PROJECT: GEOLOGY AND HYDROLOGY TECHNICAL REPORT ON THE COSO GEOTHERMAL STUDY AREA

IN SUPPORT OF: COSO GEOTHERMAL DEVELOPMENT ENVIRONMENTAL STATEMENT

U.S. Department of the Interior
Bureau of Land Management
Bakersfield District Office
800 Truxtun Avenue, Room 311
Bakersfield, CA 93301

Rockwell International

Atomics International Division
Air Monitoring Center
2421 West Hillcrest Drive
Newbury Park, California 91320

805/498-6771

April 1980

Contract No. YA-512-CT8-216

PROJECT: GEOLOGY AND HYDROLOGY TECHNICAL REPORT ON THE COSO GEOTHERMAL STUDY AREA

IN SUPPORT OF: COSO GEOTHERMAL DEVELOPMENT ENVIRONMENTAL STATEMENT

U.S. Department of the Interior
Bureau of Land Management
Bakersfield District Office
800 Truxtun Avenue, Room 311
Bakersfield, CA 93301

Rockwell International

Atomics International Division
Air Monitoring Center
2421 West Hillcrest Drive
Newbury Park, California 91320

805/498-6771

April 1980

Contract No. YA-512-CT8-216

FOREWORD

Geologic and hydrologic studies are closely related. Data from each is relevant to the other and topics in each aspect may relate to or reference topics in the other. The reports are therefore presented as two parts in one volume. Part I - Geology Technical Report, and Part II - Hydrology Technical Report. However, each part is discrete and also may stand alone.

ACKNOWLEDGEMENTS

This report was prepared by Harding-Lawson Associates (HLA). Hydro-Search, Inc. prepared surface water sections for the hydrology report. Major participants in the project are:

Project management:	Frank C. Kresse, HLA Richard B. Weiss, HLA
Geology:	Theodora O. Coffey, HLA
Hydrology:	Richard B. Weiss, HLA Mike Bergstrom, Hydro-Search John Sharpe, Hydro-Search

Throughout the project many organizations and individuals cooperated generously. We appreciate the contribution these people have made to this report. They include:

Phil Hennis, Rose Valley Ranch

Los Angeles Department of Water and Power - Jerry Gewe, Duane Georgeson and P. H. Lane

Glen Roquemore, University of Nevada

U.S. Geological Survey - Charles Bacon, Leonard Jorgenson, Dick Moyle, Alan Walter

U.S. Naval Weapons Center - Tom Dodson, Pierre St. Amand, Jim Whelan

PART I

GEOLOGY TECHNICAL REPORT

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

SECTION 1

INTRODUCTION

This report describes the geologic character of the Coso geothermal study area (CGSA). It includes discussion of geologic structure, lithology and seismicity; subsurface data derived from geophysical exploration techniques and drill holes; history of geothermal exploration; a description and model of the geothermal system and a section on the potential environmental and engineering geologic hazards of geothermal development.

The scope of work included a thorough review of all pertinent literature plus one week of field investigation. Numerous geothermal exploration surveys and published geologic and geophysical reports have provided much background and detailed information. The significant previous studies are cited in the "References Cited" section.

A review and update of geology, geophysics and geochemical data and interpreations for the Coso area will be published by the Journal of Geophysical Research by the end of 1979. It will include papers on:

a. volcanic history of the Coso area including revised radiometric age dates

b. distribution of rhyolites

c. Quaternary faulting

d. upper crustal structure

e. microseismicity

f. teleseismic residuals

g. gravity and aeromagnetics

h. electrical surveys including telluric survey

i. heat flow

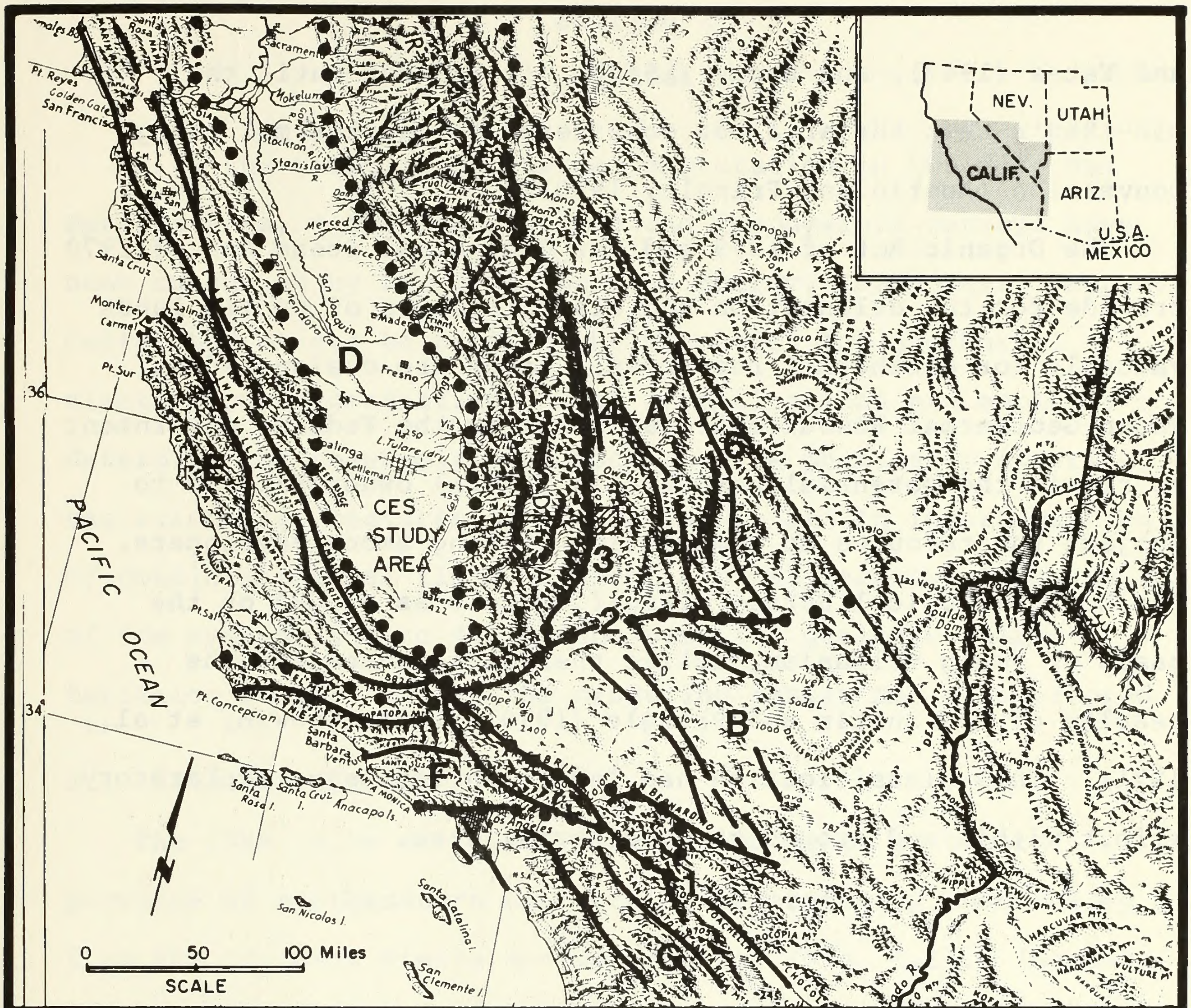
j. water chemistry

k. seismic attenuation

These papers may revise or alter some details of the interpretation of the geology discussed in this report and should be consulted for precise, current data when they are published.

The CGSA consists of roughly 126 square miles in the southern Coso Range and Rose Valley, California (Fig. 1.1). It is about 30 miles north of China Lake and immediately east of the Sierra Nevada. The main target geothermal areas lie within the U.S. Naval Weapons Center, hence any development of the field in this area would be subject to Navy regulation.

Thermal phenomena of the Coso area have been documented for many years (Fraser, et al. 1943; Waring, 1965). The springs" at Coso were used as a medicinal and holy place by early California Indians, and were also previously developed into resort operations and a mineral water bottling enterprise. The associated low-grade mercury deposits of the Devils Kitchen and Nicol Prospect were discovered in 1929 and subsequently studied by Wilson and Hendry (1940), Fraser, et al. (1943), Ross



EXPLANATION

Quaternary fault zone (after Jennings, 1975)

Physiographic province boundary

FAULT ZONES

1 San Andreas
2 Garlock
3 Sierra Nevada
4 Owens Valley
5 Panamint Valley
6 Death Valley - Furnace Creek

PHYSIOGRAPHIC PROVINCES

A Basin and Range
B Majave Desert
C Sierra Nevada
D Great Valley
E Coast Ranges
F Transverse Ranges
G Peninsular Ranges

Location Map Showing Physiographic Provinces and Major Faults

Figure 1.1

and Yates (1943), and Dupuy (1948). It was not until the mid-1960's that the area was considered for geothermal energy conversion (Austin and Pringle, 1970).

The Organic Act of 1879 and the Geothermal Steam Act of 1970 provide for the delineation and classification of public lands valuable for geothermal resources. Lands are designated as Known Geothermal Resource Areas (KGRA) by the Federal government to retain the potential resource in Federal ownership and to subject the resource to competitive bidding among developers. The U.S. Geological Survey classified Coso as a KGRA on the basis of young volcanism, active thermal features and the results of the Austin and Pringle (1970) study (Godwin, et al., 1971). This classification had led to an intensive exploratory effort within and around the geothermal area.

SECTION 2

GEOLOGY

With the onset of geothermal exploration in the Coso Hot Springs area, extensive geologic and geophysical surveys have been conducted by the Department of Energy, USGS, Naval Weapons Center and others to predict the potential for geothermal electric power generation. Such investigations are employed to determine the reservoir host rock and its physical properties, the structural features of the region to aid in interpretation of possible thermal fluid movement and the structural boundaries of the system, and to define the baseline geologic characteristics of the site so the producing system may be monitored.

2.1 REGIONAL GEOLOGY

The CGSA is in the western Basin and Range structural province of southeastern California, separated by Rose Valley from the adjacent Sierra Nevada province (Fig. 1.1). The CGSA is about 45 miles north of the east-west trending Garlock fault which forms the boundary between the Mojave Desert and Basin and Range provinces.

The Basin and Range province is characterized by northerly trending fault block mountains separated by a deep alluvial valley. It is an area of high heat flow and general east-west crustal extension. In California, the ranges are formed from many different types of rocks and range in age from Precambrian to Holocene (Jennings, 1977).

The oldest rocks exposed in the western Basin and Range province are complexly folded Precambrian, low to middle grade metasediments and metavolcanics. These are intruded by Jurassic to late Cretaceous stocks and plugs. The intrusives range in composition from gabbro to granite, with quartz-monzonite and granodiorite predominant. These small intrusive bodies are probably related to, or are satellites of, the Sierra Nevada batholith.

Late Cenozoic volcanics, ranging from rhyolite to basalt, unconformably overlie the intrusives and older rocks. These are interbedded with terrestrial clastic and lacustrine sedimentary deposits. This late Cenozoic volcanism includes the silicic volcanics of the Coso rhyolite dome field, which is immediately west of the Coso Hot Springs area.

Relief of the western Basin and Range is rugged, due primarily to movement on the northerly trending, high angle normal faults. However, a number of major Basin and Range faults such as the Panamint Valley and Death Valley - Furnace Creek fault zones east of the Coso KGRA and the Owens Valley to the north (Fig. 1.1) have features in common with the San Andreas fault, e.g. great length and consistent right-lateral offset. Several active right-lateral faults also occur within and south of the Coso Range (Roquemore, 1978b).

2.2 LOCAL GEOLOGY

Topography of the CGSA is typical of Basin and Range structure, with highest elevations in the north and a gradual southwest slope. Maximum elevations reach 5,947 feet in the northeast corner of the CGSA, along the eastern Coso Range. The minimum elevation of 2,800 feet is in Coso Basin. Most of the area is accessible with some portions being quite rugged.

Basement in the Coso Range consists of granitic to gabbroic plutons of probable late Mesozoic age, with numerous widespread pendants of older, possibly Paleozoic, metasedimentary and metavolcanic rocks. Atop these is a section of late Tertiary and Quaternary volcanic rocks ranging in composition from highly silicic rhyolite to olivine basalt. Quaternary unconsolidated rocks range in texture from coarse volcanic breccia and conglomerate to windblown fine sand, silt and ash, and to playa clay and silt. Late Cenozoic silicic volcanics include the domes, pyroclastic deposits and flows of the Coso rhyolite dome field. Highly dissected older alluvial units on the flanks of the range demonstrate that uplift is presently continuing. The distribution of these units and structure of the area is shown on the Geologic Map, Plate I-1.

Volcanology of the Coso Range has been studied in detail by Duffield and Bacon (1977), Duffield (1975), Lanphere, et al. (1975), Babcock (1977) and Duffield, et al. (in press). Evernden, et al. (1970) has studied the Coso intrusive rocks.

Mapping by Hulen (1978) has concentrated on the area around the Coso Hot Springs where lithologic units, including the complex relationship between metamorphic and intrusive rocks and surface hydrothermal alteration have been described in detail. Roquemore (1978a and 1978b) and St. Amand and Roquemore (1978) concentrated on structural interpretations of this tectonically active area.

2.2.1 Lithology

Descriptions of lithologic units exposed in the CGSA are summarized below and on the explanation sheet of Plate I-1.

Metamorphic Rocks--

Intermediate to mafic metamorphic rocks of diverse textures are the oldest exposed rocks in the CGSA. These rocks are of uncertain, but pre-Late Cretaceous age. They occur as isolated roof pendants, septa and xenoliths in granitic rocks in the northern part of the study area (Hulen, 1978). The metamorphics consist of predominantly biotite schist and gneiss, metadiorite and metadiabase, intermediate metavolcanics, amphibolite, chlorite schist, with minor locally associated rocks and hybrid rocks along granite intrusive contacts (Hulen, 1978). South of Devil's Kitchen, metamorphic rocks are intruded by quartz latite porphyry and felsite dikes and pods. In the south part, where the metamorphics form high topographic ridges, they occur as a relatively continuous, highly fractured mass.

Because of their complex relationships, granitic and metamorphic rocks are not differentiated on the geologic map. They are combined as basement rocks of the Coso Range (symbol "b") on Plate I-1.

Late Cretaceous (?) Granitic Rocks--

West of the Coso Hot Springs, metamorphic rocks in the Coso Range and intruded by a granitic stock with associated marginal plugs. These plugs are predominantly leucocratic biotite granite, the same as that commonly found at depth in CGEH No. 1 (Galbraith, 1978). Granitic rocks are, in turn, intruded by small dikes and pods of aplite, alaskite and quartz-potash feldspar pegmatite (Hulen, 1978).

The absolute age of granitic rocks in the Coso Range has not been determined. However, they are most probably related to the composite batholith of the Sierra Nevada, exposed a few miles to the west. Based on structural relations and a K-Ar age date of 86.7 $\pm$2.6 million years for a rock in the west central part of the range, the granites have been assigned a late Cretaceous age (Duffield, 1975).

Cenozoic Volcanic and Sedimentary Rocks--

Tertiary sedimentary and volcanic rocks of the Coso formation (symbols "C" and "P" on Plate I-1) crop out extensively northwest and to a lesser extent, north and northeast of the CGSA. They consist of fanglomerates, arkosic sandstones and siltstones, tuffaceous lacustrine beds and silicic tuffs. The formation ranges in age from 2.5 to at least 6 million years before present (b.p.) (Bacon, et al., 1979). Bedding generally strikes north to northeast and dips west. The Coso formation underlies the northwest part of Rose Valley and parts of Coso Basin (Stinson, 1977; and Hulen, 1978).

Volcanism in the Coso Range began about 5 million years ago, in the Pliocene, and has continued up to the very recent past. Volcanic rocks occur as (Duffield and Bacon, 1977):

1) late Pliocene intermediate to basic volcanic rocks, locally overlain by the associated fanglomerate of the Coso formation; and

2) Pleistocene basalt and rhyolite sequences, which include the domes, flows and unconsolidated debris of the Coso rhyolite dome field

The most recent volcanic activity in the Coso Range occurred as the eruption of the Sugarloaf Mountain rhyolite dome (44,000 ± 22,000 years b.p.) and the Volcano Peak basalt flow and cinder cone (39,000 ±33,000 years b.p.) (Bacon, et al., 1979).

The Pleistocene Coso silicic sequence consists of at least 38 separate extrusions of porphyritic rhyolite and associated pyroclastic deposits extending about 10 miles in a north-south direction (Bacon, et al., in press). Typically, the rhyolite domes consist of a dense, stony core of devitrified glass surrounded by an obsidian shell. This shell is enclosed by a pumaceous to perlitic carapace (Hulen, 1978). Domes are steep sided and from 130 to 1150 feet in height (Duffield and Bacon, 1977). Silicic rocks of this field include perlite, pumice, obsidian, rhyolite, and dacite.

There is limited spatial overlap between the rhyolite and basalt field, at the south end of the rhyolite sequence. The basalt field extends about a dozen miles farther south, mostly as basalt flows. Most of the flows are outside the area of the principal geothermal anomaly.

Hydrothermal Alteration--

Areas of present and past active thermal phenomena, particularly between Sugarloaf Mountain and the Coso Hot Springs, are associated with surficial hydrothermal alteration (Hulen, 1978). Surficial hydrothermal alteration includes:

1) alteration of host rocks or alluvium to varying proportions of clay-opal-alunite,
2) deposition of stockwork calcite veins and veinlets, locally associated with calcareous sinter, and
3) deposition of various hydrous sulfates, sulfides, native sulphur, cinnabar and hematite.

Austin and Pringle (1970) reported hydrothermal alteration in subsurface rocks of the clay-alunite-opal assemblages in Coso No. 1. Galbraith (1978) reported only weak argillic alteration with depth in CGEH No. 1.

Quaternary Alluvium and Landslide Deposits--

Surficial deposits mapped as alluvium (symbol "al" on Plate I-1) consist of unconsolidated, well drained, unsorted gravels and sands, and slope wash and playa deposits in closed depressions within the rhyolite dome field.

Older alluvium (symbol "oal" on Plate I-1) consists of unconsolidated to semiconsolidated, well drained, unsorted gravel and sands. These deposits have generally been uplifted and deeply dissected and have silica-cemented hardpan layer development at shallow depth. Older alluvium units have also been delineated on the basis of the detailed soils mapping, conducted as part of the ES study (see Soils Technical Report).

A rotational landslide has been noted on the slope north of Coso Hot Springs in the granitic and metamorphic basement assemblage (Plate I-1). The landslide consists of angular to subangular, jumbled blocks of basement rock and soil. Rockfalls may also be present along steep slopes in highly fractured bedrock along the southeastern portion of the CGSA.

2.2.2 Structure

The Coso Mountains are structurally complex. Regionally, they occur as a tectonic block on the westernmost border of the Basin and Range Province. This block is bounded by faults of the Owens Valley graben, which splay around the eastern and western sides of the Coso Mountains (Babcock, 1977). Smaller scale internal north-south trending graben structures are present throughout the range. Strike-slip faulting has complicated these internal horst and graben structures. Faulting occurs both as dip-slip and strike-slip movements, characterizing fault movements from both the bordering geomorphic provinces (Fig. 1.1). Some folding is apparent in the beds of the Coso formation in the northern range and in the White Hills near Airport Lake.

Faults--

Fault maps of the rhyolite dome field and vicinity have been produced by Duffield and Bacon (1977), St. Amand and Roquemore (1978), Roquemore (1977) and Hulen (1978). Dominant fault patterns are common to each but the number and location of individual faults differ in each one. The map by Duffield and Bacon (1977) and St. Amand and Roquemore (1978) are presented on Plates I-1 and I-2, respectively. Both are included to illustrate the diversity of the structural interpretations in this area.

The Coso Range is extensively faulted and contains several active fault systems. Dominant fault trends occur as older, high angle northwest to west-northwest and east-northeast striking faults of uncertain displacement and as younger high-angle north-northwest and north-northeast faults with both vertical and horizontal movement (Hulen, 1978). The high degree of faulting and shearing can be seen in the southeast part of the CGSA where basement rocks are pervasively fractured and occur as small blocks, about 3 feet on a side (Hulen, 1978).

The northwest trending Little Lake fault (the Charlie fault of Roquemore, 1978a) can be traced from Little Lake south through Indian Wells Valley to the Garlock fault (Roquemore, 1979, personal communication). It is part of the Sierra Nevada fault zone which also continues northward along the east slope of the Sierra Nevada. It exhibits indications of recent right-lateral movement, with almost no dip-slip component which is more typical of Pacific coastal faults (Roquemore, 1979, personal communication; see also Roquemore, in press).

The most conspicuous active fault in the CGSA is the Coso Hot Springs fault zone. It is a set of at least three right-stepping en echelon faults, each one kilometer long. The zone exists as a part of a larger en echelon left-stepping fault zone extending from Airport Lake to Haiwee Spring. Field evidence by Roquemore (1978a, 1979) suggests the Haiwee, Coso Hot Springs and Airport Lake faults are all part of the same, left-stepping en echelon fault system. As such, this fault zone mimics Sierra frontal fault characteristics, being left-stepping with movement dominantly normal with some right-lateral component (Roquemore, 1979, personal communication, see also Roquemore, in press).

Other possibly active faults in the CGSA are those related to active surface thermal features at Devil's Kitchen, Nicol Prospect, Wheeler Prospect and several other areas where either fumaroles or hydrothermally altered ground is present.

A highly dissected older fan on the west side of the Coso Range in Rose Valley is an indicator of uplift continuing along the west part of the range. Gravity data (Healy and Press, 1964) show that alluvium in this part of the valley abruptly deepens several thousand feet. This large displacement and the dissected fan suggest normal frontal faults bound the southwestern Coso Range.

Structural Constraints of the Geothermal System--

The geothermal system at Coso is structurally controlled. Fluid is "piped" along subsurface faults and other fractures which form secondary permeability in otherwise impermeable basement rocks. The older northwest to west-northwest and east-northeast faults are important in development of permeability. Crushed zones within these faults are brittle. When these faults are cut by younger faults, permeable zones are produced. This process of permeability development and resultant reservoirs of thermal fluid along intersecting fault zones has also been proposed for Roosevelt Hot Springs, Utah geothermal system (Nielson, et al., 1978).

The geothermal system is bounded on the east by the Coso Hot Springs fault where high heat flow values abruptly terminate. Boundaries on the north, south and west are not as clear.

Earlier estimates of the reservoir size were much greater due to previous structural interpretation of the geothermal reservoir area as a "caldera-like feature" (Duffield, 1975). It was envisioned as encompassing a 1500 square kilometer oval-shaped zone of late Cenozoic ring faulting (Duffield, 1975; Renner, et al., 1975). However, evidence to support this ring fault structure has been lacking and current structural interpretations omit this feature (Duffield and Bacon, 1977).

SECTION 3

GEOTHERMAL PROCESSES

The geothermal system in the CGSA consists of surface thermal manifestations, fractured crystalline rock containing hot fluids and a heat source. Presently the subsurface features of the geothermal resource at Coso are not well defined. Details of any geothermal system can be confirmed only through exploration drilling, well tests and fluid production. A basic discussion of the types of geothermal systems, the components of the Coso system that are known and exploratory drilling to date are discussed below.

3.1 TYPES OF GEOTHERMAL SYSTEMS

Three types of naturally occurring geothermal resources are commonly recognized: hydrothermal convection systems, hot dry rock resources and conduction dominated areas (White and Williams, 1975). The great majority of geothermal resources that are being developed throughout the world are hydrothermal convection systems. Hot dry rock and conduction dominated resources are currently not considered producible due to a lack of efficient heat extraction technology. Hydrothermal convection systems tend to develop where circulating fluids convect heat from depth to near surface. High temperature systems usually develop where a shallow heat source and favorable hydrologic conditions exist. Low temperature systems may develop without a recognizable shallow heat source in areas of thin crust.

3.2 BASIC MODEL OF A HYDROTHERMAL CONVECTION SYSTEM

A basic model of a hydrothermal convection system contains four features. They are: 1) a natural, usually magmatic, heat source; 2) a mass of permeable rock (reservoir); 3) a water supply sufficient to saturate the permeable rock; and 4) a cap-rock (Facca, 1973). The relationship of these features is depicted in Fig. 3.1 and described below.

A shallow magma chamber supplies heat to the reservoir by conduction. Large scale thermal convection cells, modified by faults and fractures, develop as the fluid in the fractures is heated. The convecting hydrothermal solutions circulate within the crystalline rock mass, depositing silica and/or carbonate near the top of the convection cell, thereby sealing the system. The reservoir is most likely bounded by faults, and may contain faults within its boundaries. The boundary faults may conduct meteoric, fluvial or lacustrine water to recharge the reservoir. The interior faults may conduct some of the hydrothermal solutions to the surface, thus producing surface geothermal manifestations. These may be warm or hot springs, geysers, steam, hydrothermal rock alteration, silica and travertine sinter, warm ground water, fumaroles and solfataras or hot soils. The lack of surface manifestations does not preclude the existence of a subsurface geothermal reservoir, and

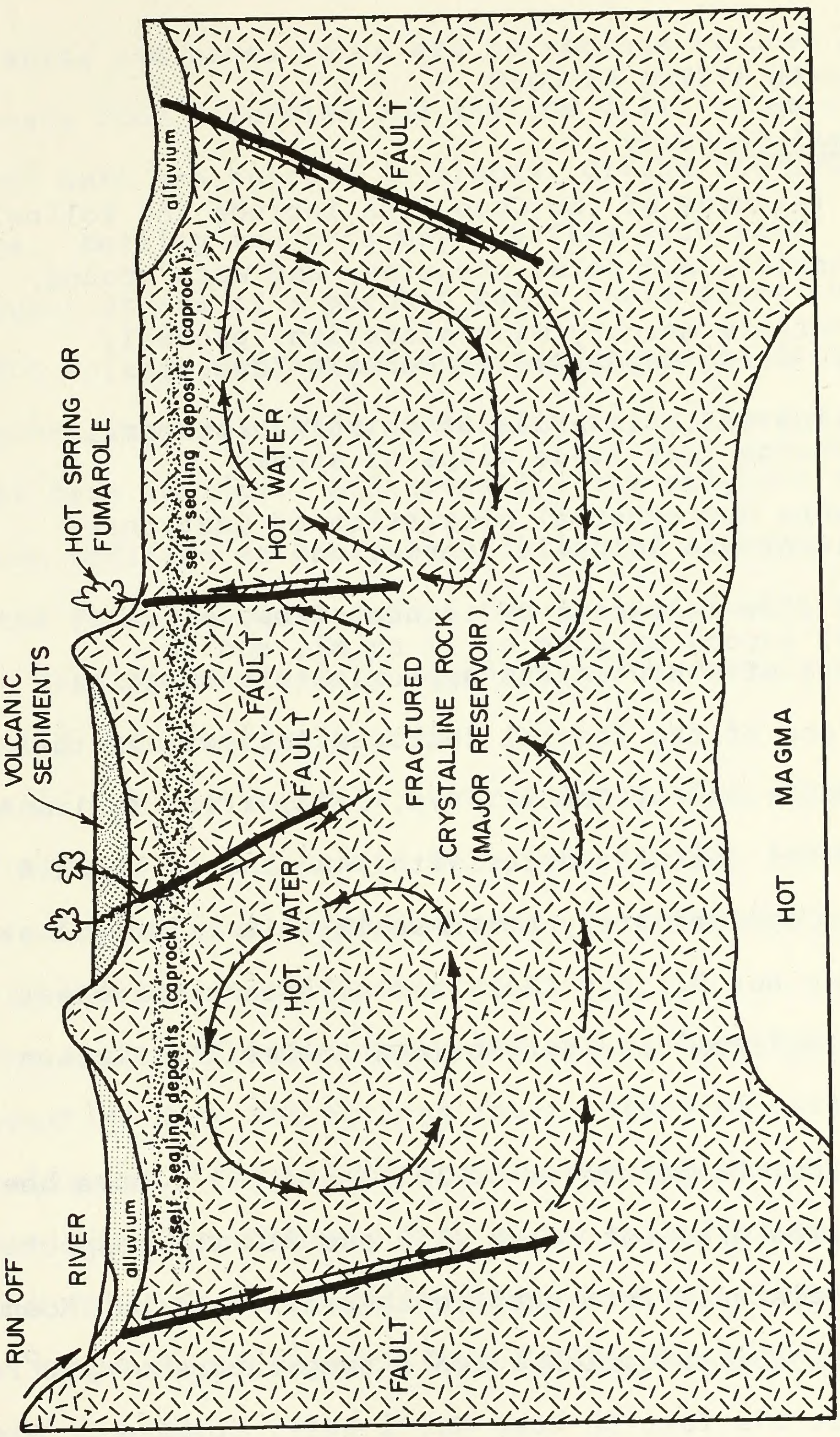


Figure 3.1 Schematic diagram of a hydrothermal reservoir (modified from Meidav and Sanyal, 1976)

surface manifestations do not imply the existence of an exploitable resource.

3.3 GEOTHERMAL SYSTEM AT COSO

3.3.1 Thermal Features

Thermal features of the Coso area include the following:

- Fumaroles, mud pots, steaming, and warm ground,
- Quaternary mercury mineralization, probably still being deposited at certain fumaroles,
- Shallow wells in areas of no surface thermal discharge that issue wisps of steam,
- Intense hydrothermal alteration of Quaternary sediment and volcanic debris, and
- Heat flow in excess of 10 heat flow units (HFU) across an area of 17 sq mi, and in excess of 5 HFU across approximately 32 sq mi

All but one of the thermal features fall within the zone of 10 HFU, as described by Combs (1975, 1976) (Fig. 4.1). At a minimum, thermal features occur within a zone of about 6 or 7 sq mi, elongated approximately north-south on a principal axis along the Coso Hot Springs fault and northeast-southwest on a secondary axis, from Coso Hot Springs to Devil's Kitchen (Plate I-1).

In addition, temperatures of 102°F and 199°F have been found in shallow gradient holes (150 and 312 ft, respectively) at over 1 mi distance from surface thermal features (Koenig, 1978, personal communication); and a temperature of 288°F was encountered at 375 feet in Coso No. 1 hole, drilled in the principal fumarole zone at Coso Hot Springs (Austin and Pringle, 1970).

Despite its name, there are no springs at Coso Hot Springs. Condensate from fumaroles and shallow drill holes collects and runs off onto the surface in places, giving the appearance of springs. Boiling mud pots may overflow with water after infrequent storms or a perched water table along the fault at Coso Hot Springs may have discharged at the surface at infrequent intervals after unusually rainy seasons. But these are not true springs. Additionally, the original thermal regime has been modified severely by drilling of numerous shallow holes into the fumarole bank at Coso Hot Springs during periods of resort development; and by excavation for mercury at several fumaroles and alteration zones.

Fumaroles are found at several localities across a zone two miles wide (E-W) and over a mile long (N-S). Several of these align on a northeast trending zone, corresponding at least in part to the Coso Hot Springs fault.

The most well known fumaroles are at Coso Hot Springs, where the youthful Coso Hot Springs fault, trending north-northeast, cuts alluvium. Fumaroles, boiling mud and steaming ground are present for approximately 1 mi along this feature. Underflow of thermal fluid in the shallow subsurface has elevated ground water temperatures beneath Coso Valley for several hundred feet east of the fault.

On snow-cover photographs, this entire zone along the Coso Hot Springs fault appeared snow-free, along with several near-circular, smaller points aligned at a small angle to the fault (Koenig, et al., 1972). These may represent a second fracture, perhaps not as young as the main fault, nor cutting the surface, along which leakage to the surface is discontinuous (Koenig, et al., 1972). Additionally, there are two small areas of steaming ground and hydrothermal clays, at the base of a steep hillside less than 1/2 mi west of Coso Hot Springs. These are on prominent northwest-trending faults. One and one-half mi south of Coso Hot Springs, steaming ground is found on a NNE-trending fault cutting Quaternary alluvium.

The Nicol mercury prospect contains small fumaroles and numerous steaming mine adits, drill holes and pits, in an area of intense hydrothermal alteration of rock and alluvium. Devil's Kitchen is another area of intense hydrothermal alteration, fumaroles, steaming ground, one notable boiling pool of steam condensate, and numerous drill holes and pits excavated for mercury. Fumarole discharge may still be depositing mercury.

One-half mile northwest of Devil's Kitchen, in a moat between a rhyolite dome and its surrounding tuff ring, is a small pit excavated for mercury, from which wisps of steam are sometimes emitted.

There are patches of hydrothermally altered ground on the summit of Sugarloaf Mountain. The perlitic rhyolite is such an effective insulator that although temperatures of 190°F are encountered 6 feet below the surface, no thermal anomaly is detectable at the surface (Koenig, 1978, personal communication). On the western flank of Sugarloaf, a series of shallow drill holes in altered ground produce wisps of low pressure steam. No surface thermal discharges existed prior to this drilling.

With the exception of Sugarloaf Mountain and two perlitic domes south and northwest of the Devil's Kitchen, no thermal features are known at any other of the 38 volcanic domes. Many of these domes lie outside of the 5 HFU heat flow anomaly as presently defined by drilling (Combs, 1975, 1976).

No thermal features are observed in association with the youngest basaltic cinder cones and flows, despite their equivalence in age to the rhyolite domes. The few heat flow holes drilled near or within the Quaternary basalt field have heat flow values of about 2.5 to 3 HFU.

3.3.2 Geothermal Reservoir and Fluid at Coso

The extent, permeability or exact bounds of the geothermal reservoir have not yet been defined. However, it is known that the geothermal reservoir rocks are fractured Mesozoic granitic basement rocks of the southern Coso Range. It is envisioned as a boiling water table system (Galbraith, 1978, pp. 22-25). Based on currently determined ground and water level elevations the top of the reservoir at about 3660 feet (see Hydrology Section 3.4.1). The depth of the fluid circulation is not known.

Primary porosity of reservoir rocks is nil with secondary fracture porosity developed. Fracture porosity will vary widely from place to place, depending on the size and openness of fractures. Based on the known hydraulic properties of similar reservoirs, porosity of the Coso geothermal fluid bearing rocks probably varies from 3 to 5 percent (see Appendix B, ES Chapter 1 for discussion). Direction of thermal water flow, storage and the extent of the reservoir is structurally controlled.

Fractures in basement rock occur as joints, cleavage planes, young fault zones and shatter zones at major fault intersections. Dominant fracture trends are north-northeast, east-northeast and west-northwest. Intersections of north-northeast and east-northeast faults appear to control major thermal discharges at Coso Hot Springs, Devil's Kitchen and the Nicol Prospect.

Geothermal fluid is sodium chloride water with total dissolved solids of around 5,000 to 6,000 mg/l. Localized steam caps above the thermal water table may be present in fumarole areas (Austin and Pringle, 1970). Appendix C2 of the Hydrology Report gives typical geothermal water analyses from the two exploration wells, Coso No. 1 and CGEH-1. Maximum equilibrium reservoir temperatures estimated by Fournier, et al. (1978) from water chemistry data are 240°C to 275°. Maximum observed temperature in CGEH-1 was 195°C (382°F) at 1900-foot depth along a fracture zone (Galbraith, 1978).

The heat source at Coso is presumed to be a shallow, silicic intrusion associated with young, rhyolitic volcanism. To identify this heat source, Combs and Jarzabek (1977) conducted a teleseismic survey across the Coso geothermal area. A large mine blast about 35 km east of the hot springs area was used as a source of waves which were recorded on seismographs 100 km from the shot point. The attenuation of the seismic waves suggests the existence of a localized body of low velocity rock at depth, possibly a magma chamber in the area immediately north of Airport Lake.

Based on a reversed refraction line and local seismicity, Weaver and Walter (in press) found no evidence for anomalous material at depths less than 8 to 10 km. Rosenberg, et al. (in press) outlined a low velocity zone centered a couple of kilometers southeast of Devil's Kitchen. The zone is between 5 and 20 km deep and 5 to 10 km in diameter, becoming elongated with depth to the north-northeast and south-southwest. The cause of the low velocity is not clear. It may be due to the presence of a melt or to the effects of the Coso Hot Springs fault system.

3.3.3 Geothermal Exploration Drilling

The first exploratory drill hole, Coso No. 1, was drilled into the Coso Hot Springs fault in an area of active thermal features (Austin and Pringle, 1970). It is a 375 ft, 7-inch-diameter well with a 4-inch slotted liner. It penetrates approximately 200 feet of alluvium and fault gouge above 175 feet of granitic bedrock. During flow tests, 40 gpm of high temperature brine was produced for short periods of time.

Austin and Pringle (1970) concluded that the recharge rate to Coso No. 1 is insufficient to maintain production. They suggest deeper and/or larger diameter wells for production in this area. However, Federal regulations bar this part of the Coso Hot Springs fault, along with the entire Coso Hot Springs National Historic Site, from any surface disturbance.

The first deep exploratory hole, CGEH-1, was completed in December 1977 to a depth of 4,845 ft. This hole was the second of two holes attempted; the first, an experimental hole, utilizing casing less than 4 inches in diameter, BDSH No. 1, was abandoned in May 1977 at 1,350 ft due to technical problems in drilling.

The CGEH-1 drill site is located in a closed valley about 2 mi west of the Coso Hot Springs (Plate II-1). The site is bounded by four rhyolite domes to the west and south and high granitic ridges to the east and north. The site is roughly at the center of the 10 HFU contour, as defined by Combs (1975, 1976).

CGEH-1 encountered predominantly metamorphic rocks to 1,000 ft and alternating zones of metamorphic and granitic rocks to its total depth (Galbraith, 1978). Highest temperature in the well (382°F) was encountered in a fracture zone at 1,900 ft (Galbraith, 1978). Only weak hydrothermal alteration was observed in the drill cuttings (Galbraith, 1978). The well was cased and cemented to 3,500 ft. Table 3.1 presents well description data.

Lost fluid circulation and hole deviation from vertical were recurrent problems during drilling. Fig. 3.2 is a schematic block diagram showing a three-dimensional view of the hole and intersecting fault zones. Largest mud losses occurred at 1,900 ft, 2,700 ft, 3,500 ft and at the bottom of the hole (Fig. 3.3). The large mud losses which occurred directly below the casing (at 3,500 ft) and at the bottom of the hole render these zones unlikely for production due to severe formation clogging.

Electrical, natural gamma ray, neutron porosity, acoustic and caliper logs were run in the hole to indicate rock types and to identify fracture zones (Galbraith, 1978). Temperature logs were run at intervals during and after the completion of the well. These logs indicate zones of maximum heat flux. Five representative temperature logs are shown on Fig. 3.3. Zones of high mud loss which indicate fractures, are also shown on this figure. Convective heat flow and temperatures greater than 350°F occur only along the open fracture system encountered at 1,850 to 2,775 ft. Decreasing temperature below 3,000 ft, impiles flow of geothermal fluids is structurally controlled in this part of the system. In this hole, only a few fracture zones are present which transmit geothermal fluids and there is no clear evidence of a large fractured reservoir.

Table 3.1 CGEH NO. 1 WELL DATA

Location: NW 1/4, Sec. 6, T22N, R39E

Surface Elevation: 4,360 ft

Depths Measured from: Kelly Bushing (21.6 ft above surface grade)

Total Depth: 4,845 ft

Main Hole Diameter: 7 inches

Completion: 7-inch casing to 3,507 ft,
open 8-3/4 inch hole to 4,845 ft

Date of flow tests: 11/2/77, 12/1/77

Observed flow rate: No significant flows after initial tests. Severe well bore skin damage suspected (Goranson and Schroeder, 1978)

Observed maximum temperature: 382°F at 1,900 (Galbraith, 1978)

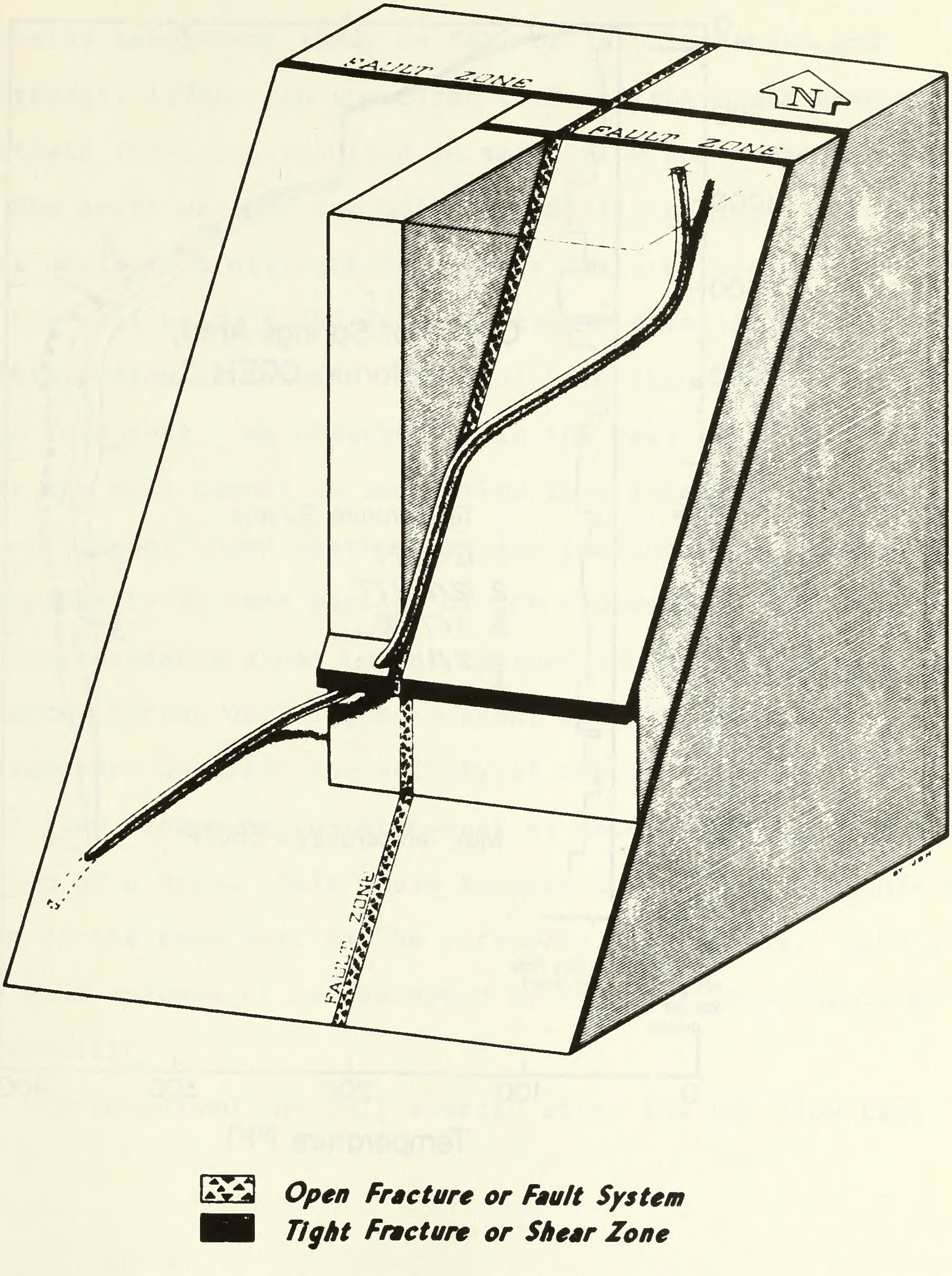


Figure 3.2 Conceptual Schematic of Structural Control in Well CGEH-1 (Galbraith, 1978)

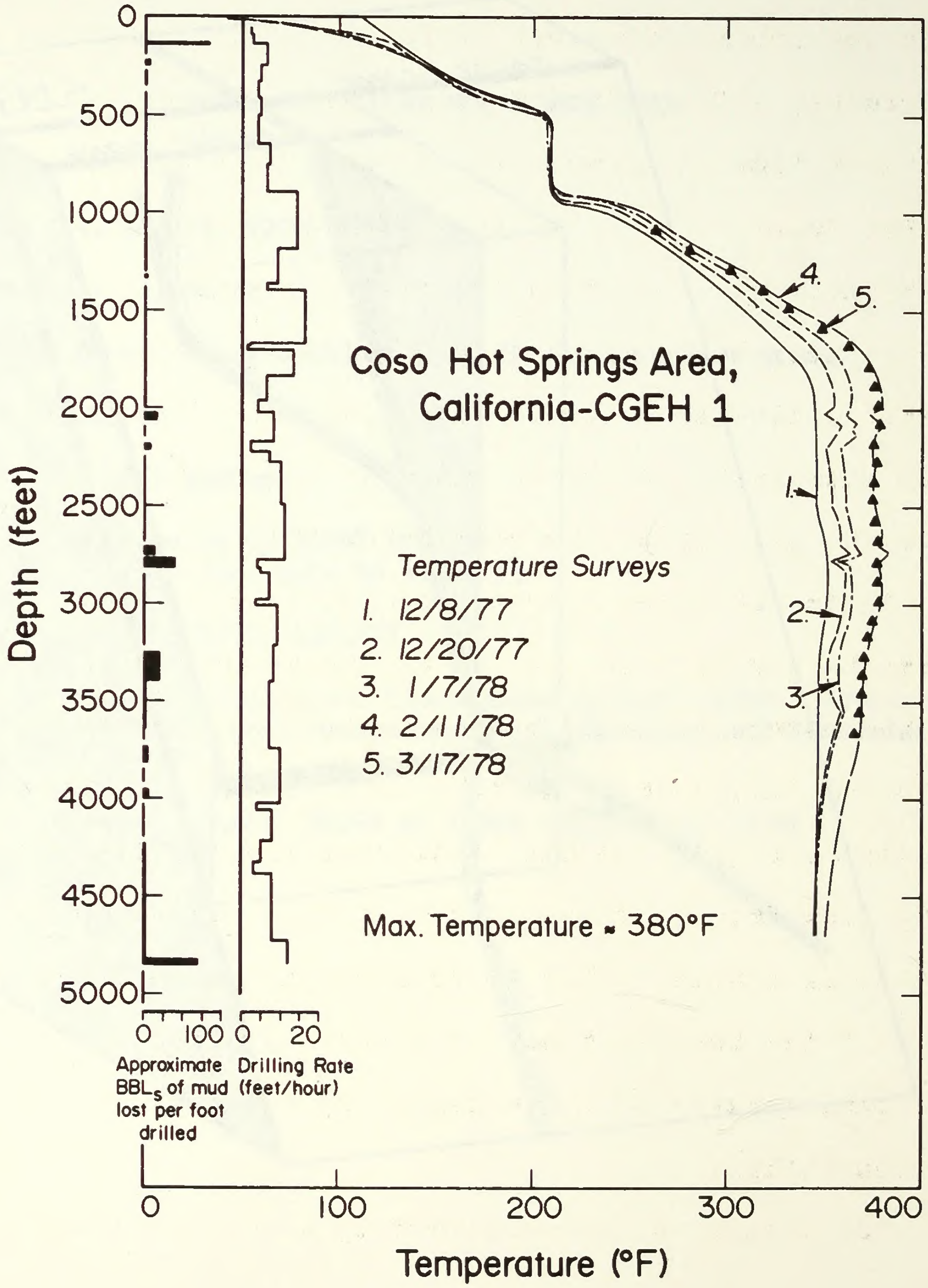


Figure 3.3 Temperature logs, mud loss and drilling rate - CGEH-1 (Goranson and Schroeder, 1978)

Two flow tests of CGEH No. 1 were performed by Lawrence Berkeley Laboratory (LBL) in fall of 1978 (Goranson and Schroeder, 1978). In the first test, nitrogen was used to initiate flow, but resulted in small flow and subsequent filling of the lower part of the hole with drill cuttings. The second test utilized a nitrogen-foam-water mixture to clean the portion of the well below 4,700 ft and nitrogen stimulation was used to initiate flow as before. Flows of less than 5 gpm were reported from this test. An obstruction in the well at 4,500 ft implies that the well cannot be used below this interval.

It is not known whether the low production is due to low permeability in this portion of the reservoir or due to plugging of the permeable zones by the copious amounts of mud that were injected during drilling to prevent loss of circulation. Some researchers question the ability of the drilling mud to hold back flow from a hydrostatic heat of about 4,000 feet at the bottom of a hole. This would support the belief that this section of the reservoir may be virtually impermeable. Others cite the vast volumes of mud accepted by the rock as evidence of its permeability.

DOE abandoned the well shortly after the LBL flow test.

SECTION 4

EXPLORATION GEOPHYSICS

Exploration geophysical techniques are employed to detect anomalous conditions indicative of a geothermal reservoir at depth, to define its limits and to define target areas for deep exploratory drilling. Techniques used at Coso include heat flow, shallow ground temperature, seismic ground noise, electrical resistivity, gravity and low altitude aeromagnetics. The geophysical anomalies defined in these surveys generally coincide, lie within the 10 heat flow unit (HFU) contour and converge around the active thermal manifestations of the region (Fig. 4.1). Together, the geologic, geochemical and geophysical data indicate the possible extent of the geothermal system at Coso.

4.1 HEAT FLOW

Heat flow surveys provide a direct method for assessing the potential and defining the areal extent of a geothermal anomaly. Surveys conducted by Combs (1975, 1976, in press) show the Coso area is characterized by high subsurface temperatures. Temperatures were obtained from depths up to 410 m in 18 boreholes, with most about 100 m deep. They are located on Plate II-1 and data for each of these holes are summarized in Appendix B1 of the Hydrology Technical Report. They are identified by a "H" in the "Well Use" column.

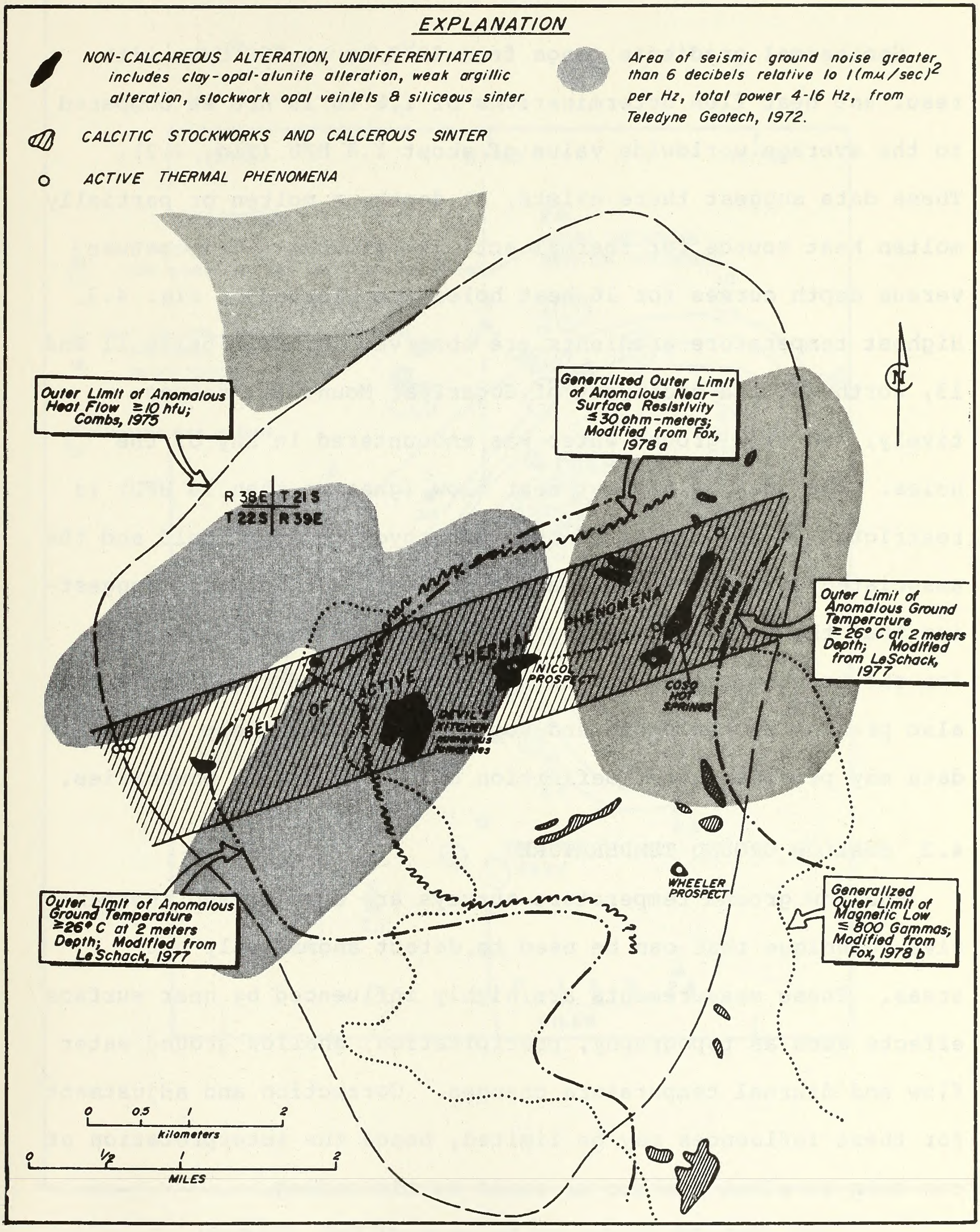


Figure 4.1 Generalized Alteration and Geophysical Map (modified from Hulen, 1978)

Geothermal gradients range from 28°C/km to 350°C/km with resultant heat flow determinations of 1.8 to 18 HFU as compared to the average worldwide value of about 1.5 HFU (Fig. 4.2). These data suggest there exists, at depth, a molten or partially molten heat source for thermal activity at Coso. Temperature versus depth curves for 16 heat holes are plotted on Fig. 4.3. Highest temperature gradients are observed in drill holes 11 and 13, northwest and southwest of Sugarloaf Mountain, respectively. No free ground water was encountered in any of the holes. The area of highest heat flow (greater than 10 HFU) is restricted to the middle of the Coso rhyolite dome field and the associated active thermal features at Coso Hot Springs, suggesting that the Coso Hot Springs fault forms an eastern boundary for the anomalous area. Distinct boundaries of the anomaly are also present to the north and south. Additional deep heat flow data may provide better definition of the reservoir boundaries.

