for areas comprising hundreds of square miles to have no wells and hence, no data. In such instances, hydrologists must often infer the hydrologic conditions on the basis of regional data and analog models based upon similar environments in other basins.

As discussed previously, there are only 7 existing water wells in Pahroc Valley and only four of them have water level data usable in the model. The other wells are either dry or do not have any data. Probably, all of these wells tap ground water from the alluvial aquifer. This is not definitely known because there were no well logs available from the wells of Pahroc Valley. To address this data deficiency, wells located in the valley and regional hydrogeologic characterizations were used to develop the conceptual model of Pahroc Valley. In areas where data are not available within the basin or in adjacent valleys, the hydrologic conditions were inferred on the basis of known conditions in similar environments.

If data from peripheral valleys are taken into account in this manner and supplemented with sound hydrologic interpretations of data deficient areas, then a valid conceptual model can be developed for valleys with limited, or no data. The development of a valid conceptual model of this nature is essential to the formulation of any mathematical simulations through modelling.

The data that were used in developing both the conceptual and numerical models of Pahroc Valley are believed to be accurate. The data used were derived from government agencies, particularly the USGS, and from published sources. It is believed that the data were collected using the standard procedures of the individual organizations and represent reliable and accurate information.

Numerical simulations require the use of mathematical expressions that approximate the flow of ground water. The computer code for MODFLOW is well documented and widely used and is considered an appropriate code for simulations of ground-water flow of large basins such as those found in Nevada. There are, however, limitations in the model, as in all models, that should be taken into consideration in assessing the accuracy of any model output.

The distribution and variability of well data and the gradient of the potentiometric surface are two key constraints on the application of the MODFLOW code to hydrographic basins such as Pahroc Valley. MODFLOW uses a block-centered approach rather than a point-centered approach in representing an area. In the point-centered approach, input values for hydrologic parameters and the output from the model are for the four corners of a grid cell. Thus each corner (or node) represents a single point in space and it is possible to interpolate between nodes.

In the block-centered approach, the input values for hydrologic parameters and the output from the model are for entire area represented by the grid cell, in the case of Pahroc Valley, one square mile. Thus, each grid cell is represented by a unique value for the elevation of the potentiometric surface. This representation may become a source of error in areas where the presence of steep hydraulic gradients results in lower potentiometric surface elevations on the downgradient edge of the area represented by the grid cell.

The limitations discussed above are inherent to all models when they are applied to large areas and are not unique to MODFLOW, the code used in this investigation. Because the MODFLOW code was able to provide simulations that closely approximate the configuration of the potentiometric surface (both elevation and slope) as well as the elevation of the potentiometric surface observed at single wells located in areas where these limitations do not occur, the resulting simulations are believed to be accurate representations of the steady-state hydrologic system of Pahroc Valley.

SUMMARY

The hydrogeologic system of Pahroc Valley was characterized based on available existing data. A conceptual model of the hydrologic system was then assembled. Based on the conceptual model of the valley, a steady-state ground-water flow model was constructed. The flow model was calibrated to measured or inferred water levels in the valley and the estimated water budget of the valley. The resulting ground-water flow model is believed to provide a reasonable accurate representation of the steady-state hydrologic system of Pahroc Valley. The steady-state model indicates that substantial water resources exist in the aquifer system of Pahroc Valley.

The developed model simulates time-invariant aquifer responses only, and is thus incapable of predicting responses to stress over time, such as the stress that would be imposed by pumping the proposed District wells. A transient regional model is being constructed by the District incorporating the steady-state model presented in this report and will be used to simulate aquifer responses to pumpage (both District and other) over time.

