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BASELINE HYDROGEOLOGY EVALUATION REPORT

for

Telephone Flat Geothermal Project
Medicine Lake, California

prepared for

CalEnergy Company Inc.
302 South 36 Street, Suite 400
Omaha, NE 68131

August 20, 1997

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WA Job # 166-1303

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Weiss Associates work for the Telephone Flat Geothermal Project Baseline Hydrology and Potential Environmental Impact Report was conducted under my supervision. To the best of my knowledge, the data contained herein are true and accurate and satisfy the scope of work prescribed by the client for this project. The data, findings, recommendations, specifications or professional opinions were prepared solely for the use of CalEnergy Company, Inc. in accordance with generally accepted professional engineering and geologic practice. We make no other warranty, either expressed or implied, and are not responsible for the interpretation by others of the contents herein.

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CONTENTS

FIGURES

TABLES

APPENDICES

PLATES

ACRONYMS/ABBREVIATIONS

A-ft	Acre-ft
A-ft/yr	Acre-feet/year
asl	above sea level
bgs	below ground surface
BPA	Bonneville Power Administration
BTU	British Thermal Unit
°C	Degree Centigrade
CEC	CalEnergy Company
DWR	California Department of Water Resources
EIS/EIR	Environmental Impact Statement/Environmental Impact Report
ET	Evapo-transpiration
°F	Degree Fahrenheit
ft	feet
FRRCD	Fall River Resource Conservation District
FRS	Fall River Springs
in	inches
gal	gallons
gpd	gallons per day
lbs/hr	pounds pr hour
kph	thousands of pounds per hour
kV	kilovolt
mi	mile
LLNL	Lawrence Livermore National Laboratory
MLB	Medicine Lake Basin
MLC	Medicine Lake Caldera
MLH	Medicine Lake Highlands
MLH-RSA	Medicine Lake Highlands-Regional Study Area
MLHSA	Medicine Lake Highlands Study Area
MLV	Medicine Lake Volcano
msl	mean sea level
MW	Megawatt
NCG	Noncondensible gas
psia	pounds per square inch – absolute
ppm	parts per million
TFGP	Telephone Flat Geothermal Project
TGH	Temperature Gradient Hole
USFS	United States Forest Service
USGS	United States Geological Survey
wt	weight

SUMMARY

CalEnergy Company, Inc., has proposed to site a 48 megawatt geothermal power plant at Telephone Flat, in the Glass Mountain Federal Unit, Medicine Lake Highlands (MLH), Siskiyou County, California. This report presents the hydrological baseline setting for the proposed Telephone Flats Geothermal Project in the context of the MLH and the surrounding region, referred to as the MLH Study Area (MLHSA) and the MLH-Regional Study Area (MLH-RSA), respectively.

This proposed project is be sited within the constructional basin, referred to as the Medicine Lake Basin (MLB) at the summit of the MLH. The MLH is a recent bi-modal shield volcano covering approximately 1,800 square kilometers (km^2, 648 square miles (mi^2) and located approximately 50 km (30 mi) northeast of Mount Shasta. The volcano is related to, but physically offset to the east from, the High Cascade Range of volcanoes, which range from northern California to southern British Columbia. The MLH lies on the Modoc Plateau, an older volcanic province formed by plateau basalts filling and covering a still older basin and range-type faulted valleys.

The MLH appears to lie at the intersection of three structural fault trends: north-south, northwest-southeast, and north, northeast-south, south, southwest. It appears to be located on the buried west rim of the north-south trending Tule Lake Graben and north, northeast of the northeast rim of the north, northwest trending Fall River Valley Graben. These fault controlled valleys appear to pass beneath the eastern and southern to southwestern portions of the MLH and may intersect southeast of the summit.

Average annual precipitation in the MLH-RSA ranges from a high of 82 cm/yr (32 in/yr), within the MLB, to 28 cm/yr (11 in/yr) at Tule Lake. In spite of high precipitation rates, there is very little surface drainage, because the fractured and porous nature of the surface volcanics allows percolation downward.

The hydrology of the MLH-RSA is dominated by three major hydrogeologic units (1) MLH volcanic massif, (2) Modoc Plateau, and (3) MLH Geothermal Reservoir. Regional hydrogeology suggests shallow ground water flow within the Modoc Plateau basalts filling the Tule Lake and Fall River Valley Grabens is from Tule and Klamath Lakes in the north to the Fall River Springs and other associated high volume discharge springs feeding Little Tule and Fall Rivers in the Lower Fall River Valley to the south. Shallow ground water in the MLH is a perched water system above the regional shallow ground water aquifer in the Modoc Plateau. The predominant shallow ground water flow within the MLH hydrogeologic unit is radially outward from the Medicine Lake area and downward to the regional aquifer within the Modoc Plateau. The MLH geothermal reservoir is believed to reside in the rocks of both the MLH and the Modoc Plateau. Communication between the shallow, cold ground water system in MLH and the deeper, hot geothermal system appears to be both very limited and very localized. Recharge to the geothermal system is interpreted to be from deep ground water within the Modoc Plateau within the MLHSA.

Geochemically, virtually all the springs, surface waters, and shallow ground waters in the MLH-RSA generally have a very low total dissolved solids and their delta oxygen-18 and delta deuterium isotopic values fall on the worldwide meteoric water line. This indicates that all these regional springs, surface waters, and shallow ground water represent a meteoric water source with no

evidence of any geothermal fluid component. The geothermal reservoir fluids, by contrast, show the distinct delta oxygen-18 shift typical of geothermal fluids that have undergone water-rock interaction. The delta deuterium isotopic values of the geothermal reservoir fluid are consistent with a Modoc Plateau source region.

The largest surface water body, within the MLH, is Medicine Lake, located at the MLB. In addition to Medicine Lake, there are several small lakes and springs. Two perennial springs occur, and the longest perennial stream is Paynes Creek, which flows for approximately 2.5 km (1.5 mi) from Paynes Springs until it disappears below the surface. The nearest significant surface water bodies surrounding the MLH are Tule and Klamath Lakes, approximately 33 km (20 mi) north of Medicine Lake and the numerous high volume springs feeding the Little Tule and Fall Rivers, approximately 55 km (33 mi) south of Medicine Lake. One of these high volume springs, the Fall River Springs are among the largest spring groups in the United States flowing at a rate of about 1.3 billions gallons per day.

Essentially, no hydrologic, surface expression of the geothermal resource under MLH is evident. There is, however, a "Hot Spot" in the northeastern portion of the MLB which appears to originate from heated meteoric water infiltrating around Big Glass Mountain, a recent silicic extrusion, being conductively heated by the associated underlying igneous rocks, and exiting at the surface as heated water vapor.

There are at least three distinct hydrologic regimes with the MLHSA (1) the shallow, cold ground water, (2) the geothermal system whose top is defined by the 38°C (100°F) isotherm, and (3) the geothermal reservoir. Water level differences between the shallow ground water wells in MLB and the top of the geothermal system as represented by the 38°C (100°F) isotherm in the TGHs indicate that there is a pressure differential of about 200 – 400 m (61 – 122 ft) with the shallow ground water system being at the higher head. This pressure differential indicates a good confining layer between these two ground water systems.

A hydrologic water balance of the MLHSA indicates that the estimated average annual net recharge to the MLB is 23,123 A-ft/yr and the recharge to the Modoc Plateau from the MLHSA is estimated at about 86,570 A-ft/yr. The primary consumptive water use of shallow ground water by the proposed geothermal project consists of water used during the drilling of production wells. The projected drilling water consumptive water usage will range from 0.089% to 0.015% of the annualized estimated net recharge to the MLB.

The consumptive water use of waters from the geothermal reservoir consists of cooling tower water loss. This loss is estimated at 1,850 A-ft/yr or about 13% of the reservoir fluid produced. This fluid loss is expected to be replaced by waters entering the geothermal reservoir from the deep, ground water system in the Modoc Plateau. As such, the Fall River Springs water flow and a typical area recreational water use for waters in the Modoc Plateau were used as a frame of reference for a consumptive use comparison. The estimated evaporative water loss from the geothermal reservoir of 1,850 A-ft/yr represents about 0.13 % of the FRS' discharge. This consumptive water use is also less than the annual water use of about three golf courses in the region.

Based on similar oxygen-18 isotopic values between Fall River Springs and waters at MLB, Rose et al. (1996) and Davisson (1997a) postulated that the source of the waters issuing from the springs is from MLH some 55 km (33 mi) north of the springs. However, the annual net recharge to the MLB can only account for about 2% of the ground water flow at the Fall River Springs. If the entire MLHSA was considered as a potential FRS recharge source, the isotopic signature of FRS would need to be heavier than measured because of the significant contribution of water from lower elevations than the MLB. Even without satisfying the isotopic signature of the FRS, the total MLHSA recharge would only account for about 5% of the FRS discharge.

Additionally, Mariner (1997b) reported that there is no evidence of any MLH geothermal reservoir fluid contribution to the waters at Fall River Spring. This is based on his analysis of delta deuterium isotopic values and chloride concentrations in the fluid chemistry from the FRS, hot springs in the Modoc Plateau, and the MLH geothermal reservoir

Since the shallow ground water in the MLB and the MLH are unable to supply the Fall River Springs discharge, and the geothermal reservoir is not contributing any measurable flow to the springs, a preliminary reconnaissance of potential recharge areas was conducted. This investigation has identified six potential recharge sources to feed the FRS discharge.

1. INTRODUCTION

1.1 Project Description

This report presents the hydrogeology baseline setting for the CalEnergy Company, Inc. (CEC) 48 Megawatt (MW) Telephone Flat Geothermal Project (TFGP) located in the Glass Mountain Federal Unit, Siskiyou County, northeastern California (Figure 1). Its purpose is to describe, within the constraints of the available data (Section 1.3), the:

1. regional and local geology and hydrology of the TFGP area; and,
2. interrelationship of the planned geothermal development and the local hydrological conditions.

This work is intended to support the TFGP Environmental Impact Statement/Environment Impact Report (EIS/EIR).

The TFGP is located on Federal Geothermal Leases issued by the U.S. Bureau of Land Management (BLM). These leases are on lands administered by the U.S. Forest Service Modoc National Forest (USFS). The TFGP occur within the Medicine Lake Caldera (MLC) which lies at the summit of Medicine Lake Highlands (MLH). The terms MLH and Medicine Lake Volcano (MLV) are used interchangeably herein. The term MLH is used for geographical reference, while the term MLV is used in a geological context. Similarly, the terms MLC and Medicine Lake Basin (MLB) are used interchangeably, with the former referring to the geology and the latter to the hydrology of the study area. The TFGP area is approximately 0.8 kilometer (km, 0.48 mile (mi)) from the eastern edge of Medicine Lake (Figure 2).

As reported by CEC (1997c), this proposed geothermal development would require:

1. drilling, testing, and completing up to 25 development wells to obtain 10 - 20 production wells and five injection wells with 60 MW of reserve in the reservoir;
2. siting a 48 MW (gross) pilot power plant with supporting facilities; and,
3. building a 230 kilovolt (kV) connecting transmission line to the existing Bonneville Power Administration (BPA) 230 kV Malin to Warner transmission line, near Tionesta, California (Figure 1).

The proposed TFGP wellfield and power plant layout is presented in Figure 3. This proposed facility will generate electrical energy by using "a flash technology" unit with a condensing steam turbine and wet cooling tower. Plant systems will be designed for a project life of 50 years. Production wells will utilize geothermal fluids produced at depths from about 1 to 3 km (3,000 - 10,000 ft) "below the ground surface" (bgs). Most production wells will be drilled and completed directionally, from multiple well drilling pads. The project is designed as a "closed-loop" system

Table 1. Geothermal System Classifications Based on Heat Transfer and Geologic Environments (after Rybach, 1981)

Type of Geothermal System	Characteristics
Convective	1. Hydrothermal systems resulting from shallow, young silicic intrusions in generally high to moderate porosity/permeability environments*
	2. Hydrothermal systems resulting from young mafic intrusions in generally high to moderate porosity/permeability environments
	3. Hydrothermal systems resulting from deep circulation of waters in areas of high to normal regional heat flow, in generally moderate to low porosity-fracture permeability environments
Conductive	1. Low temperature/low enthalpy aquifers in high porosity/permeability sedimentary sequences in regions of normal to slightly elevated heat flow
	2. High temperature/low permeability hot dry rock environments

Notes:

* = The proposed Telephone Flats Geothermal System is of this type.

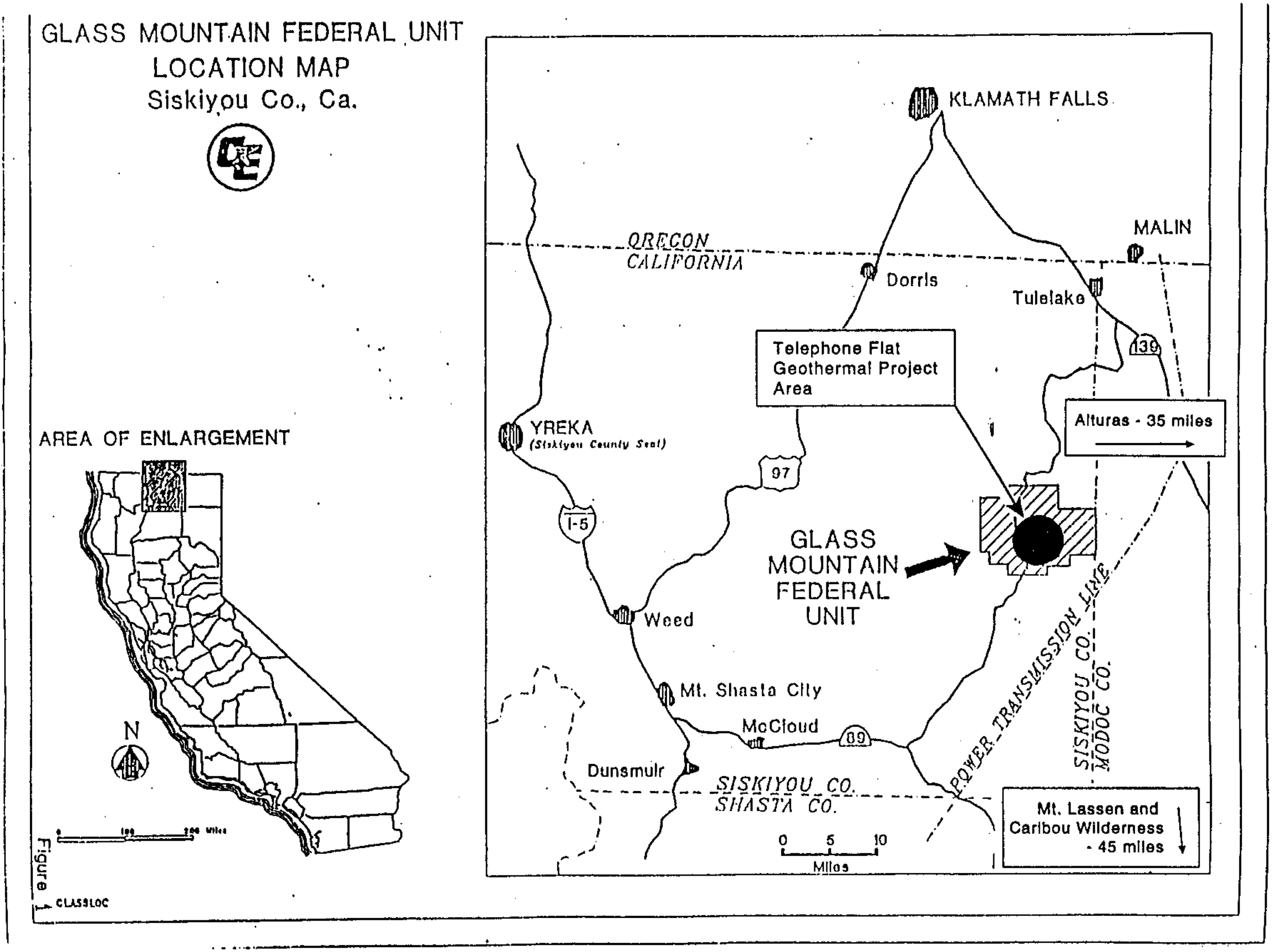


Figure 1. Location Map for the Proposed Telephone Flat Geothermal Project (afer CEC, 1997b)

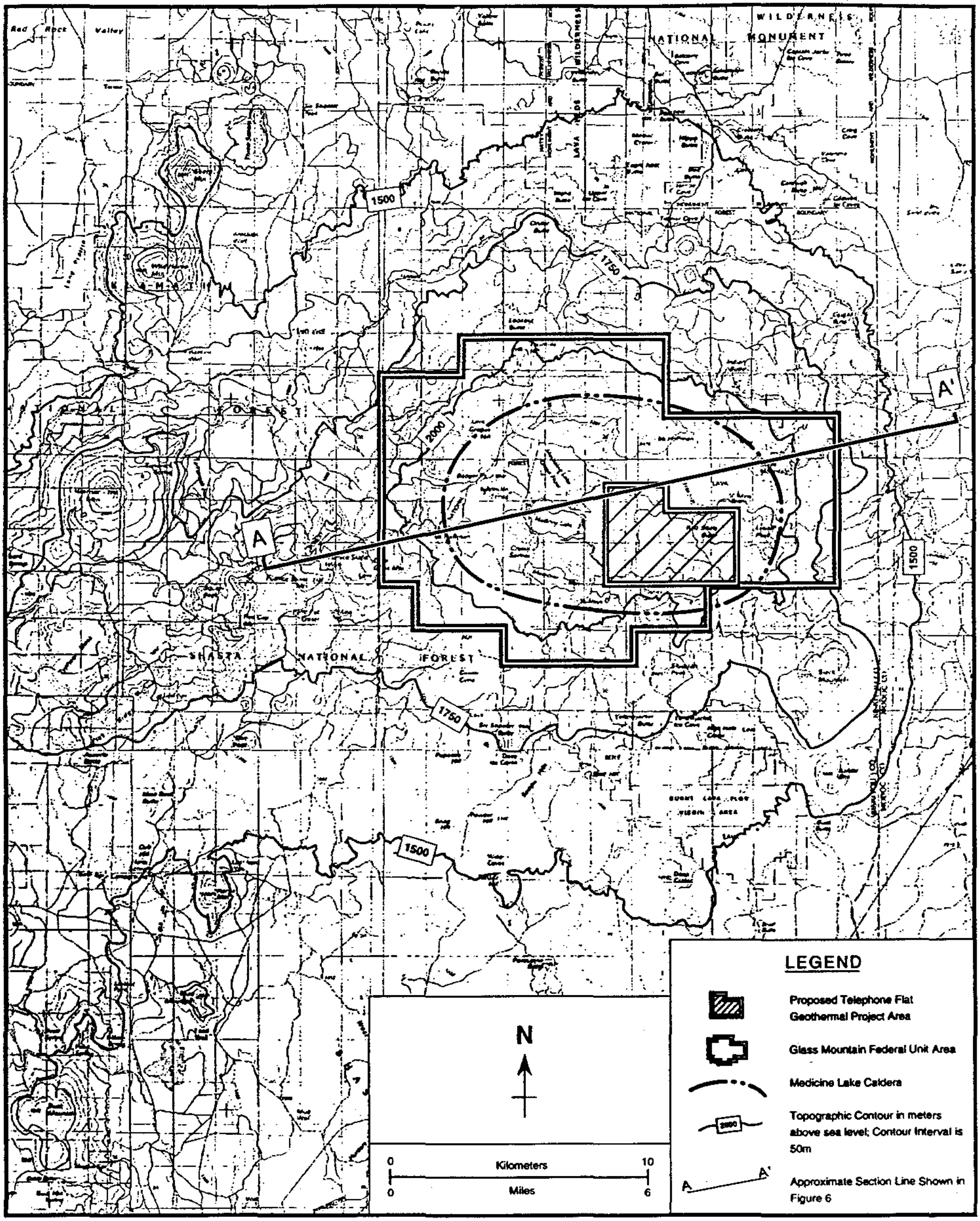
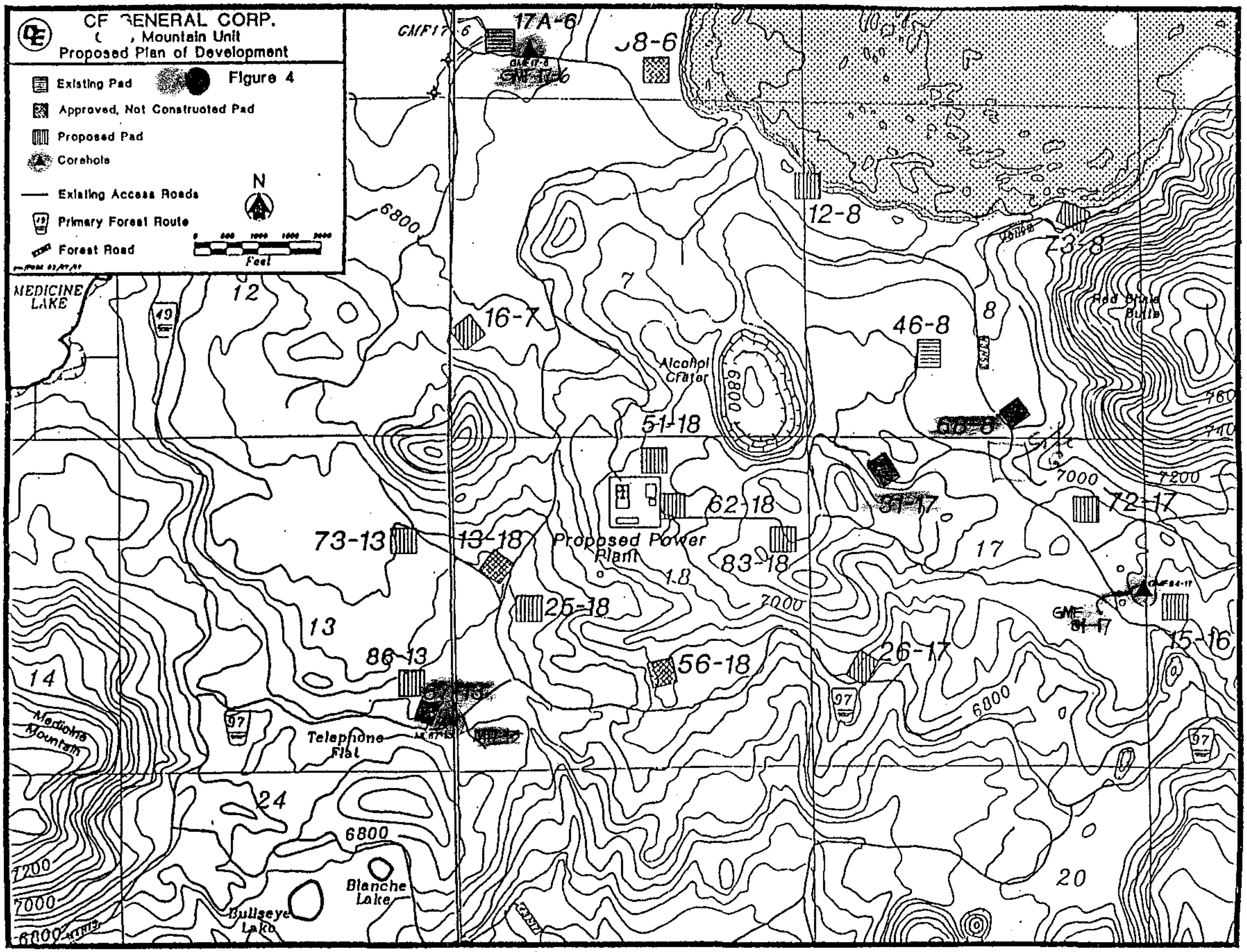


Figure 2. Location Map for the Proposed Telephone Flat Geothermal Project within the Medicine Lake Caldera at the Summit of Medicine Lake Highlands; also shown is the Glass Mountain Federal Unit, see Figure 1



igure 3. Map of Proposed Telephone Flat Geothermal Project Showing Locations of Proposed Well Pads and Power Plant (from CEC, 1997b)

with approximately 83% of the geothermal fluids withdrawn for production of electricity returned to the reservoir via injection wells at depths similar to or deeper than the producing intervals in the production wells.

1.2 Scope of Evaluation

The scope of the evaluation included a comprehensive collection, review, synthesis, and interpretation of available geological, geochemical, geophysical, and hydrological data. This involved review of published and unpublished data and/or personal contact with staff from the following Federal, State, or local agencies:

- California Department of Water Resources (DWR), Red Bluff;
- DWR, Sacramento;
- DWR, Division of Flood Control, via internet;
- California Division of Water Rights, Sacramento;
- California State Water Resources Control Board, Sacramento;
- Colorado School of Mines, Golden, Colorado;
- Fall River Resource Conservation District, Fall River Mills, California;
- Lawrence Livermore National Laboratory (LLNL), Livermore, California;
- Stephen P. Teale Data Center, Sacramento, California;
- United States Geological Survey (USGS) in Menlo Park and Redding, California;
- US BLM, Ukiah, California;
- USFS in Alturas, California;
- United States National Park Service at the Lava Beds National Monument, California; and,
- Western Region Climate Center in Reno, Nevada.

Additionally, proprietary CEC geothermal geological, geophysical, hydrological, and geochemical data were also reviewed as part of this investigation and incorporated into this report, as needed while maintaining the proprietary nature of the data. A one-day field visit to the project area was conducted with representatives of the USFS and the EIS/EIR contractor.

1.3 Methodology

The project lies in a remote portion of northeastern California (Figure 1), and the hydrology of the area has had limited investigation. As a result of the paucity of published hydrology data, the methodology employed to develop this report was to:

1. review the TFGP hydrogeology in context of its (a) regional hydrological and geological setting, (b) the MLH setting, and (c) the MLB setting;
2. integrate a variety of published and unpublished databases collected at different times by different organizations under the assumption that the data are accurate, and representative of the phenomena being investigated; and,
3. interpret and extrapolate the various data sets analyzed in item No. 2 above.

For the purposes of this investigation, the MLH-Regional Study Area (MLH-RSA) extends from Lower Klamath Lake and Tule Lake on the north to the Fall River Mills area on the south, and from Timber Mountain on the east to Garner Mountain on the west (Plate 1). The USGS McArthur and Tule Lake, California 1:100,000-scale topographic maps were used as the primary base map for this investigation.

