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REGIONAL SYSTEMS DEVELOPMENT FOR
GEOTHERMAL ENERGY RESOURCES, PACIFIC
REGION (CALIFORNIA AND HAWAII)

Task 3—Water Resources Evaluation. Topical Report

March 19, 1979

Work Performed Under Contract No. ET-78-C-03-1530

System Development Corporation
Santa Monica, California

U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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**REGIONAL SYSTEMS DEVELOPMENT FOR GEOTHERMAL ENERGY RESOURCES
PACIFIC REGION (CALIFORNIA AND HAWAII)**

TASK 3 - WATER RESOURCES EVALUATION

TOPICAL REPORT

19 MARCH 1979

Prepared for
Department of Energy
Division of Geothermal Energy
Washington, D.C.

CONTRACT NO. DE-AC03-78ET-28432

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PREFACE

This Draft Topical Report was prepared by VTN Consolidated, Inc., under subcontract JO-1202 to System Development Corporation, Santa Monica, California (the Regional Systems Development Contractor for Geothermal Energy Resources in California and Hawaii), in partial fulfillment of the terms of Contract DE-AC03-78ET-28432 with the Department of Energy, Division of Geothermal Energy.*

*Formerly EG-78-C-03-1530

FOREWORD

Our contract with the Federal Department of Energy (which designated System Development Corporation as a Regional Systems Development Contractor for electrical power generation applications) was centered upon three basic tasks that were directed toward "Regional Systems Development for Geothermal Energy Resources in the Pacific Region" (California and Hawaii).

Task 1 - Development of Regional Geothermal Energy Implementation Plans

Task 2 - Regional Program Monitoring and Progress Evaluation

Task 3 - Evaluation of the Water Resources Regionally Available for Geothermal Energy Development

These tasks were intimately interrelated and required a number of iterations both individually among the elements of each task and severally among the tasks. In developing implementation plans under Task 1, we needed to establish the status of existing projects (determined in Task 2) and to be aware of the available water resources (assessed in Task 3). In turn, the evaluation of existing projects and the analysis of water availability was heavily influenced by the plans, i.e., the type of power plant and the rate at which power would be brought on-line. An overview of the tasks is presented in Figure F-1.

The tangible results of these tasks, and the recommendations that we developed, were reviewed with government and industry. Their comments and suggestions have been incorporated into our final contractual products. In a very real sense, we have served to "cross-pollinate" the industry and governmental agencies at several levels by prudently facilitating the exchange of information and by discussing problems and potential (or realized) solutions with many individuals.

Figure F-1. Overview of Program Tasks

ABSTRACT

We undertook three major tasks under DOE Contract DE-AC-03-78ET-28432. They all relate exclusively to the utilization of geothermal energy resources for the generation of electrical power in California and Hawaii. Task 3 is presented in this topical report. (Separate topical reports have been prepared for Tasks 1 and 2.)

Task 1 - Development of Implementation Plans for the Commercialization of Geothermal Resources.

Eleven implementation plans were prepared. They represent some 21 reservoir-site developments and 48 geothermal power plant developments. The plans consist of three integrated elements: (1) a bar-chart schedule that depicts interdependencies among activities and shows significant milestones on the path from initial exploration to power on-line, (2) task descriptions, and (3) the responsible performers. During the preparation of the implementation plans, the tasks required for resource development at each KGRA were defined on a generalized work breakdown structure (WBS) diagram. A generalized WBS dictionary (task descriptions) was also compiled. In addition, a specific WBS for each KGRA was prepared in a tabular and indented format. The tasks formed the basis for the schedular activities. Institutional responsibilities, based upon the WBS, were identified and are also shown on the tabular WBS. In this manner, implementation plans evolved whose schedular, task, and responsibility elements were integrated with one another.

Each plan is based in large measure upon discussions with developers and utilities, and with the governmental entities with which they must interact. Based upon our analysis of all the acquired data and the historical track records, we have made judgments with respect to power on-line dates and certain activities that are not necessarily consonant with the stated opinions or plans of each specific interviewee. However, the implementation plans have been reviewed with the various parties concerned and do represent a reasonable consensus for the near-term (to 1990).

In order to provide logically consistent time estimates, and a reasonable basis for comparison, schedule modules were developed for some recurring activities which are essentially common to all KGRAs. These modules are effectively lower tier schedules which are presented in the form of flow charts that define responsibilities and specify elapsed times. The majority of the modules are permit-specific since the regulatory requirements usually constitute the driving process and are widely relevant to all the KGRAs. In their application to the implementation plans, some adjustment to the time spans was made on occasion to accommodate local (site-unique) peculiarities.

In the preparation of multiple plant schedules for a given KGRA, the interactive effects of power development on the ancillary resources of the area were considered so that interfaces and constraining situations would be identified. Within Imperial County, this process was taken one step farther to include the influence that development at the several close-lying KGRAs would have upon one another.

A set of recommendations for the accelerated development of geothermal energy resources was prepared and the potential implementors were suggested.

Task 2 - Regional Program Monitoring and Progress Evaluation.

All the objectives have been met through personal contacts and the review of data. They are as follows:

- a. To determine the existing status of power plant projects and future plans.
- b. To identify major problem areas for each project (technical, financial, regulatory) that are affecting progress.
- c. To analyze the data and to develop recommendations directed toward resolving problems.

The results have been presented in a tabular summary format that is accompanied by explanatory text covering 25 projects.

Task 3 - Water Resources Evaluation

The fundamental objective of the water resources analysis was to assess the availability of surface and ground water for potential use as power plant make-up water in the major geothermal areas of California. The analysis was concentrated on identifying the major sources of surface and ground water, potential limitations on the usage of this water, and the resulting constraints on potentially developable electrical power in each geothermal resource area. If data on water resources were not available or sufficient for a given locale to complete this analysis, procurement specifications were prepared that can be used by DOE at some future date to acquire the necessary information.

Analyses were completed for 11 major geothermal areas in California: four in the Imperial Valley, Coso, Mono-Long Valley, Geysers-Calistoga, Surprise Valley, Glass Mountain, Wendel Amedee, and Lassen. The lack of complete data on resource characteristics and ultimate reservoir capacity precluded an analysis of constraints for areas not designated as a KGRA. One area in Hawaii, the Puna district, was also included in the analysis.

The water requirements for representative types of energy conversion processes were developed using a case study approach. Cooling water requirements for each type of energy conversion process were estimated based upon a specific existing or proposed type of geothermal power plant. The make-up water requirements for each type of conversion process at each resource location were then estimated as a basis for analyzing any constraints on the megawatts which potentially could be developed.

Clearly, the activities (and outputs) of the three contractual tasks are interrelated and interdependent. The results were in fact integrated into a self-consistent product.

SUMMARY

The Task 3 Topical Report is organized in ten independent parts. The first nine parts describe the water resources at individual known Geothermal Resource Areas (KGRAs) or at groupings of KGRAs in California and Hawaii. Each part contains its own summary, conclusions, recommendations, and technical discussions. The tenth part describes the power plant water utilization case studies that were used in conjunction with the Task 1 power on-line estimates to project achievable megawattage at certain KGRAs.*

All of the appendices are contained in a separate appendix volume which is compiled by KGRAs in the same sequence as the main text.

Due to the organizational concept applied in the preparation of this report, a certain measure of redundancy exists in the explanatory or "boiler plate" sections from part-to-part. However, we feel that this condition is outweighed by the convenience afforded a given user in being able to remove and refer to those self sufficient parts that are of specific interest to him.

1.0 WATER RESOURCES ANALYSES

1.1 INTRODUCTION

The fundamental objective of the water resources analysis was to assess the availability of surface and ground water for potential use for power plant make-up water in the major geothermal areas of California. The analysis concentrated on identifying the major sources of surface and ground water, potential limitations of usage of water from any of these sources, and ultimately indicating constraints on the megawatts which could potentially be developed in each geothermal resource area. If data on water resources were

* The Jet Propulsion Laboratory's time-phase estimates (JPL-PUB-77-63) were used as a basis to develop water requirements in the period not covered by the Task 1 report: 1990 to the full realization of a given resource's potential.

not available or sufficient to complete this analysis, procurement specifications were prepared to acquire the necessary information.

Analysis was completed for 11 major geothermal areas in California: four in the Imperial Valley, Coso, Mono-Long Valley, Geysers-Calistoga, Surprise Valley, Glass Mountain, Wendel-Amedee, and Lassen. The lack of complete data on resource characteristics and ultimate reservoir capacity precluded an analysis of constraints for areas not designated as a KGRA. One area in Hawaii, the Puna district, was also included in the analysis.

The water requirements for each type of energy conversion process which could potentially be utilized were developed using a case study approach. Under this approach, cooling water requirements for each type of energy conversion process were estimated based upon a specific existing or proposed type of geothermal power plant. The make-up water requirements for each type of conversion process at each resource location were then estimated as a basis for analyzing any constraints on the megawatts which potentially could be developed. Based on this approach, it should be noted, a change in any of the parameters affecting the power plant would produce a resultant change in the cooling water requirements.

Beyond the constraints which can be identified in this manner, the legal and institutional aspects of water use in California are major considerations. The use of water in California includes a complex history of legal decisions involving rights to both surface and ground water. Thus, notwithstanding the availability of surface or ground water, legal or institutional considerations may, in some areas, be the overriding constraint to geothermal power plant development.

1.2 SUMMARY OF FINDINGS

1.2.1 Surface Water

The wide variations in climatological, topographical and geologic conditions produce considerably different surface water resources in

the geothermal resource areas of California. Precipitation varies from less than three inches annually in the Imperial Valley to over 60 inches in certain portions of The Geysers-Calistoga area. Topographic conditions vary from the relatively flat areas in the Imperial Valley to the mountainous terrain in the Geysers-Calistoga and Mono-Long Valley areas. The wide variations in the geologic conditions of the areas also affect the occurrence of surface runoff.

Based on an analysis of these physical factors, certain major findings related to surface water for each of the geothermal areas in California were developed. First, surface water in sufficient quantity for geothermal power plant cooling is not available from runoff in the four Imperial Valley areas, Coso and Glass Mountain.

Secondly, in the remaining areas (Mono-Long Valley, The Geysers-Calistoga, Wendel-Amedee, Surprise Valley and Lassen) agricultural, domestic and hydroelectric generation all compete for the surface water which might otherwise be available for use in geothermal power plants. Given the various constraints on the availability and competing uses, surface water from natural runoff sources does not appear to be a viable alternative for geothermal power plant cooling purposes.

In addition to problems created by competing uses for surface water, seasonal factors affect the feasibility of using surface water as a source of cooling water for geothermal power plants in areas where surface water is available. High rates of consumption in the summer periods and low rates of precipitation act to create seasonal variations which add to the complexity of using surface water on a year-round basis. Under these conditions, if surface water is to be used as a source of cooling water, storage facilities and distribution systems will have to be developed. The engineering/economic feasibility of developing the required storage facilities and distribution systems

will require additional analysis.