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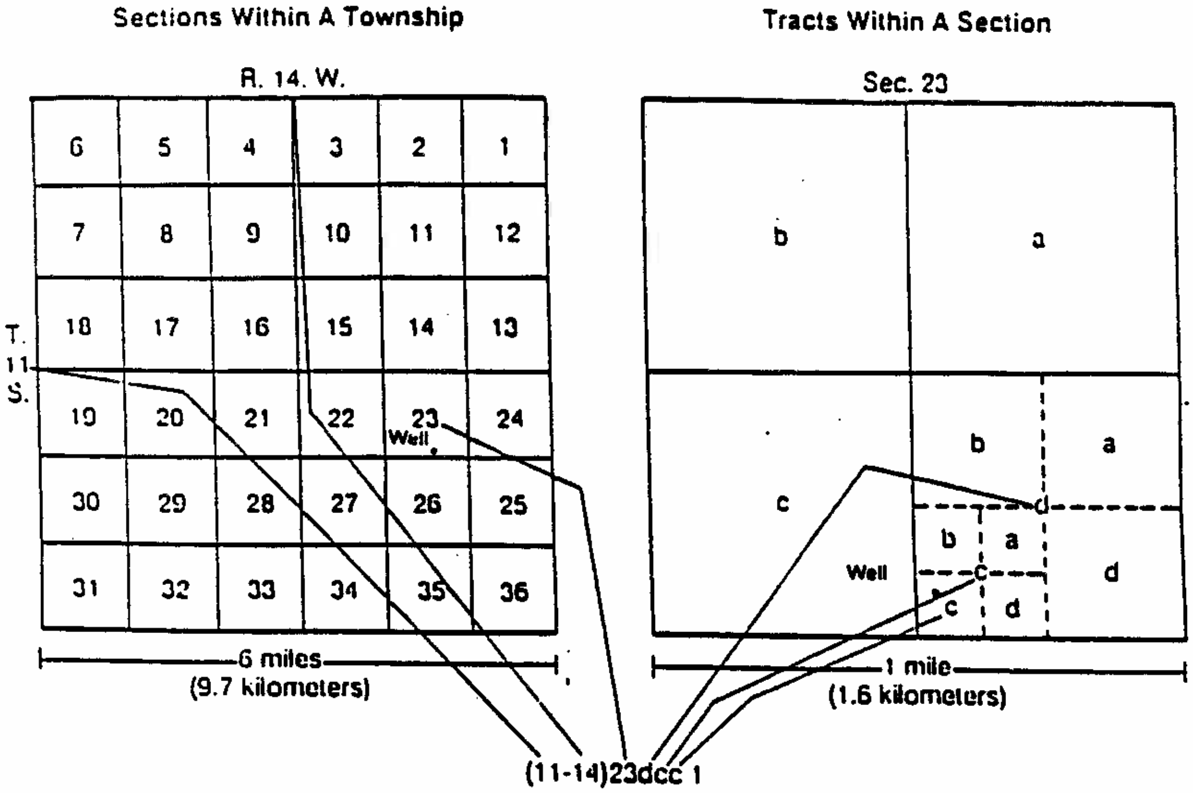
APPENDIX A

Location Designation

LOCATION DESIGNATION



Well and spring locations are designated with respect to the Mount Diablo baseline and meridian as shown diagrammatically above. The first number within the parentheses represents the township south of the baseline and the second number represents the range east of the meridian. The section number follows along with the section 1/4, section 1/16th, and section 1/64th. The letter designations a, b, c, and d refer to the northeast, northwest, southwest, and southeast, respectively. If more than one well occurs within the same 1/64th section, a numerical identifier is added to the end of the designation. Thus (28-63) 27aba1 represents the first well of record in the northeast quarter-section of the northwest quarter-section of the northeast quarter-section of Township 28 South, Range 63 East, Section 27.

APPENDIX B

Water Quality Data in the Vicinity of Pahroc Valley

Water quality data for the vicinity of Pahroc Valley (USGS unpublished data).

Parameter	Units	332517115012001	332522115003901
Station Name		207 N07 E62 31accc	207 N07 E62 21adcd
Latitude		33 25 17 N	33 25 21 N
Longitude		115 01 20 W	115 00 39 W
Date		01/17/84	07/13/81
Temperature Water	Degrees C	23.00	16.50
Temperature Air	Degrees C	-8.00	
Barometric Pressure	(mm of Hg)		
Agency Collecting Sample		1028	1028
Agency Analyzing Sample		80020	80020
Discharge	CFS		
Gage Height	Feet		4.50
Turbidity	NTU		
Specific Conductance	US/cm	420.00	401.00
Oxygen	mg/l		6.10
Oxygen	Percent		
pH	Standard Units	7.50	7.31
pH, Lab	Standard Units	7.50	7.40
Carbon Dioxide Dissolved	mg/L as CO2	14.00	23.00
Alkalinity, Tot FET	mg/l as CaCO3		
Alkalinity, Tot IT	mg/l as CaCO3		
Carbonate Water DIS IT	mg/l as CO3		
Bicarbonate Water WH IT	mg/l as HCO3	270.00	250.00
Bicarbonate Water DIS IT	mg/l as HCO3		
Nitrogen, Organic Total	mg/l as N		
Nitrogen, Ammonia	mg/l as N		
Nitrogen, Ammonia Total	mg/l as N		
Nitrogen, Nitrite	mg/l as N		
Nitrogen, Ammonia + Organic	mg/l as N		
Nitrogen, NO2 + NO3 Dissolved	mg/l as N		
Phosphate, Ortho, Dissolved	mg/l as PO4		
Phosphorous Total	mg/l as P		
Phosphorous Dissolved	mg/l as P		
Phosphorous, Ortho, Dissolved	mg/l as P		
Phosphorous Total	mg/L as PO4		
Hardness Total	mg/l as CaCO3	210.00	210.00
Hardness Noncarb, WH WAT Total	mg/l as CaCO3	0.00	0.00
Calcium Dissolved	mg/L as Ca	50.00	47.00
Magnesium Dissolved	mg/L as Mg	21.00	22.00
Sodium Dissolved	mg/L as Na	10.00	6.00
Sodium Adsorption Ratio		0.30	0.20
Sodium	Percent	9.30	6.00
Potassium Dissolved	mg/L as K	1.40	2.50
Chloride Dissolved	mg/L as Cl	6.50	4.70
Sulfate Dissolved	mg/L as SO4	12.00	8.00

