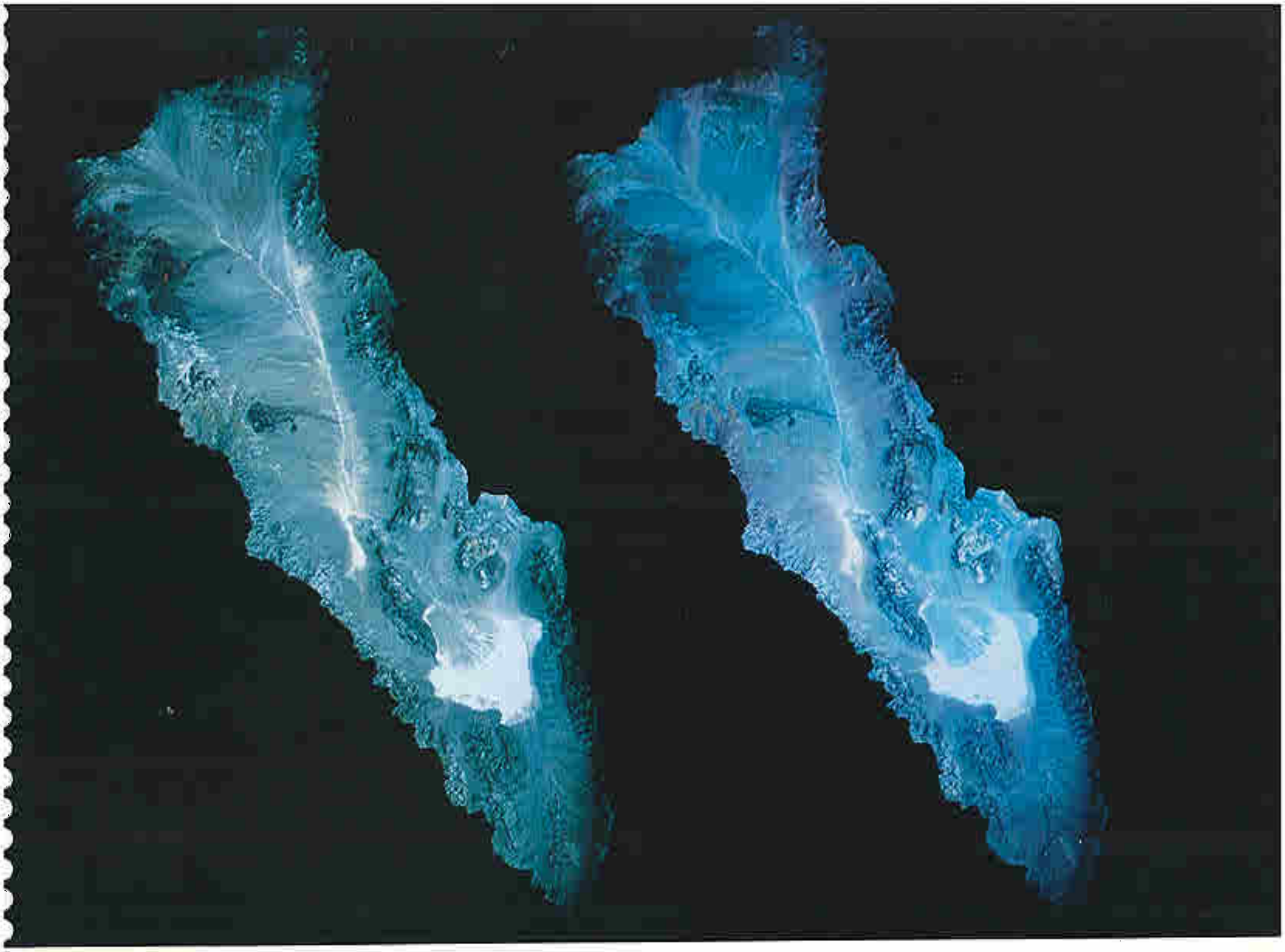

HYDROLOGY AND STEADY STATE GROUND-WATER MODEL OF TIKABOO VALLEYS NORTH AND SOUTH, CLARK AND LINCOLN COUNTIES, NEVADA

1992

Las Vegas Valley Water District

COOPERATIVE WATER PROJECT
Water for Nevada's Future
Report No. 6
Hydrographic Basin 169 A & B

HYDROLOGY AND STEADY STATE GROUND-WATER MODEL OF TIKABOO VALLEYS NORTH AND SOUTH, CLARK AND LINCOLN COUNTIES, NEVADA

1992

By

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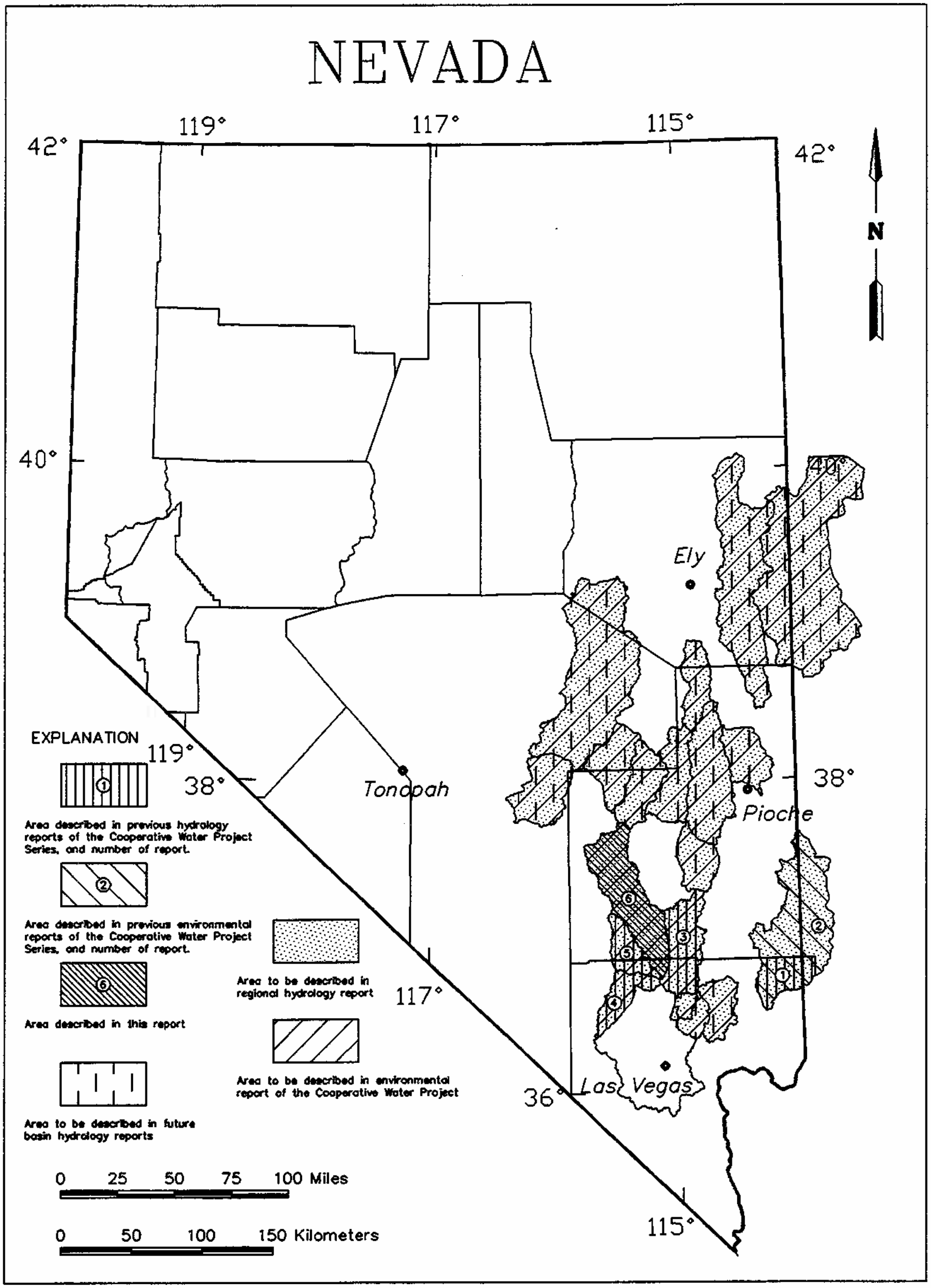


Areas described in previous reports of this series, the area described in this report and the areas to be described in future reports.

INTRODUCTION

Purpose and Scope

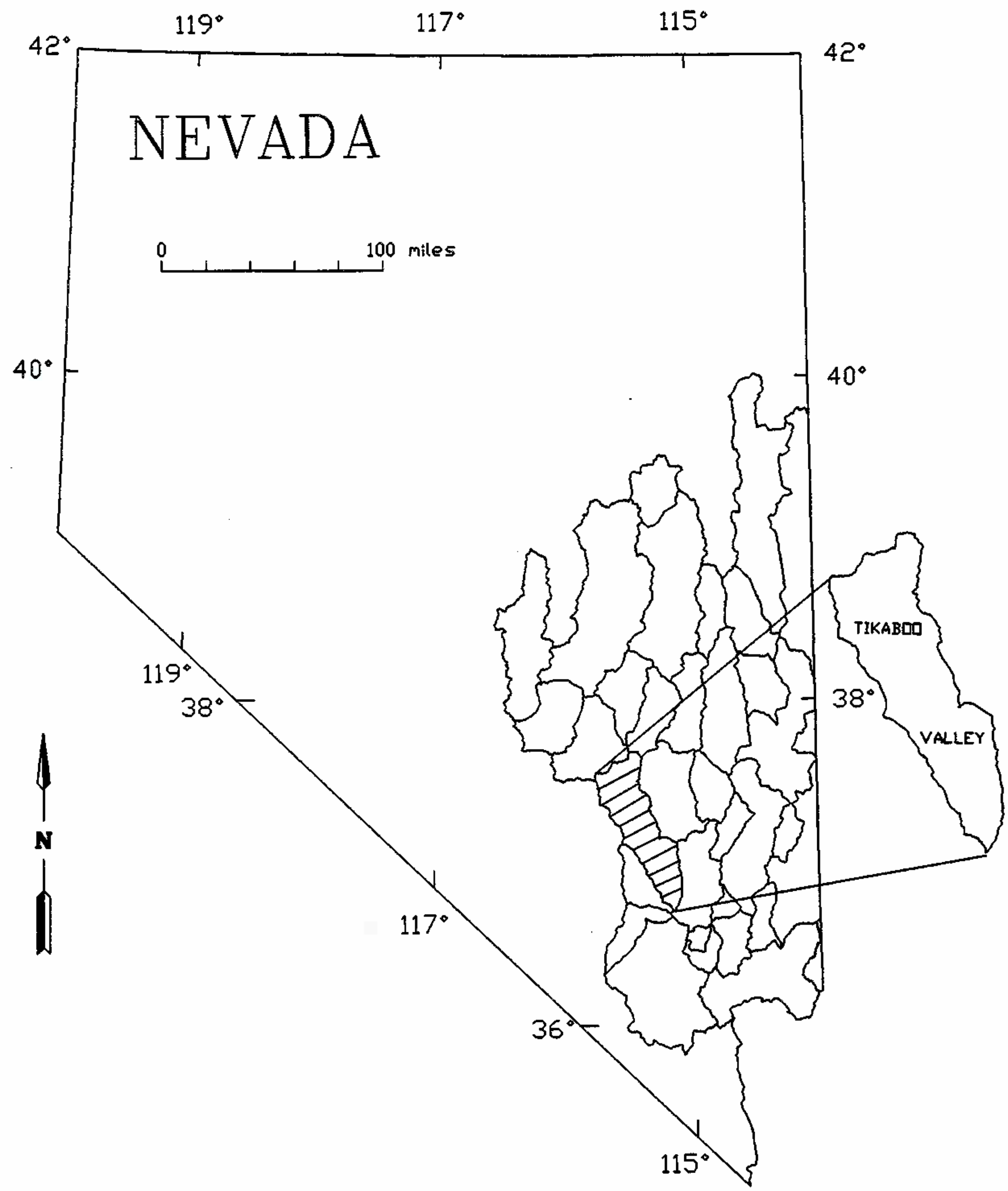
In October of 1989 the Las Vegas Valley Water District (District) filed for water rights in twenty-eight (28) hydrographic basins in eastern and central Nevada. A detailed investigation of each basin was conducted with the purpose of preparing a report summarizing the hydrologic characteristics for presentation to the State Engineer at the public water rights hearings. Major work objectives include:

- Update land use and water level data;
- Compile and review all available data;
- Interpret this data and define the hydrologic characteristics of the basin;
- Inventory all existing and pending water rights permits and applications; and
- Prepare a computer model to simulate ground-water and surface-water flow in the basin.

To achieve these objectives, a detailed investigation of the hydrologic conditions in Tikaboo Valley was conducted by Summit Engineering Corporation and Geraghty & Miller, Incorporated. The scope of work included collecting land use and water level data in April of 1990, reviewing all available published and unpublished geologic and hydrologic data, evaluating the occurrence and movement of ground water, compiling existing water chemistry data, conducting an inventory of the State Engineer's water rights files, developing conceptual and numerical models of the hydrologic regime, and calibrating the model to steady-state conditions.

Location and Physiographic Setting

Tikaboo Valley is in the Great Basin in south-central Nevada. The basin is largely within Lincoln County with a small portion in Clark County, Nevada, and is enclosed by latitude 37°40'N to 36°53'N and longitude 115°45'W to 115°06'W (Figure 1). The basin is



GERAGHTY & MILLER, INC.
Environmental Services

Location Map of Tikaboo Valley and Sorrounding Areas.

FIGURE 1

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FILE NO.: -
PRJCT NO.: -
DWG DATE: -

approximately 1,007 square miles in area and extends for approximately 80 miles in the north-northwest direction. In the north, the basin is nearly 15 miles wide, and in the south it tapers to a width of 3 miles between bedrock exposed at the foothills of the surrounding mountain ranges.

Tikaboo Valley is in the Basin-and-Range Physiographic Province as defined by Fenneman (1931). The basin is bordered on the north by the Timpahute Range, on the northwest by the Groom Range, on the west by the Jumbled Hills, on the southwest by the Desert Range, on the south by the East Desert Range, and on the east by the Pahranagat and the Sheep Ranges. Relief ranges from 4,000 feet on the valley floor to 9,380 feet on the Bald Mountain Summit in the Groom Range.

Availability of Data

All available data was supplied by Summit Engineering Corporation, Geraghty & Miller Incorporated, and the District. The District performed field measurement of water levels and total depth of existing wells in Tikaboo Valley. Summit Engineering researched water right applications and performed a visual survey of land use in the basin. Sources of data included the United States Geological Survey (USGS), the Nevada Department of Conservation and Natural Resources, Division of Water Resources, the Nevada Bureau of Mines and Geology, and published articles in geologic and hydrologic journals. Data format included published reports, driller's logs, correspondence, and unpublished databases. A complete list of references is provided at the end of this report.

Methods

Once the database was compiled, all data were subsequently reviewed and analyzed in order to conceptualize the geologic, climatic, and human controls on ground-water and surface-water conditions in the basin. The conceptual model was created to help visualize the existing hydrogeologic conditions in the basin and to aid in the construction of the numerical model. The hydrogeologic conditions identified in the conceptual model were then integrated into the numerical code of MODFLOW (McDonald and Harbaugh, 1988). Numerical model simulations were performed for steady state conditions.

Numbering System for Hydrologic Sites

The numbering system for hydrologic sites in this report indicates location on the basis of the rectangular subdivision of public lands, referenced to the Mount Diablo base line and meridian. Each number consists of three units: the first is the township north or south of the base line; the second unit, separated from the first by a space, is the range east of the meridian; the third unit, separated from the second by a space, designates the square-mile section. The section number is followed by letters that indicate the quarter section, quarter-quarter section, and so on; the letters A, B, C, and D designate the northeast, northwest, southwest, and southeast quarters, respectively. The letters are followed by a sequence number. As an example of the application of the numbering system, District application #53947 (well 169A-1A), location S10 E58 31DA, is located within a 40 acre tract identified as NE 1/4, SE 1/4, of section 31, Township 10 South, Range 58 East, and it is the first application recorded in that tract.

GENERAL GEOLOGIC FEATURES

Regional Stratigraphy

The geologic history of eastern and central Nevada includes episodes of Paleozoic continental shelf deposition, Mesozoic thrust faulting and folding, Late Cenozoic extension, volcanism and basin-filling sedimentation. Most of the basins and ranges were formed by Late Cenozoic extensional faulting that displaced Paleozoic sedimentary strata and Miocene to Pliocene volcanic and sedimentary rocks.

During the Late Proterozoic and throughout the Paleozoic Era, eastern and central Nevada was part of an elongate subsiding trough of the Cordilleran continental shelf where nearly 37,000 feet of marine sediments were deposited (Stewart, 1980; Bedinger, et al., 1989). Facies and formation thicknesses change drastically from east to west in the region due to varying depths of deposition and nearness to clastic sources. Approximately 15,000 feet of Late Proterozoic and Early Cambrian clastic sediments lie uncomfortably on the Proterozoic crystalline basement. Both Clark and Lincoln Counties, Nevada, lie within the quartzite and siltstone province as recognized by Stewart (1980). The quartzite and siltstone province consists of fine- and medium-grained quartzite and sand units separated by units of siltstone and fine-grained quartzite and siltstone. Rare conglomerate occurs within the quartzite, as well as minor layers of limestone and dolomite.