Water in the agricultural drain system in the Imperial Valley is the only

potential source of surface water which can be used for geothermal power plant purposes. Water from this source is available in sufficient quantity to be a viable source of cooling water for geothermal power plants. The use of this source of water is, however, limited by constraints from the energy conversion process and the method of power plant effluent disposal. Since the use of agricultural waste water would act to alleviate certain problems related to the level of the Salton Sea, utilization of this source of surface water is considered a viable alternative as a source of cooling water for geothermal power plants. It should be noted, agricultural waste water which can be used for geothermal power plant cooling purposes is limited to the Imperial Valley in California.

1.2.2 Ground Water

Given the constraints on the availability of surface water, ground water was examined as a potential alternative source of geothermal power plant cooling water. However, the lack of complete data on ground water resources in five of the geothermal areas (Mono-Long Valley, Surprise Valley, Wendel-Amedee, Glass Mountain and Lassen) precluded a complete analysis of constraints on power plant development. Procurement specifications were developed to acquire the requisite data in each of the areas identified as lacking information. Once the data are known, further analysis on constraints on geothermal power plant development can be undertaken.

The ground water data lacking included information on storage capacity and usable capacities. Data on storage capacity will be required for Mono-long Valley; information on usable capacities needs to be developed for the Surprise Valley, Wendel Amedee, Glass Mountain and Lassen areas.

Ground water data were complete for Imperial Valley, Coso and The Geysers-Calistoga areas. Within each of these areas, the ground water basins were identified, storage capacities developed and the potential for development delineated. Despite the presence of the potential sources of ground water, the long-term usage of this source of water for geothermal power plant cooling purposes is not clearly established. As with the case of surface

water, competing uses from different institutions for the various sources of ground water may act as a constraint for utilization of this water for geothermal power plant cooling purposes.

In addition to these various constraints from institutional considerations, the legal aspects of using ground water for power plant cooling purposes are not clearly known. (Normally, in California, ownership of land also includes access to any water below the ground surface.) These ownership considerations make the use of ground water for geothermal power plant cooling purposes highly uncertain.

In addition to constraints on development due to competing uses and the ownership issue, the feasibility of distribution of ground water is a consideration requiring further analysis. The engineering/economic aspects related to the distribution of ground water will have to show production of power at a price competitive with other sources of electrical power.

1.2.3 Developable MWe

The sources of surface and ground water were examined to identify constraints on the megawatts of electrical energy which could potentially be developed from each geothermal area. Of the various factors affecting developable megawatts, the energy conversion process utilized and cooling water availability are the critical variables. Under current technology, outside water requirements vary from zero with flashed steam processes using condensate for cooling purposes to binary cycles which rely totally on an external source of water. The temperature of the geothermal resource is also a key variable since it affects both the conversion cycle which may be utilized and, thus, the related amount of cooling water required. The solids content of the make-up water and method of disposal of power plant effluent also influence cooling water requirements.

Given the identifiable constraints on water availability, the conversion process utilized and the temperature of the geothermal resource, projections on

developable megawatts from each geothermal resource area could be estimated. Using this method of analysis the estimates shown on Figures S-1, S-2, and S-3 were developed. Although not shown in graphic format, sufficient water is available to develop the hot water geothermal resources in The Geysers-Calistoga area in any of the energy conversion processes.

Figure S-1 Developable Megawattage: Heber and East Mesa KGRA

ASSUMPTIONS:

- A: FLASHED STEAM - ZERO MAKE-UP WATER
- B: FLASHED STEAM - COMPLETE INJECTION, RIVER/AGRICULTURAL DRAIN WATER
- C: FLASHED STEAM - INDIRECT CONTACT CONDENSER, CANAL WATER
- D: FLASHED STEAM - INDIRECT CONTACT CONDENSER, GROUNDWATER
- E: BINARY CYCLE - CANAL WATER
- F: BINARY CYCLE - GROUNDWATER
- G: BINARY CYCLE - RIVER/AGRICULTURAL DRAIN WATER

notes, 1978.

Figure S-2 Developable Megawattage: Salton Sea and Brawley KGRAs

ASSUMPTIONS:

- A: FLASHED STEAM - ZERO MAKE-UP WATER
- B: FLASHED STEAM - COMPLETE INJECTION, RIVER/AGRICULTURAL DRAIN WATER
- C: FLASHED STEAM - INDIRECT CONTACT CONDENSER, CANAL WATER
- D: FLASHED STEAM - INDIRECT CONTACT CONDENSER, GROUNDWATER
- E: BINARY CYCLE - CANAL WATER
- F: BINARY CYCLE - GROUNDWATER
- G: BINARY CYCLE - RIVER/AGRICULTURAL DRAIN WATER

Source: VTN Estimates, 1978..

SUMMARY OF DEVELOPABLE MWe

TOTAL CAPACITY: 2000 MWe

- A: FLASHED STEAM – ZERO MAKE-UP WATER**
- B: FLASHED STEAM – COMPLETE INJECTION, SURFACE WATER**
- C: FLASHED STEAM – INDIRECT CONTACT CONDENSER, SURFACE WATER**
- D: FLASHED STEAM – INDIRECT CONTACT CONDENSER GROUNDWATER (< 4,000 ppm TDS)**
- E: FLASHED STEAM – INDIRECT CONTACT CONDENSER, GROUNDWATER (< 1,000 ppm TDS)**
- F: BINARY CYCLE – SURFACE WATER**
- G: BINARY CYCLE – GROUNDWATER (< 4,000 ppm TDS)**
- H: BINARY CYCLE – GROUNDWATER (< 1,000 ppm TDS)**

Source: VTN Estimates, 1978.

Figure S-3 Developable Megawattage: Coso KGRA

2.0 INSTITUTIONAL RESPONSIBILITY FOR WATER USE

Access to potential sources of cooling water is a critical issue in the development of geothermal resources in California. The use of water, however, involves certain historical practices, a complex set of legal issues and a whole series of court decisions. The entire area of rights to water usage requires a separate analysis focusing specifically on the major concerns of the subject. The analysis developed in this section covers only the basic issues of water rights and institutional responsibilities.

As a normal rule, in California, ownership of land generally carries with it the right to use the water on or below the surface of the property. Notwithstanding this general rule, access to the water depends upon certain specific rights. The right to use the water may be right derived under state law or from expressed or implied federal reservations of land for specific purposes. Various state water rights apply to surface and ground waters. These water rights may involve riparian rights to surface water which is adjacent to the land or appropriative rights to use surface water from a more distant source. Ground water rights could be either overlying, which implies right to use of ground water beneath the overlying land, or the appropriative right to use ground water from a more distant source.

Federal reserved water rights attach to land which has been reserved by the Congress for specific purposes, such as national parks or forests. These federal rights are limited to the amount of water which is necessary to fulfill the purposes of the land reservation.

Beyond this basic analysis, the institutions involved in the rights to use either surface or ground water will depend upon the specific property and rights involved. The institutional responsibility for administering water rights rests with the California Water Resources

Control Board. The actual rights to use any surface or ground water can be ascertained only through a determination made by the Water Resources Control Board on a case by case basis.

3.0 RECOMMENDATIONS

The Task 3 Topical Report is organized into nine independent "parts" each of which address a given geothermal anomaly, or a grouping of geothermal anomalies in California and Hawaii.* In Section 3.0 of each part, certain recommendations are presented and discussed in view of who might best take the lead in implementing them (federal, state, county or local government) and, in several instances, in view of site-specific considerations. Here, we shall summarize these recommendations with respect to six categories:

- (1) Planning
- (2) Subsidence
- (3) Blow-Down Disposal
- (4) Make-up water distribution
- (5) Ground Water Data Acquisition
- (6) Legal and Institutional Factors

3.1 PLANNING

Whether or not power plant makeup water is needed in the first place, and the quality and quantity that might be required, is dependent upon several factors. Therefore, we recommend that systems analyses be performed to determine the most cost effective and environmentally acceptable power plant thermodynamic cycle and design as a function of resource temperature,

* See P.ii: "Consolidated Table of Contents."

subsidence limitations/injection requirements, make up water availability, blow-down disposal limitations, and noxious emissions. Clearly, a general study will not in itself suffice. Site-specific considerations must be addressed, too.

Assuming a need for geothermal power plant make up water is identified at a given KGRA or site and this is not a foregone conclusion (Geysers-Steam plants have not needed any and none is likely to be needed at Puna, Hi.) -- then long range planning should be directed toward the dedication of a ground and/or surface supply sufficient to support the planned power plant development.

Both the potentially available water resources and the stage of geothermal development differ from anomaly to anomaly. The formulation of any given long range water allocation plan -- to say nothing of its implementation -- will require extensive coordination and cooperation among many of the following elements of federal and California State government:

- Imperial Irrigation District
- Coachella Valley Irrigation District
- California Water Quality Control Board
- California Department of Fish and Game
- U.S. Navy (Coso KGRA)
- Los Angeles Department of Water and Power
- U.S. Forest Service
- California Department of Water Resources
- California Water Resources Control Board
- California Division of Oil and Gas
- County Planning Departments

DOE should take the lead responsibility for "getting the ball rolling", but specific counties or the state, as determined by the circumstances in each case, should assume responsibility for detailed planning and implementation. Thus, the needs and concerns of those who will be most affected can be satisfied best. In this regard, the establishment, under state auspice

of regional or local forums would provide a useful vehicle for bringing industry, government, and other interested parties together for an exchange of views, concerns, and plans. (Also see Section 4.2 of the Task 1 Topical Report.)

3.2 SUBSIDENCE

Subsidence, per se, is not necessarily a significant environmental consideration. In some areas, the geologic formations may be such as to mitigate against, or preclude, its occurrence, e.g., Puna, Hi. and the Geysers-Steam, Ca. Wherever subsidence is not a problem, for whatever reason, a power plant design can be chosen that does not require an outside source of cooling water, e.g., flashed steam. In other locales, almost any subsidence would be catastrophic, e.g., all of the Imperial County, Ca. geothermal anomalies with the possible exception of East Mesa.* Here the reinjection of the expended geothermal fluid is probably a necessity, but the extent of reinjection is debateable.

For those areas where potential subsidence is viewed as a problem, we recommend that field tests be conducted to determine whether total reinjection is in fact a sine qua non or if 70%, 80% ... reinjection would suffice.

Significance: Approximately 80% reinjection can be accommodated by a flashed steam plant energy conversion cycle without the need for additional cooling water.

3.3 BLOW-DOWN DISPOSAL

The quantity of any make up water that might be required is influenced by its own quality and by the quality and quantity of the power plant blow-down discharge vis-avis regulations restricting pollution, i.e., temperature, salinity, and the toxicity content (e.g., As, Bo, Hg).

Subsidence would disrupt the intricate gravity drainage system that is in use and would have a major impact upon the agricultural industry.

We recommend that an objective and pragmatic study be made to evaluate the existing restrictions with the intent of lowering them, where feasible, at those locations where makeup water is both needed and in short or questionable supply, e.g., Imperial County, Coso, Mono-Long Valley. Additionally the commercial feasibility of processing the discharge to recover marketable minerals, coupled with alternative methods of blow-down effluent disposal, should be investigated.

3.4 MAKEUP WATER DISTRIBUTION

Given the inherent conditions underlying the development of a geothermal resource, i.e., the power plant must be built where the fuel (resource) is located, the distribution of makeup water to the plants can pose a problem of its own. For example, in Imperial County, makeup water could be drawn from the aquifer, from the Salton Sea (and suitably processed), or from the irrigation canals. The canals themselves may prove to be an adequate distribution system, but lacking that possibility a different approach will have to be developed.