Water quality data for the vicinity of Pahroc Valley (USGS unpublished data).

Parameter	Units	382517115012201	382522115004201
Fluoride Dissolved	mg/L as F	0.23	0.13
Silica Dissolved	mg/L as SiO2	25.00	23.00
Arsenic Dissolved	ug/L as As		
Barium Dissolved	ug/L as Ba	74.00	50.00
Boron Dissolved	ug/L as B		30.00
Bismuth Dissolved	ug/L as Bi		
Beryllium Dissolved	ug/L as Be	< 0.50	< 1.00
Cadmium Dissolved	ug/L as Cd	< 1.00	< 1.00
Chromium Dissolved	ug/L as Cr		
Cobalt Dissolved	ug/L as Co	< 3.00	< 3.00
Copper Dissolved	ug/L as Cu	< 10.00	< 10.00
Iron Dissolved	ug/L as Fe	< 3.00	< 10.00
Lead Dissolved	ug/L as Pb	10.00	< 10.00
Manganese Dissolved	ug/L as Mn	2.00	< 1.00
Molybdenum Dissolved	ug/L as Mo	< 10.00	< 10.00
Nickel Dissolved	ug/L as Ni		
Silver Dissolved	ug/L as Ag		
Strontium Dissolved	ug/L as Sr	180.00	170.00
Vanadium Dissolved	ug/L as V	< 6.00	< 5.00
Zinc Dissolved	ug/L as Zn	17.00	37.00
Antimony Dissolved	ug/L as Sb		
Tin Dissolved	ug/L as Sn		
Aluminum Dissolved	ug/L as Al		
Cesium Dissolved	ug/L as Cs		
Gallium Dissolved	ug/L as Ga		
Germanium Dissolved	ug/L as Li		
Lithium Dissolved	ug/L as Li	22.00	13.00
Rubidium Dissolved	ug/L as Rb		
Selenium Dissolved	ug/L as Se		
Titanium Dissolved	ug/L as Ti		
Zirconium Dissolved	ug/L as Zr		
Tritium Total	pCi/L		4.00
Gross Beta Dissolved	pCi/L as Cs-137		
Gross Beta, Suspended,	pCi/L as Cs-137		
Radium-226, Radon Method	pCi/l		
Uranium, Natural, Dissolved,	ug/l as U		1.70
Carbon 14, Diss., Apparent Age	Years BP		7600
Coliform, Fecal, 0.7 UM-MF	Cols./100 ml		
Streptococci, Fecal, KF AGAR	Cols./100 ml		
Alkalinity WAT DIS TOT IT Field	mg/l as CaCO3		
Solids, Susp., Residue, Dissolved	110 degrees C, mg/L		
Solids, Residue, Dissolved	180 degrees C, mg/L		
Solids, Sum of Constituents,	mg/l	252	241
Solids Dissolved	Tons per Day	0.00	3.02
Solids Dissolved,	Tons/Acre-Foot	0.35	0.33
Sediment Suspended	Sieve Diam. < 0.062 m		

Water quality data for the vicinity of Pahroc Valley (USGS unpublished data).

Parameter	Units	392517115012001	392524115004001
Nitrogen, Ammonia Dissolved	mg/l as NH4		
Nitrogen, Nitrate Dissolved	mg/l as NO3		
Nitrogen, Nitrite Dissolved	mg/l as NO2		
Bromide Dissolved	mg/L as Br		
Mercury Dissolved	ug/l as Hg		
Elevation of Land Surface Datum	feet above NGVD	5290.00	5320.00
Depth of Well	Feet		
C-13/C-12 Stable Isotope Ratio	Per Mil	-7.80	
H-2/H-1 Stable Isotope Ratio	Per Mil	-125.00	-105.00
O-18/O-16 Stable Isotope Ratio	Per Mil	-14.30	-14.20
S-34/S-32 Stable Isotope Ratio	Per Mil		1.83
U-234/U-238 Stable Isotope Ratio	Per Mil		4.70
Carbon 14, Modern	Percent		
Uranium Dissolved, Extraction	ug/l		
Gross Alpha, Dissolved	ug/l as U-Nat		
Gross Alpha, Suspended	ug/l as U-Nat		
Gross Beta, Dissolved	pci/l as Sr/Yt-90		
Gross Beta, Suspended	pci/l as Sr/Yt-90		
Sediment, Suspended	mg/l		
Sediment, Discharge, Suspended	T/Day		
Drainage Area	Sq. Miles		
Sampling Method Codes			
Specific Conductance, Lab	us/cm	444	435
Alkalinity, Lab	mg/l as CaCO3		
Bromide, Dissolved	ug/L		
Call USGS for Expl. of Code 99890			