4.2 SHALLOW GROUND TEMPERATURE

Shallow ground temperature surveys are a quick and inexpensive technique that can be used to detect anomalously hot areas. These measurements are highly influenced by near surface effects such as topography, precipitation, shallow ground water flow and diurnal temperature changes. Correction and adjustment for these influences may be limited, hence the interpretation of the data is often tenuous or could be misleading.

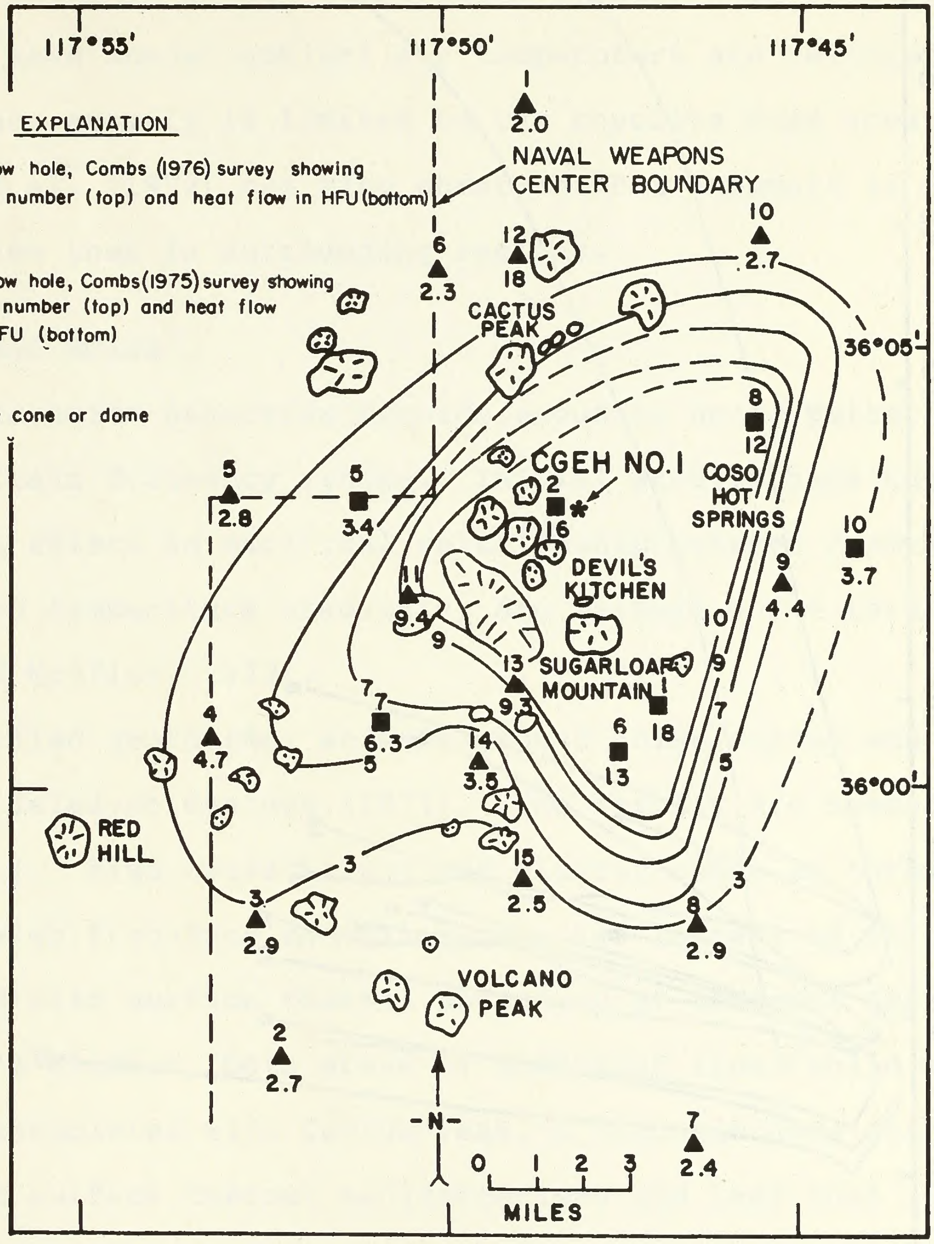


Figure 4.2 Heat flow of the Coso area (modified from Combs, 1976)

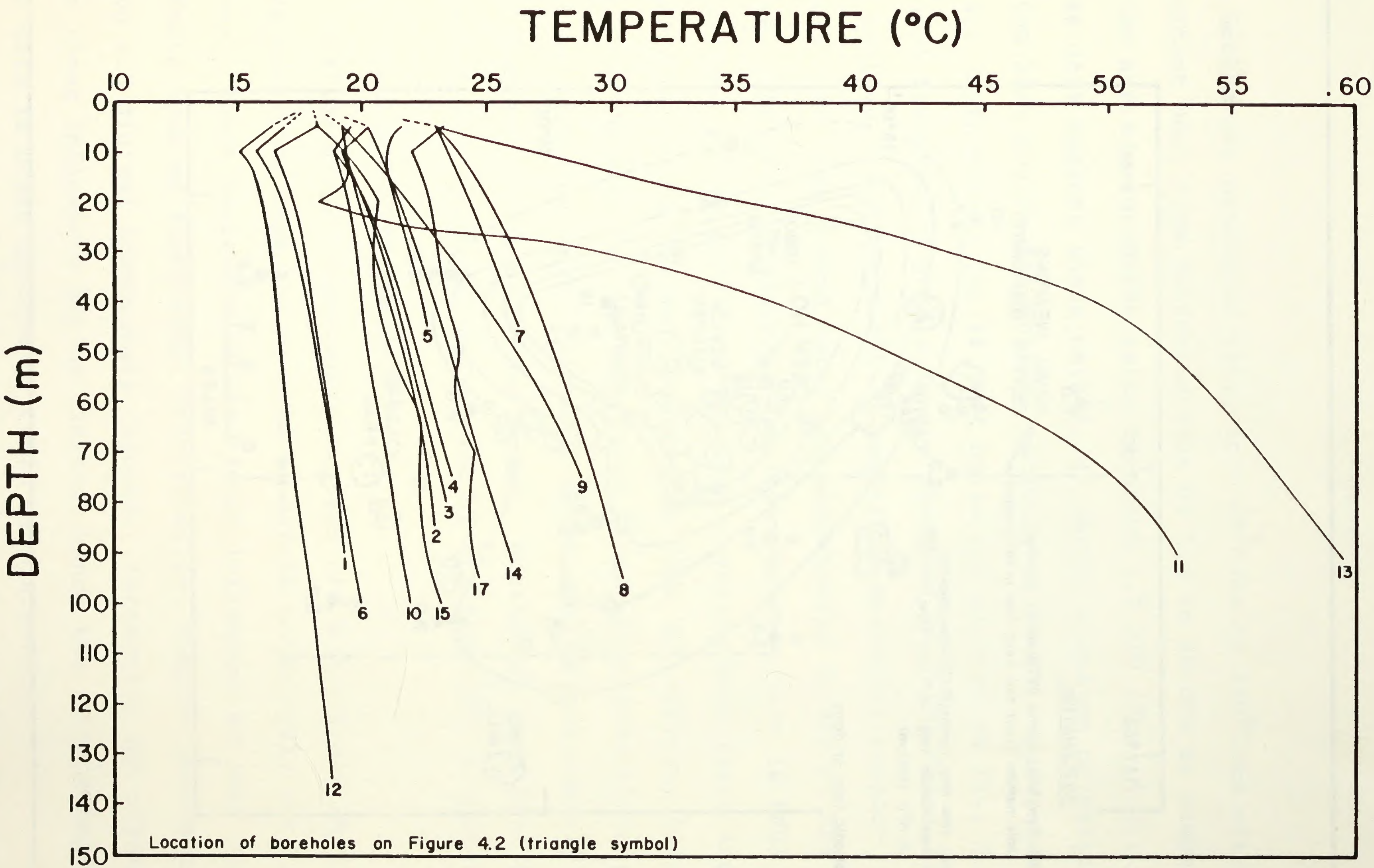


Figure 4.3 Temperature versus depth curves for selected Coso heat flow boreholes (modified from Combs, 1976)

Shallow (2-meter) ground temperatures were mapped in the Coso area by LeSchack (1977). These data are summarized on Fig. 4.1 where areas of ground temperature greater than 25°C or 7°C above mean annual ambient air temperature are delineated. This surface anomaly is limited to the rhyolite dome area. Koenig, et al. (1972) has also observed that snowmelt is quicker in this area than in surrounding regions.

4.3 SEISMIC NOISE

Seismic noise detection records acoustic noise patterns within certain frequency ranges. Initial studies have suggested that there exists an empirical relationship between reservoir depth, high temperature gradients, and seismic noise levels (Combs and Muffler, 1973).

A detailed geothermal seismic ground noise survey was performed by Teledyne Geotech (1972). The results are summarized on Fig. 4.1. High noise levels are clearly shown as three separate high frequency anomalies, the two largest of which are associated with surface thermal phenomena at Coso Hot Springs and Devil's Kitchen, both areas of high heat flow, while the third is associated with Cactus Peak, a volcanic dome with no associated surface thermal manifestations and less than 10 HFU.

4.4 ELECTRICAL RESISTIVITY

Electrical resistivity data are available for the Coso Range in Jackson, et al. (1977). The area around the rhyolite dome and Coso Hot Springs are is covered by Fox (1978a) and Furgerson (1973). Additional electrical studies in the Coso area will appear in Jackson and O'Donnell (in press).

High resistivity to very high resistivity values are associated with bedrock, rock above the regional ground water table or steam. Resistivity is reduced by increased clay content of altered rock, increased electrolytic character of saline fluids compared to meteoric waters and by higher temperatures. The latter features would generally be associated with a hydrothermal reservoir. Hence, a hydrothermal reservoir would be expected to exhibit lower resistivity than surrounding areas.

Resistivity data show a shallow resistivity low, covering an area of 6 to 8 sq mi, in areas of thermal activity (Fig. 4.1). These apparent resistivities of less than 25 ohm-meters, are an order of magnitude lower than the apparent resistivity of local bedrock. However, nothing in the electrical data clearly reflects a magma or plastic intrusion (Koenig, 1978, personal communication).

Two east-northeast trending faults have been identified from the resistivity data (Fox, 1978a). One of these possibly serves as a major conduit for thermal fluids. It passes through the valley north of Devils Kitchen, bisects the Nicol Prospect and continues east to the Coso Hot Springs fault. This Nicol Prospect fault also corresponds closely to a magnetic low lineament reported by Fox (1978b). The surface trace of this fault is mapped by Hulen, 1978 (Plate I-1).

4.5 GRAVITY

Gravity surveys are an indirect method of geothermal exploration. They are used to both outline major structural features and to delineate positive anomalies which can be produced by local structural highs, buried volcanic rocks, intrusive rocks or hydrothermally metamorphosed rock (Combs and Muffler, 1973). However, such local positive anomalies can be produced by other factors than those associated with an active geothermal system. Therefore, gravity data must be carefully interpreted and used in conjunction with other exploration techniques.

The gravity field of the Coso Range is dominated by intense Bouguer lows of the Owens Lake basin to the northwest and the Indian Wells Valley basin to the south (Chapman, et al., 1973). No clear evidence of a magma body is viewed in the gravity data, although no residual maps have yet been published. Plouff and Isherwood (in press) will present one.

4.6 LOW ALTITUDE AEROMAGNETICS

Magnetic anomalies are, in general, the geophysical method least useful in defining geothermal drilling targets. However, magnetic anomalies can be interpreted to delineate zones of subsurface hydrothermal alteration of magnetite, areas of very young intrusive or volcanic rocks associated with a geothermal system (Combs and Muffler, 1975) or major structural elements.

Fox (1978b) conducted a low altitude aeromagnetic survey to locate local variations in rock magnetization and magnetic features related to structures that would help delineate the boundaries of the geothermal area. The aeromagnetic data reveal numerous bands of higher and lower total intensity. These bands are probably related to polarity effects and the high magnetic susceptibility of magnetite-rich bodies such as basalt flows and certain metamorphic pendants.

Part of the magnetic low delineated by Fox (1978b) is coincident with the geothermal area (Fig. 4.1). It lies generally southeast of Sugarloaf Mountain and Devil's Kitchen with an areal extent of 10 square miles. Coso Hot Springs lies at the northeasternmost corner of this anomaly. The anomaly is probably due in part to alteration of magnetite and the gross structural trend also defined by seismicity (see Seismicity section).

Additional aeromagnetic data for the Coso area will be presented in Plouff and Isherwood (in press).

SECTION 5

SEISMICITY

The CGSA lies near several of the most seismically active areas of California. Large active fault systems within 100 miles of the Hot Springs include the Owens Valley fault zone (about 20 miles north), the southern Sierra Nevada fault zone (about 10 miles west), the Panamint Valley fault zone (about 30 miles east), the Furnace Creek - Death Valley fault zone (about 55 miles east) and the Garlock fault zone (about 40 miles south (Fig. 1.1). Smaller active faults which lie within the KGRA include the Haiwee Spring - Coso Hot Springs - Airport Lake fault zone and the Little Lake fault (Plate I-1). Microearthquake patterns infer a north-northeast trending seismically active zone of crustal spreading (Weaver and Hill, 1978/79; Walter and Weaver, in press).

5.1 EARTHQUAKE HISTORY

The southern Sierra Front and surrounding area is characterized by a high level of strain release (Allen, et al. 1965), microseismic activity and generation of several large to moderate magnitude earthquakes. More than ten events of magnitude 5 to 5.9, two of magnitude 6 to 6.9 and one of magnitude 8+ have occurred within 100 kilometers (62 miles) of the study area since 1872.

Fig. 5.1 shows the location of earthquakes occurring from 1900 to 1974 reported by the California Division of Mines and Geology, California Institute of Technology and the National Oceanic and Atmospheric Administration (Real, et al. 1978) with the location of the 1872 Owens Valley earthquake added. Events prior to 1930 are located mainly from reports by people who felt the earthquake in specific areas. Most earthquakes occurring after 1932 are instrumentally located.

The areas of highest seismicity within a 100-kilometer radius of the Coso Hot Springs occur in Owens Valley and the Sierra Front southeast of Little Lake. The great 1872 earthquake and another large reported earthquake in 1790 were located in Owens Valley (Coffman and von Hake, 1973). A series of magnitude 5 to 6 earthquakes occurred southeast of Little Lake in 1946 (Real, et al., 1978).

Owens Valley Earthquake of 1872--

The Owens Valley earthquake of 1872 is generally regarded as the largest shock in California history. The earthquake has been assigned a Modified Mercalli intensity of X-IX (Table 5.1) and magnitude greater than 8. Earthquake damage extended from the California Coast Ranges, to the Mojave Desert. It was reported to have been felt over an area of 125,000 square miles (from Shasta to San Diego Counties) (Coffman and von Hake, 1973). Damage to the adobe-built communities in the Owens Valley was total and at least 60 deaths were attributed to the shock.

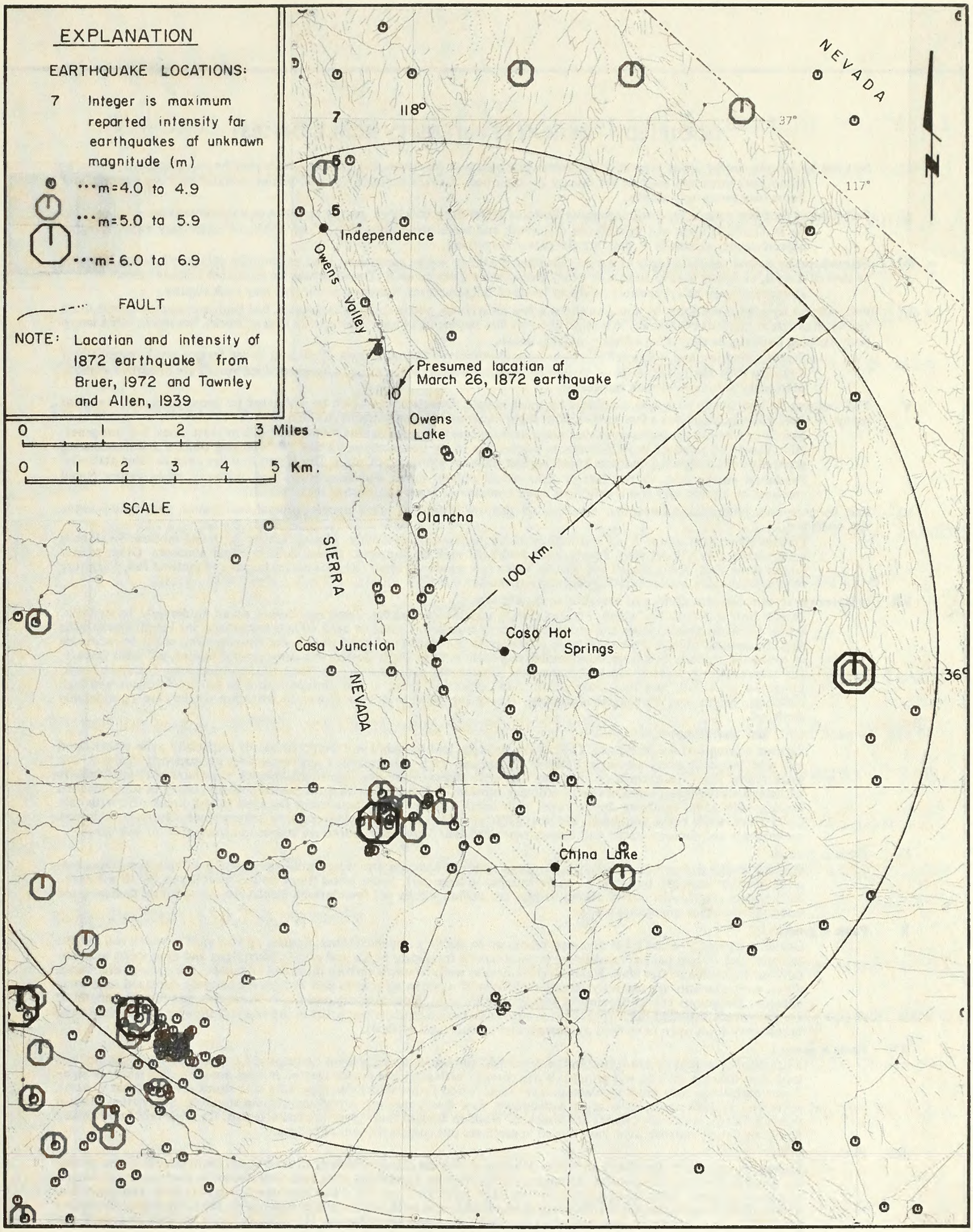


Figure 5.1 Historic Seismicity for the Coso Area, 1900-1974, (with location of 1872 earthquake) (modified from Real, et al.,1978)

MODIFIED – MERCALLI INTENSITY SCALE OF 1931

I **Not felt by people, except under especially favorable circumstances. However, dizziness or nausea may be experienced.**
Sometimes birds and animals are uneasy or disturbed. Trees, structures, liquids, bodies of water may sway gently, and doors may swing very slowly.

II **Felt indoors by a few people, especially on upper floors of multi-story buildings, and by sensitive or nervous persons.**
As in Grade I, birds and animals are disturbed, and trees, structures, liquids and bodies of water may sway. Hanging objects swing, especially if they are delicately suspended.

III **Felt indoors by several people, usually as a rapid vibration that may not be recognized as an earthquake at first. Vibration is similar to that of a light, or lightly loaded trucks, or heavy trucks some distance away. Duration may be estimated in some cases.**
Movements may be appreciable on upper levels of tall structures. Standing motor cars may rock slightly.

IV **Felt indoors by many, outdoors by few. Awakens a few individuals, particularly light sleepers, but frightens no one except those apprehensive from previous experience. Vibration like that due to passing of heavy, or heavily loaded trucks. Sensation like a heavy body striking building, or the falling of heavy objects inside.**
Dishes, windows and doors rattle; glassware and crockery clink and clash. Walls and house frames creak, especially if intensity is in the upper range of this grade. Hanging objects often swing. Liquids in open vessels are disturbed slightly. Stationary automobiles rock noticeable.

V **Felt indoors by practically everyone, outdoors by most people. Direction can often be estimated by those outdoors. Awakens many, or most sleepers. Frightens a few people, with slight excitement; some persons run outdoors.**
Buildings tremble throughout, Dishes and glassware break to some extent. Windows crack in some cases, but not generally. Vases and small or unstable objects overturn in many instances, and a few fall. Hanging objects and doors swing generally or considerable. Pictures knock against walls, or swing out of place. Doors and shutters open or close abruptly. Pendulum clocks stop, or run fast or slow. Small objects move, and furnishings may shift to a slight extent. Small amounts of liquids spill from well-filled open containers. Trees and bushes shake slightly.

VI **Felt by everyone, indoors and outdoors. Awakens all sleepers. Frightens many people; general excitement, and some persons run outdoors.**
Persons move unsteadily. Trees and bushes shake slightly to moderately. Liquids are set in strong motion. Small bells in churches and schools ring. Poorly built buildings may be damaged. Plaster falls in small amounts. Other plaster cracks somewhat. Many dishes and glasses, and a few windows, break. Knick-knacks, books and pictures fall. Furniture overturns in many instances. Heavy furnishings move.

VII **Frightens everyone. General alarm, and everyone runs outdoors.**
People find it difficult to stand. Persons driving cars notice shaking. Trees and bushes shake moderately to strongly. Waves form on ponds, lakes and streams. Water is muddied. Gravel or sand stream banks cave in. Large church bells ring. Suspended objects quiver. Damage is negligible in buildings of good design and construction; slight to moderate in well-built ordinary buildings; considerable in poorly built or badly designed buildings adobe houses, old walls (especially where laid up without mortar), spires, etc. Plaster and some stucco fall. Many windows and some furniture break. Loosened brickwork and tiles shake down. Weak chimneys break at the roofline. Cornices fall from towers and high buildings. Bricks and stones are dislodged. Heavy furniture overturns. Concrete irrigation ditches are considerably damaged.

VIII **General fright, and alarm approaches panic.**
Persons driving cars are disturbed. Trees shake strongly, and branches and trunks break off (especially palm trees). Sand and mud erupts in small amounts. Flow or springs and wells is temporarily and sometimes permanently changed. Dry wells renew flow. Temperatures of spring and well waters varies. Damage slight in brick structures built especially to withstand earthquakes; considerable in ordinary substantial buildings, with some partial collapse; heavy in some wooden houses, with some tumbling down. Panel walls break away in frame structures. Decayed pilings break off. Walls fall. Solid stone walls crack and break seriously. Wet grounds and steep slopes crack to some extent. Chimneys,columns, monuments and factory stacks and towers twist and fall. Very heavy furniture moves conspicuously or overturns.

IX **Panic is general.**
Ground cracks conspicuously. Damage is considerable in masonry structures built especially to withstand earthquakes; great in other masonry buildings - - some collapse in large part. Some wood frame houses built especially to withstand earthquakes are thrown out of plumb, others are shifted wholly off foundations. Reservoirs are seriously damaged and underground pipes sometimes break.

X **Panic is general.**
Ground, especially when loose and wet, cracks up to widths of several inches; fissures up to a yard in width run parallel to canal and stream banks. Landsliding is considerable from river banks and steep coasts. Sand and mud shifts horizontally on beaches and flat land. Water level changes in wells. Water is thrown on banks of canals, lakes, rivers, etc. Dams, dikes, embankments are seriously damaged. Well-built wooden structures and bridges are severely damaged, and some collapse. Dangerous cracks develop in excellent brick walls. Most masonry and frame structures, and their foundations, are destroyed. Railroad rails bend slightly. Pipe lines buried in earth tear apart or are crushed endwise. Open cracks and broad wavy folds open in cement pavements and asphalt road surfaces.

XII **Panic is general.**
Disturbances in ground are many and widespread, varying with the ground material. Broad fissures, earth slumps, and land slips develop in soft, wet ground. Water charged with sand and mud is ejected in large amounts. Sea waves of significant magnitude may develop. Damage is severe to wood frame structures, especially near shock centers, great to dams, dikes and embarkments, even at long distances. Few if any masonry structures remain standing. Supporting piers or pillars of large, well-built bridges are wrecked. Wooden bridges that "give" are less affected. Railroad rails bend greatly and some thrust endwise. Pipe lines buried in earth are put completely out of service.

XII **Panic is general.**
Damage is total, and practically all works of construction are damaged greatly or destroyed. Disturbances in the ground are great and varied, and numerous shearing cracks develop. Landslides, rock falls, and slumps in river banks are numerous and extensive. Large rock masses are wrenched loose and torn off. Fault slips develop in firm rock, and horizontal and vertical offset displacements are notable. Water channels, both surface and underground, are disturbed and modified greatly. Lakes are dammed, new waterfalls are produced, rivers are deflected, etc. Surface waves are seen on ground surfaces. Lines of sight and level are distorted. Objects are thrown upward into the air.

Table 5.1 Modified Mercalli Intensity Scale

Dominant motion was dip-slip with up to 23 feet of vertical displacement. Right-lateral strike-slip displacement was up to 20 feet. The dip-slip motion is characteristic of Basin and Range faulting, while the strike-slip motion is characteristic of San Andreas type faulting. Surface rupture along the fault extended for over 100 miles from Haiwee Reservoir north to Big Pine. Fault scarps are well preserved.

5.2 MICROSEISMICITY

Microearthquakes in the Coso area have been studied by Combs (1975) and by Walter and Weaver (in press). These studies indicate that Coso is an area of high seismic activity, occurring in swarm-type sequences and with relatively shallow hypocenters. The survey by Combs (1975) was of limited scope and duration. The additional data provided by the longer term, more comprehensive study conducted by Walter and Weaver (in progress) lead to different conclusions than those indicated by the Combs (1975) study.

Microearthquake activity in the rhyolite dome area was monitored by Combs (1975) for 33 days. More than 2,000 events were detected in predominantly swarm-type sequences. Hypocenters were between 1 and 6 km with a decrease in focal depth from the west and northwest toward the Coso Hot Springs.

Areas of high seismic noise delineated in the Teledyne Geotech (1972) study correlate with areas of high microearthquake activity. However, this survey period was short, and seismic trends (such as areas with predominant focal depth, and areas of high seismic activity) are not apparent in more long-term data collection.

Walter and Weaver (in press) conducted a two-year microearthquake survey with an array of 16 stations within 30 miles of Sugarloaf Mountain centering around the rhyolite dome field.

This study revealed an apparent belt of seismicity trending northwest-southeast from Haiwee Reservoir to Sugarloaf Mountain then south towards China Lake. Focal depths were generally from 4 to 8 kilometers. Historic data also infers a northwest trend of seismicity in this region. Seismic activity was variable with very high levels (more than 100 events per day) to lower levels from month to month. However, some areas, such as Sugarloaf Mountain, were recurrently active. Focal mechanisms of microearthquakes are both strike-slip and dip-slip. The predominant trends are north-northeast trending dip-slip, northwest-trending, right-lateral strike-slip, and northeast-trending left-lateral strike-slip (Walter and Weaver, in press). No mappable surface faults were correlated with microseismic activity.

Earthquake swarms were noted around Sugarloaf Mountain, as they were during the Combs (1975) survey. However, in disagreement with the Combs survey, no clustering of events shallower than 2 kilometers was noted around active thermal areas.

SECTION 6

MINERAL RESOURCES

Mineral resources of the CGSA include low-grade mercury and sulfur deposits associated with present and past active thermal surface phenomena of the Coso geothermal system, cinders, granitic rock for building stone, adobe and extensive undeveloped deposits of sand and gravel. Uranium, traces of copper and possibly tungsten have also been found in the vicinity of the CGSA (Austin, personal communication, 1979). Tuff and pumice have been commercially mined from the Coso formation for many years a few miles beyond the northwest boundary of the CGSA (California Division of Mines, 1966). Several pumice claims are located in the north-central portion of the CGSA (Fig. 6.1) and pumice has been mined there (Chesterman, 1956).

Minor production of mercury and sulfur has occurred at the Devil's Kitchen, Wheeler and Nicol prospects (Fig. 6.1) since their discovery in the early part of the 20th century. Mercury occurs as cinnabar commonly with hematite in small, irregular veinlets, and as films and crusts lining cavities and open fractures in silicified and kaolinized pyroclastic debris and granite (California Division of Mines, 1966; Hulen, 1978). In 1948, the U.S. Bureau of Mines conducted an extensive exploration program of these deposits. However, commercial concentrations of ore were not discovered (Dupuy, 1948).

Commercial mining of cinders at Red Hill is the only known active mining in progress within the CGSA.

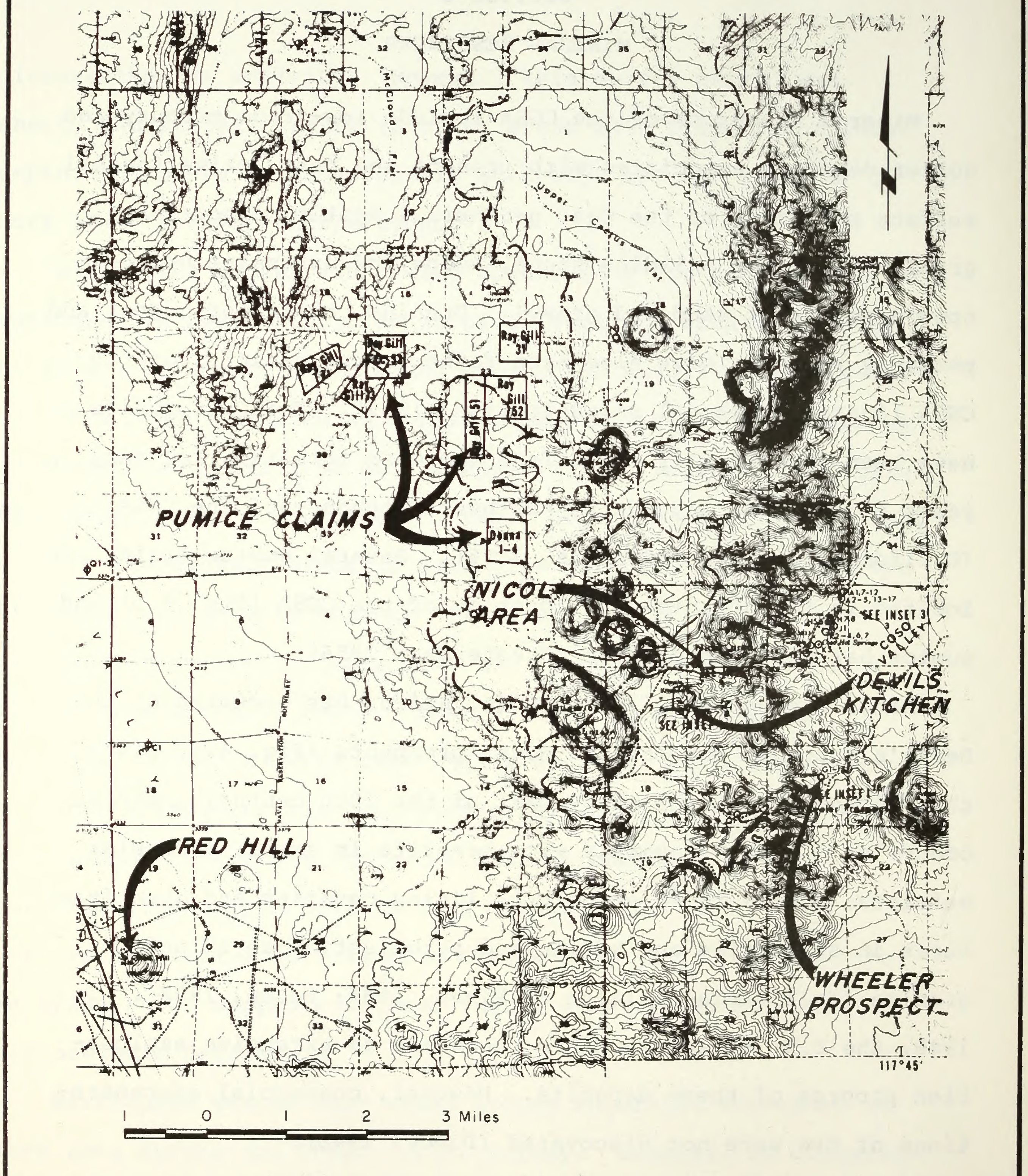


Figure 6.1 Location of pumice claims and mineral prospects.

SECTION 7

GEOLOGIC HAZARDS

7.1 SEISMIC HAZARDS

Earthquake associated damage can result from surface fault rupture, strong ground motion (shaking), ground failure induced by earthquake shaking (landsliding, settlement, liquefaction) or any combination of these effects. The great majority of earthquake damage is caused by strong ground motion and the geologic hazards in the CGSA will largely be those associated with earthquake shaking.

The Coso region is seismically active. There are several active fault zones within 50 miles (Fig. 1.1), including some within the CGSA boundary (see Section 3.2.2 and Section 5). The study area could experience significant ground shaking from a major earthquake on any of these fault zones.

Ground Shaking--

The extent of earthquake damage to man-made structures depends on many variables: earthquake magnitude, focal distance and depth, duration and intensity of shaking, subsurface soil conditions and response characteristics and structural design.

Unless a structure is astride an active fault and can be directly affected by fault displacement, proximity to an active fault is usually less important than ground response in determining earthquake damage. Important input in evaluating the duration, frequency and intensity of ground motion and potential for ground failure is the historic seismicity and the maximum expectable bedrock acceleration. Some general relations are outlined below.

An earthquake frequency vs. magnitude relation, or recurrence curve, depicts the level of historic seismicity. Figure 7.1 is a recurrence curve for earthquakes of magnitude 3 or larger recorded in the southern Sierra Nevada from 1932 to 1971. It can provide a good estimate of the probability of future earthquake activity if the historic record is detailed enough and covers a sufficiently long time span. This is a probablistic approach and provides no assurance that earthquakes on any fault system might not become more frequent or larger. The curve indicates, for example, that a magnitude 6 earthquake has a probability of occurring once every 333 years per 1000 square kilometers or about once every 40 years for the entire southern Sierra region. It should be noted that these estimates are based on a relatively short instrumental record and are subject to considerable uncertainty.

Relationships between maximum acceleration in rock, magnitude of earthquake and the distance of the site from the zones of energy release have been proposed by a number of investigators and summarized by Seed, et al. (1969). Schnabel and Seed (1972) have provided the most comprehensive estimate of

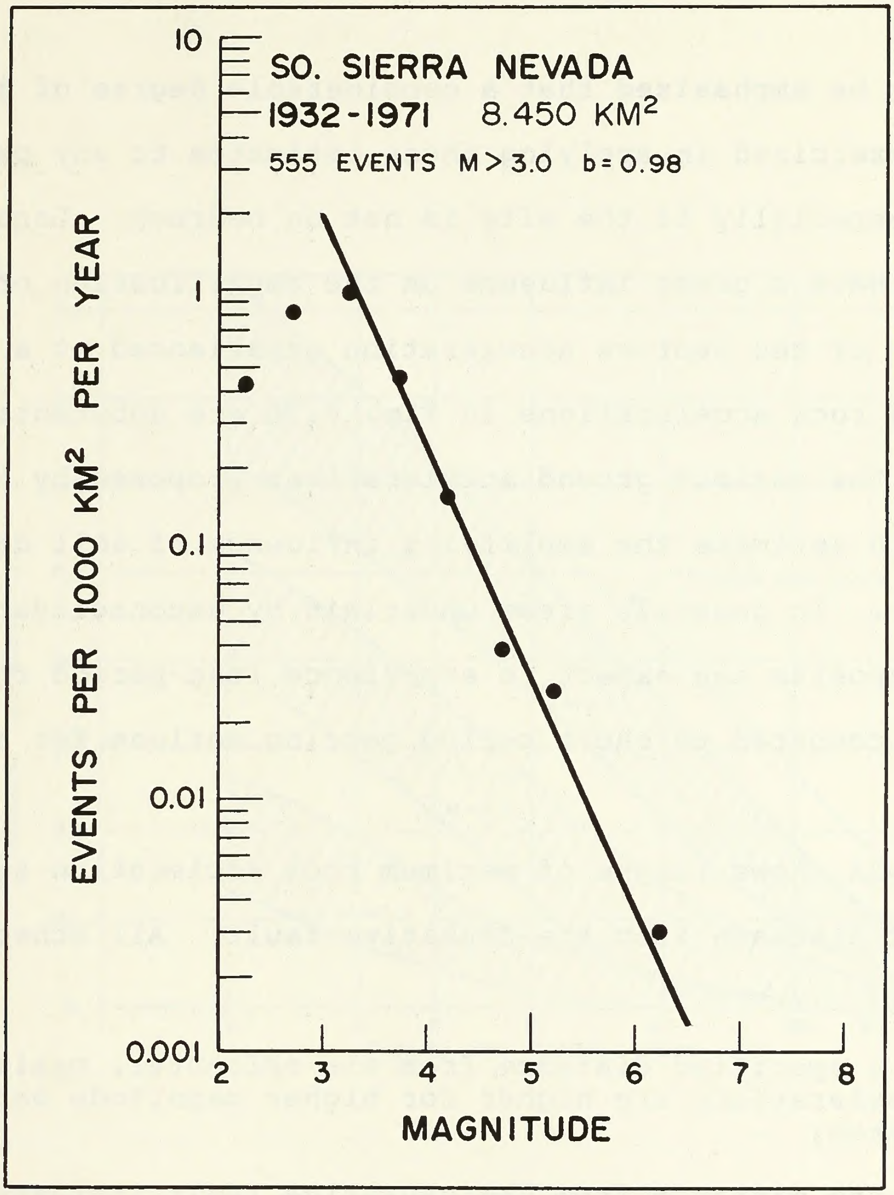


Figure 7.1 Recurrence curve for earthquakes in the Southern Sierra Nevada Region (Hileman, et al., 1973)

maximum rock accelerations utilizing data recorded from the San Fernando, California earthquake of 1971 and new analytical techniques.

It must be emphasized that a considerable degree of judgment should be exercised in applying these estimates to any particular site, especially if the site is not on bedrock. Local soil conditions have a great influence on the amplification or attenuation of the bedrock acceleration experienced at a site. The maximum rock accelerations in Fig. 7.2A are substantially lower than the maximum ground accelerations proposed by Housner (1965) which estimate the amplifying influence of soil deposits (Fig. 7.2B). In general, areas underlain by unconsolidated alluvial deposits can expect to experience long-period rolling motions as compared to short period jarring motions for areas in bedrock.

Fig. 7.2A shows ranges of maximum rock accleration as a function of distance from the causative fault. All other things being equal:

1) at a specified distance from the epicenter, maximum accelerations are higher for higher magnitude earthquakes;

2) as the distance from the causative fault increases, the maximum acceleration decreases for any given magnitude;

3) greater acceleration will be experienced at sites underlain by unconsolidated or poorly consolidated deposits.

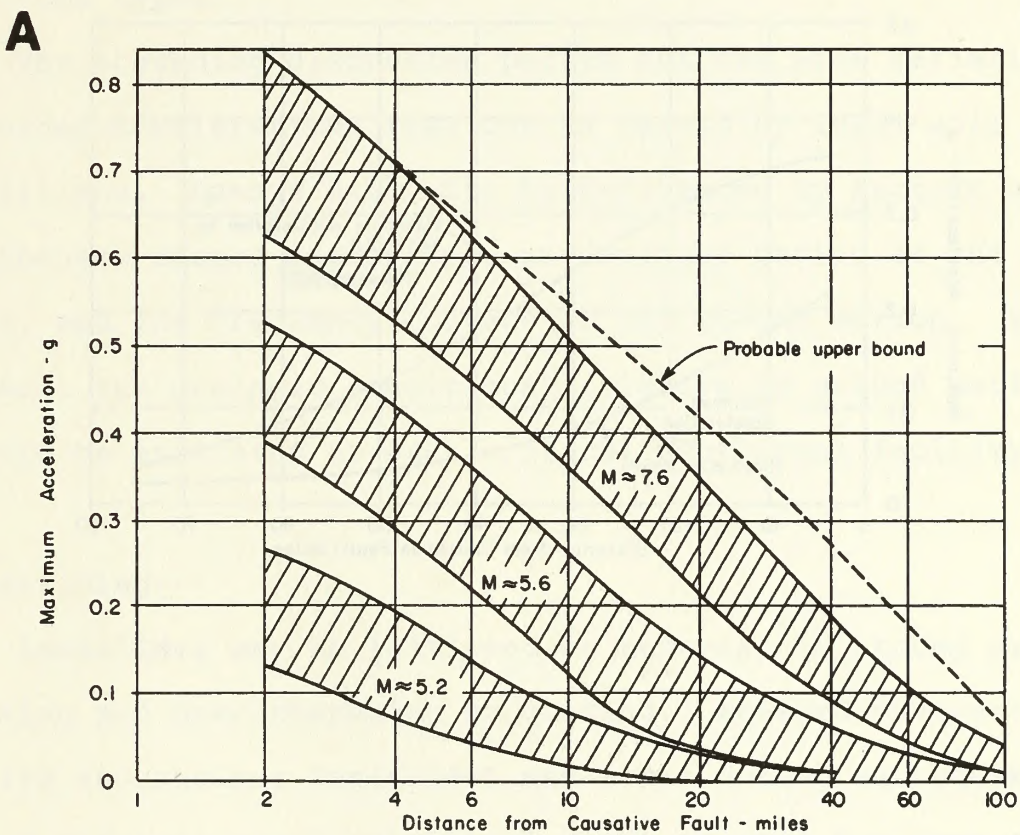


Figure 7.2A Ranges of maximum acceleration in rock

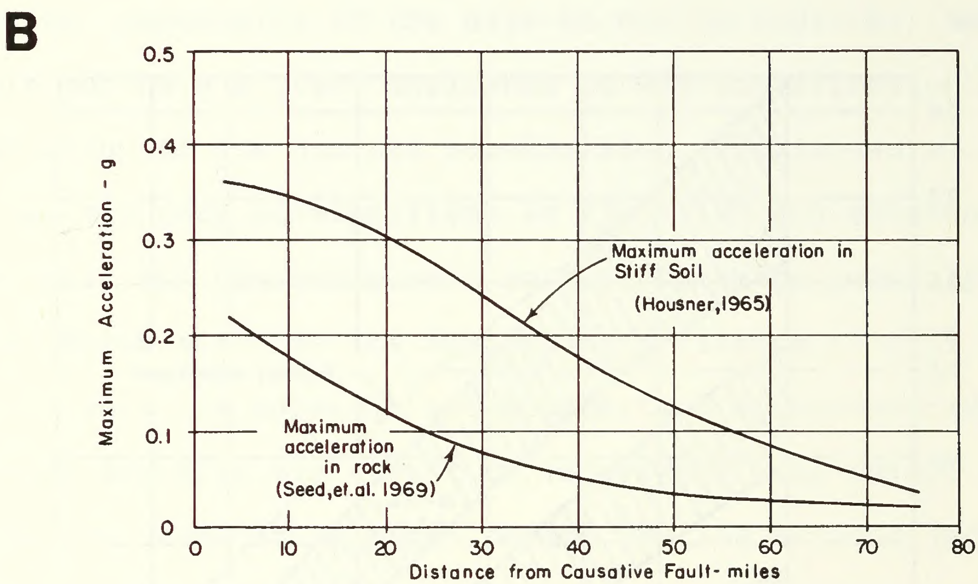


Figure 7.2B Comparison of maximum acceleration in rock and stiff soil deposits for earthquakes of magnitude 7

Fig. 7.2A shows, for example, that an earthquake of magnitude 5.6 occurring at a distance of 10 miles from a given structure will most likely generate a rock acceleration of about 0.12 to 0.26 times the acceleration of gravity (g). This range in the estimate of maximum acceleration takes into account the effect of different source mechanisms, travel paths, topography and rock types.

The preceding discussion points out the wide variations in recorded accelerations that can be caused by local soil and rock conditions. Damage will also be influenced by factors such as earthquake source mechanisms, predominant period of the structure, and the frequency content of the ground motion. For this reason, the geologic conditions, relative to ground motion, should be evaluated at each critical geothermal facility site.

Landsliding--

Landslides may be initiated by response to strong earthquake shaking and oversteepening by grading. Renewed movement on both active and ancient landslides may occur during earthquakes.

A moderate-sized rotational slide in soil has been observed on a steep slope north of the Coso Resort Area (Plate I-1, T21S/R39E-Sec. 33). Naturally steep slopes are common in areas where basement rock of the Coso Range crops out. Soil thickness on these slopes ranges from moderate to deep. Rockfalls can be anticipated on these steep slopes, especially in areas where bedrock is pervasively shattered, such as the southeast part of the study area.

Slopes in the pyroclastic debris are gentle, except in the periphery of the rhyolite domes. Slopes in these areas are relatively stable.

Surface Faulting--

Several active faults exist in the study area. Some of these are associated with the surface thermal manifestations at Coso. While there is always some possibility of future faulting in any locality in a seismically active region, the historical occurrences of surface faulting have generally closely followed the trace of existing recently active faults. Therefore, future surface faulting or rupture is most likely to occur on known active traces of faults in the study area.

Other Ground Failure Induced by Shaking--

Settlement or densification may occur in loose sandy soils above the ground water table or earth filled areas during earthquake loading due to densification of particles. A potential for earthquake induced settlement exists in alluvium covered areas.

Liquefaction occurs only in saturated soils. It is not expected in most parts of the CGSA because of deep ground water conditions. However, seasonal perched shallow ground water has been noted in the valley area between Devil's Kitchen and Coso Hot Springs.

7.2 NONSEISMIC HAZARDS

7.2.1 Weak Soils

Geologic hazards can result from weak or compressible soils or erosion problems. Soil investigations should be performed at each prospective building site to determine soil conditions for site development and foundation design.

Surface soils may be further weathered in arid, desert climates from frost heaving. Frost heaving occurs during cold months when wet ground freezes and thaws diurnally. This expansive freezing has a weakening effect on soils.

7.2.2 Erosion and Flooding

During periods of heavy rainfall, sheet erosion can displace large amounts of soil. Soil protection on slopes by vegetation or riprap lessens this effect. Heavy precipitation also causes flooding of enclosed basins forming playas. Erosion and sediment yield is also discussed in Section 2.4 of the Hydrology report.

7.2.3 Hazards from Volcanoes

Since the volcanic field at Coso is not considered active, the hazard from renewed volcanism in the CGSA is considered small.

7.3 POTENTIAL HAZARDS FROM GEOTHERMAL DEVELOPMENT

Two types of geologic hazards may result from production and injection of geothermal fluids. These are induced seismicity and subsidence. Potential ground water pollution from geothermal production is discussed in the Hydrology Technical Report.

7.3.1 Induced Seismicity

The possibility of triggering earthquakes by geothermal production and injection is of some concern. Although existing producing fields at The Geysers, California, and Wairakei, New Zealand have long been associated with preexisting earthquake activity, no associations have been drawn between geothermal production and induced earthquake activity.

Existing oil field and waste well data have yielded clues to the effect of fluid injection on triggering earthquakes. Of the thousands of existing oil field and waste injection wells, only a few instances of earthquakes triggered by fluid injection have been cited in the literature. One of them is at the Rocky Mountain Arsenal waste disposal well near Denver, Colorado, and another is at the Rangely Oil Field in northwestern Colorado (Raleigh, et al. 1976). The largest event registered at Rangely was a magnitude 6 earthquake. Earthquakes are inferred to be caused by an increase in pore pressure, which reduces the normal stress across fracture surfaces thereby resulting in shear failure. However, regional tectonics, the stress field and rock properties in other areas are different from Rangely, so the Rangely experience may not be applied universally to all injection programs.

Withdrawal of geothermal fluids may alter deep ground water flow patterns, and perhaps even flow from springs. The effect of these alterations on the tectonic stress regime is unknown.

Two criteria can be considered useful in detecting induced earthquakes: frequency-magnitude statistic changes in the area of the geothermal field; and changes in depth and location of events from pre-production activity (Phelps and Anspaugh, 1976). It will require many years of continuous monitoring activity, superimposed on the known background seismicity, to understand the possible effects of withdrawal and injection of fluids on seismicity.

7.3.2 Subsidence

Ground subsidence can result from fluid (oil, gas, steam or water) withdrawal from unconsolidated sediments or poorly consolidated rock. Since the geothermal reservoir rocks at Coso are the strong, fractured crystalline basement rocks of the Coso Range and spent fluids will be reinjected, subsidence from production of geothermal fluids in the producing geothermal field is not anticipated.

However, extensive long-term ground water extraction in the alluvial sediments of Rose Valley may induce ground subsidence. Such effects have been noted in the San Joaquin and Santa Clara Valleys in California, south-central Arizona, and many other places in the U.S. and other parts of the world (Bouwer, 1978, p. 314).

REFERENCES

Allen, C. R., P. St. Amand, C. F. Richter and J. M. Nordquist, 1965. Relationship Between Seismicity and Geologic Structure in the Southern California Region. Bulletin of the Seismological Society of America, Vol. 55, No. 4, pp. 753-798.

Austin, C. F., and J. K. Pringle, 1970. Geologic Investigations at the Coso Thermal Area. U.S. Naval Weapons Center Tech. Publ. 4878.

Austin, C. F., 1979. CES Geology Technical Report Review to BLM.

Babcock, J. W., 1977. The Late Cenozoic Coso Volcanic Field, Inyo County, California. Unpublished Ph.D. Thesis, University of California, Santa Barbara.

Bacon, C., 1978. Personal communication. U.S. Geological Survey, Menlo Park, California.

Bacon, C. R., W. A. Diffield, and K. Nakamura, in press. Distribution of Quaternary rhyolite domes of the Coso Range, California: Implications for extent of the geothermal anomaly. Jour. Geophys. Res.

Bacon, C. R., D. M. Giovannetti, W. A. Duffield, and G. B. Dalrymple, 1979. New constraints on the age of the Coso Formation. Geol. Soc. Amer. Abstr. Programs, Vol. 11, No. 3, p. 67.

Bouwer, H., 1974. Ground Water Hydrology. McGraw-Hill Book Company, New York, 480 pp.

Bruer, W. G., 1972. Preliminary Earthquake Epicenter Map of California 1934 - 1971 (June 30), Showing Selected Earthquakes Greater than Magnitude 6 which occurred prior to 1934. Division of Mines and Geology Seismic Safety Information Map 72-3.

California Division of Mines, 1966. Mineral Resources of California. California Division of Mines Bulletin 191, 450 pp.

Chapman, R. H., D. L. Healey, and B. W. Troxel, 1973. Bouguer Gravity Map of California--Death Valley Sheet. California Division of Mines and Geology Map.

Chesterman, C. W., 1956. Pumice, Pumicite and Volcanic Cinders in California: California Division of Mines Bulletin 174, 119 pp.

Coffman, S. L., and C. A. von Hake, 1973. Earthquake History of the United States, revised edition. National Oceanic and Atmospheric Administration Publication 41-1, 208 pp.

Combs, J., 1975. Heat Flow and Microearthquake Studies, Coso Geothermal Area, China Lake, California. Advanced Research Projects Agency, Contract No. N00123-74C-2099, final report.

Combs, J., 1976. Heat Flow Determinations in the Coso Geothermal Area, California. The Coso Geothermal Project Technical Report No. 3, U.S. Energy Research and Development Administration, Contract E(45-1)-1830, 24 pp.

Combs, J., in press. Heat flow in the Coso geothermal area, Inyo County, California. Jour. Geophys. Res.

Combs, J., and D. Jarzabek, 1977. Seismic Evidence for a Deep Heat Source Associated with the Coso Geothermal Area, California. The Coso Geothermal Technical Report No. 4, U.S. Energy Research and Development Administration, Contract E(45-1)-1830, 13 pp.

Combs, J., and L. J. P. Muffler, 1973. Exploration for Geothermal Resources in Geothermal Energy. P. Kruger and Co. Otte, editors, Stanford University Press, pp. 95-128.

Duffield, W. A., 1975. Late Cenozoic Ring Faulting in the Coso Range area of California. Geology, Vol. 3, pp. 335-338.

Duffield, W. A., and C. R. Bacon, 1977. Preliminary Geology Map of the Coso Volcanic Field and adjacent areas, Inyo County, California. U.S. Geological Survey Open-File Map 77-311.

Duffield, W. A., C. R. Bacon, and G. B. Dalrymple, in press. Late Cenozoic volcanism, geochronology, and structure of the Coso Range, Inyo County, California. Jour. Geophys. Res.

Dupuy, L. W., 1948. Bucket Drilling in Coso Mercury Deposit, Inyo County, California. U.S. Bureau of Mines, Report Investigation 4201, 45 pp.

Evernden, J. F., and R. W. Kistler, 1970. Chronology of Emplacement of Mesozoic Batholithic Complexes in California and western Nevada. U.S. Geological Survey Professional Paper 623.

Facca, G., 1973. The Structure and Behavior of Geothermal Fields in Geothermal Energy (Earth Sciences, 12), Paris, The UNESCO Press, pp. 61-72.

Fournier, R. O., J. M. Thompson and C. F. Austin, 1978. Chemical Analyses and Preliminary Interpretation of Waters Collected from the CGEH No. 1 Geothermal Well at Coso, California. USGS Open-File Report 78-434, 10 pp.

Fox, R. C., 1978a. Dipole-dipole Resistivity Survey of the Coso Hot Springs KGRA, Inyo County, California. U.S. Department of Energy, Division of Geothermal, Contract EY-76-S-07-1601.

Fox, R. C., 1978b. Low-altitude Aeromagnetic Survey of the Coso Hot Springs KGRA, Inyo County, California. U.S. Department of Energy, Division of Geothermal, Contract EY-76-S-07-1601.

Fraser, H. J., J. B. D. Wilson and N. W. Hendry, 1943. Hot Spring Deposits of the Coso Mountains. California Journal of Mines & Geology, Vol. 38, pp. 223-242.