1.4 Report Organization

The geology of MLH is described in Section 2 along with the types of geothermal systems, the geothermal system at TFGP, and the structures controlling the geothermal and hydrological systems. The hydrology of MLH and the surrounding region are discussed in Section 3. Acronyms and abbreviations used in this report are listed on page viii.

2. GEOLOGY OF MEDICINE LAKE HIGHLANDS AND SURROUNDING AREA

2.1 Regional Geology

MLH is a Pleistocene to Holocene shield volcano covering about 1,800 km^2 (648 mi^2) with a volume of about 600 km^3 (130 mi^3), Donnelly-Nolan (1990). It lies at the boundary of the Cascade Range and Modoc Plateau physiographic provinces, 83 km (50 mi) south of the Oregon border and 50 km (30 mi) northeast of Mount Shasta. The different forces that created both of these geomorphologic provinces have significantly influenced the topography and geology of the MLH.

2.1.1 Cascade Range

The Cascade Range, extending from northern California through Oregon, Washington, and British Columbia, is a volcanic arc formed by subduction of the Juan de Fucca Plate beneath the North American Plate. These mountains are subdivided into the Western Cascade Range and the High Cascade Range. The Western Cascades are composed of Eocene to Miocene lava flows, beds of pyroclastic debris, and interbedded non-marine and shallow marine sediments. Rocks of the High Cascades are Pliocene to Holocene in age, overlie those of the Western Cascades, and principally range in composition from basalt to dacite, but are primarily andesites. The Cascade Range in northern California is a southeastward trending chain of shield and composite volcanoes (Zucca et al., 1986). The young volcanic rocks of MLH are generally included in the Cascade geomorphic province (Norris and Webb, 1976). Connecting MLH to Mount Shasta in the High Cascades is a prominent northeast-trending volcano-tectonic belt referred to as the Vulcan Lineament by Ciancanelli (1983).

2.1.2 Modoc Plateau

The Modoc Plateau is situated north, south, and east of MLH, and also underlies it. The Plateau is a relatively level expanse of land ranging from 1,220 to 1,524 m (4,000 to 5,000 ft) high, which covers approximately 27,778 km^2 (10,000 mi^2) of the southwestern corner of the Columbia Plateau.

The oldest known rocks in the MLH region are considered to be the pyroclastic basalts and andesites of the Miocene Cedarville Series. Miocene to Pliocene faulting deformed the Cedarville series and created numerous Basin and Range-like north-south trending block-faulted ranges that traverse the Plateau. The Pliocene Warner basalt, a series of flood-like flows averaging 30 m (100 ft) thick that covered a large portion of the Plateau, overlies the Cedarville series. The basalts minimized relief on the Modoc Plateau as the flows filled in many of the down-dropped basins created by the faulting. Sections of the Warner basalt are in turn overlain by a massive andesite tuff of uncertain origins.

According to Anderson (1941), that is reported by Donnelly-Nolan (1989) as the best published geologic mapping of MLV, the tuff is possibly derived from pelean-style eruptions which form a glowing avalanche of pumice and ash. The actual source for this andesite tuff has not been found. Exposed in sections as thick as 60 m (200 ft) near the base of Medicine Lake, the tuff is considered by Anderson (1941) to be part of the basement rock of the MLH. Several obsidian domes and platy rhyolite flows, possibly the same age as the andesite tuff, are found around the margins of MLH, while lake deposits and volcanic structures such as small shield volcanoes and composite cinder cones are scattered throughout the Plateau (Anderson, 1941).

2.2 Regional Structure

Figure 4a illustrates the major structural features of the MLH-RSA. Figure 4b presents a generalized geologic map for the region. The regional structural setting is reviewed to determine its role in controlling the shallow ground water flow in (1) the Modoc Plateau, (2) the MLH, and (3) the geothermal system at the TFGP.

MLH appears to lie at the focus of several intersecting structural trends. Regional gravity analysis, places MLH at the intersection of the north-south trending low, corresponding to the Cascade Range and a series of northeast-southwest trending linear interruptions in gravity anomalies, suggesting deep seated faulting, which may, or may not, extend to the surface (Blakely and Jachens, 1990). Dzurisin et al. (1991) updated the regional geologic map of Gay and Aune (1958) with air photo interpreted faults (Figure 5). They show a series of:

- north-south trending Basin and Range type normal faults north of MLH being deflected to northeast-southwest trending faults at MLH; and,

- with northwest-southeast trending horsts and grabens to the south, southwest, and northwest of MLH (Figures 4a, 4b, and 5).

The northeast-southwest trending faults may represent the refraction of the north-south trending normal faults at their intersection with the northeast-southwest trending Vulcan Lineament (Ciancanelli, 1983). Directly to the north of MLH is a north-south trending graben (Dzurisin et al., 1991), which Heiken (1978) refers to as the Tule Lake Graben (Figures 4a, 4b, and 5). Medicine Lake is on strike with western margin of this graben.

Heiken (1978) extended the trends of faults shown on the Gay and Aune (1958) regional map to produce the MLH structural setting interpretation shown in Figure 4a and 4b. Northwest-southeast trending normal fault trends intersect with north-south and north-northwest-south-southeast normal fault trends at the MLH crater. This structural intersection occurs near the southern extension of the margin of the Tule Lake Graben. The Modoc Plateau in the MLH-RSA forms a gentle regional slope from the ~1,300 m (4,264 ft) elevation of Tule Lake sump in the north to the ~1,000 m (3,280 ft) at the Fall River Springs (FRS) in the south.

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FIG. 4a ?

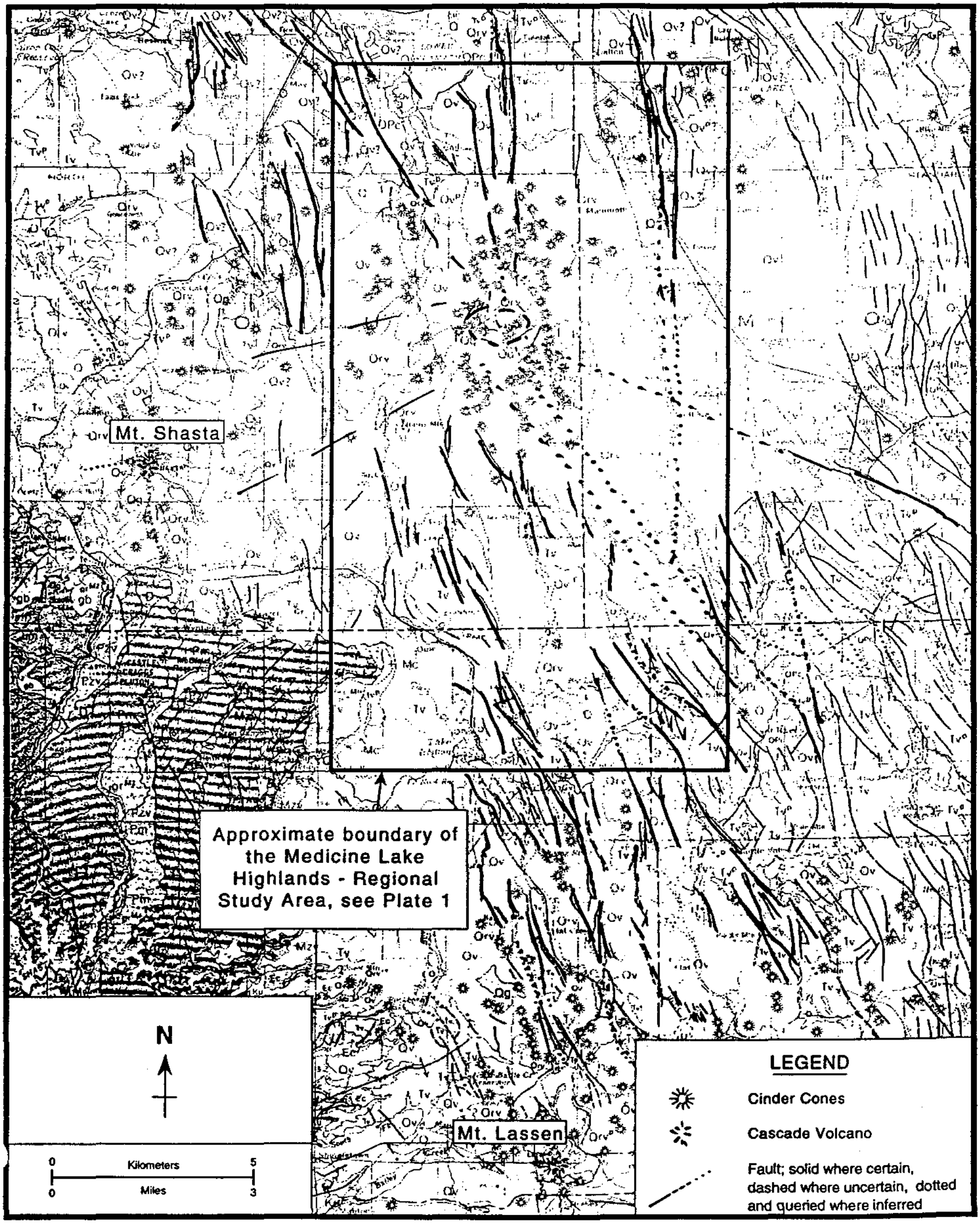
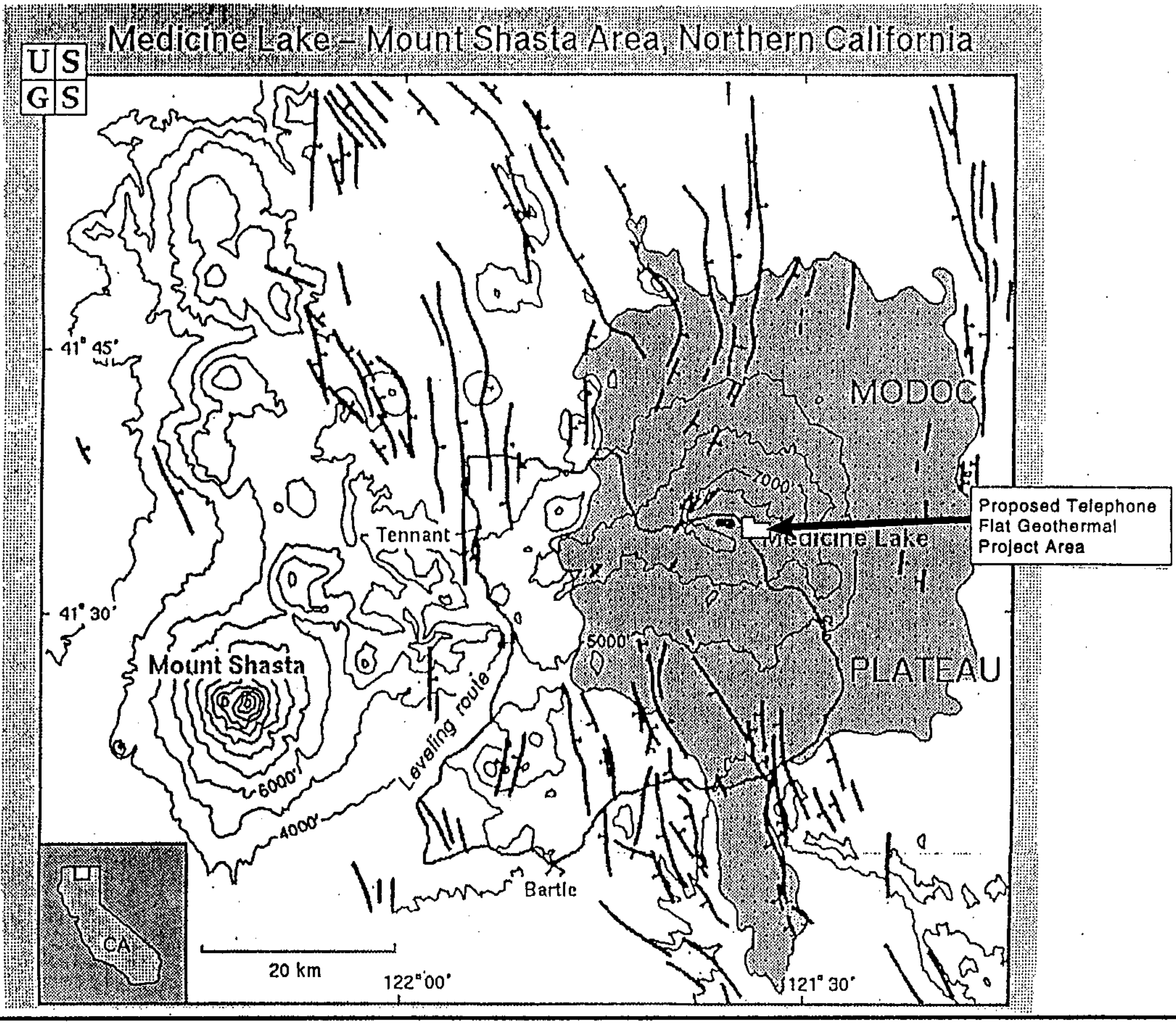


Figure 4b Generalized Geologic Map for the Study Area (modified after Jennings et. al., 1973; and Heiken, 1978)



igure 5. Geologic Structural Map for the Medicine Lake Highlands (stippled pattern) Mount Shasta Area (from Dzurisin et al., 1991)

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The regional gravity, seismic and electrical survey data provide a consistent subsurface model, with a shallow high resistivity, high density, and high velocity inhomogeneity under MLH (Stanley et al., 1990; Zucca et al., 1986). This has been interpreted by Dzurisin et al. (1991) as an intrusive complex, most probably a dike complex, rather than a single magma chamber.

2.3 Local Geology of Medicine Lake Highlands and Medicine Lake Basin

MLH is a volcanic massif dominated by the MLV itself, a Pleistocene and Holocene shield volcano. The most recent volcanic eruption occurred about 900 years ago, and at least 17 eruptions have occurred in the last 12,000 years, with an average of one to two eruptions per century (Donnelley-Nolan, 1990). MLV is located on the southern extension of the western margin of the Tule Lake Graben at the locus of several intersecting structural linears (see Figures 4a, 4b, 5, and Section 2.2).

MLV encompasses the broad, gently sloping shield volcano itself and the elevated area formed by successive lava flows that immediately surround the volcano. The MLH is roughly 32 km (20 mi) in diameter and converges upward to an elliptical rampart, formed by cones and domes, that is about 7 by 10 km (4 by 6 mi) in diameter (Anderson, 1941). Mt. Hoffman, which has an elevation of 2,417 m (7,928 ft), is the highest point on MLV. The rampart surrounds an elongated basin, approximately 5 km long by about 3 km wide (3 by 2 mi). Medicine Lake is situated at the western end of this basin, at an elevation of about 2,035 m (6,676 ft).

Medicine Lake is about 2.5 km long by 0.3 km wide (1.5 by 0.5 mi) and is located in the large crater-like depression at the summit of the volcano (Figure 2). Anderson (1941) reports that the lake varies in depth, but is generally shallow, with 50% of it being less than 6 m (20 ft) deep, but a funnel-shaped depression at the eastern end of the lake has been measured at 44.5 m (146 ft). A California Department of Fish and Game bathymetric survey of Medicine Lake ca. 1956, confirmed the presence of this funnel-shaped depression.

The lavas of the MLV overlie the basement rocks of the Cedarville Series and the Warner basalts of the Modoc Plateau (Section 2.1.2). The rocks found in the MLH are characterized by bimodal volcanism that produced flows varying in composition from basalt to andesite, dacite, and rhyolite.

According to Anderson (1941, p. 351-353), the MLH developed as fluid andesites erupted over the rocks of the Cedarville Series and the massive Warner basalts, forming a broad shield volcano about 33 km (20 mi) wide, with a shallow slope of approximately 3°. The initial shield is estimated to have reached a height of 762 m (2,500 ft). Subsequent collapse of the summit formed a caldera 10 km long by 7 km wide (6 by 4 mi), whose rim was located 152 m (500 ft) below the former summit. Fractures along the edge of the volcano served as conduits for andesitic lava that later flowed into the caldera, forming cones that reached heights greater than the edge of the caldera rim, allowing lava to spill down the outer flanks of the volcano. These cones formed rim volcanoes that eventually obscured the boundaries of the original caldera, creating a new, constructional basin, MLB, in its place.

Recent eruptions of more silicic lavas such as dacites and rhyolites, which are predominantly found in the center and the rampart of MLH followed the post caldera andesites. Concurrent with the silicic eruptions, basaltic lavas were discharged from vents at the lower flanks of the shield. These basalt flows, which covered all but the western side of the volcano, and much of the surrounding Plateau, are the source of the basalts found to the north at Lava Beds National Monument. Numerous basaltic cinder cones formed along the slopes of the volcano and coalesced into a broad ridge along the southeastern side of the shield. The basaltic eruptions are believed to be Late Pleistocene to Recent in age.

The generally north-south faults that permeate the region are also visible throughout the volcano (Figures 4a, 4b, and 5). Anderson (1941) identifies several major faults, such as recent northeast-trending faults located along the northwest rampart of MLV along with other swarms of minor faults in the area. In general, the faults show only minor amounts of vertical displacement, and there is no consistency as to which side is downthrown. Many fissures, vents, craters, and cinder cones show distinct linear alignment, several of which coincide with the circular rampart surrounding the MLB (Anderson, 1941). Donnelly-Nolan (1990) reports that vent alignments are generally oriented north-south or approximately 30° east of north, as are many of the faults; open fissures generally oriented north-northeast to north-northwest at various locations on the flanks of the volcano.

2.4 Geothermal Systems

2.4.1 Geothermal Resource

A geothermal resource consists of a concentration in the natural heat of the earth close enough to the surface that it can be extracted and utilized economically. A geothermal power plant differs from a conventional fossil fuel-fired plant (coal, oil, or natural gas) by substituting the natural heat of the earth for fossil fuel-fired boilers to generate the steam to run the turbines that generate electricity. Three things are needed for a viable geothermal energy resource:

1. shallow concentrations of heat energy;
2. a working fluid to bring this heat near (less than or equal to about 3 km (10,000 ft)), to the surface for utilization;
3. a permeable subsurface geothermal reservoir; and,
4. a lithologic and/or hydrothermal alteration seal around the reservoir.

Heat energy is indicated by temperature. The temperature within the earth rises with depth beneath the surface, on average, only a few degrees F every 100 ft. With this normal geothermal gradient, temperatures needed to generate electrical power at the surface are not reached at normal drilling depths. Only under certain geologic conditions (e.g., young volcanoes) is the normal geothermal gradient exceeded, bringing high subsurface temperatures close enough to the surface, that the geothermal reservoirs can be economically tapped to supply the working fluid to power electrical generating plants.

The working fluids can either be steam or water depending on the thermodynamic conditions of the reservoir and the production characteristics of the field. The origin of the water is generally old meteoric water or seawater. Magmatic fluids are rare.

The geothermal reservoir contains the heat and the working fluid. The permeability of the reservoir allows for the circulation of the working fluid and heat exchange between the fluid and the host rock. It will also control the commercial viability of the reservoir.

The seal separates the hot, geothermal fluids from the surrounding cold, ground water system. This seal allows the geothermal reservoir to reside in a different chemical and pressure regime than the surrounding cold ground water.

2.4.2 Types of Geothermal Systems

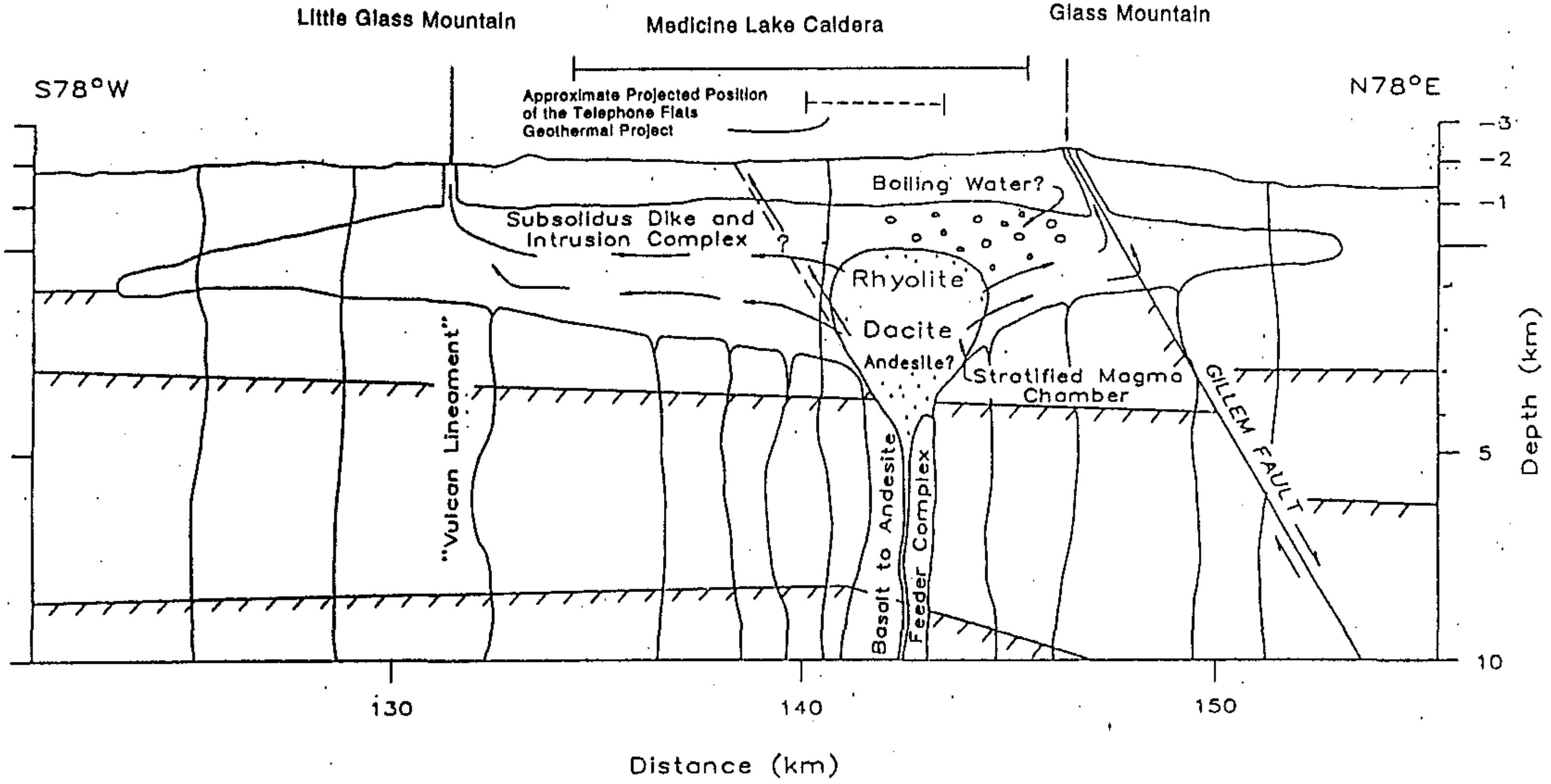
Rybach (1981) used the geologic environments and heat transfer mechanisms to classify geothermal systems (Table 1). The type of fluids can also classify geothermal systems. Those systems, which produce steam are termed "vapor dominated," while those systems which contain predominantly high temperature liquids in their reservoirs are termed "liquid dominated." Most vapor-dominated systems do produce some liquids and many high temperature liquid dominated systems, under certain conditions, will flash to steam in the wells and in the formation.

2.4.3 Geothermal Systems at Telephone Flat

Figure 6 shows a conceptual cross section of the MLV geothermal system model showing the Glass Mountain/Telephone Flat area (Evans and Zucca, 1988). The TFGP geothermal system is liquid dominated, possibly two-phase (boiling) hydrothermal system related to shallow and recent silicic intrusions. At a depth of approximately 2.5 km (1.5 mi) below the surface, a high density/velocity dike complex may exist.

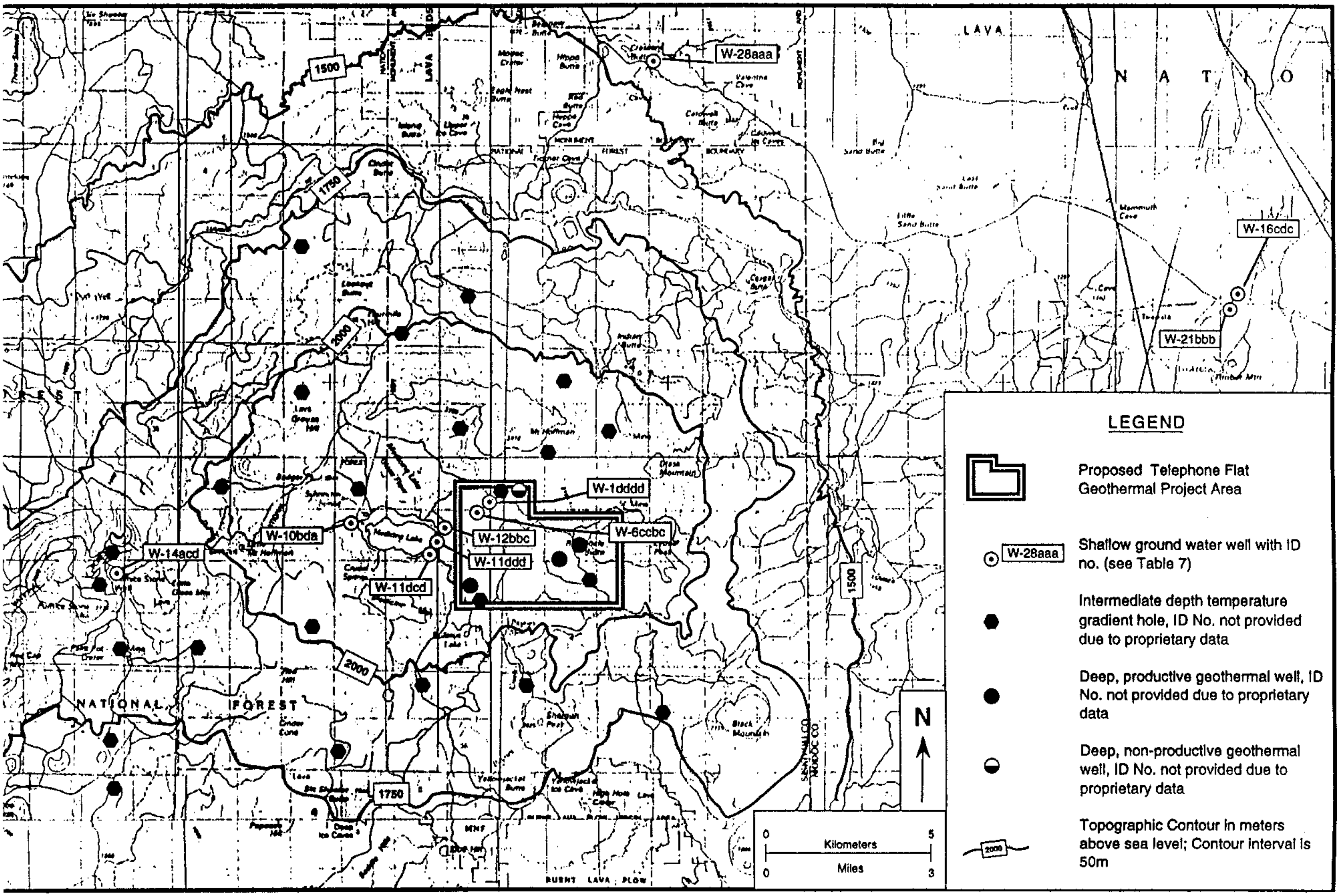
Near the Glass Mountain side of this section are semi-melted silicic intrusions interpreted by Evans and Zucca (1988) as supplying the heat for TFGP geothermal system. Water introduced to this igneous system will become heated. As this heated hydrothermal fluid migrates through the permeable reservoir in and around the rhyolitic intrusion, it hydrothermally alters the country rock.