In Mid Cambrian through Permian time, a thick sequence of carbonate strata was deposited in continuous shelf deposition with the underlying clastic wedge. In the western Clark and Lincoln County area, these carbonate shelf sediments are nearly 25,000 feet thick (Bedinger, et al., 1989). Mid Cambrian through Permian carbonates consist predominately of limestone and dolomite, but locally clastic rocks such as conglomerate, quartzite, sandstone and shale occur within the section (Table 1).

Uncomfortably overlying Paleozoic strata are Triassic and Jurassic marine and continental sedimentary rocks. In eastern Nevada, Early Triassic shallow marine carbonate and fine-grained clastic rocks underlie a Late Triassic to Jurassic sequence of continental sandstone, conglomerate and claystone with abundant volcanic detritus (Longwell, et al., 1965; Stewart, 1980). Measured sections in western Clark County and southern Lincoln County indicate that as much as 5,000 to 6,000 feet of Late to Mid Mesozoic sedimentary strata were deposited in the region (Longwell, et al., 1965; Tschanz and Pampeyan, 1970).

Rocks of the Cretaceous to Mid Eocene time are rare in the region, and consist of conglomerate and minor sandstone. The region appears to have been a highland throughout the Cretaceous to Mid Eocene, undergoing erosion. Only local accumulations of clastic sediments occurred in deep basins (Stewart, 1980).

WESTERN LINCOLN COUNTY

AQUIFER	ALLUVIUM
AQUITARD	VOLCANIC AND INTRUSIVE ROCKS
AQUITARD	CLASTIC ROCKS CHINLE FORMATION MOENKOPI FORMATION
AQUIFER	LOWER PERMIAN AND PENNSYLVANIAN LIMESTONE
AQUITARD	UPPER MISSISSIPPIAN CLASTIC ROCKS
AQUIFER	JOANA LIMESTONE MERCURY LIMESTONE BRISTOL PASS LIMESTONE
AQUITARD	PILOT SHALE
AQUIFER	GUILMETTE FORMATION SIMONSON DOLOMITE SEVY DOLOMITE LAKETOWN DOLOMITE ELY SPRINGS DOLOMITE
AQUITARD	EUREKA QUARTZITE
AQUIFER	POGONIP GROUP CAMBRIAN LIMESTONE AND DOLOMITE
AQUITARD	DUNDERBURG SHALE
AQUIFER	HIGHLAND PEAK FORMATION
AQUITARD	PROSPECT MOUNTAIN QUARTZITE

TIKABOO BASIN

AQUIFER	ALLUVIUM
AQUITARD	VOLCANIC AND INTRUSIVE ROCKS
AQUITARD	CLASTIC
AQUIFER	LOWER PERMIAN AND PENNSYLVANIAN LIMESTONE
AQUITARD	UPPER MISSISSIPPIAN CLASTIC ROCKS
AQUIFER	JOANA LIMESTONE MERCURY LIMESTONE BRISTOL PASS LIMESTONE
AQUITARD	PILOT SHALE
AQUIFER	GUILMETTE FORMATION SIMONSON DOLOMITE SEVY DOLOMITE LAKETOWN DOLOMITE ELY SPRINGS DOLOMITE
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AQUITARD	DUNDERBURG SHALE
AQUIFER	HIGHLAND PEAK FORMATION
AQUITARD	PROSPECT MOUNTAIN QUARTZITE

MODEL LAYERS

LAYER 1	VALLEY FILL, EXPOSED CARBONATES, VOLCANICS AND CLASTIC ROCKS
LAYER 2	VOLCANIC ROCKS, LESSER ALLUVIUM AND CARBONATE
LAYER 3	LOWER CARBONATE AQUIFER

TABLE 1. HYDROSTRAGRAPHICAL CHARACTERISTICS OF LITHOSTRATIGRAPHIC UNITS (Longwell et al., 1965: Tschanz and Pampeyan, 1970)

Volcanism and associated sedimentation were dominant during the Mid to Late Cenozoic Era. Volcanic rocks in the region originated as pyroclastic and lava flows. Tertiary sediments associated with the volcanic rocks consist of conglomerates, tuffaceous sandstone and siltstone, calcareous lacustrine tuff, claystone, and freshwater limestone. Tertiary rocks overlie Precambrian and Paleozoic strata with angular uncomformity. A conglomerate or breccia commonly lies at the base of the Tertiary section. Most volcanic rocks are Miocene and Pliocene; some are Oligocene in age. The thickness and areal extent of Tertiary volcanic rocks in the region are highly variable, because deposition is controlled by topographic relief, prevailing winds, and modes of emplacement (Bedinger, et al., 1989).

Regional Structural Geology

Much of the physiography of the Basin-and-Range Physiographic Province was created by extensional faulting and volcanism in the Mid to Late Tertiary Period, with later surficial modification by climatic changes in the Late Pleistocene and Holocene Epochs. During the Mid Tertiary, east to west directed extension of eastern and central Nevada resulted in north-striking low to high-angle normal faults. These faults broke up, thrust faulted and folded Proterozoic, Paleozoic and Mesozoic sedimentary strata and Tertiary, volcanic and sedimentary rocks. Bedrock was further disrupted by synthetic and antithetic faults. Down dropped blocks became sites of alluvial and fluvial sedimentation. The following summary of the tectonic evolution of the region is derived largely from the work of Bedinger, et al. (1989), Stewart (1980), Longwell, et al. (1965) and Tschanz and Pampeyan (1970).

The Precambrian and Paleozoic sedimentary strata of the region were first significantly disrupted by the Mesozoic to Early Tertiary Sevier Orogeny. Thrusting of probable Late Triassic to Early Jurassic age is recorded in eastern and central Nevada (Stewart, 1980). Tectonic events include east directed thrusting, folding and strike-slip faulting. Thrust faults generally bring Early Paleozoic strata over Late Paleozoic and Mesozoic strata.

The Early Cenozoic history of the region is little-known, because rocks of this age are rare. The deficiency of sedimentary strata of this age indicates that much of the region was uplifted and eroded. Indeed, by the Mid Tertiary, much of the region was lacking in relief, as evidenced by the widespread occurrence of voluminous ash flow sheets with relatively uniform stratigraphic sequences from area to area in central and eastern Nevada. Approximately 17 million years ago (Ma), extensional faulting was widespread in the region. Late Cenozoic extension of the region was accomplished by both high-angle and low-angle normal faulting (Wernicke, 1981).

Strike-slip faults that record Late Cenozoic movement are also present throughout the region. The northwest-trending Walker belt extends along the western margin of Nevada and into California. Stratal rotation associated with right-lateral strike-slip faulting is pronounced in this region. In southern Nevada, the northwest-trending right-lateral Las Vegas Valley shear zone has produced pronounced bending of structural trends of the surrounding mountain ranges (Longwell, et al., 1965; Stewart, 1980).

Local Geology of Tikaboo Valley

The following summary of the geology of the basin fill and the surrounding mountain ranges of Tikaboo Valley is derived from Bedinger, et al. (1989), Stewart (1980), Tschanz and Pampeyan (1970), and Longwell, et al. (1965). Plate 1 is a generalized geologic map of the Tikaboo Valley Basin.

The Timpahute Range, on the north end of the valley, is composed of Paleozoic limestone, dolomite, quartzite, shales, and Tertiary volcanic and minor intrusive rocks. At least two major thrust faults, the Lincoln and Schofield thrusts, occur in the range. Many north-striking normal faults disrupt Paleozoic sedimentary strata in the Timpahute Range. According to the county geologic map (Tschanz and Pampeyan, 1970) few, minor, normal faults displace Tertiary volcanic rocks. However, it is likely that many more normal faults disrupt the little known volcanic stratigraphy.

The Groom Range is an east-tilted fault block that exposes Early Paleozoic carbonate strata on the west side, and Tertiary volcanic rocks on the east side. Most of the normal faults in the Groom Range strike northeast, but a few strike north-northwest. The Jumbled Hills, south of the Groom Range, consist of a chaotic mixture of Early Paleozoic dolomite, limestone, shale, and silty-shaly limestone, and Tertiary volcanic rocks, clastic sediments, and lacustrine limestone. Normal faults are the dominant structure in the Jumbled Hills, and most strike to the north; a few strike to the northeast.

The Desert and East Desert Ranges consist of Early Paleozoic limestone, dolomite, and shale. High-angle reverse faults in the Desert Range may be thrust faults that were later steepened by eastward tilting of the range (Tschanz and Pampeyan, 1970). Two sets of normal faults occur in the Desert Range. The older set has a dominant strike to the northeast; the younger set (limited to the northern most portion of the range) has a dominant strike to the north.

On the eastern margin of Tikaboo Valley lies the Pahranagat Range made up of intensely faulted and folded Early Paleozoic limestones, dolomites, and shales, and Tertiary volcanic rocks. Tertiary volcanic rocks in the central portions of the Pahranagat range have few mapped faults (Tschanz and Pampeyan, 1970), but detailed geologic mapping may reveal many more. Thrust faults terminate in the south against a zone of east-northeast striking left-lateral strike-slip faults. The western side of the Pahranagat Range is disrupted by abundant normal faults that strike east and northeast, and few that strike north.

The Sheep Range forms the southeast margin of the basin and is composed of Early Paleozoic carbonates and shale, with minor outcrops of Paleozoic quartzite and Tertiary volcanic rocks in the northern portion of the range. The structure of the Sheep Range is dominated by numerous normal faults. East-northeast striking normal faults that cut across the range generally have less than 100 feet of displacement (Longwell, et al., 1965). North-northwest striking normal faults are abundant. The western front of the Sheep Range is a fault scarp produced by movement on a major north-northwest striking normal fault (Longwell, et al., 1965). Fault scarps also occur in the alluvial fan on the west side of the Sheep Range.

The basin is blanketed by alluvium of varying composition and age. Late Tertiary to Quaternary semiconsolidated to unconsolidated older gravels and older alluvium occur near the Pahranagat, East Desert and Sheep Ranges. Older alluvium and older gravels consists of varying proportions of gravel, sand, silt, and clay, deposited in alluvial fans and in continuous aprons along mountain fronts. Intermediate lake beds (Pleistocene) composed of silt and clay occur in the central portion of the basin. Quaternary and Holocene sediments consist of younger alluvium, playa deposits, and dune sand (Plate 1).

Plate 2 is a reproduction of part of two geologic cross sections published by Bedinger, et al. (1989), showing inferred geological relationships at depth in Tikaboo Valley. In both cross sections, Tertiary volcanic rocks underlie Quaternary Alluvium. In the northern section (A' - A") approximately 1,600 feet of Quaternary alluvium overlies nearly 4,600 feet of Tertiary volcanic rocks in the center of the basin. In the southern section (B' - B") the thickness of Quaternary alluvium is nearly the same as in A' - A", but Tertiary volcanic rocks thin to approximately 2,000 feet in thickness. Beneath Tertiary volcanic rocks in both cross sections lie Mid Cambrian to Permian Carbonate strata (Pz_2) nearly 25,000 feet thick that in turn overlie Late Proterozoic and Early Cambrian clastic sediments with minor carbonate strata approximately 15,000 to 25,000 feet thick (Pz_1).

Geology of Proposed District Wells

Little detailed data is available on the subsurface geology of Tikaboo Valley. Plate 2 shows that most of the surficial alluvium is underlain by Tertiary volcanic rocks. However, on the eastern side of the valley, near the Pahranagat Range, fault-bound Mid Cambrian to Permian carbonate strata may underlie the alluvium. District application numbers 53948 (Well 169A-1r), 53951 (Well 169B-2r) and 53952 (Well 169B-2r) are all located on the eastern edge of the valley and are intended to develop consolidated rock aquifers.

Application 53948 is located in S06 E58 24AB at an elevation of approximately 4,750 feet above sea level. The geology consists of a veneer of Quaternary alluvium, that may be underlain by

Mid to Late Devonian Carbonate strata of the Simonson Dolomite and Guilmette Formation, as these formations crop out nearby. However, unexposed normal fault(s) may lie just west of the Pahranagat Range. If this is the case it is likely that other Paleozoic formations, or even Tertiary volcanic strata may occur beneath the alluvium. The Late Devonian Guilmette Formation is 1,300 to 3,500 feet thick and consists predominately of several hundred feet of massive limestone with interbedded reef breccias up to 100 feet thick, and in this location, contains several prominent sandstone beds (Tschanz and Pampeyan, 1970). The Mid Devonian Simonson Dolomite varies from 680 to 1,250 feet in thickness and consists of alternating dark and light gray dolomite with textures ranging from coarsely crystalline to fine-grained. This unit also contains biostromes and stromatoporoid bioherms in the middle of the section (Tschanz and Pampeyan, 1970).

Application 53951 is located in S11 E61 29AD near the western edge of the Sheep Range, at an elevation of about 3,700 feet above sea level. Late Tertiary to Quaternary semi-consolidated to unconsolidated alluvium (older alluvium) forms the surficial geology. Beneath the alluvium, Late Cambrian Limestone and Dolomite Undifferentiated and Dunderburg shale may occur, as these rock types crop out in the nearby Sheep Range. Again, other formations may lie beneath the alluvium due to faulting that has not been recognized. Measured sections to the north, in the Pahranagat Range, assign a thickness of 340 feet to the Dunderburg Shale, and 2,200 feet to the Late Cambrian Limestone and Dolomite Undifferentiated (Tschanz and Pampeyan, 1970).

District application 53952 (Well 169B-2r) is located in S10 E60 15CC at an elevation of approximately 3,600 feet above sea level and occurs on a surface of older alluvium. Nearby bedrock consists of Eureka Quartzite and Pogonip Group (both Ordovician in age). Precluding complication by as yet unrecognized faults, either of these Ordovician formations may occur beneath the older alluvium. The Eureka Quartzite is a white to light gray massive or cross-bedded, fine- to medium-grained orthoquartzite that measures 386 to 552 feet in thickness in western Lincoln County. Stratigraphically below the Quartzite is the Pogonip Group. The Pogonip Group is composed of alternating grayish to brownish, thick-bedded, cliff-forming limestone and thin-bedded silty shaly limestone. The Pogonip Group is approximately 2,600 feet thick on the west flank of the Pahranagat Range.

Application 53949 (Well 169-2r) is located in S04 E56 36AA in the northeastern portion of Tikaboo Valley, near the foothills of the Timpahute Range. This well is also intended to develop a consolidated rock aquifer. Bedrock exposed in the nearby Timpahute Range consists of highly faulted Mid to Late Paleozoic dominantly carbonate strata overlain by Tertiary volcanic rocks. Either or both of these rock types may occur beneath the surface of Quaternary alluvium at the well site, and it is likely that volcanic rocks overlie Paleozoic strata.

The other two District applications in Tikaboo Valley (53947, Well 169A-1A; and 53950, Well 169B-1A) are located on a surface of older alluvium and older gravels respectively. These wells are intended to develop unconsolidated aquifers. Application 53947 is located in S06 E58 31DB at an elevation of about 4,350 feet above sea level on a surface of older alluvium. Older alluvium typically consists of highly variable amounts of gravel, sand, silt and/or clay, and in places, may be underlain by older lake beds that are composed of fine sand, silt, and clay (Tschanz and Pampeyan, 1970). Application 53950 is located in S12 E61 30AA at an elevation of about 4,300 feet on a surface of older gravels. Older gravels consist of gravels and alluvium eroded from nearby mountain ranges with variable sorting and rock types.

GENERAL HYDROLOGIC FEATURES

Regional Hydrologic Features

Tikaboo Valley is in the Death Valley flow system which includes 30 hydrographic basins as defined by Harrill, et al. (1988). Tikaboo Valley discharges ground water via underflow to Three Lakes Valley North, the next valley down gradient. This flow ultimately discharges in Death Valley, the lowest point in the system. Winograd and Thordarson (1975) estimated ground-water velocity through carbonate aquifers in the Nevada Test Site region to range from 0.02 to 2 feet per day. Based one this range, and an estimated flow path length of 100 miles, the travel time for ground water discharged from Tikaboo Valley to Death Valley is about 720 to 72,000 years.

Tikaboo Valley may also be part of the White River flow system which is part of Colorado flow system and, if so, may discharge about 7,000 acre-feet per year of ground water via underflow to Coyote Springs Valley to the east (Harrill, et al., 1988). Some portion of this flow may be discharged at the Muddy River Springs, a tributary to the Colorado River.

Geomorphology

The geomorphology of Tikaboo Valley is characterized by mountain front alluvial fans that grade basinward to broad gently sloping pediments. The basin is commonly divided into north and south sub-basins, separated by bedrock of the Pahranagat Range in the south central part of the basin (Plate 1). The surface of alluvium exhibits a minor degree of dissection, except for deposits of older alluvium in the southern end of the basin (Plate 1). Older alluvium is deeply incised and exhibits ballena topography. Intermediate lake beds are also deeply incised and are overlapped by both older and younger alluvium. Holocene playa and dune sand deposits occur in the low and central parts of the basin, east of the intermediate lake beds and east of the Quaternary playa deposit in southernmost Tikaboo Valley.