Furgerson, R. B., 1973. Progress Report on Electrical Resistivity Studies, Coso Geothermal Area, Inyo County, California. China Lake Naval Weapons Center Technical Publication 5497.

Galbraith, R. M., 1978. A Geological and Geophysical Analysis of Coso Geothermal Exploration Hole No. 1, Coso Hot Springs KGRA, Inyo County, California. U.S. Department of Energy, Department of Geothermal, Contract 78-C-07-1701.

Godwin, L. H., L. B. Haigler, R. L. Rioux, D. E. White, L. J. P. Muffler, and R. G. Wayland, 1971. Classification of Public Lands Valuable for Geothermal steam and Associates Geothermal Resources. U.S. Geological Survey Circular 647.

Goranson, C., and R. Schroeder, 1978. Static Downhole Characteristics of Well CGEH-1 at Coso Hot Springs, China Lake, California. Lawrence Berkeley Laboratory Report LBL-7059, 27 pp.

Healy, J. H., and F. Press, 1964. Geophysical Studies of Basin Structures along the Eastern Front of the Sierra Nevada, California. Geophysics, Vol. 24, No. 3, pp. 337-359.

Hileman, J. A., C. R. Allen and J. M. Nordquist, 1973. Seismicity of the Southern California Region, 1 January 1932 to 31 December 1972. Seismological Laboratory, California Institute of Technology, 560 pp.

Housner, G. W., 1965. Intensity of Earthquake Ground Shaking Near The Causative Fault. Proceedings, Third World Conference on Earthquake Engineering, New Zealand, Vol. 1.

Hulen, J. B., 1978. Geology and Alteration of the Coso Geothermal Area, Inyo County, California. U.S. Department of Energy, Report No. 1DO-1701-1, 28 pp.

Isherwood, W., 1978. Personal communication. U.S. Geological Survey, Menlo Park, California.

Jackson, D. B., J. E. O'Donnell, and D. I. Gregory, 1977. Schlumberger Soundings, audio-magnetotelluric soundings and telluric mapping in and around the Coso Range, California. U.S. Geological Survey Open-file Report 77-120, 50 pp.

Jackson, D. B., and J. E. O'Donnell, in press. Electrical studies in the Coso geothermal area, California. Jour. Geophys. Res.

Jennings, C. W., 1975. Fault Map of California with Locations of Volcanoes, Thermal Springs and Thermal Wells, California Division of Mines and Geology, California Geologic Data Map Series, Map No. 1.

Jennings, C. W., 1977. Geologic Map of California. California Division of Mines and Geology, California Geologic Data Map Series.

Koenig, J. B., S. J. Gawarecki, and C. F. Austin, 1972. Remote Sensing Survey of the Coso Geothermal Area, Inyo County, California. U.S. Naval Weapons Center Technical Publication 5233.

Koenig, J. B., 1978. Personal communication. Geothermex, Inc., Berkeley, California. Draft report on Geology and Geothermal Potential of the Coso Environmental Statement Area.

Lanphere, M. A., G. B. Dalrymple, and R. L. Smith, 1975. K-Ar Ages of Pleistocene Rhyolitic Volcanism in the Coso Range, California. Geology, Vol. 3, pp. 339-341.

LeSchack, L. A., 1977. Preliminary 2-meter Temperature Map, 22-23 September, Coso, California. Development and Resources Transportation Company Map under ERDA Contract EG 77-C-01-4021.

Meidav, H. T., and S. K. Sanyal, 1976. A Comparison of Hydrothermal Reservoirs of the Western U.S. Electric Power Research Institute Topical Report ER-364, Project 580, 170 pp.

Nielson, D. L., B. S. Sibbett, D. B. McKinney, J. B. Hulen, J. N. Moore and S. M. Samberg, 1978. Geology of the Roosevelt Hot Springs KGRA, Beaver County, Utah. Department of Energy, Division of Geothermal Energy, Contract No. EG-78-C-07-1701, 120 pp.

Phelps, P. L. and L. R. Anspaugh, 1976. Imperial Valley Environmental Project: Progress Report. Lawrence Livermore Laboratory UCRL-50044-76-1, 214pp.

Plouff, D., and W. F. Isherwood, in press. Aeromagnetic and gravity surveys in the Coso Range, California. Jour. Geophys. Res.

Raleigh, C. B., J. H. Healy and J. D. Bredehoeft, 1976. An Experiment in Earthquake Control at Rangely, Colorado. Science, Vol. 191, pp. 1230-1236.

Real, C. R., T. R. Toppozada, and D. L. Parke, 1978. Earthquake Epicenter Map of California, 1900 through 1974. California Division of Mines and Geology, Map Sheet 39.

Reasenberg, et al., in press. Paper to be published in Fall 1979 issue of Jour. Geophys. Res.

Renner, J. L., D. E. White and D. L. Williams, 1975. Hydrothermal Convection Systems; in Assessment of Geothermal Resources of the United States - 1975, D. E. White and D. L. Williams, eds., U.S. Geological Survey Circular 726.

Roquemore, G., 1977. The Cenozoic History of the Coso Mountains as Determined by Tuffaceous Lacustrine Deposits. Unpublished M.A. Thesis, California State University, Fresno, 65 pp.

Roquemore, Glenn R., 1978a. Active Faults and Related Seismicity of the Coso Mountains, Inyo County, California. Seismological Society of America Earthquake Notes, Vol. 49, No. 1, p. 24.

Roquemore, Glenn R., 1978b. Evidence for Basin and Range/Sierra Nevada Transitional Zone Structures in the Coso Mountains, California (abs.). Geological Society of America Abstracts with Programs, Vol. 10, No. 3, p. 144.

Roquemore, G., in press. Structure, tectonics and stress field of the Coso Range, Inyo County, California. Jour. Geophys. Res.

Roquemore, G., 1979. Personal communication. University of Nevada, Reno.

Ross, C. P., and R. G. Yates, 1943. The Coso Quicksilver District, Inyo County, California. U.S. Geological Survey Bulletin 936-Q, pp. 395-416.

Schnabel, P. B., and H. B. Seed, 1972. Accelerations in Rock for Earthquakes in the Western United States. Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley, Report No. EERC 72-2, 15 pp.

Seed, H. B., I. M. Idriss and F. W. Kiefer, 1969. Characteristics of Rock Motion During Earthquakes. Journal of the Soil Mechanics and Foundations Division, American Society of Civil Engineers, Vol. 95, pp. 1199-1218.

St. Amand, P., and G. Roquemore, 1978. Preliminary Structural Interpretation of the Coso Area. Unpublished U.S. Naval Weapons Center Map.

Stinson, M. C., 1977. Geology of the Haiwee Reservoir 15' Quadrangle, Inyo County, California. California Division of Mines and Geology Map Sheet 37.

Teledyne Geotech, 1972. Geothermal Noise Survey of the Coso Hot Springs Area, Naval Weapons Center, China Lake, California. Unpublished U.S. Naval Weapons Center Technical Report 76-76.

Townley, S. D., and M. W. Allen, 1939. Descriptive Catalogue of Earthquakes of the Pacific Coast of the United States 1769 to 1928. Bulletin of the Seismological Society of America, Vol. 29, No. 1, 297 pp.

United States Naval Weapons Center, 1978. Draft Environmental Impact Statement for the Navy Coso Geothermal Development Program, Vol.1. U.S. Naval Weapons Center Technical Publication No. TS-78-59.

Walter, A. W., and C. S. Weaver, in press. Seismicity of the Coso Range, California. Jour. Geophys. Res.

Waring, G. A., 1965. Thermal Springs of the United States and Other Countries--A Summary. USGS Professional Paper 492, 383 pp.

Weaver, C. S., and D. P. Hill, 1978/79. Earthquake swarms and local crustal spreading along major strike-slip faults in California. Pure and Applied Geophysics, Vol. 177, pp. 51-64.

Weaver, C. S. and A. W. Walter, in press. Upper crustal structure studies in the Coso Range, California. Jour. Geophys. Res.

White, D. E., and D. L. Williams, 1975. Assessment of geothermal Resources of the United States - 1975. U.S. Geological Survey Circular 726.

Wilson, H. D. B., and N. W. Hendry, 1940. Geology and Quicksilver Deposits of the Coso Hot Springs Area. Geological Society of America Bulletin, Vol. 51, No. 12, Part 2, p. 1965.

PART II

HYDROLOGY TECHNICAL REPORT

TABLE OF CONTENTS

APPENDICES

FIGURES

TABLES

PLATES

SECTION 1

INTRODUCTION

This section presents the results of the Hydrology Task Investigation portion of the Coso Geothermal Environmental Statement Study. It covers surface and ground water hydrology and will serve as supporting technical data for the forthcoming chapters of the environmental statement (ES).

1.1 BACKGROUND

Geothermal development requires cooling water, which could displace other uses or degrade other supplies. In the Coso geothermal study area (CGSA) another hydrologic issue of particular importance is possible alteration of the Coso Hot Springs. Hence, the following possible hydrologic aspects of geothermal power production in the CGSA must be assessed:

1. The Quantity of Available Cooling Water - this would have a great influence on the economics and feasibility of geothermal development at Coso. An estimated 323 acre-feet of cooling water, in addition to that available from the geothermal reservoir, will be required for each prospective 50 MWe power plant. In the preliminary power plant design, it was assumed that makeup water would be at a premium; hence, the design incorporated the minimum amount of makeup water for its operation.

   Increased water consumption may lower regional or local water tables. This would reduce the amount of ground water in storage, and alter ground water flow rates and direction. In certain situations, it could affect natural surface vegetation and/or water quality. Additionally, some residents of Indian Wells Valley believe that a severe depletion in Rose Valley will reduce the underflow into Indian Wells Valley, thereby reducing the amount of ground water available to them.

2. Maintenance of Natural Water Quality - This involves currently used water resources as well as potentially usable resources. Degradation may occur in shallow aquifers from pumping for makeup water or deeper ones from geothermal production and injection.

3. Effects on the Thermal Manifestations at the Coso Hot Springs National Historic Site - The hot springs, fumaroles and steaming ground are considered a sacred site by some Paiute and Shoshone Indians. Any disturbance of these manifestations by geothermal power production activities would be considered a serious infringement upon Native American values in this area (California Indian Legal Services, 1978).

1.2 SCOPE

The objective of the Hydrology Technical Report is to make the most viable assessment of the hydrologic conditions in the CGSA within the constraints of the available data. Particular emphasis is placed on how the hydrologic conditions would relate to the three issues outlined above.

The scope of work included comprehensive collection, review, synthesis and interpretation of available data. This included collection of published as well as unpublished data and personal contacts with persons knowledgeable about the area. Limited field work and water sampling and chemical analysis was conducted, with additional field data input from the geology and soils teams.

Surface water, ground water, hydrologic balance and water use and availability are outlined in the following chapters. Much of the detailed data that the report was based on are presented in appendices. These include explanation of the well numbering system used in this report, well and spring data tables, chemical analyses and inundation maps for South Haiwee Dam.

SECTION 2

SURFACE WATER

The CGSA is located in the northern Mojave Desert, encompassing Rose Valley, Coso Basin, and several smaller enclosed basins located between Rose Valley and Coso Basin (Fig. 2.1, Plate II-1).

2.1 WATERSHED FEATURES

The drainage areas of Rose Valley, Coso basin, and the enclosed basins are shown in Table 2.1. Rose Valley is bounded by the Sierra Nevada on the west and the Coso Range on the east. The Coso Basin encompasses a major portion of the Coso Range. The crest of the range serves as the eastern and northern boundaries of the basin. The western and southern boundaries of the Coso Basin are comprised of upland cinder cones and lava flows and the White Hills. The enclosed basins are bounded by the complex topography of the lower Coso Range.

Table 2.1 Areas of Watersheds in the CGSA

Watershed	Area: Acres	Area: Square Miles
Rose Valley	89,640	140.07
Coso Basin	132,750	207.42
Upper Cactus Flat	10,350	16.18

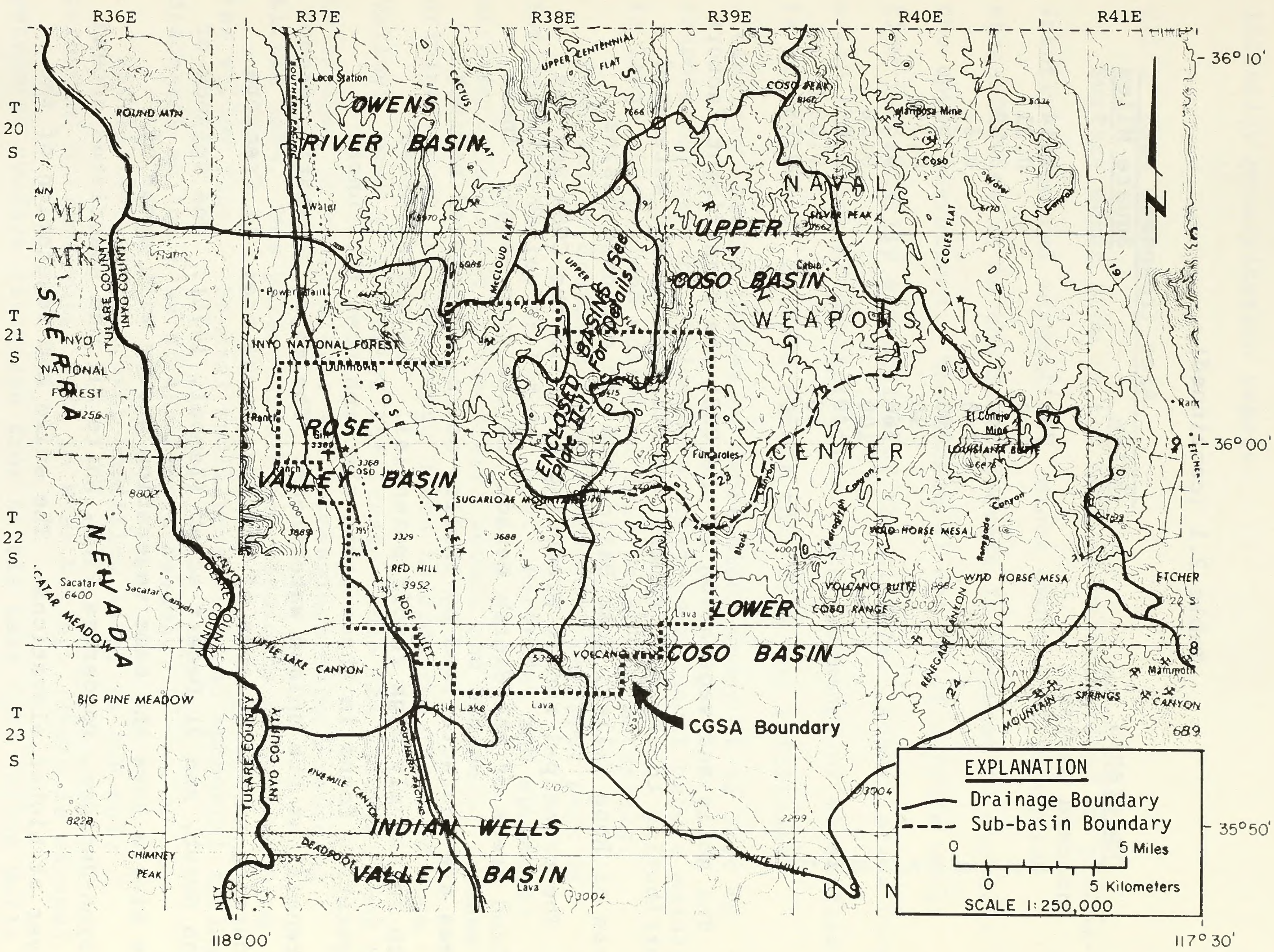


Figure 2.1 Watershed Boundaries - CGSA

Table 2.1 (continued)

Watershed	Area (rounded) Acres	Square Miles
Enclosed Basins		
A	730	1.14
B	200	0.31
C	3,840	5.99
D	260	0.41
E	990	1.55
F	90	0.14
G	360	0.56
H	100	0.16
I	40	0.06
J	50	0.08
K	30	0.05

The soils and vegetation in the CGSA are significant factors contributing to the high runoff potential of upland watershed areas of Rose Valley, Coso Basin, and the enclosed basins.

The principal runoff producing areas in the CGSA are the upland areas of the Sierra Nevada and the Coso Range. These areas are characterized by shallow soils and exposed bedrock with relatively high runoff potential. The sparse brush vegetation found in these areas also enhances the runoff potential of the upland watersheds. The major vegetation groups occurring in the uplands of the Coso Range are: 1) Creosote Bush Scrub, and 2) Desert scrub (Zembal, 1978). The uplands of the Sierra have the same vegetation groups with areas of Pinyon-Juniper, Ponderosa Pine, White Fir and associated ground cover at higher elevations. The soils and vegetation of the

CGSA are capable of retaining the moisture from most low intensity precipitation events.

2.1.1 Flow Regime

Surface water flow in the CGSA is characterized by predominantly ephemeral streamflow. Minor amounts of perennial streamflow exist in the Sierra Nevada in response to snowmelt at the upper elevations. The ephemeral nature of surface water flow is primarily a function of the climate. Desert areas have a low frequency of precipitation. The frequency of streamflow is still lower. Surface runoff that does not infiltrate ultimately reaches playas or depressions where it is lost to evapotranspitation. Voluminous short-term runoff occurs mainly in large steep sided washes of less permeable materials.

Rose Valley drains southward towards the upper part of Indian Wells Valley at Little Lake. Perennial and ephemeral streams originating in the Sierra Nevada and ephemeral streams originating in the Coso range drain towards the floor of Rose Valley. Most of the water infiltrates into the alluvial fans or is trapped in small playas and depressions before reaching Little Lake. The perennial streams terminate before reaching the valley floor. Several small perennial and ephemeral springs discharge at the base of the Sierra Nevada.

Little Lake, an emergent underflow lake, is the only perennial surface water body in Rose Valley. There is minimal perennial surface discharge from Little Lake into Indian Wells Valley. It is a flat bottomed spring fed lake with an area of about 100 acres. When its level is low two wells (23S/37E-8D1 and 8D2) pump water into it. In the spring of 1979 it is near its highest level up to 5 feet deep and averaging about 3-1/2 feet. During the dry year of 1976 it was about three feet lower (Bate, 1979, personal communication).

Little Lake is in a remnant of a former Owens River channel. It was a marshy area until a dam was constructed. Little Lake may be a sag-pond type feature associated with the northerly trending pre-Quaternary Little Lake fault (Plate I-1). This fault may be a ground water barrier and, in conjunction with the basement complex approaching the surface near Little Lake, water may be trapped by these features.

Coso Basin drains internally into Airport Lake on the south. Runoff from the Upper Coso Basin drains into the Lower Coso Basin via Coso Wash. Runoff from the Lower Coso Basin drains directly to Airport Lake. No perennial streams or water bodies occur in Coso Basin.

The enclosed basins in the Coso Range drain internally into small depressions and playas. Numerous springs flow on the east slope of the Coso Range. Perennial fumaroles and hot springs exist in the enclosed basins and Upper Coso Basin, particularly at Coso Hot Springs and Devil's Kitchen. Airport Lake is a large playa which contains water only after heavy rainfall. Its water is eventually lost by evaporation, and possibly to a minor extent by recharge to ground water.

2.2 RUNOFF

The CGSA has an arid to semiarid climate, characteristic of the Mojave Desert. Under these climatic conditions surface flow occurs on a relatively rare basis. In most years, surface water runoff may occur only several times (Table 2.2). Only in years of unusually high precipitation will streams flow onto the valley floors all year. This situation requires that the surface water hydrology be evaluated on an event basis as well as an annual basis.

The surface hydrology of a desert area is greatly influenced by the precipitation patterns of that area. Other major factors influencing the behavior of surface water are: 1) soils, 2) topography, and 3) vegetation. Precipitation in the Mojave Desert is produced by three types of storms: 1) general-frontal, 2) convective, and 3) tropical. The general-frontal storm is a low intensity, long duration event. This type of storm usually results in only minor surface runoff. The infiltration capacity of soils and interception capacity of vegetation are generally able to retain the precipitation. The convective storm is a high intensity, short duration event having limited areal extent. This storm can produce large amounts of runoff concentrated in highly localized areas. Generally, the intensity of convective storms exceeds the infiltration capacity of the soils. Tropical storms come from the incursion of moist, warm air from the south. They

Table 2.2. Streamflow at Little Lake Creek Near Little Lake, California for Water Years 1964 through 1967.*

Water Year	Date	Discharge (cfs)
1964	10-17-63	0.20
	8-04-64	0.20
1965	7-16-65	0.10
1966	10-19-65	0.20
	10-20-65	0.60
	10-21-65	0.30
	10-22-65	0.10
	11-16-65	0.10
	12-29-65	0.30
1967	12-06-66	0.50
	1-24-67	0.30
	4-02-67	0.10
	9-19-67	0.10

*Streamflow occurred only on days listed.
Location: Lat. 35°57'35", Long. 117° 54'50", in NW¼SE¼ Sec. 6, T23S, R38E, (Jorgensen, et al., 1971).

produce prolonged, steady, hard rains that are torrential at times. They are associated with high infiltration and severe runoff. Larger precipitation events probably occur when convective activity takes place within a large frontal storm system. Maximum precipitation events occur as tropical storms.

2.2.1 Annual Basis

The annual runoff in the CGSA is dependent on the temporal and spatial distribution of precipitation throughout the year. About seventy percent of the average annual precipitation occurs between November and March. During this period, the precipitation is caused by frontal activity which results in a minimal contribution to annual runoff. During late summer and early fall, convective storms can produce runoff volumes disproportionate with the precipitation amounts occurring during the storms. If convective precipitation made up a sizeable fraction of the annual precipitation, it would be possible to have a maximum annual runoff during a year of minimal annual precipitation. Estimates of average annual runoff were made, based on the annual precipitation estimates of Hydro-Search, Inc. and Rockwell International (Table 2.3). The annual runoff estimates were influenced greatly by the large variation observed in annual runoff data. It is questionable whether annual runoff statistics can be used to accurately describe the nature of surface water runoff in arid areas.

Table 2.3. Average Annual Precipitation and Runoff in the CGSA

Watershed	Average Annual Precipitation,[1] in.	Average Annual Runoff in.	Average Annual Precipitation,[2] in.	Average Annual Runoff in.
Rose Valley	7.5-8.0	± 2.0	7.2	1.8
Upper Coso Basin	8.6	2.2	5.2	1.3
Lower Coso Basin	6.7	1.7	4.8	1.2
Upper Cactus Flat	8.3	2.1	5.2	1.3
Enclosed Basins				
A	6.6	1.6	5.2	1.3
B	6.2	1.6	5.2	1.3
C	6.3	1.6	5.2	1.3
D	6.3	1.6	5.2	1.3
E	6.3	1.6	5.2	1.3
F	6.0	1.5	5.2	1.3
G	6.6	1.6	5.2	1.3

[1]Hydro-Search, Inc., 1978
[2]Rockwell International, 1979

2.2.2 Event-based

Event-based analysis is generally used to pinpoint the effects of extreme hydrologic occurrences. Analysis of extreme flood conditions is essential to the overall hydrologic evaluation of the CGSA.

The 100-year design storm was chosen for analysis as the extreme precipitation occurrence. A design storm analysis was made for each of the storm types occurring at the Coso KGRA. The 100-year 24-hour storm is representative of extreme frontal activity. The 100-year 6-hour storm is representative of extreme convective activity. The point precipitation for each storm over the CGSA was determined from the Precipitation-Frequency Maps for California (NOAA, 1972). The point precipitation values were adjusted for areal variation and durational variation (Hansen, et al., 1977). The mass rainfall distribution for each storm was estimated for each watershed in the CGSA (Tables 2.4 and 2.5).

Estimates of surface runoff were made using the hydrologic model, HYMO (Williams and Hann, 1972). The rainfall-runoff relationships of HYMO are based on the Soil Conservation Service (SCS) method of estimating runoff from small ungaged watersheds (1000 square miles). The mass rainfall distributions for each design storm and parameters representing the characteristics of the watersheds in the CGSA are used as input to HYMO. The parameters used are: 1) watershed area, 2) SCS runoff curve

Table 2.4 Mass Rainfall Distribution of 100 Year 24-Hour Storm.

Time	Cumulative Rainfall, inches			
	Rose Valley	Upper Coso Basin	Lower Coso Basin	Upper Cactus Flat and Enclosed Basins
12.00	0.00	0.00	0.00	0.00
13.00	0.25	0.19	0.16	0.19
14.00	0.49	0.38	0.32	0.38
15.00	0.74	0.56	0.48	0.56
16.00	0.98	0.75	0.63	0.75
17.00	1.23	0.94	0.79	0.94
18.00	1.48	1.12	0.95	1.12
19.00	1.72	1.31	1.11	1.31
20.00	1.97	1.50	1.27	1.50
21.00	2.21	1.69	1.42	1.69
22.00	2.46	1.88	1.58	1.88
23.00	2.70	2.06	1.74	2.06
24.00	2.95	2.25	1.90	2.25
25.00	3.20	2.44	2.06	2.44
26.00	3.44	2.62	2.22	2.62
27.00	3.69	2.81	2.38	2.81
28.00	3.93	3.00	2.53	3.00
29.00	4.18	3.19	2.69	3.19
30.00	4.42	3.38	2.85	3.38
31.00	4.67	3.56	3.01	3.56
32.00	4.92	3.75	3.17	3.75
33.00	5.16	3.94	3.32	3.94
34.00	5.41	4.12	3.48	4.12
35.00	5.65	4.31	3.64	4.31
36.00	5.90	4.50	3.80	4.50

Table 2.5 Mass Rainfall Distribution of 100 Year 6-Hour Storm.

	Cumulative Rainfall, inches			
Time	Rose Valley	Upper Coso Basis	Lower Coso Basin	Upper Cactus Flat and Enclosed Basins
16.00	0.00	0.00	0.00	0.00
16.25	0.04	0.03	0.02	0.03
16.50	0.07	0.06	0.05	0.06
16.75	0.10	0.09	0.08	0.08
17.00	0.14	0.12	0.10	0.11
17.25	0.20	0.16	0.14	0.16
17.50	0.26	0.20	0.18	0.20
17.75	0.32	0.25	0.22	0.25
18.00	0.38	0.29	0.26	0.29
18.25	0.65	0.58	0.45	0.68
18.50	0.92	0.86	0.64	1.07
18.75	1.18	1.14	0.83	1.46
19.00	1.45	1.43	1.02	1.85
19.25	1.54	1.50	1.08	1.93
19.50	1.64	1.57	1.14	2.02
19.75	1.73	1.64	1.21	2.10
20.00	1.82	1.71	1.27	2.18
20.25	1.86	1.74	1.30	2.21
20.50	1.90	1.78	1.32	2.24
20.75	1.94	1.81	1.35	2.27
21.00	1.98	1.84	1.38	2.30
21.25	2.01	1.86	1.40	2.32
21.50	2.04	1.87	1.42	2.34
21.75	2.08	1.89	1.44	2.36
22.00	2.11	1.90	1.46	2.38

number, 3) difference in elevation from the top of the watershed to its outlet, and 4) distance from the top of the watershed to its outlet. The SCS curve number is based on the hydrologic condition of the soils, the vegetation type and density, and land use. The parameters for watersheds in the CGSA are shown in Table 2.6.

Surface runoff and peak discharge estimates were computed by HYMO. The results are shown in Table 2.7. In general, the 24-hour storm produced greater quantities of runoff than the 6-hour storm and the 6-hour storm produced larger peak flows than the 24-hour storm. The principal effects of the 6-hour storm are due primarily to the peak discharge. The effects of the 24-hour storm are due primarily to the total volume of run-off.

The suface water runoff resulting from the design storms will move through the watersheds as described in Section 2.1. However, a significant portion of the runoff may be lost as channel infiltration. Runoff from Upper Rose Valley will flow to playas in the center of the valley and eventually into Little Lake. Little Lake will behave similar to a reservoir, storing some water as lake levels increase and discharging water via the south end of the lake. The runoff eventually discharges into Indian Wells Valley - approximately 31,000 AF from the 24-hour storm or 6,500 AF from the 6-hour storm. Runoff from Upper Coso Basin will flow down Coso Wash into the Lower Coso Basin and

Table 2.6. Watershed Parameters of the CGSA for Use in SCS Runoff Estimates

Watershed	Area, mi.^{2}	SCS Curve Number	Height Watershed, ft.	Watershed Length, mi.
Upper Rose Valley	136.633	85	5892	16.769
Lower Rose Valley	3.435	85	1694	3.107
Upper Coso Basin	65.381	89	4730	14.000
Lower Coso Basin	142.039	90	4820	17.500
Upper Cactus Flat	16.176	86	2587	6.500
Enclosed Basin				
A	1.143	84	635	0.888
B	0.311	84	687	0.543
C	5.994	84	1335	3.156
D	0.409	84	680	0.789
E	1.547	84	768	1.381
F	0.136	84	400	0.197
G	2.131	84	1286	2.466

Table 2.7. Estimates of Runoff from Watersheds in the CGSA for the 100-year Design Storms

		24-Hour Storm				6-Hour Storm			
		Precipitation, in.	Runoff, in.	Runoff, AF	Peak Discharge, cfs	Precipitation, in.	Runoff, in.	Runoff, AF	Peak Discharge cfs
Rose Valley	Upper	5.90	4.22	30730	20051	2.11	0.88	6391	21095
	Lower	5.90	2.07	378	258	2.11	0.88	161	939
Coso Basin	Upper	4.50	3.28	11250	7354	1.90	0.95	3250	12904
	Lower	3.80	2.74	20718	32143	1.46	0.65	4939	14782
Upper Cactus Flat		4.50	3.36	2899	2025	2.41	1.15	989	5616
Enclosed Basin									
A		4.50	0.43	26	19	2.41	1.08	66	670
B		4.50	0.09	2	1	2.41	0.46	8	80
C		4.50	2.29	731	532	2.41	1.04	334	2315
D		4.50	0.26	6	4	2.41	0.79	17	182
E		4.50	0.62	52	38	2.41	1.07	88	806
F		4.50	0.00	0	1	2.41	0.15	1	12
G		4.50	1.03	117	85	2.41	1.06	120	954

combine with runoff from the Lower Coso Basin. The runoff accumulates in Airport Lake - approximately 32,000 AF from the 24-hour storm or 8,200 AF from the 6-hour storm. The runoff in the enclosed basins terminates in depressions and playas.

The existence of Haiwee Reservoir presents an extreme hydrologic condition not normally considered in an event-based analysis. A large volume of surface water is stored in the Haiwee Reservoir. Failure of the dam or inflow into the reservoir from a major precipitation event would cause flow of surface water into Rose Valley. As a safety measure, the operational high water level of the South Haiwee Dam is set at 3744 feet elevation, 15 feet below the spillway (Lane, 1979). In the case of failure of the dam, estimates of the inundation of Rose Valley and Indian Wells Valley are shown in Appendix D.

2.3 SURFACE WATER QUALITY

The quality of surface water in the CGSA is influenced by the type of runoff generated by precipitation events. The chemical quality of runoff from frontal events probably varies little from that of convective events. The principal difference in water quality resulting from frontal and convective storms is suspended sediment. Frontal storm runoff generally produces minor channel and upland erosion, while convective storm runoff produces significantly greater channel and upland erosion.

Water quality data are difficult to obtain due to the infrequency of runoff events in the CES area. The locations of surface water sampling points are shown on Plate II-1. Water quality characteristics of surface runoff and surface water bodies are shown in Table 2.8. Chemical analyses for the Portuguese Canyon, Little Lake and Little Lake Canyon samples are presented in Appendix C4. They indicate that the chemical characteristics of surface runoff from the Sierra Nevada and Coso Range are consistent. Water from the surface water bodies, Airport Lake and Haiwee Reservoir, have lower specific conductance (are less mineralized) than streamflow water.

Since much of the surface runoff in the CGSA terminates in playas, Airport Lake is probably representative of the water quality of surface runoff in the Coso Basin. In arid areas, sediment is often the most important water quality parameter. Consequently, the sample from Airport Lake was analyzed for total suspended solids (TSS). A TSS value of 104 mg/l was determined using a 5-10 micron glass fiber filter and a TSS value of 3170 mg/l was determined using a 0.45 micron filter. The value of 3170 mg/l is characteristic of the fine suspended sediment found in the playa waters.

2.4 EROSION

Major runoff events can mobilize large amounts of sediment, particularly on steep slopes. In the CGSA, sheet erosion

Table 2.8. Water Quality Characteristics of Surface Waters in the CGSA

Sample Date	Location	Temperature, degrees C	pH	Specific Conductance, μmhos/cm @ 25 degrees C
2/7/79	Mountain Springs Canyon	13.5	8.28	826
2/7/79	Airport Lake	15.0	7.99	160
2/8/79	Little Lake Canyon	5.5	8.20	676
2/8/79	Sacatar Canyon	2.5	8.40	670
2/8/79	Portuguese Canyon	8.0	8.28	446
2/8/79	Haiwee Reservoir	4.0	7.99	263
4/0/79	Little Lake	--	8.8	1600

and wind erosion produce only minor sediment yields relative to channel erosion (Glosser, 1979). The soils in the CGSA are fairly stable and not susceptible to significant amounts of sheet erosion. The principal cause of upland erosion in the Coso Range is wind.

Wind erosion is most prevalent during the non-vegetative period of the year (October to May). The wind-eroded materials are generally deposited in stream channels, which further increases the potential for stream channel erosion.

Channel erosion and sediment transport are governed by the amount and duration of runoff and degree of channel development (Water Management Subcommittee, 1968). Frontal storms with associated convective activity produce long duration high flows, necessary for maximum sediment transport. Storms of this nature are characteristic of the CGSA. The amount of runoff and subsequent erosion are greatly reduced by infiltration to the stream bed. The porous materials in the stream beds in the CGSA are capable of sustaining large stream bed losses during runoff periods.

Estimates of annual sediment yield for the watersheds in the CGSA were made using the procedure described by the Water Management Subcommittee (Table 2.9).

Table 2.9 Estimates of Annual Sediment Yield for Watersheds in the CGSA

Watershed	Probable Range Annual Sediment Yield, AF/mi 2	Probable Value Annual Sediment Yield, AF/mi 2
Rose Valley	0.5 - 1.0	0.60
Coso Basin	0.5 - 1.0	0.75
Enclosed Basins	0.5 - 1.0	0.70

Although average annual values are not large, individual storms can produce large quantities of sediment in stream channels and playas in the CGSA. The annual sediment yield is moderated by the infrequent occurrence of large convective storms, which produce the high sediment yields.

SECTION 3

GROUND WATER

The ground water aspects of the hydrology task are outlined in this section. It includes discussion of hydrologic units and their water bearing properties, ground water movement, chemical characteristics of ground water, hydrologic models of the geothermal reservoir and cooler ground water system and a discussion of potential ground water degradation.

Well and spring data tables are presented in Appendix B. The descriptions of wells and exploration holes include state number, owner, drilling and completion data and water and well use. The description of springs includes state number, discharge, altitude, improvements and water use. A compilation of water levels in wells is also included.

Chemical analyses of water are presented in Appendix C. This is divided into tables for nonthermal wells, thermal wells, geothermal exploration wells, springs and surface water.

3.1 HYDROLOGIC UNITS

Hydrologic units are traditionally divided into two major categories: 1) non-water-bearing units; and 2) water-bearing units. The major water bearing unit in the CGSA are the Quaternary alluvial sediments. The fractured granitic and metamorphic areas of the Pre-Tertiary basement complex, the

Tertiary and Quaternary volcanic areas and the Tertiary Coso formation are not considered water-bearing units (Dutcher and Moyle, 1973, p. 8).

The aerial distribution of these units is shown on Plate I-1 (Geology Map) and their geologic descriptions are in the Geology Technical Report. The extent and hydrologic characteristics of each of these units is described below. Since aquifer test data and ground water basin development is extremely limited in the CGSA, descriptions of the hydrologic characteristics are based largely on the characteristics of analogous lithologic units in nearby areas.

3.1.1 Non-water-bearing Units

The basement complex is exposed along the east front of the Sierra down to an elevation of about 4200 feet and along the east and west sides of the Coso Range. It is several kilometers thick. The volcanics cover an area of several square miles within the study area and continue extensively southward. They are several hundred feet thick (Kunkel and Chase, 1969, p. 22). The Coso formation occurs in the northern part of Rose Valley and has a maximum thickness probably over 1000 feet (Stinson, 1977).

The basement complex rocks typically have no primary porosity. Their porosity is wholly contained in the fractures and it is generally quite low, usually much less than one percent, compared with porous sedimentary deposits. The storage capacity is generally low since the storage is limited only to the fractures. The sustained specific yield is also generally low due to the low storage and limited interconnection between fractures. The permeability will be highly variable depending upon whether a fracture is intercepted and its size.

These fractures may range in size from microscopic to several meters wide, with associated alteration and gouge zones. One of the characteristics of fracture porosity is that it is extremely variable from location to location. Fractures may or may not be hydraulically conductive depending on the number per unit volume, their respective size and orientation (particularly with respect to ground water flow direction) and whether they are filled with impermeable material. Each of these parameters may change along a given fracture from one location to another.

Although fractured crystalline rocks are considered non-water-bearing in traditional ground water development, these rocks are the potential geothermal reservoir. Its porosity is not known but is estimated to range from less than 1% to 6% (Combs, 1976a). The crystalline rocks of the Coso Range are extensively fractured into blocks about 1/3 to 1 m (1 to 3 ft) on a side (Duffield and Bacon, 1976; Hulen, 1978). The pervasiveness of this fracturing suggests good hydraulic communication within the reservoir. Whether the storage capacity of these fractures is sufficient for geothermal power production is not known. Assumptions about the geothermal reservoir and its hydraulic characteristics are described in ES Chapter 1 - Appendix B. A model of the reservoir is presented in Section 3.4. Its geologic characteristics are discussed in Section 2 of the Geology Technical Report.

The volcanics are largely basalt flows. They are composed of many separate flows interbedded in some places with scoria, pumice, obsidian, younger alluvium and probably andesite (Kunkel and Chase, 1969, p. 22). In general, permeability of basalts is highly variable, the more permeable zones being between lava beds and along lava tubes, cracks and joints (Walton, 1970, p. 38-39). The basalts of the study are are mostly quite dense and impermeable. They will yield only limited amounts of water from cracks, fractures, scoria and pumice (Kunkel and Chase, 1969, p. 23).

The Coso formation is a consolidated sedimentary and volcanic deposit consisting of interlayered fanglomerate, lacustrine beds and rhyolitic pyroclastic rocks. Its hydrologic properties are analogous to the Ricardo formation which crops out in Indian Wells Valley (Moyle, 1979, personal communication). Since these deposits are indurated and poorly sorted, yields of water are insignificant. Local lenses may be more permeable and water most likely occurs in fractures beneath the water table (Kunkel and Chase, 1969, p. 16).

3.1.2 Water-Bearing Units

The Quaternary alluvial sediments (Qal) are the principal water-bearing unit in the CGSA. It consists mainly of alluvial fan and stream deposits. The fans are irregularly bedded and consist of a heterogeneous mixture of unconsolidated clay, silt, sand, gravel and boulders. Alluvial sediments contain primary, intergranular porosity. They are typically multi-layered, heterogeneous with anisotropic and nonhomogeneous permeability. Consequently, perched or semi-perched aquifers may overlie confined or semi-confined beds, as is seen in the Owens Valley ground water basin.

The alluvium in the central or west portion of Rose Valley is composed of finer and better sorted debris than the fans aproning the Sierra front. These units have a wide range of permeability depending on the degree of sorting and grain size in each specific locality. Production for a given well is generally proportional to the quantity of coarse, well sorted material penetrated beneath the water table. Any properly constructed well in the central alluvial area could be expected to yield moderate to large quantities of water (Kunkel and Chase, 1969, p. 26). Some wells in the alluvium of Indian Wells Valley yield more than 4000 gpm (Dutcher and Moyle, 1973, p. 8).

The fans are not as consistently good aquifers as the more central alluvial sections. Wells located on the fans tend to require larger pumping lifts and hence are more expensive than comparable wells located off the fans (Kunkel and Chase, 1969, p. 25).

Thickness of Alluvial Deposits--

Estimated thickness of alluvium in Rose Valley is shown on Fig. 3.1. This was interpreted from gravity data (Healy and Press, 1964) with geophysical and geologic borehole logs for control in a few areas. Maximum valley fill thickness reaches 5,600 feet (Healy and Press, 1964) in the north-central part of the valley. The fill thickens most rapidly in the north and east portion of the valley. The structural interpretation derived from the gravity data implies displacement on a Coso Range frontal fault of up to 5000 feet (Fig. 3.3). It shows a steep-sided, deep trough in the north end of Rose Valley (Fig. 3.4). The frontal fault displacement is not unreasonable for the east side of the Sierra. The trough on the north end of the valley appears anomalous. Conceivably it could be due to an ancient large displacement NNE-NE trending fault. Such a fault is shown on the St. Amand and Roquemore (1978) preliminary structural interpretation (Plate I-2, Geology Technical Report).

Three gravity profiles were run each trending ENE across the valley. Agreement between the gravity profiles and drill hole data is best along the southern gravity line. The eastern parts of the north and middle gravity lines do not agree well with drill hole data, and in these cases, drill hole data have been used for contouring. The discrepancy in the northeast appears to be due to the two-layered model used for gravity

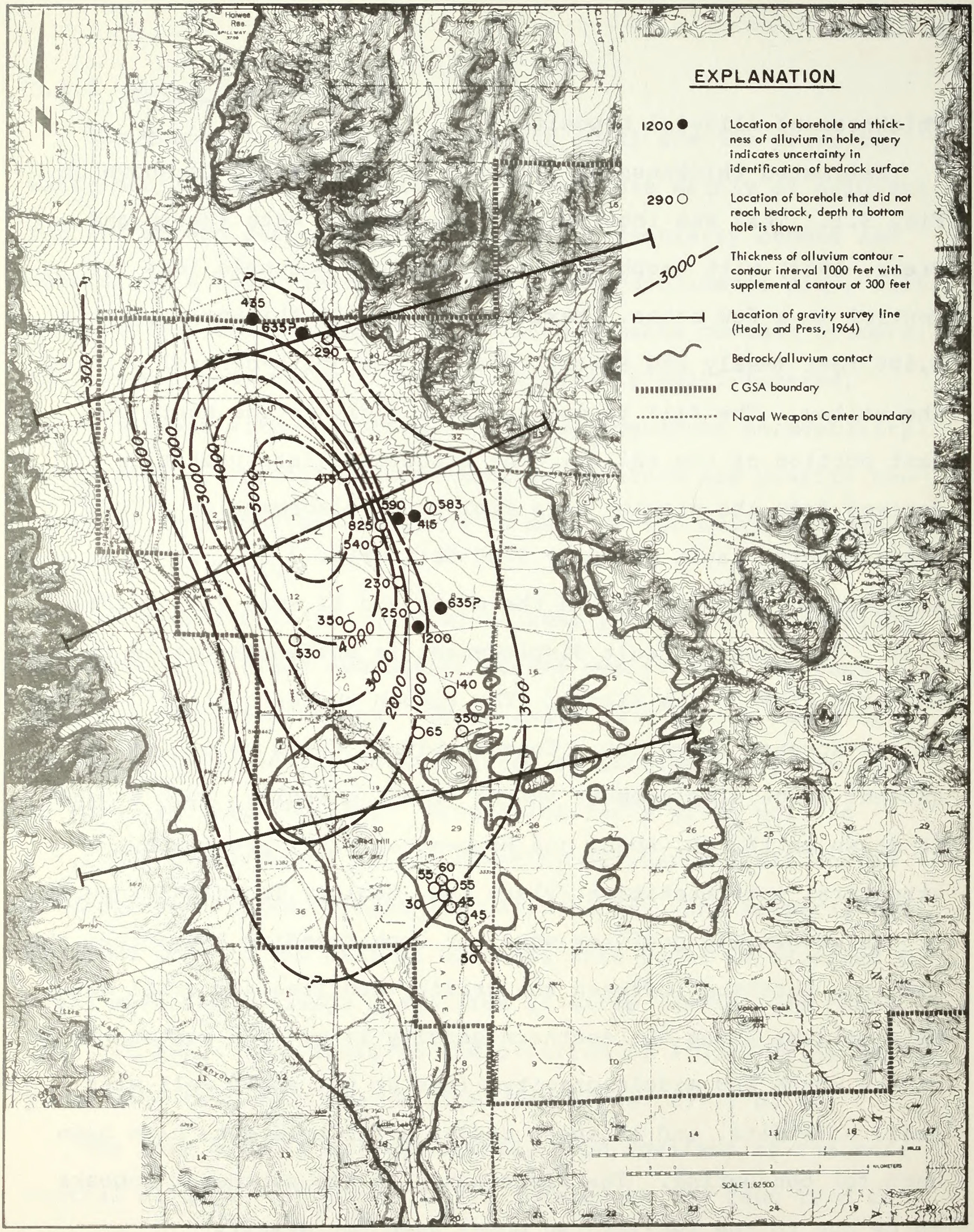


Figure 3.1 Estimated thickness of alluvium in Rose Valley

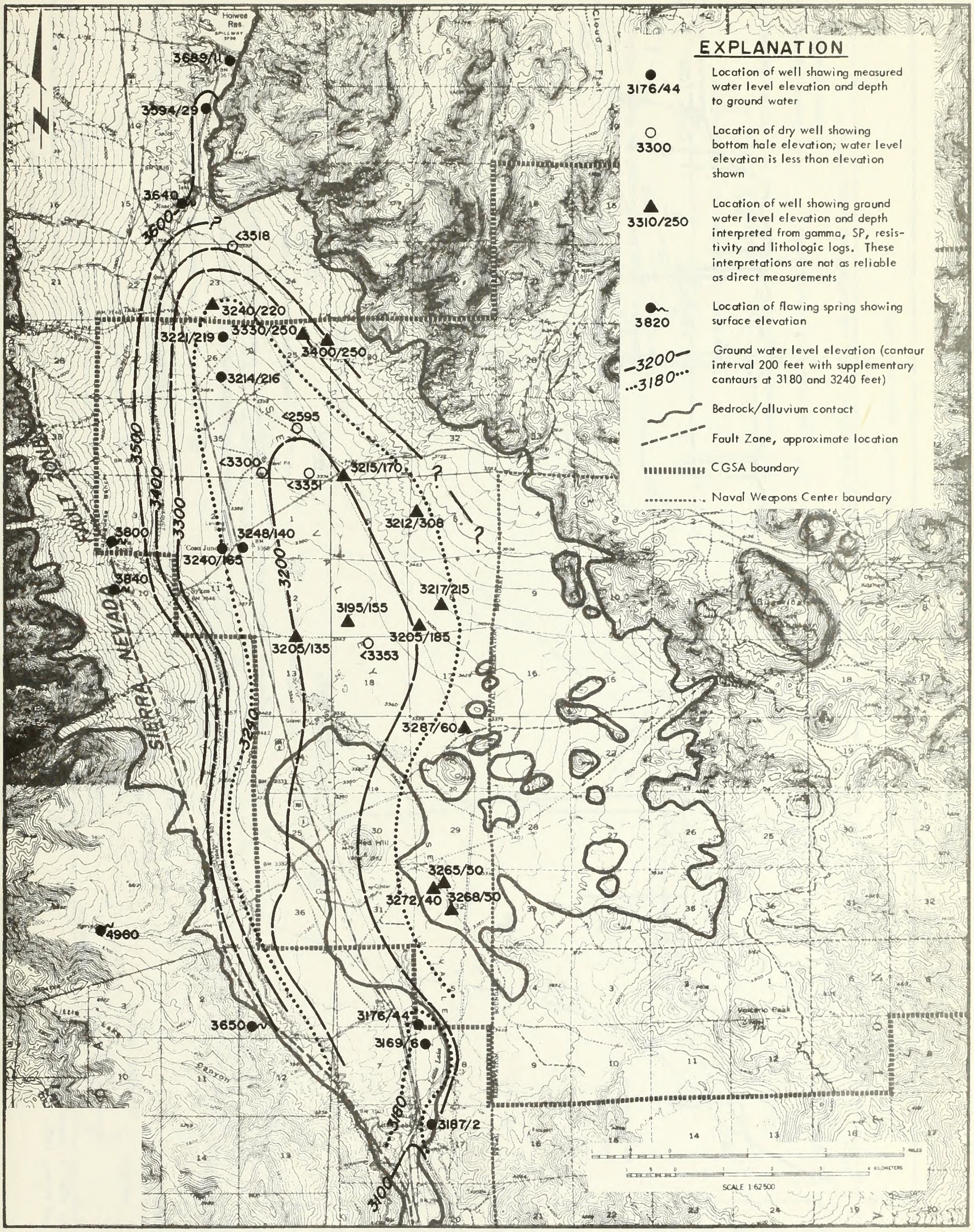
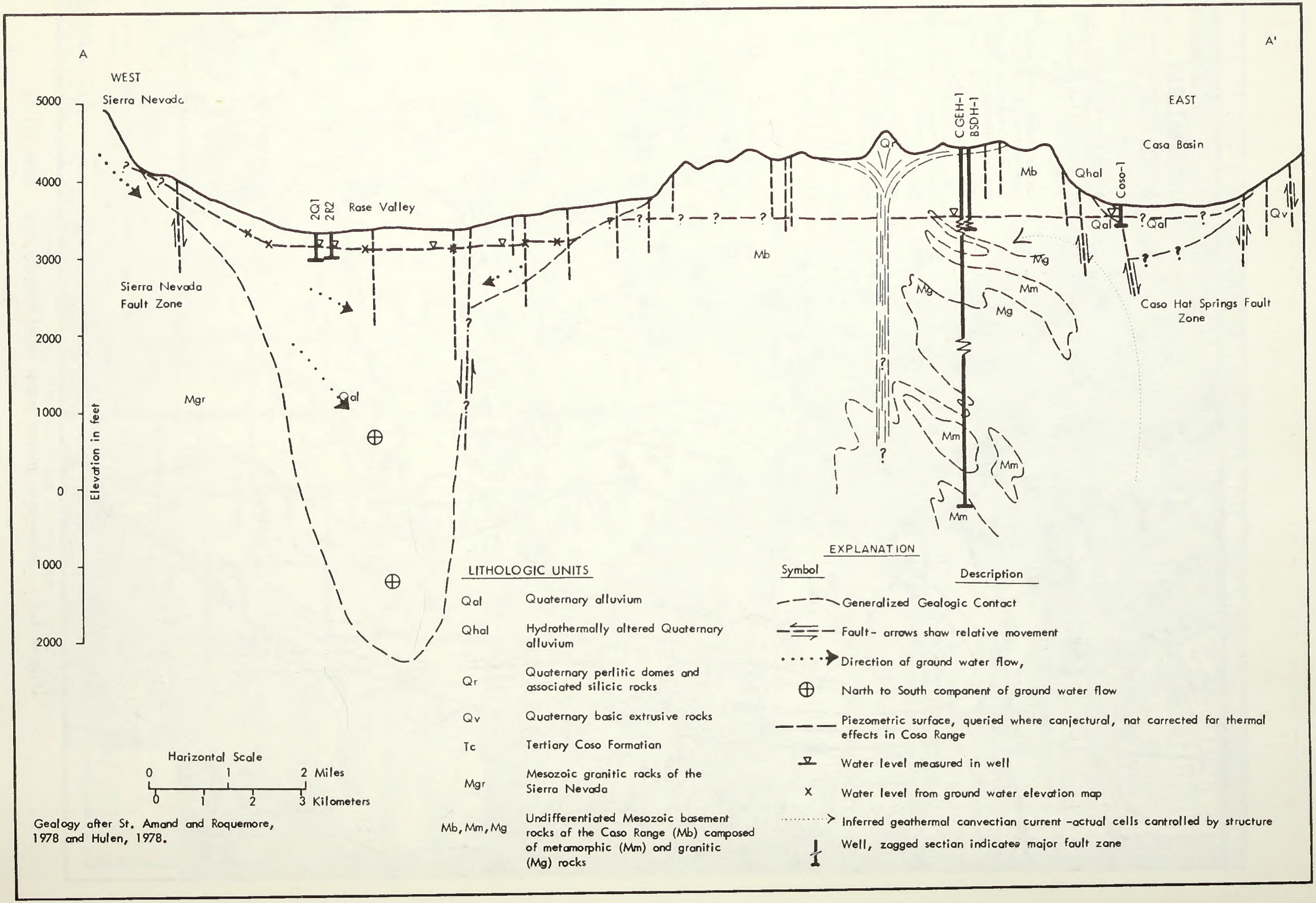


Figure 3.2 Schematic ground water level contour map - Rose Valley

Figure 3.3 East-west section across the CGSA



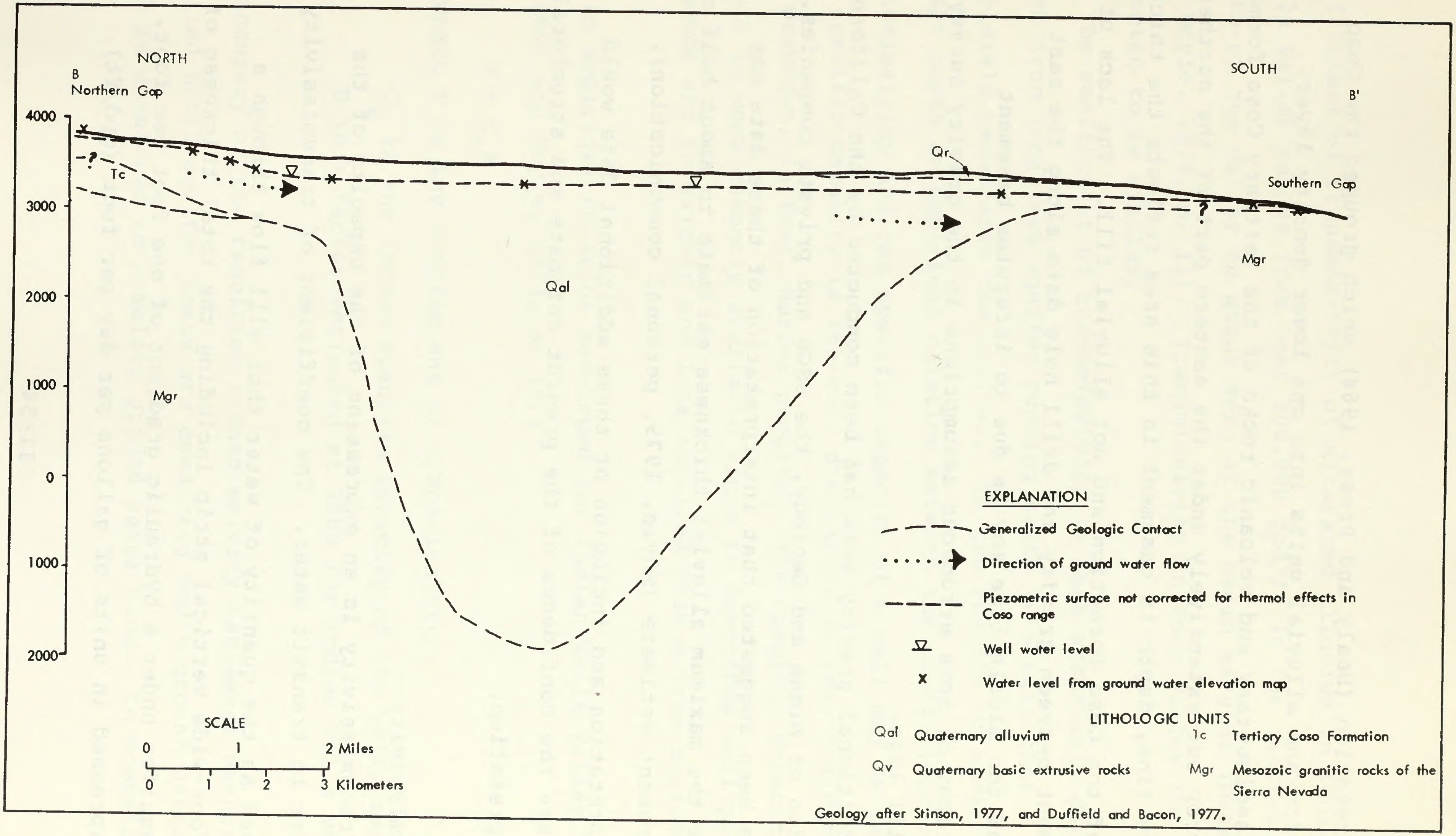


Figure 3.4 North - South section across Rose Valley

interpretation (Healy and Press, 1964) which grouped the Coso formation and alluvial units into one lower density layer. Since sedimentary and volcanic rocks of the Tertiary Coso formation crop out extensively under the eastern part of the northern gravity line, depth to basement in this area reflects the thickness of the Coso formation and not alluvial fill. The lack of agreement between gravity and drill hole data along the east part of the middle line may be due to irregular basement topography or some erroneous assumptions in the gravity survey or drill logs.