We recommend that a study should be undertaken to determine the economic and technical feasibility in the Imperial County area of:

- (1) Pumping water from the aquifers into the irrigation canals. Salient considerations are the cost, ground water compatibility with the canal water (with respect to irrigation quality requirements), and subsidence due to depletion of the aquifers. The determination of flow rates within the canals at strategic locations and investigating the possibility of recovering the power expended in pumping (by means of hydroelectric generation) are corollary needs.
- (2) Processing Salton Sea Water to make it suitable for makeup purposes and defining methods to dispose of the resulting sludge.
- (3) Developing a trade off plan by virtue of which water users in the Los Angeles area would exchange some of that water for power generated in Imperial County.

PART I
IMPERIAL VALLEY

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PART I

IMPERIAL VALLEY

1.0 SUMMARY

The major objective of this report is to assess the following for the four major Known Geothermal Resource Areas (KGRAs) in the Imperial Valley, California.

- water resources that are available for geothermal electric power plant development
- power plant make-up water requirements
- the developable megawatts based on available make-up water at East Mesa, Heber, Brawley and Salton Sea Known Geothermal Resource Areas (KGRAs) (see Figure I-1)
- the need for additional water resource data

The availability of outside sources of make-up water for power plant cooling purposes is a major consideration in developing geothermal resources in the Imperial Valley. Surface water resources were analyzed as to source, quality, quantity and availability for use in geothermal power plants. Ground water resources were assessed in a similar manner. The demand for water was based upon the geothermal power plant utilization case study (Part X). Based upon an analysis of water resources constraints, the total megawatts which could be developed at each KGRA were identified for a series of different alternative power conversion cycles and sources of water. The various conditions and the developable megawatts are shown in Section 2.2.

Figure I-1

LOCATION MAP OF EAST MESA, HEBER,
BRAWLEY, AND SALTON SEA KGRA
IN IMPERIAL VALLEY, CALIFORNIA

1.1 Surface Water Supply

Analysis of surface water resources in the Imperial Valley indicate the following:

- The Imperial Irrigation District (IID) has a vested right to control of surface water in the canal and waste drainage system in the Imperial Valley.
- Excluding water in the irrigation canals and the agricultural waste drainage system, surface water of suitable quality and quantity is not sufficient to meet the make-up water requirements for geothermal power plant requirements.
- The Alamo River outlet at the Salton Sea is a potential source of surface water which could be used for make-up water in a binary cycle plant or a flashed steam plant using an indirect contact condenser system.
- At current levels of water quality and temperature, the Alamo River outlet at the Salton Sea could provide up to 110,000 acre-feet per year of make-up water for binary cycle plants or flashed steam plants using an indirect contact condenser and the resource from the Salton Sea KGRA (this level of usage would still meet discharge requirements in terms of solids content and temperature).
- At the international border, the Alamo and New Rivers do not contain water of suitable quality to meet make-up water requirements for binary cycle plants or flashed steam plants using an indirect contact condenser.
- Assuming compatibility of the two fluids, water from the agricultural waste drainage system could be used to supplement the geothermal fluid to achieve 100% injection requirements.
- Extensive use of agricultural waste drain water could potentially impact the salinity and level of the Salton Sea.
- Use of water from the agricultural waste drainage system for make-up or injection purposes would require coordination and agreement with the Imperial Irrigation District and the California Regional Water Quality Control Board.
- Use of surface water from the irrigation canal system is limited to 75 MWe of net electrical output per geothermal resource area for a five-year period by the Geothermal Element of the Imperial County General Plan.

- An agreement for 5,000 acre-feet of water for five years has been finalized between IID and San Diego Gas and Electric for the Heber KGRA.
- Tentative agreements similar to the one for Heber have been developed for Brawley and East Mesa.
- The use of irrigation canal water is not considered a viable long-term source of make-up water for geothermal power plants.

1.2 Ground Water Supply

Analysis of ground water resources in Imperial County indicate the following:

- Outside of the agricultural production areas, four areas have been identified which contain groundwater of suitable quality and temperature for use as a source of make-up water for geothermal power plant development.
- These areas contain ground water which could be used in binary cycle or indirect contact condenser cooling systems in flashed steam geothermal power plants.
- The areas identified include two areas on the eastern side of the Valley, east of the East Highline Canal, and two on the western side, west of the Westside Main Canal.
- Total ground water in storage in the four identified areas is estimated to be approximately 31.9 million acre-feet in 1977.
- The ground water source surrounding the East Mesa KGRA contains about two-thirds of the total estimated groundwater in storage about 22.0 million acre-feet in 1977.
- The two ground water areas on the east side of the Valley receive an estimated recharge of 126,000 acre-feet/year, primarily as a result of seepage from the All American and Coachella Canals.
- Completion of the lining of the Coachella Canal would eliminate the recharge from this source.

- Areas west of the Westside Main Canal do not receive measurable recharge.
- These areas are approximately 20-25 miles away from the major geothermal resource areas.
- Although detailed engineering/economics studies have not been developed, the use of ground water for make-up water purposes for geothermal power plants located at East Mesa appears to be potentially feasible.
- Notwithstanding the availability of ground water in-storage, legal/institutional considerations to utilize this water are not clearly established.

1.3 Power Plant Water Requirements

Analysis of the current or planned operating practices for the various types of geothermal power plants indicate:

- Based on data developed in the case study, a 50 MWe geothermal power plant using a binary cycle will have the following make-up water requirements at each of the resource areas:

<u>Area</u>	<u>Annual Water Requirements*</u>
Heber	7,750 acre-feet
East Mesa	8,250 acre-feet
Salton Sea	3,500 acre-feet
Brawley	7,100 acre-feet

* Based on make-up water of 1,000 mg/l total dissolved solids and blow-down discharge of 4,000 ppm TDS.

- A flashed-steam cycle conversion process requiring water to replace the evaporative loss to achieve total injection of the geothermal fluid, will have the following make-up water requirements at each of the resource areas:

<u>Area</u>	<u>Annual Water Requirements*</u>
Heber	3,300 acre-feet
East Mesa	3,500 acre-feet
Salton Sea	1,600 acre-feet
Brawley	3,200 acre-feet

- A flashed-steam cycle conversion process using an indirect condenser will require make-up water to replace evaporative loss and blow-down; water requirements for a 50 MWe power plant at each resource area are estimated to be:

<u>Area</u>	<u>Annual Water Requirements*</u>
Heber	4,500 acre-feet
East Mesa	4,700 acre-feet
Salton Sea	2,200 acre-feet
Brawley	4,300 acre-feet

- Based on make-up water of 1,000 mg/l total dissolved solids and blow-down discharge of 4,000 ppm TDS.
- For planning purposes, based on a 30-year period, the total water required for a specific plant will be a function of on-line date of the plant and the power conversion cycle utilized.

2.0 CONCLUSIONS

Analysis of the availability of water resources and the geothermal power plant make-up water requirements provides a method for identifying constraints on power development in the Imperial Valley. This analysis of constraints is a function of four key factors:

- (a) estimated ultimate capacity of the geothermal reservoir
- (b) specific characteristics of the geothermal reservoir, primarily the resource temperature
- (c) type of power plant conversion cycle utilized
- (d) the scheduled on-line date of the power plants
- (e) blow-down discharge requirements

The interaction of these variables determines the quantity and quality of water demanded for geothermal development.

Contrasted to these variables which determine demand for water is the supply of water from both surface and ground sources. The available supply of water to meet the demand requirements is also a function of certain key factors: (a) quality of water resources required; (b) quantity of the water required; (c) location of the water resource relative to the geothermal resource area or power plant site; (d) blow-down discharge requirements, and (e) legal/institutional considerations relative to the use of any water resource identified.

To provide a basis of analysis of any constraints on geothermal development in the Imperial Valley, a series of analyses were conducted based on these key water requirement and availability factors. The analysis was developed to show best and worst case conditions and the intermediate conditions which could occur.

The implementation plans developed from interviews with utilities and producer/developers were used as a basis for projecting the various on-line dates for the power plants (see Task 1). The ultimate geothermal reservoir development is based on USGS, EPRI and JPL estimates for each of the four geothermal areas in Imperial Valley.

The data developed in the following analyses are based upon the case study. The data have been converted for analysis of general conditions, however, specific detail engineering specifications which differ from the case study may alter the water requirements.

2.1 Make-up Water Availability

To assess the availability of cooling water in the Imperial Valley, certain parameters for the make-up water were assumed. These assumptions permitted a systematic evaluation of all sources of surface and ground water. The critical factor in the assessment of the availability of cooling water was the method of disposal of discharge. Thus, the following restrictions were used:

- Blow-down would be discharged into the irrigation waste drain system.
- The blow-down discharged would meet the objectives delineated by the Regional Water Quality Control Board.
- Blow-down discharge average would not exceed an annual average of 4000 ppm of total dissolved solids (TDS).
- Blow-down discharges would not increase the water temperature in the agricultural waste drain system by more than 5°F.

The temperature of the outside water to be used was not considered to be a critical selection criteria since the design of the cooling tower determines the blow-down temperature. However, for analysis purposes, cooling water exceeding 100°F (37.8°C) was not considered to be suitable for geothermal power plant cooling.

The data presented in this report is based on 1977 figures since it represented a year of low rainfall and hence would show constraints.

2.1.1 Surface Water

2.1.1.1 Irrigation Canal Water

Irrigation canal water can be regarded as a source of excellent cooling water since it has an average TDS of generally less than 1,000 mg/l and an average annual temperature of less than 20°C. It is imported by IID in volumes on the order of 3 to 3.5 million acre-feet per year. However, the irrigation canal waters are appropriated by IID for agricultural irrigation purposes and are not specifically for use in geothermal energy development. Thus, use of canal water for geothermal power plant cooling purposes will require agreement with IID. Moreover, the Geothermal Element of Imperial County General Plan limits the use of fresh agricultural water to 75 MWe net electrical output for five years from any single Geothermal Resource area. The use of irrigation canal water for power plant cooling purposes could potentially displace future agricultural production. This source of make-up water is not considered a viable long-term alternative.

2.1.1.2 River Water

Inflow from the New River across the international boundary is not suitable for use as cooling water because the TDS exceeds 4,000 mg/l. Due to the mixing of other waters, outflow to the Salton Sea from the New River normally has a TDS of less than 3,600 mg/l and an average

temperature of less than 25°C. The available quantity at the Salton Sea outlet is at about .413 maf per year and .107 maf at the international border. Based on discharge requirements, however, only a limited quantity of this water can be used under conventional methods unless treatment before disposal is considered. If compatible with the geothermal fluid, this water could be used for injection purposes.

Inflow from the Alamo River across the international boundary is generally not suitable for geothermal power plant cooling having a TDS reading of generally less than 3,500 mg/l. In addition, it is available at a quantity of about only 1,400 acre-feet per year. Outflow from the Alamo River to the Salton Sea could be considered suitable for geothermal plant cooling with a TDS of less than 3,000 mg/l and temperature generally less than 25°C. The available quantity at the Salton Sea outlet is approximately .615 maf per year. Discharge requirements will, however, limit the suitable water to .110 maf per year.