Lithologic and Hydrologic Features

The formations present in North and South Tikaboo Valley are listed in Table 1. The formations can be divided into three units on the basis of their hydrologic properties: consolidated carbonate rocks, consolidated noncarbonate rocks, and unconsolidated alluvium. Distribution of the units within the basin is shown in Plate 1. The vertical relationship of the units is illustrated in a basin cross section in Plate 2. For the purpose of discussion the units are placed into two groups: (1) consolidated rocks and (2) unconsolidated rocks.

Consolidated Rocks

The water bearing characteristics of consolidated rocks are extremely variable. Rush (1971) identified two types of consolidated rock ground-water reservoirs: volcanic-rock and carbonate-rock aquifers. Winograd and Thordarson (1975) considered the consolidated clastic rocks of the area, such as shale and quartzite, to be aquitards. Primary permeability of consolidated rocks is generally low. However, secondary permeability from joints and fractures may allow these rocks to transmit large quantities of water. The hydraulic characteristics of the consolidated rock aquifers are discussed in the modeling section of this report. Water level data are sparse for Tikaboo Valley. However, a test well drilled in southern Tikaboo Valley, in the foothills of the East Desert Range, and completed in limestone had a static water level of 216 feet below land surface (Table 2, and unpublished Drillers Report). Rush (1971) states that ground-water movement within the consolidated rocks is generally from the volcanic-rock aquifer to the underlying carbonate-rock aquifer.

Unconsolidated Rocks

Unconsolidated rocks which make up the valley fill include Late Tertiary to Quaternary alluvium (older alluvium), Pleistocene lake sediments and Quaternary sediments of younger alluvium, playa deposits and dune sand. Ground water occurs in these formations at varying depths dependent on location in the basin. Rush (1971) speculates that the depth to water is greater than 500 feet in the valley fill of northern Tikaboo Valley. In southern Tikaboo Valley, a well thought to be completed in unconsolidated deposits has a depth to water of approximately 160 feet (Table 2 and USGS, GWSI Database). The hydraulic characteristics of these formations are discussed in the modeling section of this report. Rush (1971) states that ground water moves vertically and/or laterally through the unconsolidated deposits to the underlying consolidated rock aquifers.

Table 2. Historical and Recent Water Level Measurements for Wells in Tikaboo Valley.

Location	Well Depth (feet)	Elevation (feet)	Date	Depth to Water (feet)	Water Level Elevation (feet msl)	Use
S11 E61	420	3,210	03/18/87	159.6	3,050.4	Unknown
			04/26/90	158.4	3,051.6	
S12 E60 10AD	460	3,250	01/21/89	216.0	3,034.0	Test
			02/05/89	216.1	3,033.9	
			04/26/90	214.2	3,035.8	

WATER-RESOURCE APPRAISAL

Surface Water

General Conditions

There is no perennial surface flow in Tikaboo Valley. Surface flow occurs as runoff from surrounding mountain ranges during spring snow melt or flash flooding, and flows toward the lower central part of the basin.

Available Records

Estimates of mountain front runoff, surface water inflow and outflow and surface water evaporation are listed in Scott, et al. (1971). No partial recording stations on ephemeral channels exists, and no spring discharge measurements are available.

Runoff

Scott, et al. (1971) estimates that mountain front runoff in Tikaboo Valley is 1,800 acre-feet per year (afy). Northern Tikaboo Valley receives no surface water inflow but contributes some (significant, but not quantified) surface water to southern Tikaboo Valley. Surface water evaporation is listed as some in northern Tikaboo Valley and as minor (less that 500 afy) in southern Tikaboo Valley. No surface water outflow occurs from southern Tikaboo Valley.

Ground Water

Occurrence

Ground water in Tikaboo Valley occurs in both unconsolidated deposits and consolidated rocks of the area. The water is derived from a combination of precipitation within the drainage basin and subsurface inflow from Pahranagat Valley to the northeast (Harrill, et al., 1988).

Rain and snow falling in the mountains provides most of the recharge contribution from precipitation (Rush, 1971). Part of the water infiltrates the consolidated rock of the mountain blocks and part runs off in streams which are absorbed in alluvial fan deposits. The bulk of this water is lost to evaporation and the remainder recharges the ground-water reservoir. Precipitation falling on the valley floor is generally lost to evapotranspiration before it can recharge the ground-water reservoir.

Table 2 lists the historical and recent water level measurements used in the basin study. The total thickness of the ground-water reservoir is unknown because no wells penetrate the entire aquifer.

Movement

Local ground-water movement is generally from the mountain areas toward the center of the valley. This flow pattern is modified by regional ground-water movement from the northeast part of the basin, where most inflow occurs, to the southern portion of the basin, where most outflow occurs (Harrill, et al., 1988).

Chemical Quality

The chemical quality of ground water depends on the solubility, volume, distribution of rock materials, and the amount of time that rock materials are in contact with the ground water. Chemical concentration in ground water generally increases with time, as ground water moves from recharge to discharge areas.

Data are sparse on the chemical quality of ground water in Tikaboo Valley. Table 3 lists the two available chemical analyses of ground water from the basin. The sample locations are in southern Tikaboo Valley. Both sources meet USEPA primary and secondary drinking water standards.

Budget

The annual ground-water budget for Tikaboo Valley is summarized in Table 4. Recharge to the basin is from a combination of precipitation and interbasin inflow. Recharge from precipitation is distributed over mountainous areas and can be modeled using a method described by Eakin et. al. (1951). The total recharge contribution from precipitation is approximately 6,000 acre-feet per year (afy) for northern and southern Tikaboo Valley (Harrill, et al., 1988). Subsurface basin inflow from Pahranagat Valley accounts for 7,000 afy which flows into the basin through the lower carbonate aquifer system (Harrill, et al., 1988).

Table 3. Chemical Analyses of Ground Water in Southern Tikaboo Valley.

Location	Date	Temperature °C	pH	Ca mg/l	Mg mg/l	Na mg/l	K mg/l	SO_4 mg/l	Cl mg/l	HCO_3 mg/l	F mg/l	Conductivity omhs/cm	TDS mg/l
Sheep Spring													
S12 E61 23ABCB	05/19/88	15	8.10	31	40	7.9	1.1	13	7.1	--	0.2	469	249
Desert Valley Well													
S11 E61	03/18/87	19	7.86	22	27	35	5.7	48	8.9	207	0.6	452	

Table 4. Summary of Ground-Water Budgets in Acre-Feet per Year for Tikaboo Valley North and South.

FROM REFERENCES:

INFLOW	FROM	OUTFLOW	TO	RECHARGE	EVAPOTRNS	P.YLD	REFERENCE
7,000	Pahranagat Valley	6,000 7,000	Three Lakes Valley North Coyote Springs Valley				Harrill, Gates and Thomas, 1988, Estimates for Tikaboo North and South.
		2,600	Tikaboo Valley South	2,600	Some	1,300	Scott, Smales, Rush, and Van Denburgh, 1971, Tables 1 and 2, Estimates for Tikaboo North.
2,600	Tikaboo Valley North	6,000	Three Lakes Valley North	3,400	Minor	3,000	Scott, Smales, Rush and Van Denburgh, 1971, Tables 1 and 2, Estimates for Tikaboo South.
6,000	Pahranagat Valley						Winograd and Friedman, 1972, Estimate for Tikaboo North.
				6,000			Rush, 1971, Estimate for Tikaboo North and South.

REFERENCE SUMMARY:

INFLOW	FROM	OUTFLOW	TO	RECHARGE	EVAPOTRNS	P.YLD	
7,000	Pahranagat Valley	6,000	Three Lakes Valley North	6,000	0	4,000	Scott, Smales, Rush, and Van Denburgh, 1971, Tables 1 and 2, Estimates for Tikaboo North.
		7,000	Coyote Springs Valley				

STEADY STATE MODEL:

INFLOW	FROM	OUTFLOW	TO	RECHARGE	EVAPOTRNS
6,760	Pahranagat Valley	6,000 6,760	Three Lakes Valley North Coyote Springs Valley	6,000	0

Ground water is naturally discharged from the basin by evaporation, transpiration, and subsurface outflow through the southern basin boundaries. Ground-water pumpage for stock, and domestic use accounts for the remaining discharge. Natural discharge by evapotranspiration is estimated to be minor (Scott, et al., 1971). Basin outflow travels through the lower carbonate aquifer to Three Lakes Valley North and Coyote Springs Valley at rates of 6,000 and 7,000 afy, respectively (Harrill, et al., 1988).

The water balance for the steady state model has a total of 6,760 afy entering the northeastern basin boundary through the lower carbonate system. Approximately 6,000 afy and 6,760 afy exit through the lower carbonate aquifer at the southwestern and southeastern basin boundaries, respectively. These calculated basin in flows and outflows closely match the water budget estimated by Harrill, et al. (1988) and Harrill (personal communication, September 9, 1990).

Perennial Yield

The perennial yield is the quantity of water that can be extracted for use each year over an indefinite period of time without depleting the ground-water reservoir (Scott, et al., 1971). The perennial yield cannot exceed the natural recharge to aquifer systems, and in some aquifers it is probably less than the total natural recharge. Perennial yield for the basin is estimated at 4,000 afy (Scott, et al., 1971, Table 1).

Storage

The amount of water in storage is equal to the volume of water present in the saturated pore space of the ground-water aquifer. Changes in storage result from changes in the rate of ground-water recharge and discharge. Recoverable ground-water storage is that part of the stored water which will drain by gravity from the aquifer plus the amount released due to compressibility of the aquifer matrix and water. The volume of recoverable ground water is equal to the product of the storage coefficient or specific yield of the aquifer, saturated thickness, and the area.

Using an approximate basin fill area of 215,000 acres (Scott et. al., 1971) and a specific yield of 0.10 as suggested by Rush (1971), the recoverable volume of water per foot of drawdown in the basin fill aquifer is 21,500 acre-feet. The calculation of recoverable ground-water storage per foot of drawdown for the basin fill aquifer is shown in Equation (1).

(1) Area x Specific Yield x Unit Saturated Thickness = Volume Water per foot of drawdown

215,000 acres x 0.10 x 1.0 foot = 21,500 acre feet

Dinwiddie and Schroder (1971) estimate storage coefficients ranging from 1×10^{-3} to 1×10^{-7} for the volcanic rock aquifer north of Tikaboo Valley in the Hot Springs area of Nevada. Assuming the volcanics underlie approximately half of the basin area of 644,480 acres, the amount of recoverable fresh water ranges from .032 to 320 acre-feet per foot of drawdown across the basin. Low permeabilities of the unfractured portion of the volcanic rock aquifer may limit ground-water extraction rates in some areas, however. The calculation of recoverable ground-water storage for the volcanic aquifer is shown in Equation (2).

(2) Area x Storage Coefficient x Unit Saturated Thickness = Volume Water per foot of drawdown

322,240 acres x 1×10^{-3} x 1.0 foot = 320 acre-feet

322,240 acres x 1×10^{-7} x 1.0 feet = .032 acre-feet

Dettinger (1989) states that the carbonate-rock aquifer has a porosity on the order of 1 to 10 percent. Assuming the lower carbonate-rock aquifer underlies the entire basin area of 644,480 acres and using a porosity of 1 percent, the amount of water stored per foot of saturated carbonates across the basin is on the order of 6,400 acre-feet. The amount of recoverable water in storage will probably be less. Winograd and Thordarson (1975) estimated storage coefficients ranging from 1×10^{-3} to 1×10^{-6} for the carbonate aquifer near the Nevada Test Site. Using these ranges and a basin area of 644,480 acres, the amount of recoverable water is estimated to range from .64 to 640 acre-feet per foot of drawdown across the basin. The calculation of recoverable ground-water storage for the lower carbonate aquifer is shown in Equation (3).

(3) Area x Storage Coefficient x Unit Saturated Thickness = Volume Water per foot of drawdown

$$644{,}480 \times 1 \times 10^{-3} \times 1.0 \text{ foot} = 640 \text{ acre-feet}$$

$$644{,}480 \times 1 \times 10^{-6} \times 1.0 \text{ feet} = .64 \text{ acre-feet}$$

INVENTORY OF WATER RIGHTS, PUMPAGE, AND LAND USE

Present Development

Present water resource development in Tikaboo Valley is limited to a total of 72 afy of consumptive use, according to a recent survey performed by Summit Engineering Corporation in 1990. Diversion is mainly from surface water and is used for stock-watering and limited domestic supply. No diversions are listed for irrigation, municipal, industrial, or commercial use. A visual survey performed in 1990 confirmed that presently no irrigation occurs in Tikaboo Valley.

Ground-Water Pumpage

The major use of ground water in the basin is stock-watering. Consumptive totals of ground-water use in the basin is a mere 6.76 afy and is designated as stock-watering use.

Land Use

According to a recent survey of both the State Engineer's water rights permits and a recent visual survey of the basin, there is no irrigated acreage in Tikaboo Valley. During the visual survey, only one dwelling was observed in the basin. This dwelling is located in S07 R57E

Section 10. Land use in the basin is restricted to cattle grazing. South of Township 8 South, access is restricted because the remaining part of the basin is designated as a wildlife refuge.

Future Development

Future development of Tikaboo Valley will probably be restricted to those parts north of Township 7 South, because of the wildlife designation. We know of no future plans for water resource development in Tikaboo Valley other than the District's proposed development.

GROUND-WATER MODELING

Purpose and Scope of Modeling

A steady state model was prepared for each hydrographic basin in which the District is requesting water rights. Early in the modeling process a consistent overall approach was established for the preparation of each of the individual models. The constraints established included matching the USGS hydrologic budget as closely as possible which included using the Eakin (1951) method for distributing ground-water recharge as was done in the individual reconnaissance reports and preserving the regional inflow and outflow numbers established for each basin. Transmissivity and leakance values could then be varied to provide a "calibrated" steady state model matching existing water levels as closely as possible.

The preservation of the regional inflow and outflow values (Harrill, et.al., 1988) were to be established by general head boundaries, based on regional water levels and appropriate conductances. The ground-water levels established by Thomas et al. (1986) were used to essentially tie these individual steady state models into the regional system. The transmissivity values established by the steady state models will then be put in the District's regional model of the project area for transient simulations.

This section of the report provides a summary of the flow model construction and calibration. The ultimate objective of this model application is to develop a tool for use in evaluating resource management alternatives in an effort to maximize efficient water resource planning.

Model Data Base

The modeling data base sources included existing hydrogeologic reports and maps, drillers logs, unpublished reports and documents, and personal correspondence. Aquifer tests performed locally in Tikaboo Valley were not available. Therefore, data from previously published and unpublished documents from surrounding areas were used as a guide in deriving hydraulic parameters for Tikaboo Valley. The following discussion briefly summarizes the content of the data sources.

Plume and Carlton (1988) have constructed a generalized geological map of the Great Basin flow system. The Plume and Carlton map was used as a guide for selection of ground-water model parameters and the definition of model boundaries. Water bearing properties of each geological unit are summarized in addition to the lithological descriptions. A more detailed geologic map constructed by Summit Engineering (Plate 1) based on the work of Longwell, et al. (1965) and Tschanz and Pampeyan (1970) served to refine model parameter zones.

Thomas, et al. (1986) have constructed contoured water level maps for parts of southern Nevada which include water levels in the basin fill deposits and the consolidated rock (carbonate) aquifer. Continuous water level contours on a regional scale are not available; nevertheless, this report was useful in defining general trends of local flow systems.

Regional theoretical flow maps by Harrill, et al. (1988) provided a framework for the definition of the model boundary conditions. The generalized flow directions and water level information were used as a guide in defining the general trends of the regional flow system.

Winograd and Thordarson (1975) have compiled a list of aquifer test information for the area surrounding the Nevada Test site encompassing about 7,100 square miles of Clark, Lincoln, and Nye Counties in south-central Nevada. Permeabilities derived from sample rock cores and estimates of carbonate rock storage coefficients are included, and estimates of ground-water gradients and flow directions are made for Three Lakes Valley South. The Winograd and Thordarson report discusses Tikaboo Valley but encompasses a much larger study area.

Rush (1971) studied regional ground-water systems in the Nevada Test Site area in Nye, Lincoln and Clark Counties. Three types of ground-water reservoirs are identified and characterized: valley fill, volcanic rock, and carbonate rock aquifers. The Rush study describes flow directions and hydrologic budgets for a region incorporating 16 hydrographic areas between Tonopah and Las Vegas, Nevada.

Schaefer, et al. (1988) has compiled a list of well construction data, aquifer test results and water chemistry data in unpublished tables. The tables contain data for selected wells in the lower carbonate and non-carbonate clastic aquifers of southern Nevada. Estimates of transmissivity and hydraulic conductivity are included for carbonate and clastic noncarbonate rocks.

The USGS has constructed a three-dimensional steady state numerical model of the area between Death Valley and the Great Salt Lake (Harrill, personal communication, June 13, 1990). Model grid block sizes are approximately 5 miles by 7.5 miles. The large scale of the model permitted simulation of the Great Basin flow system on a regional scale. The calculated flow maps served as a guide in hydrologic basin budget estimates and helped to refine the regional flow system described by Harrill, et al. (1988).