Additional gravity work has been conducted by the California Division of Mines and Geology, the USGS and private companies. It has been suggested that interpretation of these data may reduce the maximum alluvial thickness estimate to about half of the present estimate (Moyle, 1979, personal communication). Interpretation and inclusion of these additional data would increase the confidence of the present estimate and structural interpretation.

Transmissivity--

Transmissivity is an expression of the capacity of the aquifer to transmit water. The coefficient of transmissivity is defined as the quantity of water that will flow through a one-foot-wide vertical strip including the total thickness of the aquifer under a hydraulic gradient of one foot per foot. It is expressed in units of gallons per day per foot (gpd/ft). The coefficient of transmissivity of saturated alluvium in Indian Wells Valley ranges from over 300,000 gpd/ft in the central parts of the valley to about zero at the basin margins (Dutcher and Moyle, 1973, p. 11). Transmissivity in Rose Valley can be expected to be similar.

The coefficient of transmissivity is most accurately determined from long-term aquifer pumping tests in a well that completely penetrates the aquifer. In the absence of such direct tests an empirical relation between the coefficient of transmissivity and the specific capacity of a well may be used. The specific capacity is the well discharge, in gpm, divided by the drawdown, in feet, during pumping. The specific capacity of a well is more commonly available since it describes well performance and is quicker and less involved than a true aquifer test.

An empirical relation developed for Indian Wells Valley is (Dutcher and Moyle, 1973, p. 10):

$$T = C_s B$$

where T is the coefficient of transmissivity,

C_s is the tested specific capacity of the well, and

B is a factor estimated at 2000 for Indian Wells Valley

The accuracy of the resulting transmissivity estimates cannot be verified until aquifer tests are conducted and a ground water model is developed to simulate ground water flow. In comparing

Indian Wells Valley with other basins having similar geologic conditions the relationship is expected to be valid using the B factor of 2000. Assuming the hydrologic situation in Rose Valley is analogous, coefficients of transmissivity were computed (Table 3.1). For the few wells with data, they range from about 10,000 to over 150,000 gpd/ft.

Other Sediments--

Other sediments with primary intergranular porosity are the Quaternary older alluvium (Qoal) and the Quaternary rhyolite pyroclastic deposits (Qrp).

The pyroclastics (Qrp) occur in the rhyolite dome area in several small (generally less than 1 square mile) isolated deposits adjacent to most of the rhyolite domes. The maximum thickness is 200 feet (Stinson, 1977). it is very porous and has moderate permeability (Peters, 1979, personal communication; Walton, 1970, p. 39). Rapid infiltration of rainfall was observed on this unit. The depth to water is not known, but is probably quite deep and may have some hydraulic continuity with the geothermal reservoir.

The older alluvium (Qoal) occurs in the northeastern portion of Rose Valley. It is distinguished from the younger alluvium by its dissection. The feldspar minerals in the matrix of these deposits has been altered to clay (Kunkel and Chase, 1969, p. 18) and the mineral grains are cemented by silica (Peters, 1979,

TABLE 3.1 ROSE VALLEY WELL HYDRAULICS
(modified from Moyle, 1977)

Explanation

Data Source: M = Moyle, 1977; S = Southern California Edison, 1977, 1978 and 1979; L = LADWP, 1979; A = Antelope Valley Pump Services, 1977.

Time: Time of measurement, in minutes, after pump was started.

Static water level: Depth to water, in feet below or above (+) land surface datum, prior to start of test.

Pumping water level: Depth to water, in feet below or above (+) land surface datum, at end of test. Q means flowing above land surface.

Drawdown: Difference, in feet, between the static and pumping water levels.

Yield: Yield of the well, in gallons per minute, for drawdown indicated.

Specific capacity: Yield, in gallons per minite per foot of drawdown. In a fully efficient and fully penetrating well, specific capacity directly reflects aquifer transmissivity. A declining specific capacity, with time, indicates deteriorating well condition. An increasing specific capacity indicates continuing development of the aquifer near the well. For a given amount of available drawdown, a well with a large specific capacity will have a greater yield than a well with a small specific capacity.

Coefficient of Transmissivity: Computed from the following formula (Dutcher and Moyle, 1973, p. 10)

$$T = C_s B$$

where T is the coefficient of transmissivity

C_s is the tested specific capacity of the well

B is a factor estimated at 2000 for Indian Wells Valley. It is used for Rose Valley, assuming analogous conditions.

Table 3.1 (continued)

State Number	Data Source	Date	Time (min)	Static Water Level (ft)	Pumping Water Level (ft)	Drawdown DD (ft)	Yield (gpm)	Specific Capacity (gpm/ft of DD)	Estimated Coefficient of Transmissivity (gpd/ft)
21S/37E-2K1	M	12/30/74	300	10.6	74.6	64.0	290.0	4.50	9,000
21S/37E-2K1	M	11/12/75			43.4		260.7		
21S/37E-2K1	L								20,000
21S/37E-11C1	M	35				38.0	493.7	13.00	26,000
21S/37E-26B1	M	03/18/71				240.0	2700.0	11.20	22,400
	S	06/25/76		237.2	263.2	26.0	2013	77.4	154,800
	S	06/28/77		236.9	263.6	26.7	2063	77.3	154,600
	S	08/14/78		244.8	275.5	30.7	2361	76.9	153,800
21S/37E-26K1	S	06/10/76		215.7	247.0	31.3	1089	34.8	69,800
	S	06/28/77		205.9	238.5	32.6	1133	34.8	69,600
	S	08/11/78		218.7	250.7	32.0	1286	40.2	80,400
22S/37E-2Q1	A				220		200		
22S/37E-2R2	M	56		142.0			20.0		
22S/37E-2R2	M	10/26/61					20.0		
22S/39E-4H8	M	06/27/67					40.0		
23S/38E-8D1	M	11/10/75			6.1		60.0	34.00	64,000
23S/38E-iD2	M	11/10/75			11.2		100.0		
23S/38E-17D2	M	11/13/75			Q6.1		1122.0		

personal communication). This combination of conditions results in low permeability.

3.2 GROUND WATER MOVEMENT

Ground water, like surface water, flows down gradient. While surface water gradients are defined by topography, ground water gradients are defined by water levels in the ground. These water levels are generally determined by measurements in wells. When enough data are available, a ground water level contour map may be constructed. Direction of ground water movement can then be derived, since flow direction is downslope, perpendicular to the contours. Very little data are available for the CGSA. However, compilation and interpretation of all data has allowed construction of a schematic ground water level contour map for Rose Valley (Fig. 3.2)

3.2.1 Ground Water Flow in Rose Valley

A schematic ground water level contour map of Rose Valley was constructed from available water level measurements and interpretation of geophysical well logs (Fig. 3.2). The water level elevations shown are only a generalized representation of the existing water table due to the following limitations and assumptions:

1) All the water levels were not determined at the same time, hence seasonal, annual or long-term variations may introduce some distortion of the contours.

2) The measured water levels were acquired from various sources, hence the conditions and accuracy of measurement is not known.

3) Most of the water levels determined from the geophysical well logs appear consistent with the measured levels, but interpretation of these data is considered to be more tenuous than actual measurements.

4) Top of casing elevations have been reported by Moyle (1977) to the nearest 10 feet. Other well elevations have been determined from topographic maps with an 80-foot contour interval and may be off by ±40 feet.

5) An unconfined single aquifer was assumed.

6) The water level measurements were not corrected for temperature

The ground water level contours shown in Figure 3.2 show that ground water is flowing into Rose Valley from the east and west with perhaps another component from the north. The contours on the Sierra side of the valley are constructed to show the Sierra Nevada fault zone as a ground water barrier.

Two cross sections were constructed from the geologic and hydrologic data: one trending east-west (Fig. 3.3), the other trending north-south (Fig. 3.4). The locations of these sections are shown on Plate II-1. Relationships that can be seen on the east-west cross section (Fig. 3.3) are:

a) the water levels in the Sierra are higher than the water levels in Rose Valley

b) the water levels in the Coso Range are higher than the water levels in Rose Valley

c) the water level elevations in CGEH-1 and Coso No. 1 are about the same at 3460 feet.

d) the hydraulic gradient from the Sierra into Rose Valley is steeper than the gradient from the Coso Range into Rose Valley

e) the water table is relatively flat at about 3200 feet elevation east-west across Rose Valley.

Relationships that can be seen on the north-south cross section (Fig. 3.4) are:

a) water levels are higher in the north than they are in the south

b) the water table intersects the ground surface in the southern part of Rose Valley

c) the ground water elevation gradient is much steeper just south of Haiwee Reservoir in the northern part of Rose Valley

d) the water table is closer to the surface in the south than in the north. This can also be seen in the depth to water contour map (Fig. 3.5)

e) the slope of the topography from about Red Hill south to Little Lake is much greater than the slope of the water table. The ground surface drops about 280 feet over this distance while the water table drops only about 40 feet.

From the foregoing observations we can draw the following implications about ground water flow in Rose Valley:

a) the major component of ground water flow is from west to east from the Sierra, and the Sierra Nevada fault zone apparently acts as a ground water barrier.

b) the configuration of the contours impiles an east to west component of flow from the Coso Range into Rose Valley. If this is true, then there is hydraulic connection between the geothermal reservoir and the ground water in Rose Valley. Alternatively, a ground water barrier prevents flow between Rose Valley and the geothermal reservoir. Presently there is not enough water level elevation data to determine which of these interpretations is correct.

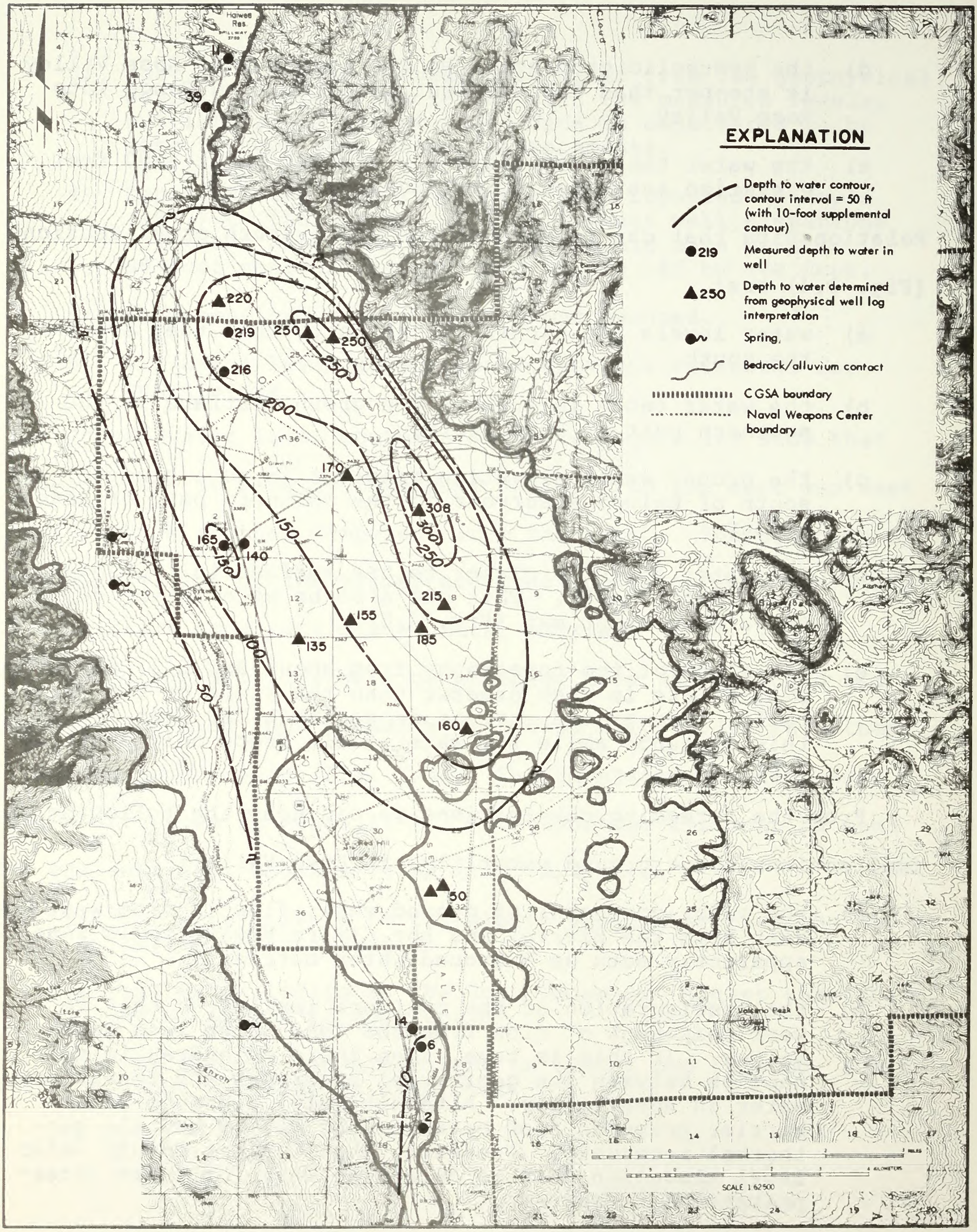


Figure 3.5 Schematic depth to water contour map - Rose Valley

3.2.2 Ground Water Flow in the Coso Range

There are several hypotheses for ground water movement in the Coso Range, particularly with respect to recharge of the geothermal reservoir. Implications that can be drawn about ground water flow within the Coso Range from Figure 3.3 are:

a) CGEH-1 and Coso No. 1 are in hydraulic communication

b) the water table in the Coso Range is essentially horizontal at 3460 feet

c) if the water table is relatively flat, as b) implies, then there is either very good hydraulic conductivity within the reservoir or the fluid has had a long time to equilibrate

d) not considering thermal and chemical effects on water density the fact that the water table appears higher in the Coso Range than in Rose Valley would tend to indicate that the reservoir is not being recharged from the Sierra

e) if there is not hydraulic barrier between the Coso Range and Rose Valley, then ground water would flow from the geothermal reservoir into Rose Valley. This implication may be negated if the water levels were corrected for temperature effects.

f) if the reservoir is not being recharged from the Sierra and the flat water table implies essentially no east to west or west to east flow, then recharge, if any, would have to come from the north.

The hypothesis suggesting that deep recharge flows east from the Sierra to the geothermal reservoir (Spane, 1978) appears quite tenuous. This water would flow in easterly trending fractures in the crystalline rock of the Coso Range. A similar mechanism for recharge is suggested for the Roosevelt geothermal area in

Utah where recharge is reported to come from the Tushar Range, beneath an alluvial valley, into the geothermal reservoir (Whelan, 1979, personal communication). Another hypothesis suggests magmatic water mixing with other recharge from precipitation. Recharge from precipitation percolating directly downward into the reservoir is unlikely due to the extremely low rainfall on the Coso Range. A third hypothesis suggests that flow comes from the mountains to the north or conceivably from the Owens Lake area. Recharge following this path would parallel the major structural trends of the region. This is more likely than easterly flow transverse to the regional structure.

In addition to the deep reservoir system in the Coso Range, shallow ground water apparently occurs as one or more perched water tables above the geothermal reservoir. The water level of the reservoir occurs at a depth of several hundred feet and shallow ground water most probably flows along the contact between porous rocks and the basement complex surface beneath it. These porous rocks would include the rhyolite pyroclastic debris, weathered basement rock, and Quaternary alluvium.

3.3 WATER CHEMISTRY

Water chemistry data can serve two purposes in a hydrologic study. First, water chemistry can establish the baseline conditions existing in the surface and ground water environments prior to development. This is a necessary requirement for an

ES. The second function is to provide clues to the origin, genesis and relationships between the various water regions and regimes in the area. That is, it can help to define areas of similar water characteristics, the relationship between ground, surface and geothermal waters or what processes each water may undergo. The degree to which the data can serve these purposes is directly related to the quality and quantity of available data. In the Coso area the data are quite limited. Hence many of the hypotheses remain tentative.

Water chemistry data for wells, springs and surface waters in the Coso area were compiled and plotted using modified Stiff diagrams and Langelier-Ludwig diagrams. Interpretation of these diagrams suggests that there are three fairly distinct "parent" waters in the CGSA. They are a sodium sulfate water, a sodium chloride water and a calcium carbonate water (Fig. 3.6). All natural water in the CGSA result from these "parent" waters or some mixture of them.

3.3.1 Methodology

Limited water sampling and analysis were conducted for this project. Analyses were available for all wells and springs that could have been sampled. A sampling and analysis program that would provide sufficient detail to improve on the existing available data is beyond the scope of this study. An isotope study is presently being conducted by the USGS (Fournier, 1979,

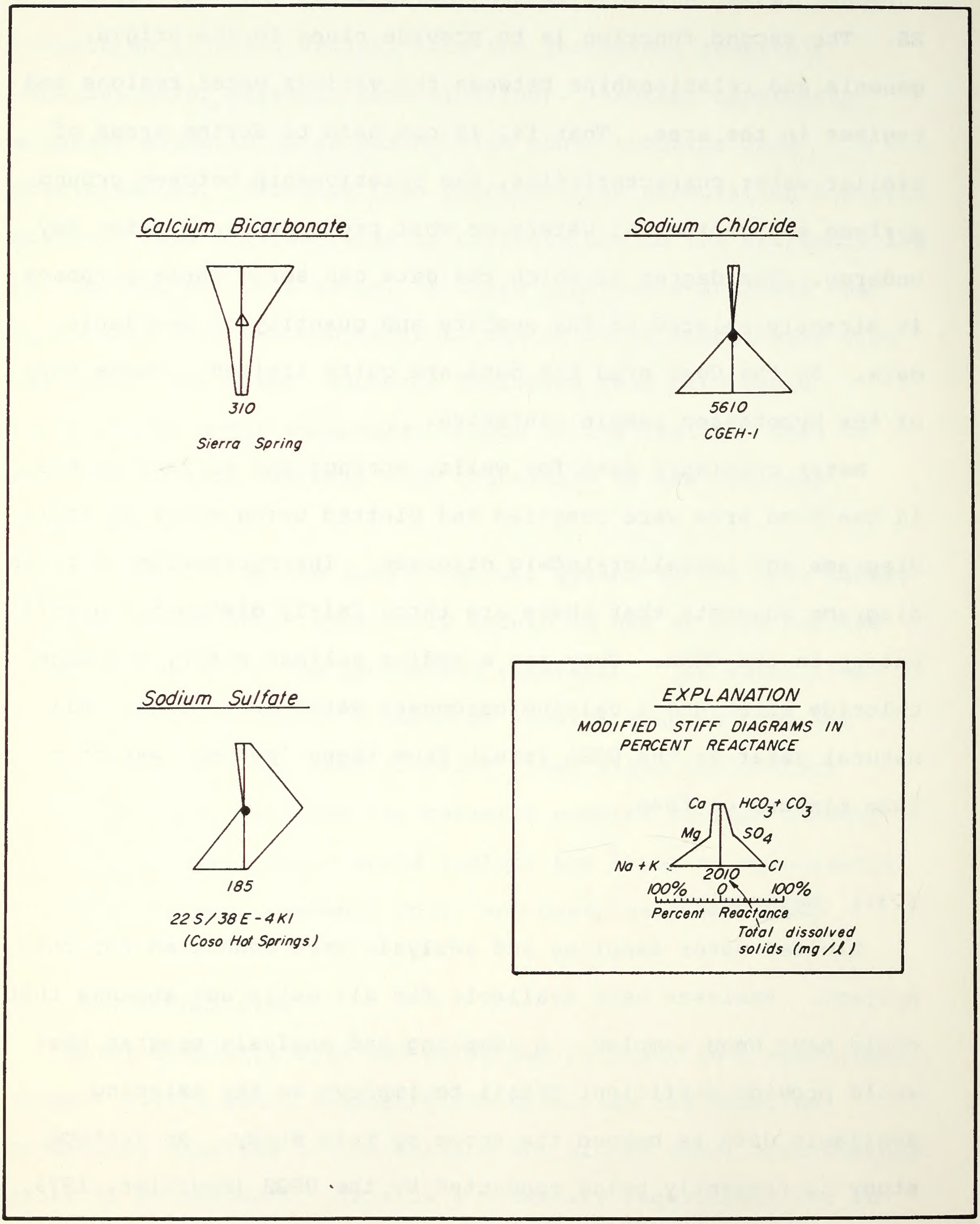


Figure 3.6 Natural water types - CGSA

personal communication). The results of this study should provide much information on the origin, movement, and genesis of waters in the CES area.

The chemical analyses used in this report are presented in Appendix C. The analyses were checked for internal consistency with an anion-cation balance calculation. Except for a few highly acidic, silica-rich thermal waters, analyses which did not balance were not used or reproduced in Appendix C.

The Stiff and Langelier-Ludwig diagrams are commonly used in ground water quality studies. Use of either has limitations with respect to interpretation and aquifer correlations. Stiff diagrams permit representation of the areal distribution of waters, but it is difficult to delineate chemical groupings and mixing relationships from them. They would be most useful when comparing only a few characteristic water types within a limited concentration range. The Langelier-Ludwig plots depict chemical groupings of waters and can represent, with their salinity cross sections, mixing and rock-water interactions, as well as concentration and dilution.

The methods used provide suggestions of aquifer-water correlations and provide a useful basis for comparison with future water chemistry surveys to determine changes from a baseline condition. Additional data collection and study will be necessary to further define the relationships of different waters and aquifers.

Modified Stiff Diagrams--

Stiff diagrams (Stiff, 1951) are closed polygons which show relative concentrations of major ionic constituents of water (Fig. 3.6). Water with similar chemical characteristics will have Stiff diagrams with similar shapes. The modified Stiff diagrams used for this study are plotted with ionic concentrations expressed as percent reactance in order to accommodate the range in total dissolved solids (TDS). For each diagram the well number and TDS in mg/l are shown by adjacent numbers. The Stiff patterns are plotted on a base map to show the areal distribution of different types of waters (Plate II-2).

For this study the Stiff diagram is constructed with a vertical line bisecting three horizontal axes (Fig. 3.6, Plate II-2). The axes to the left of the vertical line represent the major cations, from top to bottom, calcium, magnesium and sodium plus potassium, in percent reactance from zero to one hundred. Similarly, the major anions, bicarbonate plus carbonate, sulfate and chloride, are represented from top to bottom on the right side of the diagram. The percent reactance values are calculated separately for cations and anions as the individual ion concentration expressed in milliequivalents per liter divided by the respective total anion or cation concentration expressed in milliequivalents per liter. These diagrams differ from those originated by Stiff (1951) in that he used milliequivalents per liter for the scale and had the ions represented in a different order.

Langelier-Ludwig Diagrams--

The Langelier-Ludwig (L-L) diagram (Langelier and Ludwig, 1942) (Figs. 3.7, 3.8, 3.9, 3.10, 3.11) is similar to the rhombohedral section of the Piper diagram (Piper, 1944). It is a square plot of percent reactance of alkalic cations (Na+K) ascending from 0 to 100 on the left hand vertical axis and hardness cations (Ca+Mg) descending from 100 to 0 on the right hand vertical axis (Fig. 3.8). The horizontal axes plot percent reactance of carbonate anions (HCO_3+CO_3) and noncarbonate anions (SO_4+Cl), with each axis reciprocating the scale of the oppposite axis. This diagram provides a method for "segregating analytic data for critical study with respect to sources of the dissolved constituents in waters, modifications in the character of water as it passes through an area and related geochemical problems" (Piper, 1944). It allows for investigation of compositional relations among samples and statistical populations of samples in the form of clusters of points.

Salinity sections (Figs. 3.9, 3.10 and 3.11) can be drawn at any orientation on the Langelier-Ludwig diagram to depict changes in concentration. These sections are constructed by projecting all the data points desired to be included in the section onto a straight line extending from one L-L diagram axis to an opposite axis. A triangle is formed by extending two lines from above at an angle of about 90° to intersect the

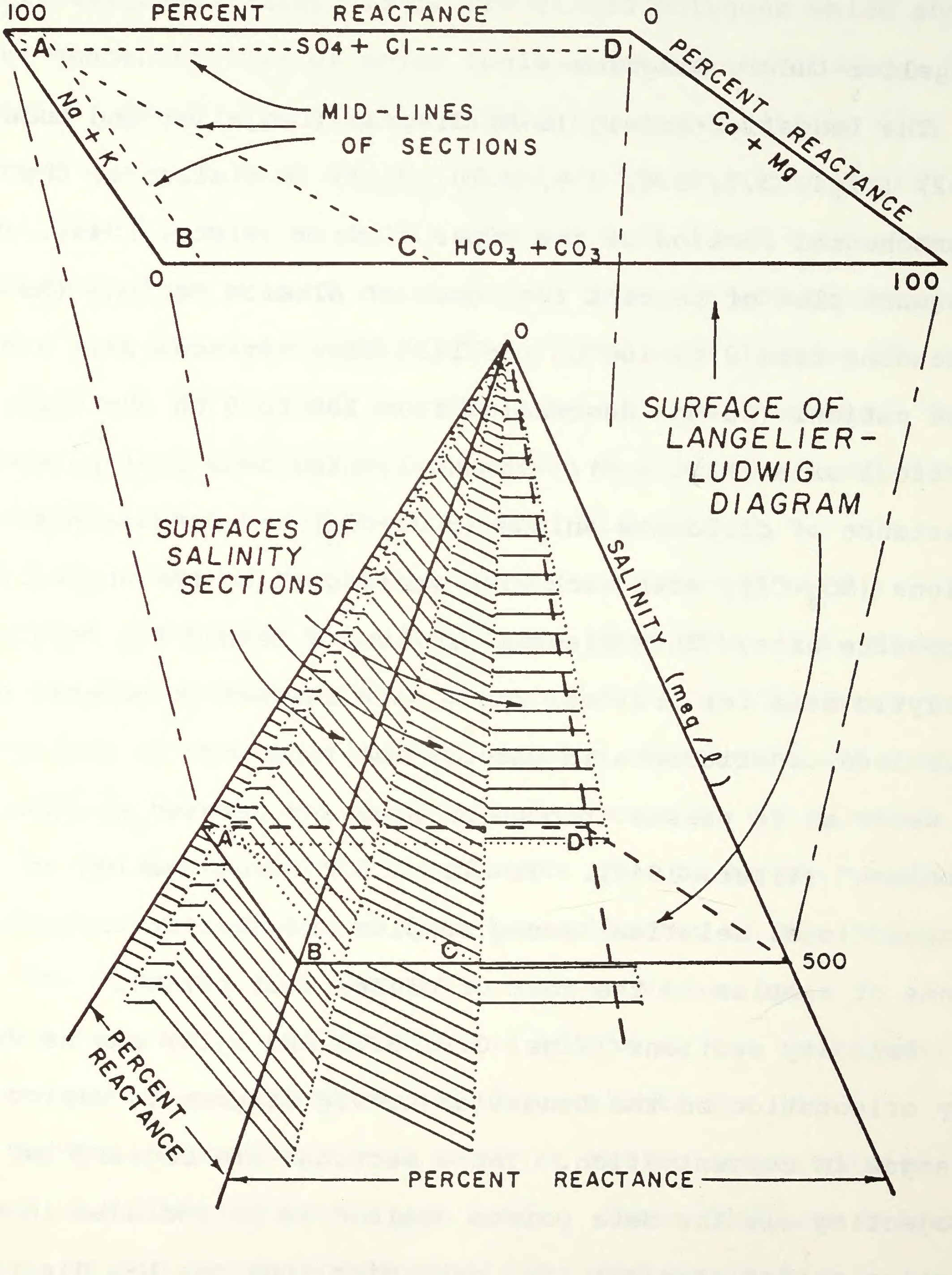


Figure 3.7 Three-dimensional perspective of a Langelier-Ludwig diagram showing surfaces of salinity sections. (Geonomics, 1978)

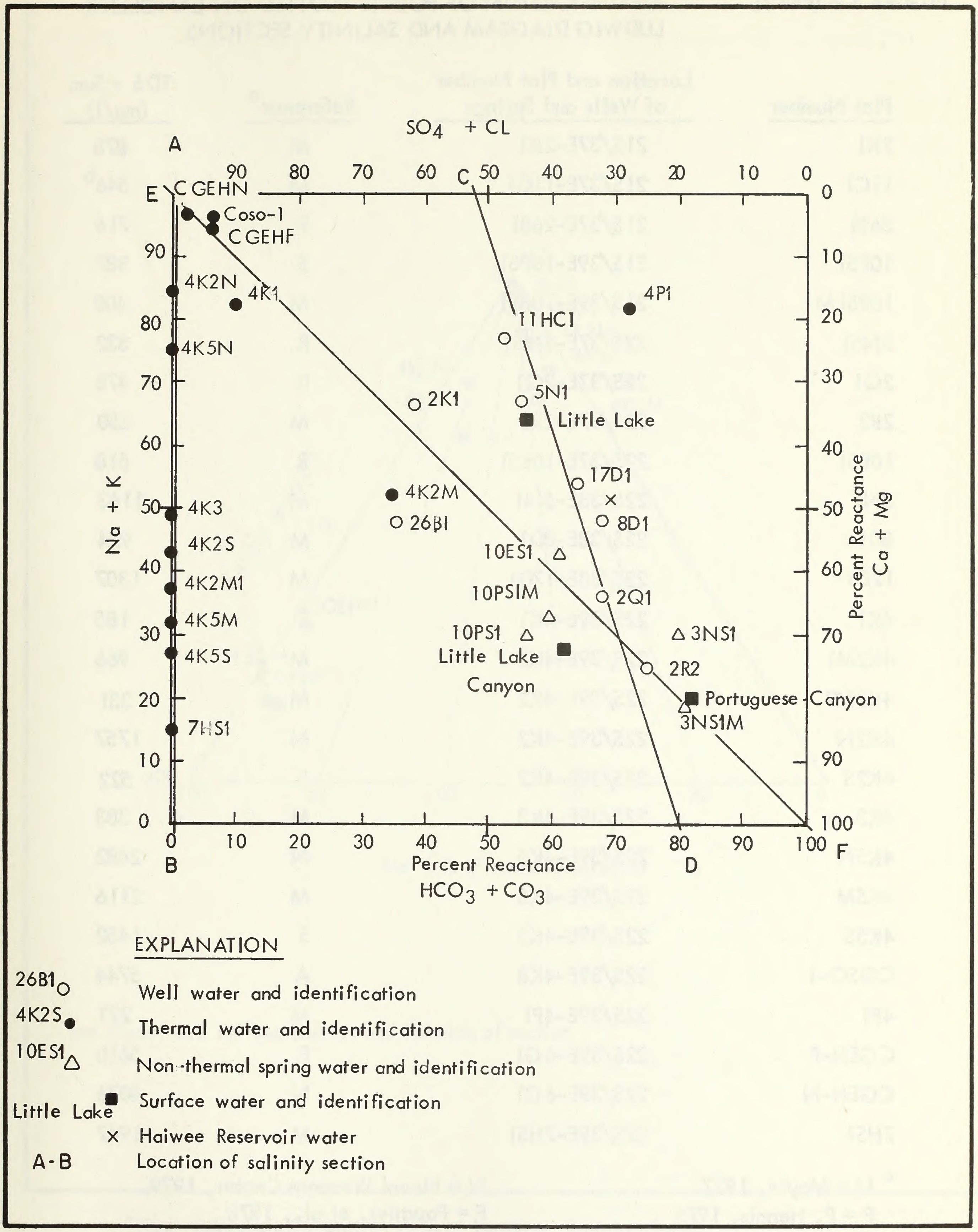


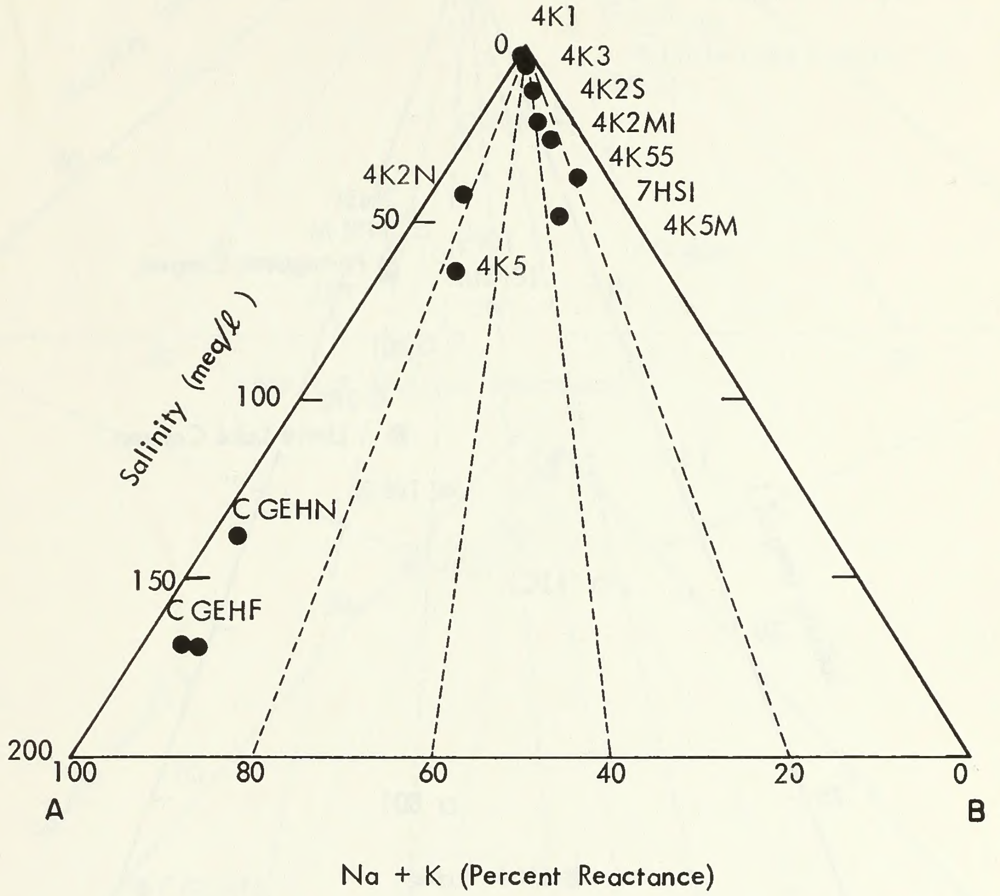
Figure 3.8 Langelier - Ludwig diagram for CGSA

FIGURE 3.8 (con't) IDENTIFICATION OF POINTS PLOTTED ON LANGELIER-LUDWIG DIAGRAM AND SALINITY SECTIONS

Plot Number	Location and Plot Number of Wells and Springs	Reference[a]	TDS - Sum (mg/l)
2K1	21S/37E-2K1	M	878
11C1	21S/37E-11C1	M	546[b]
26B1	21S/37E-26B1	P	716
10PS1	21S/39E-10PS1	S	387
10PS1M	21S/39E-10PS1	M	408
3NS1	22S/37E-3NS1	R	332
2Q1	22S/37E-2Q1	R	478
2R2	22S/37E-2R2	M	550
10ES1	22S/37E-10ES1	R	618
5N1	22S/38E-5N1	M	1163
8D1	22S/38E-8D1	M	974
17D1	22S/38E-17D1	M	1307
4K1	22S/39E-4K1	S	185
4K2M1	22S/39E-4K2	M	966
4K2M2	22S/39E-4K2	M	331
4K2N	22S/39E-4K2	N	1757
4K2S	22S/39E-4K2	S	522
4K3	22S/39E-4K3	M	388
4K5N	22S/39E-4K5	N	2482
4K5M	22S/39E-4K5	M	2116
4K5S	22S/39E-4K5	S	1452
COSO-1	22S/39E-4K8	A	5744
4P1	22S/39E-4P1	M	271
CGEH-F	22S/39E-6G1	F	5610
CGEH-N	22S/39E-6G1	N	4076
7HS1	22S/39E-7HS1	M	1947

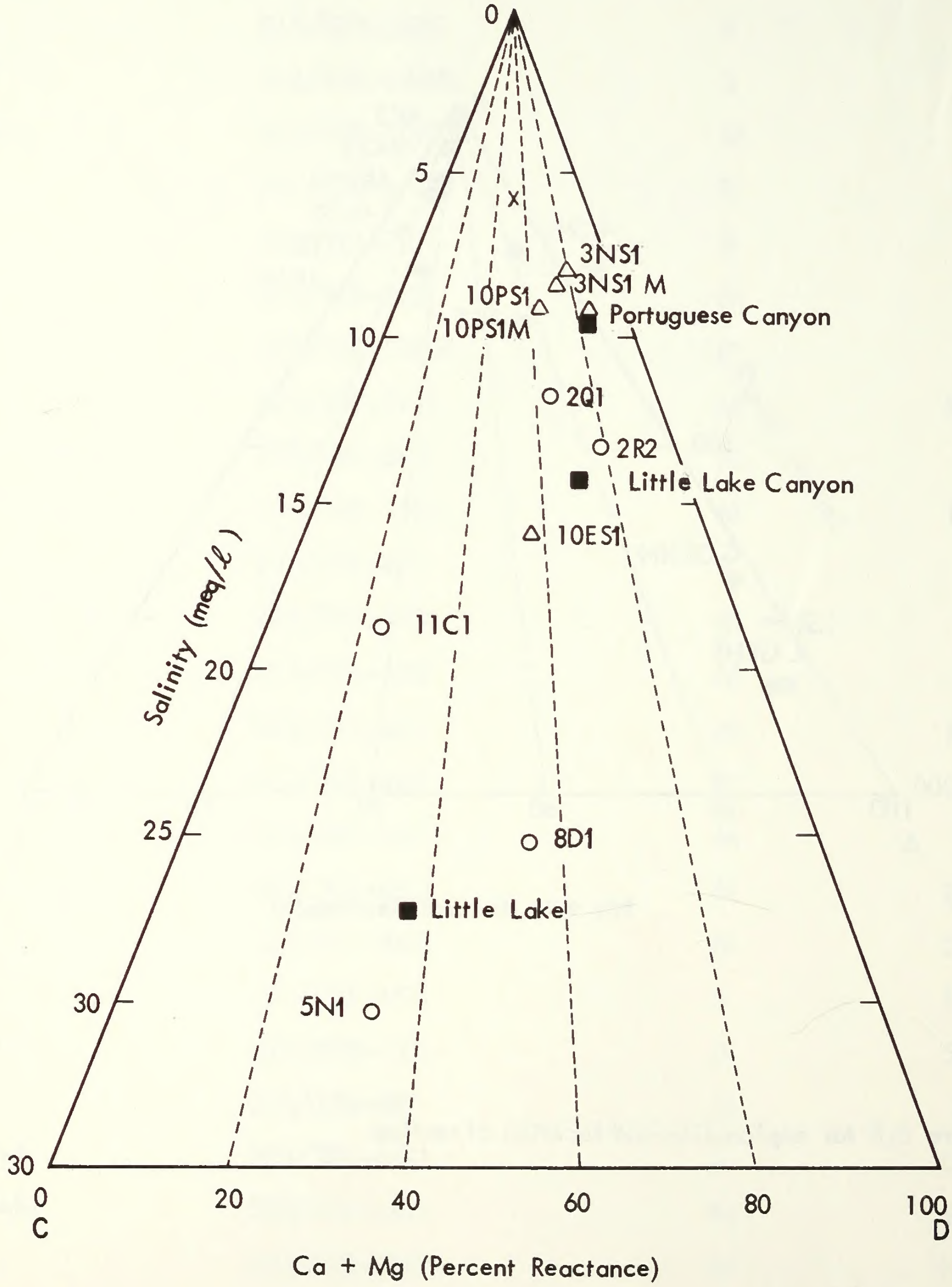
[a] M = Moyle, 1977
P = P. Hennis, 1979
S = Spane,
R = R. Lane, 1979
N = Naval Weapons Center, 1979
F = Fournier, et al., 1978
A = Austin and Pringle, 1970

[b] TDS residue on evaporation



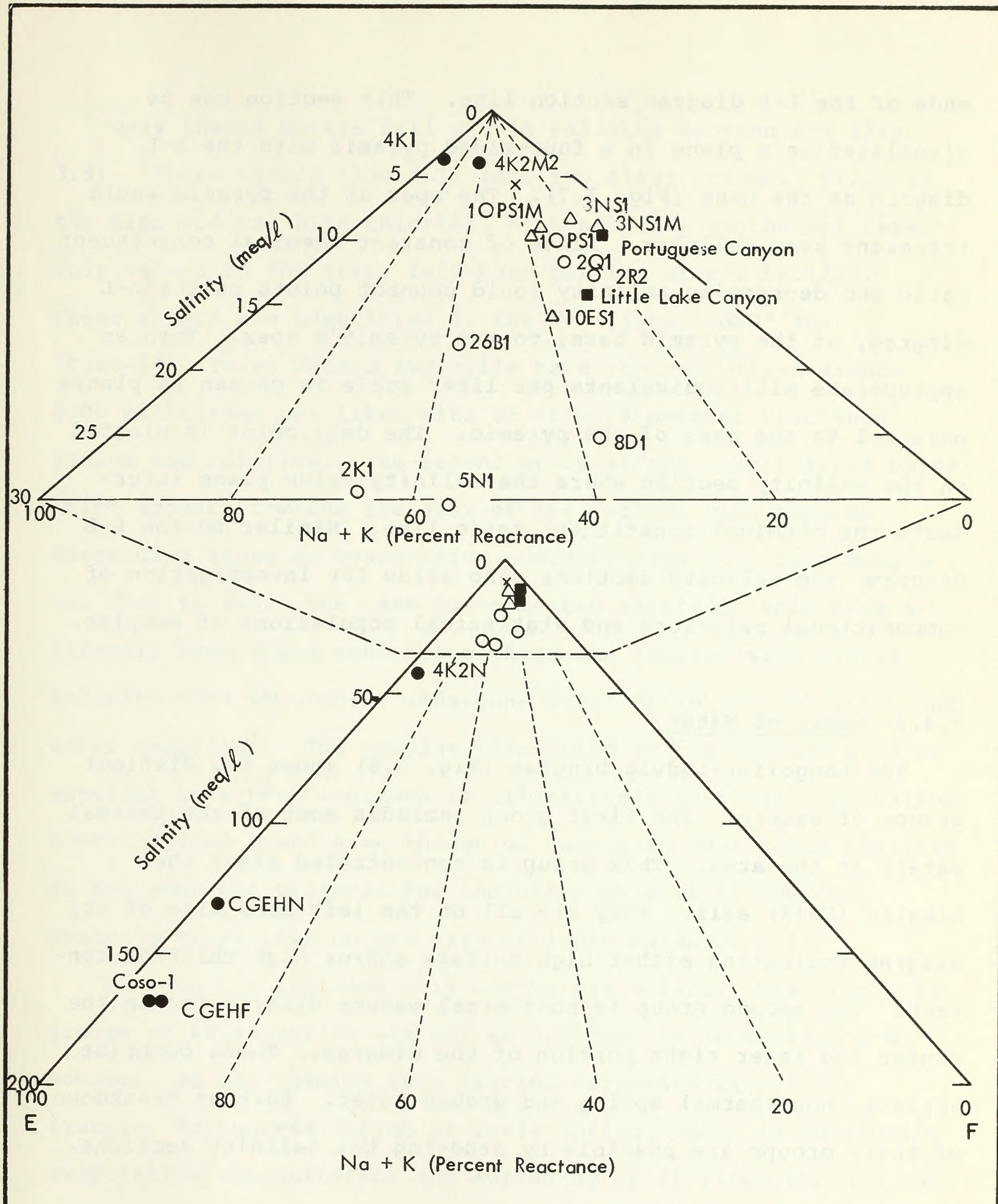
See Figure 3.8 for explanation and location of section

Figure 3.9 Salinity section A-B of Langlier -Ludwig diagram



See Figure 3.8 for explanation and location of section.

Figure 3.10 Salinity section C-D of Langelier - Ludwig diagram



See Figure 3.8 for explanation and location of section

Figure 3.11 Salinity section E-F of Langelier - Ludwig diagram ends of the L-L diagram section line. This section can be visualized as a plane in a four-sided pyramid with the L-L diagram as the base (Fig. 3.7). The apex of the pyramid would represent zero salinity. Lines of constant chemical constituent ratio and decreasing salinity would connect points on the L-L diagram, at the pyramid base, to the pyramid's apex. Then an appropriate milliequivalents per liter scale is chosen as planes parallel to the base of the pyramid. The data point is plotted on the salinity section where the salinity value plane intersects the chemical constituent ratio line. Similar to the L-L diagram, the salinity sections also allow for investigation of compositional relations and statistical populations of samples.

3.3.2 Types of Water

The Langelier-Ludwig Diagram (Fig. 3.8) shows two distinct groups of waters. The first group includes most of the thermal waters in the area. This group is concentrated along the alkalic (Na+K) axis. They are all on the left hand side of the diagram indicating either high sulfate and/or high chloride content. The second group is nonthermal waters distributed in the center and lower right portion of the diagram. These comprise surface, non-thermal spring and ground water. Further breakdown of these groups are possible by studying the salinity sections.

Only themal waters fall within salinity Section A-B (Fig. 3.9). These waters also fall into two clear groups. First is the high sodium, high chloride, high salinity geothermal reservoir waters in the lower left-hand portion of the section. These waters are identified by the notations "CGEH" and "Coso-1". These waters typically have concentrations around 6000 milligrams per liter with 95 or more percent reactance sodium and chloride. The second group is the high sulfate water which appears towards the apex of the section with samples descending along an evaporative concentration line from Sample 4K1 down to 4K5. The less concentrated waters in this area are directly from steam condensate while the samples with higher salinity have apparently undergone evaporative concentration and other reactions. The samples identified on the section with an asterisk have been included to illustrate a possible evaporative concentration trend even though we recognize that these analyses do not meet our criteria for inclusion as a valid chemical analysis since they do not have an ionic balance.

Section C-D includes only nonthermal waters. The trends in groups on this section are not as apparent as in Section A-B. However, we can observe that calcium carbonate water (for example, Portuguese Canyon or Lewis Spring, 3NS1) is undergoing evaporative concentration and softening as it flows through the sediments. Softening is the replacement of calcium and magnesium by sodium. This can occur as ion exchange with clay minerals.

Thermal and nonthermal waters are included in Section E-F. The distribution of the points on this section can be explained by the mixing of three end member or "parent" waters, evaporative concentration and reaction with sediments in the ground. The three end members would be:

a) calcium carbonate water - this would be water derived from surface runoff from the mountains, for example, Portuguese Canyon,

b) sodium chloride water - this would be the water that is found in the geothermal reservoir; for example, the water from CGEH-1, and

c) sodium sulfate water - this is the water that is typically found in the surface thermal manifestations at Coso; for example, 22S/38E-4K1.

3.3.3 Distribution of Waters

The sodium chloride water is only found in the geothermal reservoir. The sodium sulfate water is found mostly in the surface thermal manifestations. The calcium carbonate water originates as spring and surface water from the mountains surrounding the study area (e.g. the waters from Portuguese Canyon, Little Lake Canyon and Lewis Spring from the Sierra and Haiwee Spring in the Coso Range) (Plate II-2). Other waters in the CGSA can be viewed as mixtures of these three basic types undergoing various chemical reactions in the hydrosphere. Comparison of chemical characteristics of waters can suggest genetic and other relationships between different waters.

In the northern part of Rose Valley Wells 21S/37E-2K1 and 21S/37E-26B1 appear to have sodium sulfate water mixed with calcium carbonate, that perhaps have undergone some evaporative concentration. In Fig. 3.8 these waters occur in the middle of Section E-F and in the salinity section they occur in an evaporative concentration trend beneath some of the near-surface thermal waters. It is not clear what the genesis of this water is, or its relationship, if any, to the thermal waters. However, the temperature of the water from Well 26B1 is about 10 degrees above ambient. Ground water flow in this area is generally from the north-northwest, then southward. One implication is that the water type in Well 2K1 is proceeding southward to Well 26B1. However, this picture is complicated by the water of different character in Well 21S/37E-11C1.

The water in Little Lake appears to be calcium carbonate water that has undergone evaporative concentration, softening and chloride increase. The softening is most probably due to cation exchange with clay minerals as the water flows through the alluvium. The increase in chloride may be due to flow through evaporite deposits from playas in Rose Valley.

The composition of the waters from the Sierra front, for example at Lewis Spring, are similar in character to the water in the wells at Coso junction. All of these waters appear to be calcium carbonate waters with fairly low total dissolved solids. The similarity in character of these waters supports the conceptual picture of the ground water flow system in Rose Valley with the water flowing from the Sierra down into the alluvial filled valley.

The water from the surface thermal manifestations in the Coso Hot Springs area is acidic and high in sulfate, whereas the water from the geothermal reservoir is alkaline and high in TDS and sodium chloride. These are clearly two different types and have distinctive origins, which are discussed further in Section 3.4, Hydrologic Models.

Well 22S/39E-4P1 appears to be a mixture of sodium sulfate and calcium carbonate waters. This well is located at the mouth of a valley where shallow ground water flows into Coso Valley in the winter. This shallow ground water flowing from the mountains, would provide the calcium carbonate to the sodium sulfate thermal waters to produce a water of the composition found in 4P1.

3.4 HYDROLOGIC MODELS

Models of ground water and geothermal ground water systems can be fairly simple or very complex. They may involve only a qualitative conceptual framework or a detailed, three-dimensional, multivariable computerized mathematical representation. The goal of any model is to predict the behavior of particular fluids. No models can be as detailed as a natural system, but the more accurately the model represents the actual field situation the better it will predict the migration of fluid fronts. All models are based on many assumptions, simplifications and boundary conditions as well as the known physical and chemical parameters of the actual system.

Ideally, a model will predict the effects of geothermal production and injection on the existing ground water systems. Much detailed information on the hydrologic, physical and chemical properties of the system are necessary. In the resource assessment stage, such as this, data is sufficient only for a simple, qualitative conceptual model of the system. Such conceptual models for the geothermal system and the cooler ground water system are outlined below. A conceptual model for volcanic geothermal systems in general is outlined in Section 3 of the Geology Technical Report.

3.4.1 Conceputal Model of the Geothermal System

The geothermal reservoir at Coso is in fractured granitic and metamorphic rocks. It is essentially a liquid dominated system with a boiling water table (Galbraith, 1978, p. 22). The great number of fractures and the complexity of the fracture distribution may compartmentalize the reservoir. Evidence to date suggests that vapor dominated sections occur as steam caps above the boiling water table. Since there is no evidence of a continuous caprock at Coso there must be a low heat flux, deep water table (Galbraith, 1978, p. 22) and/or channel deposition partially filled by hydrothermal alteration products to account for the limited surface manifestations. The hydraulic properties, temperature and areal extent of the reservoir are described in Chapter 1, Appendix B, and in the Geology Technical Report. To summarize, the hydraulic properties of the reservoir are based on the following assumptions:

a) the rock matrix of the reservoir has no primary porosity; no deep primary aquifers have been identified by drilling or geologic mapping (Hulen, 1978, p. 24)

b) all flow and storage is in fractures with direction of flow probably entirely structurally controlled (Hulen, 1978, p. 24); and

c) the porosity will vary widely depending on the size and openness of fractures

Based on heat flow studies (Combs, 1976) the eastern boundary of the reservoir appears to be well defined at the Coso Hot Springs fault. The western boundary appears to be gradational, with cooler parts of the reservoir extending into or under Rose Valley. The northern and southern boundaries extend several miles to the north and south, respectively, of the Devils Kitchen area.