Water quality data for the vicinity of Pahroc Valley (USGS unpublished data).

Parameter	Units	382214115285201	382239115223101	382257115090901
Station Name		207 N05 E34 Big Spg - Grant Rng	207 N05 E59 13daa Forest Home Spring	207 N05 E61 13aa 1
Latitude		38 22 14 N	38 22 39 N	38 22 57 N
Longitude		115 28 52 W	115 22 31 W	115 09 09 W
Date		07/24/85	07/24/85	07/13/81
Temperature Water	Degrees C	12.50	14.00	12.50
Temperature Air	Degrees C			
Barometric Pressure	(mm of Hg)			
Agency Collecting Sample		1028	1028	1028
Agency Analyzing Sample		80022	80022	80022
Discharge	CFS			20.30
Gage Height	Feet			
Turbidity	NTU			
Specific Conductance	US/cm			530.00
Oxygen	mg/l		5.30	1.50
Oxygen	Percent			
pH	Standard Units	8.10	7.63	7.22
pH, Lab	Standard Units	7.30	8.20	7.70
Carbon Dioxide Dissolved	mg/L as CO2	1.40	12.00	27.30
Alkalinity, Fet FET	mg/l as CaCO3	220.00	254.00	
Alkalinity, Fet IT	mg/l as CaCO3			
Carbonate Water DIS IT	mg/l as CO3			
Bicarbonate Water WH IT	mg/l as HCO3	268.00	310.00	280.30
Bicarbonate Water DIS IT	mg/l as HCO3			
Nitrogen, Organic Total	mg/l as N	0.17	0.28	
Nitrogen, Ammonia	mg/l as N	0.01	0.02	
Nitrogen, Ammonia Total	mg/l as N			
Nitrogen, Nitrite	mg/l as N			
Nitrogen, Ammonia + Organic	mg/l as N	0.20	0.30	
Nitrogen, NO2 + NO3 Dissolved	mg/l as N	0.25	1.40	
Phosphate, Ortho, Dissolved	mg/L as PO4			
Phosphorous Total	mg/l as P			
Phosphorous Dissolved	mg/l as P		< 0.01	
Phosphorous, Ortho, Dissolved	mg/l as P		< 0.01	
Phosphorous Total	mg/L as PO4			
Hardness Total	mg/l as CaCO3	220.00	260.00	233.00
Hardness Noncarb, WH WAT Total	mg/l as CaCO3	5.00	9.00	5.00
Calcium Dissolved	mg/L as Ca	78.00	62.00	53.00
Magnesium Dissolved	mg/L as Mg	7.00	25.00	21.00
Sodium Dissolved	mg/L as Na	6.90	9.30	24.00
Sodium Adsorption Ratio		0.10	0.30	0.70
Sodium	Percent			18.30
Potassium Dissolved	mg/L as K			5.50
Chloride Dissolved	mg/L as Cl	2.10	6.30	10.30
Sulfate Dissolved	mg/L as SO4	13.00	19.30	15.00

Water quality data for the vicinity of Pahroc Valley (USGS unpublished data).