In addition to the above documents, two water level measurements taken in April 1990 by the USGS permitted a match of observed water levels to those calculated by the model in the southern portion of Tikaboo Valley. This permitted the initial model parameters and basin budget to be modified to match the observed conditions in the basin.

Model Development

Modeling Approach

Development of the ground-water flow model for Tikaboo Valley consisted of two separate phases. In the first phase, a conceptual model was developed for the Tikaboo Valley ground-water system. The conceptual model is a concise statement of the important characteristics of ground-water flow system that guides development of the numerical model. The conceptual model identifies four primary components: (1) ground-water flow directions and water levels, (2) geologic framework, (3) hydraulic properties, and (4) system boundaries. The geologic framework and some of the system boundaries have been described in the previous sections. The following sections will elaborate on the remaining components of the conceptual model of Tikaboo Valley.

A calibrated steady-state ground-water flow model was constructed in the second phase of modeling. The steady-state model is a numerical representation of the conceptual model. In most modeling studies, the steady-state model is calibrated to water level measurements obtained from wells in the study area. Only two water level measurements located in the southern portion of Tikaboo Valley were available, however. In the absence of observed water level data, water levels and flow directions have been inferred based on data from surrounding basins and from regional work performed by the USGS.

The goal of the calibrated model is to simulate the movement of ground water in the aquifer system. No observed hydraulic parameter values and only two water level measurements were available within Tikaboo Valley. Therefore, the model calibration consisted of matching the available water levels with estimated basin flow budgets (Harrill, et al., 1988; Harrill, personal communication, September 9, 1990) using hydraulic parameters from studies in surrounding basins. Regional flow maps constructed by the USGS (Harrill, et al. 1988 and Harrill, personal communication, June 13, 1990) were used to estimate general flow patterns within the basin.

The MODFLOW computer code (McDonald and Harbaugh, 1988) was used in the construction and calibration of the three-dimensional ground-water flow model. MODFLOW is a thoroughly tested and publicly available finite-difference ground-water flow code. MODFLOW is well accepted in the scientific community and has all of the capabilities required to model ground-water flow in Tikaboo Valley.

Modeling Assumptions

The aquifer system of the basin was discretized as three layers in the vertical direction. The upper aquifer (layer 1) contained carbonates, volcanic and alluvial fill deposits. The intermediate aquifer (layer 2) consisted primarily of volcanics with lesser amounts of alluvium and carbonate rock. The lower aquifer (layer 3) represented the lower carbonate aquifer. Recharge was applied (to layer 1) only in the mountainous areas of the basin. Rush (1971) calculates the recharge to the basin, based on the Eakin method (1951) to be about 6000 acre-feet/year. For modeling purposes the 6000 acre-feet/year were distributed equally over the layer 1 bedrock nodes. Transmissivities used in the model were consistent with studies mentioned previously in the Model Data Base section of this report.

Hydrologic budgets estimated by Harrill, et al. (1988) and Harrill (personal communication, September 9, 1990) were used to derive calculated basin inflows and outflows. Harrill (personal communication, September 9, 1990) indicated approximately 7,000 afy enters the northwestern boundary from Pahranagat Valley. Local precipitation recharge accounts for an additional volume of 6,000 afy distributed over the mountainous areas. Harrill, et al. (1988) estimates 6,000 afy flows through the lower carbonate system from Tikaboo Valley into Three Lakes Valley North. It is likely that the remaining water, an estimated 7,000 afy, flows through the lower carbonate system exiting the eastern basin boundary into Coyote Springs Valley. The latter was an assumption used in the Tikaboo model.

The well inventory of permitted pumpage in the basin indicated a potential appropriated consumptive use of less than 7 afy. All permitted pumpage is designated for stock watering.

Stock watering requires only sporadic pumping to fill small tanks or surface depressions. Therefore, existing pumpage is negligible and was assumed to be zero for the steady-state conditions.

Hydraulic Characteristics

A component of the conceptual model is the identification of aquifer hydraulic properties. These properties determine the ability of the aquifer system to transmit ground water and are required for any modeling study. The most important aquifer properties include transmissivity or hydraulic conductivity, vertical hydraulic conductivity or leakance, and storage. Hydraulic conductivity is a measure of the capacity of an aquifer to transmit water. Transmissivity equals the hydraulic conductivity multiplied by the saturated thickness of the aquifer and is the rate at which water is transmitted through a unit width of an aquifer under a unit hydraulic gradient. Leakance is the hydraulic conductivity in the vertical direction divided by the distance between the mid-points of the aquifers resulting in the units of length per time per length. Aquifer storage coefficients and specific yield represent the fraction of a unit volume of aquifer that is available from ground-water storage. Hydraulic characteristics of the Tikaboo Valley aquifer system were inferred from regional studies in surrounding basins.

Hydraulic Conductivity and Transmissivity

Winograd and Thordarson (1975) list several estimates of transmissivity for the basin fill and lower carbonate aquifers on the Nevada Test Site. The median values of transmissivity for the valley fill, volcanic and carbonate aquifers are 1,470 ft^2/day, 281 ft^2/day and 1,470 ft^2/day, respectively (See Table 5). Winograd and Thordarson have estimated hydraulic conductivities of the carbonate aquifer ranging from 0.02 ft/day to 1.53 ft/day with a median value of 0.18 ft/day. Schaefer, et al. (1988) compiled a summary of aquifer test results for the carbonate rock aquifers and non-carbonate clastic lower aquifer. The Schaefer study includes carbonate transmissivity and hydraulic conductivity values with median values of 2,100 ft^2/day and 5.40 ft/day, respectively. The Schaefer study lists a range of carbonate transmissivity values from

11 to 250,000 ft^2/day. The clastic noncarbonate aquifer exhibits the lowest conductivity values of any other of the aquifer materials tested with a median value of 0.0015 ft/day. Plume and Carlton (1988) have reported an average hydraulic conductivity of basin fill deposits of 74 ft/day based upon 18 aquifer tests in 14 basins. Hydraulic conductivity values from the Plume and Carlton study (1988) range between 0.02 ft/d and 140 ft/d.

Table 5. 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)
	2,592	-	-	1	USGS Regional (Harrill, personal communication, June 13, 1990)[a]
Tuff/Volcanic	6.7	9,090	281	5	Winograd and Thordarson (1975)
Carbonate	174	11,496	1,470	11	Winograd and Thordarson (1975)
	11	250,000	2,100	31	Schaefer (1988)
	86	43,200	4,320	22	USGS Regional (Harrill, personal, communication, June 13, 1990)[a]
		Hydraulic Conductivity (ft/day)			
Aquifer	Minimum	Maximum	Median	Number of Samples	Reference
Valley Fill	0.02	140	74[b]	7	Plume and Carlton (1988)
Carbonate	0.01	940	5.40	38	Schaefer (1988)
	0.02	1.53	0.18	8	Winograd and Thordarson (1975)
Clastic	0.006	0.10	0.02	4	Schaefer (1988)

[a] Values from Tikaboo Valley
[b] Average value for 18 tests in 14 basins.

Transmissivity values used in the model were selected based on two requirements: (1) the transmissivity value should fall within the range of values reported in the literature, preferably near the median, and (2) the model-calculated hydraulic gradient in Tikaboo Valley must be consistent with measured water levels and the USGS regional ground-water flow maps (Harrill, et al., 1988). The second requirement was achieved through the iterative calibration process during which transmissivity values in the steady-state model were adjusted within the observed range (Table 5) to achieve an acceptable match between the potentiometric surface calculated by the model and that estimated by Harrill, et al. (1988).

The value of transmissivity in the upper aquifer (layer 1) and the intermediate aquifer (layer 2) for the volcanics was assigned 281 ft^2/day which is the median value from tests contained in Winograd and Thordarson (1975). The alluvium in the upper and intermediate aquifers (layers 1 and 2) was assigned a value of 2,600 ft^2/day. The USGS regional ground-water model (Harrill, personal communication, June 13, 1990) represented areas of alluvial fill in Tikaboo Valley with a transmissivity of 2,592 ft^2/day. The carbonates in the upper, intermediate and lower aquifer (layers 1, 2 and 3) were assigned a uniform value of 4,320 ft^2/day. The median value used by the USGS in the area of Tikaboo Valley is 4,320 ft^2/day.

Vertical Leakance

Leakance is a parameter used to characterize the vertical movement of ground water within the model. Leakance is the hydraulic conductivity in the vertical direction divided by the distance between the midpoint of aquifer units. For ground-water modeling purposes, vertical leakance was calculated by dividing an assumed vertical hydraulic conductivity value by the corresponding layer thickness. No wells penetrate the entire thickness of the aquifer units within the basin boundary. In addition, anisotropy in the vertical direction due to the bedding planes or fractures creates variable hydraulic conductivities in the vertical direction. For modeling purposes the thickness of the alluvial, volcanic and carbonate aquifers were assumed to be an average of 1,000 ft, 5,000 ft, and 10,000 ft, respectively based on the work of Bedinger, et al. (1989). Using an average hydraulic conductivity of 74.00 ft/day for the alluvium (Plume and Carlton, 1988), 0.18 ft/day for the volcanics (Winograd and Thordarson, 1975) and 5.4 ft/day for the carbonate rocks (Schaefer, 1988), the average vertical conductance ranges from about 1 x 10^{-3} 1/day to 1 x 10^{-5} 1/day. These values were used as initial estimates prior to calibration. The leakance terms were varied during calibration to match observed water levels and theoretical flow directions (e.g. Harrill, et al., 1988). Leakance values derived during calibration were 2.25 x 10^{-5} 1/day for the volcanics and 7.50 x 10^{-3} 1/day for the alluvial fill and carbonates.

Storage Coefficient and Specific Yield

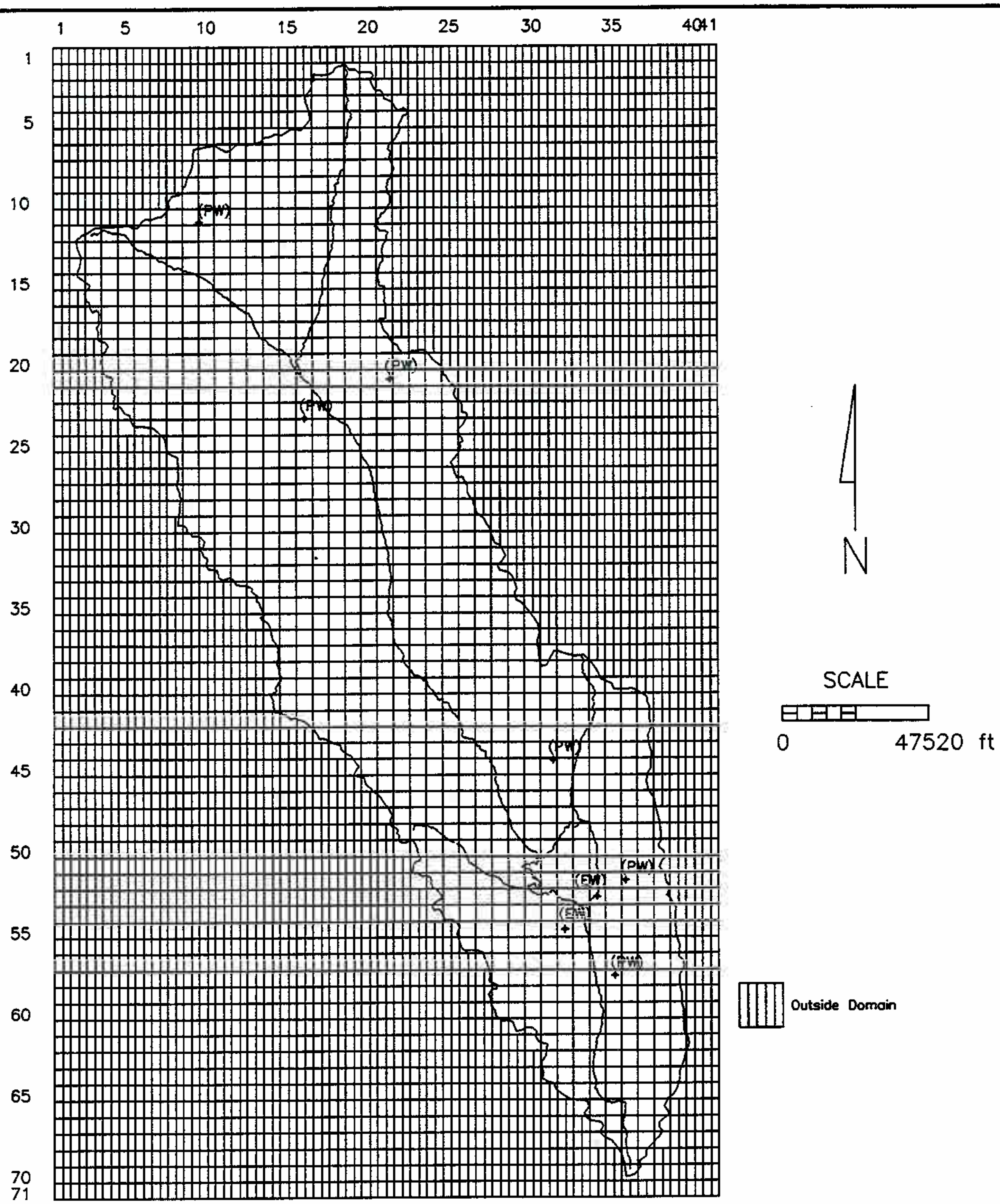
The model presented in this report is steady-state; therefore, aquifer storage properties were not specified.

Steady-State Model Simulations

Model Discretization

Model discretization refers to the process of dividing the physical aquifer system into a network of rectangular regions or cells. Cells are aligned in rows (east-west line of cells) and columns (north-south line of cells). Each cell in the Tikaboo model measures one mile on each side. Aquifer properties are assigned to each cell in the model and the model calculates a hydraulic head or water level at the center of each model cell. The network of cells used to represent the Tikaboo Valley ground-water system is shown in Figure 2.

The numerical model for Tikaboo Valley extends from the Timpahute and North Pahranagat Mountains in the north and borders Three Lakes Valley North and Coyote Springs Valley on the southern boundary. The eastern and western boundaries of the model follow the basin boundaries defined by the State Engineers Office. Figure 2 shows the finite difference grid consisting of 71 rows, 41 columns, and 3 layers. Figure 2 also shows the basin boundaries in relation to the model grid. Each model cell is one mile on a side.



Tikaboo Valley Ground-Water Model Grid
(EW) = Existing Well (PW) = Proposed District Well

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Ground-Water Model Grid for Tikaboo Valley.

FIGURE 2

Three model layers represent the vertical extent of the aquifer system. All three layers were simulated as confined aquifers. In a confined system, transmissivity (hydraulic conductivity multiplied by layer thickness) is assigned to each model cell. Because the layer thickness is contained within the transmissivity term, no explicit layer thickness is specified in the model.

Boundary Conditions

In order to represent the variety of physical boundaries to the aquifer system in Tikaboo Valley, several types of boundary conditions were prescribed in the ground-water flow model. A boundary condition is a numerical representation of a physical boundary or process effecting the aquifer system. These physical boundaries and processes in the Tikaboo Valley model include recharge from precipitation and ground-water efflux and influx at basin boundaries.

Two types of boundary conditions were used in this model to represent the physical boundaries of the system. Boundary conditions are constant flux (wells, recharge, and no-flow boundaries) and head-dependent flux boundaries. In a constant flux boundary, a constant amount of water is injected or withdrawn from the model. Constant flux cells are most commonly used to represent water supply wells and precipitation recharge. A special form of constant flux boundary, known as a no-flow boundary is used to represent areas where no ground water enters or leaves the system. In a head-dependent flux boundary, the amount of water entering or leaving the model is calculated based upon the head in the model cell and the head assigned to the boundary. A special form of head-dependent flux boundary, known as a general-head boundary, was used in the Tikaboo Valley model to represent ground-water inflow and outflow along the northeastern and southern edges of the basin.