Twenty-four intermediate depth temperature gradient holes (TGHs) and four exploration wells have been drilled in and around the proposed TFGP (Figure 7). Unocal, Phillips Petroleum, and Occidental Geothermal drilled these TGHs between 1981 and 1984. These holes were used to measure the temperature gradient and to identify the lithology in the vicinity of the corehole. Based on the results of this drilling program, Phillips Petroleum and Occidental Geothermal drilled in 1984, a deep exploration well, GMF 17A-6. Unocal drilled three additional deep exploration wells between 1985 and 1991, GMF 31-17, GMF 87-13, and GMF 68-8. In 1993, CEC acquired all the geothermal rights held by Unocal in the MLH.



Interpretive model of Medicine Lake volcano along a section striking N78°E between Little Glass Mountain and Glass Mountain. There is no vertical exaggeration; the distance scale is the same as that of *Zucca et al.* [1986, Figures 15 and 17]. The bars show flow positions; Medicine dacite flow is out of section to the north. Many details are only schematic. Flow arrows show inferred magma paths during the youngest silicic eruptions. The magma chamber is drawn near the upper limit of possible volumes; it may be smaller.

Figure 6. East-West Section through the Medicine Lake Volcano Showing the Geothermal System in the Glass Mountain/Telephone Flat Area (after Evans and Zucca, 1988)



igure 7. Location Map for Shallow Ground Water Wells and Geothermal Exploration Intermediate Depth Temperature Gradient Holes and Deep Wells in the Medicine Lake Highlands Study Area

These geothermal holes and wells are not identified in any of the figures in this report because CalEnergy considers the data proprietary. The data from this drilling activity along with the characteristics of the geothermal reservoir at the TFGP are described in Section 2.4.3.2.

2.4.3.1 Geophysical Data Summary

Investigators from the USGS have conducted numerous geophysical studies of MLV such as, gravity, magnetotelluric, Schlumberger sounding, time-domain electromagnetic, seismic refraction, seismicity and heat flow. These studies were aimed at defining the regional tectonic setting. Shallow variations in electrical resistivity were also defined by the USGS based on an airborne electromagnetic survey. Electrical resistivity surveys measure the electrical properties of the subsurface. This is of particular importance in geothermal exploration and development because rocks in contact with geothermal fluids are generally more conductive than those that are not.

Figure 8 shows the elevation of the 38°C (100°F) isotherm based on the TGHs drilled in and around MLC. The elevation of this isotherm in the TFGP area is about 1,800 m (about 5,900 ft) or within 300 m (1,000 ft) of the surface. Appendix A presents in tabular form the depth and elevation of the 100°F for the TGHs and geothermal wells used in this analysis. This isotherm, selected as representative of the top of the geothermal system at MLC, forms two crescent shaped areas. one 200 m (about 650 ft) deeper than the other. These anomalies occur along the west, southeast and northeast sections of the MLC rim.

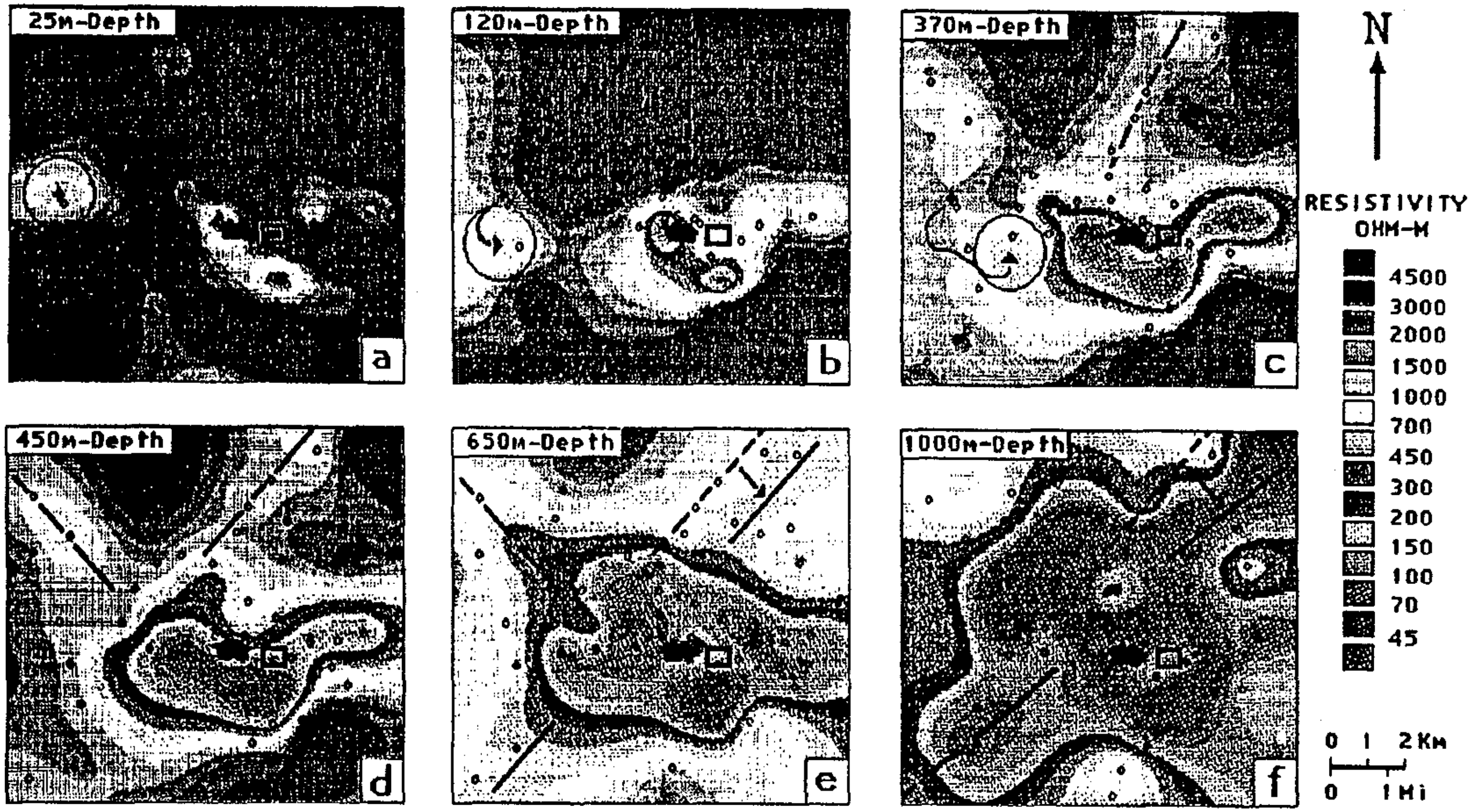
Schlumberger sounding electrical models (Zohdy and Bisdorf, 1990) show shallow, low resistivity (high conductivity) anomalies near Medicine Lake, and along the west, southwest and eastern rim of MLC (Figure 9). This also shows that between about 25 m (20 ft) to 650 m (198 ft), an east-west rending low resistivity zone exists roughly centered around Medicine Lake at 650 m (198 ft). These resistivity anomalies are interpreted to be a composite of the thermal anomaly and the shallow ground water in the area. Correlating these effects to the shallow ground water wells and intermediate depth temperature gradient holes is beyond the scope of this evaluation.

Results of geothermal exploration drilling of these electrical conductivity anomalies at MLV show an excellent correlation between these low resistivity geophysical anomalies (Figure 9) and an increase in clay content in the volcanic rocks obtained from the geothermal exploration TGHs (CEC, 1997b). The increase in clay content is attributed to argillic alteration caused by the interaction of the geothermal fluids and the country rock (Figure 10). This relationship appears to be consistent throughout the MLHSA. The correlation between the low resistivity anomalies and increasing clay content, supported by review of proprietary data suggests that this argillic alteration forms a hydrothermal alteration seal around the top of the geothermal reservoir.

2.4.3.2 Well Drilling and Testing Summary

The 24 TGHs (Section 2.4.3) range in depth from 183 to 1,222 m-bgs (600 to 4,009 ft-bgs). The four exploration wells (GMF-68-8, GMF 87-13, GMF 31-17, and GMF 17A-6) range in depth from 948 to 2,932 m-bgs (3,110 to 9,620 ft-bgs). Three of the four geothermal exploration wells are productive; GMF 17A-6 is not (Figure 7). These TGHs and wells, while designed to provide geothermal resource data, do provide some data on the shallow ground water system.

CEC (1997b) reports the following expected reservoir characteristics based on the 24 intermediate depth TGHs and four exploration wells and geophysical data. The geothermal resource



Six maps showing contours of interpreted resistivity at depths ranging from 25 to 1000 m. Maps were selected from a set of 42 maps used in computer animation. Colors depict resistivities in ohm-m.

Figure 9. **Schlumberger Sounding Apparent Interpreted Resistivity at Medicine Lake Volcano; Medicine Lake Is Shown in Black. The Approximate Area of the Telephone Flat Geothermal Project Is Shown as an Open Square (after Zohdy and Bisdorf, 1990)**

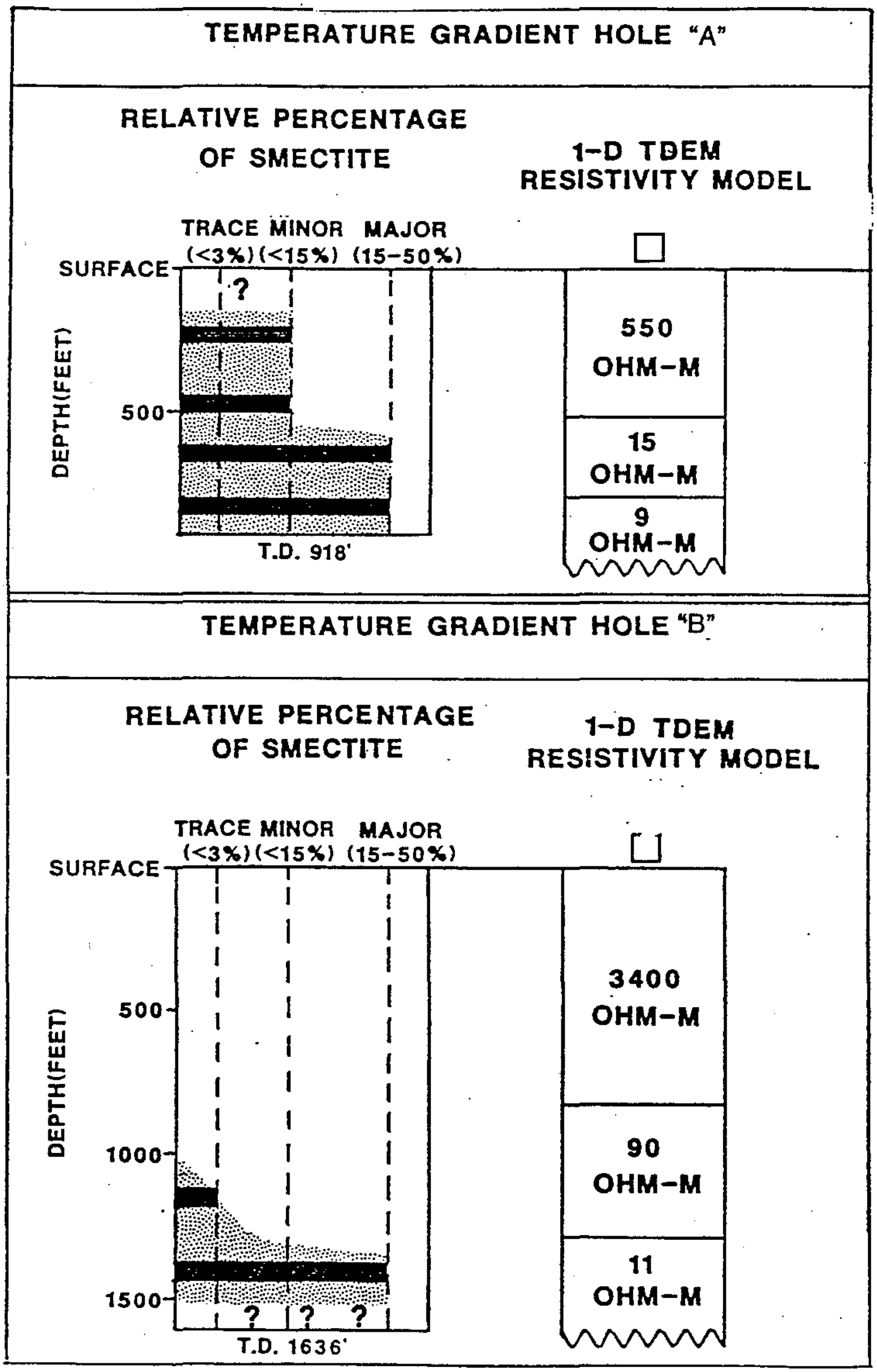


Figure 10. Relationship between Increasing Clay Content in Medicine Lake Highlands Boreholes and Interpreted

Table 2. Telephone Flat Geothermal Reservoir Characteristics (from CEC, 1997b)

Resource Parameter	Probable	Range
Reservoir Temperature in °F (°C)	480 (249)	430 – 550 (221 – 288)
Reservoir Enthalpy (BTU/lb)	470	410 - 550
Reservoir Total Dissolved Solids (ppm by wt)	2,500	1,500 – 7,000
Reservoir NGC[1] (ppm by wt)	2,500	500 – 10,000
Wellhead Temperature in °F (°C)	364 (185)	335 – 517 (168 – 270)
Wellhead Pressure (psia)	160	110 - 330
Total Mass Flow per well (kph)	400	200 - 800

<u>Notes:</u>

[1] = Noncondensible Gas Content

is expected to be liquid dominated, with temperatures in excess of 200°C (400° F) at depths of 1,829 to 2,438 m-bgs (6,000 to 8,000 ft-bgs). The expected Telephone Flat geothermal reservoir characteristics are given in Table 2. These data are reported by CEC (1997b) as adequate for conceptual design purposes.

2.5 Regional and Local Structures Controlling Geothermal and Hydrological Systems

MLH is a 25 km (15 mi) diameter composite shield volcano, on the western margin of the Modoc Plateau and 55 km (33 mi) east of Mount Shasta and the main north-south trending chain of the High Cascade volcanoes. The volcano lies within a 100 km depression filled with Pliocene and Holocene volcanic rocks, overlying the Modoc Plateau which is built up of late Tertiary tuffs, basalts, and inter-flow sediments, cut by northwest-southeast trending normal faults (**Figures 4a and 4b**, Heiken, 1978). The Fall River Valley to the south is a graben, bounded by stepped northwest-southeast trending normal faults and separated by a northwest-southeast trending horst (**Figures 4a and 4b**, Grose, 1996; Rose, et. al., 1996).

The north-south normal fault trend through the MLH crater is on strike with the western boundary of the Tule Lake Graben (**Figures 4a and 4b**). This alignment of structural features and the Quaternary sediments of the Tule Lake Graben are compatible with the postulation by Macdonald (1966) that Tule Lake and Lower Klamath Lake are the main source for the high volume discharge springs in the Fall River Valley (Section 3.3.7 and 3.5.1).

Ciancanelli (1983) conducted a detailed fault analysis of MLH based on observed scarps, sag depressions, fissures and vent alignments, supplemented by LANDSAT, high altitude infrared and radar imagery linear analyses. His analysis shows a rather complex structural setting, but fault families with north-south, northeast-southwest, and north-northeast-south-southwest trends can be discerned. Many of these features may be surficial, related to structures formed in flowing lavas. As such, these features may serve as local controls on subsurface water movement, but may have little effect on the regional aquifer.

Ciancanelli (1983) named a major northeast-southwest trending volcano-tectonic feature connecting MLH to Mt. Shasta the Vulcan Lineament (**Figure 4b**). This feature appears to be compatible with the northeast-southwest trending block boundaries of Blakely and Jachens (1990) and structural interpretations by Dzurisin et al. (1990) and Evans and Zucca (1988). This northeast-southwest trending feature may form a subsurface block to north-south water movement between Mt. Shasta and MLH.

Structures controlling the geothermal systems have not been identified to date. The Schlumberger resistivity data (**Figure 9**) suggest that northeast-southwest trending faults may play a role in localizing the flow of geothermal fluids in the near surface.

The structural setting of the MLH-RSA suggests that the Tule Lake Graben north and east of MLH and the northwest-southeast trending faults south of MLH-RSA (**Figures 4a and 4b**) may play a significant role in controlling the flow of shallow ground water in the Modoc Plateau (Section 3.3.7 and 3.5.1).

3. HYDROLOGY OF MEDICINE LAKE HIGHLANDS AND SURROUNDING AREA

3.1 Regional Hydrology

Plate 1 shows the occurrence of surface water (i.e., lakes, reservoirs, streams, and creeks) and ground water (i.e., springs and wells) within the MLH-RSA. The regional hydrology of this area is dominated by the following three major hydrogeologic features (1) MLH itself, (2) the Modoc Plateau, and (3) the FRS. Both MLH and the Modoc Plateau are principally comprised of basaltic rocks that are highly permeable and typically such terrains contain sparse surface water. The FRS, located 55 km (33 mi) south of Medicine Lake, are among the largest spring groups in the United States flowing at a rate of approximately 1.3 billion gallons per day (gpd), Macdonald (1966).

3.1.1 Regional Surface Water

Surface waters are very sparse in the MLH-RSA because of the permeable nature of the surface rocks both in the highland and in the Modoc Plateau. The first major surface water bodies north of Medicine Lake are the Lower Klamath Lake and Tule Lake. Clear Lake is located to the northeast. Tule Lake is the largest surface water body in the region. It is approximately 33 km (20 mi) due north of Medicine Lake, which is located at the summit of MLH. A number of smaller lakes occur in the Lower Klamath and Tule Lakes area that appear to be aligned along north-south and northwest-southeast trending faults occur in the areas of Lower Klamath and Tule Lakes (Plate 1, Figures 4a and 4b, and Section 2.2). To a lesser extent similar structurally controlled small lakes occur near the west end of Clear Lake.

Numerous lakes, reservoirs, and rivers occur in the region south of MLH in the Whitehorse and Big Valley Mountains, and the lower Fall River Valley. Located approximately 55 km (33 mi) to the south of Medicine Lake, the Little Tule River is the beginning of the first major tributary in the region.

3.1.1.1 Water Quality

Limited water quality data for surface waters in the MLH-RSA were obtained for this investigation. These data consist of chemical and isotopic analysis from Todd Lake, a seasonal lake located south-southeast of Medicine Lake, and isotopic analysis for the FRS (Figure 4a, Table 3, and Plate 1). The surface water data are limited because its occurrence is sparse in the MLH-RSA. Delta deuterium and delta oxygen-18 isotopic values presented in Table 3 for:

1. Todd Lake indicate that its waters are highly evaporated; and,
2. FRS water have a meteoric water source.

Table 3. Chemical and Isotopic Analyses for Surface Water, Ground Water; and Geothermal Reservoir in the Medicine Lake Highlands – Regional Study Area; All Samples with Designator ML-83-x or xx Reflect the Year Samples Were Collected Followed by the Sample Number Used in this Report

Constituent (ppm)	ML-83-1[a]	ML-83-2[a]	ML-83-3[a]	ML-83-4[a]	ML-83-5[a]	ML-83-6[a]	ML-83-7[a]
Calcium	1.1	8.6	2.4	1.2	1.2	4.6	3.8
Magnesium	0.44	2	0.7	0.4	0.44	1.5	1.1
Sodium	0.9	3.1	1.5	1	0.8	3.4	2.6
Potassium	0.5	1	0.6	0.4	0.2	1.8	1.3
Carbonate	0	0	0	0	0	0	0
Bicarbonate	3.5	41.6	10.4	3.5	0	23.4	20.8
Chloride	<1.8	<1.8	<1.8	<1.8	<2.1	<1.8	<1.8
Sulfate	<5.0	<5.0	<5.0	<5.0	<5.0	6	<5.0
Nitrate	<0.4	<0.4	0.9	2.2	2.7	2.2	<0.4
Iron	0.08	<0.05	0.11	<0.05	0.07	<0.05	0.08
Manganese	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02
Copper	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Dissolved Solids	10	88	24	12	14	85	59
Boron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silica	4	32	8	6	6	42	29
Lithium	NR	NR	NR	NR	NR	NR	NR
Hardness as	4.6	29.8	8.9	4.7	4.8	17.7	14
$CaCO_3$(pm) as above in gr/gals	0.3	1.7	0.5	0.3	0.3	0.1	0.8
Electrical Conductivity (Micromhos)	21	77	29	20	24	60	47
pH	5.7	6.7	6.2	5.7	4.2	6.1	6.4
Resistivity	467.19	129.87	344.83	500	416.67	166.7	212.77
Delta Oxygen-18	-9.85	-13.55	-11.96	-11.32	-9.86	-13.77	-13.87
Delta Deuterium	-82	-99	-92	-87	-84	-102	-98
Type of Sample							
Surface Water	Medicine Lake		Little Medicine Lake	Bullseye Lake	Blanche Lake		
Ground Water, Spring		Schonchin Spring				Paynes Springs (west spring)	Paynes Springs (north spring)
Ground Water, Well							
Geothermal Reservoir Fluid							

Notes:

a = Data from Cosens-Gallinatti (1984)
b = Data from Leivas et al. (1981)
c = Data from Hotchkiss (1968)
d = Data provided by Dr. Davidson from Lawrence Livermore National Laboratory
e = Data from CalEnergy Company, Inc.
f = Data from BLM et al. (1995)
g = Data from four separate flow tests at two geothermal wells in the proposed TFGP (CEC, 1997e)
NR = Not Reported

Table 3. Chemical and Isotopic Analyses for Surface Water, Ground Water; and Geothermal Reservoir in the Medicine Lake Highlands – Regional Study Area; All Samples with Designator ML-83-x or xx Reflect the Year Samples Were Collected Followed by the Sample Number Used in this Report (Continued)

Constituent (ppm)	ML-83-8[a]	ML-83-9[a]	ML-83-10[a]	ML-83-11[a]	ML-83-12[a]	ML-83-13[a]
Calcium	3.1	3.1	9.4	6.9	6.3	4.3
Magnesium	1	0.56	4.7	1.3	2.9	1.6
Sodium	2.1	1.3	4.4	2.3	2.5	1.3
Potassium	1	1.2	1.4	0.2	0.5	6.3
Carbonate	0	0	0	0	0	0
Bicarbonate	17.3	13.9	62.4	24.3	38.1	31.2
Chloride	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8
Sulfate	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
Nitrate	<0.4	<0.4	<0.4	4	<0.4	0.9
Iron	<0.05	<0.05	<0.05	<0.05	<0.05	19.6
Manganese	<0.01	<0.01	<0.02	<0.01	<0.01	1.4
Copper	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Dissolved Solids	54	36	126	65	80	64
Boron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silica	29	16	44	26	30	19
Lithium	NR	NR	NR	NR	NR	NR
Hardness as	11.9	10.1	42.9	22.6	27.7	17.3
$CaCO_3$(pm) as above in gr/gals	0.7	0.6	2.5	1.3	1.6	1
Electrical Conductivity (Micromhos)	40	32	107	58	68	64
pH	6.6	6.3	6.8	6.5	6.8	6.4
Resistivity	250	312.5	93.46	172.41	147.1	156.2
Delta Oxygen-18	-13.48	-12.93	-14.52,-14.46	-13.79	NR	-10.74
Delta Deuterium	-99	-95, -96	-103	-100	-98	-92
Type of Sample						
Surface Water						
Ground Water, Spring	Paynes Springs (south spring)		Tamarack Spring	Lost Spring	Harris Spring	Lost Iron Well
Ground Water, Well		Pumice Stone Well				
Geothermal Reservoir Fluid						

Notes:

a = Data from Cosens-Gallinatti (1984)
b = Data from Leivas et al. (1981)
c = Data from Hotchkiss (1968)
d = Data provided by Dr. Davidson from Lawrence Livermore National Laboratory
e = Data from CalEnergy Company, Inc.
f = Data from BLM et al. (1995)
g = Data from four separate flow tests at two geothermal wells in the proposed TFGP (CEC, 1997e)
NR = Not Reported
NRH = Not Reported Herein
NA = Not Analyzed