The source of fluid, its movement and relation to other ground water bodies are described below.

Source of Fluid and Movement--

The fluid in the reservoir may be relatively static circulating as convection cells, or part of a deep circulation system. Isotope studies provide valuable data on hydrologic processes and directions of water movement in a geothermal area. An isotope study presently being conducted by the USGS

(Fournier, 1979, personal communication) will hopefully provide such data for the Coso area. In the meantime, possible sources of the geothermal fluid are discussed below in terms of genesis and location.

Genetically water may be (Ellis and Mahon, 1977, p. 28):

a) juvenile - water newly introduced into the hydrosphere from magma, i.e. water coming to the source for the first time;

b) magmatic - meteoric or connate water derived from magma;

c) meteoric - water recently derived from precipitation;

d) connate - "fossil" sea or fresh water trapped in sediment;

e) metamorphic - connate water derived from recrystallization of hydrous minerals to less hydrous forms

White (1957a, b) found no conclusive evidence that water in thermal spring areas has juvenile origin. Hem (1970, p. 42) notes that it is very difficult to distinguish between waters of meteoric and magmatic origin. It is quite possible that, since the study area had prehistorically experienced much higher precipitation, the geothermal reservoir was recharged by meteoric water at that time. Recharge to the reservoir may presently be slight since there is no evidence that it is losing much water.

In terms of location, geothermal reservoir fluid may originate from the Sierra to the west, the Coso Range or Owens Lake area to the north, a genetic source below or some combination. Precipitation presently appears to be insufficient to provide a significant amount of recharge to the reservoir by direct downward percolation. Recharge from the Coso Range to the east is unlikely due to its relatively lower hydrostatic potential and low precipitation.

Coso No. 1 and CGEH-1 are about 2 miles apart and terminate at depths of 375 feet and 4794 feet, respectively. The water level elevations are virtually the same, within the limits of the top of casing elevation determinations, in both wells. This suggests nearly horizontal water table at about 3460 feet. The marked similarity in composition of the reservoir fluid from these two test wells suggests that convective currents within the reservoir may mix and "homogenize" the fluid.

3.4.2 Coso Hot Springs

The acid sulfate fluid from in the Coso Hot Springs is distinctly different from the sodium chloride fluid found in the deeper reservoir. Acid sulfate waters, as those found in Coso, may be derived from steam condensing into surface waters. Oxidation of hydrogen sulfide to sulfate contributes to the acidity of the water. Other constituents in the water are leached mainly from rocks and sediments surrounding the pools (Ellis and Mahon, 1977, p. 60).

The Coso Hot Springs are not springs in the traditional sense but rather areas where steam condensate accumulates over near-surface impermeable clay layers (Austin and Pringle, 1970). The fluid levels, concentration and temperature of the springs all vary with precipitation, temperature and quantity of shallow ground water (Spane, 1978; Austin and Pringle, 1970). In the winter, when precipitation is greater, the fluid levels in the mud pots rise and the temperature of the fluid decreases. In the summer evaporation increases and contribution from shallow ground water stops. This lowers the fluid levels and allows the fluid temperature and concentration to increase. Possibly pure shallow ground water contributes to the hot springs at times. The precise mechanism and relation between all the hydrologic, chemical and climate parameters are not presently known. Better definition and understanding of these relationships may provide more insight into the mechanism of the hot springs and its relationship to the geothermal reservoir.

Some possible mechanisms for the surface thermal manifestations are:

1) steam rises from the reservoir, condenses at or near the surface and accumulates above an impermeable clay layer several feet below the surface;

2) same as above but steam bubbles through the shallow ground water and heats it;

3) shallow ground water flows from the small alluvial valleys west of the hot springs. It percolates deep enough to be heated and boiled by the hot ground and steam. The steam from the reservoir and ground water then ascends through fractures to the surface, condensing and accumulating on the impermeable clay layer several feet below the surface.

The first mechanism, with fluid composed totally from reservoir steam condensate, would not explain the marked increase in fluid levels during the rainy seasons. If the second mechanism were valid the fluid composition should reflect mixing with shallow ground water. Shallow ground water in the surrounding area is most commonly a calcium carbonate water. Assuming a similar shallow ground water composition for the Coso area would require a hot spring fluid composition indicative of mixing the calcium carbonate and acid sulfate waters. This is only observed in Well 22S/37E-4P1 located at the mouth of the largest valley above the hot springs. The process of elimination presently suggests the third mechanism as most likely.

3.5 POTENTIAL GROUND WATER DEGRADATION

Three types of potential ground water degradation must be considered in geothermal development at Coso. The first type involves the effects of large scale fluid extraction and injection in the geothermal reservoir. The second type involves ground water withdrawal in Rose Valley. The third involves accidental escape of undesirable water at the surface.

Large scale fluid extraction from the geothermal reservoir could change existing hydraulic gradients and flow patterns. It is possible that reservoir boundaries, recharge and discharge flow paths and hydraulic gradients may change when the reservoir is disturbed from its natural equilibrium condition. Currently the western boundary of the geothermal reservoir is not well defined. The pattern of the heat flow contours (Combs, 1976) suggests that there may be a gradational reservoir boundary under the eastern side of Rose Valley. If this is correct and ground water extraction in Rose Valley created a sink near this boundary the geothermal fluid would be induced to migrate westward, thereby degrading water in Rose Valley. Conversely, pumping in the geotheraml reservoir would produce the opposite effect, thereby reducing possible saline water intrusion from the reservoir into Rose Valley.

Natural or existing water quality is discussed below, followed by an outline of potential pollutant mechanisms and pathways.

3.5.1 Natural or Existing Water Quality

Most known ground and surface water in the CGSA appears suitable for domestic, agricultural and livestock use, except for the thermal waters and somewhat more mineralized waters in the Little Lake area. There are presently no chemical data for water on the east side of Rose Valley or at depth. These data are necessary to define baseline conditions. In addition to spatial variation the chemical composition of natural waters will vary with time. For example, the several analyses included for surface thermal waters, for Haiwee Spring and Lewis Spring show some variation. In order to determine if natural water is being degraded, some idea of this natural variation must also be established.

Waters that may be suitable for one purpose may not be suitable for another purpose. Table 3.2 shows inorganic chemical water standards for drinking water, irrigating water, and livestock feeding water. The U.S. Environmental Protection Agency (EPA) has defined maximum contaminant levels in the National Interim Primary Drinking Water Regulations (EPA, 1976) and in the National Secondary Drinking Water Regulations (EPA, 1977). These more current National Interim Primary and Secondary Drinking Water Regulations conform fairly closely with the U.S. Public Health Service (1962) regulations that have been in effect for many years. Some industrial waters may contain

Table 3.2 Inorganic Chemical Water Standards

Substance	Drinking Water	Irrigating Water [a] (ppm) Threshold	Irrigating Water [a] (ppm) Limiting	Livestock Feeding Water [a] (ppm) Threshold	Livestock Feeding Water [a] (ppm) Limiting
Arsenic	0.05[b]	1.0	5.0	1	--
Barium	1.0[b]	--	--	--	--
Bicarbonate	--	--	--	500	500
Boron	--	--	0.5	--	--
Cadmium	0.01[c]	--	--	5	--
Calcium	--	--	--	500	1000
Chloride	250[c]	100	350	1500	3000
Chromium	0.05[b]	--	--	--	--
Copper	1.0[c]	0.1	1.0	--	--
Fluoride	1.4-2.4[b,d]	--	--	1	6
Hydrogen sulfide	0.5[c]	--	--	--	--
Iron	0.3[c]	0.3	--	--	--
Lead	0.05[b]	--	--	--	--
Magnesium	--	--	--	250	500
Manganese	0.05[c]	--	--	--	--
Mercury	0.002[b]	--	--	--	--
Nitrate	10[b]	--	--	200	400
Selenium	0.01[b]	--	--	--	--
Silver	0.05[b]	--	--	--	--
Sodium	--	--	--	1000	2000
Sulfate	250[c]	200	1000	500	1000
Zinc	5[c]	--	--	--	--
TDS	500[c]	500	1500	2500	5000
pH	6.5-8.5[c]	7.0-8.5	6.0-9.0	6.0-8.5	5.6-9.0

[a] Todd, 1970
[b] Maximum contaminant level specified in National Interim Primary Drinking Water Regulations (U.S. EPA, 1976)
[c] Maximum contaminant level specified in National Secondary Drinking Water Regulations (U.S. EPA, 1977)
[d] Maximum recommended concentration is temperature dependent.

even higher total dissolved solids than those listed for any category in Table 3.2.

The spring and surface waters from the Sierra and the Coso Range are calcium carbonate in character. They generally contain about 300 to more than 500 milligrams per liter TDS. The TDS of this type of water in the ground is generally somewhat greater than that in the surface runoff due to some evaporative concentration and solution of minerals.

The character of the water from Well 21S/37E-2K1 and 26B1 is different than the typical Sierra calcium carbonate water in that it appears to have a significant contribution of the sodium sulfate type water. The total dissolved solids concentration in Well 21S/37E-26B1 is over 700 milligrams per liter.

Wells and surface water in the Little Lake area have TDS contents up to more than 1300 milligrams per liter. A boron concentration of 6 mg/l for the surface water makes it totally unsuitable for agricultural applications.

The surface thermal manifestations are acid sulfate waters with TDS ranging from less than 200 to more than 2000 milligrams per liter, depending on the contribution from ground water and the degree of evaporative concentration. The several analyses for Wells 22S/39E-4K2, 4K3 and others, show that the composition and concentration of hot spring waters varies with time. The seasonal characteristics of these springs are discussed in Section 3.4 - Hydrologic Models.

Trace amounts of mercury were found in water samples from the Coso resort area (Austin and Pringle, 1970). Well

21S/37E-2K1, just south of Haiwee Reservoir contained 0.59 milligrams of arsenic per liter (Moyle, 1977, p. 47). The drinking water standard for arsenic is 0.05 milligrams per liter (U.S. EPA, 1976).

The geothermal reservoir fluid would probably not be suitable for any other use than perhaps for cooling since it has high total dissolved solids, and likely high concentrations of toxic constituents. An arsenic content of 7.5 ppm and a boron content of 71.6 ppm have been reported (Austin and Pringle, 1970, p. 36).

3.5.2 Potential Pollutant Mechanisms and Pathways

Insufficient data are available to define the present character of water throughout Rose Valley, the possible locations of water withdrawal, or the details of hydraulic gradients. This also applies to the geothermal reservoir. Although it is premature to define specifics, the following discussion largely extracted from Harding-Lawson Associates (1978) outlines general potential chemical and thermal ground water pollution mechanisms and pathways that may be associated with waste injection. These include:

1. improperly constructed or deteriorated injection well;
2. improperly constructed, deteriorated or ineffectively abandoned wells nearby;
3) escape of injected fluid from the receiving formation through structural or stratigraphic pathways;

4) hydrofracturing of confining formations with high-pressure injection;

5) accidental spills at the ground surface;

6) percolation from storage ponds (enhanced by higher temperatures);

7) percolation from discharge of mineralized fluids through leaks in surface conveyances which are part of the injection system;

8) chemical migration through confining beds due to osmotic forces.

These potential pathways and mechanisms are illustrated and discussed below. Although the figures (Figs. 3.12, 3.13 and 3.14) show sedimentary reservoirs, the mechanisms for a fractured crystalline reservoir, such as Coso, would be similar.

Improper construction, deterioration or failure of well seals would allow fluids to flow vertically up or down the well bore, depending on where the failure occurred (Fig. 3.12-A). Casing failure could occur by corrosion (Fig. 3.12-B). This mechanism can occur in the injection well or other wells in the area. They may be abandoned, producing or infrequently used wells.

Fig. 3.13 shows a hypothetical example of a potential escape path for injected fluid through an abandoned well and another well penetrating an aquifer overlying the confining bed of the injection aquifer. This case illustrates an example of an improperly plugged abandoned well, where the cement plug is placed far above the perforated interval of the well. This has allowed fluid to flow upwards in the well bore, through the

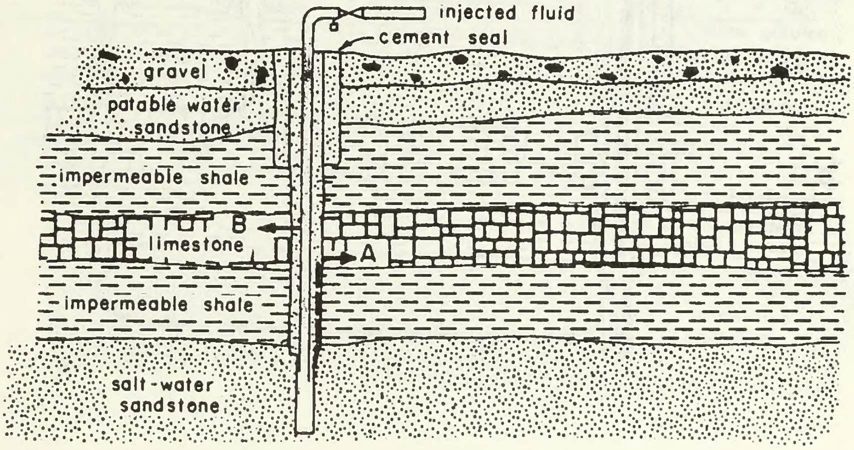


Figure 3.12 Escape of injected fluid through deteriorated cement seal (A) and through hole in casing (B). (Harding-Lawson Associates, 1978)

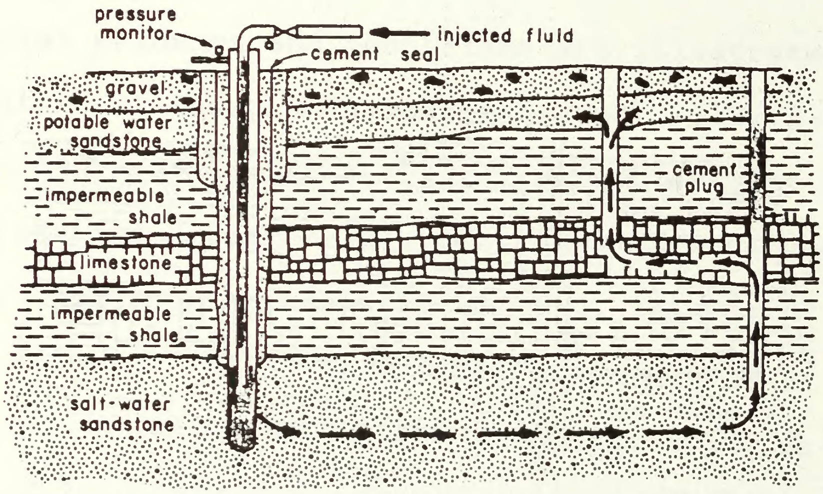


Figure 3.13 Escape of injected fluid through abandoned borehole

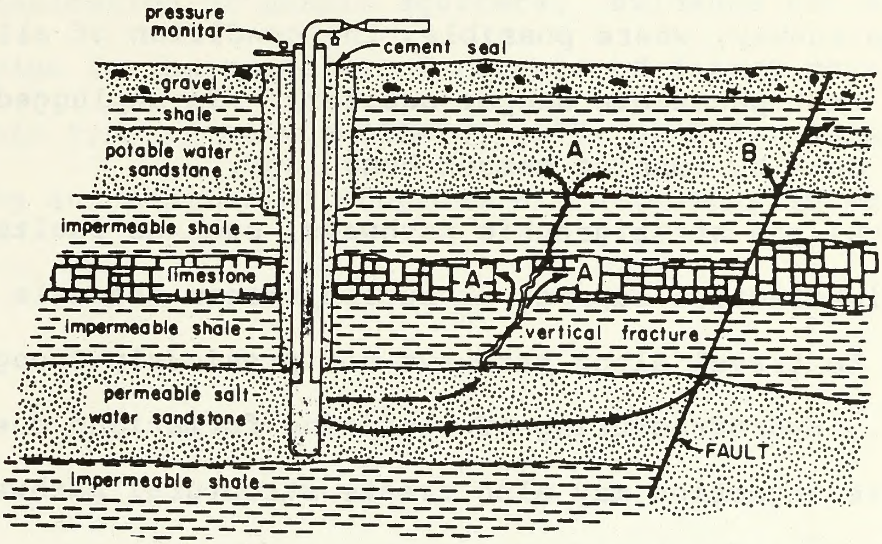


Figure 3.14 Escape of injected fluid through fractures and faults (Harding-Lawson, 1978)

confining bed, into an overlying aquifer that is penetrated by another well. This pathway could also exist by virtue of deteriorated well seals around the casing or corroded casing. To identify locations where this mechanism may occur it is important to survey, where possible, the condition of all wells in the area that penetrate deeper aquifers. In unplugged wells this may be done by running cement bond logs.

Structural and stratigraphic pathways, such as faults, fractures, ineffective caprock or buried stream channels may allow fluid to travel along pathways not previously recognized (Fig. 3.14). Hydrofracturing of confining formations due to high-pressure injection may also create structural pathways in the form of micro-fractures or joints.

Accidental spills at the surface, percolation from holding ponds, or leakage from surface conveyances would entail similar pathways. The fluids would percolate from the surface downward directly into the nearer surface aquifers. A spill, if not contained, may also discharge fluid directly to surface streams, lakes or canals.

Osmotic forces can cause slow migration of chemical constituents of the waste fluid to an aquifer through an intervening caprock, which may act as an osmotic membrane. However, pollution due to this effect is anticipated to be minor and insignificant.

Although escape of fluids by any of these mechanisms is of concern, the greatest risk of fluid escape is through the injection well itself (Talbot, 1972). Currently prescribed well construction practices and the large vertical distances between the injection zones and usable aquifers, reduce the probability of contamination of usable aquifers. Evidence for this conclusion is the scarcity of reports of direct contamination from this type of source (TEMPO, 1973, p. 2-9). Rigorous planning and monitoring programs are necessary to maintain this record.

SECTION 4

HYDROLOGIC BALANCE

A hydrologic balance describes the water cycle of an area. It is an estimate of how much and by what paths and processes water enters and leaves an area. It is important to define the hydrologic balance prior to development for three reasons:

1) to establish baseline conditions

2) to estimate whether the available water resources in the area are sufficient to supply the existing and proposed consumptive uses

3) to determine whether the geothermal reservoir development or consumptive use will affect adjacent ground water basins.

The hydrologic balance is a tally of all water entering and leaving a specified drainage area. The amount of water entering the area must equal the amount of water leaving to maintain water resources. If more water enters than leaves, then water in storage is increased. If more water leaves than enters, then water in storage is reduced. Calculation of the hydrologic balance will allow estimation of the practical sustained yield. That is, the amount of water that may be withdrawn from the system without producing undesirable effects.

Generally, the practical sustained annual yield should not exceed the mean annual recharge. In arid regions where there may be large volumes of ground water in storage, water in excess of mean annual recharge may be withdrawn like depletable mineral resources are mined. Evaluation of such mining yield must consider the amount of extractable and usable water, the cost of extraction, the effects of lowering the water table and the effect of reducing ground water available to future generations.

All water entering a drainage area is called recharge. This is comprised of direct precipitation, ground water inflow, surface water inflow, percolation from streams or other water conveyances and imported water.

All water leaving a drainage area is called discharge. This may occur through surface water outflow, evaporation, evapotranspiration, ground-water outflow or consumptive use.

Water may be stored in a surface water body, a ground water reservoir or as soil moisture. The difference between recharge and discharge is expressed as a change in total storage, ΔS_t, as:

$$\Delta S_t = P + I_s + I_g + W_i - O_s - O_g - E - W_e$$

where: $\Delta S_t = \pm \Delta S_g \pm \Delta S_s \pm \Delta S_m$

and ΔS_g is change in ground water storage,
ΔS_s is change in surface water storage,
ΔS_m is change in soil moisture,
P is precipitation,
I_s is surface inflow,
I_g is subsurface (ground water) inflow,
W_i is imported water,
O_s is shallow outflow,
O_g is subsurface (ground water) outflow,
W_e is water exported, and
E is evaporation and evapotranspiration.

Precipitation is a component of the surface water regime. Inflow, outflow, change in storage, and consumptive use are components of both the ground and surface water regimes. Long-term equilibrium exists between surface inflow and outflow in Rose Valley. Essentially, there is no surface water inflow from Owens Valley or outflow to Indian Wells Valley. Water is discharged from Haiwee Reservoir through Rose Valley via two aqueducts. Coso Basin and the enclosed basins do not receive surface water inflow or generate surface water outflow.

The remaining components of the surface water regime of the CES area approach long-term equilibrium with components of the ground water regime. Precipitation will equal evapotranspiration and increases in ground water storage. Precipitation becomes interception, runoff and infiltration. Interception and runoff are eventually lost to evapotranspiration. Infiltration is the only component of the surface water regime which interacts with the ground water regime. Infiltration in most parts of the CGSA remains near the ground surface and is lost to evapotranspiration. In areas of higher precipitation infiltration recharges the ground water system. A more detailed discussion of precipitation as related to recharge is presented in Section 4.1.2.

In the CGSA, there has been so little water use and so few wells drilled that, at best, the parameters necessary for a hydrologic balance must be rough estimates. These estimates would be based largely on a conceptual model of the general ground water situation in the area, empirical relationships and analogy from other areas and a few points of factual control. As more wells are drilled and more data become available, these estimates can be modified to reflect the added control.

A summary of the hydrologic balance for Rose Valley is presented in Table 4.1. Derivation of the individual estimates are described below.

4.1 RECHARGE

No water is contributed to Rose Valley by surface water inflow. Rainfall on the valley floor is insufficient to percolate downward and contribute to the ground water reservoir. Recharge to Rose Valley is derived from precipitation infiltration on the Sierra and alluvial fans abutting the Sierra, ground water inflow from the north, infiltration from irrigation and leakage from the Los Angeles aqueducts. All sources and quantities of recharge to Rose Valley have not been definitively established. Several investigators in the area have widely varying estimates regarding the amount of underflow from the north and the contribution from precipitation on the Sierra. For example, an estimate of 22,000 acre-feet/year for total recharge was made by Austin in NWC, 1979; the LADWP (1976) estimated the subsurface underflow component of recharge from the deeper aquifer in the

Table 4.1 ESTIMATED HYDROLOGIC BALANCE FOR ROSE VALLEY

Recharge	Quantity (acre-feet/year)
Precipitation	56,000 to 60,000
Surface inflow	0
Subsurface inflow	600[a]
Imported water	300
	57,000 to 61,000
Discharge	
Evaporation and transpiration	56,000 to 61,000
Surface outflow	0
Subsurface outflow	45 to 500
Exported water	0
	56,000 to 62,000

Assumption: No hydraulic connection with the geothermal reservoir

[a] Additional subsurface inflow may originate in the northern part of Haiwee Reservoir and flow through the alluvial fans west of the reservoir and then into Rose Valley (see Section 4.1.1)

Owens Valley at 10,860 acre-feet/year. The NWC (1979) using a method described by Spane (1978) estimated 611 acre-feet/year ground water recharge from precipitation. Recharge estimated in this report is summarized in Table 4.2 and detailed below.

Techniques used to estimate recharge by equating it with evaporative discharge (e.g. Dutcher and Moyle, 1973) have not been used. They are not applicable to this region due to the deep water table and absence of phreatophytic vegetative cover necessary to estimate consumptive use.

4.1.1 Ground Water Inflow

Subsurface inflow to Rose Valley from the north could be derived as underflow from Haiwee Reservoir, underflow from the deeper aquifer in Owens Valley, leakage from the Los Angeles aqueduct, or possibly underflow through the alluvial fans west of Haiwee Reservoir.

Subsurface inflow from the shallow aquifer of Owens Valley does not contribute to Rose Valley since a shallow ground water basin divide presently crosses the northern end of Haiwee Reservoir, with water flowing north or south, respectively, on each side of the divide (Fig. 4.1). Wells south of Owens Lake Bed have water level elevations around 3730 to 3740 feet (Table 4.3). Ground water levels drop to the north. They are below the land surface elevation of the dry Owens Lake bed, which is

Table 4.2 SUMMARY OF GROUND WATER RECHARGE AND DISCHARGE FOR ROSE VALLEY

Recharge	Estimated Annual Quantity (acre/feet/year, rounded)
Underflow from Haiwee Reservoir	600
Underflow from alluvial fans west of Haiwee Reservoir	?
From precipitation on Sierra	1,900 - 3,000
From precipitation on Coso Range	0
From precipitation on valley floor	0
Imported water	100
Irrigation	900
	3,500 - 4,600
Discharge	
Irrigation withdrawal	3100
Little Lake surface evaporation	830
Evapotranspiration, other vegetated areas around Little Lake	40
Underflow to Indian Wells Valley	45,[a]/200-500[b]
Domestic and stock withdrawal	20
Springs	30 / 190
	4,100 - 4,700

[a] Bloyd and Robson, 1971, p. 15

[b] This report

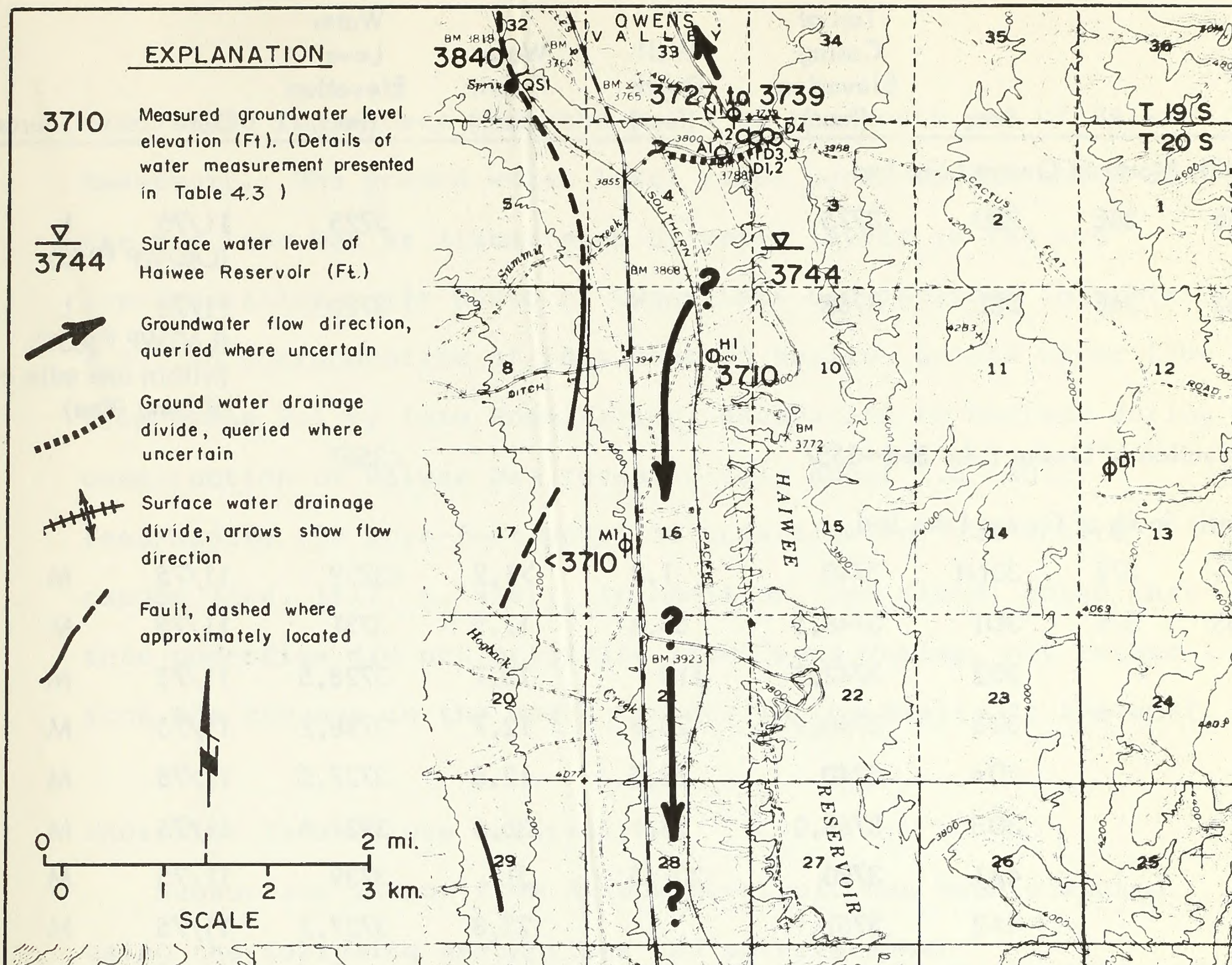


Figure 4.1 Ground water elevations and flow in the vicinity of Haiwee Reservoir

Table 4.3 WATER LEVEL ELEVATIONS IN THE VICINITY OF HAIWEE RESERVOIR

T	R	Sec.	Top of Casing Elevation (feet)	Well Depth (feet)	Water Depth (feet)	Water Level Elevation (feet)	Date	Source[a]
Wells North of Owens Lake Bed								
15S	36E	28D	3775			3725	11/75 (LADWP #255)	L
15S	36E	28L	3768			3720	11/75 (LADWP #360T) (within one mile east of Lone Pine)	L
Elevation of Owens Lake Bed ~3557						<3557		
Wells South of Owens Lake Bed								
19S	37E	33N1	3740	1.2	>1.2	<3739	11/75	M
20S	37E	3D1	3748.5	63.4	17.5	3731	11/75	M
		3D2	3742.2	110	13.7	3728.5	11/75	M
		3D3	3740.9	20.3	12.7	3728.2	11/75	M
		3D4	3740	23.5	12.5	3727.5	11/75	M
		3D5	3768.0	53.1	36.6	3731.4	11/75	M
		4A1	3790	201.5	51	3739	11/75	M
		4A2	3751.1		23.8	3727.3	11/75	M
Wells West of Haiwee Reservoir								
20S	37E	9H1	3860	203	149.6	3710	3/76	M
		16M1	4010	300	dry	<3710	11/75	M
21S	37E	6H1	4920	4.3	+.4	4920	11/75	M
Haiwee Reservoir Surface						3744		L
Rose Spring						3640		M
Wells South of Haiwee Reservoir								
21S	37E	2K1	3700	101	10.6	3689.4	12/74	M
		11C1	3833.4	78.3?	39.3	3594.1	11/75	M
21S	37E	26B1	3440		219	3221	3/5/79 (static for 6 mos.)	H
		26K1	3430		216	3214	3/18/79	H

[a] Source Code: M = Moyle, 1977; H = Phil Hennis, 1979, personal communication; L = LADWP, 1978, p. A6-39 and Lane, 1979, personal communication.

almost 200 feet lower than the wells at the north end of Haiwee Reservoir. The ground water level rises again to the north of the dry lake bed as illustrated by water levels in the two representative wells north of Owens Lake bed included in Table 4.3. In corroboration of this lack of shallow ground water flow from Owens Valley into Rose Valley, excavation to bedrock during construction of Haiwee Dam revealed only about 1.5 cubic feet/minute (18 acre-feet/year) of underflow for the entire canyon (Lee, 1912, p. 410). In addition, Lee (ibid) noted that this underflow did not originate from Owens Valley, but rather from the streams in the small canyons in the Sierra to the west.

Underflow from Haiwee Reservoir--

Subsurface inflow from Haiwee Reservoir has been computed using the following assumptions and observations:

1) all water leaking from the reservoir flows in the alluvial section overlying the Coso formation (the Coso formation is assumed to be essentially impermeable - see Section 3.1.1)

2) the saturated thickness of the alluvial section averages about 100 feet. This is derived from well logs (LADWP, personal communication, 1979) and water levels in the gorge

3) average width of the section is about 1000 feet

4) a hydraulic gradient of 0.026 derived from water levels in the wells 21S/37E-2K1 and 11C1 (Moyle, 1977)

5) an average transmissivity for the alluvial section of 20,000 gpd/ft derived from a step drawdown test conducted by LADWP (1979, personal communication)

Substituting in the relation Q=TIL, where

Q = quantity of flow (gpd)

T = transmissivity (gpd/ft)

I = hydraulic gradient (ft/ft)

L = length of section (ft),

these data result in underflow from Haiwee Reservoir of about 600 acre-feet/year. The Los Angeles Department of Water and Power believes Haiwee Reservoir contributes essentially no underflow to Rose Valley (LADWP, 1979, personal communication).

Deep Underflow from Owens Valley--

Underflow from the deeper aquifer in Owens Valley has been estimated at 10,860 acre-feet/year (LADWP, 1976). This estimate is a rough approximation based on an estimated cross sectional area, permeability and hydraulic gradient. However, the hydraulic characteristics of the subsurface materials in the canyon between Owens and Rose Valley and the hydraulic gradient suggest that this underflow may be overestimated. Under questioning the LADWP has not defended this estimate (LADWP, 1979, personal communication).

Units in Indian Wells Valley similar to those beneath Haiwee Reservoir are considered essentially non-water-bearing, although some lenses and fractures may be somewhat permeable. Geologic mapping by Stinson (1977) shows two members of the Coso formation beneath Haiwee Reservoir. They lie under a fairly thin alluvial blanket on the order of 100 feet or less thick. The two members of the Coso formation extend to at least a thousand foot depth. The first member, composed of undifferentiated rhyolite pyroclastics including tuff and tuff breccia, extends to a depth of several hundred feet. The second member, extending for several hundred feet beneath the first, is composed of undifferentiated sedimentary rocks. These units are described in more detail in the geology section and the hydrologic units section (Section 3.1.1). Hence, if water is transmitted beneath the water gap at Haiwee Reservoir it probably would be transmitted through a hydraulically conductive fault. St. Amand and Roquemore (1978, unpublished) (Plate I-2) mapped an aerial photo lineament trending NNE along the east side of the gorge below Haiwee Reservoir which may serve that function.

In addition the hydraulic gradient in the southern Owens Valley indicates northward flow of ground water, as discussed in the beginning of Section 4.1.1.

Underflow Through Alluvial Fans--

Construction of Haiwee Dam has apparently changed the natural ground water flow paths in its vicinity. Prior to construction of Haiwee Reservoir the ground water divide was located more towards the center of the current location of the reservoir. However, the data compiled in Table 4.3

indicates that the wells west of the reservoir (T20S/R37E-4H1 and 16M1) have lower water levels than the reservoir itself or the wells in Sections 3 and 4 at the north end of the reservoir (Fig. 4.1). This suggests that, if there is hydraulic conductivity between the reservoir and the fans to the west, water is flowing north and west from the reservoir. This would place a ground water divide between the wells in Sections 3 and 4 and Well T20S/R37E-9H1 (Fig. 4.1).

A geologic section constructed by Stinson (1977) through the northern part of the reservoir indicates that the reservoir is directly in contact with the alluvial fans which would suggest some degree of hydraulic conductivity between the basn and the reservoir. Water flowing from the reservoir westward would then have to continue southward since there is a ground water divide to the north. The elevation of Rose Spring (in the fan) indicates a slight hydraulic gradient southward. To verify this mechanism additional field surveys and/or drilling would be necessary.

Upper Cactus Flat--

The Upper Cactus Flat ground water basin is reported to contribute about 15 acre-feet/year to upper Coso Basin ground water basin (Spane, 1978, p. 22) and perhaps the remaining recharge of 30 acre-feet/year southward into the geothermal reservoir.

4.1.2 <u>Direct Precipitation</u>

Recharge from precipitation is a function of the amount of precipitation as well as of terrane, soil and rock properties. Factors to estimate recharge from precipitation for the specific Rose Valley area have not been established. In fact, estimating contribution to ground water from precipitation in any area, particularly those with low to moderate rainfall, is difficult and uncertain (Meinzer, 1932, pp. 102-104). Considering the region and type of data available, two methods are described below which have been applied to achieve crude estimates of recharge from precipitation to the CGSA, particularly Rose Valley. The first method correlates precipitation zones with recharge, the second assumes a measured stream discharge / alluvial fan infiltration relation. Discussion of alternative recharge mechanism follows the description of these two methods.

Precipitation Zone Method--

Ground water recharge factors have been empirically estimated for Basin and Range areas in east-central Nevada (Eakin, et al., 1949; Maxey and Eakin, 1949). These areas are considered hydraulically analogous to the CGSA in many respects. The factors are based on several conceptual relations as follows:

a) precipitation increases with elevation,

b) a minimum amount of precipitation is required before ground water recharge begins,

c) the percentage of precipitation going to ground water recharge increases with increasing precipitation, and

d) in the Basin and Range province the consolidated rocks of the mountainous higher elevations promotes runoff and the alluvial valleys absorb runoff (Miller, 1977, p. 21)

These "first approximation" recharge estimates were based on studies of valleys in east-central Nevada where recharge was assumed to equal discharge by natural losses. This was then expressed as a percentage of precipitation and balanced by trial and error against the estimated discharge losses. They defined recharge based on precipitation zones as follows:

Precipitation Zone	Recharge to Ground Water (%)
Less than 8 inches	0
8 to 12 inches	3
12 to 15 inches	7
15 to 20 inches	15
Greater than 20 inches	25

The precipitation zone intervals were chosen to correspond with the precipitation zones used on the Precipitation Map of Nevada (Hardman, 1936). The derived recharge percentages are substantiated, particularly in the higher elevations, by other studies in the Great Basin Region in general, (Eakin, et al., 1976, pp. 6-10), Las Vegas Valley, Nevada (Maxey and Jameson, 1948), and Roswell Basin, New Mexico (Fielder and Nye, 1933).

Observations of soil profiles during this study showed that after a rainfall the upper 6 to 8 inches of the soil, sometimes down to 2 feet at most, would be wet. A continuous zone of soil moisture connecting with a water table was not observed in any of the soil observation trenches or test holes (Peters, 1979, personal communication). All this near surface, capillary held water would be discharged by evaporation or evapotranspiration before a sufficient quantity could accumulate to reach the water table. Since rainfall in most of the study area is estimated to be less than 8 inches, this corroborates part of the findings of the above studies.

This precipitation zone method has been applied to the Upper Coso Basin by Spane (1978) using a regional precipitation-elevation relation he derived for that study. This resulted in a recharge estimate of 375 acre-feet/year from direct precipitation on the basin (Table 4.4).

This technique was also applied to Rose Valley using the same precipitation-elevation relation, with a resulting recharge estimate of 611 acre-feet/year from the east slope of the Sierra (NWC, 1978, p. 66). In reviewing this application it was found that the area of the precipitation zones was overestimated. In addition, the precipitation-elevation relation developed by Spane (1978) included stations over 100 miles from the study area. Such a curve must be used with caution since its applicability is limited to a confined region of similar

Table 4.4 ESTIMATED AVERAGE ANNUAL PRECIPITATION AND POTENTIAL RECHARGE TO UPPER COSO BASIN - PRECIPITATION ZONE METHOD (Spane, 1978)

Elevation Zone, feet	Area, acres	Estimated Precipitation: Range, inches	Estimated Precipitation: Average feet	Estimated Precipitation: Average acre-feet	Estimated Potential Recharge: Percentage of the total precipitation	Estimated Potential Recharge: Acre-Feet per year
> 8,000	25	12	1.	25	7	---
7,000 - 8,000	4,420	9.6 - 12	.9	3,980	3	120
6,000 - 7,000	11,580	8.0 - 9.6	.74	8,570	3	255
5,000 - 6,000	10,320	6.8 - 8.0	.62	6,400	minor	---
4,000 - 5,000	9,085	5.7 - 6.8	.53	4,815	minor	---
3,480 - 4,000	5,240	4.6 - 5.7	.43	2,255	minor	---
Total	40,670			26,045		375

Assigned estimates for average precipitation taken from Figure 4.2; estimates of potential recharge percentages for precipitation zones adapted from procedure outlined in Section 4.1.2

physiography, geology and climate (Steinhauser, 1967). It is probable that the Spane (1978) relation is applicable to the Coso Valley area while the east slope of the Sierra is a somewhat different, more transitional climatic regime. A higher precipitation estimate, to account for the microclimate of the east slope of the Sierra, would make a significant change in the computed recharge to Rose Valley.

Precipitation on the East Slope of the Sierra--Precipitation has not been directly measured on the upper slopes of the Sierra adjacent to Rose Valley so it must be estimated. Rantz (1969) shows precipitation of 12 to over 16 inches for the upper slopes of the Sierra adjacent to the northern section of Rose Valley. These isohyets are generalized and were estimated using a regional precipitation-elevation relation and could be off by as much as 5 inches (Wahl, 1979, personal communication). The precipitation situation is additionally complicated in the South Lahontan area due to precipitation from three distinct sources: (1) frontal storms over the Sierra; (2) tropical storms from the south; and (3) convective storms.

The Sierra Nevada produces a rain shadow effect on the area east of the mountain range, thereby greatly reducing the amount of precipitation falling to the east. More of this lost moisture may be dropped on the east slope of the Sierra than on areas to the east, hence more rain would fall there than in the Coso Basin to the east.

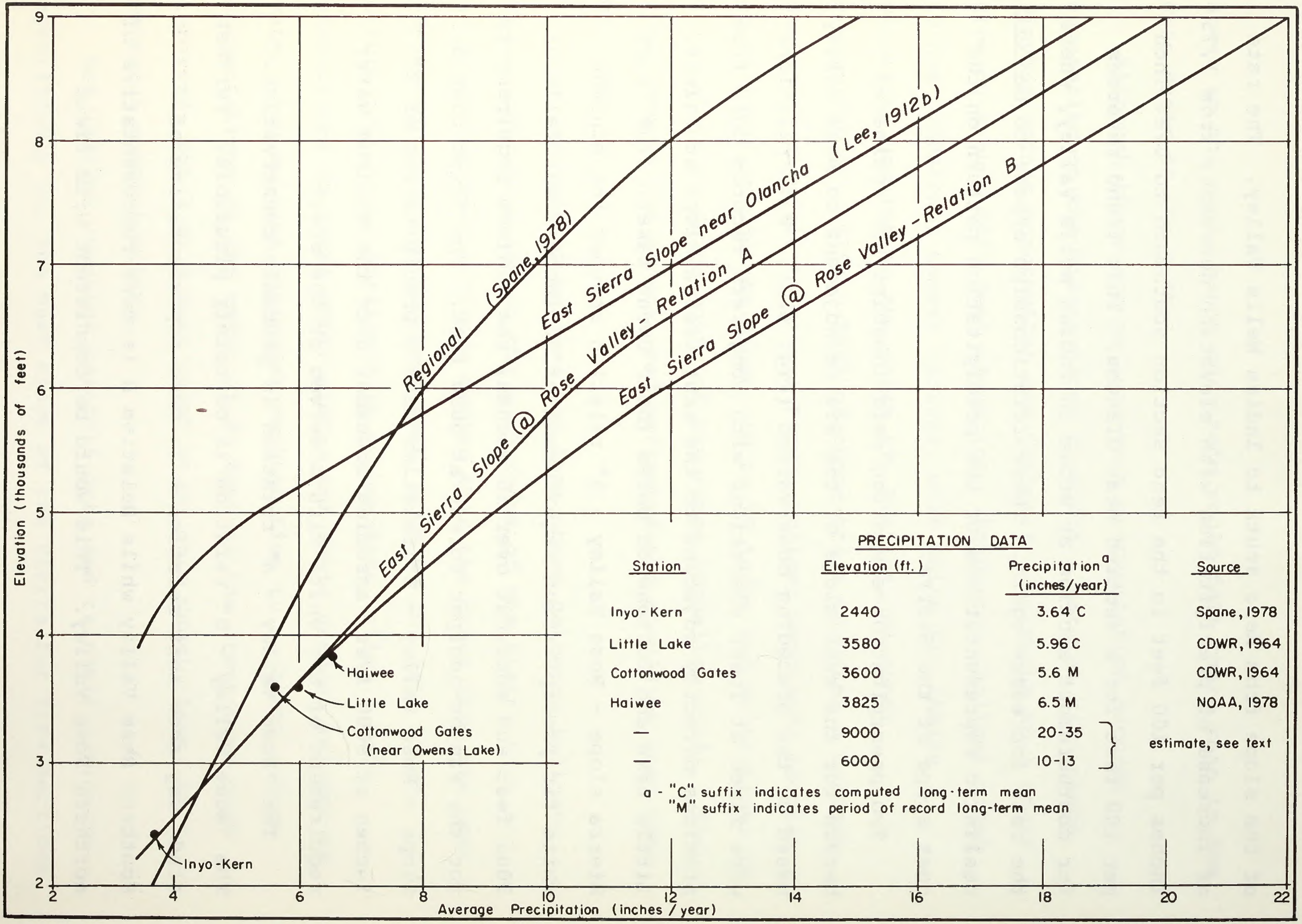
Although there are no long-term precipitation records, vegetation on the Sierra slope provides a natural rain gauge. Pinyons (pinus monophylla) and junipers (Juniperus sp.) start growing around 6000 feet elevation. Ponderosa (yellow) pines (pinus ponderosa) appear upslope, with white fir (Abies concolor) growing at the crest (T. Barling, personal communication, 1979). Each of these trees requires a certain amount of rainfall to grow. Pinyon-juniper woodlands require 10 to 15 in/yr, ponderosa pines, 10 to 15 in/yr and white firs, 20 to 35 in/yr in drier parts of its range (Fowells, 1965). These requirements are generalized estimates and should be used with caution.

Observations of weather and snow cover patterns indicate higher precipitation on the east slope of the Sierra than in areas to the east. Clouds coming over the crest from the west descend up to a few thousand feet, hugging the east slope, before continuing horizontally across Rose Valley. Snow accumulates on these upper slopes and their gradual release of water when melting increases contribution to recharge. Snow accumulations on the order of 20 feet at the crest have been reported, but 7 to 8 feet seems to be more usual (Lane, 1979, personal communication).

Lee (1912a) compiled rainfall data and rainfall estimates specifically for the east slope of the Sierra for five sections of the slope from Reno south to Indian Wells Valley. The rate of increase of precipitation with elevation decreases from 1.75 inches per 100 feet in the Reno section southward to 0.34 inch per 100 feet for a section near Olancha. This trend reverses for southernmost section at Brown in Indian Wells Valley, where the rate increases again. These relationships appear to be realistic representations of the precipitation pattern on the east slope of the Sierra.

Two precipitation-elevation relationships are estimated herein for the east slope of the Sierra adjacent to Rose Valley based on the preceding observation (Fig. 4.2). Both relations were fixed at lower elevations with long-term records only from stations directly adjacent to the east Sierra slope at Haiwee, Little Lake and Cottonwood Gates (near Owens Lake). The "East Sierra slope - Rose Valley - A" relation assumes the minimum white fir precipitation requirement of 20 inches/year falls at 9000 feet and somewhat over 10 inches, the minimum requirements for the Pinyon-juniper forest at 6000 feet. The "East Sierra Slope - Rose Valley - B" relation uses a precipitation of 22 inches at 9000 feet, assuming somewhat over the minimum water requirement of the white firs observed at the crest.

The "Rose Valley - A" relation is probably conservative. The "Rose Valley - B" relation is certainly plausible. Further study may show that relation A is more representative of southern Rose Valley while Relation B is more representative of northern Rose Valley. This would be consistent with field



Station	Elevation (ft.)	Precipitation[a] (inches/year)	Source
Inyo-Kern	2440	3.64 C	Spane, 1978
Little Lake	3580	5.96 C	CDWR, 1964
Cottonwood Gates	3600	5.6 M	CDWR, 1964
Haiwee	3825	6.5 M	NOAA, 1978
—	9000	20-35	estimate, see text
—	6000	10-13	estimate, see text

a - "C" suffix indicates computed long-term mean
"M" suffix indicates period of record long-term mean

Figure 4.2 Precipitation - elevation relationships observations of the east slope that suggest somewhat greater precipitation for the northern part of the valley.

Recharge from East Slope of the Sierra--Table 4.5 presents recharge estimates for Rose Valley using planimetered areas for each elevation zone based on the drainage basin boundaries outlined on Plate II-1 and Fig. 2.1. The Spane (1978) precipitation/elevation relation and the higher precipitation relations outlined above were used. This results in potential recharge estimates of 500, 1900 and 3000 acre-feet/year, respectively. It is apparent from these results that the assumed precipitation pattern makes a significant difference in the potential recharge estimate.

Stream Discharge / Alluvial Infiltration Method--

Stream flow has been gauged by the USGS for two drainages adjacent to the study area. (USGS, 1970, pp. 608-610; USGS, 1973, pp. 167 and 235; USGS, 1974, pp. 730-733; Jorgensen, 1979, personal communication). One is near the foot of the alluvial fan below the Little Lake Canyon. The other drainage is about seven miles south, within Ninemile Canyon, about one mile before the stream enters the alluvial fan. The period of record for both stations is 10 years. The difference in the measured mean annual flow from these two drainages is quite remarkable considering their proximity and similar physiography, geology

Table 4.5 ESTIMATED AVERAGE ANNUAL PRECIPITATION AND POTENTIAL RECHARGE FOR ROSE VALLEY BASIN PRECIPITATION ZONE METHOD[a]

Elevation Zone (feet)	Area (acres)	Regional Relation (Spane, 1978) Estimated Precipitation: Range in/yr	Regional Relation (Spane, 1978) Estimated Precipitation: Average acre-ft/yr (rounded)	Regional Relation (Spane, 1978) Estimated Potential Recharge: % Total Precipitation	Regional Relation (Spane, 1978) Estimated Potential Recharge: Total acre-ft/yr (rounded)	East Sierra Slope at Rose Valley - Relation A Estimated Precipitation: Range in/yr	East Sierra Slope at Rose Valley - Relation A Estimated Precipitation: Average acre-ft/yr (rounded)	East Sierra Slope at Rose Valley - Relation A Estimated Potential Recharge: % Total Precipitation	East Sierra Slope at Rose Valley - Relation A Estimated Potential Recharge: Total acre-ft/yr (rounded)	East Sierra Slope at Rose Valley - Relation B Estimated Precipitation: Range in/yr	East Sierra Slope at Rose Valley - Relation B Estimated Precipitation: Average acre-ft/yr (rounded)	East Sierra Slope at Rose Valley - Relation B Estimated Potential Recharge: % Total Precipitation	East Sierra Slope at Rose Valley - Relation B Estimated Potential Recharge: Total acre-ft/yr (rounded)
> 8000	3200	12.0 - 15.0	3,600	7	250	16.8 - 20	4,900	15	740	18.8 - 22	5,400	25	1,350
7000-8000	4900	10 - 12	4,500	3	140	13.4 - 16.8	6,200	11[b]	680	15.3 - 18.8	7,000	15	1,050
6000-7000	3100	8 - 10	2,300	3	70	10.5 - 13.4	3,100	5	160	11.9 - 15.3	3,500	7	250
5000-6000	11600	6.8 - 8.8	7,200	-	-	8.5 - 10.5	9,200	3	280	9.0 - 11.9	10,100	3	300
4000-5000	10200	5.6 - 6.8	5,300	-	-	6.7 - 8.5	6,500	-		6.8 - 9.0	6,700	-	-
< 4000	16600	4.8 - 5.6	7,200	-	-	4.8 - 6.7	8,000	-		6.0 - 7.0	9,000	-	-
Totals (rounded)	49600		30,000		500		37,900		1,900		41,700		3,000

[a] Precipitation on the Caso Range, on the east side of Rose Valley is less than 8 inches per year and therefore makes no contribution to ground water recharge

[b] The average annual precipitation for this elevation zone fell on the boundary between the 7 and 15% potential recharge zones so an average potential recharge of 11% of total precipitation is used.

[c] The average annual precipitation for this elevation zone fell on the boundary between the 3 and 7% potential recharge zones so an average potential recharge of 5% of total precipitation is used.

and climate. However, the behavior of ephemeral streams in this environment can explain this phenomena and help define one component of ground water recharge.

Observations in Rose Valley itself, as well as in similar environments (e.g. Death Valley and Utah), have shown that water flowing from ephemeral streams onto the alluvial fans that apron the mountain fronts infiltrates rather rapidly into the coarse-grained sediments of the fans. These fans are quite porous and capable of absorbing a great proportion of the water flowing over them, even during periods of peak flow.

The gauge in Ninemile Canyon is located well before the stream enters the alluvial fan. The gauge for the Little Lake drainage is located on the alluvial fan, at the intersection of the stream channel and Highway U.S. 395, about 1-1/2 miles from the canyon mouth. To estimate the amount of water that infiltrates we assume these streams have similar drainage characteristics and the difference in their discharge measurements is due to infiltration of the Little Lake stream flow into the fan. Observation of similar ephemeral drainages dying out on the fans in Rose Valley makes this hypothesis quite plausible. Most of them disappear before they reach Highway U.S. 395.

The computation and data for this estimate are outlined in Table 4.6. This results in an estimated recharge of about 700 acre-feet/year through all the alluvial fans on the Sierra front.