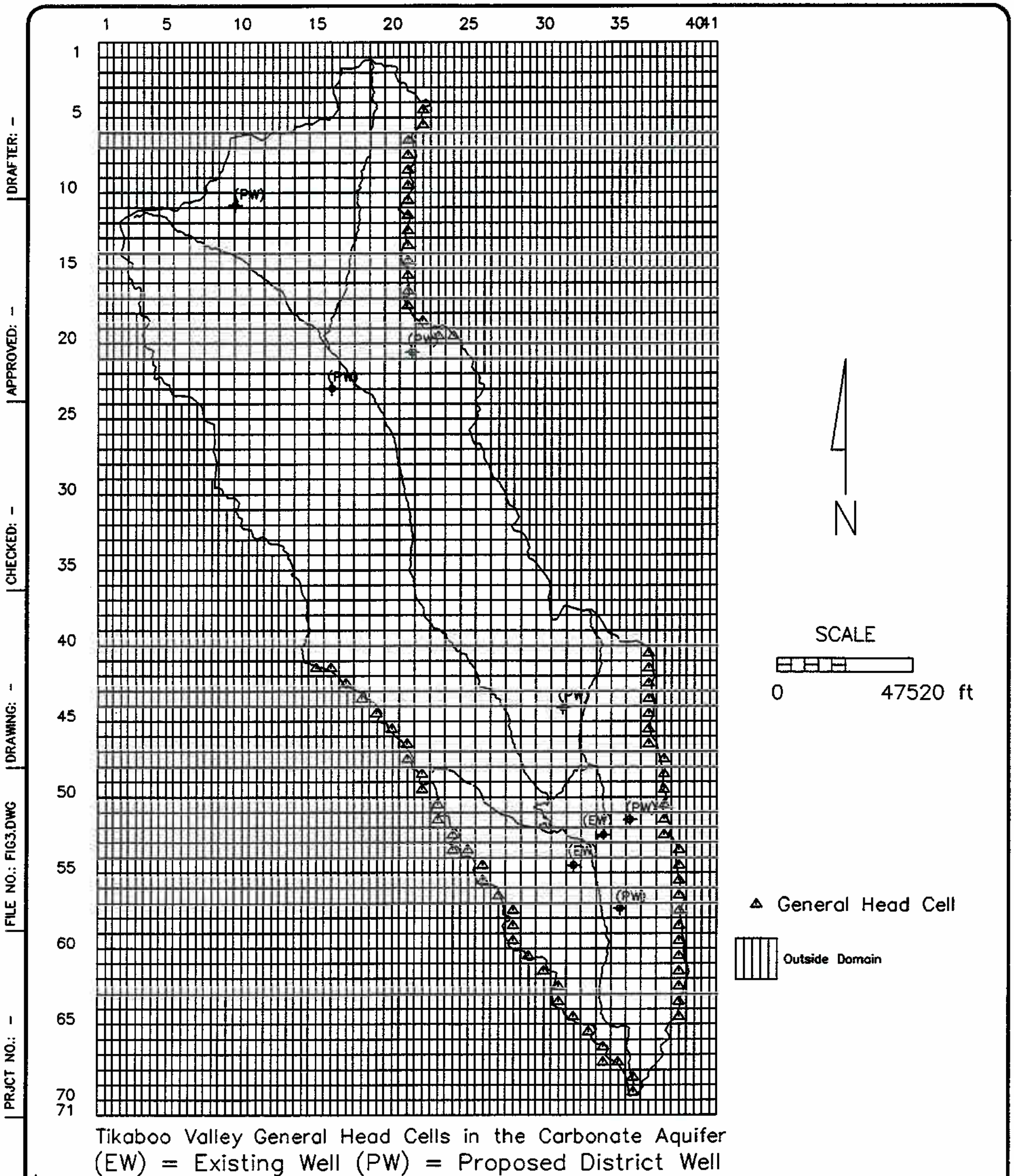
Table 6 summarizes the boundary conditions assigned across the model domain. A series of general head and no-flow boundary conditions were selected based upon the hydrogeologic information available and the conceptual understanding of the flow system.

Table 6. Summary of General Head Boundary Conditions for the Tikaboo Valley Model.

Boundary	Specified Range of Water Level Elevations (ft AMSL)	Conductance (ft^2/day)
Northeastern	3,508-3,380	1,500
Southwestern	3,190-2,976	1,500
Southeastern	3,061-2,977	1,500

A series of general-head boundary conditions were assigned on the northeastern, southwestern and southeastern model boundary to account for ground water entering and exiting the model domain from the regional aquifer system. The remainder of the model boundaries were represented as no-flow boundaries. Figure 3 illustrates the placement of the general-head boundary cells in the lower carbonate (layer 3) aquifer. Water levels for these general-head boundaries were initially based on the regional flow map (Harrill, et al., 1988) in Figure 4 and refined based on the results of the USGS regional flow model (Harrill, personal communication, June 13, 1990). The conductance value assigned to each general-head boundary cell determines the amount of ground-water influx or efflux to the basin. The conductance values were varied to match the regional ground-water flux estimated by Harrill, et al. (1988).

Harrill, et al. (1988) have estimated the amount of recharge flux reaching the ground-water table as 6,000 afy. Most of this recharge occurs in mountainous areas above 5,000 ft (Eakin et. al. 1951, and Rush 1971) on the eastern and western edges of the basin. The 6,000 afy of recharge was distributed over these higher regions within the basin as mountain recharge. Rush (1971) estimated depth to water to be near 500 feet which is too great for discharge by phreatophytes (greater than 50 ft) and too great for appreciable evaporation from bare-soil areas (greater than 15 ft). Therefore, evapotranspiration was assumed to be zero in the model simulations.



Tikaboo Valley General Head Cells in the Carbonate Aquifer
(EW) = Existing Well (PW) = Proposed District Well

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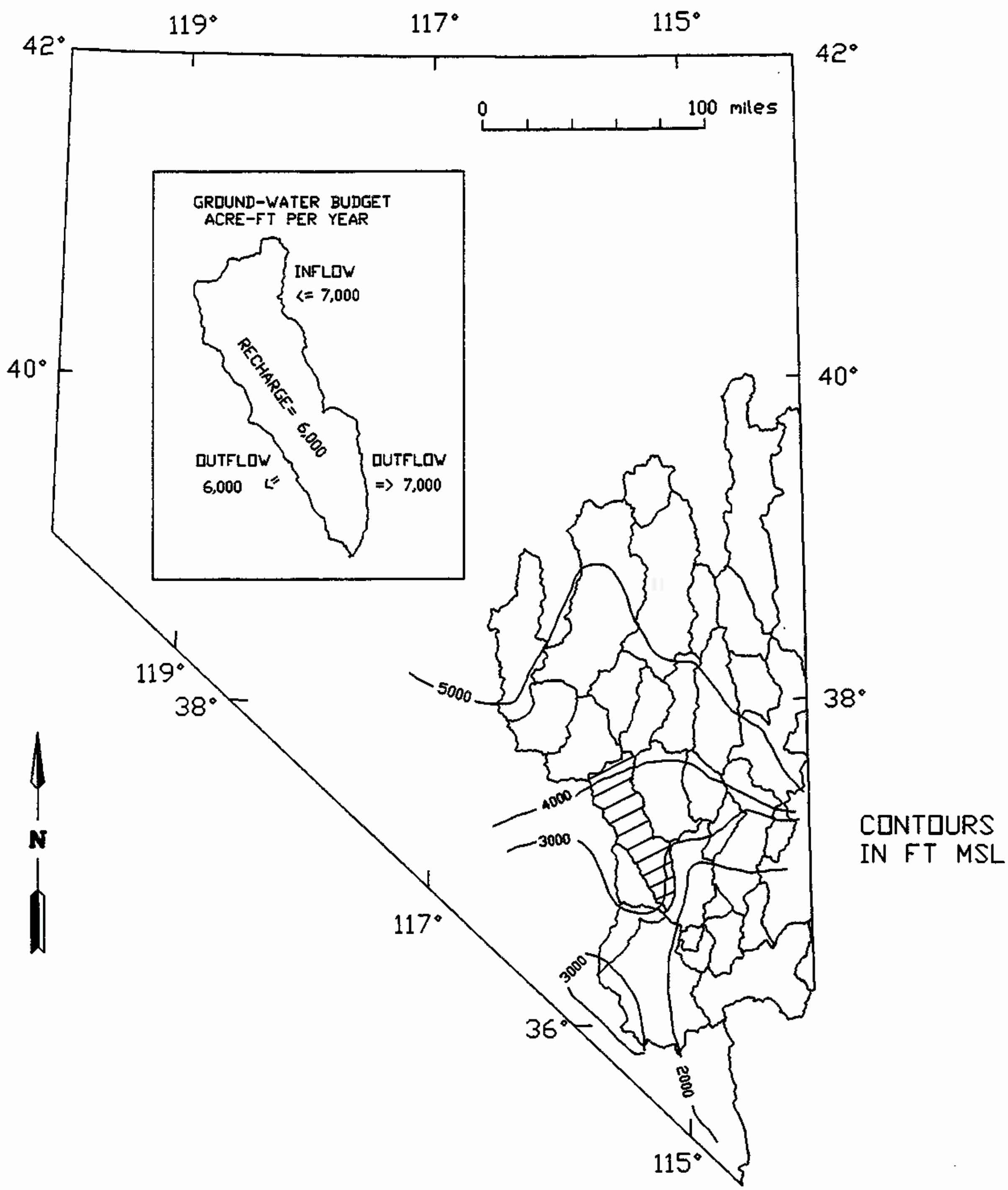
General Head Boundary Cells in the Lower Carbonate Aquifer (Layer 3).

FIGURE 3



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Theoretical Regional Flow System of the Great Basin Near Tikaboo Valley and Ground-Water Budget (after Harrill, et al. 1988 and Thomas, et al., 1986)

FIGURE 4

Hydraulic Parameters

A ground-water model is calibrated by adjusting aquifer properties and boundary conditions within reasonable limits to achieve an acceptable match between observed and calculated water levels or other physical measurement. The reasonable limits within which model parameters may be varied are determined by field testing and by values reported in the scientific literature. An acceptable match between observed and calculated water levels is determined through graphical and statistical analysis of model residuals or the difference between observed and calculated heads. Unfortunately, no direct measurements of aquifer parameters and only two ground-water levels are available for Tikaboo Valley. Therefore, the calibration consisted of adjusting aquifer properties and boundary conditions within ranges cited in the literature such that the hydraulic gradient across the basin was consistent with published maps, the two observed water levels and water budgets (Harrill, et al., 1988, for example). Water levels computed by a USGS regional model (Harrill, personal communication, June 13, 1990) were also instrumental in characterizing the basin-flow system and selecting all final boundary conditions.

Transmissivity was varied spatially within the model to account for changes in lithology. Areas of similar transmissivity were grouped together in zones of equal value according to geologic information. Three zones of transmissivity were assigned in the upper and intermediate aquifers. The distribution of zones was based on the lithologic characteristics of the valley-fill sediments, volcanics and carbonates. Table 7 gives the parameter zone numbers and their values for each model layer. Figures 5 and 6 illustrate the spatial distribution of the transmissivity for the upper aquifer (layer 1) and the intermediate aquifer (layer 2), respectively. The lower carbonate aquifer (layer 3) was assumed to have a uniform transmissivity of 4,320 ft^2/day. These parameters are consistent with other field studies done in southern Nevada (Table 5). Vertical leakance was set to a constant value 2.25×10^{-5} 1/day to reflect the bulk hydraulic conductivities of the volcanics and 7.50×10^{-3} 1/day to reflect the bulk hydraulic conductivity of the alluvial fill and carbonates. Figure 7 shows the distribution of the leakance zones across the model domain.

Table 7. Tikaboo Valley Ground-Water Model Calibration Parameters.

Hydraulic Transmissivity:

Layer	Parameter Zone Number	Value (ft^2/day)
1	1	2,600[a]
	2	281[b]
	3	4,320[c]
2	1	2,600[a]
	2	281[b]
	3	4,320[c]
3	3	4,320[c]

Recharge:

Layer	Parameter Zone Number	Value(ft/day)
1	1	0.0
	2	$4.59x10^{-5}$[d]

Leakance:

Layer	Parameter Zone Number	Value(1/day)
1/2	1	$2.25x10^{-5}$[e]
	2	$7.50x10^{-3}$
2/3	1	$2.25x10^{-5}$
	2	$7.50x10^{-3}$

Storage:

Layer	Parameter Zone Number	Value
1	1	0.10[f]
2	2	$5.0x10^{-4}$[g]
3	3	$5.0x10^{-4}$[h]

a Based on transmissivity of 2,592 ft^2/day used for the alluvial aquifer in the USGS regional model (Harrill, personal communication, June 13, 1990)

b Median transmissivity value of tests contained in Winograd and Thordarson (1975).

c Based on median value (4,320 ft^2/day) used for the lower carbonate aquifer in the USGS regional model Harrill, personal communication, June 13, 1990).

d 6,000 afy of recharge distributed over higher elevations of carbonates and volcanics (Harrill, Gates and Thomas 1988).

e Hydraulic conductivity divided by distance between mid-points of layers. Higher value of $7.50x10^{-3}$ reflects areas of alluvium and carbonate. Lower value of $2.25x10^{-5}$ reflects areas of volcanic aquifer.

f Specific yield of alluvium is between 0.05 and 0.10 (Rush 1971).

g Based on storage coefficients in volcanic aquifer ranging from $1x10^{-3}$ to $1x10^{-7}$ (Dinwiddie and Schroder, 1971).

h Based on storage coefficients in carbonate aquifer ranging from $1x10^{-3}$ to $1x10^{-6}$ (Winograd and Thordarson 1975).

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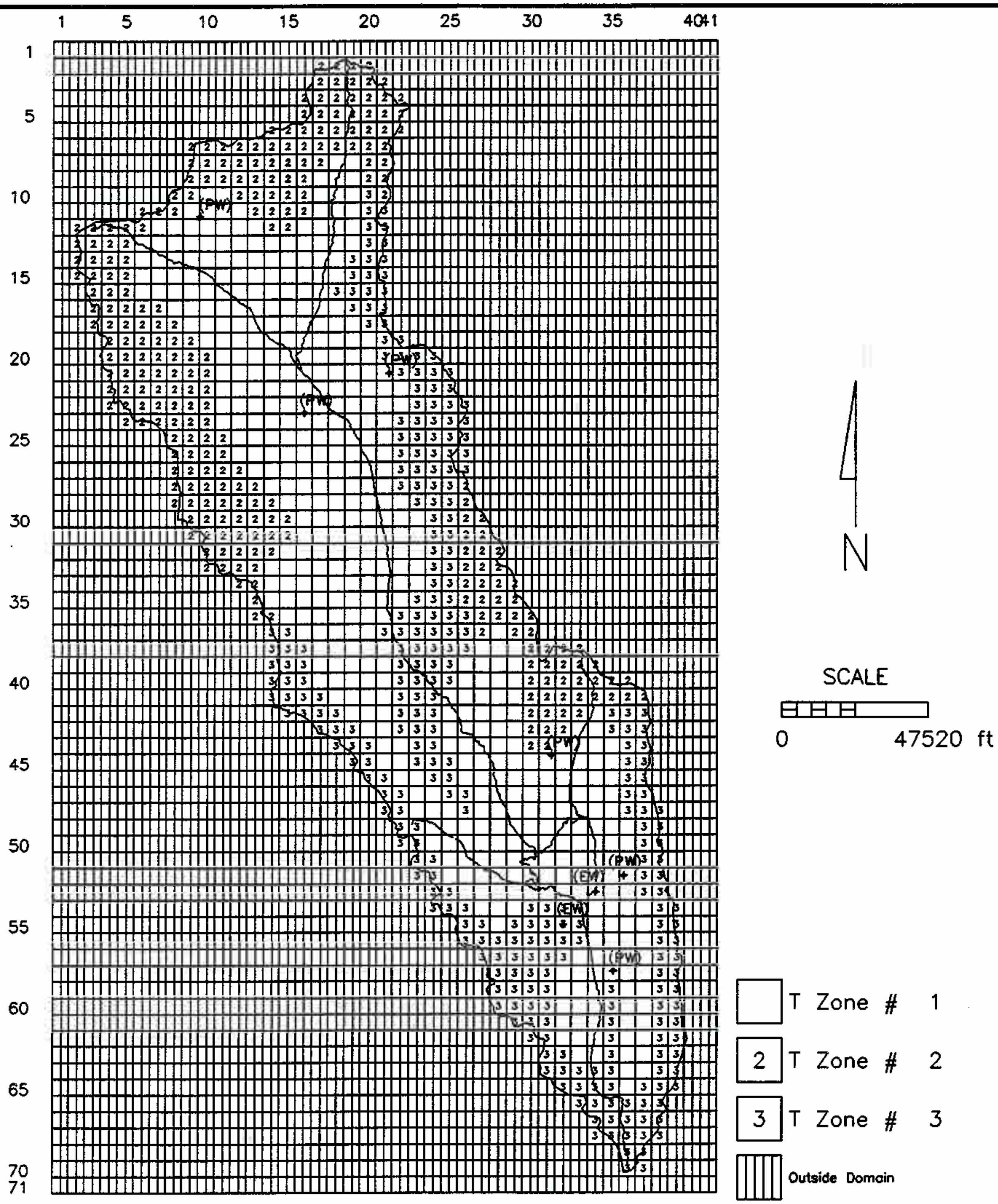

Tikaboo Valley Transmissivity Zones for Layer 1
(EW) = Existing Well (PW) = Proposed District Well