Table 3. Chemical and Isotopic Analyses for Surface Water, Ground Water; and Geothermal Reservoir in the Medicine Lake Highlands – Regional Study Area; All Samples with Designator ML-83-x or xx Reflect the Year Samples Were Collected Followed by the Sample Number Used in this Report (Continued)

Constituent (ppm)	ML-83-14[a]	ML-83-15[a]	ML-83-16[a]	ML-83-17[a]	ML-83-18[a]	ML-83-19[a]
Calcium	3.8	3.7	4.4	1.4	5.2	3.8
Magnesium	1.7	1.4	2.3	0.87	3.1	1.8
Sodium	1.8	2	1.8	2.5	2.2	2
Potassium	0.6	0.4	0.3	2.3	0.3	0.4
Carbonate	0	0	0	0	0	0
Bicarbonate	20.8	20.8	24.3	6.9	31.2	20.8
Chloride	<1.8	<1.8	<1.8	<1.8	<1.8	<1.8
Sulfate	<5.0	<5.0	5	5	<5.0	<5.0
Nitrate	1.3	<0.4	<0.4	6.2	<0.4	<0.4
Iron	0.08	<0.05	0.05	0.25	<0.05	<0.01
Manganese	0.05	0.02	0.02	0.01	<0.01	<0.01
Copper	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Total Dissolved Solids	52	46	58	36	66	51
Boron	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silica	22	18	20	11	24	22
Lithium	NR	NR	NR	NR	NR	NR
Hardness as	16.5	15.0	20.5	7.1	25.8	16.9
$CaCO_3$(pm) as above in gr/gals	1	0.9	1.2	0.4	1.5	1
Electrical Conductivity (Micromhos)	45	41	50	36	62	47
pH	6.7	6.5	6.6	5.9	6.5	6.4
Resistivity	222.22	243.9	200	277.8	161.3	212.8
Delta Oxygen-18	-12.87	-12.91, -12.90	-13.08	-1.02	-13.08	-12.89
Delta Deuterium	-93	-90	-98	-48	-93	-93
Type of Sample						
Surface Water				Todd Lake		
Ground Water, Spring	Belnap Spring	Point Spring	Deter Spring		Slagger Spring	Red Tank Spring (?)
Ground Water, Well						
Geothermal Reservoir Fluid						

Notes:

a = Data from Cosens-Gallinatti (1984)
b = Data from Leivas et al. (1981)
c = Data from Hotchkiss (1968)
d = Data provided by Dr. Davidson from Lawrence Livermore National Laboratory
e = Data from CalEnergy Company, Inc.
f = Data from BLM et al. (1995)
g = Data from four separate flow tests at two geothermal wells in the proposed TFGP (CEC, 1997e)
NR = Not Reported
NRH = Not Reported Herein
NA = Not Analyzed

Table 3. Chemical and Isotopic Analyses for Surface Water, Ground Water; and Geothermal Reservoir in the Medicine Lake Highlands – Regional Study Area; All Samples with Designator ML-83-x or xx Reflect the Year Samples Were Collected Followed by the Sample Number Used in this Report (Continued)

Constituent (ppm)	ML-83-20[a]	ML-83-21[a]	ML-83-22[a]	ML-83-23[a]	ML-83-24[a]	ML-83-25[a]
Calcium	2.9	NRH	NRH	NRH	NRH	NRH
Magnesium	1.1	NRH	NRH	NRH	NRH	NRH
Sodium	1.7	NRH	NRH	NRH	NRH	NRH
Potassium	0.4	NRH	NRH	NRH	NRH	NRH
Carbonate	0	NRH	NRH	NRH	NRH	NRH
NRH	13.9	NRH	NRH	NRH	NRH	NRH
Chloride	<1.8	NRH	NRH	NRH	NRH	NRH
Sulfate	<5.0	NRH	NRH	NRH	NRH	NRH
Nitrate	<0.4	NRH	NRH	NRH	NRH	NRH
Iron	<0.01	NRH	NRH	NRH	NRH	NRH
Manganese	<0.01	NRH	NRH	NRH	NRH	NRH
Copper	<0.01	NRH	NRH	NRH	NRH	NRH
Total Dissolved Solids	39	NRH	NRH	NRH	NRH	NRH
Boron	<0.01	NRH	NRH	NRH	NRH	NRH
Silica	19	NRH	NRH	NRH	NRH	NRH
Lithium	NR	NRH	NRH	NRH	NRH	NRH
Hardness as CaCO$_3$(pm) as above in gr/gals	11.8 0.7	NRH	NRH	NRH	NRH	NRH
Electrical Conductivity (Micromhos)	34	NRH	NRH	NRH	NRH	NRH
pH	6.6	NRH	NRH	NRH	NRH	NRH
Resistivity	294.1	NRH	NRH	NRH	NRH	NRH
Delta Oxygen-18	-12.86	-12.91	-12.57	-13.66	-13.16	-14.79
Delta Deuterium	-94	-93	-85	-102	-94	-111
Type of Sample						
Surface Water						
Near Rainbow Mountain	Sheephaven Spring	Cramer Spring	Dry Spring	Near Rainbow Mountain	Near Rainbow Mountain	Cold Spring
Ground Water, Well						
Geothermal Reservoir Fluid						

Notes:

a = Data from Cosens-Gallinatti (1984)
b = Data from Leivas et al. (1981)
c = Data from Hotchkiss (1968)
d = Data provided by Dr. Davidson from Lawrence Livermore National Laboratory
e = Data from CalEnergy Company, Inc.
f = Data from BLM et al. (1995)
g = Data from four separate flow tests at two geothermal wells in the proposed TFGP (CEC, 1997e)
NR = Not Reported
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NA = Not Analyzed

Table 3. Chemical and Isotopic Analyses for Surface Water, Ground Water; and Geothermal Reservoir in the Medicine Lake Highlands – Regional Study Area; All Samples with Designator ML-83-x or xx Reflect the Year Samples Were Collected Followed by the Sample Number Used in this Report (Continued)

Constituent (ppm)	ML-83-26[a]	ML-83-27[a]	ML-83-28[a]	ML-83-30[a]	ML-83-31[a]	ML-83-32[a]
Calcium	NRH	NRH	9.6	1.9	3.9	6.9
Magnesium	NRH	NRH	3.7	0.46	1.1	5.7
Sodium	NRH	NRH	3.9	1.2	2.3	2.8
Potassium	NRH	NRH	0.7	0.4	0.8	1
Carbonate	NRH	NRH	0	0	0	0
Bicarbonate	NRH	NRH	52	6.9	20.8	48.5
Chloride	NRH	NRH	<1.8	<1.8	<1.8	<1.8
Sulfate	NRH	NRH	<5.0	<5.0	<5.0	<5.0
Nitrate	NRH	NRH	<0.4	<0.4	<0.4	0.4
Iron	NRH	NRH	0.05	<0.05	<0.05	<0.05
Manganese	NRH	NRH	<0.01	<0.01	<0.01	0.03
Copper	NRH	NRH	<0.01	<0.01	<0.01	<0.01
Total Dissolved Solids	NRH	NRH	106	31	57	88
Boron	NRH	NRH	<0.01	<0.01	0.03	<0.01
Silica	NRH	NRH	36	20	28	23
Lithium	NRH	NRH	NR	NR	NR	NR
Hardness as CaCO$_3$(pm)	NRH	NRH	39.3	6.7	14.3	40.7
as above in gr/gals			2.3	0.4	0.8	2.4
Electrical Conductivity (Micromhos)	NRH	NRH	94	24	44	95
pH	NRH	NRH	6.9	6.1	6.6	7.1
Resistivity	NRH	NRH	106.4	417	227.3	105.3
Delta Oxygen-18	-15.22	-13.16	-14.07	-13.54,-13.51	-13.88	-12.58
Delta Deuterium	-107	-93	-105,-106	-96	-98	-96
Type of Sample						
Surface Water						
Ground Water, Spring	Trapper Spring	Near Rainbow Mountain	Baird Spring	Meadow near Crystal Spring	Crystal Spring	
Ground Water, Well						Hambone Well
Geothermal Reservoir Fluid						

Notes:

a = Data from Cosens-Gallinatti (1984)
b = Data from Leivas et al. (1981)
c = Data from Hotchkiss (1968)
d = Data provided by Dr. Davidson from Lawrence Livermore National Laboratory
e = Data from CalEnergy Company, Inc.
f = Data from BLM et al. (1995)
g = Data from four separate flow tests at two geothermal wells in the proposed TFGP (CEC, 1997e)
NR = Not Reported
NRH = Not Reported Herein
NA = Not Analyzed

Table 3. Chemical and Isotopic Analyses for Surface Water, Ground Water; and Geothermal Reservoir in the Medicine Lake Highlands – Regional Study Area; All Samples with Designator ML-83-x or xx Reflect the Year Samples Were Collected Followed by the Sample Number Used in this Report (Continued)

Constituent (ppm)	ML-83-33[a]	ML-34[b]	ML-66-35[c]	ML-36[d]	ML-37[d]	ML-38[d]	ML-39[d]	ML-40[d]
Calcium	NRH	78	3	NR	NR	NR	NR	NR
Magnesium	NRH	1	0.9	NR	NR	NR	NR	NR
Sodium	NRH	223	26	NR	NR	NR	NR	NR
Potassium	NRH	5	1.8	NR	NR	NR	NR	NR
Carbonate	NRH	0	0	NR	NR	NR	NR	NR
Bicarbonate	NRH	48	89	NR	NR	NR	NR	NR
Chloride	NRH	141	11	NR	NR	NR	NR	NR
Sulfate	NRH	365	3	NR	NR	NR	NR	NR
Nitrate	NRH	NR	0.6	NR	NR	NR	NR	NR
Iron	NRH	0.28	0	NR	NR	NR	NR	NR
Manganese	NRH	<0.27	NR	NR	NR	NR	NR	NR
Copper	NRH	<0.06	NR	NR	NR	NR	NR	NR
Total Dissolved Solids	NRH	913	150	NR	NR	NR	NR	NR
Boron	NRH	4.3	0.3	NR	NR	NR	NR	NR
Silica	NRH	68	49	NR	NR	NR	NR	NR
Lithium	NRH	NR	NR	NR	NR	NR	NR	NR
Hardness as	NRH	NR	36	NR	NR	NR	NR	NR
$CaCO_3$(pm) as above in gr/gals		NR	NR	NR	NR	NR	NR	NR
Electrical Conductivity (Micromhos)	NRH	1625	185	NR	NR	NR	NR	NR
pH	NRH	7.7	7.8	NR	NR	NR	NR	NR
Resistivity	NRH	NR	NR	NR	NR	NR	NR	NR
Delta Oxygen-18	NA	NR	NR	-13.7	-13.7	-13.8	-13.2	-13.4
Delta Deuterium	-94	NR	NR	-97	-98	NR	-99	NR
Type of Sample								
Surface Water								
Ground Water, Spring	Widow Spring	Little Hot Spring		Schonchin Spring	Crystal Springs	Payne Springs	Seep, Hopkins Chocalate Cave, Lava Beds Nat Monu	Harris Spring
Ground Water, Well			Nat Park Ser Well at Crescent Butte					
Geothermal Reservoir Fluid								

Notes:

a = Data from Cosens-Gallinatti (1984)
b = Data from Leivas et al. (1981)
c = Data from Hotchkiss (1968)
d = Data provided by Dr. Davidson from Lawrence Livermore National Laboratory
e = Data from CalEnergy Company, Inc.
f = Data from BLM et al. (1995)
g = Data from four separate flow tests at two geothermal wells in the proposed TFGP (CEC, 1997e)
NR = Not Reported
NRH = Not Reported Herein
NA = Not Analyzed

Table 3. Chemical and Isotopic Analyses for Surface Water, Ground Water; and Geothermal Reservoir in the Medicine Lake Highlands – Regional Study Area; All Samples with Designator ML-83-x or xx Reflect the Year Samples Were Collected Followed by the Sample Number Used in this Report (Continued)

Constituent (ppm)	ML-41[d]	ML-42[d]	ML-94-43[d]	ML-95-44[d]	ML-91-45[c]	ML-91-46[c]	ML-91-47[c]
Calcium	NR	NR	NR	NR	<1.0	1	4.5
Magnesium	NR	NR	NR	NR	<1.0	<1.0	2.3
Sodium	NR	NR	NR	NR	<1.0	1.1	3.3
Potassium	NR	NR	NR	NR	<1.0	<1.0	3
Carbonate	NR	NR	NR	NR	NR	NR	NR
Bicarbonate	NR	NR	NR	NR	NR	NR	NR
Chloride	NR	NR	NR	NR	1.9	1	1.2
Sulfate	NR	NR	NR	NR	1.3	1.3	<1.0
Nitrate	NR	NR	NR	NR	<0.2	<0.2	<0.2
Iron	NR	NR	NR	NR	NR	NR	NR
Manganese	NR	NR	NR	NR	NR	NR	NR
Copper	NR	NR	NR	NR	NR	NR	NR
Total Dissolved Solids	NR	NR	NR	NR	8	10	37
Boron	NR	NR	NR	NR	NR	NR	NR
Silica	NR	NR	NR	NR	5.4	9.7	27
Lithium	NR	NR	NR	NR	NR	NR	NR
Hardness as	NR	NR	NR	NR	4	4	22
$CaCO_3$(pm) as above in gr/gals	NR	NR	NR	NR	NR	NR	
Electrical Conductivity (Micromhos)	NR	NR	NR	NR	15	16	57
pH	NR	NR	NR	NR	NR	NR	NR
Resistivity	NR	NR	NR	NR	NR	NR	NR
Delta Oxygen-18	-13.1	-13.6	-13.6	-13.3	NR	NR	NR
Delta Deuterium	NR	-98	NR	-94	NR	NR	NR
Type of Sample							
Surface Water					Medicine Lake @ Campground	Bullseye Lake	
Ground Water, Spring	Red Tank Spring	Fall River Springs	Fall River @ McArthur Rd Bridge	Fall River @ McArthur Rd Bridge			
Ground Water, Well							W-1dddd (Table 6)
Geothermal Reservoir Fluid							

Notes:

a = Data from Cosens-Gallinatti (1984)
b = Data from Leivas et al. (1981)
c = Data from Hotchkiss (1968)
d = Data provided by Dr. Davidson from Lawrence Livermore National Laboratory
e = Data from CalEnergy Company, Inc.
f = Data from BLM et al. (1995)
g = Data from four separate flow tests at two geothermal wells in the proposed TFGP (CEC, 1997e)
NR = Not Reported
NRH = Not Reported Herein
NA = Not Analyzed

Table 3. Chemical and Isotopic Analyses for Surface Water, Ground Water; and Geothermal Reservoir in the Medicine Lake Highlands – Regional Study Area; All Samples with Designator ML-83-x or xx Reflect the Year Samples Were Collected Followed by the Sample Number Used in this Report (Continued)

Constituent (ppm)	ML-91-48[e]	ML-88-49[f]	ML-88-50[g]	ML-88-51[g]	ML-88-52[g]	ML-88-53[g]
Calcium	4.1	8	NR	NR	NR	NR
Magnesium	2.8	0.1	NR	NR	NR	NR
Sodium	3.8	632	NR	NR	NR	NR
Potassium	3	108	NR	NR	NR	NR
Carbonate	NR	NR	NR	NR	NR	NR
Bicarbonate	NR	49	NR	NR	NR	NR
Chloride	0.5	1021	NR	NR	NR	NR
Sulfate	<1.0	47	NR	NR	NR	NR
Nitrate	<0.2	NR	NR	NR	NR	NR
Iron	NR	NR	NR	NR	NR	NR
Manganese	NR	NR	NR	NR	NR	NR
Copper	NR	NR	NR	NR	NR	NR
Total Dissolved Solids	43	NR	NR	NR	NR	NR
Boron	NR	NR	NR	NR	NR	NR
Silica	42	582	NR	NR	NR	NR
Lithium	NR	3.1	NR	NR	NR	NR
Hardness as	28	NR	NR	NR	NR	NR
$CaCO_3$(pm) as above in gr/gals	NR		NR	NR	NR	NR
Electrical Conductivity (Micromhos)	63	NR	NR	NR	NR	NR
pH	NR	8.6	NR	NR	NR	NR
Resistivity	NR	NR	NR	NR	NR	NR
Delta Oxygen-18	NR	NR	-9.03	-8.81	-8.71	-8.37
Delta Deuterium	NR	NR	-94.82	-97.07	-94.31	-96.08
Type of Sample						
Surface Water						
Ground Water, Spring	Payne Springs					
Ground Water, Well						
Geothermal Reservoir Fluid		TFGP[1]	TFGP	TFGP	TFGP	TFGP

Notes:

a = Data from Cosens-Gallinatti (1984)
b = Data from Leivas et al. (1981)
c = Data from Hotchkiss (1968)
d = Data provided by Dr. Davidson from Lawrence Livermore National Laboratory
e = Data from CalEnergy Company, Inc.
f = Data from BLM et al. (1995)
g = Data from four separate flow tests at two geothermal wells in the proposed TFGP (CEC, 1997e)
1 = Telephone Flats Geothermal Project, see text
NR = Not Reported
NRH = Not Reported Herein
NA = Not Analyzed

3.2 Regional Ground Water

Plate 1 shows the occurrence of ground water in the MLH-RSA. Several springs occur about 16 km (10 mi) south, 27 km (16 mi) southeast, and 16 km (10 mi) west of Medicine Lake. No springs are found north of the lake, except for one reported seep at Lava Beds National Monument (Davisson, 1997b, 1997c). One of the largest spring groups in the United States, the FRS, are about 53 km (32 mi) south-southeast of Medicine Lake. Water supply wells are located north, northeast, and southwest of MLH with several wells in the Medicine Lake area itself (Plate 1).

Regional geology and hydrology suggests that regional shallow ground water flow in the MLH-RSA is from north to south or from the Lower Klamath and Tule Lakes area to the Fall River Mills area via the Warner Basalts and Cedarville Series, which underlie the MLH (Macdonald, 1966; Hotchkiss, 1968). The following evidence supports this ground water flow pattern:

1. ground water elevation data from the Tule Lake – Lava Beds National Monument – northern MLH area indicate that ground water is flowing from the Tule Lake area south to at least the area between Timber Mountain on the east and MLH on the west (Hotchkiss, 1968; Section 3.3.6); and,
2. Lower Klamath and Tule Lakes are about 1,300 m-asl (4,264 ft-asl) and the FRS to the south are 300 m lower, at 1,000 m-asl (3,284 ft-asl).

The hydrologic gradient between the Tule Lake and the FRS areas is 0.0035ft/ft (0.009 m/m). This regional ground water flow analysis is in contrast with the BLM et al. (1997) who report that the direction of surface drainages north of the northern rim of MLC suggest ground water flow to the north.

One hot spring occurs in Little Hot Spring Valley at the southeastern tip of the Whitehorse Mountains, located some 50 km (30 mi) south-southeast of Medicine Lake. This geothermal feature occurs along northwest-southeast trending Basin and Range style faulting (Plate 1, and Figures 4a and 4b). Its geothermometery, according to Leivas et al. (1981), indicates a reservoir temperature of about 212 - 230°F (100 - 110°C). The current authors interpret that the genesis of this hot spring is (1) most likely intermediate depth circulation and upwelling along northwest-southeast trending Basin and Range faulting, and (2) unrelated to the geothermal system in MLH.

3.2.1 Regional Hydrologic Units

There are three important hydrological units, listed below, in the MLH-RSA, which are diagrammatically illustrated in Figure 11.

- Hydrologic Unit No. 1 = Medicine Lake Highlands volcanic massif
- Hydrologic Unit No. 2 = Modoc Plateau
- Hydrologic Unit No. 3 = Medicine Lake Highlands Geothermal Reservoir

Hydrologic Unit No. 1 - The young volcanic rocks of MLH are considered to constitute a unique hydrologic unit within the study area. Ground water occurs in MLH as a perched water system above both the geothermal reservoir and the Modoc Plateau regional ground water aquifer. Recharge to this hydrologic unit is through infiltration of precipitation.

Hydrologic Unit No. 2 - The Modoc Plateau consists of mostly volcanic rocks with some lake sediments in local areas. The main hydrologic units in the region are located within the Pliocene to Recent lava flows (Warne, 1963; Hotchkiss, 1968). These younger basalt flows are highly fractured and porous with many interconnected lava tubes and are, therefore, very permeable. The older the basalt flows the more likely that weathering of the basalt has altered the rock to clay "which seals the openings in the rock" (Warne, 1963). The shallow ground water flowing through these basalts is unconfined. Localized lake sediments in the Tule Lake area and the Fall River Mills area can also provide ground water. The lake sediments are generally less permeable than the basalts in the same hydrologic unit.

The thickness of these water-bearing units varies from the Tule Lake area to the Fall River Mills area. High quality ground water in the Tule lake Region is present from approximately 46 m-bgs (150 ft-bgs) to below 823 m-bgs (2700 ft. bgs), Hotchkiss, 1968. High quality ground water in the Fall River Mills area is present only to an approximate depth of 122 m-bgs (400 ft.-bgs), Warne (1963).

Recharge to ground water from surface water and underflow in the Tule Lake region is believed to be the principal source of recharge to this hydrologic unit (Macdonald, 1966).

Hydrologic Unit No, 3 – The MLH geothermal reservoir constitutes the third major ground water unit in the study area. The known physical and chemical characteristics of this geothermal system are described in Sections 2.4.3, 2.4.3.1, and 2.4.3.2, and Table 2. Figures 6, 8, 10, 11, 12, and 15 illustrate some aspect of the physico-chemical characteristics of the geothermal system. The hydrologic unit is believed to reside in the rocks of both MLH and the Modoc Plateau. Recharge to the geothermal reservoir is interpreted to be from deep ground water within the Modoc Plateau within the MLHSA (Figure 11; BLM et al., 1997). The Modoc Plateau is believed by these authors to be recharged from the greater Modoc Plateau region and the eastern flank of the Cascade Range.

3.2.1.1 Water Quality

Table 3 presents the results of chemical and stable isotopic analyses surface waters, springs, shallow ground waters, and geothermal reservoir fluids in the MLH-RSA. Table 4 presents the location of the ground water samples collected along with field observational data obtained.

With the exception of ML-34, the low temperature hot spring in Little Hot Spring Valley, all the remaining shallow ground waters show very low total dissolved solids (Table 3) and their delta oxygen-18 and delta deuterium isotopic values (Figure 12) fall on the worldwide meteoric water line. This indicates that all these regional springs and shallow ground water from wells identified in Table 3 (with the exception of ML-34) represent a meteoric water source with no evidence of any geothermal fluid component (Cosens-Gallinatti, 1984). The geothermal reservoir fluids, by contrast, show the distinct delta oxygen-18 shift (Figure 12) typical of geothermal fluids that have undergone water-rock interaction. The delta deuterium isotopic values of the geothermal reservoir fluid are consistent with a Modoc Plateau source region.