Parameter	Units	392214115235231	382237115222131	382259115232101
Fluoride Dissolved	mg/L as F			0.70
Silica Dissolved	mg/L as SiO2	9.53	14.00	23.00
Arsenic Dissolved	ug/L as As			
Barium Dissolved	ug/L as Ba	43.00	57.00	122.00
Boron Dissolved	ug/L as B			130.00
Bismuth Dissolved	ug/L as Bi			
Beryllium Dissolved	ug/L as Be		< 0.50	< 1.00
Cadmium Dissolved	ug/L as Cd		< 1.00	< 1.00
Chromium Dissolved	ug/L as Cr			
Cobalt Dissolved	ug/L as Co		< 3.00	< 3.00
Copper Dissolved	ug/L as Cu		< 13.00	< 10.00
Iron Dissolved	ug/L as Fe			< 13.00
Lead Dissolved	ug/L as Pb			< 10.00
Manganese Dissolved	ug/L as Mn			< 1.00
Molybdenum Dissolved	ug/L as Mo			< 10.00
Nickel Dissolved	ug/L as Ni			
Silver Dissolved	ug/L as Ag			
Strontium Dissolved	ug/L as Sr			420.00
Vanadium Dissolved	ug/L as V			< 6.00
Zinc Dissolved	ug/L as Zn			< 3.00
Antimony Dissolved	ug/L as Sb			
Tin Dissolved	ug/L as Sn			
Aluminum Dissolved	ug/L as Al			
Cesium Dissolved	ug/L as Cs			
Gallium Dissolved	ug/L as Ga			
Germanium Dissolved	ug/L as Ge			
Lithium Dissolved	ug/L as Li	7.00	9.00	66.00
Rubidium Dissolved	ug/L as Rb			
Selenium Dissolved	ug/L as Se			
Titanium Dissolved	ug/L as Ti			
Zirconium Dissolved	ug/L as Zr			
Tritium Total	pCi/L			2.00
Gross Beta Dissolved	pCi/L as Cs-137			
Gross Beta, Suspended,	pCi/L as Cs-137			
Radium-226, Radon Method	pCi/L			
Uranium, Natural, Dissolved,	ug/L as U			1.50
Carbon 14, Diss., Apparent Age	Years BP			25500
Coliform, Fecal, 0.7 UM-MF	Cols./100 ml			
Streptococci, Fecal, KF AGAR	Cols./100 ml			
Alkalinity WAT DIS TOT IT Field	mg/L as CaCO3			
Solids, Susp., Residue, Dissolved	105 degrees C, mg/L			
Solids, Residue, Dissolved	180 degrees C, mg/L			
Solids, Sum of Constituents	mg/L	243	297	333
Solids Dissolved	Tons per Day	0.00	0.00	13.20
Solids Dissolved,	Tons/Acre-Foot	0.34	0.01	0.45
Sediment Suspended	Sieve Diam. < 0.062 mm			

Water quality data for the vicinity of Pahroc Valley (USGS unpublished data).

Parameter	Units	382214115235201	382237115223101	37225911509[illegible]
Nitrogen, Ammonia Dissolved	mg/l as NH4	0.04	0.04	
Nitrogen, Nitrate Dissolved	mg/l as NO3			
Nitrogen, Nitrite Dissolved	mg/l as NO2			
Bromide Dissolved	mg/L as Br			
Mercury Dissolved	ug/l as Hg			
Elevation of Land Surface Datum	Feet above NGVD			5225.00
Depth of Well	Feet			
C-13/C-12 Stable Isotope Ratio	Per Mil			
H-2/H-1 Stable Isotope Ratio	Per Mil	112.00	104.90	-113.00
O-18/O-16 Stable Isotope Ratio	Per Mil			-13.50
S-34/S-32 Stable Isotope Ratio	Per Mil			
U-234/U-238 Stable Isotope Ratio	Per Mil			4.73
Carbon 14, Modern	Percent			
Uranium Dissolved, Extraction	ug/l			
Gross Alpha, Dissolved	ug/l as U-Nat			
Gross Alpha, Suspended	ug/l as U-Nat			
Gross Beta, Dissolved	pci/l as Sr/Yt-90			
Gross Beta, Suspended	pci/l as Sr/Yt-90			
Sediment, Suspended	mg/l			
Sediment, Discharge, Suspended	T/day			
Drainage Area	Sq. Miles			
Sampling Method Codes				
Specific Conductance, Lab	us/cm	354	518	557
Alkalinity, Lab	mg/l as CaCO3			
Bromide, Dissolved	ug/L			
Call USGS for Expl. of Code 73490				

Water quality data for the vicinity of Pahroc Valley (USGS unpublished data).