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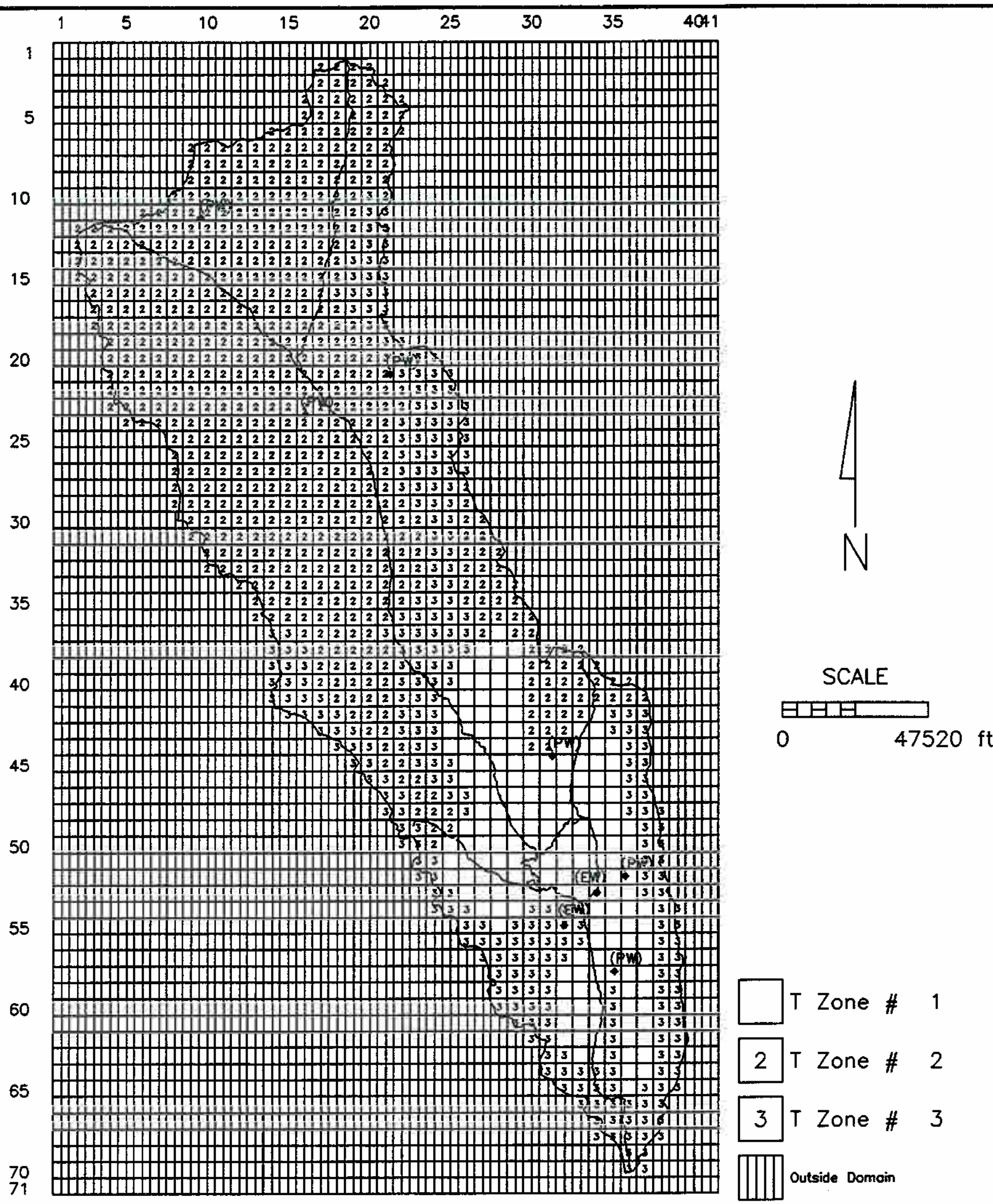
Transmissivity Zones of the Upper Aquifer. Zone 1 = 2,600 ft2/day, Zone 2 = 281 ft2/day, Zone 3 = 4,320 ft2/day.

FIGURE 5



Tikaboo Valley Transmissivity Zones for Layer 2
(EW) = Existing Well (PW) = Proposed District Well

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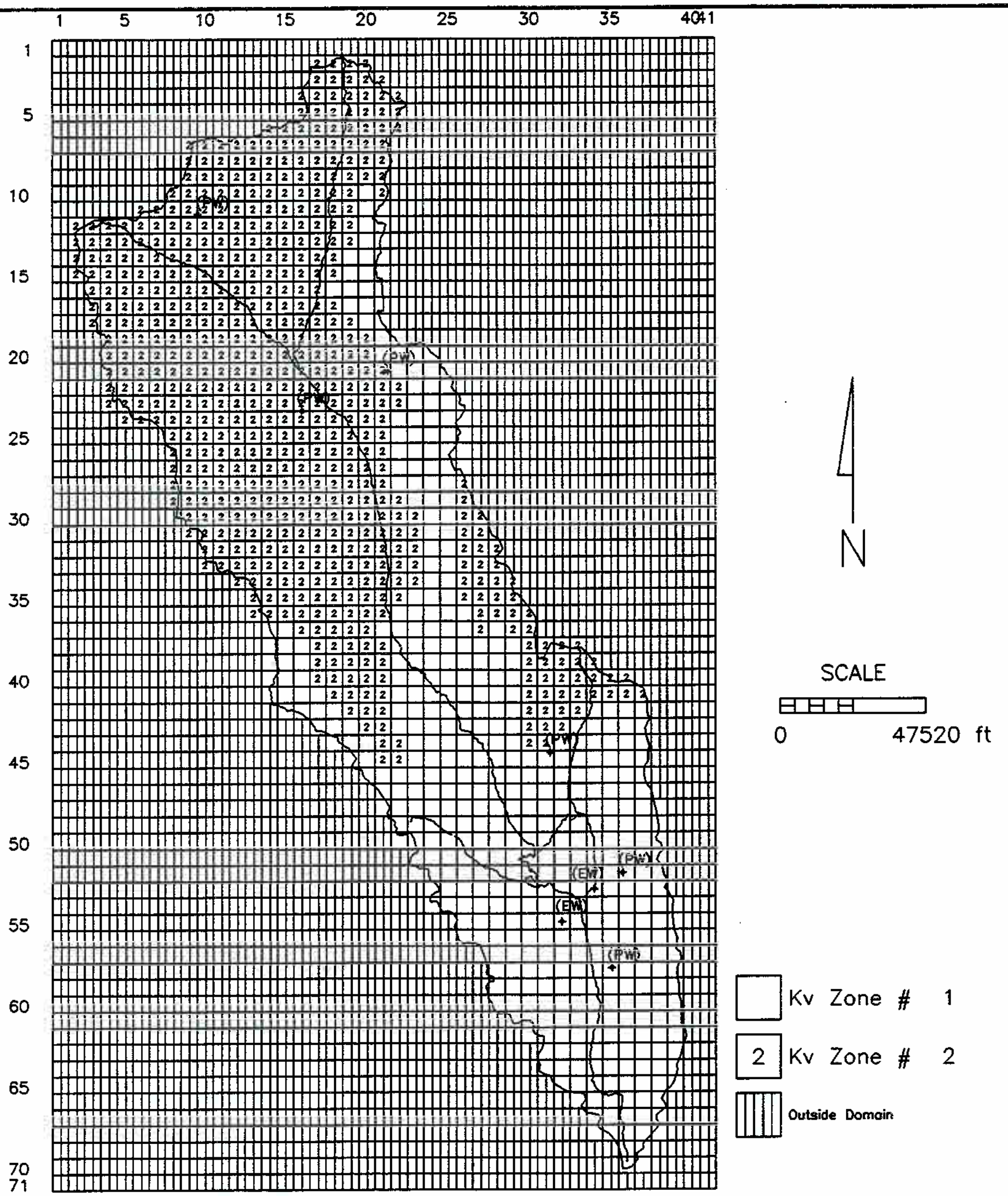
Transmissivity Zones of the Intermediate Aquifer. Zone 1 = 2,600 ft2/day, Zone 2 = 281 ft2/day, Zone 3 = 4,320 ft2/day.

FIGURE 6



Leakance Zones for Layer 1 and Layer 2
(EW) = Existing Well (PW) = Proposed District Well

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Leakance Zones of the Upper Aquifer and Intermediate Aquifer. Zone 1 = 2.25X10^(-5)1/day, Zone 2 = 7.50X10^(-3)1/day.

FIGURE 7

Two zones of recharge were selected to represent mountain recharge and lowland areas where recharge is absent. Recharge zone number 1 represents the lowland areas which lack sufficient precipitation for ground-water recharge. Recharge zone number 2 represents the areas of mountain recharge in the basin. Recharge zone 2 was given a value of 4.59 x 10^{-5} ft/day with the spatial distribution shown in Figure 8. The total volume of recharge within the spatial domain of zone 2 is 6,000 afy. This volume of recharge was estimated by Harrill, et al. (1988) for Tikaboo Valley.

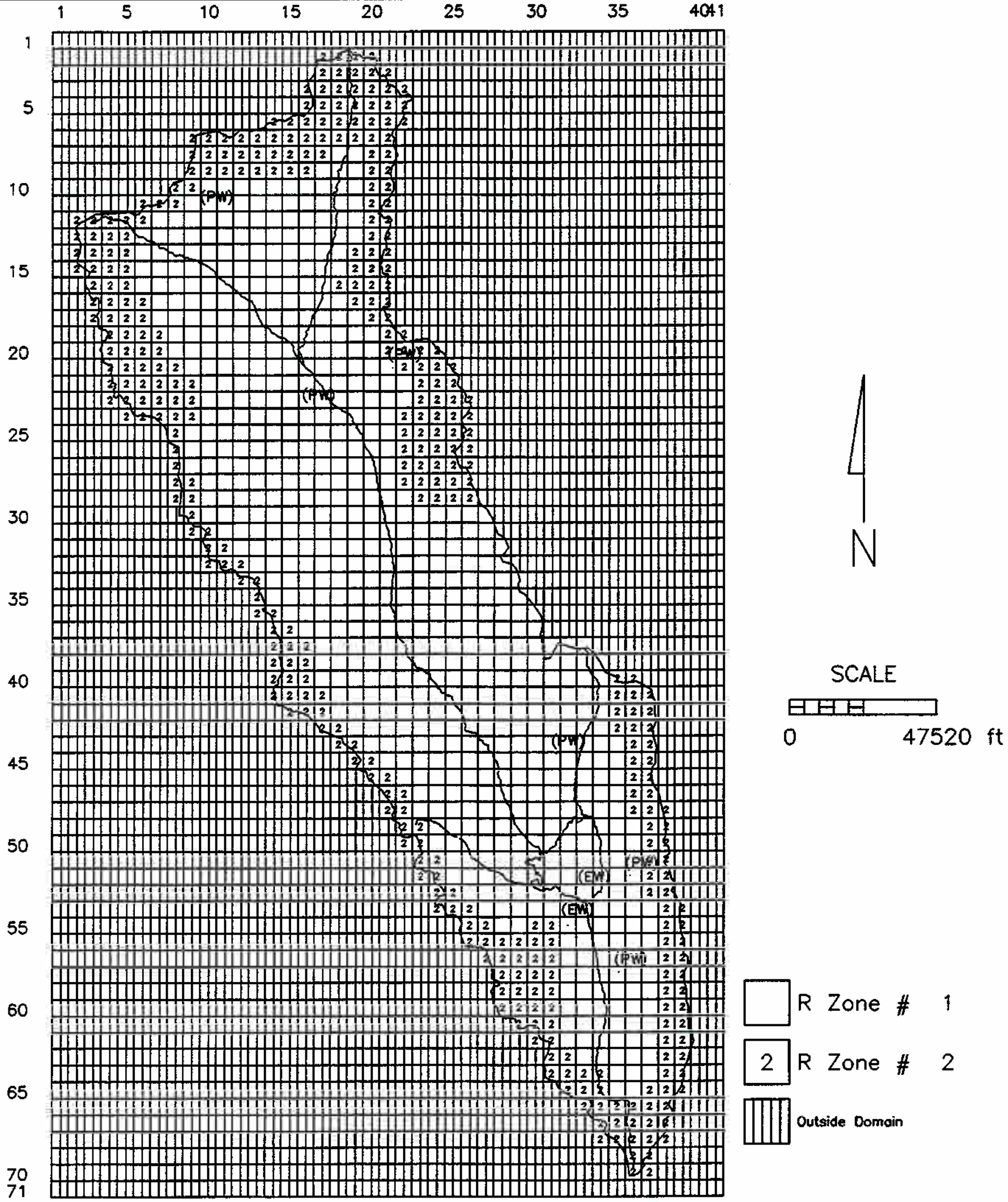
Ground-Water Levels

Since the regional flow map in Figure 4 was constructed by the USGS (Harrill, et al., 1988), two wells located in southern Tikaboo Valley were measured in April 1990. Based on this new information, Harrill (personal communication, September 9, 1990) suggested the water levels in Tikaboo may be lower than shown in Figure 4. In addition, the surface elevations of the two observation wells in southern Tikaboo Valley are not surveyed. Harrill (personal communication, September 9, 1990) indicated the measured water levels are accurate to plus or minus 5 feet of the observed value. Therefore, during the calibration, calculated water levels were matched to within plus or minus 5 feet of the observed water levels. Figure 9 illustrates the steady-state water levels for the upper aquifer (layer 1) and the residual (calculated minus observed water level) for each well. Table 8 shows the calculated and observed water levels for each observation well. Figures 10 and 11 show the steady-state water levels for the intermediate aquifer (layer 2) and the lower carbonate aquifer (layer 3).

Table 8. Water Level Elevations and Model Locations for Observation Wells Used in the Calibration of Tikaboo Valley North.

Well	Row	Column	Layer	Observed Level	Calculated Level	Residual[a]
T-1	53	34	1	3,052.0	3,047.3	4.9
T-2	55	32	1	3,036.0	3,041.1	-5.0

[a] Residual is observed water level minus calculated water level.



Tikaboo Valley Precipitation Recharge Zones
(EW) = Existing Well (PW) = Proposed District Well

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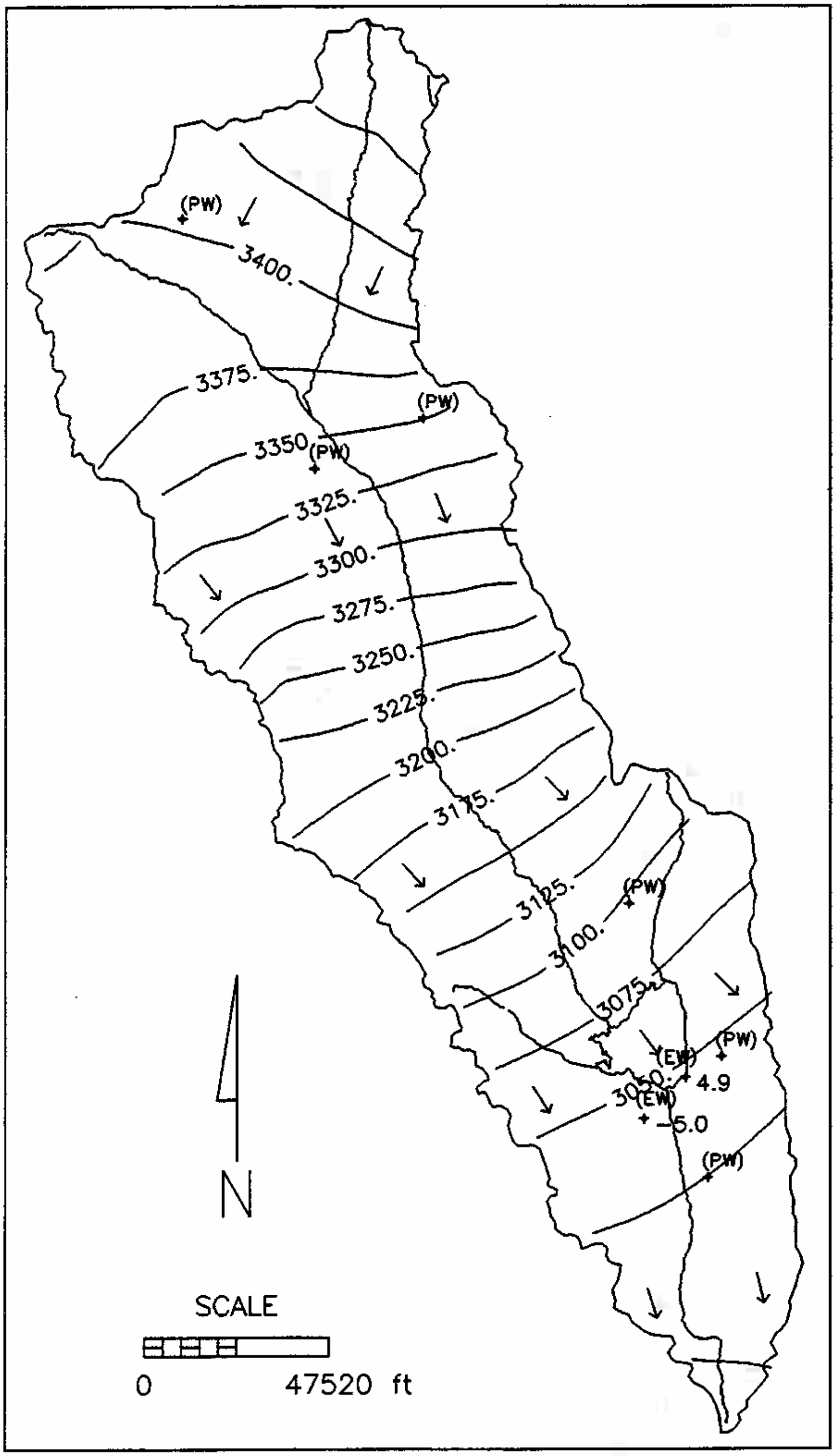
Recharge Zones of the Upper Aquifer. Zone 1 = 0.0 ft/day, Zone 2 = 4.59X10^(-5)ft/day.