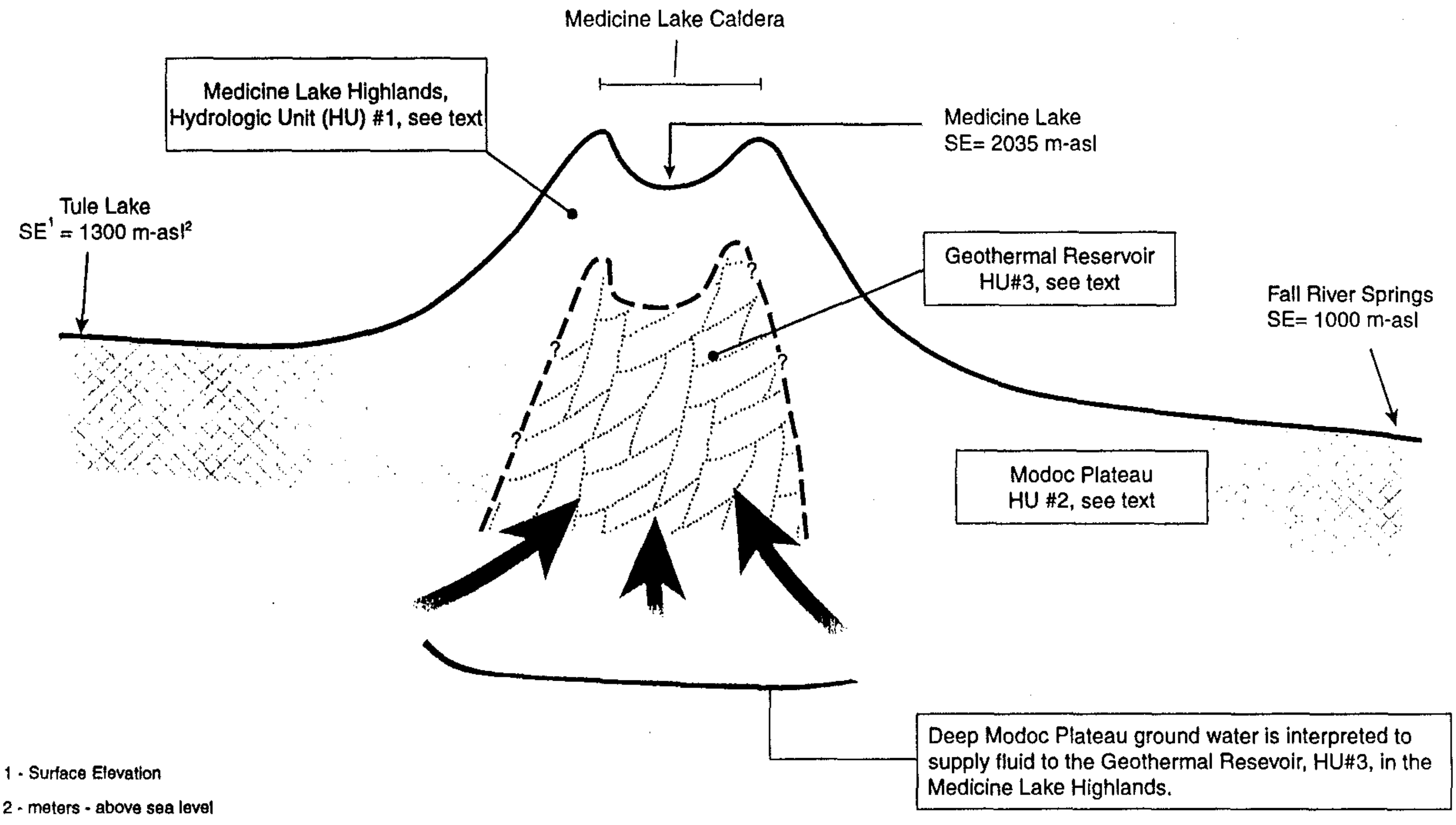


Figure 11. Diagrammatic Illustration of Hydrologic Units within the Medicine Lake Highlands-Regional Study Area

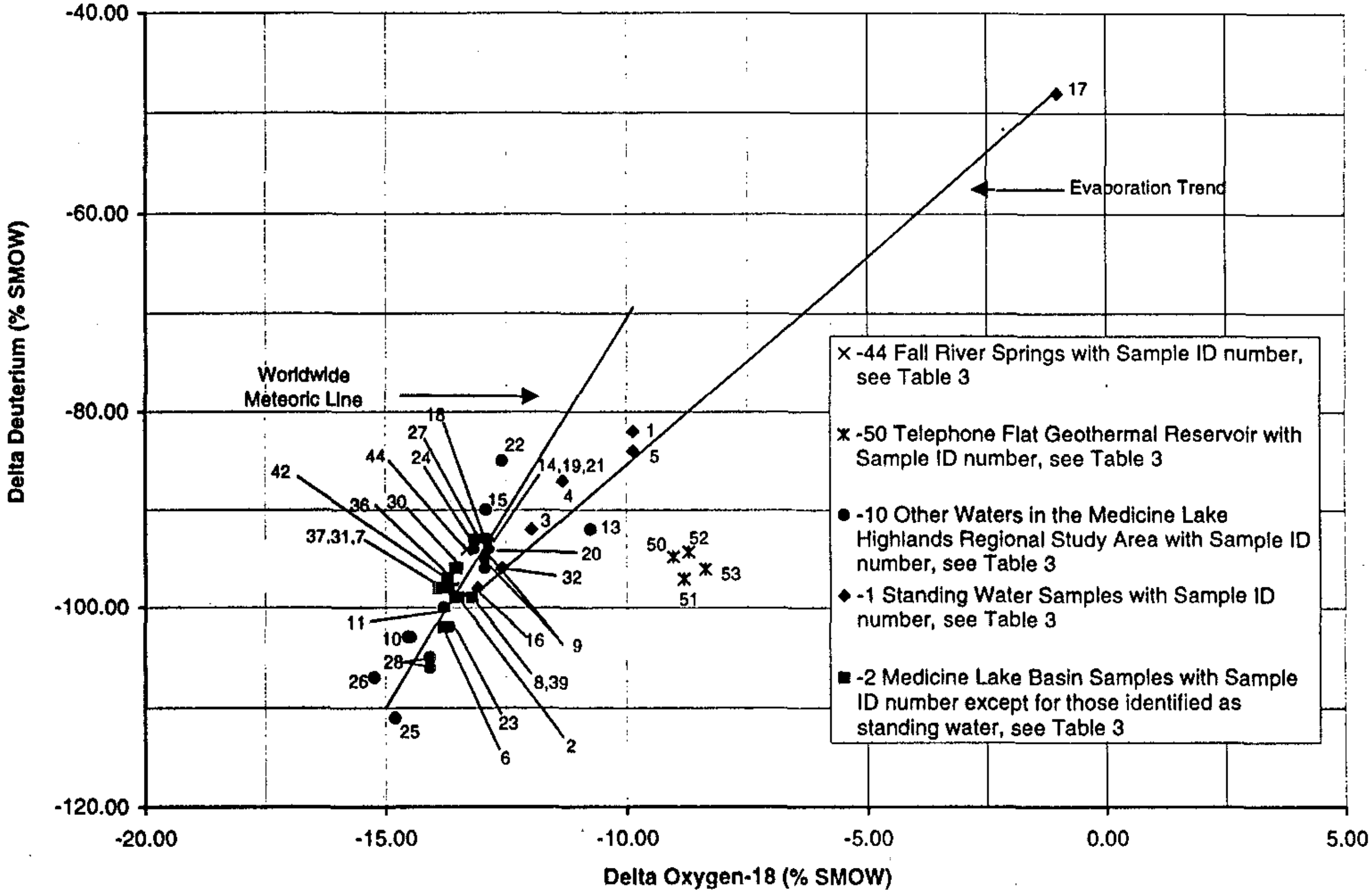


Figure 12. Delta Deuterium vs. Delta Oxygen-18 Plot for Surface Water, Ground Water, and Geothermal Reservoir Water in the Medicine Lake Highlands Regional Study Areas (after Cosens-Gallinatti, 1984)

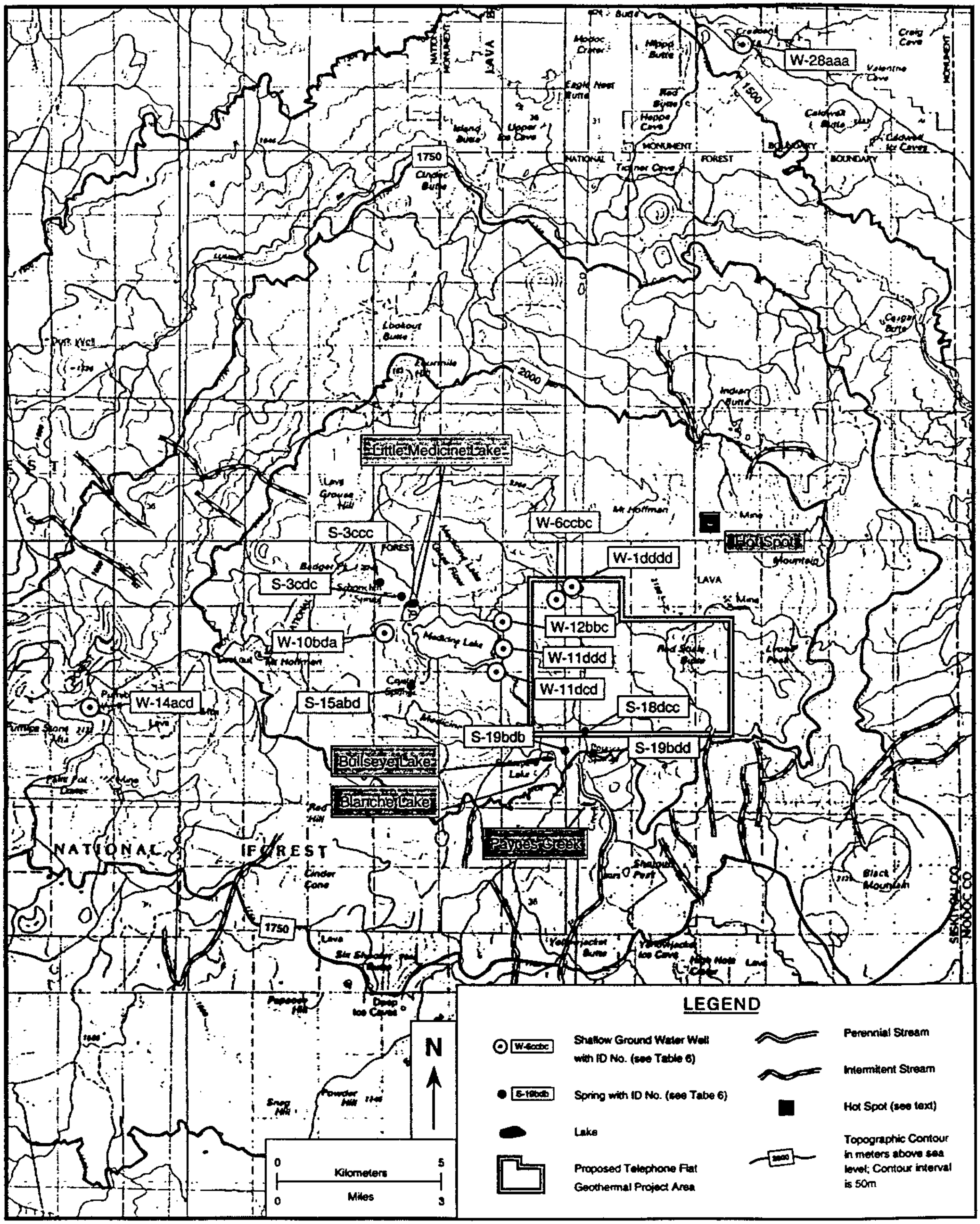
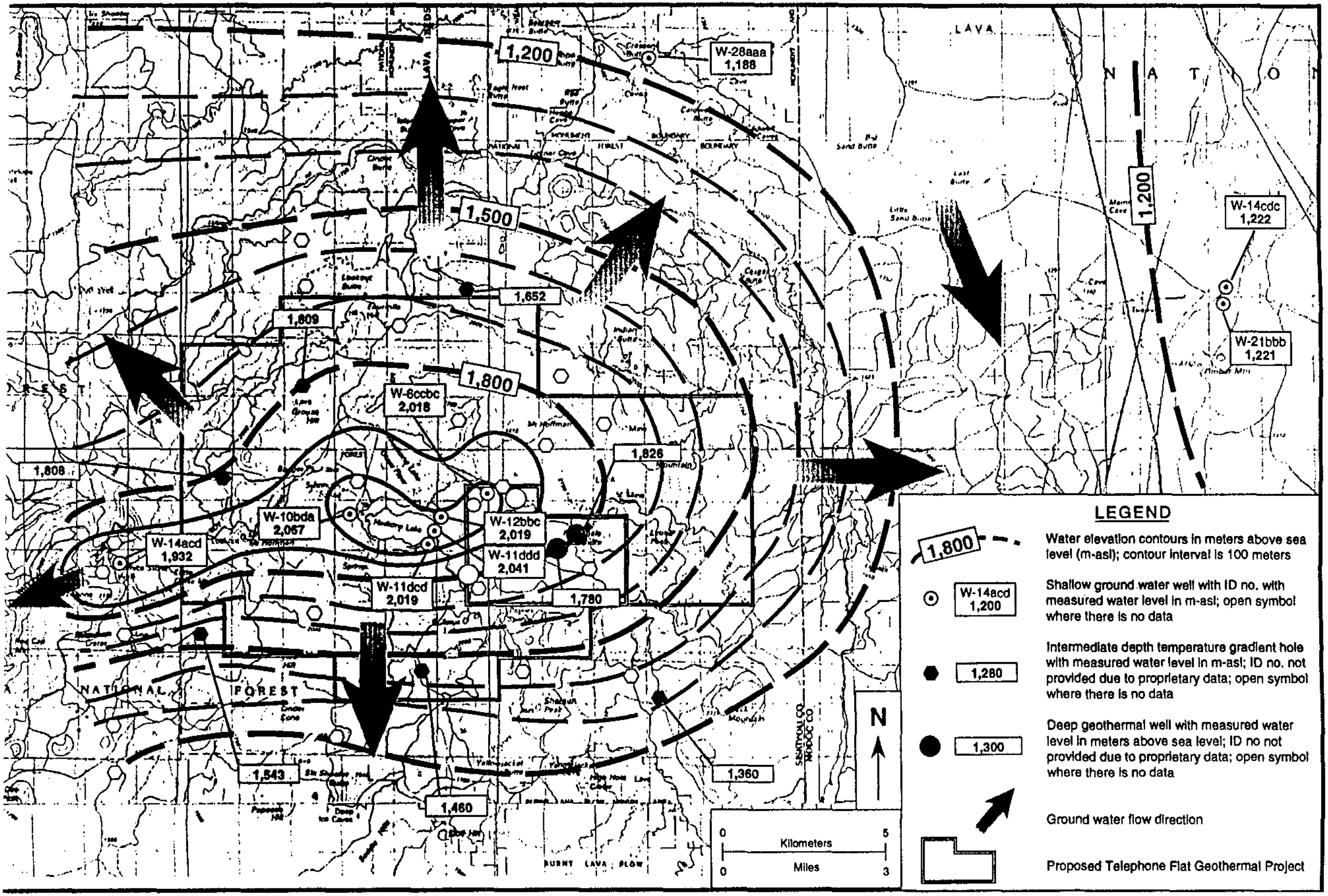


Figure 13. Location Map for Surface Waters, Springs, Streams, Shallow Water Wells, and Geothermal Manifestations in the Medicine Lake Highlands Study Area



igure 14 Water Level Elevations for the Shallow Ground Water Wells, Intermediate Depth Temperature Gradient Holes, and Deep Geothermal Wells in the Medicine Lake High lands Study Area

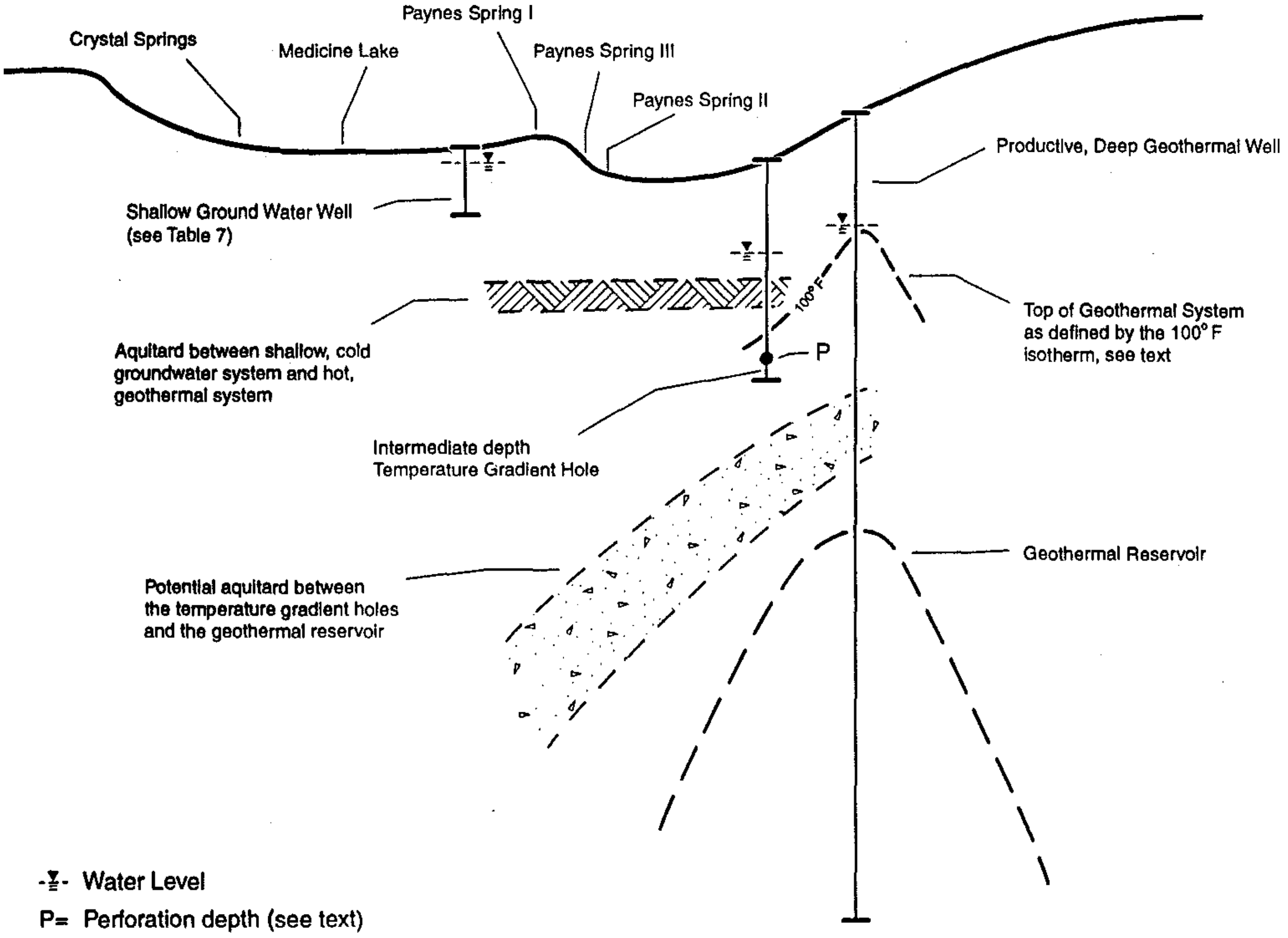


Figure 15. Diagrammatic Illustration of Key Hydrologic Relationships in the Medicine Lake Highlands Study Area

Table 4. Surface and Ground Water Sample Location and Field Collected Data at the Time of Sampling (from Cosens-Gallinatti, 1984)

ID #	Water Sample	Township	Location Range	Section	Temperature °C	Temperature °F	Water Flow (l/min)	Remarks
1	Medicine Lake	43N	3E	11	23	73.4	standing	
2	Schonchin Spring	43N	3E	3	8	46.4	~10	Flow rate estimated
3	Little Medicine Lake	43N	3E	10	21	39.8	standing	
4	Bullseye Lake	43N	3E	24	23	73.4	standing	
5	Blanche Lake	43N	3E	24	17	32.6	standing	
6	Paynes Springs (West Spring)	43N	4E	19	9	48.2	~50	Flow rate estimated
7	Paynes Springs (North Spring)	43N	4E	18	8	46.4	~100	Flow rate estimated
8	Paynes Springs (South Spring)	43N	4E	19	8	46.4	~10	Flow rate estimated
9	Pumice Stone Well	43N	2E	14	11	51.8	>1500	Flow rate estimated
10	Tamarack Spring	43N	2E	5	14	57.2	~100	Flow rate estimated
11	Lost Spring	43N	2E	31	17	62.6	~10	Flow rate estimated
12	Harris Spring	42N	2E	30	6	42.8	~20	Flow rate estimated
13	Lost Iron Well	42N	2E	28	12	53.6	~10	Flow rate estimated
14	Benap Spring	41N	1E	13	11	51.8	~5	Flow rate estimated
15	Point Spring	41N	1E	14	14	57.2	~5	Flow rate estimated
16	Deter Spring	41N	1E	15	15	59	standing	
17	Todd Lake	41N	2E	9	27	80.6	standing	
18	Slagger Spring	41N	1E	36	7	44.6	100	Flow rate estimated
19	Red Tank Spring (?)	40N	1E	1	7	44.6	20	Flow rate estimated
20	Sheepheaven Spring	40N	1E	11	9	48.2	100	Flow rate estimated
28	Baird Spring	43N	1E	15	18	64.4	~10	Flow rate estimated
30	meadow near Crystal Spring	43N	3E	15	5	41	~50	Flow rate estimated
31	Crystal Spring	43N	3E	15	5	41	>100	Flow rate estimated
32	Hambone Well	41N	3E	31	19	66.2	standing	

close to their source. These intermittent streams only flow after snowmelt and as intense storm runoff. The infiltrating water becomes part of the ground water flow at lower elevations.

3.3.1.1 Water Quality

Table 3 presents the results of chemical and stable isotopic analyses for surface waters in MLH. The conditions under which these samples were collected are given in Table 4.

All these surface waters have very low total dissolved solids (Table 3) and their oxygen-18 and deuterium isotopic values (Figure 12) fall on the worldwide meteoric water line. This indicates that all these surface waters represent meteoric water source and there is no evidence of any geothermal fluid component in these waters (Cosens-Gallinatti, 1984). This finding is consistent to similar analyses conducted by the USGS (Mariner, 1997).

Water samples from Medicine Lake (ML-83-1), Little Medicine Lake (ML-83-3), Bullseye Lake (ML-83-4), and Blanche Lake (ML-83-5), among others, have isotopic values which indicate that they have undergone evaporation (Figure 12).

3.3.2 Local Ground Water

Springs in the MLH include the three separate springs comprising Paynes Springs, Schonchin Springs, Crystal Springs and a private spring (Figure 13). The elevations of these features are taken from Schneider and McFarland (1995.

Surface Water	Elevation (ft/m)
Payne Springs I	6,558/2,074
Payne Springs II	6,471/1,973
Payne Springs III	6,678/2,036
Schonchin Springs	6,820/2,074
Crystal Springs	6,860/2,092
Private Springs	6,700/2,043

Schonchin and Crystal Springs discharge at higher elevations than the surface of Medicine Lake (Table 5) and are believed to represent local, perched ground water above MLB. Paynes Springs, located 2.5 km (1.5 mi) southeast of Medicine Lake, discharge at a lower elevation than Medicine Lake, and probably represent local ground water discharge from MLC (Ciancanelli, 1983). The three springs comprising Paynes Springs have a combined, single point in time flow measurement of 98.7 cubic feet per second (Schneider and McFarland, 1995).

In addition to the springs, there are six ground water wells in the MLB (e.g., W-10-bda) and two additional ground water wells in the greater MLH study area, W-14acd and W-28aaa (Figure 13 and Table 6). The hydrologic units for the MLH study area are discussed below.

Table 5. Medicine Lake Caldera Spring Data (after Schneider and McFarland, 1995)

Spring Location	Spring ID No.	Spring Name	Altitude (feet/meter)	Date	Temperature (°C)	Specific Conductance	Remarks
43N/3E	S-3cdc	South Schonchin Spring	6820/2074	9/15/92	--	--	Dry.
43N/3E	S-10acb	Private Spring (Latunich)	6700/2043	9/15/92	6.6	56.0	Discharge 28.7 gal/min, measurement made approximately 600 ft down-stream and approximately 100 ft from lake edge.
43N/3E	S-15abd	Crystal (Government) Springs	6820/2074	6/2/92 9/16/92	2.6 2.6	47.3 43.0	Discharge 3.4 gal/min.
43N/4E	S-19bca	Paynes Spring I	6558/1999		12.6	56.0	Discharge 75.4 gal/min, measured 600 ft downstream on west fork of Paynes Creek.
43N/4E	S-19bdb	Paynes Spring II	6471/1973	9/16/92	7.8	--	Discharge 23.3 gal/min, measurement made in small channel about 15 ft from orifice.
43N/4E	S-18cdcc	Paynes Spring III	6678/2036	9/16/92	--	--	Seeps only. No discharge measurement made.

Table 6. Medicine Lake Highlands Study Area Well Data (after Schneider and McFarland, 1995)

Well Location[1]	Well ID No.[2]	Name/Owner	Date Drilled	Altitude		Depth of Well		Depth of Open Interval (Top/Bottom)		Depth to Water		Water Level Elevation (amsl[4])			Temp[5]	Sp Con[6]	Source of Data	Remarks
				(feet)	*(meters)*	(feet)	*(meters)*	(feet)	*(meters)*	(feet)	*(meters)*	(feet, amsl)	*(meters, amsl)*	Date measured	(degree C)	(micromhos)		
45N/4E	28-aaa	Lava Beds National Monument/NPS[3]	04/22/05	4,570	*1,393*	758	*231*	709/758	*216/231*	674	*205*	3,896	*1,188*	07/26/62	17	189	Schneider and McFarland (1995)	7/26/62 water level reported by driller
										653	*199*	3,917	*1,194*	03/02/66			Schneider and McFarland (1995)	
										658	*201*	3,912	*1,193*	09/17/92			Schneider and McFarland (1995)	
43N/2E	14-acd	Pumice Stone well	NA	6,339	*1,933*	5	*1*	0/4.7	*0/1.4*	3	*1*	6,336	*1,932*	09/16/92	NA	NA	Schneider and McFarland (1995)	Dug by hand
43N/3E	1-dddd	Unocal water well	NA	6,721	*2,049*	200	*61*	NA	NA	NA	*NA*	NA	*NA*	NA	NA	NA	Schneider and McFarland (1995)	
43N/3E	10-bda	Guard station well/ U.S. Forest Service	NA	6,788	*2,070*	NA	*NA*	NA	NA	7	*2*	6,781	*2,067*	06/02/92	NA	NA	Schneider and McFarland (1995)	No log
										12	*4*	6,776	*2,066*	09/15/92			Schneider and McFarland (1995)	
43N/3E	11-ddd	Old Sawmill well	NA	6,700	*2,043*	14	*4*	NA	NA	7	*2*	6,693	*2,041*	09/16/92	NA	NA	Schneider and McFarland (1995)	No log
43N/3E	11-dcd	Bob Tadina	NA	6,760	*2,061*	172	*52*	NA	NA	137	*42*	6,623	*2,019*	09/16/92	NA	NA	Schneider and McFarland (1995)	Newest well
43N/3E	12-bbc	Medicine Lake Campground well/ U.S. Forest Service	10/01/88	6,800	*2,073*	220	*67*	180/220	*55/67*	179	*55*	6,621	*2,019*	09/15/92	NA	NA	Schneider and McFarland (1995)	
43N/4E	6-ccbc	Phillips water well	10/11/81	6,717	*2,048*	535	*163*	NA	*NA*	98	*30*	6,619	*2,018*	09/16/92	NA	NA	Schneider and McFarland (1995)	
43N/3E	26-dbd	NR	07/24/84	6360[a]	*1,939*	2,180	*665*	1,926	*587*	1,570	*479*	4,790	*1,460*	07/26/84	NA	NA	Gaddis (1984)	Open Interval = Perforated Target Depth Pressure measured water level
43N/3E	19-dcb	NR	07/24/84	6080[a]	*1,854*	2,198	*670*	1,650	*503*	1,020	*311*	5,060	*1,543*	07/26/84	NA	NA	Gaddis (1984)	Open Interval = Perforated Target Depth Pressure measured water level
43N/3E	6-dab	NR	07/24/84	6740[a]	*2,055*	1,997	*609*	1,652	*504*	810	*247*	5,930	*1,808*	07/26/84	NA	NA	Gaddis (1984)	Open Interval = Perforated Target Depth Pressure measured water level
44N/3E	28-cac	NR	07/25/84	6700[a]	*2,043*	2,138	*652*	1,728	*527*	765	*233*	5,935	*1,810*	07/26/84	NA	NA	Gaddis (1984)	Open Interval = Perforated Target Depth Pressure measured water level
44N/3E	13-bdc	NR	07/25/84	6130[a]	*1,869*	2,968	*905*	2,961	*903*	710	*216*	5,420	*1,653*	07/26/84	NA	NA	Gaddis (1984)	Open Interval = Perforated Target Depth Pressure measured water level
43N/4E	27-cdd	NR	NA	5800[a]	*1,768*	NA	*NA*	NA	*NA*	1,340	*409*	4,460	*1,359*	NA	NA	NA	CEC (1997d)	
43N/4E	17-bba	NR	NA	6990[a]	*2,131*	NA	*NA*	NA	*NA*	1,150	*351*	5,840	*1,780*	NA	NA	NA	CEC (1997d)	
43N/4E	8-dca	NR	NA	6990[a]	*2,131*	NA	*NA*	NA	*NA*	1,000	*305*	5,990	*1,826*	NA	NA	NA	CEC (1997d)	
44N/6E	16-cdc	E. Hawkins	05/17/05	4,220	*1,287*	271	*83*	NA	*NA*	236	*72*	3,984	*1,215*	11/04/64	NA	NA	Hotchkiss (1968)	
										213	*65*	4,007	*1,222*	05/11/66				
44N/6E	21-bbb	E. Hawkins	05/17/05	4,232	*1,290*	NA	*NA*	NA	*NA*	227	*69*	4,005	*1,221*	05/11/66	NA	NA	Hotchkiss (1968)	

Notes:

1	=	Township and Range
2	=	Based on the rectangular system for subdivision of public lands (Schneider and MacFarland, 1995)
3	=	National Park Service
4	=	above mean sea level
5	=	Temperature
6	=	Specific Conductance
NA	=	Not Available
NR	=	Not reported because of proprietary data
a	=	Elevation obtained from topographic map
b	=	Target depth of perforation

The BLM et al. (1995; 1997) report that the depth to the first major aquifer in the MLC is about 61 m (200 ft). On the flanks of MLH, the depth to the aquifer ranges from 92 m (300 ft) to over 305 m (1,000 ft). At the base of MLH (i.e., the Modoc Plateau), the depth of the water table is approximately 153 m (500 ft).