Table 4.6 COMPUTATIONS OF RECHARGE FROM EPHEMERAL STREAM FLOW ON ALLUVIAL FANS IN ROSE VALLEY

1) Measured mean annual flow:

Little Lake Canyon - nil

Ninemile Canyon - 0.68 cfs

2) Drainage areas:

Ninemile Canyon = 10.4 sq mi above Elevation 4000 ft

Entire Rose Valley Sierra front = 51.6 sq mi above Elevation 4000 ft

3) Proportion of Ninemile Canyon Drainage area to analagous

Entire Rose Valley Sierra Front drainage area (i.e. above 4000 ft) = 51.6 sq mi/ 10.4 sq mi = 4.96 $\approx$ 5.0

4) Assuming discharge is proportional to drainage area for drainages with similar characteristics leads to an estimated 5 x 0.68 cfs = 3.4 cfs for entire Sierra front on Rose Valley

5) Assuming 30% of ephemeral stream flow goes to ground water recharge (Mower and Cordova, 1974, p. 17-18)

$$3.4 \text{ cfs} \times 30\% = 1.02 \text{ cfs} \times 724 \frac{\text{acre-ft/yr}}{\text{cfs}} \approx 700 \text{ acre-ft/yr}$$

recharge to ground water from ephemeral stream flow on alluvial fans in Rose Valley

An Alternative Recharge Mechanism--

Another interpretation is proposed by Austin (NWC, 1978; personal communication, 1979). He suggests a mechanism where recharge from precipitation falling west of the Sierra crest and east of the South Fork of the Kern River infiltrates into east dipping fractures. According to Austin this infiltration flows eastward, below the Sierra crest, to the ground water reservoir in Rose Valley and under Rose Valley to the geothermal reservoir. This mechanism would in essence increase the catchment area for the Rose Valley ground water basin. The poorly developed drainage Austin notes in this area in support of this hypothesis may be explained by the topography and rainfall. The slopes here are less steep than the east facing slopes and mean annual rainfall is reported to be 10 inches or less (Rantz, 1979). Although the actual amount of precipitation may be different than that presented by Rantz (1969) the pattern indicates significantly less precipitation just west of the crest than surrounding areas. In response to a similar mechanism suggested for Indian Wells Valley the USGS concluded that they "have seen no conclusive evidence that precipitation which falls west of the crest of the Sierra Nevada finds it way eastward into the Indian Wells Valley ground water basin" (Bloyd, 1979).

Conclusion--

The estimates of recharge into the Rose Valley drainage basin by the Precipitation Zone Method (Table 4.5) are based on many assumptions and extrapolations. They are rough approximations at best. The Spane (1978) relation of 500 AF/yr appears low; "Relation A" (1900 AF/yr) and "Relation B" (3000 AF/yr) are more realistic. It is not clear what proportion of the Precipitation Zone Method estimate is derived from alluvial fan infiltration, but the 700 acre-feet (Table 4.6) seems to be a reasonable proportion of the total estimate of 1900 to 3000 acre-feet/year. Hence total recharge to Rose Valley from precipitation is crudely estimated at about 1900 to 3000 acre-feet/year.

4.1.3 Other Ground Water Recharge

Two other sources of ground water recharge in Rose Valley are leakage from the Los Angeles Aqueduct and percolation from irrigation water at Rose Valley Ranch.

In a study of the Milford Valley area, Utah, it is estimated that about 30% of water applied for irrigation contributes to ground water recharge (Mower and Cordova, 1974, pp. 18-21). Milford Valley is a semi-arid, Basin and Range area comparable to Rose Valley. Hence this factor can be applied to Rose Valley.

Rose Valley Ranch presently applies about 3130 acre-feet/year for irrigation. This would result in recharge to the ground water reservoir of about 900 acre-feet/year.

There is no direct measure of leakage from the Los Angeles Aqueduct. Assuming equal water loss throughout its length and that about 10 percent of the total length of the aqueduct between Haiwee Reservoir and Fairmont Reservoir lies in Rose Valley, then about 10 percent of the total water lost between these two gauging stations would be lost in Rose Valley. This has been estimated at about 350 to 450 acre-feet/year (LADWP, 1979, personal communication). The aqueducts are at or near the surface for most of their course through Rose Valley. The soil characteristics of the area suggest that little of this leakage reaches the water table. Assuming the water application is similar to irrigation application or stream channel loss it can be estimated that about 30% goes to ground water recharge. Using an average leakage of 400 acre-feet/year results in an estimated recharge of 120 acre-feet/year from Los Angeles Aqueduct leakage. The roughness of this estimate justifies rounding it off to 100 acre-feet/year.

4.2 DISCHARGE

The great majority of water in the CGSA is discharged through evaporation and transpiration. Ground water is discharged through irrigation, domestic and stock withdrawal, subsurface outflow, evaporation and transpiration and springs.

These components of discharge are summarized in Tables 4.1 and 4.2 and are discussed below.

4.2.1 Evaporation and Evapotranspiration

Most water enters the study area as precipitation. However, the amount of precipitation is so low that the great majority of it evaporates from the surface or shallow soils before it can recharge ground water reservoirs or maintain perennial streams. Hence, most water entering the CGSA is discharged via evaporation and transpiration. This discharge is summarized in Tables 4.7 and 4.8.

The Blaney-Criddle method has been widely accepted for use in arid areas to estimate average annual evapotranspiration (ET) (Chow, 1964). However, this method is not applicable to the CGSA since it assumes that the soil moisture supply is not a limiting factor in the evapotranspiration process. The limited availability of soil moisture prevents actual evapotranspiration from equaling potential evapotranspiration in desert areas. Annual evapotranspiration, of over 50 inches per year, estimated for the CGSA by the Blaney-Criddle method more clearly represents potential evapotranspiration rather than actual evapotranspiration. Based on an adjustment for the moisture deficiency, Holmes (1961), actual evapotranspiration in the CGSA was estimated to be 21 percent of the Blaney-Criddle method potential evapotranspiration estimate (Table 4.8). This still exceeds the actual average annual precipitation. More accurate estimates of evapotranspiration must be made by estimating

Table 4.7 SUMMARY OF EVAPORATIVE LOSSES FROM ROSE VALLEY AND UPPER COSO BASIN

Rose Valley	Estimated Annual Quantity (acre-feet/year, rounded)
Overall surface and soil moisture	53,000 - 58,000
Rose Valley Ranch agricultural	2,100
Little Lake surface	830
Other vegetated and irrigated areas and domestic use in Rose Valley	70
Springs	30/190
	56,000 - 61,000
Upper Coso Basin	
Overall surface and soil moisture	25,000

Table 4.8 Estimates of Average Annual Precipitation and Natural Evapotranspiration for the CGSA

	Average Annual Precipitation, inches	Average Annual Precipitation,[1] inches	Average Annual Evapotranspiration, inches	
Rose Valley	7.5 - 8.0[2]	7.2	10.7[4]	7.1 - 7.8[5]
Coso Basin	7.6[3]	5.0	11.8[4]	---
Upper Cactus Flat and Enclosed Basins	7.3[3]	5.2	11.1[4]	---

[1] Rockwell International, 1979

[2] HLA, this report

[3] Hydro-Search, Inc., 1978

[4] Blaney-Criddle Method adjusted according to Holmes, 1961

[5] Assuming ET equals precipitation minus ground water recharge

annual soil moisture availability. This can be derived for Rose Valley by assuming ET equals precipitation minus ground water recharge as follows:

1) Precipitation in the Rose Valley drainage basin can be approximated by adding the quantity computed for the Sierra slope in Section 4.1.2 with an estimate of the rainfall on the eastern side of the drainage basin. Estimating an average elevation of about 3800 feet results in an estimated average annual precipitation of about 5-1/2 inches using the Spane (1978) elevation-precipitation relation (Fig. 4.2). Multiplying this by an estimated area of 62.5 square miles results in a rough estimate of about 18,000 acre-feet/year for precipitation recharge for the eastern half of the Rose Valley drainage basin, or a total of 56,000 to 60,000 acre-feet/year for the entire drainage basin.

2) Based on concepts outlined in preceding discussions on ground water recharge (Section 4.1.2) we estimate that essentially all the precipitation falling on the east side of the Rose Valley drainage basin is evaporated or transpired.

3) All but the 1900 to 3000 acre-feet/year from Sierra precipitation estimated to recharge the ground water reservoir is also evaporated or transpired.

4) This results in water losses from surface and soil moisture evaporation and transpiration of about 18,000 acre-feet/year on the east side of Rose Valley and 35,000 to 40,000 acre-feet/year on the west, for a total of 53,000 to 58,000 acre-feet/year. This converts to 7.1 to 7.8 inches estimated average actual annual evapotranspiration in Rose Valley (Table 4.8).

Evaporative Losses from the Ground Water Reservoir--

Evaporative losses at Rose Valley Ranch, Little Lake and natural springs originate from the ground water reservoir. Minor evaporative losses from ground water occur at the vegetated area south of Little Lake, Coso Junction rest area and Lewis Ranch.

At Rose Valley Ranch, 70 percent of the 3100 acre-feet/year applied for irrigation (Mower and Cordova, 1974, p. 21) or 2200 acre-feet/year is estimated to be consumptively used. The remainder goes to ground-water recharge.

Evaporative losses from Little Lake were estimated to be about 830 acre-feet/year. This is based on an estimated surface area of 100 acres and an evaporation rate of 8-1/3 feet/year for the free water surface (NWC, 1978, p. 96).

The vegetated area just south of Little Lake is estimated to be about one-quarter the area of Little Lake, or about 25 acres. Assuming consumptive use in this area to be equivalent to a 100 percent salt grass cover with a four-foot water table results in an evaporation rate of about 1-1/2 feet/year (Kunkel and Chase, 1969, p. 67) or a total estimated consumptive use of about 40 acre-feet/year.

Domestic, minor irrigation and stock consumptive use in Rose Valley (detail in Section 5.2.2) is estimated to be about 30 acre-feet/year.

4.2.2 Springs

Seven flowing nonthermal springs and one thermal spring occur within the drainage basins included in the study (Appendix B2). The Coso Hot Springs, as noted previously (Section 3.4.2) are not actually springs but areas where steam condensate accumulates near the ground surface. For purposes of this discussion, however, we will consider them springs since they do discharge ground water at the surface.

Discharge has not been gauged on a regular basis at any of these springs. Flow rate has been estimated for a few by Moyle (1977) but these estimates do not represent long-term annual means. In fact, during our field survey Rodney Lane (1979, personal communication) reported significantly higher flows from the springs around Rose Valley (Appendix B2). This is based on observation an measurements by Lane for the past several years and reports from former residents who have witnessed the spring flows for the past 50 years. These longer term observations may be more representative of average flows than the Moyle (1977) estimates.

Discharge from springs is computed using both estimates. Springs listed as "flowing" are not included in the total. The resulting total flow from springs in the Rose Valley drainage is 17.6 gpm or about 30 acre-feet/year from the Moyle (1977) data and about 120 gpm or 190 acre-feet/year using Lane's (1979, personal communication) estimates.

For the Coso Valley drainage the total is 10 gpm from Haiwee Spring or about 16 acre-feet/year plus the discharge of 13.5 acre-feet/year from Coso Hot Springs described below.

<u>Quantity of Flow From Coso Hot Springs</u>--The total flow from all the fumaroles, mud pots and steaming ground at the Coso Hot Springs National Historic Site has never been measured. The

widespread occurrence, varying shape and size of discharge areas and combination of water, steam and other gases emanating from these manifestations makes such measurement extremely difficult. However, Moyle (1977, p. 4) and NWC (1978, p. 85) have measured the flow of steam from several wells in the resort area.

Moyle (1977) set up a condenser on Well 22S/39E-4K3 which yielded 3 gal/min; the actual yield of this well was somewhat higher since some of the steam was not collected in the condenser. Four wells the Navy had monitored for eight months have yielded an average flow of about 1/3 gal/min per well (NWC, 1978, p. 85). They have documented that the flow varies with the season. The maximum flow of 86 gal/hr for all four wells was observed during the winter. The minimum flow of 72 gal/hr was observed during the summer.

The total flow from the resort area manifestations has been estimated by Dr. Carl Austin at about 13.5 acre-feet/year (NWC, 1978, p. 85). This is based on the following assumptions: a) one well produces an average flow of 3 gal/min; b) six wells produce an average flow of 1/3 gal/min; and c) the remaining 33 known wells produce an average flow of 1/10 gal/min.

Upper Coso Basin--

Evaporative losses in Upper Coso Basin are assumed to equal precipitation minus subsurface outflow. Precipitation has been estimated to be about 26,000 acre-feet/year (Spane, 1978) and subsurface outflow between about 400 and 1000 acre-feet/year (see Section 4.2.2). Thus about 25,000 acre-feet/year are lost to evaporation. Evaporative loss from springs is insignificant.

4.2.3 Subsurface Outflow

Ground water discharges as underflow from Rose Valley and Upper Coso Basin. The quantities and paths of this underflow are not well defined. They range from about 45 (Boyd and Robson, 1971, p. 15) to 500 acre-feet/year for Rose Valley and from about 400 to 1000 (Bloyd and Robson, 1971, p. 15) acre-feet/year for Upper Coso Basin. An unestimated quantity of ground water may also flow from Rose Valley in a buried river channel southeast of Volcano Peak.

Underflow From Rose Valley--

Several mechanisms for underflow from Rose Valley are possible. Ground water may discharge from Rose Valley through the alluvial fill in the water gap south of Little Lake, it may discharge through faults and fractures paralleling the Sierra front and/or it may escape through an old buried river channel southwest of Volcano Peak (Duffield and Smith, 1978, p. 88). Currently, estimates for the water gap mechanism range from about 45 to 500 acre-feet/year. Flow through the buried river channel is not known, but there is no evidence that this mechanism contributes any significant quantity of water to Indian Wells Valley.

A hydrologic model of Indian Wells Valley suggest that the underflow contribution from Rose Valley into Indian Wells Valley through the water gap is only about 45 acre-feet/year (Bloyd and Robson, 1971, p. 15). Another estimate of this underflow may be derived by estimating the flow in this gap using the modification of Darcy's Law, Q = TIL, that was used in Section 4.1.1 to calculate underflow from Haiwee Reservoir.

Transmissivity in this gap has been estimated by Dutcher and Moyle (1973, Plate 4) as 10,000 to 25,000 gpd/ft and the constraining width is about 1500 feet. The gradient can be estimated by noting the water table essentially at the surface well into the gap as indicated by the occurrence of Little Lake and the perennial ponds south of Little Lake. These ponds extend into the gap to the 2960-foot topographic contour. The occurrence of cottonwood trees throughout the gap indicates that the ground-water surface remains within about 10 feet of the surface. The reddish tinge noted on color IR photos indicates some vegetative cover which also suggests near surface ground water. The 10-foot depth to ground water contour can be roughly located adjacent to Double Canyon where these shallow ground water indicators stop. The ground surface elevation here is about 2840 feet, making the estimated ground water elevation 2830 feet. The distance between the 2950 and 2830 ground water elevation is about 10,000 feet resulting in a rough estimate for the hydraulic gradient of 0.013. Substituting in the flow equation:

$$Q = (10{,}000 \text{ to } 25{,}000 \text{ gpd/ft})\ (0.013)\ (1500 \text{ ft})$$
$$= 195{,}000 \text{ to } 487{,}500 \text{ gpd}$$
$$\approx 200 \text{ to } 500 \text{ acre-feet/year for underflow through this gap.}$$

Since lava and granite lie very close to the surface at the southern end of the valley (Thompson, 1929, p. 151), the amount of underflow leaving Rose Valley would be limited by the hydraulic conductivity of these rocks. The hydraulic conductivity of the crystalline rocks would be very low unless they contain significant north-south trending conductive faults and fractures. The active Little Lake fault (Roquemore, 1978) may serve this function. Although water table data are limited for the northwest corner of Indian Wells Valley, just below Rose Valley, the hydraulic gradients that have been derived do not indicate appreciable ground water contribution from the section of Rose Valley south of Little Lake or southeast of Volcano Peak. Additional water level and transmissivity data in this area would be required to more accurately determine the underflow contribution from Rose Valley.

Underflow from Upper Coso Basin--

If it is assumed that the natural ground water system in Upper Coso Basin is in equilibrium then recharge will equal discharge. Discharge from Upper Coso Basin drainage via Haiwee

Spring and underflow. The discharge at Coso Hot Springs is small and its relation to the Upper Coso Basin ground water system is not known.

Recharge to the Upper Coso Basin is estimated at about 400 acre-feet/year (rounded from Spane, 1978). Haiwee Spring discharges at an estimated 10 gpm (Moyle, 1977, p. 21) or about 16 acre-feet/year. Therefore, based on these assumptions and within the accuracy of the estimates, discharge from the Upper Coso Basin could be estimated at about 400 acre-feet/year.

Another estimate of 1000 acre-feet/year underflow from Upper Coso Basin is suggested by Bloyd and Robson (1971, p. 15). This estimate was used in their ground water model of Indian Wells Valley. However, Kunkel and Chase (1969, p. 72) note that subsurface outflow from Coso Valley is "very minor". A fourth estimate of 4000 acre-feet/year is attributed to Thompson (1929) by NWC (1978, p. 68).

4.3 STORAGE

Water in storage in the CGSA is a combination of surface and ground-water storage. Storage as soil moisture is not considered for two reasons. First, the water table is so deep in most of the area that the soil moisture capillary zone is too deep to be affected by evaporative losses. Second, near-surface soil moisture is an ephemeral feature in this climate since potential evaporation exceeds precipitation on the valley floors. This results in essentially no ground water storage as shallow soil moisture.

The surface water storage in Rose Valley, Coso Basin, and the enclosed basins is in equilibrium on a long-term basis. Short-term increases in storage in the enclosed basins are due to surface runoff. Generally, the long-term change in storage of surface water is not affected by the short-term storage of ephemeral runoff.

In Rose Valley, Little Lake is the only perennial surface water body; other surface water storage is ephemeral, in playas and depressions. (Haiwee Reservoir is not considered since it is part of the Los Angeles water supply.) Water levels in Little Lake are primarily a function of ground water levels and secondarily a function of major runoff in Rose Valley. Presently Little Lake has an area of 100 acres and an average depth of 3-1/2 feet, resulting in an estimated storage of 350 acre-feet.

Ground water in storage is the volume of water that fills interstitial pore spaces of sediments and/or fractures in sedimentary or crystalline rocks. Water bearing capacities are most often much greater in porous sediments than in fractured rocks. Ground water in storage may be considered a reserve water resource that may be drawn upon when discharge exceeds recharge. During the Pleistocene and recent past precipitation in the area was much greater and the Owens River flowed intermittently through Rose Valley. This provided more recharge than at present and increased ground water in storage in Rose Valley (NWC, 1978, p. 63).

Usable ground water in storage must have three characteristics. First, the water must be able to drain by gravity to wells during pumping. Second, it must be of acceptable chemical character for the intended purpose. Third, it must be at an economically extractable depth.

Ground water storage resources exist in Rose Valley, other alluvial filled valleys near the CGSA and the geothermal reservoir. The volume of fluid in the geothermal reservoir has been discussed in Chapter 1 of the ES. The other alluvial filled valleys are discussed in Section 5.1.2. These valleys are quite small and no ground water data exist so no water in storage is estimated. Total ground water in storage for Rose Valley has been estimated to be on the order of 3.3 to 5 million acre-feet with 1.4 to 2.2 million acre-feet within 1000 feet of the surface.

The crystalline rocks of the Sierra Nevada have also been suggested as a ground water reservoir storing water and supplying recharge to valleys to the east (Austin, 1979b). This is considered improbable. First, the storage capacity of the fractured rock is not known and it is likely that the porosity decreases with depth. Second, the degree of hydraulic conductivity within the fractured crystalline mass or the conductivity between it and the alluvial filled valleys is not known. Typically these systems are considered as essentially separate entities. "There is no conclusive evidence that these fractures are sufficiently interconnected to transmit water over the long distances that would be required to deliver this water to the basin" (Bloyd, 1979).

4.3.1 Storage Estimate for Rose Valley

Ground water in storage for Rose Valley has been estimated by assuming an average specific yield for the saturated thickness of alluvial material in the valley. The thickness of alluvium is shown in Figure 3.1 and discussed in Section 3.1.2.

Specific Yield--

The specific yield is the ratio of the volume of water that will be drawn by gravity to the total volume of reservoir material that is being dewatered or pumped. No estimates of specific yield are known for Rose Valley. The specific yield is generally fairly consistent for a given material, but the alluvium in Rose Valley is quite heterogeneous (see Section 3.1.1 - Description of Hydrologic Units). Specific yields in Indian Wells Valley have been estimted by Kunkel and Chase (1969, p. 80) from 3% for clay to 20% for medium to very coarse, fairly well sorted, clean sand. Specific yield will decrease with decreasing grain size, poorer sorting, increased cementing material and increased compaction. In general, this means that specific yields will decrease with depth and with distance from range fronts in alluvial fans. Average specific yield in Rose

Valley is roughly estimated at 10 to 15% for the following storage calculation.

Storage Calculation--

The volume of saturated fill was computed using the edge of the alluvium as the reservoir boundary and an average water level depth of 125 feet for the entire valley (Fig. 3.5, Depth to Water, Rose Valley). Using an average water level depth instead of the contoured water level surface would not significantly affect the resulting saturated volume considering the depth of the valley fill. The resulting total volume of saturated fill is about 33 million acre-feet.

Assuming an unconfined aquifer with a 10 to 15% specific yield, the total volume of water in storage is 3.3 to 5 million acre-feet. Of this total 1.4 to 2.2 million acre-feet is within 1000 feet of the surface. Most of the water in storage is believed to be usable but the geothermal reservoir fluid may extend into the alluvial material on the east side of the valley or salaine water may occur in other locations.

SECTION 5

WATER AVAILABILITY AND USE

No surface water is available for use in or near the CGSA. Water is potentially available from several ground water basins. Areas that contain porous materials with water-bearing properties may be considered for ground water extraction. These include the alluvial sediments in Rose Valley, Upper Cactus Flat, McCloud Flat, Upper Coso Basin and Lower Coso Basin (Fig. 2.1). Although the pyroclastic debris in the rhyolite dome area is quite porous it is not considered as a potential source of ground water due to its limited areal extent and thickness, probable deep water and possible hydraulic connection with the geothermal reservoir. Use of water extracted from the geothermal reservoir is considered in the design of the power plant system and the 323 acre-feet/year requirement per 50 MWe is in excess of that use.

Rose Valley has been emphasized throughout this study as a prime potential source of cooling water due to its size and potential ground water yield, its inclusion within the boundaries of BLM controlled land and its proximity to the primary area of projected development. Compared with Rose Valley, the other drainage basins are quite small, have lower rainfall, and much less or no data available. Use of ground water from these other basins would require further assessment of ground water resources, most likely including drilling of several observation wells. Descriptions of these basins, as well as of Rose Valley, are outlined in Section 5.1. Section 5.2 outlines present and projected water use for Rose Valley.

5.1 WATER AVAILABILITY

5.1.1 Rose Valley

Ground water in storage in Rose Valley, outlined in Section 4.3.1, is estimated to be 3.3 to 5 million acre-feet. Of this total, 1.4 to 2.2 million acre-feet is within 1000 feet of the surface. Ground water recharge is estimated at 3500 to 4600 acre-feet/year (AF/yr); discharge is 4100 to 4700 AF/yr. This indicates that ground water excess or deficiency is not more than several hundred acre-feet/year. The Rose Valley ground water basin presently is near hydraulic equilibrium.

Unless further study indicates greater recharge from precipitation or areas north of Rose Valley, available data and analyses suggest that additional significant ground water withdrawal would lower the water table. The rate of lowering could be reduced by the effects of the lowered water table, for example, a lowered water table could:

a) increase hydraulic gradients towards areas of discharge and thereby increase recharge or reduce discharge via underflow

b) reduce evaporative losses by lowering the level of Little Lake

At this point the effects of locally increased hydraulic gradients cannot be evaluated in terms of increased recharge.

It is unlikely that lowering the level of Little Lake would be environmentally acceptable.

Water availability from lowering the water table is about 2100 to 3200 acre-feet per foot of drawdown for the upper 1000 feet of sediments in Rose Valley. This calculation is based on the following assumptions:

a) the area of extraction would be within the 300-foot thickness of alluvium contour, or about 33 square miles; and

b) the average specific yield of the sediments is 10 to 15%.

The water table will not lower uniformly throughout the valley, but would be greater near pumping wells. In addition, the character of the ground water is not known throughout Rose Valley. It is quite possible that water on the east side of the valley may be affected by the proximity to or mixing with geothermal fluids. Water in some parts of the valley may be saline, depending on location and depth.

5.1.2 Other Potential Ground Water Sources

Upper Coso Basin--

Coso Valley, in the Upper Coso Basin, is directly east of the prime potential development area and would therefore be a very attractive source of cooling water. Unfortunately, there is essentially no data on this basin. The areal extent of the valley itself, excluding the hot springs area, is only about 2-1/2 square miles, hence the amount of available ground water appears to be limited. Recharge to the Upper Coso Basin has been estimated at 390 AF/yr by Spane (1978, p. 27). In a hydrologic model of Indian Wells Valley, Bloyd and Robson (1971, p. 15) estimate 1000 AF/yr underflow from Upper Coso basin into Lower Coso Basin. Assuming recharge equals discharge this implies 1000 AF/yr recharge to the Upper Coso basin. If the water characteristics are satisfactory, either interpretation suggests potential recharge to the valley is sufficient to supply cooling water for one or more 50 MWe power plants.

Upper Cactus Flat--

Upper Cactus Flat is underlain by alluvium (Duffield and Bacon, 1977). The water table is quite deep. Two heat flow holes drilled in 1975 to depths of 293 and 438 feet, respectively, did not intercept the water table (Jim Whelan, personal communication, 1979). This indicates a limited amount of water in storage and high pumping and well drilling costs for the water that is there. The total water in storage cannot be estimated since the depth of alluvium is not known. However, it would be limited since the areal extent is only about 4 square miles. Spane (1978) estimated a potential recharge of only 45 AF/yr to the Upper Cactus Flat. Hence, available ground water would be quite limited if hydrologic equilibrium is maintained.

McCloud Flat--

The conditions in McCloud Flat are unknown but probably similar to Upper Cactus Flat. The basin is even smaller with less storage and potential recharge.

Lower Coso Basin--

Lower Coso Basin is the second largest potential ground water basin in or near the CGSA and as the others except Rose Valley, there is essentially no data on ground water character or occurrence. However, considering only distance, elevation difference and water rights, it may be economically unfeasible to pump this water and/or its effects on subsuface recharge to Indian Wells valley may be considered detrimental.

5.1.3 Legal Constraints

In a legislated agreement with the LADWP, the BLM has withdrawn all BLM owned land in Rose Valley for any use other than: recreation, grazing, wildlife and fisheries management or metalliferous mining. However, LADWP has agreed to also allow water extraction in Rose Valley for geothermal development (Rockwell International, 1979, personal communication). Projected agricultural uses of land and water in Rose Valley have been limited to the privately owned or leased land.

Another legal constraint involves the potential effects of ground water withdrawal on subsurface inflow from adjacent basins and subsurface outflow to adjacent basins. Residents of Indian Wells Valley have already expressed concern that ground water withdrawal in Rose Valley may reduce the contribution of underflow from Rose Valley southward into Indian Wells Valley.

5.2 WATER USE

Current water use is quite limited in Rose Valley and nil in Coso Valley. Rose Valley Ranch is the major water user, pumping about 3130 AF/yr (Hennis, 1979, personal communication). Domestic use is small due to the low population. Water use in Rose Valley is summarized in Table 5.1 and discussed below.

5.2.1 Irrigation

Rose Valley Ranch, the only major irrigator in Rose Valley, is located in the northern part of Rose Valley in T21S, R37E, Sec. 26.

Major irrigation pumping at Rose Valley Ranch started in 1975. As of 1979 about 313 acres of alfalfa will be cultivated. Two wells are used and major pumping generally occurs between late March and October with both wells pumping 24 hours a day during mid-summer. This use pattern is anticipated to change to increase pumping at night and reduce daytime power consumption and evaporative losses.

Well 21S/37E-26B1 is near the ranch house and is used for domestic and irrigation purposes. Between November and March it is turned on once a week to fill a 10,000-gallon tank for domestic and stock use. The sustained capacity of this well is about 2000 to 2400 gallons per minute (gpm) (Southern California Edison, 1976, 1977 and 1978) with peak capacity over 3000 gpm (Phil Hennis, 1979, personal communication). It is 725 feet

Table 5-1. Estimated Water Use in Rose Valley

Use and Location	Estimated Annual Quantity (acre-feet/year)
Irrigation	
Rose Valley Ranch	3130
Cal-Trans Rest Stop	14
Domestic & Stock	
Permanent residents	7
Cal-Trans Rest Stop	14
Stock watering	3
Transient residents at Little Lake Hotel	5
	3200 (rounded)

deep with 16-inch-diameter casing perforated from 120 feet to 724 feet (Rottman Drilling Company, 1971).

Well 21S/37E-26K1 is located in the field and is used solely for irrigation. The sustained capacity is about 1000 to 1300 gpm (Southern California Edison, 1976, 1977, 1978) although it has been reported to produce up to 3600 gpm (Rottman Drilling Company, 1974).

Irrigation use at the Cal-Trans Coso Junction Rest Stop was estimated in design of the facility as equal to the domestic use, or about 14 AF/yr. Derivation of the Cal-Trans domestic use is outlined in the following subsection.

5.2.2 Domestic and Stock Watering

In addition to Rose Valley Ranch, water is also used in Rose Valley by several permanent residents, the transient population, and livestock. Domestic water use in Indian Wells Valley is estimated at 221 gpd per capita (Indian Wells Valley County Water District, personal communication, 1979). This appears to be consistent with a per capita domestic use of 215 gpd from public supplies in Nevada (Murray and Reeves, 1970), an area of similar climate. For this analysis a daily per capita water use estimate of 200 gpd seems reasonable for Rose Valley. This totals about 30 AF/yr (Table 5.1) and is detailed below.

Domestic--

It is estimated that about 30 people permanently reside in Rose Valley at Haiwee Reservoir, Dunmovin (T21S, R37E, Sec. 23), Rose Valley Ranch (T21S, R37E, Sec. 26), Lewis Ranch (T22S, R37E, Sec. 3). Little Lake (T23S, R38E, Secs. 17 and 18) and in the canyons of the Sierra slope. So domestic water use by permanent residents of Rose Valley can be estimated at about 6600 gpd, or about 7.4 AF/yr.

The one or two current residents at Dunmovin use water piped from a spring in Talus Canyon. This 4-inch pipeline, originally installed by the LADWP, has perennial flow and has been used for agriculture in the past. The residents of Lewis Ranch get their water from a spring at the range (22S/37E-3NS1). The water for the 7 or 8 residents at the Haiwee Powerhouse comes from a pipeline originating at Haiwee Creek.

The 12 or so residents at Little Lake get their water from artesian well 23S/38E-17D1. This is a 42-inch-diameter well with a 6- or 8-inch pipe going from the well to the Little Lake Hotel. One other domestic nonartesian well has been used in the past in this area (23S/38E-5N1).

Livestock--

Livestock are watered in Rose Valley in the spring. The precise number and grazing period varies. During 1979 about 450 head of cattle will graze in Rose Valley for about 4 months. Other livestock residing all year in the valley consist of about 100 sheep and goats and several other horses and cows. At consumptive rates of 15 gpd for beef cattle and horses in California (MacKichan and Kammerer, 1961), and 2 gpd for sheep and goats (Walton, 1970, p. 617) total annual consumption for livestock in Rose Valley can be estimated at about 3 AF/yr.

A one-inch pipeline extending from a spring-fed stream in Sacatar Canyon to T22S, R38E, Sec. 20 is used for stock watering in the spring (Phil Hennis, 1979, personal communication). This pipe is reported to hav many leaks. Two wells near Little Lake (23S/38E-8D2 and 23S/38E-17D2) are also reported to be used for stock watering (Moyle, 1977, p. 20).

Transient Population--

There is no measure of consumptive use for the transient populations at the Cal-Trans Coso Junction rest stop or the Little Lake Hotel. This quantity is estimated as follows:

1. The number of cars stopping at rest area ranged from about 300 to 1400 per day (Ken Deboy, 1979, personal communication). A daily average of about 850 is assumed.

2. In planning their rest areas, the California Department of Transportation estimates three people riding in each car and a water requirement of 5 gallons per person (Jerry Gabriel, 1979, personal communication).

3. This results in a total of 2550 visitors per day using an estimated 5 gallons of water each for a total of 12,750 gpd or about 14 AF/yr.

Estimating an average of about 40 visitors a day at the Little Lake Hotel, each using about half the estimated daily per capita consumptive rate for Rose Valley comes to 4400 gpd or about 4.9 AF/yr.

5.3 PROJECTED WATER USE

The major change anticipated in water use in Rose Valley will be increases due to agricultural production and geothermal development. These projections are detailed below and outlined in Tables 5.2 and 5.3.

5.3.1 Irrigation

Presently, Rodney Lane of Lewis Ranch plans to drill a well near Coso Junction. He intends to cultivate 80 acres of alfalfa by fall 1979 or spring 1980, and is planning to grow 36 acres of garlic. It is possible that Rose Valley Ranch will increase its cultivated alfalfa acreage by about 460 acres in the next four or so years (Phil Hennis, 1979, personal communication). Assuming Rose Valley Ranch expands and an irrigation application of 10 feet/acre per year for alfalfa and 5 feet/acre per year for garlic would result in an additional water use of about 5600 AF/yr within the next few years for a total agricultural use of about 8700 AF/yr. Without the Rose Valley Ranch expansion, total agricultural use would be about 4100 AF/yr.

Agricultural production in Rose Valley may or may not increase. The rate and amount of this increase will be largely related to policy decisions by Federal agencies regarding release of government lands for agricultural use and availability of water. Much of the BLM holdings are potentially

Table 5-2. Projected Water Use in Rose Valley, circa 1986[a]

Use and Location		Estimated Annual Quantity (acre-feet/year, rounded)
Irrigation		
Rose Valley Ranch	3130 [b]	
Lewis Ranch/Coso Junction	1000	
Cal-Trans Rest Stop	14	
Total irrigation		4100
Domestic and Stock -		
Permanent residents	260	
Cal-Trans Rest Area		
Transient residents	40	
Stock watering		
Total domestic and stock		300
Industrial		
Geothermal Power Plant - 60 MWe	390	
Geothermal well drilling (assume 13 wells/year)	210	
Total industrial		600
Total use		5000

[a] Or at completion of first 60 MWe of geothermal generating capacity.
[b] Irrigation application at Rose Valley Ranch could possibly increase by as much as 4600 AF/yr (see text)

Table 5-3. Projected Water Use in Rose Valley, circa 2000

Use and Location	Estimated Annual Quantity (acre-feet/year, rounded)
Irrigation	4100 [a]
Domestic and Stock	400
Geothermal	1900
Total	6600

[a] Assuming no increased consumption at Rose Valley Ranch (see text)

arable. Edwin Hall, Agricultural Commissioner of Inyo County, in a letter dated March 23, 1979, to Wilma Muth, Supervisor of Inyo County, suggested designating 3000 acres around Rose Valley Ranch for agricultural use. If this much land is brought to cultivation in the next decade or two, with application of 10 AF/yr per acre, it would result in a water use of 30,000 AF/yr. It is highly unlikely that this quantity of water would be available from Rose Valley or that BLM would release the land. Hence, the 1986 irrigation estimate is projected to the year 2000.

5.3.2 Domestic and Stock

In the "worst case" analysis, construction and operation of geothermal power plants in Rose Valley is assumed to result in development of a community of about 1500 people in Rose Valley by the year 2010 (see ES Section 3.12.1). This projection estimates a population of 1050, 1450 and 1500 for the years 1986, 2000 and 2010, respectively. This results in a projected domestic water consumption of about 260 AF/yr in 1986, 360 AF/yr in 2000 and 370 AF/yr in 2010.

Increase in consumptive use at the Cal-Trans rest area and by transient residents is assumed to be covered by the rounding up of the domestic use estimates. It is assumed that possible inaccuracies in these domestic use categories will balance each other.

Use of water in Rose Valley for stock watering is limited by BLM range regulations and is not anticipated to increase.

5.3.3 Industrial

The geothermal model assumes that the Navy 10 MWe plant will be operational by 1985 and the first 50 MWe commerical power plant by 1986. Geothermal power production is estimated to reach 260 MWe by 2000.

Water will be required for plant cooling and for drilling. Each 50 MWe plant will consumptively use 323 acre-feet of cooling water. The amount of water required for drilling depends on the drilling method used, the depth of the well and the quantity of fluid loss to the formation. It is impossible to determine this quantity at this time. However, in order to assess potential environmental impacts NWC (1978, p. 179) have roughly estimated an average of 16 acre-feet/well based on their experience in drilling CGEH-1 and other wells.

The geothermal model assumes the 10 MWe Navy plant and the first 50 MWe commercial plant will require 6 and 25 production wells, respectively. Based on the success rates estimated in the development model of 63 wells will be drilled to achieve 31 production wells. The unsuccessful wells will be used for injection. Assuming a development period of 5 years results in drilling about 13 wells per year, or about 210 AF/yr of water required for drilling.

The model estimates that a total of 600 wells will be drilled for total development of approximately 260 MWe in Zones 1 and 2 by 2000. Assuming 30 year development period results in about 15 wells drilled per year. This results in a water use of about 240 AF/yr for drilling and about 1680 AF/yr for cooling, for a total geothermal consumptive use of about 1900 AF/yr.

Athough it is extremely conjectural and hypothetical, if geothermal power production and drilling on BLM lands is extrapolated to 550 MWe by 2030 water consumption will be about 3600 AF/yr for cooling. Assuming a minimum output of 1.67 MWe per well as an economic cutoff, about 170 additional production wells will be required to bring electric generation to 550 MWe (i.e. 290 MWe at 1.67 MWe per well). Based on a replacement factor of 2.5 and a success ratio of .85 results in about 800 additional wells to be drilled. Again assuming a 30-year development period results in drilling about 27 wells per year, for a drilling water consumption of about 430 AF/yr. Assuming the resource in Zones 1 and 2 are still producing in 2030, the total geothermal water consumption would be about 4300 AF/yr.

Red Hill Mining Company plans to use 9000 gpd (10 AF/yr) in their cinder mining operation. They plan to import this water from the Indian Wells Valley County Water District and will therefore make no demand on the Rose Valley water supply (VTN, 1978).

SECTION 6

SUMMARY AND CONCLUSIONS

This section is organized to directly address the three major hydrologic issues outlined in the Introduction.

1. Cooling Water Availability

   A. Within the uncertainty of the estimates, the Rose Valley ground water basin appears to be near hydrologic equilibrium with a ground water recharge of 3500 to 4600 AF/yr and a discharge of 4100 to 4700 AF/yr. This balance is based on the following assumptions:

      a) quantity of precipitation on the east slope of the Sierra, including confirmation of the potential ground water recharge relation

      b) recharge from areas to the north, including underflow through the gorge south of Haiwee Reservoir and possibly through the alluvial fans to the west of the reservoir

      This balance may be modified by further studies which would refine precipitation and recharge estimates and assumptions.

   B. Total ground water in storage in Rose Valley is 3.3 to 5 million acre-feet. 1.4 to 2.2 million acre-feet is within 1000 feet of the surface. Most of this water is believed to be usable.

   C. Formations with transmissivity greater than 150,000 gpd per foot occur in Rose Valley.

   D. Water use in Rose Valley is presently estimated at 3200 AF/yr. By 1986 or so, anticipating development of 60 MWe geothermal power production and increased agricultural use, water use in Rose Valley will be 5000 AF/yr. By 2000, it is projected to 6600 AF/yr assuming 260 MWe geothermal power production.

E. The range in the recharge and discharge estimates and the assumptions used in deriving them make it difficult to determine at what point increased water demand in Rose Valley will overdraft the ground water reservoir. In the worst case it is presently overdrafted by over one thousand acre-feet/year. In the best case recharge presently exceeds discharge by about 500 AF/yr.

F. If the water required for geothermal development tilts the hydrologic balance, as a first approximation, 2100 to 3200 acre-feet of water will be available per foot of drawdown from the upper one thousand feet of the ground water reservoir in Rose Valley.

2. Degradation of natural water

A. Three characteristic water types occur in the CGSA. They are:

a) a predominantly calcium carbonate water with TDS content of several hundred mg/l. It is typically associated with runoff from the granitic mountains.

b) an acidic sodium sulfate water with TDS content from about 200 to 2000 mg/l. It is typically associated with the surface thermal manifestations

c) an alkaline sodium chloride water with a TDS content around 6000 mg/l. It is only found in the geothermal reservoir

B. Water quality in the CGSA is generally good except for the thermal waters and surface water in Little Lake. Water characteristics on the east side of Rose Valley or at depth are not known.

C. If proper ground water and geothermal reservoir development techniques are employed, including proper well construction design, natural water quality will not be degraded. Natural water quality will have to be defined in some parts of Rose Valley, particularly on the east side where the geothermal reservoir fluid may migrate into or under the valley.

3. Effects on thermal manifestations:

A. The chemical composition of the fluid found at the hot springs is distinctly different from the reservoir fluid. However, the hot spring fluid is wholly or partly composed of steam condensate derived from the reservoir.

B. Lowering of the water table and altering natural flow in the reservoir may affect the amount of steam condensate reaching the hot springs. This effect is impossible to quantify at this time. However, it is anticipated that the effects of geothermal development will be less than if the hot springs were fed directly and solely by geothermal reservoir fluid for two reasons:

   a) Steam is much less viscous and dense than water. It will rise above the water table and flow more pervasively than water.

   b) Shallow ground water contributes to the hot springs. This contribution will not be affected by geothermal development.

C. Detailed and comprehensive monitoring of water levels, water and air temperatures, precipitation, quantity of flow and chemical composition will be required to establish a valid baseline that will define natural temporal variations in the hot springs.

REFERENCES

Antelope Valley Pump Services, June 27, 1977. Letter (unpublished).

Austin, C. F., NWC Geothermal Program Director, 1979. Phone conversations January 12, 29, February 15, 1979, review meeting on Coso ES Hydrology Report, April 10, 1979.

Austin, C. F., NWC Geothermal Program Director, 1979b. Letter to David R. Hamilton, General Manager, Indian Wells Valley Water District evaluating ground water situation in Indian Wells Valley.

Austin, C. F., and J. K. Pringle, 1970. Geologic Investigations of the Coso Thermal Area: China Lake, California. U.S. Naval Weapons Center, NWC-TP-4878, 40 pp.

Barling, T. C., 1979. Engineering Division, Public Works Department. Statement at meeting on review of hydrology studies, April 10, 1979, at the Naval Weapons Center, China Lake, and phone conversation April 16, 1979.

Bate, R., 1979. Personal communication with Bob Feldsmeth.

Bloyd, R. M., Jr., February 9, 1979. District Chief, USGS Water Resources Division, Menlo Park, California. Letter report to Mr. David R. Hamilton, General Manager, Indian Wells Valley Water District in response to Dr. C. F. Austin's evaluation of the ground water situation in Indian Wells Valley (unpublished).

Bloyd, R. M., Jr., and S. G. Robson, 1971. Mathematical Ground-Water Model of Indian Wells Valley, California. USGS Open File Report (no number), Water Resources Division, Menlo Park, 36 pp.

California Department of Water Resources, 1964. Ground Water Occurrence and Quality, Lahontan Region. Bulletin 106-1, 439 pp.

California Indian Legal Services, 1978. Letter to Admiral Harris, Commander, NWC, China Lake, February 8, 1978; and statements transcribed from the Coso Geothermal Workshop Presentation by Dallas Atkins and Julius Murray.

Chow, V. T., 1964. Handbook of Applied Hydrology. McGraw-Hill, Inc., New York, 1418 pp.

Combs, J., 1976. Heat Flow Determinations in the Coso Geothermal Area, California, The Coso Geothermal Project. Technical Report #3, U.S. ERDA Contract #E(45-1)-1830, 24 pp.

Deboy, K., 1979. California Department of Transportation, personal communication with Keith Julian, ERG, Inc.

Duffield, W. A., and C. R. Bacon, 1977. Preliminary Geologic Map of the Coso Volcanic Field and Adjacent Areas, Inyo County, California. USGS Open File Map 77-311, 2 sheets.

Duffield, W. A., and G. I. Smith, 1978. Pleistocene River Erosion and Intracanyon Lava Flows near Little Lake, Inyo County, California. California Geology, April 1978, pp. 81-89.

Dutcher, L. C., and W. R. Moyle, Jr., 1973. Geologic and Hydrologic Features of Indian Wells Valley, California. USGS Water Supply Paper 2007, 30 pp.

Eakin, T. E., D. Price, and J. R. Harrill, 1976. Summary Appraisals of the Nations Ground-Water Resources - Great Basin Region. USGS Professional Paper 813-G, 37 pp.

Eakin, T. E., G. B. Maxey, and T. W. Robinson, 1949. Goshute-Antelope Valley, Elko County, Nevada. Nevada State Engineer Report (mimeographed), 24 pp.

Ellis, A. J. and W. A. J. Mahon, 1977. Chemistry and Geothermal Systems, Academic Press, New York, 392 pp.

Fiedler, A. G., and S. S. Nye, 1933. Geology and Ground-Water Resources of the Roswell Artesian Basin, New Mexico. U.S. Geological Survey Water-Supply paper 639, p. 246.

Fournier, R. O., January 29, 1979. Personal communication. Geochemist, USGS, Menlo Park, California.

Fournier, R. O., J. M. Thompson and C. F. Austin, 1978. Chemical Analyses and Preliminary Interpretation of Waters Collected from the CGEH No. 1 Geothermal Well at Coso, California. USGS Open File Report 78-434, 10 pp.

Fowells, H. A., 1965. Silvics of Forest Trees of the U.S. Agricultural Handbook No. 271, U.S. Forest Service, U.S. Department of Agriculture.

Gabriel, J., February 28, 1979. Personal communication. California Department of Transportation, Bishop, California.

Galbraith, R. M., 1978. Geological and Geophysical Analysis of Coso Geothermal Exploration Hole No. 1 (CGEH-1), Coso Hot Springs KGRA, California. Earth Science Laboratory, University of Utah, Salt Lake City, 39 pp.

Glosser, J., 1979. Personal communication. Soil Conservation Service, Bishop, California.

Hansen, E. M., F. K. Schwartz and J. T. Riedel, 1977. Probable Maximum Precipitation Estimated, Colorado River and Great Basin Drainages. National Weather Service, Hydrometeorological Report No. 49, 161 pp.

Harding-Lawson Associates, 1978. Ground Water Monitoring Guidelines for Geothermal Development, U.S. EPA, Las Vegas, Nevada and Cincinnati, Ohio, 215 pp.

Hardman, G., 1936. Precipitation Map of Nevada. Nevada Agricultural Experiment Station.

Hem, J. D., 1970. Study and Interpretation of the Chemical Characteristics of Natural Water, Second Edition. USGS Water Supply Paper 1473, 363 pp.

Hennis, Phil, 1979. Owner of Rose Valley Ranch. Phone conversations, January-March 1979, and meetings March 8 and 9, 1979.

Holmes, R. M., 1961. Estimation of Soil Moisture Content Using Evaporation Data. Proceeding of Hydrology Symposium No. 2 Evaporation. Queen's Printer, Ottawa, pp. 184-196.

Hulen, J. B., 1978. Geology and Alteration of the Coso Geothermal Area, Inyo County, California. Earth Science Laboratory, University of Utah, Salt Lake City, 28 pp.

Indian Wells Valley County Water District, June 20, 1979. Phone contact between David Hamilton, General Manager and Gail Jensen, ERG.

Jorgensen, L., March 28, 1979. Personal communication including computer printout (unpublished), USGS Water Resources Division, Menlo Park, California.

Jorgensen, L. N., M. A. Rose, R. D. Busch and J. S. Bader, 1971. California Streamflow Characteristics, U.S. Geological Survey, Open-File Report, p. 49.

Kunkel, F., and Chase, G. H., 1969. Geology and ground Water in Indian Wells Valley, California.

Lane, Rodney, April 9, 1979. Rancher at Lewis Ranch, Rose Valley, interview at Lewis Ranch.

Langelier, W. F., and H. F. Ludwig, 1942. Graphical Methods for Indicating the Mineral Character of Natural Waters. Journal American Water Works Association, Vol. 34, pp. 335-352.

Lee, C. H., 1912a. Ground Water Resources of Indian Wells Valley in Report of the Conservation Commission, State of California, pp. 401-429.

Lee, C. H., 1912b. Ground Water Resources of a Portion of Owens Valley, California. USGS Water Supply Paper 294, 135 pp. (Also known as An Intensive Study of the Water Resources of a Part of Owens Valley, California.)

Los Angeles Department of Water and Power, March and April, 1979. Personal communication. Aqueduct Engineering Division, Gerald A. Gewe, Hydrologic Engineering Associate; Duane Georgeson, Engineer; Melvin L. Blevins, Hydrologic Engineer.

Los Angeles Department of Water and Power, May 1976. Final Environmental Impact Report on Owens Valley Ground Water Pumping.

Los Angeles Department of Water and Power, August 1978. Draft EIR on Increased Pumping of the Owens Valley Ground Water Basin.

Los Angeles Department of Water and Power, March 12, 1979. Letter to Harding-Lawson Associates from Duane Georgeson, Engineer, Los Angeles Aqueduct.

Los Angeles Department of Water and Power, 1979. Inundation Map of South Haiwee Dam. (unpublished, 6 pp.)

Maxey, G. B., and T. E. Eakin, 1949. Ground Water in White River Valley, White Pine, Nye and Lincoln Counties, Nevada. Nevada State Engineer, Water Resources Bulletin 8, 59 pp.

Maxey, G. B., and C. H. Jameson, 1948. Geology and Water Resources of Las Vegas, Pahrump and Indian Springs Valleys, Clark and Nye Counties, Nevada. State of Nevada, Office of the State Engineer, Water Resources Bulletin 5, pp. 107-109.

Meinzer, O. E., 1927. Plants as Indicators of Ground Water. USGS Water Supply Paper 577, 95 pp.

Meinzer, O. E., 1932. Outline of Methods for Estimating Ground Water Supplies. USGS Water Supply Paper 638-C, pp. 99-144.

Miller, G. A., December 1977. Appraisal of the Water Resources of Death Valley, California-Nevada. USGS Open File Report 77-728, Menlo Park, California, 68 pp.

Mower, R. W., and R. M. Cordova, 1974. Water Resources of the Milford Area, Utah, with emphasis on ground water. State of Utah, Department of Natural Resources Technical Publication No. 43, 106 pp.

Moyle, W. R., Jr., 1979. Hydrologist, USGS, Laguna Nigel, California. Phone conversation March 1, 20, 1979; review meeting and field trip for Coso ES hydrology study, April 10 and 11, 1979.

Moyle, W. R., Jr., 1977. Summary of Basic Hydrologic Data Collected at Coso Hot Springs, Inyo County, California. USGS Open File Report 77-485, 93 pp.

Moyle, W. R., Jr., 1974. Geohydrologic Map of Southern California. USGS Water Resources Investigations, Open File Report 48-73, Menlo Park, California.

Murray, C. R. and E. B. Reeves, 1972. Estimated Use of Water in the U.S. in 1970. USGS Circular 676, 37 pp.

Naval Weapons Center, 1978. Draft Environmental Impact Statement (DEIS) for the Navy Coso Geothermal Development Program, Volume 1. Coso Programmatic DEIS. Public Works Department, 274 pp.

Naval Weapons Center, Meteorology Section, 1978. Unpublished Climatological Data for China Lake, California, Code 6234.

National Oceanic and Atmospheric Administration (NOAA), 1978. Climatological Data, Annual Summary - California, 1947-1976, Environmental Data Service, National Climatic Center, Asheville, North Carolina.

National Oceanic and Atmospheric Administration, 1972. Precipitation-Frequency Maps for California, U.S. Department of Commerce, 51 pp.

Peters, J., 1978 and 1979. Personal communication. WESCO, San Rafael, California.

Peters, J. H., 1979. Written communication. Principal/Soil Scientist, WESCO, San Rafael, California.

Piper, A. M., 1944. A Graphic Procedure in the Geochemical Interpretation of Water Analyses. Transactions, American Geophysical Union, Hydrology Papers, pp. 914-923.

Rantz, S. E., 1969. Mean Annual Precipitation in the California Region, USGS Water Resources Division, Basic Data Compilation, Map - 2 sheets.

Rockwell International, February 2, 1979. Letter from G. Lauer, Coso Program Manager, Rockwell International, Newbury Park, California to Chuck Tallos, COAR, Bureau of Land Management, Bakersfield District Office, outlining results of meeting with LADWP.

Rottman Drilling Company, April 16, 1971. Water Well Driller, Report for Well 21S/37E-26B1 (courtesy of Phil Hennis).

Rottman Drilling Company, February 14, 1974. Water Well Drillers Report for Well 21S/37E-26K1 (courtesy of Phil Hennis).

Southern California Edison Company, 1977, 1978, 1979. Hydraulic Test Results, dated June 10, 1976 (2), June 25, 1976, June 9, 1977 (2), June 28, 1977 (2), August 10, 11 and 14, 1978, Account Nos. 4-61-86-161-7020, 4-61-86-161-7035, 4-61-86-161-7030 (courtesy of Phil Hennis).

Spane, F. A., Jr., 1978. Hydrogeologic Investigation of Coso Hot Springs, Inyo County, California, Naval Weapons Center, NWC TP 6025, 42 pp.

St. Amand, P., and G. Roquemore, 1978. Preliminary Structural Map of the Haiwee Reservoir, Little Lake, Coso Peak, Mountain Springs Canyon, Monache Mountain and Lamont Peak Quadrangles, California, 1:62,500 (unpublished).

Steinhauser, C., 1967. Methods for Evaluating and Drawing Climatic Maps in Mountainous Countries. Archiv. fur Met. Geophysik und Bioklimatologie, Serie B, 4, Band 15, pp. 329-258.

Stiff, H. A., Jr., 1951. The Interpretation of Chemical Water Analysis by Means of Patterns. Journal of Petroleum Technology, Vol. 3, No. 10, pp. 15ff.