FIGURE 8



Tikaboo Valley Layer 1 Water Level Contours and Residuals
C.I. = 25 ft. (EW) = Existing Well (PW) = Proposed District Well

GERAGHTY & MILLER, INC. *Environmental Services*	**Calibrated Water Levels for the Upper Aquifer (Layer 1) and Residuals. C.I. = 25 ft. Negative Residual => Observed Higher than Calculated. Positive Residual => Observed Lower Than Calculated.**	FIGURE 9

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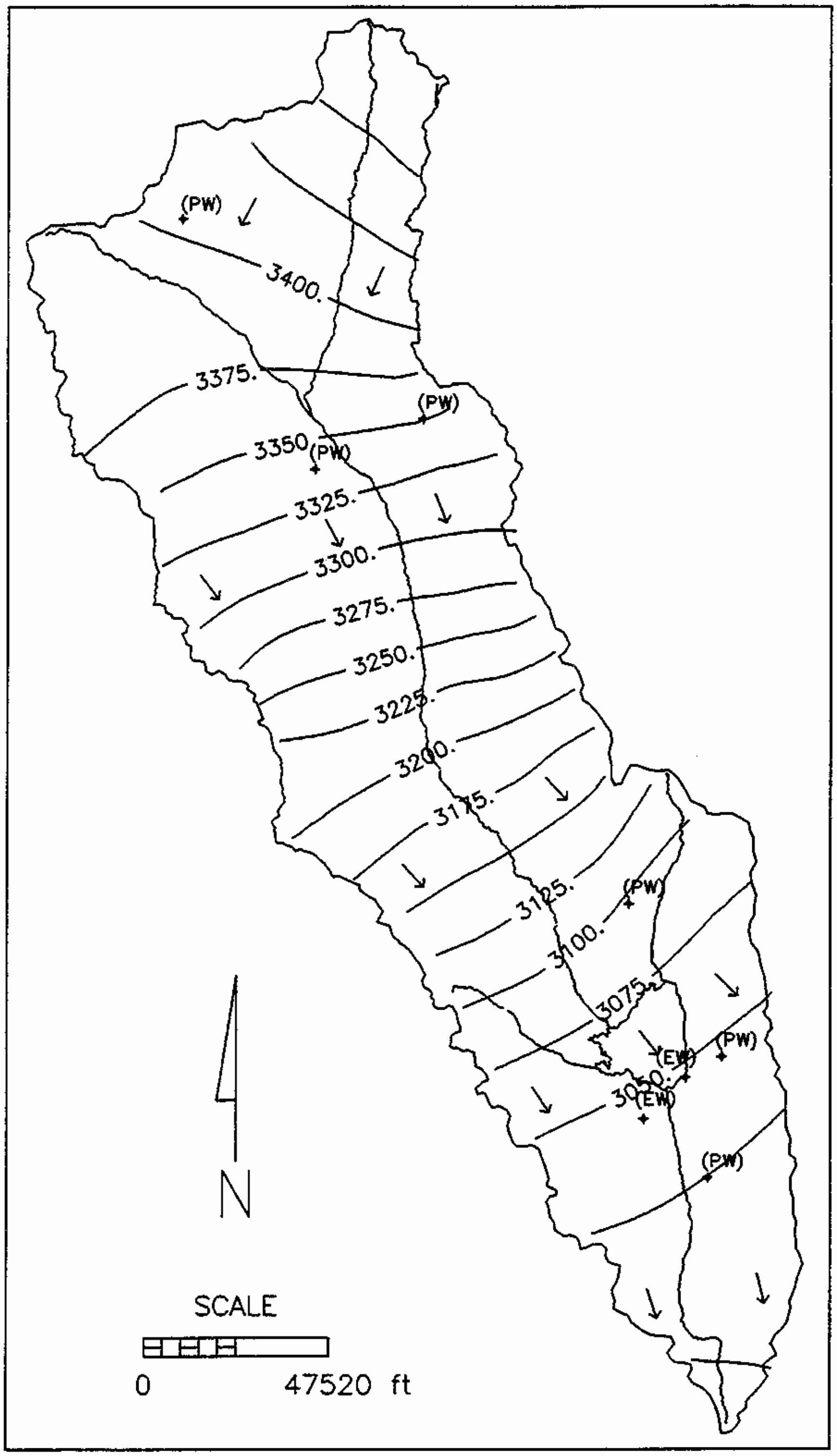

Tikaboo Valley Layer 2 Water Level Contours
C.I. = 25 ft. (EW) = Existing Well (PW) = Proposed District Well

GERAGHTY & MILLER, INC. *Environmental Services*	**Water Levels for the intermediate Aquifer (Layer 2) C.I. = 25 ft.**	FIGURE 10

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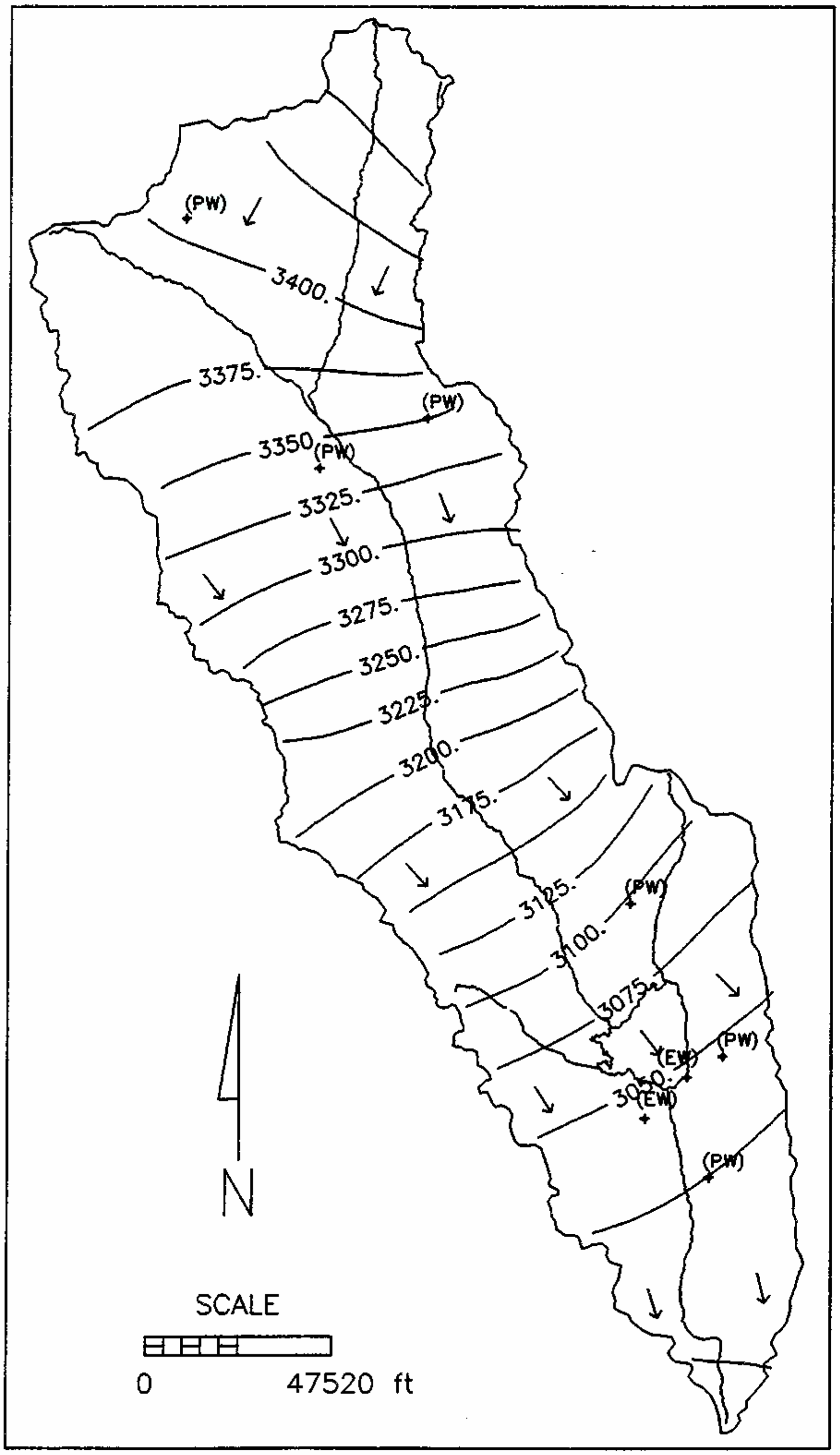

Tikaboo Valley Layer 3 Water Level Contours
C.I. = 25 ft. (EW) = Existing Well (PW) = Proposed District Well

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Water Levels for the Lower Aquifer (Layer 3) C.I. = 25 ft.

FIGURE
11

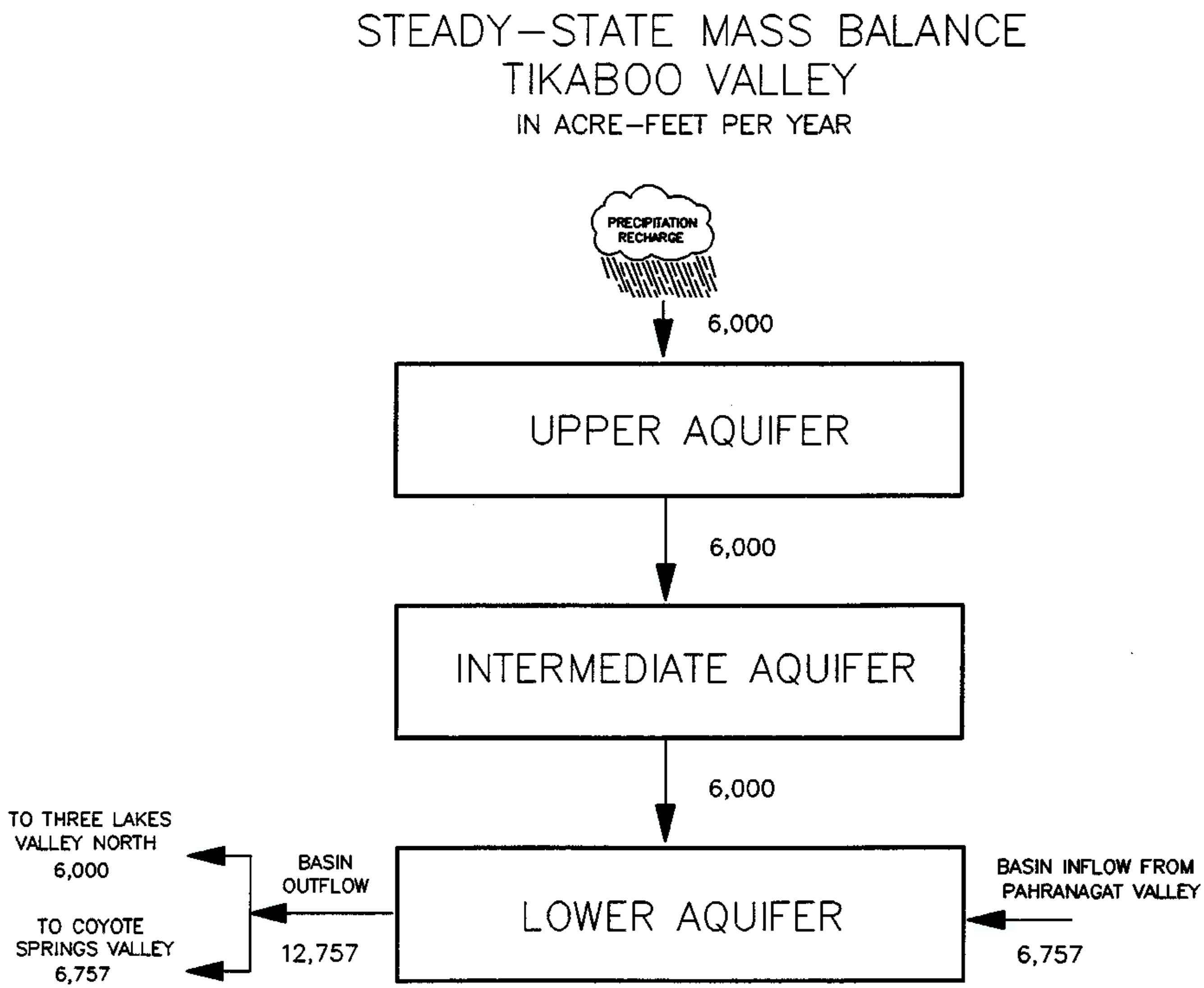
The similar water levels in Figures 9, 10, 11 demonstrate that the flow into the model domain through the lower carbonate aquifer (layer 3) largely influences the water levels in the upper (Layer 1) and intermediate (layer 2) aquifers.

Results of the USGS regional model (Harrill, personal communication, June 13, 1990) demonstrate a general north to south flow direction in the northern basin with a gradual change in direction to southeast and southwest in the southern basin. The calculated steady-state water levels in Figures 9 through 11 reflect these regional flow patterns.

The steady-state model predicts that heads in all three layers are similar. This result was caused by a lack of water level data available for calibration. Existing information describes general flow directions within the basin and estimated inflow and outflow rate (Harrill, et al. 1988). The model was developed to reproduce these general features.

Steady-State Model Water Balance

The water balance for the steady-state model in Figure 12 shows a total of 6,800 afy entering the northeastern basin boundary through the lower carbonate system and a total of 6,000 exiting the lower carbonate aquifer through the southwestern basin boundary (Three Lakes Valley North). Approximately 6,800 afy exits the southeastern basin boundary through the carbonates to Coyote Springs Valley. These calculated basin inflows and outflows closely match the water budget estimated by Harrill, et al., (1988) and Harrill (personal communication, September 9, 1990). The net vertical downward flow of 6,000 afy represents the recharge applied to the upper aquifer (layer 1) reaching the intermediate (layer 2) and lower carbonate (layer 3) aquifer.



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Steady-State Flow Balance for Tikaboo Valley.

FIGURE 12

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APPENDIX A

APPENDIX A

STEADY STATE MODEL CALIBRATION

by Dr. J.V. Tracy and K. Brothers

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. Water levels in Tikaboo Valley were limited to measurements of two wells located within two miles of each other in the southern part of the valley. Calibration of the Tikaboo Basin 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 Maxey-Eakin estimate made in Scott et al. (1971) and Rush (1970). Additional quantities of water allowed to flow into and through the basin model as a part of the regional White River ground-water flow system were based upon Harrill and others (1988). 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 adjacent portions of the Death Valley and White River ground-water flow systems 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. As most of the inflow to and outflow from the modelled area of the basin occurs from recharge and outflow through the Death Valley and White River flow systems, the properties, or parameters, related to these mechanisms of flow are constrained by these estimated flow rates.

The ground-water levels in the wells shown in Table 1 were used during the calibration. The residuals (the difference between the actual and calculated ground-water level) resulting from the calibration are shown in Figure 9.