Based on this analysis, the total river water suitable for geothermal power plant cooling is at about 110,000 acre-feet per year. At the Salton Sea outlet, however, the California Regional Water Quality Control Board (CRWQCB) is concerned about the blowdown discharge and the Salton Sea salinity problem. The following is an excerpt of CRWQCB work plan for the period 1976-1981.

"The Salton Sea is located in the geologic sink of an approximately 8,360 square mile watershed. The Sea has no drainage outlet, therefore water from the Sea is lost by evaporation, but the salts remain and accumulate in the Sea body. The total dissolved solids content (TDS) of Salton Sea is currently about 39,000 mg/l, and is increasing at an average rate of about 550 mg/l per year, caused predominantly by an estimated 4.5 million tons of salt per year entering the Sea with drainage waters. When the salinity reaches 40,000 mg/l, it is expected to have severe adverse effects on the Sea's valuable sport fishery. Above 40,000 mg/l TDS, it is likely that reproduction of corvina and other sport fishes will decline. Then, as the salinity continues to increase, the fishery will gradually or suddenly die out as the mature fish eventually succumb to the rising salinity. Other forms of water-oriented recreation and wildlife uses provided by the Sea will also become greatly diminished as the salinity increases.

Drainage waters are the predominant source of fresh water replenishment for Salton Sea. Approximately 99 percent of these drainage waters result from drainage of agricultural lands in Imperial and Coachella Valleys in California, and in the Mexicali Valley in Mexico, the latter being allowed by Treaty.

If the current inflows of drainage waters to the Salton Sea were stopped, evaporation alone would cause an increase of 7,600 mg/l TDS in one year, since 1.3 million acre-feet (20 percent of total Sea volume) evaporates per year. Therefore, to slow the rate of salinity increase in the Salton Sea, it is necessary to replace this annual volumetric loss."

If the discharge requirements are met, the use of 100,000 acre-feet of water from the Alamo River for geothermal power plant cooling purposes should affect the Salton Sea salinity or temperature. However, the extent of the impacts are not known at this time.

Water from the Salton Sea was not considered suitable for use in the currently-designed geothermal power plants unless treatment was accomplished.

2.1.2 Ground Water

The ground water system in the Imperial Valley can generally be subdivided into shallow aquifer and deep aquifer. The shallow aquifer is situated down to a maximum depth of about 2,000 feet below the land surface. This is the aquifer which has the potential to supply water suitable for geothermal power plant cooling.

Extensive data (both physical and chemical) have been collected on the shallow aquifer by various government agencies. However, no geohydrologic analysis on the delineation of ground water quality temperature, aquifer productivity and storage has been completed. Thus it was necessary to evaluate the shallow aquifer and delineate the quantity of ground water it contains and its suitability for geothermal power plant cooling.

2.1.2.1 Shallow Aquifer Assessment

The objective of the shallow aquifer assessment was to determine the volume of ground water in-storage which potentially would be available for geothermal power plant make-up water requirements. Initially, certain parameters were established as to the quality and temperature of the ground water which could be classified as suitable. Based on the findings of the case studies and the discharge requirements for blow-down into the drainage system of IID, certain parameters were chosen to assess the extent of the shallow aquifer. The parameters chosen were: (1) ground water containing less than 4000 mg/l TDS, and with (2) temperature less than 100°F (37.8°C), (3) minimum depth less than 1000 feet. In addition to these restrictions, the area between the West Side Main Canal and East Highline Canal was excluded because of the potential impact of land subsidence on the tile drain and irrigation canal system.

To fully develop the potential of the shallow aquifer, wells should penetrate at least 1,000 feet of the aquifer to produce a substantial quantity of water. Based on well logs and pumping test data done in the Imperial Valley (Loeltz, 1975), areas where aquifers exceeded 1,000 feet can be located. Copies of key well logs are included in Appendix F. Results of pump test data can be found in Table I-20.

2.1.2.2 Areas of Potential Ground Water Development

Four areas in the Imperial Valley were delineated and meet all the four characteristics as mentioned above. These areas are shown on Figure I-2. Area 1 is located near the southeast portion of the Imperial Valley, north of the All American Canal and east of the East Highline Canal. The eastern boundary was delineated based on the thickness of the aquifer. The bare spots within the area are the East Mesa, Border, and Dunes geothermal anomalies where the temperature of ground water to a depth of 1000 feet exceeds 100°F. Area 1 and Area 2 are separated by

Figure I-2
LOCATION MAP OF AREAS OF GROUNDWATER
SUITABLE FOR GEOTHERMAL PLANT COOLING

an area where the Glamis and another small geothermal anomaly are located. The East Mesa KGRA lies mostly within the southwest portion of this area. It is about 10 to 15 miles east of the Heber KGRA. This area is recharged by the Coachella, All American and East Highline canals.

Area 2 is located generally east of the Coachella Canal. The northern and eastern boundaries were delineated based on the thickness limitation of the aquifer. This area has been subjected to recharge by the Coachella Canal. The northern portion of this area is approximately 5 to 10 miles away from the Salton Sea KGRA and about 10 to 15 miles from the Brawley KGRA.

Area 3 is located in the San Felipe Creek area west of the West Side Main Canal and north of the Superstition Hill area. The boundary was delineated based on aquifer thickness limitations. It is separated from Area 4 because of the complicated geologic conditions at the Superstition Hill Area where the aquifer does not exist. This area is located about 10 to 15 miles from the Salton Sea KGRA and 20 to 25 miles from the Brawley KGRA. This area receives little recharge.

Area 4 is located south of Superstition Hill area. This area is generally called the West Mesa area. Most of the boundaries of this area were delineated based on aquifer thickness limitation. It is approximately 20 miles to the Heber, Brawley and Salton Sea KGRAs. This area also receives little recharge.

The representative data on ground water chemistry of these areas are included in Appendix E. The location of these wells can be found on Figure I-2. Individual ground water and temperature logs are also included in Appendix F.

The expected well yield of these areas was based on analysis of the specific capacity of wells previously tested in the areas. Most of the

wells tested were discharged at a rate of 1000 gpm with ease with generally less than 45 feet of drawdown. According to the USGS (Yuma, Arizona), wells which penetrate 1000 feet of aquifer in these general areas yield 2000 gpm with ease. The ground water quality of these areas in the shallow aquifer generally contain less than 4000 mg/l TDS and when produced from a composite thickness of 1000 feet, the TDS will generally be under 2500 mg/l. None of water chemistry analyses from these areas listed in Appendix E show a TDS value higher than 2500 mg/l. Also, composite temperature of ground water producing from a 1000 feet thickness is less than 35°C. Table I-1 shows the general characteristics of the shallow aquifer to a depth of 1000 feet in the four areas identified.

2.1.2.3 Estimate of Ground Water in Storage

The volume of ground water recoverable from the four selected areas to a depth of 1,000 feet in the shallow aquifer can be estimated by the following equation (Dutcher, 1973):

$$V = A b S_y$$

V = volume of groundwater in storage

A = surface area of aquifer

b = saturated sand thickness in aquifer

S_y = specific yield of aquifer

Specific yield can be defined by the percentage of water by volume that can be drained from a porous rock under gravity. Table I-2 shows the estimation of sand thickness and saturated thickness measured from individual well logs and water level readings in the four selected areas to a depth of 1000 feet.

For Area 1, the average saturated sand thickness to a depth of 1000 feet was estimated to be 650 feet which reflects a total volume of

TABLE I-1**GENERAL GEOHYDROLOGIC CHARACTERISTICS OF SHALLOW
AQUIFER AREAS SUITABLE FOR GEOTHERMAL PLANT
COOLING WATER DEVELOPMENT**

Area	Expected Well Yield		Total Dissolved Solids mg/l	Ground Water Temperature
	GPM	AF/YR		
1	> 2000	> 3200	< 2500	< 35°C
2	> 1000	> 1600	< 2500	< 35°C
3	> 1500	> 2400	< 2000	< 35°C
4	> 1500	> 2400	< 2500	< 30°C

Source: VTN Estimates, 1978.

TABLE I-2
AQUIFER SAND SATURATED THICKNESS DETERMINATION

Area	Well Owner Or Name	Approximate Thickness of Sandstone To A Depth of 1000 Feet	Approximate Thickness of Sandstone Above Static Water Level	Approximate Saturated Thickness of Sandstone To A Depth of 1000 Feet
1	LCRP11	606	24	582
1	LCRP18	360	28	332
1	LCRP12	943	40	903
1	LCRP6	734	51	683
1	RGW	947	191.5	755.5
2	SPC	548	154.5	393.5
3	TMJ	871	91	780
3	LCPR19	340	0	340
4	LCPR8	420	101	319

*Sand thickness values are interpreted from geophysical logs included in Appendix A

*Static water level readings adopted from Loeltz, 1975

Source: VTN Estimates, 1978.

ground water in storage to be 21.7 maf in 1966. For Area 2, the average saturated sand thickness was estimated to be 394 feet which reflects a total volume of ground water in storage to be 4.6 maf in 1966. For Area 3, the average saturated sand thickness was estimated to be 560 feet which reflects a total volume of ground water in storage to be 2.8 maf. For Area 4, the average saturated sand thickness was estimated to be 319 feet which reflects a total volume of groundwater in storage to be 1.4 maf. The total volume of groundwater at 1966 under these four areas in the shallow equifer to a depth of 1000 feet is estimated to be 30.6 maf. Table I-3 shows the estimated ground water in storage in the shallow aquifer.

2.1.2.4 Net Change in Ground Water Storage

Since the shallow ground water system is continuing to be subjected to recharge from the irrigation canals and other sources, the net change in ground water storage required determination. Analysis indicated Area 1 and Area 2 are subjected to recharge from the irrigation canals in the area. Based on data from IID, the canal seepage along the Coachella Canal which runs through both Area 1 and 2 was estimated to be approximately 104,000 acre-feet. Based on the equal length of the Coachella Canal that traverses the areas, it is assumed that about 52,000 acre-feet of recharge was contributed to each area. For Area 1, seepage loss from Drop 1 to the East Highline Canal was estimated to be 22,000 acre-feet in 1977.

It should be noted that Table I-3 estimations on groundwater in storage is for the year 1966. It is assumed that from 1967 to 1977, the shallow groundwater system was recharged at an annual rate of 74,000 acre-feet for Area 1 and 52,000 acre-feet for Area 2. Based on this analysis, the estimated ground water in-storage for 1977 was 31.9×10^6 acre-feet. Table I-4 shows the ground water in storage under the four selected areas for the years 1966 and 1977.

TABLE I-3

**ESTIMATION OF GROUND WATER IN STORAGE (1966) IN SHALLOW AQUIFER AT
SELECTED AREAS SUITABLE FOR GEOTHERMAL COOLING WATER DEVELOPMENT**

Location	Approximate Surface Area (Square Feet)	Approximate Average Thickness of Sandstone To A Depth of 1000 Feet	Assumed Value of Specific Yield*	Approximate Volume of Water in Storage in Sandstone To A Depth of 1000 Feet**	
				Gallons	Acre-Feet
AREA 1	9.699×10^9	651	.15	7.085×10^{12}	2.173×10^7
AREA 2	3.420×10^9	394	.15	1.510×10^{12}	4.632×10^6
AREA 3	1.440×10^9	560	.15	9.048×10^{11}	2.775×10^6
AREA 4	1.294×10^9	319	.15	4.631×10^{11}	1.421×10^6

*Taken from Dutcher, 1973.