Parameter	MAP USGS ID Number Units	372750115113001	373153115135301
Station Name		209 S05 E60 36d 1 Little Ash Spring	209 S05 E60 10ada Crystal Spring
Latitude		37 27 50 N	37 31 53 N
Longitude		115 11 30 W	115 13 58 W
Date		02/04/74	07/20/81
Temperature Water	Degrees F	96.80	81.50
Agency Collecting Sample			1028
Agency Analyzing Sample			80020
Discharge	CFS		12.00
Specific Conductance	US/cm	497.00	408.00
Oxygen	mg/l		1.80
pH, Field	Standard Units		7.34
pH, Lab	Standard Units	7.60	7.80
Carbon Dioxide Dissolved	mg/L as CO2		19.00
Carbonate Water DIS IT	mg/l as CO3	0.00	
Bicarbonate Water WH IT	mg/l as HCO3	270.00	260.00
Phosporous Dissolved	mg/l as P	< 0.10	
Hardness Total	mg/l as CaCO3	200.00	190.00
Hardness Noncarb, WH WAT Total	mg/l as CaCO3	0.00	0.00
Calcium Dissolved	mg/L as Ca	56.00	43.00
Magnesium Dissolved	mg/L as Mg	14.00	21.00
Sodium Dissolved	mg/L as Na	31.00	22.00
Sodium Adsorption Ratio		1.00	0.70
Sodium	Percent	25.00	19.00
Potassium Dissolved	mg/L as K	5.60	5.00
Chloride Dissolved	mg/L as Cl	21.00	8.90
Sulfate Dissolved	mg/L as SO4	34.00	34.00
Fluoride Dissolved	mg/L as F	8.70	0.30
Silica Dissolved	mg/L as SiO2	29.00	25.00
Arsenic Dissolved	ug/L as As	2.00	
Barium Dissolved	ug/L as Ba	320.00	90.00
Boron Dissolved	ug/L as B		100.00
Bismuth Dissolved	ug/L as Bi	< 100.00	
Beryllium Dissolved	ug/L as Be	< 5.00	< 1.00
Cadmium Dissolved	ug/L as Cd	5.00	< 1.00
Chromium Dissolved	ug/L as Cr	< 20.00	
Cobalt Dissolved	ug/L as Co		< 3.00

Water quality data for the vicinity of Pahroc Valley (USGS unpublished data).

Parameter	MAP USGS ID Number Units	372753115113001	373153115135301
Copper Dissolved	ug/L as Cu	< 20.00	< 10.00
Iron Dissolved	ug/L as Fe	< 10.00	< 10.00
Lead Dissolved	ug/L as Pb	< 20.00	< 10.00
Manganese Dissolved	ug/L as Mn	< 10.00	< 1.00
Molybdenum Dissolved	ug/L as Mo		< 10.00
Nickel Dissolved	ug/L as Ni	20.00	
Silver Dissolved	ug/L as Ag	< 20.00	
Strontium Dissolved	ug/L as Sr	320.00	270.00
Vanadium Dissolved	ug/L as V		< 6.00
Zinc Dissolved	ug/L as Zn	2000.00	11.00
Antimony Dissolved	ug/L as Sb	< 100.00	
Tin Dissolved	ug/L as Sn	< 50.00	
Cesium Dissolved	uB/L as Cs	400	
Lithium Dissolved	ug/L as Li	61.00	31.00
Rubidium Dissolved	ug/L as Rb	30.00	
Selenium Dissolved	ug/L as Se	< 1.00	
Tritium Total	pci/L		2.00
Uranium, Natural, Dissolved,	ug/l as U		3.80
Carbon 14, Diss., Apparent Age	Years BP		20500
Solids, Sum of Constituents,	mg/l	334	288
Solids Dissolved	Tons per Day	0.00	9.16
Solids Dissolved,	Tons/Acre-Foot	0.45	0.39
Nitrogen, Ammonia Dissolved	mg/l as NH4	< 0.20	
Nitrogen, Nitrate Dissolved	mg/l as NO3	0.71	
Mercury Dissolved	ug/l as Hg	< 0.50	
Elevation of Land Surface Datum	feet above NGVD	3610.00	
C-13/C-12 Stable Isotope Ratio	Per Mil		
H-2/H-1 Stable Isotope Ratio	Per Mil		-109.00
O-18/O-16 Stable Isotope Ratio	Per Mil		-14.30
S-34/S-32 Stable Isotope Ratio	Per Mil		13.85
U-238/U-236 Stable Isotope Ratio	Per Mil		3.10
Carbon 14, Modern	Percent		7.80
Specific Conductance, Lab	us/cm		492

Water quality data for the vicinity of Pahroc Valley (Bunch & Harrill, 1984).

SELECTED WATER QUALITY DATA

ID. NO.	TOWNSHIP RANGE-SECT	SRCE	MO YR	STATION NAME	TEMP DEG C	SP. COND	PH	DISS. SOLIDS	SILICA (SIO2)	CALCIUM (CA)	MAGNESIUM (MG)	SODIUM (NA)
1	3N/59E-10CD1	WE	9-80	USAF TEST WELL	23.0	443	8.1	256	24	64	13	6.0
2	3N/59E-12BD1	WE	12-80	USAF TEST WELL	23.0	430	7.7	253	35	38	19	18
3	7N/61E-29CA	SP	6-80	OCEANA SPRING	12.0	500	6.7	--	24	82	9.1	23
4	1S/59E-34CB2	WE	5-81	USAF TEST WELL	--	348	7.4	232	62	17	4.3	49
5	1S/59E-34CB2	WE	5-81	USAF TEST WELL	--	290	7.8	258	52	15	3.5	52
6	1S/59E-34CB2	WE	6-81	USAF TEST WELL	--	300	8.0	270	56	15	3.6	47
7	1S/59E-34CB2	WE	6-81	USAF TEST WELL	--	300	7.9	272	55	16	3.7	47
8	3N/63E-27CA	WE	12-80	USAF TEST WELL	27.0	650	7.3	366	24	76	30	18