Table 1: Wells used in Calibration

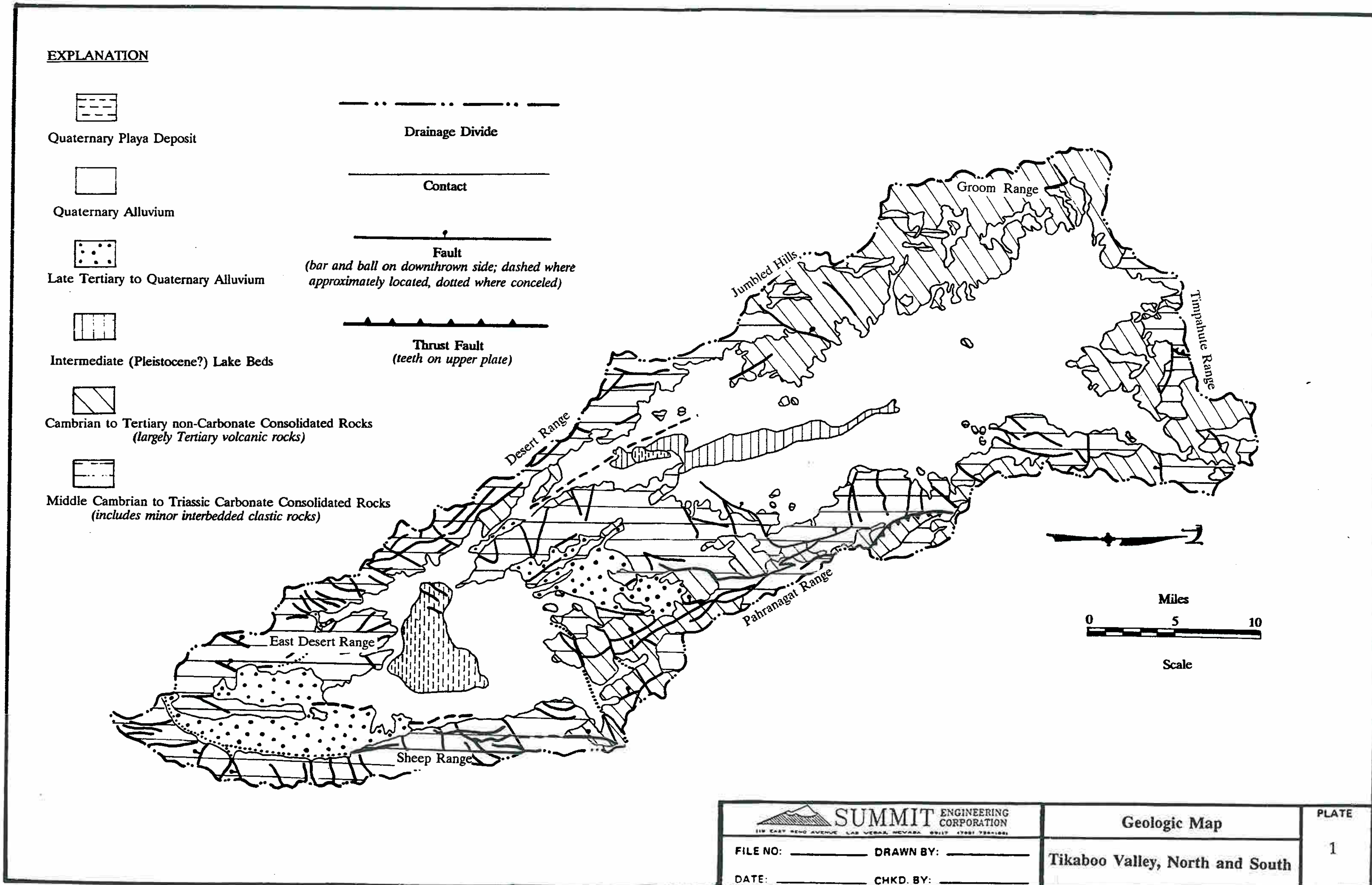
					RESULTS OF SENSITIVITY RUNS										
Well Location	Date of Meas.	R / C [1]	Actual Water Level	Δ[2]	L1 T1[3]	L1 T2	L1 T3	L2 T1	L2 T2	L2 T3	L3 T1	TK1 L1	TK2 L1	TK1 L2	TK2 L2
Valley Fill															
211 E61		53 34	3052	4.9	-3	0	0	-2	0	0	-7	0	0	0	0
212 E60 10AD		55 32	3036	-5.0	-3	0	-1	-2	0	0	-6	0	0	0	0

1) R / C = row / column
2) Difference between actual and model water level
3) Variable - Layer 1, Transmissivity 1 - change in calculated ground-water level in feet

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 zonal transmissivities (L1T1, L2T1, etc.), zonal leakances (TK1L1, etc.), and the general head conductances. 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 results of these sensitivity simulations are discussed briefly. These results are shown in the accompanying Table 1 of this appendix. The sensitivities represent the estimated change in ground-water level at the wells with a 100 percent increase (or decrease) in the calibrated values that have been previously reported in the Model Calibration section of this report.

Analyses of the sensitivity simulations resulted in several general observations and estimated model properties. First, the transmissivity of the alluvial, valley-fill aquifer and the intermediate volcanic 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. However, because of the lack of calibration points (two within a couple of miles located in the southern part of the basin) the most sensitive parameter becomes the general head conductances. As stated above, the conductances established replicate the inflow and outflow as established by Harrill and others (1988).


EXPLANATION
Quaternary Playa Deposit
Quaternary Alluvium
Late Tertiary to Quaternary Alluvium
Intermediate (Pleistocene?) Lake Beds
Cambrian to Tertiary non-Carbonate Consolidated Rocks
(largely Tertiary volcanic rocks)
Middle Cambrian to Triassic Carbonate Consolidated Rocks
(includes minor interbedded clastic rocks)
Drainage Divide
Contact
Fault
(bar and ball on downthrown side; dashed where approximately located, dotted where conceled)
Thrust Fault
(teeth on upper plate)
Groom Range
Jumbled Hills
Timpahute Range
Desert Range
Pahranagat Range
East Desert Range
Sheep Range
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Geologic Map
Tikaboo Valley, North and South
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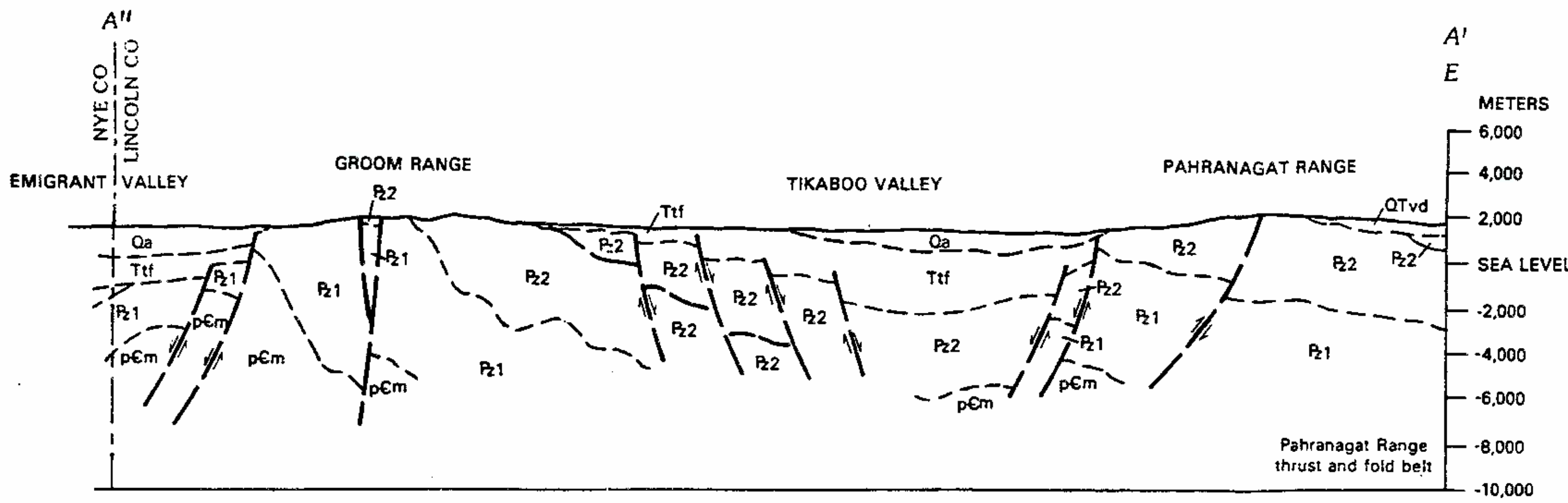

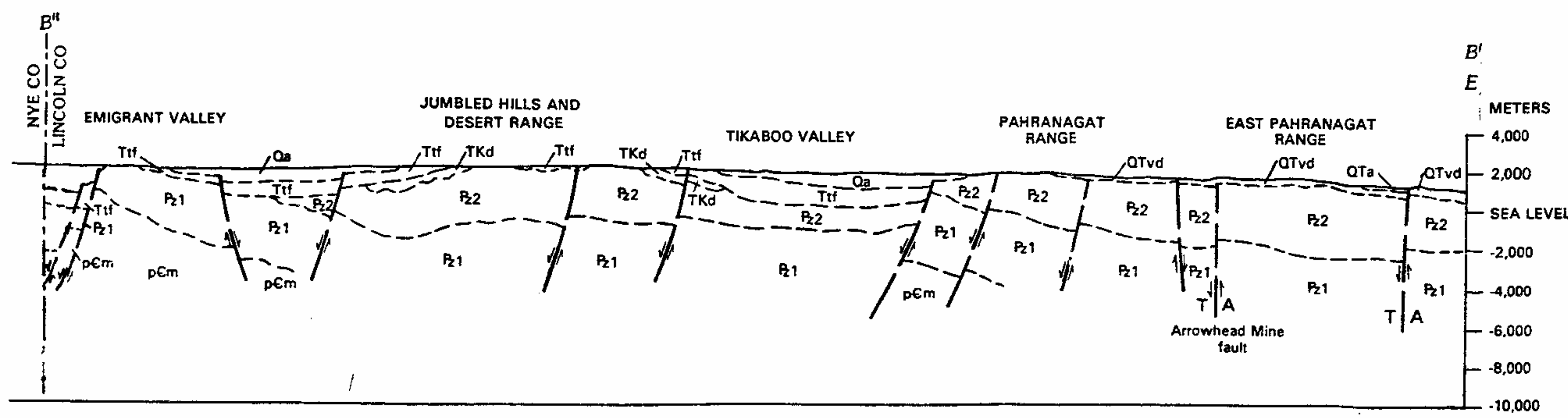

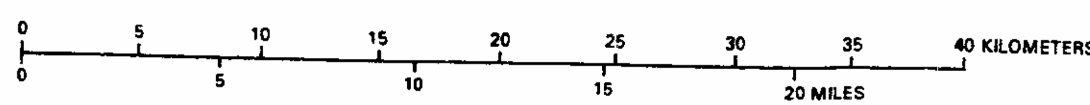

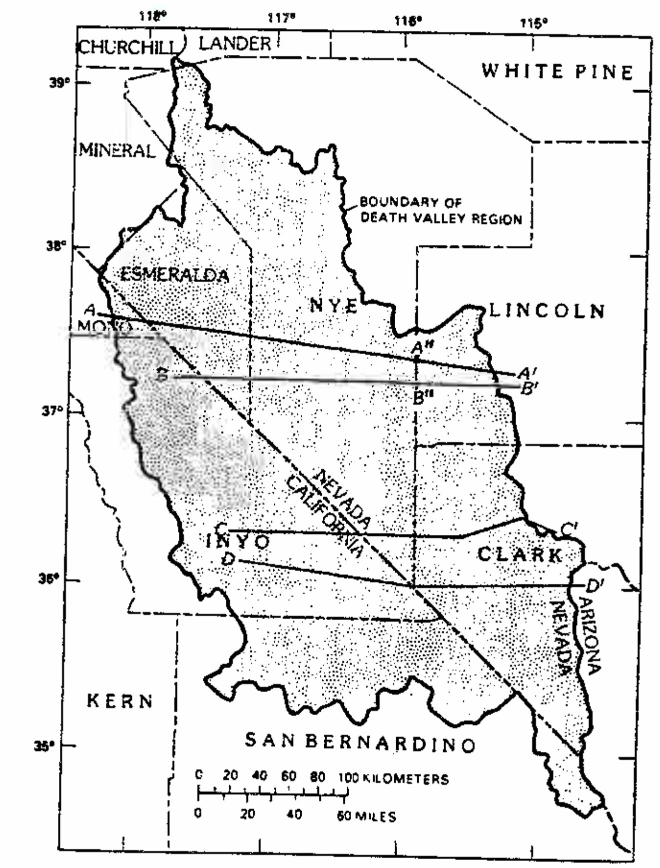

EXPLANATION

- - - - CONTACT BETWEEN LITHOLOGIC UNITS

FAULT–Arrows indicate relative vertical movement. A indicates relative movement away and T indicates relative movement towards

LQ LATE QUATERNARY FAULT

SUMMIT ENGINEERING CORPORATION	Geologic Cross Section	PLATE
FILE NO: ______ DRAWN BY: ______	Tikaboo Valley	2
DATE: ______ CHKD. BY: ______	(After Bedinger et. al., 1989)	

GEOLOGIC SECTION A-A', MONO COUNTY, CALIFORNIA, AND ESMERALDA, NYE, AND LINCOLN COUNTIES, NEVADA

STRATIGRAPHIC UNITS

Unit	Description
Qa	Alluvium and minor playa clay; Quaternary; <1,500 meters
QTv	Basalt flows; Quaternary and Pliocene (?); <600 meters; White Mountains area (Krauskopf, 1971; Stewart and others, 1974)
QTvd	Flows and tuffs undifferentiated with interbedded volcanic sediments and lake clay and silt; Quaternary, Pliocene, and Miocene; <300 meters; Pahranagat Range (Tschanz and Pampeyan, 1970, includes some sedimentary rocks probably equivalent to Pliocene Panaca and Muddy Creek Formations)
Ttf	Tuff, mostly unwelded, minor welded tuff, lava flows of silicic and intermediate composition and minor volcaniclastic interbeds; Pliocene, Oligocene(?), and Miocene; <3,000 meters; areas in eastern half of cross section (includes numerous volcanic units mapped by many geologists; see references)
Tt	Welded tuff; Pliocene, Oligocene, and Miocene; <3,000 meters; Stonewall Mountain (Cornwall, 1972)
Tvr	Silicic to intermediate flows, tuffs, and minor intrusives; Pliocene to Miocene; <1,500 meters; Palmetto Mountains area (Albers and Stewart, 1972)
Td	Continental clastic rocks, fanglomerate; Oligocene; <900 meters; west of Mount Helen volcanic center (Ekren and others, 1971)
Ti	Silicic intrusives, domes, necks, dikes; Pliocene and Miocene; major ranges and in association with inferred calderas
TJg	Granitic intrusives, granite to diorite; Tertiary to Jurassic; regional shallow "basement" in White Mountains and Silver Peak Range, Sierra Nevada "outliers"
Od	Shale-slate phyllite, chert, minor limestone and quartzite; Ordovician; <900 meters; Silver Peak Range and Palmetto Mountains (Albers and Stewart, 1972; Steward and others, 1974, their Palmetto Formation). Highly contorted and thrust faulted and generally metamorphosed to low grade
Pz2	Limestone with minor dolomite, shale, and sandstone; Pennsylvanian to Lower Cambrian; <8,000 meters; from Palmetto Mountains to Pahranagat Range (many authors as indicated). Includes many formations generally from Tippipah Limestone to upper half of Carrara Formation or Pioche Shale. Nearly all carbonates in Pahranagat Range (>90%). Contains 1,800 meters of clastic wedge of Eleana Formation in central part of section. Complexity of thrust faulting and folding within the Pz2 unit decreases from west to east
Pz1	Shale-slate-phyllite, quartzite with minor limestone and dolomite; Cambrian and Precambrian; 4,500-6,000 meters; widespread (Albers and Steward, 1972, and Cornwall, 1972, and other authors as indicated). Includes several formations from lower half of Carrara to Johnnie Formations in southern Nye County, and Harkless to Wyman Formations in Esmeralda County, and Prospect Mountain Quartzite in Lincoln County
p€m	Gneiss and schist; Precambrian(?) (Rogers and others, 1968, their gneiss and schist of Trappman Hills, exposed 8 kilometers north of geologic section)

GEOLOGIC SECTION B-B', INYO COUNTY, CALIFORNIA, AND ESMERALDA, NYE, AND LINCOLN COUNTIES, NEVADA

STRATIGRAPHIC UNITS

Unit	Description
Qa	Alluvium and minor playa clay; Quaternary; <1,200 meters
QTa	Older alluvium, mainly gravels, semi-lithified; Pleistocene and Pliocene; 900 meters
QTvi	Basaltic pipe intrusion; Pleistocene and Pliocene. Vent is 4 kilometers to south
QTvd	Volcanic rocks undifferentiated, silicic-mafic flows and tuffs, and continental detrital rocks; Quaternary, Pliocene, and Miocene; <600 meters; Pahranagat Range (Tschanz and Pampeyan, 1970, includes some sedimentary rocks probably equivalent to Pliocene Panaca and Muddy Creek Formations)
Ttf	Tuff, mostly unwelded, minor welded tuff, lava flows of silicic and intermediate composition, and minor volcaniclastic interbeds; Pliocene, Miocene, and Oligocene(?); <2,100 meters; widespread occurrence (includes numerous formations - see references). Probably greater volume of tuff than flow within calderas. Includes Thirsty Canyon and Timber Mountain and Paintbrush Tuffs, and others
TKd	Coarse continental clastic rocks, fanglomerate, lithified gravels, and so forth; Tertiary and Cretaceous(?) <600 meters; Jumbled Hills and Desert Range (Tschanz and Pampeyan, 1970, their unit TKc, older clastic rocks)
Ti	Intrusive volcanic rocks, mainly silicic caldera and subcaldera masses; Tertiary
TJg	Granitic intrusive rocks, mainly quartz monzonite to quartz diorite; Tertiary and Jurassic; western part of section as Sierra Nevada "outliers" and in Belted Range (Albers and Stewart, 1972; Gibbons and others, 1963; Barnes and others, 1963)
IPMd	Shale, argillite, quartzite, conglomerate (95%), and limestone (5%); Pennsylvanian and Mississippian; <2,400 meters; Belted Range (Barnes and others, 1963)
Pz2	Limestone with minor dolomite, shale and sandstone; Permian to Middle Cambrian; <7,600 meters; widespread occurrence (many authors as indicated). Includes many formations from Bird Spring or Tippipah Limestone to Pioche Shale or upper half of Carrara Limestone. In eastern part of section, Pz2 is nonmetamorphosed; in western part, it is recrystallized and pervasively regionally metamorphosed to low to medium grade. Complexity, extent, and degree of thrusting and folding increase from east to west
Pz1	Shale-slate-schist, quartzite, with minor limestone and dolomite; Cambrian and Precambrian; 4,500-7,600 meters; widespread but mainly in deep subsurface (Albers and Stewart, 1972; Cornwall, 1972; Tschanz and Pampeyan, 1970)
p€m	Gneiss and schist; Precambrian; interpreted to occur at relatively shallow depth (1,500-4,500 meters) beneath one area of Pahute Mesa, Emigrant Valley, and Pahranagat Range

SUMMIT ENGINEERING CORPORATION	Explanation of Symbols Used in Cross Section	PLATE 2 (cont.)
FILE NO: ______ DRAWN BY: ______		
DATE: ______ CHKD. BY: ______		