3.3.2.1 Water Quality

Table 3 presents the results of chemical and stable isotopic analyses of ground waters in the MLH region. Table 4 presents the location of surface and ground water samples collected along with field observational data.

All the ground waters in Table 3 have very low total dissolved solids and their oxygen-18 and deuterium isotopic values (Figure 12) fall on the worldwide meteoric water line. This indicates that all these springs and ground water from shallow wells in the MLHSA represent meteoric water source and there is no evidence of any geothermal fluid component (Cosens-Gallinatti, 1984). Ground water and surface water in the MLH-RSA are chemically and isotopically similar (Table 3, Figure 12, Section 3.2.1.1).

Sample ML-83-13 shows a slight delta oxygen-18 shift towards heavier isotopic values relative to other springs and shallow ground water wells in the MLH-RSA (Section 3.3.3.1). However, its chemistry is comparable to the springs and shallow ground waters in the MLH-RSA. As such, there is no chemical evidence that the ML-83-13 waters have any geothermal component.

3.3.3 Geothermal Waters

Geothermal waters are derived from the geothermal reservoir in the MLH. According to CEC (1997b), the geothermal reservoir occurs at depths of 1829 to 2,438 m-bgs (6,000 to 8,000 ft-bgs), Section 2.4.3.2. Given a nominal surface elevation in the MLC of 2,260 m-asl, then the geothermal reservoir occurs at about 400 to –178 m-asl (122 to –54 ft-asl).

3.3.3.1 Water Quality

Sample ML-49 in Table 3 represents the chemical analysis of fluids produced from the geothermal well 87-13 (BLM et al., 1995). This analysis shows that the reservoir fluids are enriched in chemical constituents such as silica, sodium, potassium, and chloride relative to the surface waters and shallow ground waters at the MLB.

Samples ML-88-50 through ML-88-53 represents delta oxygen-18 and delta deuterium isotopic values for geothermal fluids at MLH (Table 3; Figure 12, Schriener, 1997). These four sample represent mean delta oxygen-18 and delta deuterium isotopic values from four flow tests at two deep geothermal wells, two flow tests per well, corrected assuming a continuous flash content. The delta oxygen-18 isotopic values for these fluids from the geothermal reservoir at MLH shows an oxygen-18 shift typical of fluids hydrothermally interacting with the host rock within a reservoir. The delta deuterium isotopic values of the geothermal reservoir fluid are consistent with a Modoc Plateau source region.

3.3.4 *Geothermal Manifestations*

Essentially, no hydrologic, surface expression of the geothermal resource under MLH is evident. There is, however, a "Hot Spot" in the northeastern portion of MLB, east of Mt. Hoffman. Mariner (1997a) sampled and analyzed the gases for this "Hot Spot" and found that the hot gas vent consists of steam and very dilute amounts of carbon dioxide. However, he also reported that sampling of this feature was difficult. This gas vent may simply represent heated meteoric water infiltrating around Big Glass Mountain, a recent silicic extrusion, being conductively heated by the associated underlying igneous rocks, and exiting at the surface as heated water vapor.

3.3.5 *Hydrologic Units*

3.3.5.1 In Medicine Lake Highlands

In MLH, there are 2 important hydrologic units within the MLH, which are:

- the shallow ground water system principally confined to the MLH, HU # 1; and
- the geothermal reservoir, HU #3.

HU #1 represents a perched, ground water system above the Modoc Plateau regional ground water system (HU #2) because the shallow ground water in HU #1 occurs at an elevation approximately 1000 m higher than the shallow ground water in the Modoc Plateau (Figure 14). The source of the shallow ground water in this hydrologic unit is primarily snowmelt resulting from winter precipitation.

The geothermal reservoir, the third hydrologic unit (HU #3) appears to be separated from the shallow ground water by an aquitard thought to be a primary lithologic barrier (e.g., an impermeable lava flow) and/or a low permeability hydrothermal alteration halo (Section 2.4.3.1). The BLM et al. (1997) report a relatively impermeable layer of clay-rich ash flow tuffs isolating the shallow ground water system from the underlying geothermal system. Additionally, a hydrothermal alteration seal around the geothermal reservoir is present, Section 2.4.3.1. Recharge around MLH infiltrates into HU # 1 and is believed to eventually reach the regional water table in the surrounding Modoc Plateau.

3.3.6 *Existing Use*

Ground water use in the area of MLB consists of domestic use in the private homes around the lake, public use in the campground, USFS, and intermittent geothermal exploration use. These uses are seasonal and not considered significant withdrawals of ground water for the purposes of including their effect in this evaluation.

3.3.7 Ground Water Movement

All available water elevation data were used to prepare the ground water elevation map shown in Figure 14. These water elevations represent data collected by different organizations at different times from wells and boreholes that have open- or screen-intervals in different water-bearing intervals in either HU #1 or HU #3 (Table 6, Section 3.2.1). The range in total depth for these wells is presented below.

Wells/Boreholes	Range in Total Depth
9 water wells	1.5to 163 m-bgs (5 to 535 ft-bgs)
6 temperature gradient holes	1,997 to 2,968 m-bgs (6,532 to 9,738 ft-bgs)
2 geothermal wells	-435 to –545 m-bgs (-1,427 to –1,788 ft-bgs)

Due to these variations primarily in sampling times and in sampling different water-bearing intervals, this water elevation map is only a gross, generalized schematic of ground water movement. Water elevations in the shallow ground water wells range from about 2,000 m (6,560 ft) for the wells near Medicine Lake to 1,932 m (6,337 ft) in W-14acd about 9 km (5.5 mi) to the west-southwest of Medicine Lake and 1,193 m (3,913 ft) in W-28aaa about 17 km (10 mi) to the north-northeast of Medicine Lake (Table 6). Gaddis (1984) reports water levels for five of these TGHs: ML 65-26, ML 54-19, ML 75-6, ML 36-28, and ML 57-13. Additionally, CEC (1997d) reports water table elevations for a TGH, ML 27-27, and for two geothermal wells: GMF 68-8 and GMF 31-17. Hotchkiss (1968) provides water level data for the two wells near Tionesta, east of MLH.

Seven features may be deduced from the water level elevation map (Figure 14) and these relationships are diagrammatically illustrated in Figure 15.

1. There are at least three distinct hydrologic regimes evidenced by the data:
    (a) shallow, cold ground water represented by the shallow water wells around Medicine Lake, Lava Beds National Park to the north (W-28-aaa, Figure 13), near Tionesta to the east (W-16cd, and W-21bb, Figures7 and 14), and the Pumice Stone well to the west (W-14-acd, Table 6);
    (b) the geothermal system whose top is defined by the 38°C (100°F) isotherm in the TGHs; and,
    (c) the geothermal reservoir represented by the two deep wells;
2. Water levels differences between the shallow ground water wells in MLB and the top of the geothermal system as represented by the 38°C (100°F) isotherm in the TGHs indicate that there is a pressure differential of about 200 – 400 m (61 – 122 ft) with the shallow ground water system being at the higher head. This pressure differential indicates a good confining layer between these two ground water systems.
3. Water levels in the area of the deep geothermal wells are higher than the surrounding TGHs but lower than the shallow ground water wells (Figure 15). These higher water levels are interpreted to result from upwelling of geothermal fluids creating a thermally induced hydrologic bulge. This is consistent with the elevated

temperatures in this area (**Figure 8**). The hydrothermal alteration surrounding the geothermal reservoir is interpreted to be responsible for the separation of the hydraulic system related to the geothermal reservoir and the hydraulic system related to the temperature gradient holes.

4. Shallow ground water from MLB appears to flow radially outward in all directions (Figure 14; BLM et al., 1997).
5. Ground water flowing from MLB towards the east and south merges with the regional ground water aquifer in the Modoc Plateau which is flowing from north to south (Section 3.1.1).

   Part of the ground water flow moving north from MLB merges with the ground water flow moving south from Klamath and Tule Lakes (Section 3.1.1) in and around W-14acd, in the eastern portion of Lava Beds National Monument (Hotchkiss, 1968).
6. Limited data exists on the flow of ground water in the west. However, regional topographic and structural considerations suggest that ground water flows to the west and eventually to the southeast following the northwest-southeast trending regional graben structure identified in Figures 4a and 4b.
7. Regionally, the shallow ground water in the MLB is at a nominal elevation of 2,000 m-asl and shallow ground water in the Modoc Plateau is at an elevation of 1,200 m-asl. The shallow ground water at MLB is a perched water system above the regional ground water system in the Modoc Plateau. These data are consistent with the regional hydrologic units defined in Section 3.2.1.

3.3.8 Hydrologic Balance

The hydrologic balance describes the water cycle for an area. It estimates how much and by what pathways and processes water enters and leaves the area of interest. It is important to define the hydrologic balance prior to geothermal development because it:

1. establishes a baseline condition;
2. estimates whether the available water resources are sufficient to maintain existing and proposed consumptive uses; and,
3. determines whether the proposed consumptive use will affect the ground or surface water resources in the region, including geothermal manifestations, if any.

The hydrologic balance tallies all the water entering and exiting the area of interest. That is, the amount of the natural recharge into an area minus the amount of natural discharge out the area is the change in storage of water in an area. To calculate the hydrologic balance for a given ground water basin, the area of the ground water basin must be determined.

For this investigation, we defined the hydrologic balance study area as that portion of MLH approximately enclosed by the 1,500-m (4,920 ft) topographic contour (**Figure 2**). This subregion was chosen because (1) it surrounds the proposed TFGP; and (2) it provides a distinct topographic boundary between the Modoc Plateau and MLH. The MLHSA has been subdivided into three areas

(1) the MLB, (2) from the outer limits of the MLB to the 1750-m topographic contour, and (3) from the 1750-m to the 1500-m topographic contours (**Figure 16**). The 1750-m topographic contour was chosen to provide a midpoint between the MLB and the 1500-m topographic contour demarcation discussed above. The region was divided this way so precipitation on the volcano could be distributed. The area for these three regions estimated using a planimeter is provided below.

REGION	AREA (acres)
MLB	15,415
MLB to 1,750-m topographic contour	53,747
1,750-m to 1,500-m topographic contours	104,194

The precipitation recharge was then determined using these areas as discussed below.

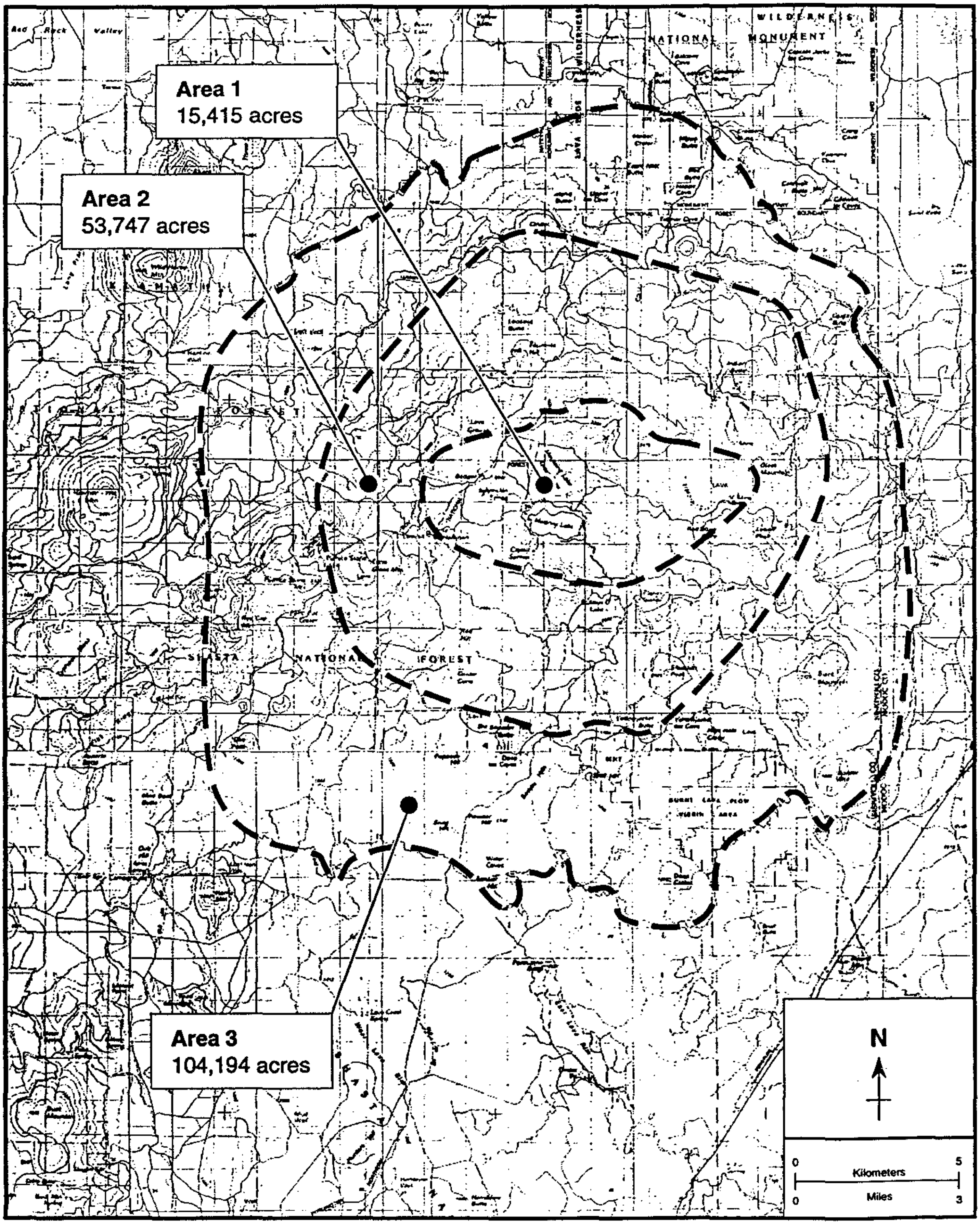
The MLB is a principal area of interest in this investigation because:

1. the TFGP area is located principally within it (Figure 2);
2. the MLB forms a natural closed basin; and,
3. the MLH may be the source region for the water issuing from the FRS (Grose, 1996; Rose et al., 1996).

Grose (1996) reports that the FRS is derived entirely from MLH. Rose et al. (1996) report that a likely source area for the voluminous FRS is the greater than 1900 km^2 (684 mi^2) lava plateau between MLH and FRS (i.e., the Modoc Plateau). However, Rose et al. (1996, p. 233) states that the FRS group's recharge is from the lava plateau of the MLH. Davisson (1997a) reported that the source of FRS appears to be MLH because of the similarity in stable isotopic values (see below). The correlation of FRS waters with those in the MLB follows because surface water only occurs in the MLB. Rose et al. (1996) investigated the origin of voluminous cold springs in the Hat Creek Basin in northeastern California, which is due south of the MLH-RSA (**Figure 17**). They used the common technique of measuring the natural variation in hydrogen and oxygen isotopic values as a function of altitude to identify recharge areas. To define this relationship, waters were collected and analyzed from creeks and springs along a 60 km (36 mi) transect from the Sacramento Valley to the highlands east of Clover Mountain (**Figure 17**). Based on the altitude and delta oxygen-18 relationship between waters from FRS and MLB, Davisson (1997a) postulated that MLH was the recharge area for the FRS, based on the similarity in oxygen-18 isotopic values between FRS and waters from MLB. The work by Rose et al. (1996) indicates that recharge to FRS comes from elevations on the order of those at MLB. Discussed in Section 3.4.2.2.1 is an estimate of the potential contribution of MLB waters to the recharge of FRS. Other potential FRS recharge sources are discussed in Sections 3.5 and 3.5.1.

3.3.8.1 Recharge

All water entering an area is called recharge, which is comprised of precipitation, ground water inflow, surface water inflow, percolation from streams or other conveyances, and imported



Area 1
15,415 acres

Area 2
53,747 acres

Area 3
104,194 acres

Figure 16. Area Designations, Medicine Lake Highlands Study Area Hydrologic Water Balance

T.P. Rose et al. / Journal of Hydrology 179 (1996) 207–236

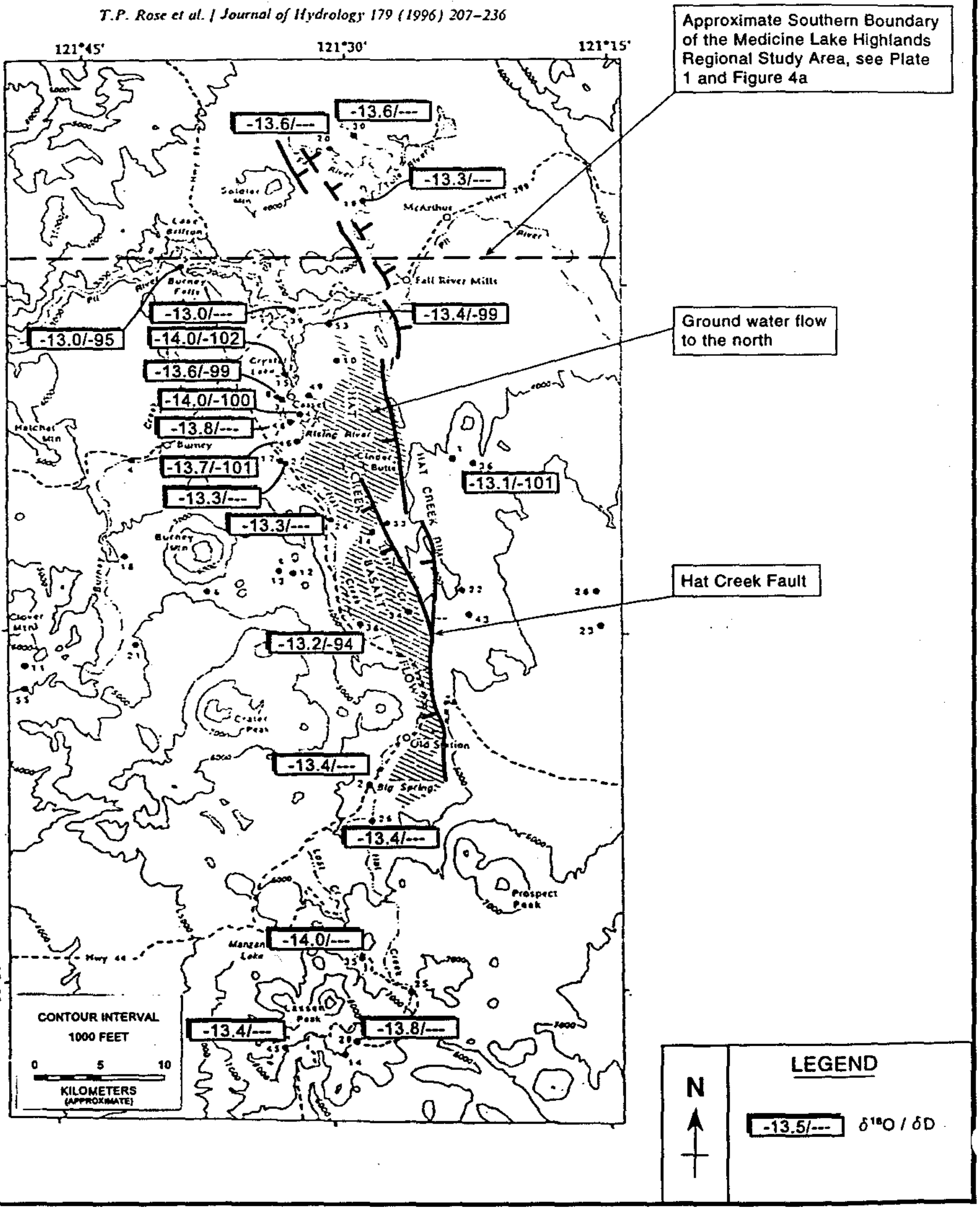


Figure 17. Delta Oxygen 18 and Delta Deuterium Isotopic Values for Waters in the Hat Creek Basin; Numbered Dots Are Sampling Locations in the Study Area (after Rose et al., 1996; and Grose, 1996)

water. At MLH, the only recharge into that hydrologic unit (HU #1, **Figure 11** and Section 3.2.1) is from precipitation. Additional assumptions in this calculation are that:

1. the effect of non-vegetated areas on the ground water recharge term is small and can be ignored;
2. recharge is to HU #1;
3. recharge moves vertically downward; and,
4. ground water flows radially away from the summit area (MLB) as shown in Figure 14.

Precipitation at MLH is primarily in the form of snow in the winter. Recharge at MLH is primarily in the form of snowmelt infiltrating the permeable volcanic soil (BLM et al., 1995; BLM et al., 1997). The BLM et al. (1997) reported that a lesser component of recharges comes from infiltration of rainfall during the summer and fall. However, this component of recharge is not considered a significant contribution to the water budget for the purposes of this investigation either by the current authors or BLM et al. (1997). The available snowfall precipitation data at MLH is limited to one measuring station at the MLC. The rainfall equivalent precipitation values for the 6700-foot elevation at MLB, based on the thickness of the snowpack and its water content, were obtained from California DWR (1997). These data are presented in Appendix B. Snowpack thickness and its water content have been measured at the location since 1938. The rainfall equivalent precipitation value, based on these data, averaged over the last 58 years is 32 inches/yr (82 cm/yr). This precipitation value is consistent with BLM et al. (1997).

Precipitation rates for the remainder of the MLH area of interest are not available (Ashby, 1997). Consequently, as a first gross approximation of precipitation rates for the area outside of MLB, were interpolated on the basis of:

1. the 58 year average rate of 32 inches/yr (82 cm/yr) at MLB (Appendix B);
2. the 25 year average rate of 11 inches/yr (28cm/yr) of precipitation at Tule Lake (Appendix C); and,
3. the elevation profile between these two areas.

Using these data, the region between MLB and the 1750-m contour was assigned a precipitation value of 22 inches/yr (56 cm/yr), and the region between the 1750-m and 1500-m contours was assigned a precipitation value of 18 inches/yr (46 cm/yr). Thus, the estimated average annual recharge rate can then be estimated for each of the regions. **Table 7a** presents the estimated average annual discharge rates for this area. Based on average annual precipitation data for the last 58 years with no ET correction, the estimated average annual recharge to the MLB is 41,621 A-ft/yr and for the recharge to the Modoc Plateau from the MLHSA is estimated at about 295,000 A-ft/yr.

3.3.8.2 Discharge

All water leaving a drainage area is called discharge. This may occur through surface water outflow, consumptive use, ground water outflow, evaporation-transpiration (ET). Each of these factors is discussed below.

Table 7a. Estimated Average Annual Recharge in the Medicine Lake Highlands Study Area

Region	Area (acres)	Precipitation Rate (ft/yr)	Estimated Average Annual Recharge Rate (acre-ft/yr)
Medicine Lake Basin	15,415	2.7	41,621
MLB to 1,750-m topographic contour	53,747	1.8	96,745
1,750-m to 1,500-m topographic contours	104,194	1.5	156,291
Medicine Lake Highland			294,657

Table 7b. Estimated Average Annual Discharge in the Medicine Lake Highlands Study Area

Region	Area (acres)	Evapo-Transpiration (ft/yr)	Estimated Average Annual Discharge Rate (acre-ft/yr)
Medicine Lake Basin	15,415	1.2	18,498
MLB to 1,750-m topographic contour	53,747	1.2	64,496
1,750-m to 1,500-m topographic contours	104,194	1.2	125,033
Medicine Lake Highland			208,207

Table 7c. Estimated Average Annual Storage in the Medicine Lake Highlands Study Area

Region	Estimated Average Annual Recharge Rate (acre-ft/yr)	Estimated Average Annual Discharge Rate (acre-ft/yr)	Estimated Average Annual Storage Rate (acre-ft/yr)
Medicine Lake Basin	41,621	18,498	23,123
MLB to 1,750-m topographic contour	96,745	64,496	32,276
1,750-m to 1,500-m topographic contours	156,291	125,033	31,258
Medicine Lake Highland	294,657	208,207	86,570

Notes:

m = meters

At MLH, there is no surface water outflow out of the highlands. Water that is discharged through springs in MLH infiltrates into the ground well before it leaves the highlands. For example, the only known perennial surface discharge out of MLB is from Paynes Creek, which becomes intermittent within 2.5 km (1.5 mi) of its source springs (Figure 13 and Section 3.3.1). This flow represents the only surface discharge of the shallow ground water system within the MLB.