ID. NO.	POTASSIUM (K)	CARBONATE (CO3)	BICARB. (HCO3)	CHLORIDE (CL)	SULFATE (SO4)	FLUORIDE (F)	NITRATE (N)	BORON (B)	IRON (FE)	MANGANESE (MN)	REMARKS	REFERENCE
1	1.9	1	255	7.3	18	.4	1.2	--	--	--	*2	ERTEC 80
2	4.0	0	221	5.0	20	.5	ND	--	--	--		ERTEC 80
3	2.0	0	303	14	26	.2	6.2	--	--	--	*2	ERTEC 80
4	5.9	--	159	9.0	24	.3	.8	200	30	ND	*2	ERTEC
5	5.9	--	134	9.0	25	--	3.6	10.0	15	ND	*2	ERTEC
6	6.3	--	136	11	24	.4	3.8	100	40	ND	*2	ERTEC
7	6.3	--	136	11	26	.4	3.9	100	20	ND	*2	ERTEC
8	6.5	0	404	5.0	20	.4	ND	--	--	--		ERTEC 80

DISSOLVED SOLIDS FOR ERTEC SAMPLES DETERMINED BY RESIDUE -ON- EVAPORATION AT 180 DEGREE C.
NEVADA LOCATIONS BASED ON MT. DIABLO BASELINE. UTAH LOCATIONS BASED ON SALT LAKE BASELINE AND MERIDIAN.
SPECIFIC CONDUCTANCE REPORTED IN MICROMHOS/CM AT 25 DEGREES C.

THE FOLLOWING CONSTITUENTS ARE REPORTED IN MICROGRAMS/LITER:
BORON IRON MANGANESE

FOOT *1 NITRATE REPORTED AS N
NOTES:*2 NITRATE REPORTED AS NO3
*3 NITRITE + NITRATE REPORTED AS N
*4 DISSOLVED SOLIDS BY SUM OF DETERMINED CONSTITUENTS
*5 NA+K AS NA
*6 HCO3+CO3 AS HCO3
ND = NOT DETECTED
ALL ANALYSIS REPORTED IN MG/L EXCEPT AS NOTED

APPENDIX C

National Drinking-Water Standards

Appendix C. National Drinking-Water Standards.

Part A. National Interim Primary Drinking-Water Standards[a], Accepted Detection Limits, and Maximum Contaminant Levels.

Constituent	Detection Limits (ug/l)[b]	Maximum Contaminant Level (MCL)[c]
Arsenic dissolved	1	0.005
Barium dissolved	100	1
Cadmium dissolved	1	0.010
Chromium dissolved	10	0.05
Lead dissolved	5	0.05
Mercury dissolved	.1	0.002
Nitrate (as N) total	TBD	10
Selenium dissolved	1	0.01
Silver dissolved	1	0.05
Fluoride dissolved	TBD	1.4-4.0
Coliform bacteria	1/100 ml	1/100 ml (mean)
Endrin total	.01	0.0002
Lindane total	.01	0.004
Methoxychlor total	.01	0.1
Toxaphene total	.1	0.005
2,4-D total	.01	0.1
2,4,5-TP Silvex total	.01	0.01
Total trihalomethanes[d]	.01	0.10
Radionuclides (dissolved)		
Radium 226 and 228 (combined)	.1	5 pCi/L
Gross alpha particle activity	TBD	15 pCi/L
Gross beta particle activity	TBD	4 mrem/yr

Part B. National Secondary Drinking-Water Standards[e].

Constituent	Maximum Contaminant Level (MCL)[f]
Chloride	250
Color	15 Color Units
Copper	1
Corrosivity	Noncorrosive
Dissolved solids	500
Foaming agents	0.5
Iron	0.3
Manganese	0.05
Odor	3 (threshold odor number)
pH	6.6-8.5 Units
Sulfate	250
Zinc	5

[a] Data from EPA (1982a), 40 CFR Part 141.

[b] Detection limits are those typically achievable using approved analytical procedures and may vary by lab and state requirements.

[c] Data are given in milligrams per liter (mg/l) unless otherwise specified.