APPENDICES

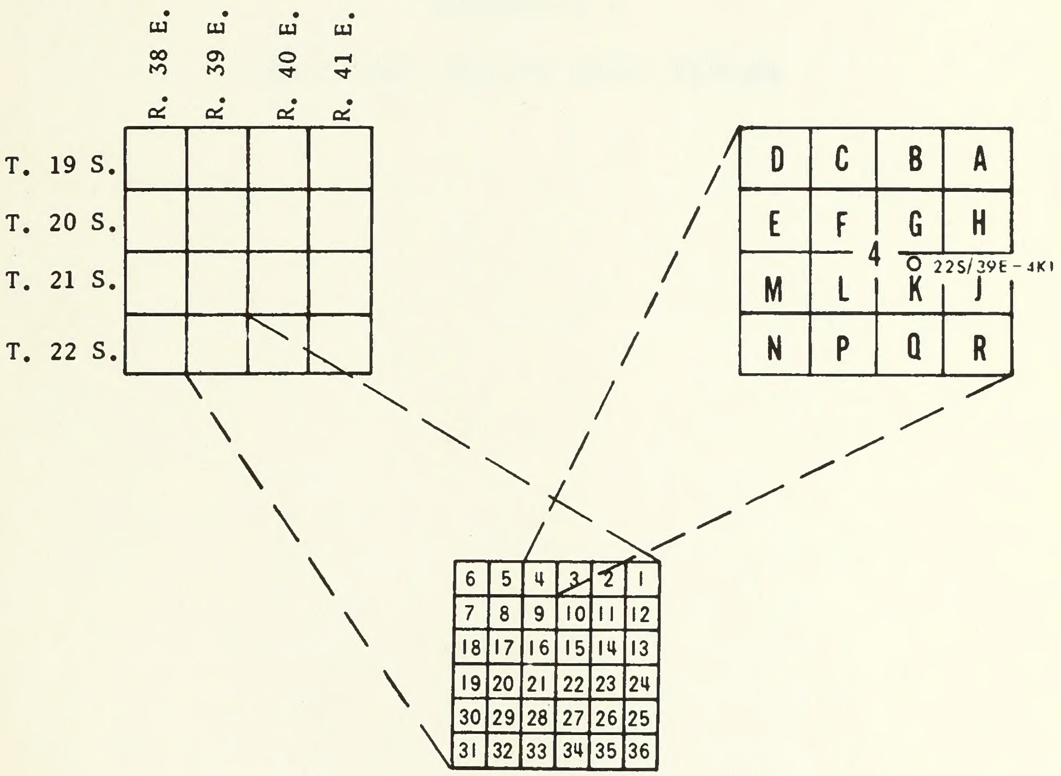
APPENDIX A

WELL AND SPRING NUMBERING SYSTEM

WELL- AND SPRING-NUMBERING SYSTEM

Wells are numbered according to their location in the rectangular system for the subdivision of public land. That part of the number preceding the slash, as in 22S/39E-4K1, indicates the township (T. 22 S.); the number after the slash indicates the range (R. 39 E.); the number after the dash indicates the section (sec. 4); the letter after the section number indicates the 40-acre subdivision of the section according to the lettered diagram below. The final digit is a serial number for wells in each 40-acre subdivision. The area lies entirely in the southeast quadrant of the Mount Diablo base line and meridian.

Springs are numbered similarly, except that the letter S is placed between the 40-acre subdivision letter and the final digit, as shown in the following spring number: 22S/37E-33HS1.



(Reproduced from Moyle, 1977)

WELL- AND SPRING-NUMBERING SYSTEM

Wells are numbered according to their location in the rectangular system for the subdivision of public land. [illegible]

[illegible]

(Reproduced from Hoyle, 1977)

APPENDIX B

WELL AND SPRING DATA TABLES

Appendix B1 DESCRIPTION OF WELLS AND EXPLORATION HOLES IN AND NEAR THE CGSA, CALIFORNIA (modified from Moyle, 1977 and California Department of Water Resources, 1963)

Location[a]	Owner[b]	Year Drilled	Well Depth (feet)	Cased Depth (feet)	Well[c] Finish	Diameter[d]	Water[e] Use	Well[f] Use	Altitude[g] LSD (feet)	Pumping Data[h]	Water Level[i]	Log[j] Data	Chemical[k] Analyses	Remarks
21S/37E-2K1	LA DWP	1974	101	29	G	12	Z	W	3700	P	X	D	C1	Haiwee Reservoir spillway
21S/37E-11C1	LA DWP	1925	170	30	P	16	U	U	3633	P	X	D	C1	South of Haiwee Reservoir
21S/37E-23B1		1975			X	72	U	U	3540		X			North Rose Valley
21S/37E-23P1		1976	540			5	U	T	3640+		X	D,E,J		North Rose Valley
21S/37E-23R1		1977	1020			4-3/4	U	T	3470+		X	D,E,J		North Rose Valley
21S/37E-24F1		1975						Z	3620					North Rose Valley
21S/37E-25A1		1976	290			5	U	T	3650+		X	D,E,J		North Rose Valley
21S/37E-25B1		1977	647			5	U	T	3580+		X	D,E,J		North Rose Valley
21S/37E-26B1	P. Hennis	1971	724	724	F	16	I	W	3440	P	X	D	C1	Rose Valley Ranch
21S/37E-26K1	P. Hennis	1974	675	675	F	16	I	W	3430	P	X	D		Rose Valley Ranch
21S/37E-31N1		1976	540			5	U	T	3385+		X	D,E,J		North Rose Valley
21S/37E-36G1						4	N	U	3382		X			North Rose Valley
21S/37E-36N1						4	U	U	3382		X			North Rose Valley
21S/37E-36N2						4	U	U	3382					North Rose Valley
21S/37E-36N3						4	U	U	3382					North Rose Valley
21S/37E-36Q1						6	U	U	3380		X			North Rose Valley
21S/37E-36Q2						6	U	U	3380					North Rose Valley
21S/37E-36Q3						6	U	U	3380					North Rose Valley
21S/38E-24NW1	U.S. Navy	1976	338		A	2	U	H	4961					BHF #6[l]
21S/39E-15N1	U.S. Navy	1976	354		A	2	U	H	4646					BHF #10[l]
21S/39E-16N1	U.S. Navy	1976	293		A	2	U	H	5269					BHF #1[l]
21S/39E-18M1	U.S. Navy	1976	438		A	2	U	H	4971					BHF #12[l]
21S/39E-18N1†	U.S. Navy	1975	59		A	2	U	H	4930					UTD #3[m]
21S/39E-32C1†	U. S. Navy	1975	118		A	2	U	H	5080					UTD #8[m]
21S/39E-34D1†	U.S. Navy	1975	59		A	2	U	H	3850					UTD #9[m]
22S/37E-2Q1	R. Lane	1971				8	H	W	3405		X		C1	Coso Junction
22S/37E-2R1	CA Div. of Highways	1946				8		Z	3380			D		Coso Junction

Appendix B1 (continued) DESCRIPTION OF WELLS AND EXPLORATION HOLES IN AND NEAR THE CGSA, CALIFORNIA (modified from Moyle, 1977 and California Department of Water Resources, 1963)

Location[a]	Owner[b]	Year Drilled	Well Depth (feet)	Cased Depth (feet)	Well[c] Finish	Diameter[d]	Water[e] Use	Well[f] Use	Altitude[g] LSD (feet)	Pumping Data[h]	Water Level[i]	Log[j] Data	Chemical[k] Analyses	Remarks
22S/37E-2R2	CA Div. of Highways	1956	370	170	F	8	H	W	3380	P	X	D	C1	Coso Junction
22S/37E-13B1		1976	533			5			3340+		X	D,E,J		Rose Valley
22S/37E-36B1					W			Z	3400					Rose Valley
22S/38E-2E1†	U.S. Navy	1975	200		A	2	U	H	4280					UTD #5[m]
22S/38E-4NW1	U.S. Navy	1976	298		A	2	U	H	3885					BHF #5[l]
22S/38E-5F1		1977	425			4-3/4	U	T	3520+		X	D,E,J		Rose Valley
22S/38E-5F2		1977	583			4-3/4	U	T	3550+			D,E,J		Rose Valley
22S/38E-6H1		1977	595			4-3/4	U	T	3480+			D,E,J		Rose Valley
22S/38E-6K1		1977	825			4-3/4	U	T	3440+			D,E,J		Rose Valley
22S/38E-6Q1		1976	540			5	U	T	3410+			D,E,J		Rose Valley
22S/38E-7H1		1976	235			5	U	T	3410+			D,E,J		Rose Valley
22S/38E-7N1		1976	250			5	U	T	3350+		X	D,E,J		Rose Valley
22S/38E-8K1		1976	340			5	U	T	3470+			D,E,J		Rose Valley
22S/38E-8L1		1977	645			4-3/4	U	T	3432+		X	D,E,J		Rose Valley
22S/38E-8M1		1976	250			5	U	T	3390+			D,E,J		Rose Valley
22S/38E-8N1		1977	1225			4-3/4	U	T	3390+		X	D,E,J		Rose Valley
22S/38E-11J1	U.S. Navy	1976					U	U	4300					West side of Sugarloaf Mountain
22S/38E-11J2	U.S. Navy	1976			W	11	U	U	4300					West side of Sugarloaf Mountain
22S/38E-11J3	U.S. Navy	1976			W	11	U	U	4300					West side of Sugarloaf Mountain
22S/38E-12M1	U.S. Navy				W	6	U	U	4280					West side of Sugarloaf Mountain
22S/38E-13R1	U.S. Navy	1976	304		A	2	U	H	4154					BHF #13[l]
22S/38E-14P1†	U.S. Navy	1975	151		A	2	U	H	3600					UTD #7[m]
22S/38E-17L1		1976	145			5	U	T	3358			D,E,J		Rose Valley
22S/38E-18C1					W	12	U	U	3360		X			South side of Sugarloaf Mountain
22S/38E-20B1		1976	350			5	U	T	3347+		X	D,E,J		Rose Valley
22S/38E-20D1		1976	85			5	U	T	3338+			D,E,J		Rose Valley

Appendix B1 (continued) **DESCRIPTION OF WELLS AND EXPLORATION HOLES IN AND NEAR THE CGSA, CALIFORNIA (modified from Moyle, 1977 and California Department of Water Resources, 1963)**

Location[a]	Owner[b]	Year Drilled	Well Depth (feet)	Cased Depth (feet)	Well[c] Finish	Diameter[d]	Water[e] Use	Well[f] Use	Altitude[g] LSD (feet)	Pumping Data[h]	Water Level[i]	Log[j] Data	Chemical[k] Analyses	Remarks
22S/38E-21E1	U.S. Navy	1976	246		A	2	U	H	3461					BHF #4[l]
22S/38E-24K1	U.S. Navy	1976	301		A	2	U	H	4449					BHF #14[l]
22S/38E-32C1		1976	55			5	U	T	3312[+]		X	D,E,J		Rose Valley
22S/38E-32C2		1976	75			5	U	T	3315[+]		X	D,E,J		Rose Valley
22S/38E-32C3		1976	55			5	U	T	3320[+]			D,E,J		Rose Valley
22S/38E-32F1		1976	85			5	U	T	3318[+]			D,E,J		Rose Valley
22S/38E-32F2		1976	45			5	U	T	3318[+]		X	D,E,J		Rose Valley
22S/38E-32K1		1976	70			5	U	T	3330[+]			D,E,J		Rose Valley
22S/38E-32R1		1976	50			5	U	T	3420[+]			D,E,J		Rose Valley
22S/38E-33J1	U.S. Navy	1976	303		A	2	U	H	3540					BHF #13[l]
22S/39E-4A1 through A17	U. S. Navy					2-28	U	U	3625-3640					Coso Hot Springs
22S/39E-4H1 through H7	U. S. Navy					3	U,H,Z		3610-3615					Coso Hot Springs
22S/39E-4H8	U. S. Navy	1967	375	320		4	U	T	3615	P	X		C3	Coso No. 1
22S/39E-4J1	U. S. Navy					3	U	U	3600					
22S/39E-4K1 through K7	U. S. Navy					2-60	U	U	3608-3660				C2	Coso Hot Springs
22S/39E-4P1 through P3	U. S. Navy					6-36	U	U	3662-3681				C2	Coso Hot Springs
22S/39E-6B1‡	U.S. Navy	1975	75		A	2	U	H	4355					UTD #12[m]
22S/39E-6G1	U. S. Navy	1977	4794	3507	0	8-3/4	U	H	4360	P	X	C,D, E, H,I, N,T	C3	CGEH No. 1
22S/39E-6G2	U. S. Navy		1350				U	H	4350					BDSH No. 1
22S/39E-6G3	U.S. Navy	1976	293		A	2	U	H	5269					BHF #1[l]
22S/39E-7H1, H2	U. S. Navy	1974		0	W	30	U	H	4145				C2	Devil's Kitchen
22S/39E-7H3 through H54	U. S. Navy	1941	10-40	0	X			Z	4112-4315			D		Devil's Kitchen
22S/39E-7J1 through J10	U. S. Navy	1941	13-44	0	X			Z	4335-4397			D		Devil's Kitchen

Appendix B1 (continued) DESCRIPTION OF WELLS AND EXPLORATION HOLES IN AND NEAR THE CGSA, CALIFORNIA (modified from Moyle, 1977 and California Department of Water Resources, 1963)

Location[a]	Owner[b]	Year Drilled	Well Depth (feet)	Cased Depth (feet)	Well[c] Finish	Diameter[d]	Water[e] Use	Well[f] Use	Altitude[g] LSD (feet)	Pumping Data[h]	Water Level[i]	Log[j] Data	Chemical[k] Analyses	Remarks
22S/38E-8B1 through B8	U. S. Navy	1941	12-48	0	X		U	Z	3943-3994			D		Nicol Prospect
22S/39E-8C1 through C40	U. S. Navy	1939-1941	9-80	0	X,W	10-84	U	U,Z	3951-4032			D		Nicol Prospect
22S/39E-8E1 through E9	U. S. Navy	1941	14-40	0	X			Z	4221-4322			D		Devil's Kitchen
22S/39E-10B1‡	U.S. Navy	1975	23		A	2	U	H	3560					UTD #4[m]
22S/39E-10C1	U.S. Navy	1976	249		A	2	U	H	3557					BHF #9[l]
22S/39E-12L1‡	U.S. Navy	1975	115		A	2	U	H	3620					UTD #10[m]
22S/39E-16G1	U. S. Navy	1975	4	0	X	6	U	U	3650					Wheeler Prospect
22S/39E-16G2 through G17	U. S. Navy	1941	2-16	0	X		U	Z	3635-3651			D		Wheeler Prospect
22S/39E-17Q1‡	U.S. Navy	1975	151		A	2	U	H	3880					UTD #1[m]
22S/39E-20E1‡	U.S. Navy	1975	315		A	2	U	H	4140					UTD #6[m]
22S/39E-31D1	U.S. Navy	1976	322		A	2	U	H	4725					BHF #15[l]
23S/38E-5N1	T. Grey	1948				14	H	W	3190		X		C1	South Rose Valley
23S/38E-8D1	T. Grey	1958				8	R	W	3175		X		C1	South Rose Valley
23S/38E-8D2	T. Grey	1974	150	0	F	8	S	W	3180	P		D		South Rose Valley
23S/38E-10M1	U.S. Navy	1976	278		A	2	U	H	3685					BHF #2[l]
23S/38E-17D1	L. L. Hotel	1943				42	H	W	3190		X			Little Lake
23S/38E-17D2	Duck Club	1973				12	S	W	3195	P				Little Lake
23S/39E-16L1	U.S. Navy	1976	158		A	2	U	H	2484					BHF #7[l]
23S/39E-21K1	U.S. Navy	1954	141			4		Z	2289			D		Airport Lake
23S/39E-21Q1	U.S. Navy	1954	78			4		Z	2289			D		Airport Lake
23S/39E-21R1	U.S. Navy	1954	102			4		Z	2289			D		Airport Lake

Appendix B1 (continued) DESCRIPTION OF WELLS AND EXPLORATION HOLES IN AND NEAR THE CGSA, CALIFORNIA (modified from Moyle, 1977 and California Department of Water Resources, 1963)

Location[a]	Owner[b]	Year Drilled	Well Depth (feet)	Cased Depth (feet)	Well[c] Finish	Diameter[d]	Water[e] Use	Well[f] Use	Altitude[g] LSD (feet)	Pumping Data[h]	Water Level[i]	Log[j] Data	Chemical[k] Analyses	Remarks
23S/39E-22L1	U.S. Navy	1954	56			4		Z	2295			D		Airport Lake
23S/39E-22N1	U.S. Navy	1954	107			4		Z	2290			D		Airport Lake
23S/39E-22P1	U.S. Navy	1954	103			4		Z	2290			D		Airport Lake
23S/39E-27E1	U.S. Navy	1954	99			4		Z	2289			D		Airport Lake
23S/39E-28C1	U.S. Navy	1954	50			4		Z	2289			D		Airport Lake
23S/39E-28H1	U.S. Navy	1954	101			4		Z	2289			D		Airport Lake
23S/39E-33P1	U.S. Navy	1976	309		A	2	U	H	3206					BHF #8[l]
24S/41E-6L1	U.S. Navy	1976	312		A	2	U	H	2950					BHF #17, not plotted on base map[l]
24S/41E-33F1	U.S. Navy		326		A	2	U	H	2638					BHF #16, not plotted on base map[l]

[a] Location: The wells are identified according to their location in the rectangular system for the subdivision of public land. The identification consists of the township number, north or south; the range number, east or west; and the section number. The section is further subdivided into sixteen 40-acre tracts lettered consecutively (excepting I and O), beginning with A in the northeast corner of the section and progressing in a sinusoidal manner to R in the southeast corner. Wells within the 40-acre tract are numbered sequentially. Letters NW, NE, SW, SE indicate wells located in the center of quarter sections.
‡ indicates boring location field checked.

[b] Owner or name: The apparent owner or user. In some cases, the local name of the well is given

[c] Well finish: A - grouted, unperforated casing; F = gravel wall, perforated or slotted casing; G = gravel wall, commercial screen; O = open end; P = perforated or slotted casing; W = walled or shored; X = open hole in aquifer (generally cased to aquifer)

[d] Diameter: inside diameter of the well, in inches; nominal inside diameter, in inches, of the innermost casing at the surface for drilled cased wells.

[e] Water use: H = domestic; I = irrigation; R = recreation; S = stock supply; U = unused; Z = other

[f] Well use: H = heat reservoir; T = test hole; U = unused; W = withdraw water; Z = destroyed

[g] Altitude of lsd: Altitude of land-surface datum, in feet, above or below (-) Mean Sea Level. Land-surface datum is an arbitrary plane closely approximating land surface at the time of the first measurement and used as the plane of reference for all subsequent measurements. + indicates approximate elevation.

[h] Pumping data: P indicates pumping data available (see Moyle, 1977)

[i] Water level: water level data given in Appendix B3

[j] Log Data: C = caliper; D = drillers or geologic; E = electric; I = induction; J = gamma ray; N = neutron; T = temperature

[k] Chemical analyses: number refers to appendix where chemical analyses are given

[l] Heat flow hole from Combs, 1975

[m] Heat flow hole from Combs, 1976

Appendix B2 DESCRIPTION OF SPRINGS IN AND NEAR THE CGSA
(modified from Moyle, 1977)

Location	Name	Date Discharge Measurement	Estimated Discharge (gpm)	Water Use[a]	Improvements	Altitude lsd[b]	Chemical Analyses[c]	Remarks
19S/37E-32QS1		3/76	1.0	S	none	3840		Owens Valley
21S/37E-6AS1		11/75	flowing	Z	none	4960		West of Haiwee Reservoir
21S/37E-14ES1	Rose Spring	11/75	flowing	u	pipeline	3640		North Rose Valley
21S/37E-32HS1	Tunawee Spring	11/75	1.60/15[d]	H	---	4360		East front Sierra Nevada
21S/39E-10PS1	Haiwee Spring	9/75	10.0	Z	none	4740	X	North Coso Valley
22S/37E-3NS1	Lewis Ranch Spring	11/75	15.0/60[d]	Z	---	3800	X	3 springs
22S/37E-10ES1	Pasture Spring	–	40[d]	U	none	3840	X	5 springs south of Lewis Ranch
22S/37E-33HS1	Sacatar Spring	11/75	1.0/5[d]	Z	pipeline	4960		East front Sierra Nevada
22S/39E-7HS1		9/75	flowing	U	none	4280		Devil's Kitchen
23S/37E-1NS1		3/76	1.0		---	3650		East front Sierra Nevada
23S/37E-18GS1		1975	dry		none	3260		SW of Little Lake
-18GS2		1975	dry		none	3200		SW of Little Lake
-18LS1		1975	dry		none	3560		SW of Little Lake
-19JS1		-	-		-	-		SW of Little Lake
23S/38E-8DS1		-	-	Z	-	-		Feeding Little Lake
-8DS2		-	-	Z	-	-		" " "
-8MS1		-	-	Z	-	-		" " "

[a] Water use: H - domestic; S - stock supply; U - unused; Z - other (wildlife, etc.)

[b] Altitude of lsd: altitude of land surface datum, in feet, above mean sea level. Land surface datum is an arbitrary plane closely approximating land surface.

[c] Chemical analyses: X indicates analysis given in Appendix C4

[d] Rodney Lane, 1979, personal communication

Appendix B-3. Water Levels
Rose Valley, California

Well Location	Date of Measurement	Depth to Water (feet)	Water Level Elevation[b] (feet)	Condition of Well[c]	Source[d]
21S/37E-2K1	12/74	10.6	3689		M
	11/75	43.44	3657	P	M
21S/37E-11C1	11/72	38.30	3595		M
	11/75	39.28	3594		M
21S/37E-23B1	10/75	dry, <22	<3518		M
21S/37E-23P1	4/76	220[a]	3240	D	H
21S/37E-25A1	3/76	250[a]	3400	D	H
21S/37E-25B1	1/77	250	3330		H
21S/37E-26B1	2/71	135	3305	D	R
	6/76	237.2	3203	A	E
	6/77	236.9	3203	A	E
	8/78	244.8	3195	A	E
	3/79	219	3221	AS	P
21S/37E-26K1	1/74	190	3240	D	R
	11/75	190.37	3240		M
	6/76	215.7	3214	A	E
	6/77	205.9	3224	A	E
	8/78	218.7	3211	A	E
	3/79	216	3214	S	P
21S/37E-36G1	1/72	dry, <800	<2595		M
21S-37E-36N1	11/75	dry, <82.2	<3300		M
21S/37E-36Q1	11/75	dry, <29	<3351		M
21S/37E-31N1	4/76	170[a]	3215	D	H
22S/37E-2Q1	1971	166	3239		M
	11/75	165.2	3240		M
22S/37E-2R2	1956	142	3238		M
	10/61	142	3238		M
	8/71	140	3240		M
22S/37E-13B1	4/76	135[a]	3205	D	H
22S/38E-5F1	2/77	308[a]	3212	D	H

Appendix B-3 (continued)

Well Location	Date of Measurement	Depth to Water (feet)	Water Level Elevation[b] (feet)	Condition of Well[c]	Source[d]
22S/38E-7N1	4/76	155[a]	3195	D	H
22S/38E-8L1	2/77	215[a]	3217	D	H
22S/38E-8N1	2/77	185[a]	3205	D	H
22S/38E-18C1	8/75	dry, <7	<3353		M
22S/38E-20B1	3/76	60[a]	3287	D	H
22S/38E-32C1	3/76	40[a]	3272	D	H
22S/38E-32C2	3/76	50[a]	3265	D	H
22S/38E-32F2	4/76	50[a]	3268	D	H
22S/39E-4H8	1967	152	3463	S	A
22S/39E-6G1	12/78	900[a]	3460	S	G
23S/38E-5N1	9/59	12.21	3178		M
	8/72	13.75	3176		M
	11/75	14.49	3176		M
23S/38E-18D1	9/59	1.71	3173		M
	8/72	4.4	3171		M
	11/75	6.07	3169	P	M
23S/38E-17D1	9/59	2.12	3188	P	M
	8/72	flowing	>3190		M
	11/75	3.30	3187		M

Footnotes:

[a] Water levels interpreted from geophysical well log data

[b] Value rounded to nearest foot, land surface datum elevation reported in Table B1

[c] A = water level measured after continuous pumping
AS = water level measured after some pumping, measurement close to static
D = water level measured after drilling
P = water level measured during pumping
S = static water level

[d] H = Harding-Lawson Associates
M = Moyle, 1977
E = Southern California Edison (personal communication, 1979)
R = Rottman Drilling Company, 1971, 1974
P = P. Hennis (personal communication, 1979)
G = Galbraith, 1978
A = Austin and Pringle, 1970

APPENDIX C

CHEMICAL ANALYSES OF WATER

Appendix C1 SELECTED CHEMICAL ANALYSES OF NONTHERMAL WELLS, ROSE VALLEY, CALIFORNIA

Well Number	21S/37E-2K1	21S/37E-11C1	21S/37E-26B1	22S/37E-2Q1	22S/37E-2R2	23S/38E-5N1	23S/38E-8D1
Date of Sample	1975	7/68	12/78	1/79	10/61	3/60	7/55
Source[a]	M	M	P	R	M	M	M
Units	mg/l	mg/l	ppm	ppm	mg/l	mg/l	mg/l
Temperature - °C	14.0	17.0	---	---	22.8	---	---
pH	7.8	8.4	7.78	7.60	7.3	8.0	8.1
Specific conductance (μmho)	1340	868	1130	570	555	1420	1070
TDS - sum	878	546[b]	716	478	550[c]	1163[c]	947[c]
Ca	52	26	67	57	58	49	67
Mg	28	10	22	13	26	31	39
Na	220	160	99	49	36	225	131
K	8.0	7.0	14	5.9	3.1	12	13
HCO_3	150	---	200[d]	240[d]	300	513	516
CO_3	---	---	---	---	0	0	0
SO_4	370	160	200	68	59	93	87
Cl	50	40	66	15	16	170	82
SiO_2	40	12	32	29	42	48	---
Others	Fe= 0.2 F = 0.9 NO_3 = 1.2 N = 0.03 NO_2 = 0.12 NH_4 = 0.0 PO_4 = 0.60 As = 0.59 B = 1.3	Fe = 0.2 F = 1.1 NO_3 = 1.0 N = 0.0 NO_2 = 0.01 NH_4 = 0.03 PO_4 = 2.4 B = 1.2	B = 1.4 Li = 0.0 NH_4 = 0.0 NO_3+NO_2=15 F = 0.0	B = 0.08 NO_2+NO_3=1.1	Fe = 0.02 F = 0.4 NO_3 = 1.0 B = 0.08 CO_2 = 19	F = 0.7 NO_3 = 9.3 B = 4.0 CO_2 = 8.2	F = 0.9 NO_3 = 2.3 B = 2.2 CO_2 = 6.6
Anions/cations (epm)	0.79	---	0.91	0.91	0.89	1.00	1.00

[a] M = Moyle, 1977; P = P. Hennis (personal communication, 1979); R = R. Lane (personal communication, 1979)

[b] TDS residue on evaporation at 180°C

[c] Recalculated from original source

[d] Value is for HCO_3+CO_3

APPENDIX C2 SELECTED CHEMICAL ANALYSES OF THERMAL WELLS, CGSA, CALIFORNIA

Well Number	22S/39E-4K1	22S/39E-4K5S	22S/39E-4K2	22S/39E-4K2	22S/39E-4K2	22S/39E-4K2	22S/39E-4K3	22S/39E-4K3	22S/39E-4K5	22S/39E-4K5	22S/39E-4P1	22S/39E-7HS1
Date of Sample	12/77	12/77	9/78	12/77	12/60	3/46	12/77	12/60	5/61	9/78	5/62	12/60
Source[a]	S	S	N	S	M	M	S	M	M	N	M	M
Units	ppm	ppm	mg/l	ppm	mg/l	mg/l	ppm	mg/l	mg/l	mg/l	mg/l	mg/l
Temperature - °C	91.2	49.5	---	31.0	26.5	40.0	78.0	---	46.1	---	97.3	96.7
pH	6.92	2.24	2.5	4.22	4.0	6.5	2.62	4.5	1.2	2.7	7.4	2.2
Specific conductance mho)	240	3800		640	1150	222	1610	350	3890		168	6440
TDS - sum	185	1452	1757	522	966	331[b]	795	388	2116[b]	2482	271	1947[b]
Ca	6.4	55	42	46.4	98	16	22.5	17	44	120	3.0	18
Mg	0.25	15.6	18	5.8	25	2.1	6	6.2	19	25	1.0	81
Na	33	32	420	42	81	22	30.6	25	36	560	1.9	14
K	5.9	4.4	73	10.5	23	4.3	16.2	8.6	9.2	15	9.4	28
HCO_3	12	---	0	---	0	40	---	0	0	0	49	0
CO_3	---	---	0	---	0	0	---	0	0	0	0	0
SO_4	83	1060	1000	250	530	59	541	130	1300	1500	13	1400
Cl	1.7	2.6	21	1.6	6.5	0.7	1	1.0	380	21	1.0	0.0
SiO_2	42	282	93	165	200	120	205	200	310	131	200	330
Others	F = 0.4	F = 0.2	NH_4 = 73 NO_2 = <0.1 NO_3 = 1.0 F = 0.1 As = <0.01 B = 0 PO_4 = 65.7 Cu = 0.4 Br = 0.0 Hg = <0.001	F = 0.3	Al = 1.4 Fe = 0.09 F = 0.8 NO_3 = 8.1 B = 0 CO_2 = 0	F = 0.2 PO_4 = 0.32 NO_3 = 6.2 CO_2 = 20 B = 40	F = 0.1	Al = 0.11 Fe = 0.06 F = 0.2 NO_3 = 0.1 B = 0.0 CO_2 = 0	Al = 3.8 Fe = 9.0 Mn = 1.7 F = 0.6 Br = 1.8 I = 0 NO_3 = 0.62 PO_4 = 0.0 CO_2 = 0.0 As = 0.0 B = 0.0 Li = 0.1 Mo = 0.004	NH_4 = 100 NO_2 = <0.1 NO_3 = 10 F = 0.2 As = 0.05 B = 0.1 PO_4 = <0.1 Cu = 0.07 Br = 0.2 Hg = <0.001	Al = 28 F = 0.5 NO_3 = 4.3 CO_2 = 3.1	Al = 44 Fe = 28 F = 0.9 NO_3 = 3.0 CO_2 = 0.0 B = 0.6
Anions/cations (epm)	0.96	4.01	0.95	0.96	1.01	0.94	3.19	1.08	6.67	0.97	0.85	3.33

[a] S = Spane, 1978; N = Naval Weapons Center (personal communication, 1979); M = Moyle, 1977

[b] Recalculated from original source

APPENDIX C3 SELECTED CHEMICAL ANALYSES OF GEOTHERMAL TEST WELLS CGEH-1 AND COSO NO. 1, CGSA, CALIFORNIA

	Makeup Water	CGEH-1 Sample Interval 3488-4824 Feet, Collected 12/1/77 (Fournier, et al. 1978)					Coso No. 1 (Austin and Pringle, 1970)		
		10:45 am	11:00 am	11:15 am	11:30 am	11:45 am	Sample 1[a] 6/27/67	Sample 2[b] 3/68	Sample 3[b] 3/68
SiO_2	63.0	710.0[c]	710.0[c]	710.0[c]	710.0[c]	710.0[c]	50.0	27.0	154.0
Ca	100.0	110.0	98.0	99.0	93.0	98.0	72.8	359.0	74.4
Mg	29.8	3.0	2.5	2.3	2.7	2.5	0.5	0.6	1.0
Na	100.0	1600.0	1600.0	1580.0	1590.0	1590.0	1764.0	2808.0	1632.0
K	0.5	122.0	123.0	125.0	126.0	126.0	154.0	172.0	244.0
Li	1.0	9.6	9.7	10.0	10.3	10.0			
Rb	<0.02	0.103	0.105	0.106	0.112	0.118			
Cs	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01			
CO_3[d]								50.4?	77.4?
HCO_3	307.0	150.0	286.0	273.0	297.0	279.0	134.2	0.0	0.0
OH[d]								76.2?	1.7?
SO_4	234.0	314.0	268.0	266.0	257.0	245.0	38.0	216.0	52.8
Cl	81.0	2330.0	2360.0	2420.0	2460.0	2480.0	2790.0	3681.0	3042.0
F	0.1	3.8	3.8	3.8	3.8	4.2	3.7	1.6	2.2
B	0.92	54.0	53.0	54.0	56.0	58.0	48.0	57.4	71.6
pH	7.67	8.14	7.74	8.15	8.14	8.22	8.9	9.8	8.5
TDS	918.0	5410.0	5518.0	5547.0	5610.0	5606.0	5744.0	6894.0	5228.0

[a] Sample taken from clear well discharge after drilling completion
[b] Well idle for 7 months; Sample 2 is from first and third bailer, Sample 3 from 13th and 14th
[c] Silica values include possible colloidal clay dispersed in water
[d] Impossible combination. Transcription error (?) by Lab or by Austin and Pringle (Note from Galbraith, 1978)

Appendix C4 SELECTED CHEMICAL ANALYSES OF NONTHERMAL SPRINGS, CGSA, CALIFORNIA

Spring Name	Haiwee Spring			Lewis Spring		Pasture Spring
Spring Number	21S/37E-10PS1			22S/37E-3NS1		22S/37E-10ES1
Date of Sample	12/60	11/77	4/79	7/55	1/79	1/79
Source[a]	M	S	H	M	R	R
Units	mg/l	ppm	mg/l	mg/l	ppm	ppm
Temperature - °C	16.7	15.5	---	21.1	---	---
pH	7.8	7.48	8.2	8.2	7.91	7.56
Specific conductance (μ mho)	447	430	430	450	460	767
TDS - sum	408[b]	387	285[c]	350[b]	332	618
Ca	35	34.8	38	48	53	74
Mg	18	17.2	13	18	12	15
Na	33	28	29	17	19	75
K	4.5	4.8	6	5.1	4.4	13
HCO_3	180	156	143	220	160[d]	270[d]
CO_3	0	---	6	0	---	---
SO_4	67	68	73	32	45	97
Cl	18	14.3	16	7.0	6.9	32
SiO_2	47	54	---	---	31	42
Others	Al = 0.14 Fe = 0.07 F = 0.4 NO_3 = 0.10 B = 0 CO_2 = 4.6	F = 0.3	F=0.4 B=0 NH_4=0.2 OH = 0 NO_3=1	F=0.4 NO_3 = 0 B = 0.04 CO_2 = 2.2	B = 0.8	B = 0.21 NO_2 =<0.09
Anions/cations (epm)	1.01	0.98	1.02	0.94	0.82	0.83

[a] M = Moyle, 1977; S = Spane, 1978; R = R. Lane (personal communication, 1979)

[b] Recalculated from original source

[c] TDS residue on evaporation at 180 °C

[d] Value is for HCO_3+CO_3

Appendix C5 CHEMICAL ANALYSES OF SURFACE WATERS, ROSE VALLEY, CALIFORNIA

Location of Sample	Haiwee Reservoir Outlet	Portuguese Canyon	Little Lake Canyon	Little Lake Canyon	Little Lake	Little Lake
Date of sample	3/79	2/79	2/79	4/79	3/52	4/79
Source[a]	L	H	H	H	I	H
Units	ppm	mg/l	mg/l	mg/l	ppm	mg/l
Temperature - °C	10	---	---	---	---	---
pH	8.41	8.28	8.20	8.8	8.4	8.8
Specific conductance (μmho)	286	446	676	590	---	1600
TDS (sum)	241	385	552	390[c]	961	1045[c]
Ca	22	57.4	74.5	54	50.4	52
Mg	3.2	10.6	18.5	15	30.6	60
Na	32	18.0	43.6	50	200	200
K	3.4	5.8	5.1	8	---	24
HCO_3	122	238	266	143	438	497
CO_3	---	---	---	27	10	69
SO_4	22	23.4	86	86	85	158
Cl	13	13	33	32	145	112
SiO_2	22	19.0	24.8	---	---	---
Others	Alkalinity = 100 NO_3 = <0.1 Fe = 0.08 B = 0.45 F = 0.56 NH_3 = <0.01 NO_2 = <0.001 PO_4 = 0.06			F = 2.4 B = 0.1 NO_3 = 1 OH = 0 NH_4 = 0.2	F = 0.5 N = 1.8 Fe = 0.17 Mn = 0.0	F = 1.4 B = 6 NO_3 = 2 OH = 0 NH_4 = 0.4
Anions/cations (epm)	1.00	0.98	1.02	0.94	0.98	1.00

[a] L = Los Angeles Department of Water and Power (personal communication, 1979)
H = Harding-Lawson Associates, this report
I = Inyo County Department of Health (personal communication, 1979)

[b] Calculated from alkalinity

[c] TDS residue on evaporation at 180°C

APPENDIX D

INUNDATION MAPS OF SOUTH HAIWEE DAM

(LOS ANGELES DEPARTMENT OF WATER AND POWER, 1979, UNPUBLISHED)

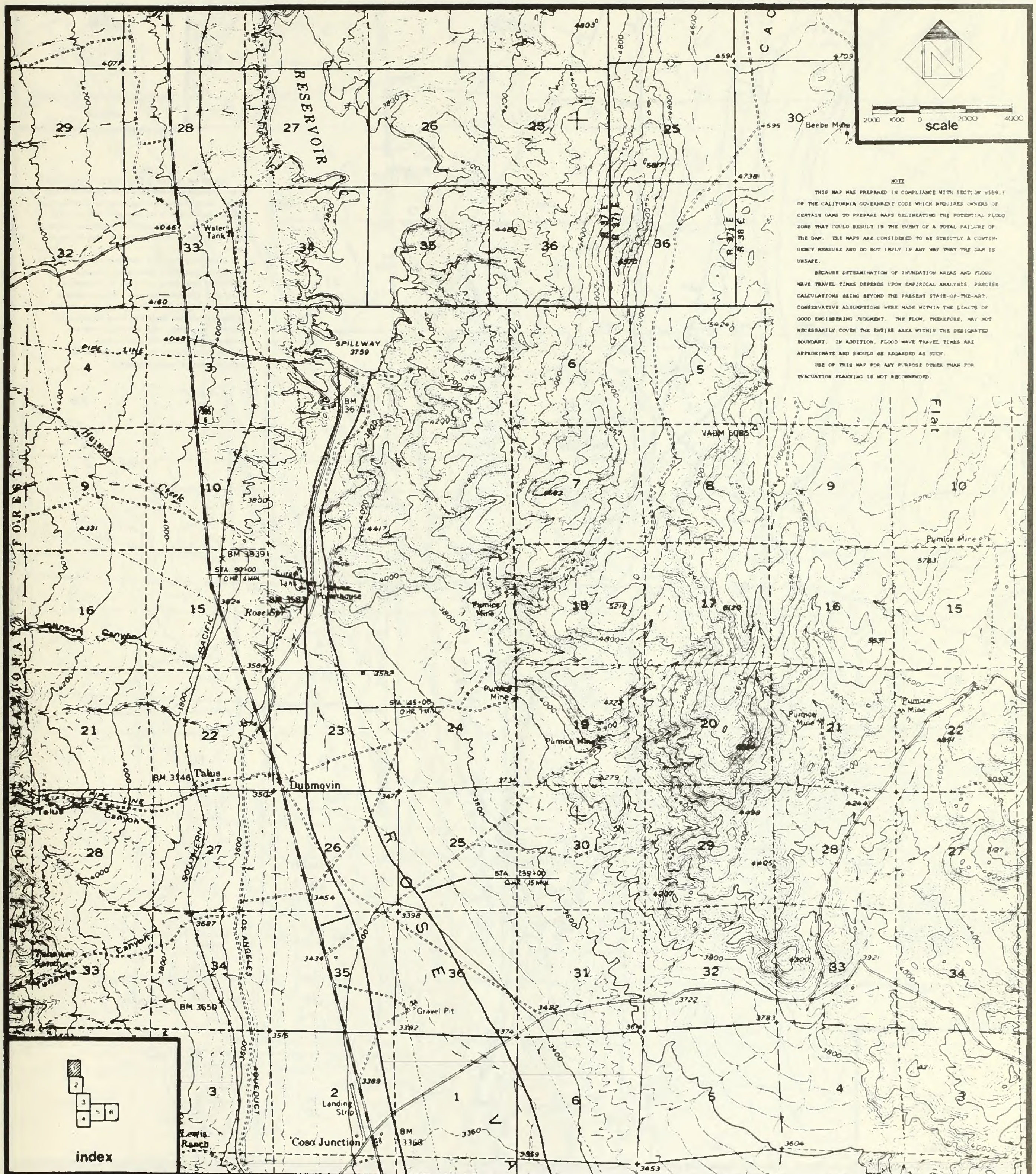


Figure D-1 Inundation Map of South Haiwee Dam (L.A.D.W.P., 1979)

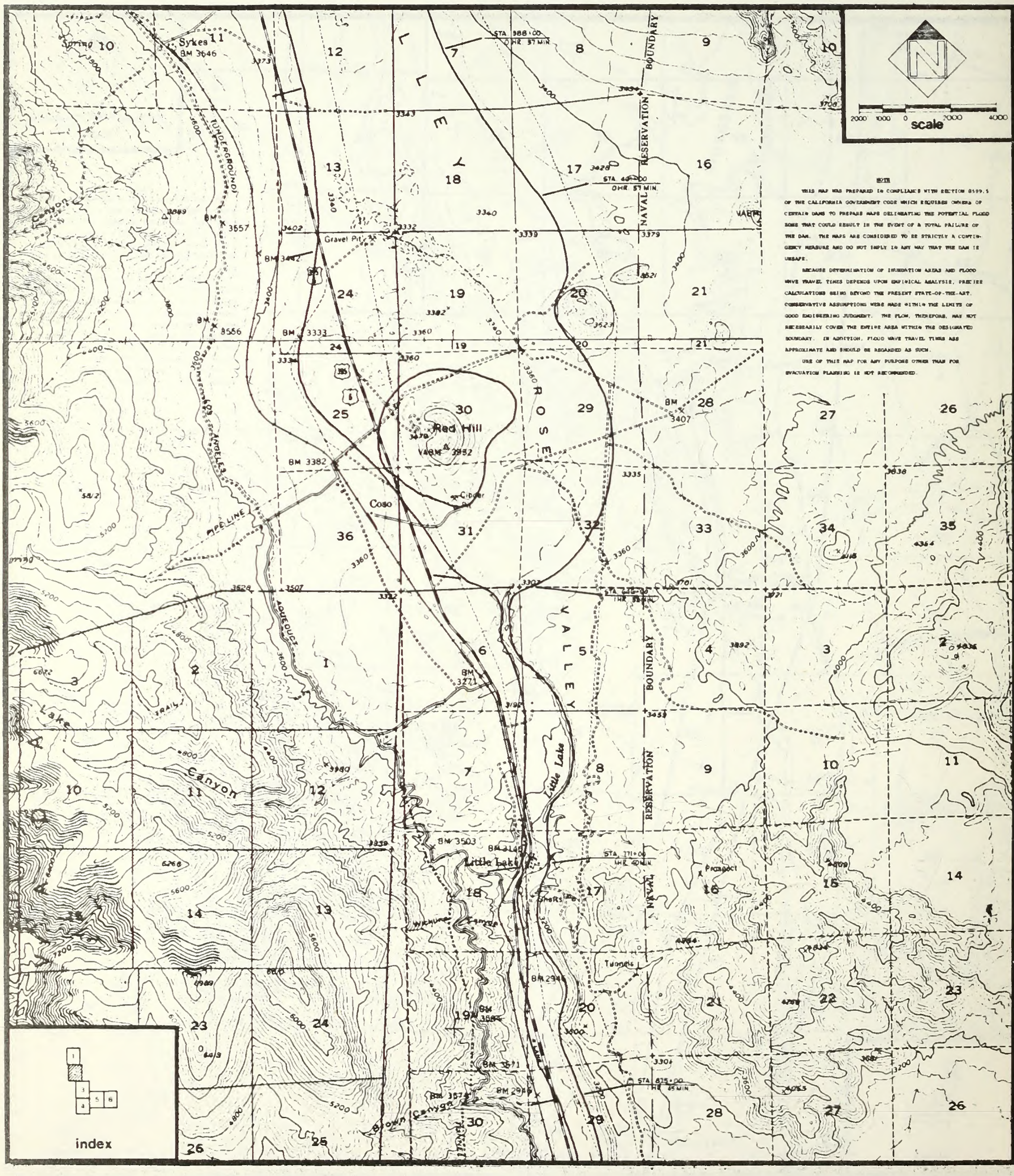


Figure D-2 Inundation Map of South Haiwee Dam (L.A.D.W.P., 1979)

GPO 694-701/153

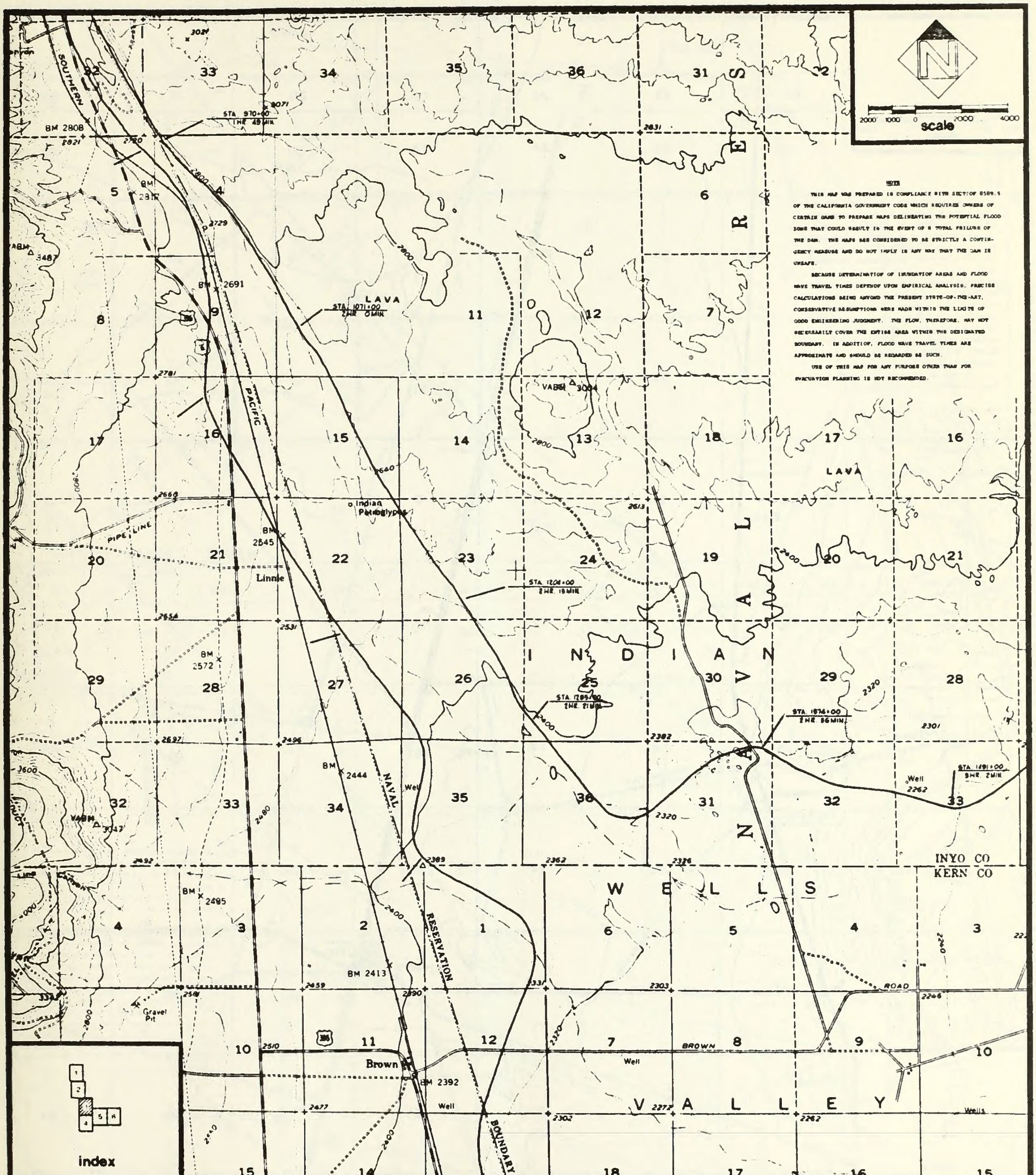


Figure D-3 Inundation Map of South Haiwee Dam (L.A.D.W.P., 1979)

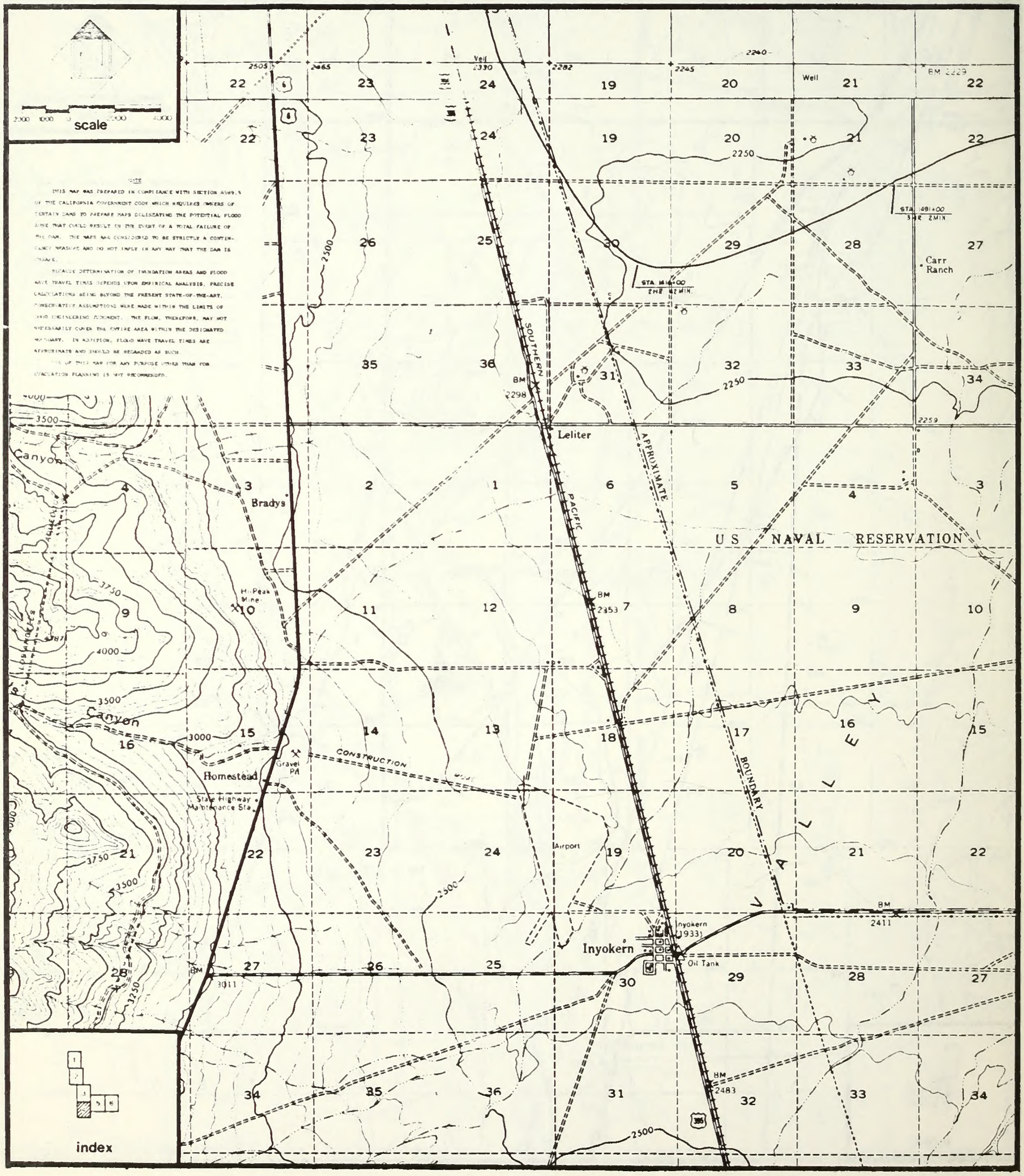


Figure D-4 Inundation Map of South Haiwee Dam (L.A.D.W.P., 1979)

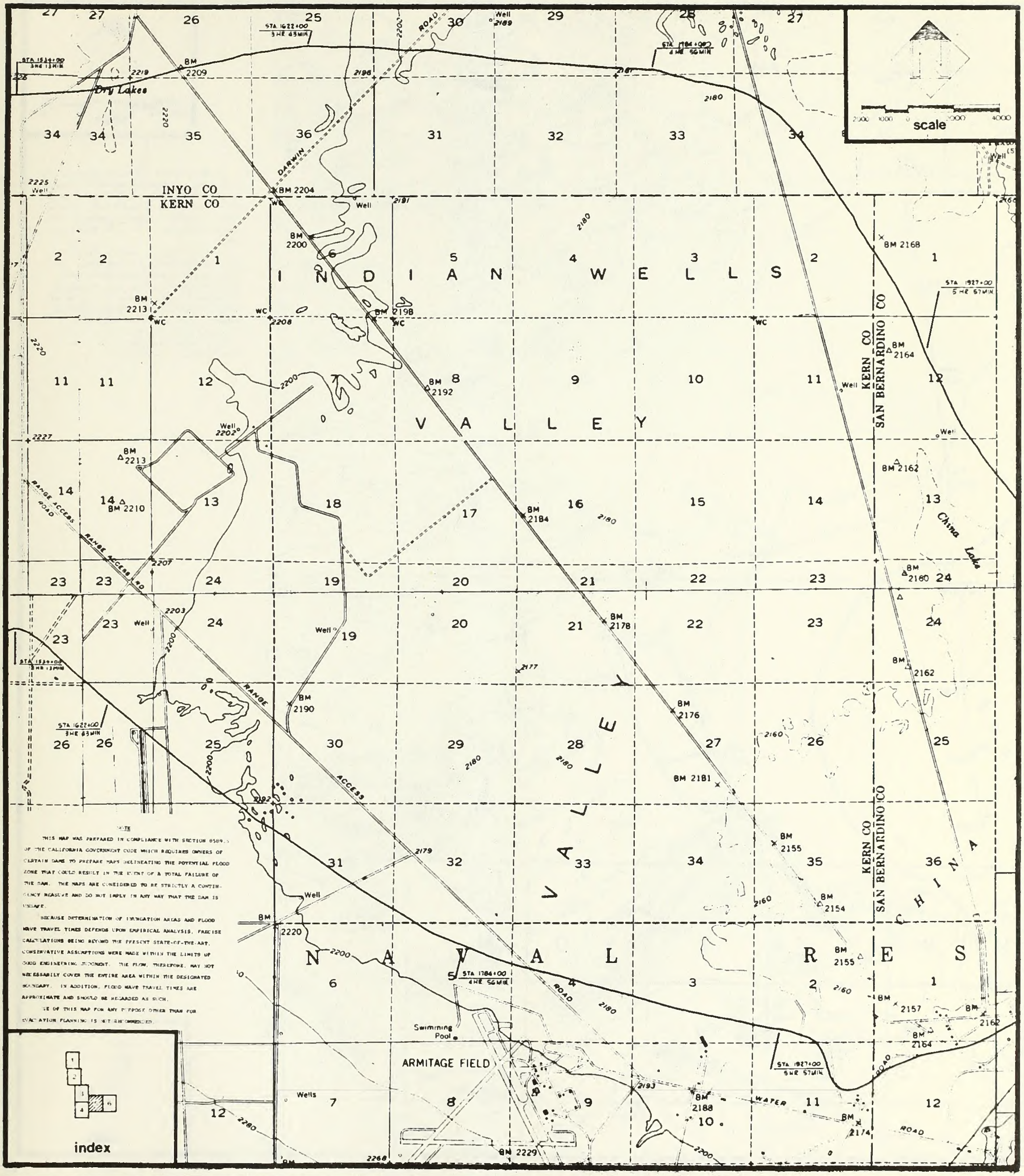


Figure D-5 Indundation Map of South Haiwee Dam (L.A.D.W.P., 1979)