**Volume of groundwater in storage equals to the product of surface area, sand thickness and specific yield.

Source: VTN Estimates, 1978.

TABLE I-4
ESTIMATE GROUND WATER IN STORAGE

	1966	1977
AREA 1	2.173×10^7	$2.154 \times 10^7^*$
AREA 2	4.632×10^6	$5.204 \times 10^6^{**}$
AREA 3	2.775×10^6	2.775×10^6
AREA 4	1.421×10^6	1.421×10^6
TOTAL	30.558×10^6	31.940×10^6

*Based on Annual Recharge of 74,000 Acre-Feet/Year.

** Based on Annual Recharge of 52,000 Acre-Feet/Year.

Source: VTN Estimates, 1978.

2.2 Developable MWe

2.2.1 Case A: Flashed Steam--Complete Injection Not Required

Flashed steam power plant conversion cycles using direct contact condensers and the steam condensate for cooling water purposes are the best case relative to water requirements. As shown by the case study analysis, under current operating practices geothermal power plants using this conversion cycle do not inject the total flow extracted from the geothermal reservoir. Moreover, this power conversion process provides its own source of cooling water and thus does not require an outside source of make-up water. Potentially, if all of the geothermal power plants to be developed in the Imperial Valley used this type of power conversion cycle, and complete injection of the geothermal fluid or its equivalent is not required, there would be no constraints on geothermal development as a result of make-up water requirements.

There are, however, several key considerations which would affect the use of this type of conversion cycle including: (a) geothermal reservoir characteristics, especially temperature and fluid constituents; (b) the potential problem of land subsidence, and (c) air pollution emission concerns, especially hydrogen sulfide (H_2S) emissions. If any one of these key considerations does not permit the use of steam condensate as the source of cooling water, an outside source of make-up water will be required. Figures I-3 and I-4 illustrate the developable MWe.

2.2.2 Case B: Flashed Steam--Complete Injection Required

If complete injection into the geothermal reservoir is required, flashed steam power plant conversion cycles using direct contact condensers and steam condensate, for cooling purposes would require an outside source of water to replace any evaporating losses from the

FIGURE I-3
DEVELOPABLE MWe

ASSUMPTIONS:

- A: FLASHED STEAM – ZERO MAKE-UP WATER**
- B: FLASHED STEAM – COMPLETE INJECTION, RIVER/AGRICULTURAL DRAIN WATER**
- C: FLASHED STEAM – INDIRECT CONTACT CONDENSER, CANAL WATER**
- D: FLASHED STEAM – INDIRECT CONTACT CONDENSER, GROUNDWATER**
- E: BINARY CYCLE – CANAL WATER**
- F: BINARY CYCLE – GROUNDWATER**
- G: BINARY CYCLE – RIVER/AGRICULTURAL DRAIN WATER**

FIGURE I-4
DEVELOPABLE MWe

ASSUMPTIONS:

- A: FLASHED STEAM – ZERO MAKE-UP WATER**
- B: FLASHED STEAM – COMPLETE INJECTION, RIVER/AGRICULTURAL DRAIN WATER**
- C: FLASHED STEAM – INDIRECT CONTACT CONDENSER, CANAL WATER**
- D: FLASHED STEAM – INDIRECT CONTACT CONDENSER, GROUNDWATER**
- E: BINARY CYCLE – CANAL WATER**
- F: BINARY CYCLE – GROUNDWATER**
- G: BINARY CYCLE – RIVER/AGRICULTURAL DRAIN WATER**

Source: VTN Estimates, 1978.

cooling process. As developed by the analysis of the case study, the outside water required in this process could not have a specific quality requirement. The purpose of outside water would be to supplement the geothermal fluid which was flashed into steam and eventually lost by evaporation through the cooling tower. Although the water to meet the complete injection required could be met by low quality water (i.e. high in total dissolved solids), the water used will have to be compatible with the geothermal fluid in order to minimize any potential problems in the injection system. Thus, the outside water used may require treatment prior to being used in the injection system. The extent and type of potential treatment is not clearly established at this time.

Notwithstanding this quality consideration, water from the river/agricultural drain system could potentially be used as a source of water for injection into the geothermal reservoir. Water from the New and Alamo Rivers and the agricultural drain system could potentially meet this requirement for injection purposes. Potentially, using water from the river/agricultural drain system would act to control the level of the Salton Sea since less water will be entering the Sea. Using river/agricultural drain water for injection purposes would, however, affect the quality of the Salton Sea itself by increasing its salinity. The use of water from these sources would depend upon agreement with the Imperial Irrigation District.

If agricultural drainage water could be used for purposes of injection into the geothermal reservoir for flashed steam cycle plants, the developable MWe for geothermal resource area would be constrained by the amount of water available in the river/agricultural drainage system. To develop constraints on developable MWe, potential injection water requirements for ultimate development of the geothermal resource area were estimated. Based upon the findings of the case study, this analysis indicated the requirements for injection purposes were: Heber, 66,700 acre-feet (af)/year; East Mesa, 35,100 af/year; Salton

Sea, 65,000 af/year, and Brawley, 63,200 af/year. Since the primary source of water for injection purposes would be the river/agricultural drainage system, the potential available water from this source was determined. Further, for estimation purposes, the river/agricultural drainage system nearest the geothermal area was assumed to be used as the source of the required water. Based on this analysis, the East Mesa area would be the only geothermal area with potential constraints on power development. Depending upon the amount of water from the Alamo River which could be used for injection purposes, the limit on developable MWe could potentially be as little as 20 MWe. This is based on a flow of 1,400 af/year for the Alamo River as it crosses the international border.

For Heber, the flow for the New River is 108,000 af/year at the international border. The New or Alamo Rivers could potentially be used by both the Salton Sea and Brawley areas since both rivers cross the KGRAs. The New River flow at the outlet to the Salton Sea is 413,000 af/year and 615,000 af/year for the Alamo River. Thus, the Heber, Salton Sea and Brawley areas could be developed to the ultimate estimated reservoir capacity if river/agricultural drain water could be used for injection purposes. A summary of the estimated water requirements and sources of water which is potentially available for injection purposes is shown in Table I-5.

2.2.3 Cases C and D: Flashed Steam--Air Pollution Emission Considerations

Potential air pollution emission considerations could also affect outside water requirements. As developed by the case study, a flashed steam conversion process system using an indirect contact condenser would require make-up water to replace the evaporative loss and blow-down effluent discharges. The make-up water required, however, would have certain quality requirements in order to meet the blow-down effluent discharge requirements and to minimize potential problems in the condenser system.

TABLE I-5
WATER REQUIREMENTS FOR INJECTION PURPOSES

Area	Ultimate Capacity (MWe)	Maximum Annual Requirements (AF)	Source/Flow (AF)
Heber	1,000 MWe	66,700 AF	New River/108,000 AF
East Mesa	500	35,100	Alamo River/1,400
Salton Sea	2,000	68,600	New River/413,000
Brawley	1,000	63,200	Alamo River/615,000

Source: VTN Estimates, 1978.

Based on this analysis, since the water river/agricultural drain system could not meet the water quality requirements, other sources of outside water would have to be utilized in this cooling system. If canal water is utilized in the cooling process, the Imperial County General Plan would potentially limit the developable power to 75 MWe of net electrical output per geothermal resource area for a five-year period (Case C, Figures I-3 and I-4).

Besides water from the canal system, there is the possibility of using ground water as a source of make-up water in this cooling process. As identified in Section 2.1.2, there are four areas of ground water in storage with water which could potentially meet the make-up water and blow-down discharge requirements. Although this ground water is in storage, its availability for use for geothermal power plant development requires further investigation and analysis for two primary reasons. First, the source of the recharge for the ground water on the eastern portion of the Valley is seepage from the All American and Coachella Canals. Thus, the institutional/legal issues concerning use of this ground water will have to be clearly established. Secondly, the engineering/ economic considerations related to the distribution of any ground water will require evaluation. Ground water distribution considerations would especially apply to the Heber, Salton Sea and Brawley areas. The East Mesa KGRA is surrounded by a source of ground water, thus distribution of the water should not be a major constraint to geothermal power plant development. Cost of acquisition and distribution of any ground water, regardless of location, will have to be such that the price of the electrical output produced is competitive with alternative sources of power generation.

Notwithstanding institutional/legal questions and engineering/economic considerations, as discussed in Section 2.1.2, ground water is available in sufficient quantity and quality to provide for development of each of the geothermal resource areas to their ultimate potential. If extensive distribution of the ground water cannot be provided on an

economic basis, the East Mesa geothermal area would, most likely, be the only field which could be developed to its ultimate capacity. The other geothermal areas, Heber, Salton Sea and Brawley, are up to 20 to 25 miles away from ground water sources, thus development would be constrained to the use of irrigation canal water. Table I-6 shows the water requirements for indirect condensers at each KGRA. Figures I-3 and I-4 show developable MWe for Case D.

2.2.4 Cases E, F and G: Binary Cycle Process

Binary cycle geothermal power plants would also require an outside source of make-up water for cooling purposes. Although not precisely the same, the cooling cycle is similar to the indirect contact cooling system, since a heat exchanger is utilized. The binary cooling system is, however, not cooling the steam condensate but is instead cooling the working fluid. The same make-up water and blow-down discharge requirements apply to binary cycle power plants as are applicable to flashed steam power plants using an indirect contact condenser cooling system. Table I-6 indicates the water requirements at each KGRA for binary cycle power plants.

Based on these considerations, if binary cycle geothermal power plants are developed and irrigation canal water is used, each geothermal area will be limited to 75 MWe of electrical output for a five year period (Case E, Figures I-3 and I-4).

As with flashed steam power plants, ground water could potentially also be used as a source of make-up water. If the distribution of the ground water can be accomplished on an economic basis (i.e., the electrical output will still be competitively priced when compared to alternative sources of power), then each of the geothermal areas can be developed to its estimated ultimate reservoir capability. Since the East Mesa area would, most likely, not require an extensive distribution, binary cycle plants could be used exclusively and still reach the

TABLE I-6

WATER REQUIREMENTS* FOR INDIRECT CONDENSERS AND BINARY CYCLE PROCESS

Area	Indirect Contact Condenser		Binary Cycle	
	1000 ppm	2500 ppm	1000 ppm	2500 ppm
Heber	1,467,000 AF	2,885,100 AF	2,518,800 AF	4,956,300 AF
East Mesa	962,300	1,892,500	1,708,410	3,492,050
Salton Sea	1,129,900	2,259,800	1,594,600	3,159,720
Brawley	1,666,800	3,314,000	2,784,600	5,588,800

*Total water required for 30-year period.

Note: Each total is based on on-line schedule from Task 1 through 1990;
after that 100 MWe per year added until ultimate capacity reached.