[d] The sum of the concentrations of bromodichloromethane, dibromochloromethane, tribromomethane (bromoform) and trichloromethane (chloroform).

[e] Data from EPA (1982b) 40 CFR Part 143.

[f] Data are given in milligrams per liter (mg/l) unless otherwise specified.

APPENDIX D

Steady State Model Sensitivity

APPENDIX D

STEADY STATE MODEL SENSITIVITY

By Kay Brothers and Dr. James Tracy

A steady state simulation is a simulation in which recharge and pumping rates are held constant with no change in ground-water storage, so that model-predicted ground-water levels are representative of long-term stabilized ground-water conditions in the natural environment. Therefore, the steady-state simulation will agree with historic measured water levels if appropriate hydraulic parameters are used in the simulation model. Model hydraulic parameters are adjusted until the steady-state simulation closely approximates the historical ground-water levels. The adjusted parameters must be reasonable. Both the number of differing and discernable values and the range of these values must be consistent with the occurrence of strata which possess these properties and the estimated range, or variabilities of these properties, based on field observations and testing of these properties of the strata.

The primary purpose of the steady-state simulations is to calibrate the model. Transmissivity can be calibrated if sufficient water level elevations are known. This was done as a part of the present study. Calibration of Pahroc Valley ground-water model was accomplished using several constraints that were identified in the Model Calibration section of this report.

The calibration of the model was carried out so that the total quantity of ground-water flow was held fixed to the estimates made in Eakin (1963) and Harrill (1988) with an additional ground-water inflow that resulted from the preparation of the Dry Lake Valley steady state model by The MARK Group. Therefore, the transmissivities of the modelled units, the leakance between these units, and the conductances used in the general head boundary conditions that connect the modelled area to the surrounding basins in the White River ground-water flow system are constrained so that only these quantities of water are available.

The calibration of the model was also carried out so that observed ground-water levels and the gradient or changes between these levels within the modelled area were also matched as well as possible with little subjective changes in the model parameters. All of the initial parameters of the model were set at the initial estimates for the hydrogeologic strata that comprised the aquifer units. All of the inflow outflow from the modelled area occurs through the White River flow system; therefore, the properties, or parameters, related to the mechanisms of flow are constrained by the estimated rate of flow. In particular, the ground-water outflow from the modelled area occurs almost exclusively through the lower carbonate aquifer from Pahroc to Pahranagat Valley so that the transmissivities and general head conductances relevant to this unit must result in the flow of this quantity of water under the known ground-water gradient.

The ground-water levels in the wells shown in Table 1 of the report were used during the calibration. The ground-water levels, resulting from the calibration are shown in Figure 24, together with the observed ground-water levels.

Model Parameter Sensitivities

Sensitivity simulations were done to determine the effects of each parameter on the ground-water levels and flows. These parameters are the transmissivities (L1T1, L2T1, etc.) and leakances (TK1). The sensitivities were performed about the calibrated values of the model and represent the linearized change in water level elevation that would occur with a change in the specific parameter value. The model rows and columns for the observation wells are listed below in Table 1 with each well in Pahroc Valley for correlation. The sensitivities represent the estimated change in ground-water level at the wells with a 100 percent increase in the calibrated values that have been previously reported in the Model Calibration section of this report. The results of these sensitivity simulations are discussed briefly.

Table 1.--Results of sensitivity runs, variations in feet.

Well Location	Row/Col	Water Level	Model Simulated W/L	Δ[2]	L1T1[1]	L1T2	L1T3	L2T1	L2T2	L2T3	TK1
<u>layer 1</u>											
4N 61E 36c1	12 12	4950	4921	-19	+23	-1	0	-96	+1	0	+8
3N 62E 17b1	14 14	4818	4824	+6	+22	0	0	-108	+1	0	+18
3N 62E 35bbb1	17 17	4706	4722	+16	+21	0	0	-98	0	0	+16
2S 61E 23d1	40 11	3891	3901	+10	+6	0	0	+9	+1	0	-1

1) Variable - Layer 1, Transmissivity 1
2) Difference between model simulated water level and actual water level

Analyses of the sensitivity simulations resulted in several general observations and estimated model properties. All of the wells are located in the alluvium. However, the transmissivity of the alluvial, valley-fill aquifer produced less significant changes in ground-water levels and flows over the modelled area than did similar changes in the lower, carbonate aquifer transmissivities. The transmissivity of the carbonate unit was based on and was constrained by the estimated outflow and the ground-water gradient across the modelled area. Changes in the volcanic aquifer and upper layer carbonate aquifer transmissivities and the leakance between the layers did not produce significant changes in the ground-water levels.