Historical and seasonal measurements on Paynes Springs discharge are lacking. A one-time measured discharge rate of 98 cubic feet per second (71, 470 A-ft/y) has been reported by Schneider and McFarland (1996), Table 5. Since this volume is only a single point measurement, it is not representative of the average yearly discharge for this spring. Crystal Spring flows into Medicine Lake at a rate of approximately 3.4 gpm (5.48 A-ft/yr). Other sources of runoff, such as the intermittent streams, were not calculated because they infiltrate into the ground prior to leaving MLH.

Current consumptive use at MLH is discussed in Section 3.3.9.2 and it is considered negligible for the purposes of this report.

There is no known data on subsurface discharge from MLH to the Modoc Plateau regional ground water system.

Site specific ET measurements for the MLH area are not available. Estimates for ET in the MLH range from 14-in (36-cm, Vantine, 1989) to 39-in (99-cm) for Medicine Lake itself (Harding, 1962) to 42-in (107-cm. Swain, 1997). Taking an average of these values gives an annual ET of 31.7-in (81 cm) which is approximately equal to the precipitation value. Newberry Volcano located about 278 km (166 mi) north of MLH is of comparable size and geographic location relative to the Cascade Range as MLH. Sammel and Craig (1983) determined that the annual ET value was 37% or 13.1-in (33-cm) of the annual precipitation of 35.3-in (90-cm). Given the similarity between MLH and Newberry Volcano, the Vantine (1989) ET value of 14-in (36-cm) is used in this investigation.

The ET corrected estimated annual discharge rate for the MLH is presented in Table 7b. Based on average annual precipitation data for the last 58 years with an ET correction of 14-in (36 cm), the estimated average annual discharge rate from the MLH study area is estimated at about 208,207 A-ft/yr.

3.3.8.3 Storage

Storage is the difference between recharge and discharge in an area. Water may be stored in a surface water body, a ground water reservoir, or as soil moisture. Since reliable estimates of discharge out of the MLB are not available, storage determinations for this area can only be grossly approximated. The estimated average annual storage in the MLH study area is presented in Table 7c and below.

Area	Quantity (A-ft/yr)
MLB	23,123
MLB to 1,750-m contour	32,276
1,750-m to 1,500-m contour	31,258
TOTAL	86,570

The foregoing determination assumes no outflow from MLB. That is, since there is only a single flow rate measurement on Paynes Creek, its discharge was not included in this analysis. In any case, the outflow from Paynes Creek infiltrates between the MLB and the 1,750-m (5,740-ft) topographic contour. Thus, irrespective of any outflows from MLB, the total recharge to MLH is the same.

The estimated average annual storage values presented above and in Table 7c also indicate the amount of ground water recharge in the various portions of the MLH study area.

3.3.9 Water Availability and Use

In this section we discuss the water availability, present water use, and projected water use in the region.

3.3.9.1 Water Availability

According to Warne (1963) and Hotchkiss (1968), water availability in the region is extensive. Although no numbers have been tabulated for the total ground water reservoir areas of the Tule Lake region and the Fall River Mills area, the discharge of the FRS, 2 mi north of Fall River Mills, is 1,444,900 A-ft/yr (Macdonald, 1966).

3.3.9.2 Water Use

Schneider and McFarland (1995) report that many of the springs in the area of Medicine Lake (Figure 13) have been used for water supply for the USFS maintained campgrounds. For example, water from Crystal Spring, with a relatively constant flow of 3.4 gpm, supplies part of the campgrounds maintained by the USFS and Little Medicine Lake cabins. Flow from Paynes Springs is used occasionally to provide water for campers and horses. No use rates were available for Paynes Springs.

The main use of water in the MLC is for private residences and USFS campgrounds. Water for the private residences is most likely supplied by ground water wells. The USFS has one ground water supply well that supplies a 30,000 gallon tank and supplies three campgrounds, a beach, and the USFS boat dock.

Specific water use rates in the MLC are not available but are expected to be negligible compared to the water in storage.

3.4 Projected Water Use

3.4.1 Non-Geothermal Use

Non-geothermal related water use in MLB would likely remain at the present rate.

3.4.2 Geothermal Use

The primary uses of ground water for the proposed TFGP will be during geothermal well drilling and electrical power production.

3.4.2.1 Water Consumption During Drilling

The proposed TFGP Plan of Operations for Development and Production (CEC, 1997c) anticipates drilling and completing 10 to 20 new production wells during the expected 50 year project life. An additional three to five injection wells will be required if poorly performing production wells can not be converted to injectors. These new wells are expected to take 45 to 90 days each to complete. Water consumption during drilling operations is expected to average 9,000 gpd, with up to 40,000 gpd used in lost circulation zones. Whenever possible, spent geothermal fluids from other wells will be utilized for drilling fluid make-up water.

According to the geothermal development drilling schedule reported by Thomas (1997), six wells will be drilled in the first year followed by five and two wells in the second and third year, respectively. Between the fourth and 50th year, 12 additional wells may be drilled. Using the water consumption values presented above and assuming 80 days to drilled a well with 10 days fighting lost circulation, the estimated water use for the 50 year drilling program will range from about 20.6 A-ft for the first year to 3.4 A-ft for years 4 through 50.

Two existing water wells in Arnica Sink (W-6ccbc and W-1dddd, Figure 13 and Table 6) within the MLB are the planned source of make-up water for drilling fluids. The ET corrected annualized average ground water recharge into MLN is estimated to be approximately 23,123 A-ft/yr (Table 7c). Given the drilling water consumption rates cited above, the projected drilling water usage will range from 0.089% to 0.015% of the annualized estimated local net recharge.

In practice, fewer than 25 new wells will probably be drilled and spent geothermal fluids from existing geothermal operations may be available for significant portions of the drilling fluid make-up waters.

3.4.2.2 Cooling Tower Water Losses

The planned TFGP power production process envisions a "closed-looped" scenario with approximately 83% of the produced geothermal fluids returned to the geothermal reservoir (Section 1.1 and 3.4.2.1). This section quantifies the amount of fluid being lost from the geothermal reservoir and discusses the significance of this fluid lost to the deep ground water system in the Modoc Plateau postulated as the source the geothermal fluids.

The current annualized estimated cooling tower losses for the proposed TFGP power plant are 502,660 lbs/hr (McClain, 1997). Using the conversion factors of 62.43 lbs/cu ft, 43,560 cu ft/A-ft, 8,760 hr/yr, and an availability factor of 0.95, the 502,660 lbs/hr cooling tower losses are 1,538 A-ft/yr. For comparison, the Newberry Baseline Hydrogeology Report estimated 1,580 A-ft/yr cooling tower losses for that power plant (Stroud and Brophy, 1994).

The material balance for the proposed TFGP power plant (CEC, 1997c, Appendix D) is based on the maximum evaporative condition, which occurs from August to October. These conditions are:

1. 50° F wet bulb humidity; and
2. 2,500 parts per million (ppm by wt) non-condensable gasses (NCGs), with 3.6 wt % H_2S in the NCG.

This analysis assumes an annualized extraction rate of 3,298,310 lbs/hr (10,625 A-ft/yr), with 574,197 lbs/hr (1,850 A-ft/yr) or approximately 17.4 % evaporative losses, resulting in an annualized geothermal fluid injection rate of 2,724,116 lbs/hr (8,775 A-ft/yr) or approximately 82.6 % of the geothermal fluids produced. The evaporative water loss derived from these data (Appendix D) yields an annual cooling tower loss of 1,850 A-ft/yr, which is a more conservative estimate than the estimated from the McClain (1997) data because it will use more water (i.e., 1,850 A-ft/yr versus 1,538 A-ft/yr).

The cooling tower evaporative loss is from the geothermal fluids interpreted to be derived from the deep, ground water system in the Modoc Plateau (Figure 11, and BLM et al., 1997). As such we will use the FRS water flow and a typical area recreational water use as a frame of reference for a consumptive use comparison.

3.4.2.2.1 Fall River Springs

The flow at the FRS is about 1.3 billion gpd or about 1.45 million A-ft/yr. The conservatively derived evaporative water loss from the geothermal reservoir of 1,850 A-ft/yr estimated water loss represents about 0.13 % of the FRS' discharge (Section 3.5).

3.4.2.2.2 Typical Area Recreational Use

For the purposes of this report, we compare the evaporative loss of water from the geothermal reservoir to typical ground water use by a golf course. In Deschutes County, Oregon where climatic conditions are expected to be similar to those in the MLH region, Stroud and Brophy (1994) report that a typical golf course uses 1 million gpd in the summertime. Gatley (1997) has indicated similar usage rates for a nine-hole golf course in Alturas, California located some 83 km (50 mi) from MLB (Figure 1). The 1,850 A-ft/yr estimated water loss from the geothermal reservoir represents about 1.65 million gpd or 1.65 times the daily summertime water consumption of a single golf course in the region.

Therefore, the annual consumptive use of water by the proposed TFGP on the deep ground water system in the Modoc Plateau is less than the annual water use of about three golf courses.

3.4.2.3 Geothermal Power Plant Production and Injection Rates

The preliminary material balance analysis (Appendix D) estimates that the proposed TFGP nominal 48 MW gross power plant will require 3,298,310 lbs/hr (10,625 A-ft/yr) water production rates to supply the electrical generators. The evaporative water losses have been calculated to be 574,630 lbs/hr (1,851 A-ft/yr), see Section 3.4.2.2. The remaining waters, 2,454,191 lbs/hr (7,906 A-ft/yr) hot water and 269,925 lbs/hr (870 A-ft/yr) steam condensate, will be reinjected back into the geothermal reservoir at a combined injection rate of 2,724,116 lbs/hr (8,775 A-ft/yr).

Large-scale fluid production from a geothermal reservoir could effect the existing hydraulic gradients and fluid flow patterns between the overlying, shallow ground water system and the deeper geothermal system. However, the following observations suggest that this potential effect should be insignificant:

1. There is under natural conditions about a 200 – 400 m pressure head differential between the top of shallow ground water system in the MLB area (HU #1) and the water in the TGHs (HU #3). This indicates a good confining layer between these two ground water systems (Figure 15).
2. There appears to be a good hydrothermal alteration seal of argillic alteration at the top of the geothermal reservoir (Section 2.4.3.1).
3. Approximately 83% of the geothermal fluid being withdrawn from the geothermal reservoir for electrical generation will be returned to the reservoir and used to maintain reservoir fluid pressures.
4. The geothermal system is believed to receive recharge from the deep ground water in the Modoc Plateau. This deep ground water system in the Modoc Plateau will also offset the cooling tower evaporation loss described in Section 3.4.2.2.

3.5 Shallow Ground Water Hydrological Conceptual Model

Available shallow ground water data for the MLH (HU # 1, Section 3.3.5 and Figure 11) suggest that it originates and flows radially outward from the MLB in all directions towards the Modoc Plateau regional ground water aquifer (Figure 14). Shallow ground water flow in the Modoc Plateau will occur in the Warren Basalts and in rocks from the Cedarville Series. Shallow ground water elevation data from Hotchkiss (1968) indicates that ground water flow is from the Tule Lake – Klamath Lake north of MLH, south to at least the Tionesta area.

Based on similar oxygen-18 isotopic values between FRS and waters at MLB, Rose et al. (1996) and Davisson (1997a) postulated that the source of the waters issuing from FRS, at a rate of 1.45 million A-ft/yr, must be from MLH some 55 km (33 mi) north of the springs (Plate 1, Section 3.3.8). The estimated average annual amount of ground water recharge non-corrected for ET (1) to the MLB is 41,621 A-ft/yr, and (2) to the MLHSA (Figure 16) is about 295,000 A-ft/yr (Table 7a).

The 41,621 A-ft/yr estimated average annual amount of ground water recharge non-corrected for ET represents a potential maximum amount of average annual ground water recharge into the MLB because it is not corrected for ET. As such, this recharge can account for only about 3% of what would be required for the ground water flow at the FRS. Considering the 295,000 A-ft/yr, potential maximum of average ground water recharge from the entire MLHSA (i.e., non-ET corrected), this flow rate would only account for 20% of the FRS outflow. Under this case, the isotopic signatures of the springs would be heavier than currently measured at FRS because precipitation at elevations lower than the MLB (i.e., heavier isotopic values) would constitute the majority of the water flow.

If the ET rate is included in the previous determinations, only 1.6% and 4.5% of the Fall River Spring outflow could be accounted for by flow from MLB and the MLHSA, respectively. The same isotopic arguments presented above would be valid under this case.

To account for the flow and isotopic signature of the FRS, recharge into the MLB would need to be about 35 times greater than the currently estimated, non-ET corrected, average annual potential recharge rate of 41,621 A-ft/yr. Accounting for ET, the recharge into the MLB would need to be about 63 times the currently estimated average annual precipitation rate to account for the FRS flow. A discussion of alternate sources of ground water for the FRS is presented below.

3.5.1 Alternate Sources of Ground Water for the Fall River Springs

The FRS, with an annualized gauged flow rate of approximately 1.3 billion gpd (Macdonald, 1966), is the largest of several high discharge springs in the Fall River and Pit River Valley systems. The six largest springs systems (including FRS) have aggregate annualized gauged flow rates in excess of 2 billion gpd (Rose et al., 1996). Neither the shallow ground water nor the geothermal reservoir fluids at MLH contribute any significant volume of waters to the FRS flow. The hydrologic balance for the MLHSA presented in Section 3.3.8 shows that the precipitation in the MLHSA can not account for more than about

1. 2% of the total water flow at FRS to be consistent with the FRS stable isotopic signature of the springs (Rose et al., 1996; Table 3); or,
2. 5% of the total water flow at FRS, but under this case, the FRS stable isotopic signature reported by Rose et al. (1996; Table 3) would not be maintained.

The reader is referred to the summary discussion in Section 3.5.

Mariner (1997b) reported that there is no evidence of any MLH geothermal reservoir fluid contribution to the waters at FRS. This is based on his analysis of delta deuterium isotopic values and chloride concentrations in the fluid chemistry from the FRS, hot springs in the Modoc Plateau, and the MLH geothermal reservoir (Table 3; BLM et al., 1995; 1997).

If the MLB and/or MLH are unable to supply the FRS discharge, what are other potential recharge sources? Six potential recharge areas for the FRS are suggested:

- Tule Lake – Klamath Lake Area;
- Southeast extension of the Fall River Graben;
- Northwest extension of the Fall River Graben;
- Pit River;
- Vulcan Lineament – Caribou Wilderness Area; and,
- Hat Creek Graben.

These potential source areas are discussed below.

3.5.1.1 Tule Lake – Klamath Lake Area

Macdonald (1966) suggested the possibility that ground waters from the Tule Lake – Klamath Lake Area, located some 92 km (55 mi) to the north of FRS, may be the source area for these springs (Figure 4a). This inference was based on ground water gradients in the area reported in an oral communication by the USGS in 1965. The authors of this report have contacted the USGS in Redding, California in order to locate the data on which that oral communication was based. No record of this 1965 data remains. However, Hotchkiss (1968) reported that ground water gradients in the Lava Beds National Monument area from about Tule Lake to Timber Mountain due east of Tionesta (Figure 7 and Plate 1), indicate that ground water flows south from Tule Lake to at least the Tionesta area. The current authors were also not able to identify any oxygen-18 and deuterium isotopic values for these waters flowing south from Tule Lake. This potential source area is also discussed in Sections 2.5, 3.2, 3.3.7, and 3.5

3.5.1.2 Southeast Extension of the Fall River Graben

The southeastern extension of the Fall River Graben (Figure 4a) follows a gentle topographic incline which peaks approximately 74 km (44 mi) to the southeast, in highlands of the Caribou Wilderness, east of Mt Lassen, between Lake Almanor and Eagle Lake (Figure 1). The Caribou Wilderness has an elevation of about 1,830 m (6,000 ft), and Lake Almanor and Eagle Lake occur at elevations of 1,370 m (4,494 ft) and 1,360 m (4,460 ft), respectively. There is a strong northwest-southeast structural feature, most likely a graben structure, that is coincidence with this referenced topographic incline. Essentially, the FRS occur at northwestern low point of this pronounced structural and topographic feature (Figures 4a and 4b).

Norris and Webb (1990) reported that the regional water table in the Fall River Valley and Pit River valley systems lies below the Pit River's channel. Thus, regional ground water flow from the southeast can potentially flow under the Pit River and issue at the FRS.

3.5.1.3 Northwest Extension of the Fall River Graben

The northwest extension of the Fall River Graben (Figures 4a and 4b) intersects the Vulcan Lineament that has elevations as high as about 1,830 m (6,000 ft). Springs and shallow ground water wells in and around this Vulcan Lineament and to the southwest within the Fall River Graben exhibit delta oxygen-18 and delta deuterium isotopic values that are either similar to or even isotopically lighter values than the FRS delta oxygen-18 and delta deuterium signature (Figures 12 and 20). These isotopic data suggest that there may be a source area for the FRS to the west of the MLB, in the region referred to as the Vulcan Lineament (see Sections 2.2 and 2.5). Ground water from the Vulcan Lineament, northwest of the FRS, would flow in a southeasterly direction down the FRS Graben to the FRS. If ground water flow was intercepted by the Giant Carter lava flow that occupies the eastern portion of the Fall River Valley Graben (Donnelly et al., 1991; Grose, 1996), then the voluminous ground water flow at FRS which "daylight" at the toe of this geological feature may be explained.

3.5.1.4 Pit River

Norris and Webb (1990) report that an important source of water to the FRS is the Pit River. These authors unfortunately do not provide any further elaboration.

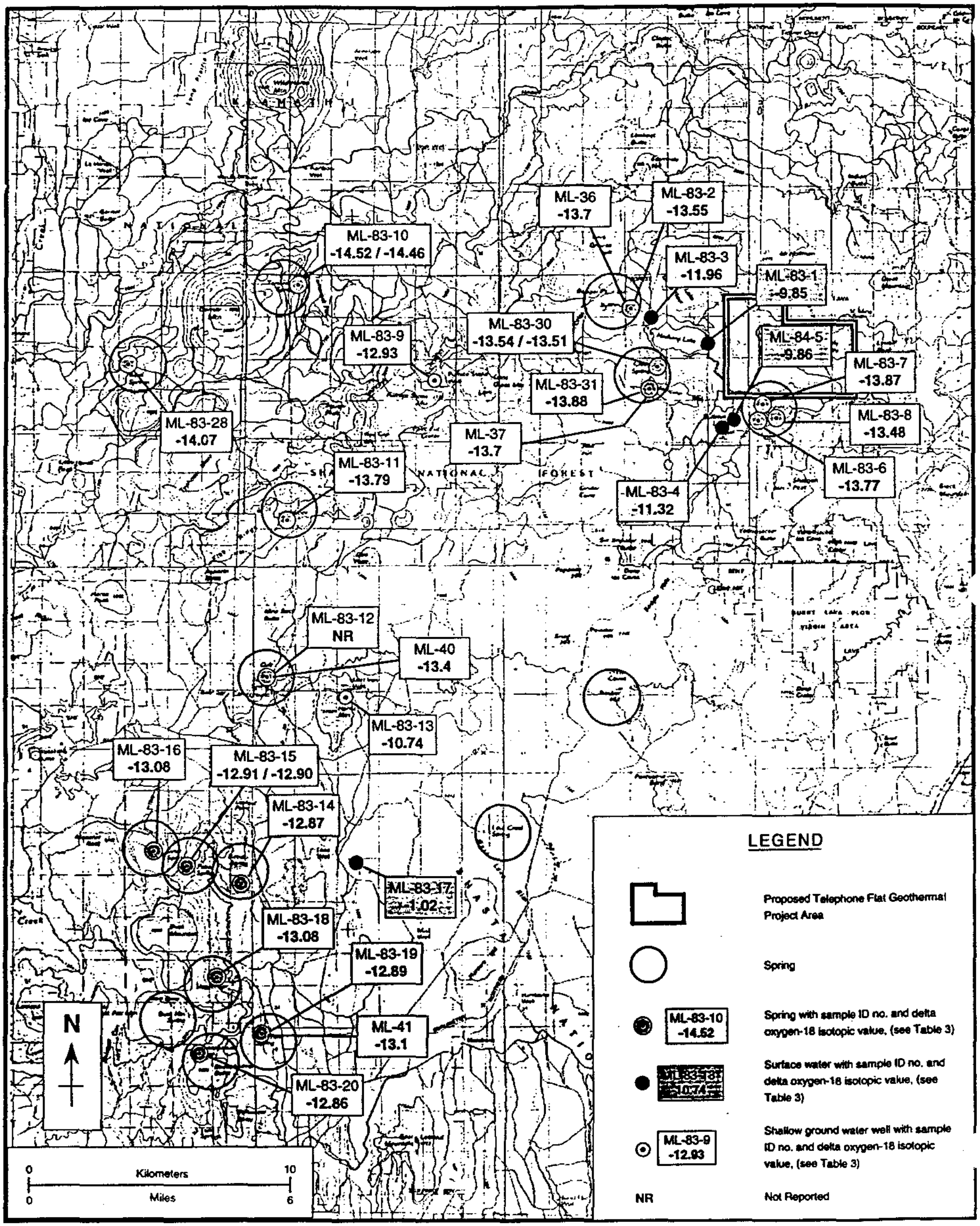


Figure 18. Selected Delta Oxygen-18 Isotopic Value for Springs, Surface Waters, and Shallow Ground Water Wells in the Medicine Lake Highlands Regional Study Area (after Cosens-Gallinatti, 1984)

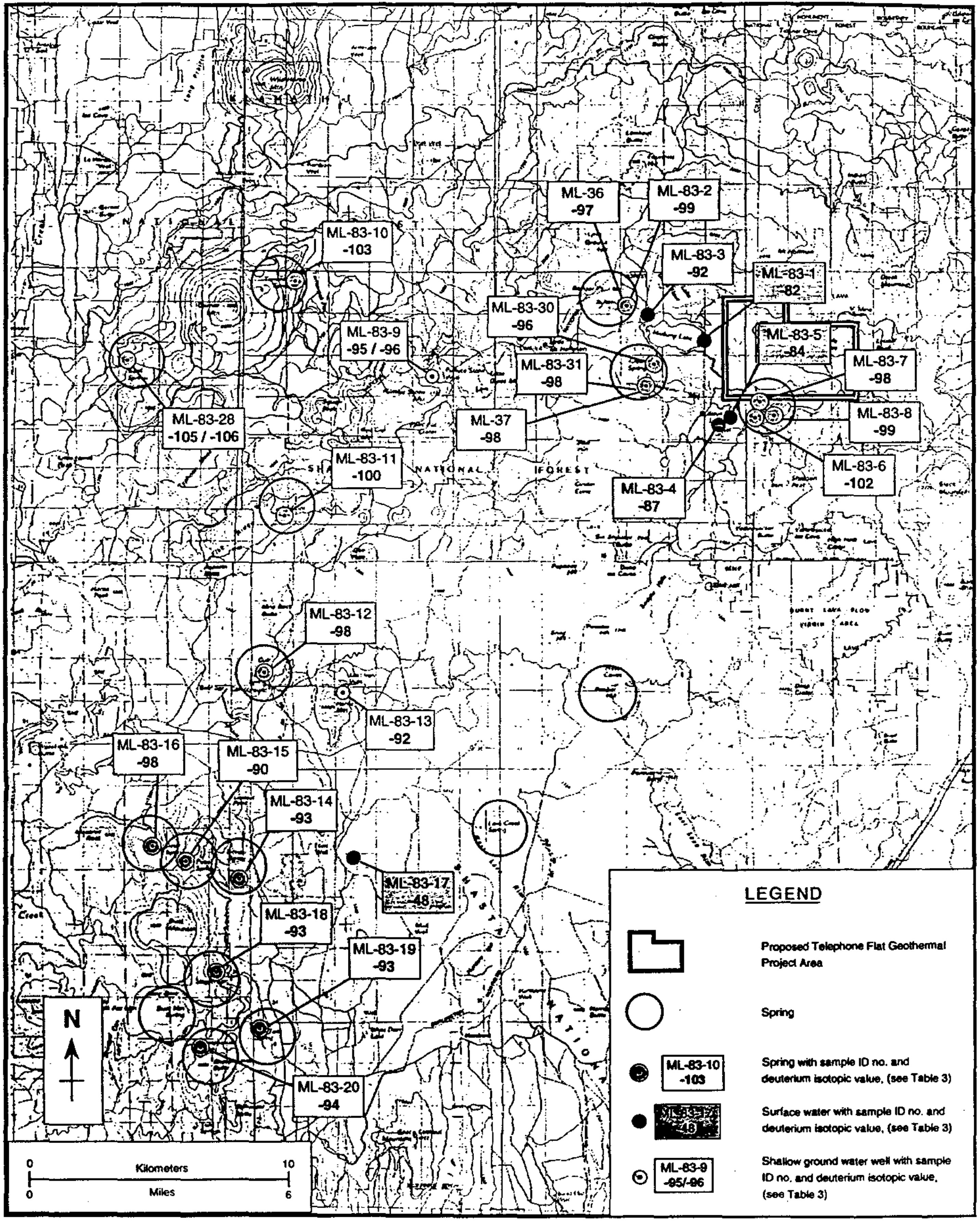


Figure 19. Selected Deuterium Isotopic Value for Springs, Surface Waters, and Shallow Ground Water Wells in the Medicine Lake Highlands Regional Study Area (after Cosens-Gallinatti, 1984)

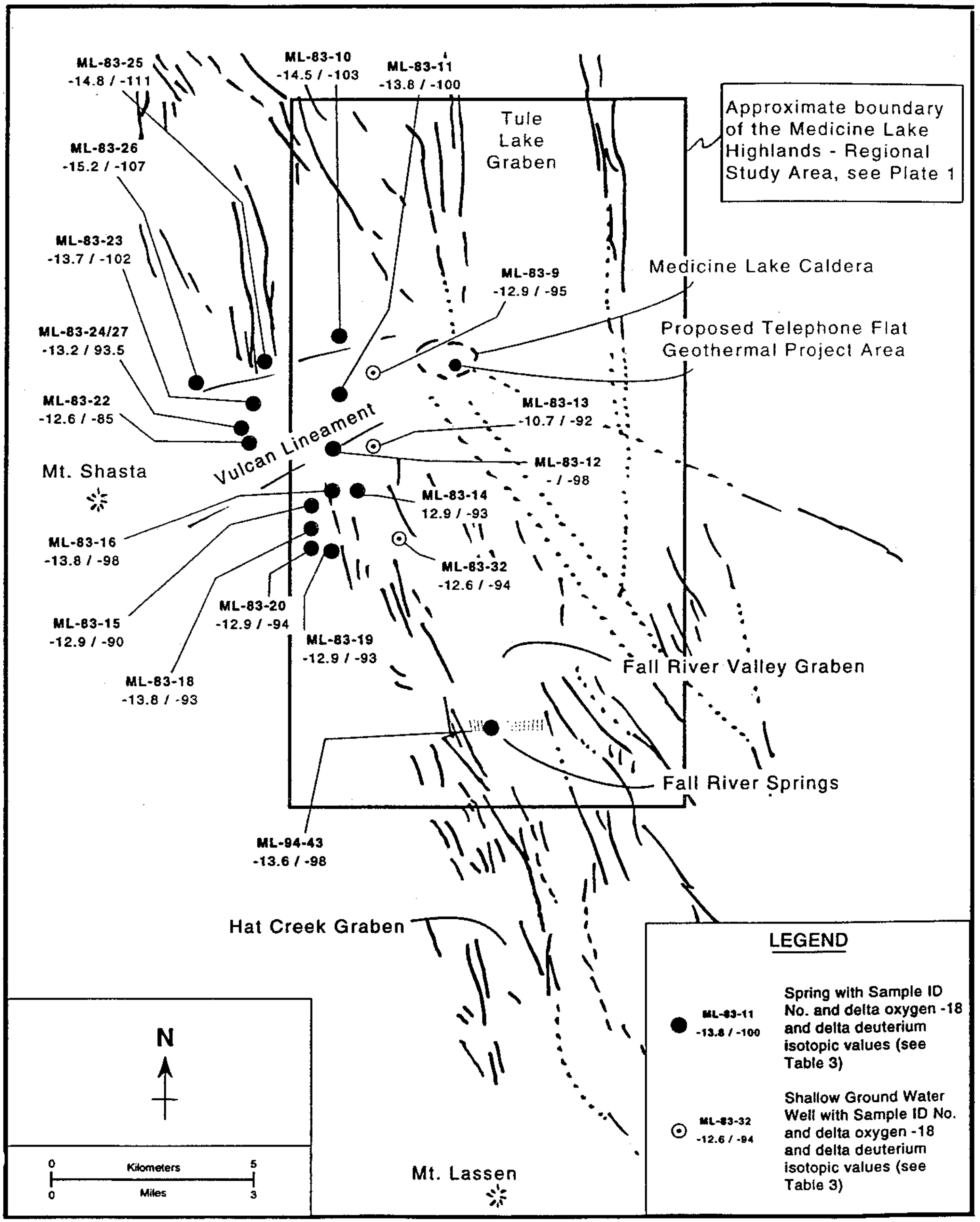


Figure 20. Delta Oxygen-18 and Deuterium Isotopic Values for Springs and Shallow Ground Water in the Vulcan Lineament and Fall River Valley Graben Areas

3.5.1.5 Vulcan Lineament – Caribou Wilderness Area

The FRS lie at the low point in the structural graben feature that intersects the Vulcan Lineament area to the northwest and the Caribou Wilderness area in the Mt. Lassen region to the southeast (Figures 1 and 4a). Ground water from both areas may flow down the topographic gradient towards the low point at the FRS. The delta oxygen-18 and delta deuterium isotopic values of the ground water flowing from the Vulcan Lineament northwest of the FRS are light enough to explain the FRS isotopic signatures (Figure 20). No comparable isotopic data were developed for ground waters that may be flowing from the Caribou Wilderness Area towards the FRS.