Source: VTN Estimates, 1978.

ultimate reservoir capability. The use of ground water for cooling purposes in the Heber and Brawley areas may, however, be constrained since distribution systems of up to 20 to 25 miles will be required to reach the potential power plant sites.

In addition to ground water as a source of cooling water for the Salton Sea area, water from the river/agricultural drain system could potentially be used. As shown in the case study, the high temperature of the geothermal resource at the Salton Sea allows the use of make-up water of high total dissolved solids content while still meeting the cooling and blow-down discharge requirements. Given this factor, water from the Alamo River outlet to the Salton Sea could potentially be used as a source of make-up water. Use of this water could potentially allow up to 1,650 MWe of electrical output at the Salton Sea KGRA using exclusively binary power plants. Due to the lower temperatures at the other resource areas, water from river/agricultural drainage systems would not be available in sufficient quantity to meet cooling and discharge requirements (Case G, Figures I-3 and I-4).

2.2.5 Non-KGRA Areas

Potential geothermal development projects have been identified in three non-KGRA areas, Westmoreland, North Salton Sea and South Brawley in the Imperial Valley (see Task 1). Notwithstanding these projects, specific data on resource characteristics, total ultimate reservoir capacity and exact location of the geothermal field have not, however, been fully established for these non-KGRA areas. Lacking these parameters, constraints on developable MWe due to the lack of water resources cannot be projected for these non-KGRA areas.

Based on the location of the identified potential projects, outside water constraints which are applicable to the Brawley and Salton Sea area would also be in effect at the non-KGRA locations. Further data on the location, extent and characteristics of the geothermal resources

will be required before constraints on development due to water requirements could be established.

2.3 Procurement Specifications

Data on water resources in the Imperial Valley were sufficient to conduct a complete assessment, thus procurement specifications are not required.

3.0 RECOMMENDATIONS

3.1 Initiatives and Activities

3.1.1 Federal

At the federal level, the primary recommendations for further analysis relative to water resources in the Imperial Valley are:

- Determine the legal/institutional considerations concerning the use of ground water for geothermal power plant development in the Imperial Valley. The position of the Imperial Irrigation District and the Coachella Valley Irrigation District relative to the use of ground water near the All American and Coachella Canals needs to be established. If access to this water is to be limited, a timely determination should be made in order to provide developers and utilities a basis for developing plans for sources of power plant make-up water.
- Determine the engineering/economic aspects of ground water pumping and distribution. The key factor in this analysis will be to determine the engineering feasibility of distribution and its related cost in terms of the sales price of the power developed. The final price of electrical output from geothermal plants will have to be competitive with other energy sources.
- If complete injection is not required, determine the possibility of alternative methods of blow-down effluent discharge disposal. One of the key parameters in determining the make-up water quality and quantity requirements is the quality of blow-down effluent discharged. At a given resource temperature, if the blow-down effluent discharge requirements are lowered (i.e., water of higher solids content and temperature), the make-up water required in terms of both quality and quantity would be lowered. Thus, the sources and quantity of make-up water would be expanded.
- Determine the subsidence potential for the Imperial Valley if the geothermal fluid is not completely injected into the reservoir. If subsidence of land in the area of geothermal development is not a consideration, potentially an outside source of water would not be required; thus there would be "zero" water needs for flashed steam power plants using direct contact condensate for cooling purposes.

3.1.2 State

Recommended initiatives at the state level are:

- Coordinate any water resource investigations with the federal level in order to ensure the inclusion of specific state concerns
- Initiate review of discharge requirements relative to disposal of cooling tower effluent in the Salton Sea. Discharge requirements lower than the present standards could potentially reduce the quantity and quality of make-up water required. The Regional Water Quality Control Board and potentially the Department of Fish and Game would be major agencies involved in this effort.
- Determine flow rates at various strategic points in the agricultural drain system. Due to the importance of this source of water, this data would result in the ability to determine alternative power plant locations within a geothermal field.
- Determine the future role of the Salton Sea as an agricultural waste water disposal site or a recreational site.

3.1.3 Counties and Local

Initiatives and activities at the county level are:

- Assume a lead role in determination of the routing of any ground water distribution system. Coordination in the planning of any water distribution system with developers and utilities should, most likely, be done at the county level. Areas of potential constraints should be identified in order to incorporate local concerns.
- Review the requirement for total injection of geothermal fluids. Easing this requirement would potentially allow flashed steam plants to use condensate for cooling purposes, thus not requiring a source of outside water to replace evaporative loads.

3.2 Site-Specific Considerations

3.2.1 Ground Water Considerations

Use of ground water for geothermal power plant cooling purposes in the Imperial Valley is a key site-specific consideration. Access to the use of agricultural canal water is limited by Imperial County policy. Water from the river/agricultural drain system is a potential source of cooling and injection water for power plants. The use of this water for injection purposes would apply to all four of the geothermal sites in the Imperial Valley. The use of water from the river/agricultural drain system for make-up water purposes in binary cycle power plants is limited to the Salton Sea site.

With limited use of surface water for geothermal power plant development in the Imperial Valley, the alternative consideration is to utilize ground water resources. Since ground water sources are available which meet specific quantity and quality criteria, this is the primary alternative method of supplying make-up water. Although an analysis of pumping and distribution factors must still be considered, ground water could be used to develop the estimated ultimate geothermal resource capacity at each resource area under worst case conditions. The use of ground water at the East Mesa site appears to be the most promising since the ground water storage area surrounds the geothermal resource itself.

3.2.2 Water Distribution Site Considerations

Distribution of any available ground water is a major site-specific consideration. The geothermal sites are up to 20 to 25 miles in distance from the ground water areas. Potentially economic distribution of ground water would not be achieved if any extensive distribution system required construction. As an alternative site-specific consideration, existing agricultural canal distribution systems could

be utilized for the distribution of ground water to the geothermal development areas as long as it was compatible with the existing water. Ground water could be added or traded within the existing distribution system to provide make-up water for geothermal power plants. The use of this system would require careful consideration in order to minimize the impact on agricultural production.

3.2.3 Trade-Off of Water and Power

Since most of the electrical output from the Imperial Valley will be used outside of the Valley, and since make-up water will be required to develop the geothermal resources, potentially a trade-off of power and water could be developed. Areas requiring power would have to be willing to trade their required power for water for power plant cooling purposes. This would especially apply to the Los Angeles area where water from the Colorado River could be traded for electrical output from the Imperial Valley.

3.2.4 Salton Sea Water

Water from the Salton Sea was not considered in this analysis since it did not meet quality requirements for make-up water under current or proposed power plant designs. Potentially, if treated to meet specific plant design requirements, water from the Salton Sea could be used as a source of make-up water. Salton Sea water in the cooling process would, however, most likely be limited to the Salton Sea geothermal area. Since this is estimated to be the largest geothermal reservoir with the highest electrical output potential, the development cost of any water treatment system could be allocated over a large number of plants. Thus, per unit cost for any water treatment system would be lower than for a smaller geothermal area.

4.0 TECHNICAL DISCUSSION

4.1 Methodology

A general method of approach was established to accomplish the major objectives of the study. The initial step of this methodology was to determine the objectives of the study. A comprehensive literature search was conducted to collect all published water resources literature required for the evaluation. Sources of data were various government agencies, institutions, and private organizations. A systematic literature review by technical key words was then conducted. Field investigations were then conducted among these groups to ascertain unpublished data and reports and also to confirm findings of previously published materials. A water budget balance was calculated for all the major water resources elements in the area.

For surface water, major surface water bodies were identified, their physical and chemical characteristics evaluated, and their capacities determined based on these evaluations.

Once the water availability was determined, cooling water requirements by quantity and quality based on case studies were determined. The water resources in the area were then classified by quantity and quality in accordance with the cooling water criteria. Finally, based on these evaluations, the geothermal energy growth with respect to cooling water availability was determined.

Figure I-5 indicates the major steps of the methodology.

4.2 Survey of Existing Information

The purpose of the literature search is to screen published reports and materials that are pertinent to the water resources evaluation. The initial step

FIGURE I-5

FLOW DIAGRAM OF METHOD OF APPROACH

of this literature search was to contact various government agencies and private organizations to collect the required data.

All the literature collected are recorded on card catalogue under a specific format. For example,

Author: O. J. Loeltz, et al.
Report Title: Geohydrologic Reconnaissance of the Imperial Valley, California
Source: USGS Professional Paper 486-K
Date or Year of Publication: 1975
Index Number: L3-I

The index number identifies the first alphabet of the principal author's last name, the number of publication listed under the alphabet, and the study area of concern. The letter I indicates Imperial Valley scenarios. Each report is then labeled by the index number.

Appendix A contains a listing of all pertinent literature collected for this study area with the appropriate index numbers. Notation of figure, table and page number of the report relative to the specific key word were recorded during the review (see Appendix B).

During the literature review process, twelve key data sources were identified and were used to provide a major input into the water resources evaluation of Imperial Valley, California. They are listed as follows:

California Department of Water Resources
1970 "Geothermal Wastes and the Water Resources of the Salton Sea area." Bulletin No. 143-7, Sacramento.

Dutcher, L. C., W. F. Hardt and W. R. Moyle, Jr.
1973 "Preliminary appraisal of ground water in storage with reference to geothermal resources in the Imperial Valley area, California." Prepared in cooperation with the U.S. Bureau of Reclamation, U.S.G.S Circular 649.

Energy Research and Development Administration

1977 "Environmental Impact Assessment for CU I Venture application for Geothermal Loan Guaranty."

Hardt, W. F., J. J. French

1976 "Selected data on Water Wells, Geothermal Wells, and Oil Test in Imperial Valley, California." U.S.G.S. Open File Report, July. Menlo Park, California.

Hely, A. G. and E. L. Peck

1964 "Precipitation, runoff and water loss in the lower Colorado River-Salton Sea area." p. B1-B16. 486-B

Hely, A. G., G. H. Hughes and B. Irelong

1966 "Hydrologic regimen of Salton Sea, California." Geologic Survey Professional Paper, 486-C. U.S. Government Printing Office, Washington, D.C.

Hely, A. G.

1969 "Lower Colorado River water supply--its magnitude and distribution." U.S.G.S. Professional Paper 486-D.

Imperial Irrigation District

1976 Water Report.

Layton, David and Donald Ermak

1976 "A description of Imperial Valley, California, for the assessment of impacts of geothermal energy development". University of California, Lawrence Livermore Laboratory.

Loeltz, O. J., et al.

1975 "Geohydrologic reconnaissance of the Imperial Valley, California." Geological Survey Professional Paper, 486-K.

McDonald, C. D. and O. J. Loeltz

1976 "Water resources of lower Colorado River--Salton Sea area as of 1971. Summary report." U.S.G.S. Professional Paper 486-A.

VTN Consolidated, Inc.

1978 Environmental Impact Report, Heber Geothermal Demonstration Project.

4.3 Location of Study Area

The East Mesa, Heber, Brawley and Salton Sea KGRAS are located in the Imperial Valley of California within Imperial County (see Figure I-1). The actual study area was delineated as a function of the hydrologic considerations and availability of data rather than on a political or jurisdictional boundary. Although some of the data in the Imperial Valley may be sparse, it is generally adequate for evaluation purposes.