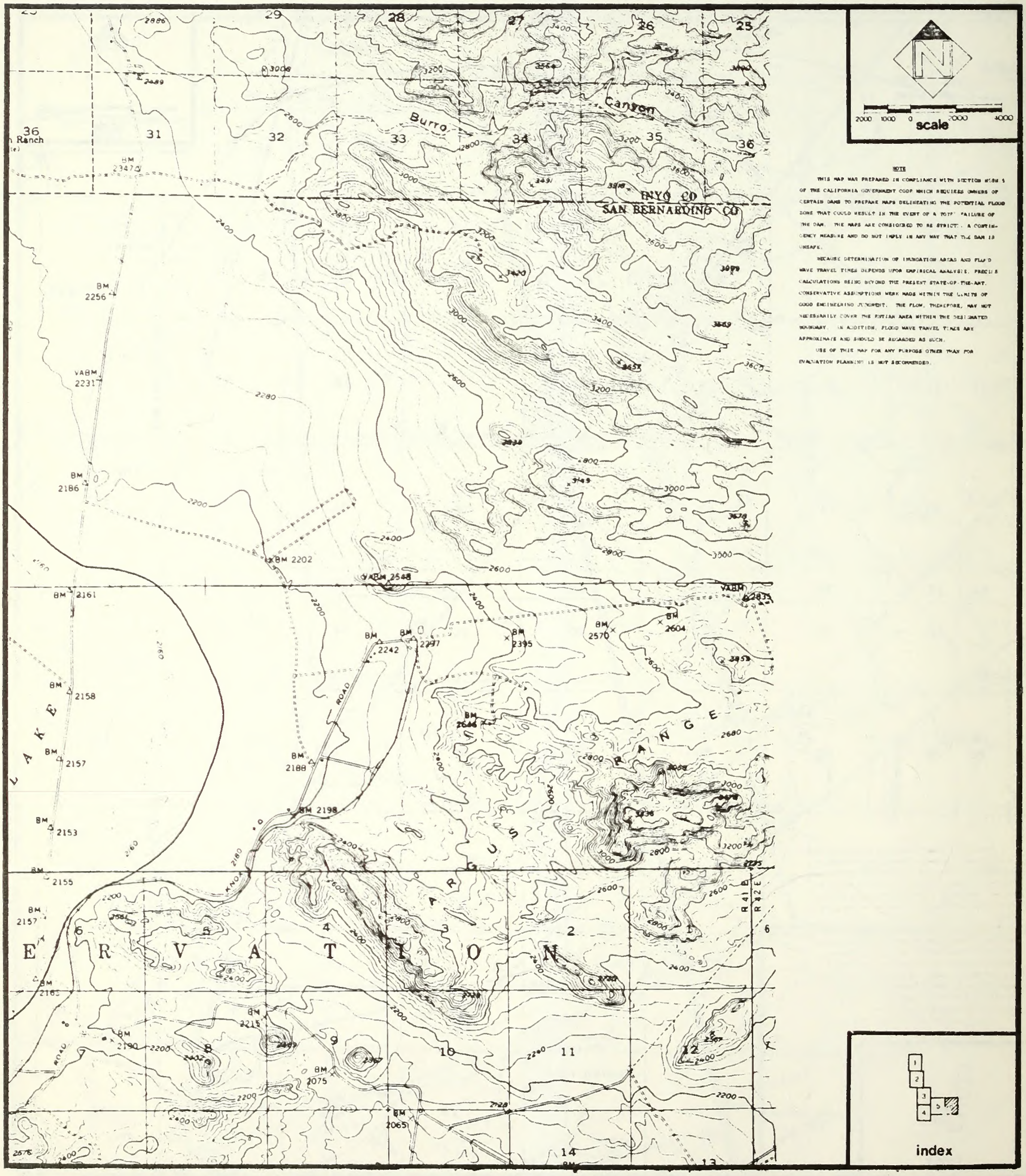
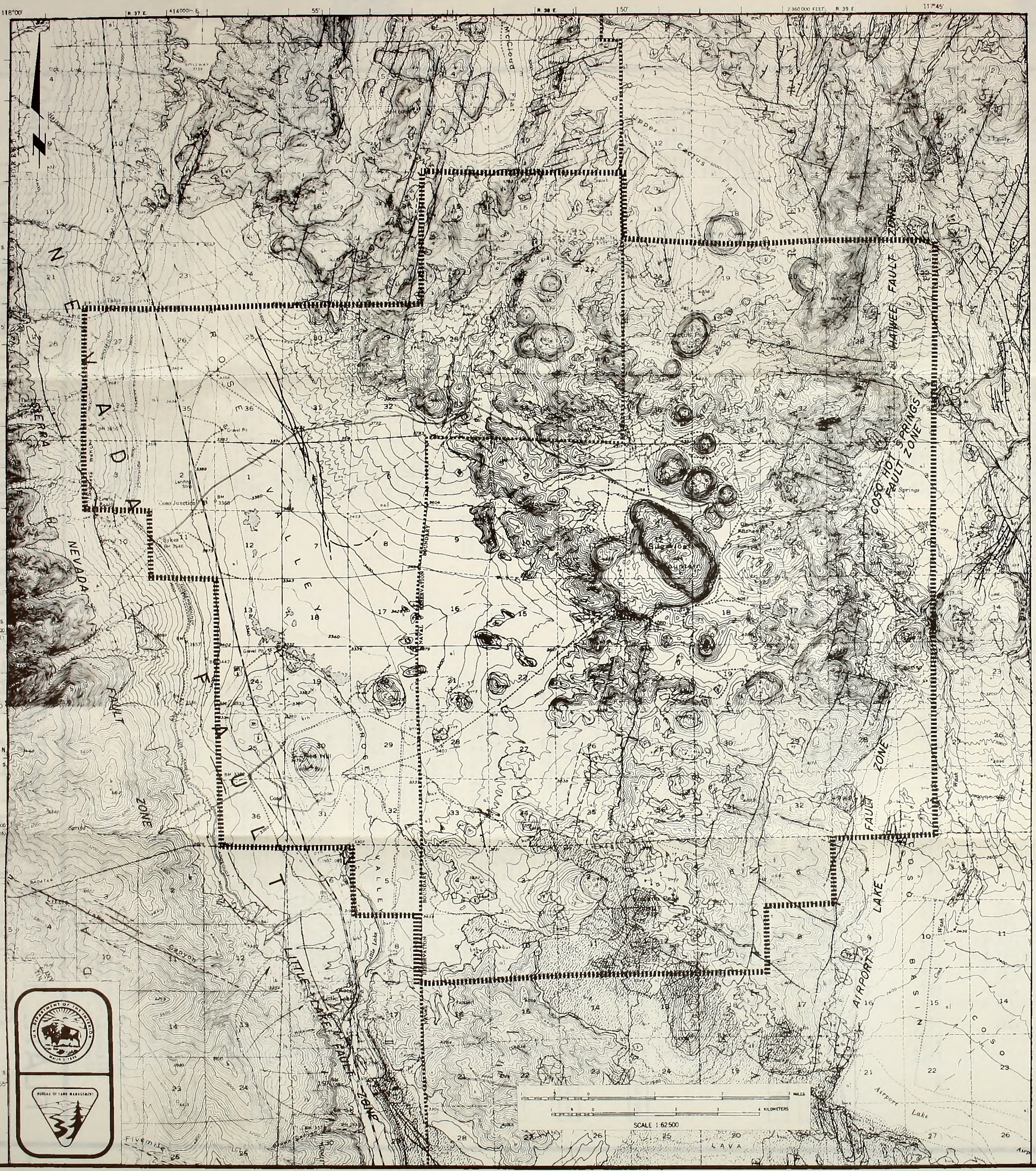


Figure D-6 Inundation Map of South Haiwee Dam (L.A.D.W.P., 1979)

BLM Library
D-553A, Building 50
Denver Federal Center
P. O. Box 25047
Denver, CO 80225-0047



EXPLANATION OF SYMBOLS

Contact, dashed where uncertain and dotted where concealed.

Fault, dashed where uncertain and dotted where concealed or inferred; bar and ball on down-thrown side. Dip of fault plane shown where known.

Topographic crest of ring of pyroclastic debris that partly surrounds some rhyolite domes.

Vents of mafic to intermediate lavas, represented by well preserved cinder cones, or eroded pyroclastic deposits. Dotted where concealed.

Strike and dip of stratified rocks

Attitude of steep flow foliation in unit dh.

Steeply dipping dike, in units omf and b only.

K/Ar age in millions of years, with arrow to sample locality.

Direction of downslope ground slippage in landslide.

Coso Geothermal Study Area boundary

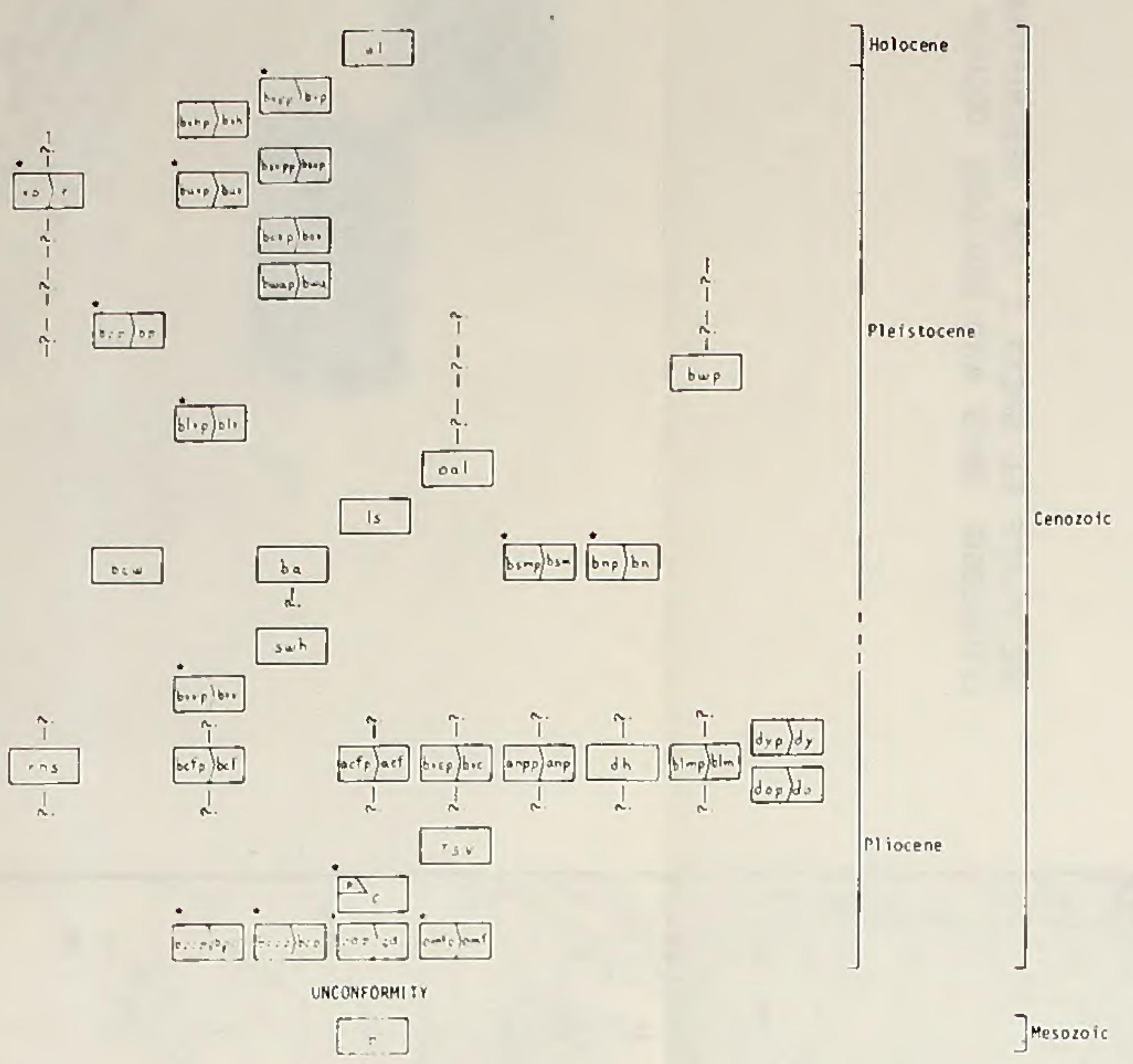
Notes:

1. In addition to being broken by the mapped faults, the Mesozoic basement rocks (b) that underlie the rhyolite dome (r) field south of Cactus Peak are shattered into pieces generally less than one meter in diameter and are locally hydrothermally altered, especially immediately west of Coso Basin and south and west of Coso Hot Springs.
2. Landslide in T21S/R39E Section 33 and fault extending east from Devil's Kitchen to Coso Basin from Hulen (1978)
3. Airport Lake, Little Lake, Coso Hot Springs and Haiwee Fault Zones named by Roquemore (1978a)
4. Faults in west Rose Valley, Sections 6, 7, and 8, T22S/R38E and Sec. 25 and 31, T21S/R38E from St. Amand and Roquemore (1978).

SEE PLATE I-1, SHEET 2 FOR DESCRIPTION OF LITHOLOGIC UNITS AND GEOLOGIC COLUMN

PLATE I-1 Preliminary Geologic Map of the CGSA, Inyo County, California (modified from Duffield & Bacon, 1977)

CORRELATION OF MAP UNITS



Note: The relative ages of units in the vertical columns are well established, whereas some of the implied relative ages for units of different columns are not well established. See descriptions of map units for known stratigraphic relations, and table for K/Ar ages. Asterisk denotes unit with K/Ar age.

DESCRIPTION OF MAP UNITS

al — ALLUVIUM Includes coarse alluvial fan deposits, stream deposits of gravel, sand and silt, wind blown sand, and deposits of silt and clay in closed depressions.

oal — OLD ALLUVIUM Includes predominantly sand to boulder-rich alluvial fan and fluvial deposits; probably ranges in age from late or middle Pleistocene to Holocene; distinguished from unit al by being partly dissected; oldest(?) part of this unit overlain by unit blr south-southeast of Little Lake.

rp r — RHYOLITE OF THE COSO GEOTHERMAL FIELD Thirty-seven separate extrusions of sparsely porphyritic, homogeneous rhyolite (r) and associated pyroclastic deposits (rp); rp includes minor playa deposits in closed depressions; rhyolite forms steep-sided, 40 to 350 meter-high domes, several of which are overlapping and three of which developed flows about 1 km long; flows and domes are covered by blocky pumiceous to perlitic carapaces through which ribs and spines of obsidian protrude locally; rhyolite contains no more than 2 percent and generally less than 1 percent phenocrysts, all less than 1 mm long; some or all of the phases quartz, sanidine, oligoclase, Fe-Ti oxides, biotite, hornblende, clinopyroxene, orthopyroxene and fayalite are present in each dome; pyroclastic deposits of pumice and obsidian together with fragments of Mesozoic basement rocks form explosion rings around some domes and a mantle over the entire area of the dome field; some domes carry scattered basaltic xenoliths and rare fragments of Mesozoic basement rocks; Pleistocene domes and basalt flows overlap in space and time; Pleistocene basalt units bp, bsm, and bcw are overlain by rhyolite pyroclastics from adjacent domes; field relations in the vicinity of Volcano Peak indicate the following succession: (1) eruption of basalt of Rose Valley (brvp) or eruption of a rhyolite dome (no overlapping relations), (2) eruption of basalt of Upper Little Lake Ranch (bur), (3) eruption of a rhyolite dome, (4) eruption of basalt of Volcano Peak (bvp); K/Ar ages of domes range from 0.96 ± 0.19 to 0.041 ± 0.021 m.y. (Lanphere and others, 1975).

bvpp bvp — BASALT OF VOLCANO PEAK Flows (bvp), cinder-bomb cone (bvpp), and adjacent cinder mantle (bvpp) of porphyritic, vesicular basalt; contains 1 percent of 0.2-1 mm olivine, 3 percent 0.2-1 mm yellowish clinopyroxene with rare opaque inclusions, 15 percent 0.5-4 mm plagioclase, and rare 0.6-3 mm embayed quartz in a granular groundmass of olivine, clinopyroxene, opaques, and plagioclase; olivine, clinopyroxene, and plagioclase phenocrysts commonly intergrown in clots; overlies units bsvp, bcr, r, bur, bwp and brv; aa flow surface and flow channels are well preserved; flows followed stream valleys; K/Ar age 0.038 ± 0.032 m.y. (Lanphere and others, 1975); probably the youngest volcanic unit in the map area; estimated average thickness of flows 2-6 meters.

bsvpp bsvp — BASALT SOUTH OF VOLCANO PEAK Flow (bsvp), cinder-bomb cone (bsvpp) and adjacent cinder mantle (bsvpp) of porphyritic, vesicular basalt; flow was fed from vent marked by the cone 0.8 km south of Volcano Peak; contains 3 percent of 0.1-0.6 mm olivine, 2 percent of 0.1-1 mm clinopyroxene commonly in clots and containing rare opaque inclusions, and 15 percent of 0.2-4 mm plagioclase with olivine inclusions in an aphanitic groundmass; overlies unit bcr; and is overlain by unit bvp; aa flow surface and flow channels well preserved; estimated thickness of flow 2-6 meters.

bcrp bcr — BASALT OF CINDER RIDGE Seven cinder-bomb cones (bcrp) adjacent cinder mantle (bcrp), and at least two flows (bcr) of porphyritic, vesicular basalt; youngest flow contains about 2 percent of 0.2 mm and smaller olivine, 2 percent of 0.1-0.8 mm pale yellow clinopyroxene, 10 percent of 0.1-1 mm plagioclase, and 3 percent of 1-10 mm plagioclase in an aphanitic groundmass; youngest flow contains relatively more plagioclase and less olivine phenocrysts than underlying flow; overlies units bwa, swh, blr, and ba, and is overlain by units bvp, and bsvp; much or all of youngest flow appears to have issued from most southerly of five aligned cinder cones; aa flow surface and flow channels well preserved; magnetic polarity normal; total thickness about 3-8 meters.

bwp — BASALT SOUTHWEST OF VOLCANO PEAK Partly buried basalt cinder cone; overlain by unit bvp.

bwap bwa — BASALT WEST OF AIRPORT LAKE Flow (bwa), cinder cone (bwap), and adjacent cinder mantle (bwap) of porphyritic, vesicular basalt; contains 1 percent of 0.1-0.2 mm opaque mineral (titanomagnetite?), 2 percent of 0.1-0.8 mm olivine, and 7 percent of 0.3-2 mm plagioclase in a groundmass of felted plagioclase laths, granular olivine, pyroxene, and opaque mineral; overlies units swh, ba, and is overlain by unit bcr; strand lines eroded into this unit along southwest edge of Airport Lake; aa surface and flow channels preserved; magnetic polarity normal; 2 to 4 meters thick.

bpp bp — BASALT OF MERCURY PROSPECT Flow (bp) and cinder cone (bpp) of vesicular basalt; contains 1 percent 0.1-0.3 mm olivine, 0.5 percent 0.1-0.6 mm opaques, and 8 percent 0.2-1.5 mm plagioclase in a groundmass of granular olivine, opaques, pyroxene, and plagioclase laths; xenoliths of Mesozoic granitic basement rocks common; overlies units bcw, c, omf, od, and oal; flow channel and aa surface preserved locally; flow followed a stream channel into Airport Lake; about 2 to 7 meters thick; magnetic polarity normal; K/Ar age 0.234 ± 0.022 m.y.

brhp brh — BASALT OF RED HILL Flow (brh) and cinder-bomb cone (brhp) and adjacent cinder blanket (brhp) of porphyritic, vesicular basalt; contains 1 percent 0.1-1 mm olivine with opaque inclusions, less than 1 percent yellowish clinopyroxene, 2 percent 0.1-1 mm plagioclase, and 5 percent 1-3 mm plagioclase in groundmass of felted plagioclase laths granular olivine, opaques, and pyroxene; xenoliths of Mesozoic granitic basement rocks common; overlies units bur and blr; flow followed Pleistocene Owens River channel at least 16 km downstream into Indian Wells Valley; aa to pahoehoe flow surface well preserved locally; magnetic polarity normal; about 4 to 10 meters thick.

burp bur — BASALT OF UPPER LITTLE LAKE RANCH Flow (bur) and cinder cone (burp) of vesicular basalt; contains 1 percent 0.2-1 mm olivine and 2 percent 0.3-1 mm plagioclase in a coarse grained, sub-ophitic groundmass of olivine, opaques, lavender clinopyroxene, and plagioclase laths; overlies units blr and brv, and is overlain by units bvp and brh; flowed down Pleistocene Owens River channel for at least 15 km; pahoehoe to aa flow surface preserved locally; magnetic polarity normal; thickness ranges from about 5 meters to a maximum exposed thickness of 25 meters where lava ponded in Owens River channel near Little Lake; overlain by rhyolite pyroclastics of unit r with K/Ar age of 0.077 ± 0.008 m.y. (see Lanphere and others, 1975, sample no. 1); K/Ar age 0.140 ± 0.089.

blrp blr — BASALT OF LOWER LITTLE LAKE RANCH Cinder-bomb cone (blrp) and at least two flows (blr), of porphyritic vesicular basalt; contains 1 percent 0.1-0.4 mm opaques (titanomagnetite?), less than 1 percent olivine, 2 percent 0.2-1 mm pale yellow clinopyroxene with opaque inclusions up to 0.1 mm, and 7 percent 0.2-3 mm plagioclase with common sieved cores in groundmass of granular olivine, opaques, clinopyroxene, and felted plagioclase laths; xenoliths of Mesozoic basement rocks present; overlain by units bcr, brh, and bur, and overlies unit oal; total thickness 3-10 meters magnetic polarity normal; K/Ar age of upper flow 0.399 ± 0.045 m.y. and K/Ar age of lower flow 0.486 ± 0.108 m.y.

This map is preliminary and has not been reviewed for conformity with U.S. Geological Survey standards and nomenclature.

ls — LANDSLIDE Landslide debris of Sierra Nevada escarpment near Little Lake; appears to be overlain by unit oal.

bcw — BASALT OF COSO WASH At least three flows of porphyritic, vesicular basalt; contains 3 percent 0.1-1 mm olivine with opaque inclusions, 1 percent 1-4 mm olivine, less than 1 percent 0.1-0.2 mm opaques, 2 percent 0.2-0.5 mm brownish clinopyroxene, rare clinopyroxene up to 2 mm, and 20 percent 0.3-2 mm plagioclase with opaque inclusions in a fine-grained groundmass of granular olivine, opaques, pyroxene, and plagioclase; smaller phenocrysts commonly intergrown in clots; xenoliths of Mesozoic basement rocks common; overlain by unit bp; flow followed stream channel; vent area is probably buried by rhyolite dome at the upstream end of the flow; magnetic polarity normal; aa surface preserved locally; thickness ranges from 7 to at least 25 meters.

ba — BASALT OF AIRPORT LAKE Porphyritic vesicular basalt flows; contain about 3 percent 0.05-6 mm olivine, 1 percent 0.2-1.5 mm clinopyroxene, 5 percent 0.1-1 mm plagioclase, 5 percent 0.5-6 mm plagioclase with sieved cores, and less than 1 percent 0.5-3 mm quartz in a groundmass of granular olivine, opaques, pyroxene, and plagioclase laths; phenocrysts commonly in clots; overlies unit swh and is overlain by units bcr and bwa; columnar jointing present locally; thickness about 3 to 7 meters.

bsmp bsm — BASALT OF SUGARLOAF MOUNTAIN Flow (bsm) and associated cinder deposits (bsmp) of porphyritic, vesicular basalt; contains about 10 percent 0.1-4 mm olivine, less than 1 percent 0.4-6 mm clinopyroxene, 20 percent 0.2-1 mm plagioclase, and 3 percent 1-10 mm plagioclase in a fine-grained groundmass of plagioclase laths and granular olivine, clinopyroxene, and opaques; flow followed stream channel; about 3-5 meters thick; K/Ar age 1.08 ± 0.06 m.y.

bnp bn — BASALT OF NAMELESS HILL Two flows (bn) and two cinder-bomb deposits (bnp) of microporphyritic, vesicular basalt. Contains 2 percent 0.3 mm and smaller olivine and 7 percent 0.2-2 mm plagioclase in a groundmass of granular olivine, opaques, pyroxene, and plagioclase; flows followed stream valleys; xenoliths of Mesozoic basement rocks common; estimated thickness 3-6 meters, K/Ar age 1.07 ± 0.12 m.y.

swh — SEDIMENTARY ROCKS OF THE WHITE HILLS Includes interbedded conglomerate, sandstone, siltstone, silty claystone, and tufa; apparently grades laterally into cobble to boulder fanglomerate near the southwest corner of Airport Lake; overlain by units ba, bwa, blr, and bcr; some beds contain reworked, rounded pumice lapilli of unit p, indicating that unit swh is younger than the Coso Formation; contrasting mammalian fauna indicate this same age relation (Roland von Huene, oral commun., 1976).

brvp brv — BASALT OF ROSE VALLEY Four cinder-bomb cones (brvp) and three flows (brv) of porphyritic, vesicular basalt; contains 2-8 percent 0.1-2 mm olivine, 2-6 percent 0.2-2 mm yellowish clinopyroxene, and 8-15 percent 0.2-4 mm plagioclase in a fine-grained groundmass of plagioclase and granular olivine, opaques, and pyroxenes; olivine and/or clinopyroxene phenocrysts commonly contain opaque inclusions up to 0.2 mm; phenocrysts commonly broken or rounded and embayed; glomero-porphyritic clots, xenoliths of Mesozoic basement rocks, and rounded quartz grains up to 0.5 mm present locally; overlain by units bur and bvp; maximum exposed thickness of flows 2-4 meters; K/Ar age 2.06 ± 0.34 m.y.

rhs — RHYOLITE SOUTH OF HAIWEE SPRING Dome or plug of flow banded, porphyritic rhyolite; contains about 1 percent 0.5-2 mm quartz, 1 percent 0.3-1 mm plagioclase, rare 1 mm sanidine, and rare 0.2-0.5 mm brown biotite in a matrix of gray devitrified rock or green hydrated, perlitic glass; bounded by normal fault on east; exposed thickness about 50 meters.

bcfp bcf — BASALT OF UPPER CENTENNIAL FLAT Two cinder deposits (bcfp) and several basalt flows (bcf) averaging a few meters thick; contains about 1 percent or less of <1 mm olivine; overlies Coso Formation, unit c, just north of map area (see Hall and MacKevett, 1962).

blmp blm — BASALT OF SILVER MOUNTAIN Two cinder deposits (blmp) and several vesicular, porphyritic lava flows (blm) averaging a few meters thick; contains 0.5-1.0 percent 0.5-2.0 mm olivine and 0.5-1.0 percent 0.5-2.0 mm plagioclase, with rare crystals of each as large as 5 mm in an intergranular groundmass of clinopyroxene, olivine, and plagioclase; contemporaneous with unit acf; maximum thickness about 30 meters.

acfp acf — ANDESITE OF CACTUS FLAT Interlayered cinders and flows (acfp) and flows (acf) averaging 10 or more meters thick of porphyritic andesite; contains about 5 percent 1-4 mm plagioclase, 1 percent 0.5-2 mm pleochroic orthopyroxene, 1 percent 0.3-0.5 mm clinopyroxene, and less than 1 percent 0.3-0.5 mm olivine, in an intergranular groundmass of pyroxene and plagioclase; erupted from lava-cinder shield at north end of Cactus Flat; overlies Coso Formation (unit c) and is contemporaneous with unit blm.

brcp brc — BASALT OF RENEGADE CANYON Five cinder cones ($brcp_{1-5}$), three eroded cinder deposits ($brcp_{6-8}$), and associated lava flows (brc, brc_{1-5}) averaging a few meters thick; flows near some cones can be traced to source vents on bases of morphology and phenocryst assemblages; phenocrysts include 3-10 percent 0.5-3.0 mm plagioclase, 1-5 percent 0.1-2.0 mm olivine and 1-4 percent 0.2-1.5 mm clinopyroxene; subunits brc_1, brc_3, and locally brc contain 1 percent 1-3 mm rounded grains of quartz; part of subunit brc_4 contains only plagioclase and olivine phenocrysts; maximum exposed thickness about 170 meters; overlies units od, omf, tsv, and p.

anpp anp — ANDESITE NORTHWEST OF PETROGLYPH CANYON Flow (anp) and associated pyroclastic deposit (anpp) of porphyritic basaltic andesite; near vent area contains about 2 percent 0.1-0.6 mm olivine, 2 percent 0.3-0.8 mm clinopyroxene, 10 percent 0.2-4.0 mm plagioclase, and rare 1-1.5 mm rounded quartz in a fine-grained matrix of clinopyroxene, opaques, and plagioclase; thickness ranges from about 5-30 meters; phenocryst content and thickness decrease away from vent area; overlies units c, p, bpc, and omf; magnetic polarity normal.

dh — DACITE OF HAIWEE RIDGE Flows of porphyritic dacite; contains rare 0.02 mm zircon, rare 0.1 mm apatite, rare 0.1-0.7 mm orthopyroxene with amphibole rims on larger crystals, rare 0.1 mm clinopyroxene(?), 1 percent 1-2 mm quartz, 1 percent 0.05-0.2 mm opaques, 3 percent 0.2-1.5 mm brown biotite with opaque and feldspar inclusions, 3 percent 0.2-1.7 mm greenish brown amphibole with opaque, feldspar, and biotite inclusions, and 15 percent 0.1-6.0 mm plagioclase with inclusions of most other phenocryst phases in a glassy groundmass now largely composed of feldspar and other microlites; overlies unit c; highly flow banded; columnar jointing developed where ponded; average thickness about 25 meters; ponded to at least 200 meters south of Haiwee Reservoir; Evernden and others (1964) report K/Ar age of 2.1 m.y.

dyp dy — YOUNGER DACITE EAST OF COSO VALLEY Small cinder deposit (dyp) and thick flow (dy) of flow banded dacite; contains less than 1 percent 1.2-2 mm quartz, 10 percent 0.6-6 mm plagioclase, less than 1 percent 0.1-0.6 mm brown amphibole, now mostly replaced by iron oxide, less than 1 percent 0.3-1.5 mm orthopyroxene, rare 0.5-0.7 mm clinopyroxene, and rare 0.3 mm biotite in a groundmass of opaque, pyroxene, and feldspar microlites in devitrified glass; overlies units bpc, omf, c, and do; thickness 10 to at least 60 meters.

dop do — OLDER DACITE EAST OF COSO VALLEY Cinder deposit (dop) and thick flow (do) of platy, flow banded dacite; contains 1 percent 0.6-1 mm quartz, 3 percent 0.6-3 mm plagioclase, less than 1 percent 0.3-1 mm brown amphibole, now mostly replaced by iron oxide, less than 1 percent 0.3-1.2 mm ragged brown biotite, less than 1 percent 0.2-0.8 mm clinpyroxene, commonly in clots, and 1 percent 0.2-5.0 mm orthopyroxene, commonly with cores of up to 1 mm forsteritic olivine in a groundmass of opaques, pyroxene, and feldspar microlites in devitrified glass; overlies units bcp and c and is overlain by unit dy; magnetic polarity normal; thickness 5 to at least 50 meters.

tsv — TUFF SOUTHWEST OF VOLCANO BUTTE Basaltic to andesitic pyroclastic deposit; well stratified vesicular ash and lapilli, with beds from a few to several centimeters-thick, locally disturbed by volcanic bomb sags 0.3-1.0 meter in diameter; maximum exposed thickness about 6 meters; overlain by unit brc.

p c — COSO FORMATION Includes fanglomerate of Mesozoic basement rocks, arkosic sandstone, tuffaceous sandstone and siltstone, tuffaceous lacustrine beds, and silicic tuff; fanglomerate, coarse-grained arkose, and tuff are predominant on the high slopes of Haiwee Ridge and interfinger with finer grained rocks and lacustrine beds to the north and west; north and east of Upper Cactus Flat and Coso Hot Springs, fanglomerate and interlayered hornblende-biotite pumice (p) predominate; overlies units b, od, bcp, bpc, and omf and is overlain by units acf, dh, bcf, do, dy, anp, and brc; K/Ar age of rhyolitic tuff in c is 3.09 ± 0.09 m.y.; K/Ar ages of p are 3.03 ± 0.20 m.y., 2.46 ± 0.98 and 2.95 ± 0.13 m.y.; Evernden and others (1964) report a K/Ar age of 2.3 m.y. for silicic tuff in c, inconsistent with results of present study.

omfp omf — OTHER MAFIC LAVAS Flows from 2 to 20 meters thick (omf) and eroded cones (omfp) of porphyritic vesicular basalt to basaltic andesite; phenocrysts include up to 7 percent 0.1-2 mm olivine, 5 percent 0.2-1 mm greenish sector-zoned clinopyroxene, and 25 percent 0.2-3 mm oscillatory-zoned plagioclase in a fine grained groundmass of plagioclase laths, granular olivine, an opaque mineral, and clinopyroxene; glomeroporphyritic texture common; some flows contain 1 mm amphibole almost entirely replaced by opaque oxides; others contain plagioclase as large as 5 mm with sieved cores and clear rims, rare alkali feldspar as large as 3 mm, and rounded grains of quartz as large as 5 mm armored by a rind of clear, brown glass in turn rimmed with clinopyroxene; total phenocryst content generally less than 20 percent; some cinder deposits are in part dacitic; basalt dikes cut cinder cones locally; some flows west of Silver Peak superficially similar to those of unit bpc; overlies unit b, interfingers with units bpc and od, and is overlain by units bcp, c, p, brc, brc_4, bp, and oal; includes both normal and reversed magnetic polarities; K/Ar ages range from 3.10 ± 0.22 m.y. to 3.66 ± 0.08 m.y.

odp od — OTHER DACITE Cinder deposits (odp) and flows and shallow intrusive bodies (od) predominantly of porphyritic biotite and/or hornblende dacite; includes minor porphyritic olivine or orthopyroxene andesitic flows near Volcano Butte; odp commonly includes mafic cinders admixed with dacitic cinders; dacite flows contain up to 30 percent 0.1-8 mm oscillatory-zoned plagioclase and various combinations of as much as 2 percent 0.8-4 mm rounded and embayed quartz, 5 percent 0.2-1.5 mm orthopyroxene, 3 percent 0.2-0.8 mm clinopyroxene, 15 percent 0.1-2.5 mm generally oxidized brown amphibole, 7 percent 0.1-1.5 mm brown biotite, 1 percent 0.2-0.5 mm opaque mineral, accessory 0.1-0.8 mm sphene and 0.1-0.2 mm zircon in a very fine-grained to glassy groundmass; as much as 1 percent 0.1-0.8 mm olivine present locally; rounded inclusions of andesite, basaltic andesite, and basalt a few millimeters to several meters in size account for as much as 30 percent of many outcrops; in such mixed rocks, coexistence of dacitic and more mafic liquids is indicated by interfingering and partial mixing on scale of a few millimeters; thickness ranges from roughly 20 meters to at least 300 meters; interfingers with units omf and bpc; overlain by units c, p, brc, tsv, bp, and oal; K/Ar ages 3.42 ± 0.10 and 2.20 ± 0.70 m.y.

bcpp bcp — BASALT OF COSO PEAK Cinder deposits (bcpp) and a few flows (bcp) of porphyritic basalt; contains 0-5 percent 0.2-3 mm olivine with spinel inclusions and 1-3 percent 0.2-2 mm greenish sector-zoned clinopyroxene in a groundmass of granular opaques, olivine, clinopyroxene, and plagioclase laths; phenocrysts commonly occur in clots; locally contains granitic xenoliths and quartz grains; at least 10 meters thick; overlies units omf and od; overlain by unit p; magnetic polarity reversed; K/Ar age 3.60 ± 0.08 m.y.

bpcp bpc — BASALT OF UPPER PETROGLYPH CANYON Cinder deposits (bpcp) and thin flows (bpc) of vesicular basalt; contains 3-5 percent 0.2-3 mm olivine with opaque inclusions and 5-10 percent 0.5-6mm oscillatory-zoned plagioclase in a coarse grained ophitic groundmass of bladed opaques, granular olivine, poikilitic brownish clinopyroxene, and plagioclase laths; typically displays vesicle cylinders and sheets, glomeroporphyritic clots, platy jointing near tops of flows, columnar jointing in flow interiors, and well-developed diktytaxitic texture; thickness 3 to at least 60 meters; overlies unit b, interfingers with units omf and od, and is overlain by units oal, c, p, anp, do, and dy; K/Ar ages 2.98 ± 0.12 and 1.50 ± 0.19 m.y.

b — UNDIFFERENTIATED BASEMENT ROCKS (Mesozoic) Principally granitic intrusive rocks of Mesozoic age; compositions range from granite to quartz diorite to quartz-free diorite or gabbro; textures range from medium- to coarse-grained to porphyritic with K-feldspar crystals up to 1.5 cm; mafic inclusions common, especially in south part of map area; metamorphic pendants as much as 0.5 km long present in east and northeast part of map area; generally northwest trending, Mesozoic(?) dikes of silicic and intermediate to mafic composition abundant locally.

PLATE I-1 (cont'd) EXPLANATION - PRELIMINARY GEOLOGIC MAP OF THE COSO ES AREA (from Duffield and Bacon, 1977)

EXPLANATION

Fault - solid line where surficial evidence of fault displacement noted, dashed where evidence is questionable, length of dash in proportion to degree of confidence of existence of fault

Geologic contact - Solid line where well located, dashed where approximately located, dotted where concealed

Mapped by aerial photo interpretation with about 75% of the fault locations field checked.

PLATE I-2 Preliminary Structural Interpretation of the Coso Area (St. Amand & Roquemore, 1978)

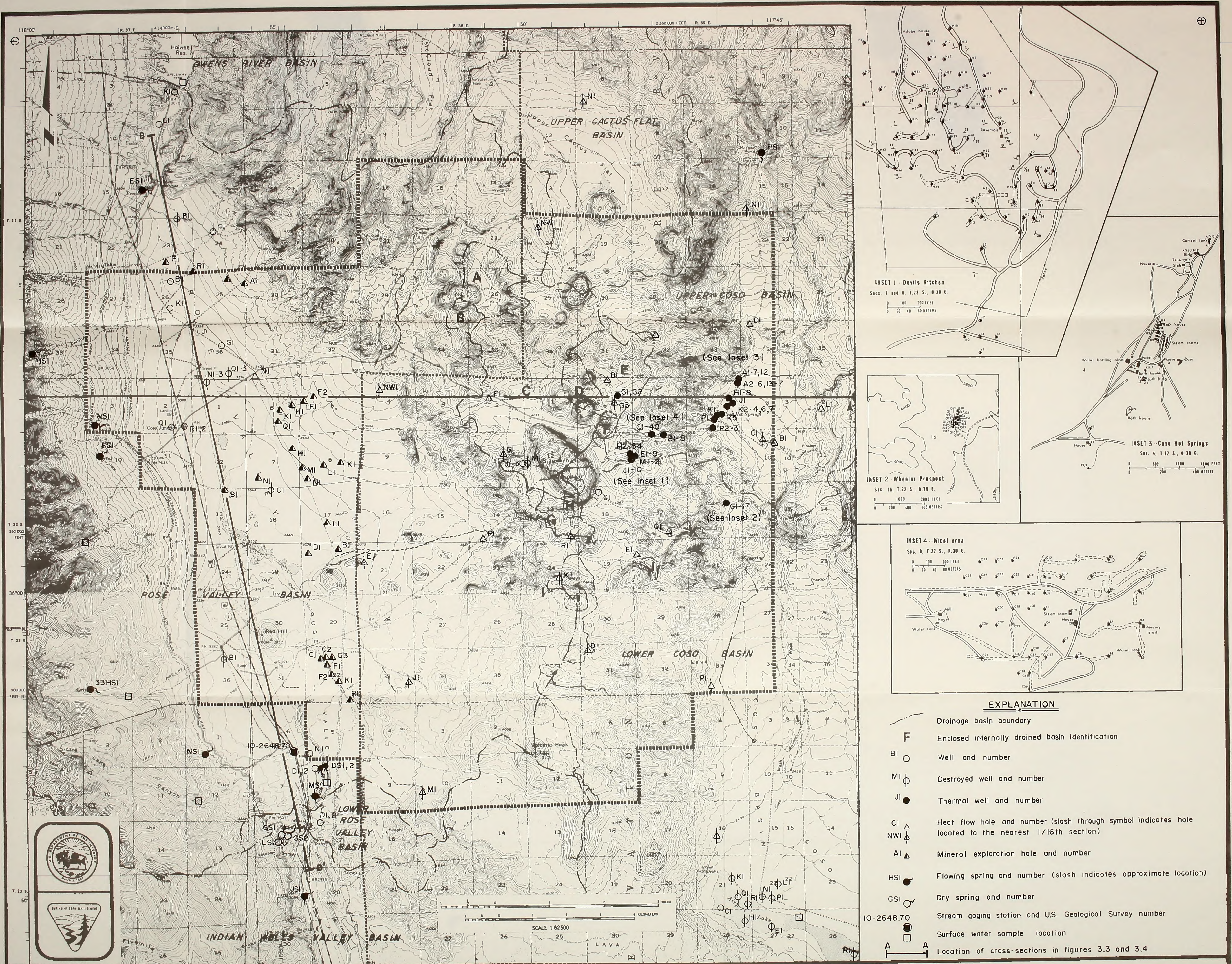
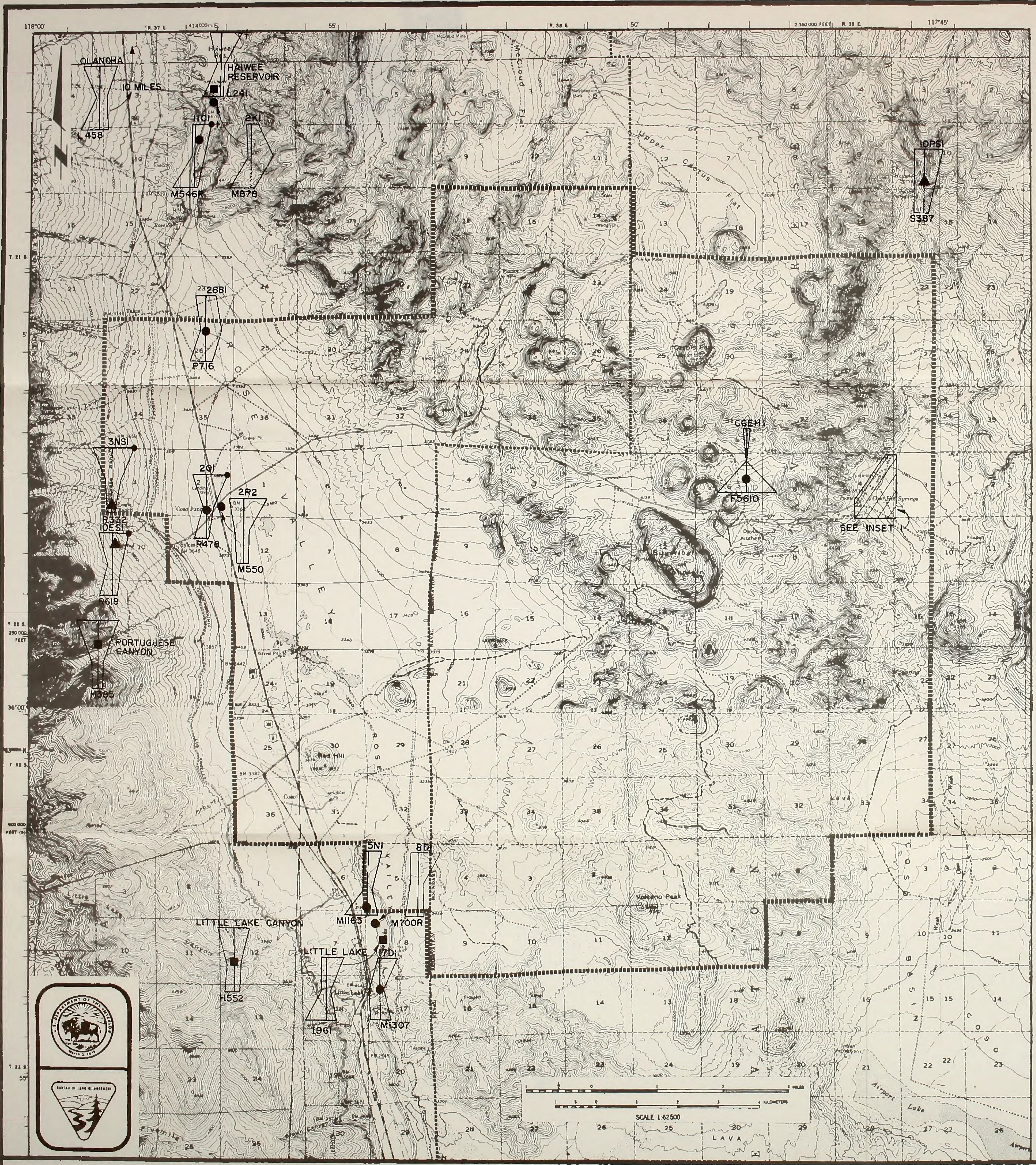
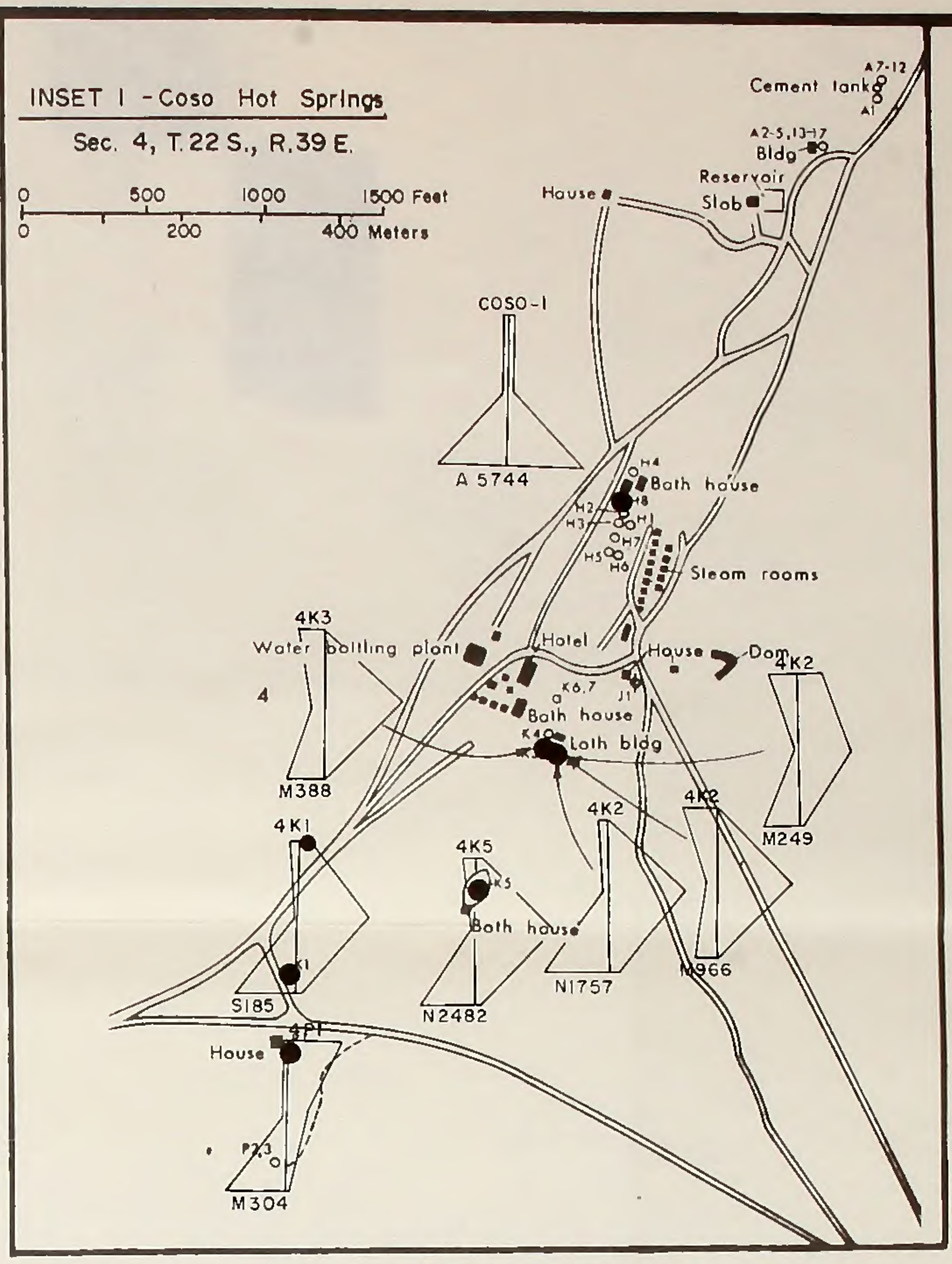


PLATE II-1 Well and Spring Locations - CGSA

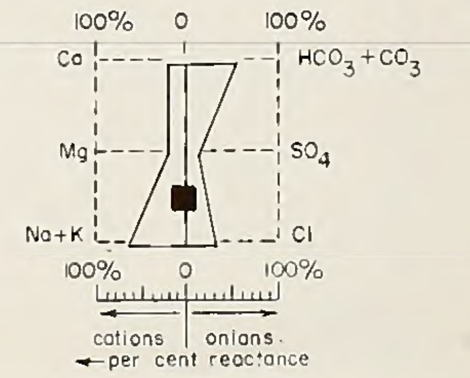




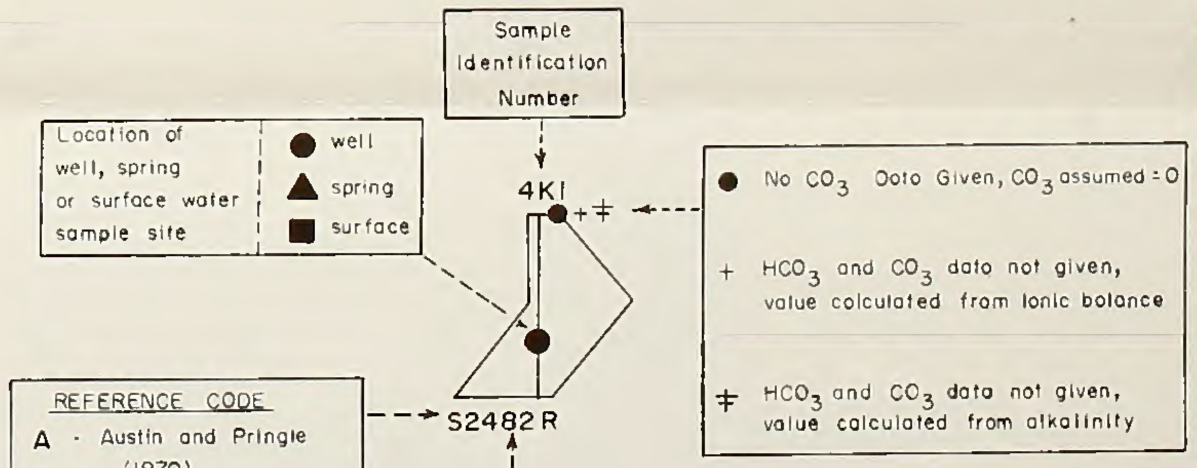
EXPLANATION

MODIFIED STIFF DIAGRAMS

Horizontal axes show per cent reactance of respective species



PER CENT REACTANCE $\left\{ \dfrac{\text{ANION SPECIES (meq/}\ell\text{)}}{\text{SUM ANIONS (meq/}\ell\text{)}} \quad \dfrac{\text{CATION SPECIES (meq/}\ell\text{)}}{\text{SUM CATION (meq/}\ell\text{)}} \right.$



REFERENCE CODE

- A - Austin and Pringle (1970)
- F - Fournier, et. al. (1978)
- H - Harding Lawson Assoc.
- I - Inyo County (pers. comm. 1979)
- L - Los Angeles Dept. of Water and Power (pers. comm. 1979)
- M - Moyle, 1977
- N - Naval Weapons Center (pers. comm. 1979)
- P - P. Hennis (pers. comm. 1979)
- R - R. Lane (pers. comm. 1979)
- S - Spane, 1978

Total Dissolved Solids TDS (mg/ℓ)	Expression of TDS: Blank - sum of constituents R- Residue at 180 C

PLATE II-2 Chemical characteristics of water - CGSA