3.5.1.6 Hat Creek Graben

Rose et al (1996) report an extensive isotopic study of waters from springs in the Hat Creek Valley, a northwest-southeast trending graben offset to the west of the Fall River Valley Graben (Figures 4a, 4b, and 17). The eastern margin of the Hat Creek Graben is on strike with the western portions of the FRS (Figure 17). Additionally, the delta oxygen-18 and deuterium isotopic data from springs in the Hat Creek Valley are very similar to those from at FRS (Figure 17). The Hat Creek Valley springs also occur at similar elevations to the FRS, approximately 1,000 m-asl (3,280 ft asl). Norris and Webb (1990) cite indications that the regional ground water aquifer lies under the Pit River, without breaking the surface. These data suggest that the Hat Creek Valley and FRS may have common recharge areas.

3.6 Relationship Between Cooler Shallow Water Systems and Deeper Geothermal System

The shallow, cold ground water system is hydraulically isolated from the top of the deeper, hot geothermal system as indicated by about 200 – 400-m (about 650 - 1300 ft) of pressure head difference between them, based on the water level elevation data presented in Figures 14 and 15. This hydraulic isolation indicates the presence of an aquitard between the two systems. The separation of these two systems is most likely due to (1) lithology, the rocks within the subsurface of MLC, and (2) hydrothermal alteration of these rocks by the high temperature geothermal system (Figure 10). These determinations are consistent with the BLM et al. (1997) which reported that:

1. there are two distinct ground water systems (a) a shallow, cold ground water aquifer, and (b) the geothermal system; and,
2. the shallow ground water system is separated from the geothermal system by a relatively impermeable clay-rich ash flow tuff layer.

This separation of the shallow ground water system from the deeper geothermal system is further supported by the chemical and isotopic data that there is no evidence of any geothermal fluid component in the shallow ground water system at MLH.

The aquitards identified in Figure 15 undoubtedly contain faults and fractures which could allow some communication between the overlying, cool shallow ground water system and the underlying, hot geothermal system. However, the available data strongly suggests that any communication, if present, is (1) very local, and (2) very limited, with no appreciable influx of geothermal fluids into the overlying shallow ground water system. The latter is based upon the lack of either a chemical or isotopic geothermal signature on the surface water and shallow ground water of MLH (Section 3.3.3.1, Table 3, and Figure 12).

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APPENDIX A

APPENDIX A

Depth and Elevation of the 32°C (100°F) Isotherm for Intermediate Depth Temperature Gradient Holes and Geothermal Wells in Medicine Lake Highlands

Table A-1. Depth and Elevation of 32°C (100°F) Isotherm in the Medicine Lake Highlands Study Area

Temperature Gradient Hole[1]/ Geothermal Well[2]	Surface Elevation[4] (ft-asl/m-asl[3])	Elevation of 100°F (ft-asl/m-asl)
ML 56-3	6,800/2,073	5,300/1,616
ML 44-33	6,940/2,116	6,040/1,841
GMF 87-13	6,720/2,049	6,220/1,896
ML 84-17	6,960/2,122	5,860/1,787
ML 17-6	6,720/2,049	4,620/1,409
ML 75-6	6,600/2,012	4,750/1,448
ML 54-19	6,200/1,890	4,000/1,220
ML 65-26	6,230/1,899	4,430/1,351
ML 51-2	5,473/1,669	NE
ML 52-30	6,380/1,945	>4,380/>1,335
ML 36-28	6,700/2,043	5,050/1,540
ML 45-36	6,960/2,122	5,660/1,726
ML 29-1A	6,640/2,024	4,590/1,399
ML 28-32	7,240/2,207	5,590/1,704
ML 57-11	6,100/1,860	3,300/1,006
ML 57-13	6,140/1,872	3,490/1,064
ML 68-16	6,330/1,930	3,930/1,198
ML 62-21	6,590/2,009	5,290/1,613
ML 86-23	6,040/1,841	3,240/988
ML 18-34	5,860/1,787	2,560/780
ML 27-27	5,800/1,768	>2,800/>854
ML 14-23	6,560/2,000	4,210/1,284
GMF 68-8	6,991/2,131	<1,000/305
GMF 31-17	7,000/2,134	<2,000/610
GMF 17A-6	6,740/2,055	4,740/1,445
ML 1-81	6,400/1,951	NE
ML 2-81	5,640/1,720	NE

Notes:

[1] = Temperature gradient holes have the designation ML XX-XX
[2] = Geothermal wells have the designation GMF XX-XX
[3] = Feet above sea level/meters above sea level, based on USGS (1993)
[4] = Based on surface elevation from USGS McArthur and Tule Lake, California 1:100,000 scale topographic maps
NE = Not Encountered

APPENDIX B

APPENDIX B

Medicine Lake Basin Precipitation Data
(from California DWR, 1997)

SNOW DATA USE

The Medicine lake Highlands Snow Survey WEB page data requires the following explanation. The snow course work is funded by U.S. Bureau of Land Management and occurs annually on or about April 1. Other locations in this work have as many as 3 - 4 snowpack measurements, but only one exists for MLH.

The snow pack probe is calibrated such that one pound of weight corresponds to one inch of water equivalent. The depth, water content (W.C.), and density columns on the WEB page are related via this calibration, such that:

$$\text{W.C.} = 100\,\frac{\text{W.C.}}{\text{Depth}}\;.$$

There is also a continuously recording weather station in MLC, northeast of Medicine Lake, transmitting hourly temperature, wind and other data. This information is used to correct the measured snowpack data to the April 1 date, for annual comparison. The MLH weather station data is not included on the web page, so it is not possible to go from the W.C. column to the Adjusted (W.C.) column (Hart, 1997).

MEDICINE LAKE (32)

Elevation	6700'
River Basin	PIT R
Cooperator	DOUBLEHEAD R.D.
Aspect	SOUTHWEST
Exposure	OPEN MEADOW
April 1 Average	32.0"

Depth and water equivalent in inches. The *adjusted* value is the water content corrected to the first of the month, based on intervening precipitation or melt.

Slot	*Measured Date*	*Depth*	*W.C.*	*Dens*	*Adjusted*
193806	22-may-1938	62.6	31.6	50%	
194004	05-apr-1940	87.8	37.9	43%	36.2
194104	23-mar-1941	87.0	39.5	45%	45.4
194204	29-mar-1942	64.2	28.5	44%	28.5
194304	27-mar-1943	71.3	34.7	49%	36.2
194404	31-mar-1944	45.8	19.7	43%	19.7
194504	29-mar-1945	77.3	30.2	39%	30.2
194604	02-apr-1946	98.6	40.6	41%	40.6
194704	27-mar-1947	64.1	23.1	36%	26.1
194804	01-apr-1948	58.4	19.7	34%	19.7
194904	30-mar-1949	82.3	26.5	32%	26.5
195004	31-mar-1950	70.1	25.1	36%	25.1
195104	02-apr-1951	70.4	30.7	44%	30.7
195204	01-apr-1952	107.5	47.1	44%	47.1
195304	01-apr-1953	79.9	33.6	42%	33.6
195404	02-apr-1954	91.4	35.5	39%	35.5
195504	05-apr-1955	61.0	22.9	38%	22.8

195604	02-apr-1956	114.1	51.7	45%	51.7
195704	30-mar-1957	56.9	22.3	39%	23.0
195804	04-apr-1958	160.0	60.0	38%	53.3
195904	31-mar-1959	54.3	20.9	38%	20.9
196004	04-apr-1960	56.0	23.9	43%	23.9
196204	27-mar-1962	110.7	42.6	38%	42.6
196304	29-mar-1963	49.5	13.8	28%	17.1
196404	30-mar-1964	60.5	24.4	40%	24.4
196504	01-apr-1965	82.4	33.4	41%	33.4
196604	01-apr-1966	80.1	36.7	46%	36.7
196704	03-apr-1967	117.2	46.8	40%	46.7
196804	01-apr-1968	59.0	24.0	41%	24.0
196904	01-apr-1969	98.8	45.8	46%	45.8
197004	01-apr-1970	73.5	33.2	45%	33.2
197104	05-apr-1971	91.4	40.3	44%	40.3
197204	31-mar-1972	69.8	31.9	46%	31.9
197304	02-apr-1973	90.2	35.0	39%	35.0
197404	03-apr-1974	150.2	66.8	44%	65.6
197504	01-apr-1975	113.6	45.2	40%	45.2
197604	01-apr-1976	64.0	22.6	35%	22.6
197704	01-apr-1977	27.7	9.6	35%	9.6
197804	30-mar-1978	79.8	24.5	31%	24.5
197904	03-apr-1979	44.4	17.8	40%	17.8
198004	01-apr-1980	89.1	37.9	43%	37.9
198104	31-mar-1981	64.6	24.8	38%	24.8
198204	09-apr-1982	123.0	45.7	37%	
198304	01-apr-1983	159.8	65.0	41%	65.0
198404	02-apr-1984	79.0	34.7	44%	34.7
198504	29-mar-1985	73.2	24.9	34%	24.9
198604	31-mar-1986	67.3	31.8	47%	31.8

198704	31-mar-1987	59.6	24.3	41%	24.3
198804	01-apr-1988	27.4	11.7	43%	11.7
198904	31-mar-1989	87.1	34.3	39%	34.3
199004	30-mar-1990	35.7	17.7	50%	
199104	29-mar-1991	66.0	20.3	31%	
199204	31-mar-1992	41.5	17.2	41%	
199304	29-mar-1993	88.3	40.2	46%	
199404	31-mar-1994	45.1	20.1	45%	
199504	31-mar-1995	133.7	52.3	39%	
199604	30-mar-1996	59.6	26.6	45%	
199704	29-mar-1997	48.2	23.4	49%	

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APPENDIX C

APPENDIX C

Tule Lake Precipitation and Evapo-Transpiration Data from 1956 – 1981
(from Western Region Climate Center, 1997)

STATION :NUMBER 049053   ELEMENT : DAILY PRECIPITATION   QUANTITY :   MONTHLY SUM
STATION : TULELAKE
FROM DATA WITH UNITS: INCHES
a = 1 day missing, b = 2 days missing, c = 3 days, ..etc..,
z = 26 or more days missing, A = Accumulations present
ong-term means based on columns; thus, the monthly row may not
sum (or average) to the long-term annual value.

MAXIMUM ALLOWABLE NUMBER OF MISSING DAYS : 5

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
1956	2.17	2.21	0.33	0.74	1.72	1.26	0.31	0.11	0.03	2.05	0.30	1.07	12.30
1957	0.87	1.23	2.21	1.02	2.13	0.00	0.74	0.00	1.64	1.44	1.84	1.98	15.10
1958	1.41	1.98	0.93	0.75	1.78	1.69	1.27	1.05	0.83	0.20	1.01	0.59	13.49
1959	0.73	0.60	0.39	0.50	0.80	0.08	0.00	0.50	0.50	0.34	0.00	0.34	4.78
1960	0.57	2.11	1.61	0.53	2.10	0.00	0.05	0.05	0.44	0.28	1.59	1.86	11.19
1961	0.26	1.57	0.71	0.14	1.71	0.71	0.01	0.20	0.21	1.04	1.14	1.32	9.02
1962	1.17	1.45	1.06	0.19	1.73	0.50	0.00	0.11	0.34	5.04	0.63	1.19	13.41
1963	0.41	1.29	0.53	1.22	1.42	0.89	0.00	0.20	0.23	1.00	1.35	0.69	9.23
1964	1.48	0.11	0.83	0.56	0.64	3.42	0.69	0.06	0.02	0.22	1.12	5.87	15.00
1965	2.54	0.10	0.07	1.50	0.39	2.26	0.07	1.90	0.03	0.06	2.76	0.69	12.37
1966	0.60	0.23	0.36	0.29	0.58	0.69	0.21	0.51	0.35	0.16	3.74	1.49	9.21
1967	1.12	0.17	1.37	1.93	0.97	1.43	0.03	0.00	0.02	0.40	0.12	0.59	8.15
1968	0.43	1.05	0.29	0.10	1.85	1.42	0.00	1.98	0.16	0.74	1.50	2.00	11.52
1969	2.82	0.95	0.55	0.59	0.45	1.42	0.28	0.00	0.04	1.99	0.53	3.60	13.22
1970	2.45	0.40	1.57	0.39	0.42	0.58	0.00	0.03	0.18	0.74	2.30	1.16	10.22
1971	0.61	0.40	2.18	1.21	1.63	1.01	0.15	0.02	0.75	0.81	0.92	1.43	11.12
1972	1.85	1.20	1.98	0.51	0.60	0.21	0.00	0.07	0.71	1.52	1.01	0.90	10.56
1973	0.87	1.19	0.00z	0.09	0.91	0.00	0.00	0.19	0.67	0.00z	3.30	0.00z	7.22
1974	0.35	0.64	1.45	0.47	0.13	0.01	0.89	0.28	0.00	0.86	0.18	1.35	6.61
1975	1.16	1.85	0.82	0.67	0.11	0.68	0.89	0.66	0.63	1.76	0.41	0.88	10.56
1976	0.62	0.82a	0.67a	0.30	0.13	0.98	0.28	4.30	0.11	0.23	0.23	0.12	8.79
1977	0.86	0.36	0.50	0.02	2.48	1.12	0.25	0.70	1.83	0.34	1.08	2.87	12.41
1978	1.38	0.50	2.18	3.26	0.40a	0.53	0.00	0.22	0.26	0.04	0.94	0.49	10.20
1979	1.20	1.55	0.65	0.65	0.44	0.14	0.02	0.97	0.26	2.89	3.03	0.60	12.40
1980	2.18	1.98	0.90	0.70	0.79	1.05	0.15	0.03	0.43	0.60	0.48	0.91	10.20
1981	0.93	1.77	1.70	1.17	1.47	0.24	0.00	0.00	0.86	1.40	2.64	3.29	15.47
MEAN	1.19	1.07	1.03	0.75	1.07	0.86	0.24	0.54	0.45	1.05	1.31	1.49	11.06
S.D.	0.73	0.68	0.66	0.69	0.72	0.79	0.35	0.94	0.47	1.11	1.05	1.27	2.59
SKEW	0.79	0.12	0.52	2.06	0.31	1.37	1.55	2.80	1.59	2.06	0.82	1.92	-0.33
MAX	2.82	2.21	2.21	3.26	2.48	3.42	1.27	4.30	1.83	5.04	3.74	5.87	15.47
MIN	0.26	0.10	0.07	0.02	0.11	0.00	0.00	0.00	0.00	0.04	0.00	0.12	4.78
YRS	26	26	25	26	26	26	26	26	26	25	26	25	25

```
STATION NUMBER 049053   ELEMENT : EVAPORATION                 QUANTITY :        MONTHLY SUM
STATION : TULELAKE
FROM DATA WITH UNITS: INCHES
a = 1 day missing, b = 2 days missing, c = 3 days, ..etc..,
z = 26 or more days missing, A = Accumulations present
Long-term means based on columns; thus, the monthly row may not
 sum (or average) to the long-term annual value.

MAXIMUM ALLOWABLE NUMBER OF MISSING DAYS :  5

YEAR     JAN      FEB      MAR      APR      MAY      JUN      JUL      AUG      SEP      OCT      NOV      DEC       ANN
1956    0.00z    0.00z    0.00z    0.91y    6.22     7.26a    8.07     6.84     5.21     2.66c    0.00z    0.00z    36.26f
1957    0.00z    0.00z    0.00z    0.00z    1.70x    9.44    10.31     9.33     6.52     2.18a    0.00z    0.00z    37.78g
1958    0.00z    0.00z    0.00z    4.25j    8.32     7.49a    9.32     9.52     6.40     4.57     0.00z    0.00z    45.62f
1959    0.00z    0.00z    0.00z    1.20w    6.75    10.03    10.98     8.86     6.57a    3.19o    0.00z    0.00z    43.18g
1960    0.00z    0.00z    0.76y    4.62     6.32     9.78    10.13     8.88     7.27a    4.11     0.78u    0.00z    51.11e
1961    0.00z    0.00z    0.00z    4.52g    6.76     8.88     9.64     8.05     7.37     0.24z    0.00z    0.00z    40.70g
1962    0.00z    0.00z    0.00z    2.84p    5.43e    8.64d    4.65o    7.55b    6.10a    2.22b    0.00z    0.00z    29.94g
1963    0.00z    0.00z    0.00z    2.71c    6.65b    8.16     9.86     8.43     6.80     3.66     0.00z    0.00z    46.27e
1964    0.00z    0.00z    0.00z    2.48p    7.44     6.81     9.51     8.95     7.10     4.16     0.49r    0.00z    43.97f
1965    0.00z    0.00z    1.97p    4.78     7.96     7.38     8.81     7.30     6.76     4.07a    0.79s    0.00z    47.06e
1966    0.00z    0.00z    0.00z    2.84q    8.40     7.64     9.38     8.76     6.43     3.69     0.41u    0.00z    44.30f
1967    0.00z    0.00z    0.28x    2.62a    7.44     7.58a    9.64     9.05     7.10     3.33     1.06p    0.00z    46.76e
1968    0.00z    0.00z    0.00z    6.01a    6.80a    8.41b   10.37     7.07     6.61     3.53     0.13z    0.00z    48.80e
1969    0.00z    0.00z    0.00z    2.90n    9.32     7.10a    9.57     9.61     8.41     2.17j    0.00z    0.00z    44.01g
1970    0.00z    0.00z    0.00z    0.72x    8.01a    7.07b    9.88     8.83a    6.53     0.00z    0.00z    0.00z    40.32g
1971    0.00z    0.00z    0.00z    4.42m    6.57     6.90     9.22     9.45     8.21     4.08     0.00z    0.00z    48.85e
1972    0.00z    0.00z    1.79q    5.21     7.98     9.12    10.10     9.31     5.98     3.37d    0.00z    0.00z    51.07e
1973    0.00z    0.00z    0.00z    6.10a    8.25     9.00     9.92     9.42     7.86a    0.00z    0.00z    0.00z    50.55f
1974    0.00z    0.00z    0.00z    3.53r    7.70a    9.35     8.47     8.66     7.65     3.31j    0.00z    0.00z    42.03g
1975    0.00z    0.00z    0.00z    1.26u    9.24     9.28     9.31     8.35     6.77a    1.71r    0.00z    0.00z    42.95g
1976    0.00z    0.00z    0.00z    0.00z    9.63     8.31a    8.66     6.32     7.76     3.15k    0.00z    0.00z    40.68g
1977    0.00z    0.00z    0.00z    0.00z    0.00z    8.82a    9.19     8.90     5.49     3.33     0.00z    0.00z    35.73g
1978    0.00z    0.00z    0.00z    0.00z    7.66a    8.74     9.32     8.02     7.16a    0.00z    0.00z    0.00z    40.90g
1979    0.00z    0.00z    0.00z    0.00z    0.00z   10.07     0.00z    0.00z    7.27     0.00z    0.00z    0.00z    17.34j
1980    0.00z    0.00z    0.00z    2.76r    7.14     7.62     9.27     9.39     0.00z    0.00z    0.00z    0.00z    33.42h
1981    0.00z    0.00z    0.00z    0.00z    0.00z    9.14     9.49     9.66     6.45     0.69y    0.00z    0.00z    34.74h


MEAN     0.00     0.00     0.00     4.56     7.55     8.39     9.52     8.59     6.87     3.50     0.00     0.00      0.00
S.D.     0.00     0.00     0.00     1.32     1.08     1.01     0.64     0.93     0.77     0.73     0.00     0.00      0.00
SKEW     0.00     0.00     0.00    -0.44     0.18     0.00    -0.07    -0.95    -0.03    -0.59     0.00     0.00      0.00
MAX  -9999.00-9999.00-9999.00     6.10     9.63    10.07    10.98     9.66     8.41     4.57-9999.00-9999.00  -9999.00
MIN   9999.00 9999.00 9999.00     2.62     5.43     6.81     8.07     6.32     5.21     2.18 9999.00 9999.00   9999.00
YRS        0        0        0       6       22       26       24       25       25       14        0        0         0
```

APPENDIX D

APPENDIX D

Stream No.	1	2	3	4	5	6	7	8	9	10
Service	Geothermal Fluid	High Press Steam	Liquid to LP Flash	LP Turbine Steam	Liquid to Injection	HP Turbine Steam	Gland Steam	Motive Steam	Exhaust Steam	1st Jet Inlet
Phase	L	V	L	V	L	V	V	V	2P	V
Pressure, psia	115	115	115	25	200	100	100	100	1.12	1.07
Temperature, °F	338	338	338	242	242	332	332	332	105	81
Total Flow, Lb/h	3,300,000	581,450	2,718,550	264,359	2,454,191	573,032	1,768	6,650	839,159	3,589
Water, Lb/h	3,298,310	579,770	2,718,541	264,350	2,454,191	571,376	1,763	6,630	837,489	1,078
NCG, Lb/h	1,690	1,680	9	9	0	1,656	5	19	1,670	2,512
Stream No.	11	12	13	14	15	16	17	18	19	20
Service	2nd Jet Inlet	Vacuum Pump Inlet	Sulfur Float Inlet	Cooling Water Return (CWR)	Cooling Water Supply	E-101 CWR	E-102 CWR	E-103 CWR	Vacuum Pump CWR	Auxiliary CWR
Phase	V	V	V	L	L	L	L	L	L	L
Pressure, psia	2.4	5.5	12.4	25	40	30	25	25	12.4	25
Temperature, °F	81	81	92	93	71	94	89	91	92	81
Total Flow, Lb/h	2,847	2,655	2,558	34,813,716	34,239,540	32,761,325	239,013	184,624	12,987	1,041,687
Water, Lb/h	326	127	54	34,813,680	34,239,540	32,761,325	239,013	184,624	12,965	1,041,687
NCG, Lb/h	2,521	2,527	2,504	36	0	0	0	0	23	0
Stream No.	21	22	23	24	25					
Service	E-102 & E-103 Condensate	Condensate From E-101	Evaporation Loss	Condensate to Injection	Air Inleakage					
Phase	L	L	V	L	V					
Pressure, psia	2.4	1.07	11.4	25.0	11.4					
Temperature, °F	92	105	84	105	65					
Total Flow, Lb/h	7,584	857,009	576,679	269,941	867					
Water, Lb/h	7,581	856,957	574,195	269,925	0					
NCG, Lb/h	4	52	2,485	16.50	867					

NOMINAL 48 MW GROSS

59 °F Wet Bulb

512 ppm NCG in resource, 3.6% H_2S in NCG

CE HOLT CO.

CalEnergy Company, Inc.
Telephone Flat
PRELIMINARY PFD MATERIAL BALANCE

DWG NO.:	10171-1-32010	REV. C
DATE:	5/9/97	
JOB. NO.:	10171	
CHK.:		
APP.:		

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