4.4 Surface Water

4.4.1 Hydrologic Environments

The Imperial Valley watershed is an area of 1,800 square miles of which 75% is in California, with the remainder in Baja California, Mexico. Mountain ranges that are roughly parallel to the Pacific Coast form the drainage divide between the southern coastal basin in California and the southern part of the Great Basin, of which the Imperial Valley watershed is a part. The whole watershed dips toward the northwest with the Salton Sea shoreline as the Imperial Valley's north boundary.

The main drainage courses consist of the New and Alamo Rivers which carry most of the Valley runoff, irrigation return water, and municipal and domestic wastewater. More than 30 minor channels account for about 10% of the annual surface runoff (Hely, Hughes and Irelan, 1966).

Both the New and Alamo Rivers originate in Mexico. The Alamo River assumes a northwestern direction along Holtville and Calipatria and discharges into the Salton Sea, southwest of the City of Niland. The New River flows northwesterly from Calexico to Seeley, then turns northeast to Brawley. North of Brawley, the New River again resumes its northwestern direction into the Salton Sea.

The New River rises about 15 miles below the international border, and flows 65 miles into the Salton Sea, draining the west side of the Imperial Valley. The river drops from sea level at the international border to 229 feet below sea level at the Salton Sea, a slope of about five feet per mile (VTN, 1977).

The Imperial Valley has a desert climate with relative humidity on a monthly average of about 30% and annual temperature of 72°F. The sun shines about 90% of the days. Air masses from the Gulf of Mexico in summer and from the Pacific in winter influence precipitation in the Imperial Valley. Over a period of 64 years, the Imperial Valley has averaged about three inches of precipitation annually.

For this region, most of the precipitation occurs in summer (August to October) and winter (December to February). The summer accounts for 36% of the annual 2.81 inches of rainfall, while the winter accounts for 42%. June is the driest month, having zero inches of rainfall. The total rainfall of May, June and July is only 0.1 inches, about 3.5% of the annual average. The monthly precipitation distribution over the last 64 years and the monthly maximum precipitation above two inches has been listed in Appendix B.

The annual average temperature in the Imperial Valley is 72.4°F with a peak in July (91°F), and troughs in December and January (55 and 54°F). The Salton Sea and irrigated areas act to stabilize temperature variations. Appendix B shows the temperature profile for the Imperial Valley.

There is good correlation between the water and air temperature fluctuations. The relation between seasonal patterns of water temperature and of air temperature enable estimation of water temperatures within a few degrees, if the air temperature is known. Appendix D shows air and water temperatures of the Salton Sea.

Relative humidity is a function of temperature and precipitation. It correlates positively with precipitation and negatively with temperature. The lowest relative humidity occurs from May to July, with June having the lowest due to the lack of rainfall. Even though the temperature is higher than June during the months of July, August and September, the occurrence of precipitation raises the humidity levels during these months higher than that of June. Appendix D shows a humidity profile for Imperial Valley.

The annual pan-evaporation is about 110 inches in Imperial Valley. The potential evaporation of June, July and August, accounts for 40% of the annual mean. The hot and dry air of the Imperial Valley promote a higher rate of evaporation. Since a pan-evaporation measurement is not an actual rate of evapotranspiration, it must be corrected by use of pan-coefficient. According to previous studies, a pan-coefficient of 0.69 approximates the actual rate evapotranspiration in the Imperial Valley. (Hely, Hughes and Irelan, 1966). Pan evaporation data are shown in Appendix D.

Runoff is a function of rainfall volume and intensity, antecedent soil moisture content, infiltration rate, vegetation cover and other soil characteristics. Natural runoff is very minimal in the Imperial Valley because the low annual rainfall of 3 inches, and the very high absorption rate of water by the soil.

All of the streams, besides the New and the Alamo Rivers, are ephemeral. The invading tropical storms and high intensity convection storms will gender surface runoff. During most of the year, the streambeds in Imperial Valley are dry. Annual runoff data for the New and Alamo Rivers are listed in Tables I-11 and I-12, and are discussed in Section 4.1.2.

4.4.2 Surface Water System

The significant surface water system in the Imperial Valley is composed of five portions: 1) the imported water from the Colorado River; 2) the irrigation return water; 3) the municipal wastewater; 4) the New and Alamo Rivers, and 5) the Salton Sea.

4.4.2.1 Imported Water from the Lower Colorado River

The Imperial Irrigation District (IID) annually transports an average of three million acre-feet of water from the Colorado River into the Imperial Valley. The water is diverted at Imperial Dam into the All-American Canal which flows westerly along the California side of the international border. Several main canals, the Coachella, the East High Line, the Central Main, and the West Side Main, branch out northward from the main trunk of the All-American Canal and bring water into the Imperial and Coachella Valleys (see Figure I-6). IID extends its services by lateral canals throughout the Valley, providing water for agricultural, industrial and municipal uses. A similar network of drainage canals drains the water from the Valley into the New and Alamo Rivers. Part of the agricultural drain water is directly discharged into the Salton Sea. (See Figure I-7).

In 1977, 4.536 million acre-feet (maf) of water was diverted from the Colorado River to the All-American Canal. Part of this water was delivered to the Yuma Project Area and other small irrigation areas, and some of the water was lost through canal seepage and evaporation.

At Drop 1, 0.494 maf was delivered to the Coachella Canal, about 15.5% of the total water received at the head of Drop 1. The net discharge at Drop 1 to IID was 2.693 maf, 84.5% of the total received at the head of Drop 1.

Figure I-6
LOCATION OF RIVERS AND CANALS
IN THE IMPERIAL VALLEY, CALIFORNIA

I-45

Source: IID 1978

FIGURE I-7
INFLOWS AND OUTFLOWS OF THE IID, 1962-1977

Within the Imperial Valley, the first main canal is the East High Line, which extends 50 miles north from the border through a portion of the Valley. This canal diverted 1.157 maf, about 43% of the IID's allocation at Drop 1, in 1977. The second canal, the Central Main, diverts water to the central area bordered by the New and Alamo Rivers. This diversion, comprising about 0.819 maf in 1977, is 30.4% of the IID total. The third canal, the West Side Main, conveyed 0.677 maf of water to the Valley west of the New River. The west side main canal accounts for 25% of the total flow of IID water. (See Table I-7)

The loss along the All-American Canal was 40,276 acre-feet from Drop 1 to the West Side Main, about 1.5% of the total. The total canal loss was .256 maf in 1977; about 60% of this loss occurred from Pilot Knob to IID's irrigation divisions, and 40% of the loss occurred in the canals between divisions and the served customers. IID has introduced a thirteen-point water conservation program, which has created significant impact upon reducing water loss (McGlocklin, 1978). From 1975 to 1977, the total canal loss dropped from 0.336 maf to 0.309 maf to 0.256 maf, a difference of 80,000 acre-feet within three years.

In addition to the All-American Canal, losses also occur along the Coachella Canal. The transmission loss was 0.112 maf from Imperial Dam to the 6A check. The Coachella Canal is not lined with concrete or any other waterproof material. Hence, the percolation loss is .120 maf annually. To prevent these losses, there is a plan to line the Coachella Canal over the next two years (Layton, 1978).

Through the three main canals, IID delivers water to each irrigation division; individual customers are then serviced through lateral canals throughout the Valley floor. These lateral canals are spaced about one mile or less apart. IID operates about 1,650 miles of irrigation canals.

TABLE I-7

**WATER DIVERSION, DISTRIBUTION AND LOSSES,
IMPERIAL IRRIGATION DISTRICT 1975-1977**

	1975		1976		1977	
	Acre-Feet	Cubic-Hectometers	Acre-Feet	Cubic-Hectometers	Acre-Feet	Cubic-Hectometers
Diversion at Imperial Dam to All American Canal	4,953,515	6,110	4,696,353	5,792	4,535,548	5,594
Diversion from Drop 1 to Coachella Canal	557,474	687	505,733	624	493,546	609
Loss - Coachella Canal from Imperial Dam to 6A check	127,786	158	128,789	159	112,285	138
Diversion from Station 60 to IID (p. 22) (Drop No. 1)	3,100,151	3,824	2,889,855	3,564	2,782,357	3,432
Losses to Drop No. 1	98,944	122	106,225	131	89,327	110
Net Discharge at Drop No. 1 (p. 15)	3,001,207	3,702	2,783,630	3,433	2,693,030	3,326
Diversion to East High Line (EHL) Check	1,281,832	1,581	1,198,953	1,479	1,156,624	1,427
Losses from Drop No. 1 to EHL	58,555	72	32,543	40	22,293	27
Discharge Below EHL to Central Main Canal (CM)	1,660,820	2,048	1,552,134	1,914	1,514,113	1,867
Losses from EHL to CM	6,848	8	9,629	12	11,974	15
Diversion to CM Check	906,893	1,122	842,272	1,039	819,283	1,010
Discharge Below CM to West Side Main (WSM)	747,079	921	700,213	864	682,856	842
Losses from CM to WSM	1,698	2	9,876	12	6,009	7
Diversion to WSM Check	745,381	919	690,357	851	676,847	835
Canal Loss After Delivered to Divisions	130,246	161	128,047	158	103,742	128
Canal Loss Below Pilot Knob to Divisions	205,872	254	181,214	223	152,553	188
Total Canal Loss	336,118	415	309,261	381	256,295	316

Sources: IID, 1977 & 1978

The annual diversion received by IID is relatively stable; the annual average was about 2.857 maf from 1954 to 1977. IID is guaranteed at least 2.6 maf of water per year delivery in the future (McGlocklin, 1978). The Lower Colorado River water is appropriated by three states, California, Arizona, Nevada and Mexico. By treaty and agreements, the total appropriated Colorado River water is 9.0 maf annually. The Rio Grande, Colorado and Tijuana Treaty (Witmer, 1956), guarantees 1.5 maf annually to Mexico. The U.S. Supreme (1964) decreed that 2.8 maf for use in Arizona, 4.4 maf for use in California, and 0.3 maf for use in Nevada.

Since the actual flow of the Colorado River is about 8.0 maf, the water has been over-appropriated. Currently, California uses more water than the treaty allotted because the upper states (Wyoming, Utah, Colorado and New Mexico) and Arizona have not fully developed their water program. When the Central Arizona Project is completed it will shift 1.2 maf of water annually to Phoenix and Tucson. California may experience a shortage of water under these conditions. A comprehensive study of the Lower Colorado River water supply was made by Hely (1969).

Water in the canals is generally the same quality throughout the entire Imperial Valley (McGlocklin, 1978). Based on a comprehensive quality monitoring study performed by the Lawrence Livermore Laboratory, the average canal quality is terms of total dissolved solids (TDS) is 992 ppm. The major contributors to the TDS reading are sodium (17%), chloride (17%), sulfate (38%), bicarbonate (14%) and calcium (9%). The water is slightly alkaline at a pH of 8.0. Table I-8 shows average TDS concentration in Imperial Valley.

Since the Colorado River is the source of virtually all irrigation, municipal and industrial water in Imperial Valley, the quality of its water at Imperial Dam is a major factor in water resources management in the Valley. Of particular concern in recent years has been the deteriorating quality of the water delivered to the Valley. Since 1948,

TABLE I-8

AVERAGE CONCENTRATIONS IN IMPERIAL VALLEY WATERS

<u>Ion</u>	<u>Canals</u>	<u>Drains</u>	<u>Sumps</u>	<u>Rivers</u>	<u>Salton Sea</u>
Na	166	678	1260	825	10600
K	6.5	21	65	33	195
Ca	93	266	829	218	850
Mg	35	125	286	117	1200
Cl	169	840	2930	1290	14730
SO ₄	375	1242	2060	913	8100
CO ₃	13	2.5	2.5	2.5	63
HCO ₃	135	276	365	216	143
TDS	992	3514	8770	3740	38600
pH	8.0	7.8	6.9	7.6	8.8
Ag	.007	.018	.023	.005	.07
As	.050	.053	.103	.011	.01
B	.236	.871	2.500	1.260	6.80
Ba	.092	.129	.489	.142	.07
Cd	.002	.011	.013	.005	.05
Cu	.042	.017	.308	.008	.08
F	.451	.516	.177	.679	1.10
Fe	.211	.164	.328	.049	.24
Hg	.001	.007	.005	.005	.0006
I, I ₂	.087	.401	2.270	.590	3.20
Mn	.084	.442	11.300	.239	.08
Ni	.010	.025	.078	.015	.20
Pb	.013	.021	.183	.010	.10
Rb	.008	.043	.096	.089	.12
Se	.003	.010	.012	.005	.02
Sr	1.540	4.000	11.100	3.770	13.50
Zn	.030	.057	1.19	.025	.03

*All values are in mg/l

Source: Pimentel, 1978

the Colorado River has shown an increasing trend of salinity. Table I-9 summarizes water quality at Imperial Dam.

This trend is caused by discharged irrigation return water from the irrigation lands above Imperial Dam. Currently the total dissolved solids at Imperial Dam is 860 ppm. The prime constituents contributing to the total dissolved solids are calcium, sodium, bicarbonate, sulfate and chloride. Appendix D shows the historical trends of salinity at Imperial Dam.

Irelan (1971) pointed out that the salinity of water in the Colorado River at Imperial Dam has increased moderately in recent years, but but it is still satisfactory for public supply and for continued irrigation if provision is made to prevent accumulation of salts in the soil.

4.4.2.2 Irrigation Return Water

The Imperial Irrigation District operates approximately 1,400 miles of drains canals throughout the Imperial Valley. Tile drainage systems installed beneath most of the Valley's irrigated fields capture the percolating irrigation water four feet or more below the ground surface, discharging it to nearby drains. Generally, drains canals in the west part of the Valley empty in the New River, while those in the east discharge into the Alamo River. A small number of drains canals discharge directly into the Salton Sea (VTN, 1977).

Irrigation return water is composed of salt-leaching and tail water. To avoid the detrimental effect of salt build-up on plants, a large quantity of water has been applied to leach the salts down below the root zone, and prevent salt rise back to the surface by means of the capillary force and diffusion. Some of this tile drain water is collected in sumps and later pumped into the drainage system. The tail water is the part of irrigation water flowing over the fields into

TABLE I-9
WATER QUALITY DATA
COLORADO RIVER ABOVE IMPERIAL DAM
OCTOBER 1975 - SEPTEMBER 1976

<u>Parameters</u>	<u>Range of Analyses</u>	<u>Mode</u>
Na	120-180	145
SO ₄	330-390	330
Cl	102-139	
Kjeldahl-N	.3-.54	.45
Total P	.00-.17	.03
Conductivity (micromhos)	1220-1570	1300
pH	7.6-8.2	8.2
Turbidity (NTU)	1-11	
Fecal Coliform (MPN/100ml)	12-70	
Streptococci (MPN/100ml)	10-120	
Dissolved oxygen	7.6-9.5	9

*Dimension in mg/l except where specified

Source: U.S.G.S. Water Resources Data for California, 1976

drains. The mixing of these waters may also occur in both the Alamo River and New River water not consumed by crops eventually flows to the Salton Sea (see Table I-10).

The quality of irrigation return water is different from the imported canal water. The salinity of a tile drain sump is about nine times that of the canal water. The total dissolved solids is about 8,770 ppm in the sump. The chlorine-sulfate ratio (Cl/SO_4) indicates the difference between sump water and canal water. For canal water, the ratio is always less than one, while for the sump water it is always higher than one.

The agricultural drainage water is the mixture of the sump water and the tail water. Hence, the salinity of the drain water is 2.5 times less than that of the sump. The average drain water has 3,514 ppm total dissolved solids, and sulfate is still dominant over chlorine, 1,242 ppm over 840 ppm. The drain water is slightly alkaline, with a pH value close to 7.8. The temperature of the drain water has increased from 65°F for irrigation water to 71°F for drain water.

The California State Water Quality Control Board has set an objective goal to curb waste water discharge in the Imperial Valley. The objective is for water not to exceed 4,000 ppm of the total dissolved solids (Swajjian, 1977). However, the agricultural return water is exempted from this restriction. The Control Board also prohibits the discharge of water which will increase the natural water temperature by 5°F.

4.4.2.3 Municipal Wastewater

The cities and towns in Imperial County have their water supplied through IID. Currently, IID furnishes about 24,000 acre-feet of water for domestic and industrial use within its service area. About 12,000 acre feet of the water is consumptively used, and half is discharged

TABLE I-10
TOTAL INFLOW TO SALTON SEA

ACRE-FEET

Year	Total Inflow to Salton Sea From New River & Alamo River	Inflow to Salton Sea From Coachella	Total Inflow to Salton Sea
1963	1,294,891	133,330	1,428,221
1964	1,012,074	120,940	1,133,014
1965	996,099	136,580	1,132,679
1966	1,109,188	130,760	1,239,948
1967	1,126,425	128,950	1,255,375
1968	1,108,515	135,670	1,244,185
1969	1,067,546	141,780	1,209,326
1970	1,121,819	129,720	1,251,539
1971	1,201,362	138,060	1,339,422
1972	1,176,137	148,020	1,324,157
1973	1,183,944	156,080	1,340,024
1974	1,236,558	151,680	1,388,238
1975	1,229,627	172,400	1,402,027
1976	1,188,952	174,541	1,363,493
1977	1,129,929	158,831	1,288,760

Source: IID, 1978.

into the New and Alamo Rivers, or put into evaporation and infiltration ponds.

The City of El Centro discharges 2.7 million gallons per day (MGD) (about 3,024 acre-feet per year) of wastewater into the Central Drain, which empties into the Alamo River. The City of Brawley discharges 1.38 MGD into the New River. The City of Calexico discharges 0.65 MGD into the New River. The total discharge of the municipal and industrial wastewater in the Imperial Valley is about 9.665 MGD, 10.814 acre feet of which 9.366 MGD is discharged into the drainage system and .3 MGD is either evaporated, infiltrated or irrigated. This discharge occurs throughout the entire Valley. Appendix D indicates the discharge of municipal and industrial wastewater in the Imperial Valley.

4.4.2.4 The New and Alamo Rivers

The New and Alamo Rivers, the main drainage courses of the Imperial Valley, carry surface runoff, agricultural return water, and municipal and industrial wastewater from Imperial Valley and Mexico into the Salton Sea.

Most of the flow in the New and Alamo Rivers is sustained by the agricultural return water. Natural surface runoff is insignificant in the Imperial and Mexicali Valleys except during a tropical thunderstorm. Measurements over a 17-year period show that the amount of water entering the United States via the Alamo River is quite small when compared with that of the New River, 1,570 versus 112,308 acre-feet per year. The New River flow is considerably greater because it conveys municipal, industrial and agricultural wastewater from the Mexicali area. However, at the Salton Sea outlet, the flow at the Alamo River is 1.54 times greater than that of the New River. Table I-11 shows annual runoff for the New River. Table I-12 indicates runoff data for the Alamo River.

TABLE I-11
ANNUAL RUNOFF OF NEW RIVER

<u>Year</u>	<u>International Border</u>		<u>Near Salton Sea Outlet</u>	
	<u>Acre-Feet</u>	<u>Cubic Hectometers</u>	<u>Acre-Feet</u>	<u>Cubic Hectometers</u>
1961	115,031	142	436,967	539
1962	132,179	163	455,330	562
1963	138,906	171	477,479	589
1964	145,087	179	365,857	451
1965	111,339	137	357,747	441
1966	102,958	127	383,469	473
1967	96,899	119	383,211	473
1968	106,019	131	384,078	474
1969	103,312	127	375,449	463
1970	99,671	123	390,487	482
1971	107,281	132	422,995	522
1972	111,165	137	418,063	516
1973	117,160	144	428,639	529
1974	111,839	138	436,575	538
1975	99,791	123	434,507	536
1976	102,888	127	435,111	537
1977	107,713	133	412,978	509
17-Year Average	112,308	138	411,702	508
Standard Deviation	13,520	16.67	32,690	40.32
Coefficient of Variation	12.04%		7.94%	

Source: Bradley, 1978

TABLE I-12
ANNUAL RUNOFF OF ALAMO RIVER

<u>Year</u>	<u>International Border</u>		<u>Near Salton Sea Outlet</u>	
	<u>Acre-Feet</u>	<u>Cubic Hectometers</u>	<u>Acre-Feet</u>	<u>Cubic Hectometers</u>
1961	1,795	2.21	675,576	833
1962	1,705	2.10	681,100	840
1963	2,158	2.66	723,765	893
1964	1,834	2.26	563,557	695
1965	1,798	2.22	535,096	660
1966	1,545	1.91	610,745	753
1967	1,556	1.92	621,091	766
1968	1,469	1.81	611,089	754
1969	1,595	1.97	592,664	731
1970	1,645	2.03	619,018	763
1971	1,510	1.86	671,770	828
1972	1,435	1.77	638,743	788
1973	1,370	1.69	638,902	788
1974	1,227	1.51	682,320	842
1975	1,568	1.93	682,345	842
1976	1,071	1.32	638,917	788
1977	1,419	1.75	615,009	758
17-Year Average	1,570	1.94	635,394	784
Standard Deviation	247	0.30	46,287	57.09
Coefficient of Variation	15.73%		7.28%	

Source: Bradley, 1978

Since the municipal and agricultural water supply are quite stable from year to year in the Imperial Valley, the flow regime in the New and Alamo Rivers do not vary much.

During the period of uncontrolled diversion, the level of Salton Sea rose to the extent that water covered more than 500 square miles and was more than 80 feet deep. During the next 12 years, the water level receded 55 feet. Because of the increasing flow of irrigation return water and waste disposal from Mexico, the trend reversed about 1925 and was generally been upward from that time until today. Appendix D shows historical elevations of the Salton Sea.

For the year 1977, the total Salton Sea volume was seven million acre-feet. Appendix D shows the relationship between water surface level and volume of water in the Salton Sea. Appendix D also shows the monthly pan evaporation measured around the Salton Sea. Table I-13 shows water balance estimates for the Salton Sea for 1977.

Hartley (1978) mentioned that during past five to six years, home construction has been progressing in Mexicali. The wastewater trends will increase if the current population growth continues. Even though Mexicali has a secondary treatment plant, it cannot accommodate all the new houses. Definitely a large quantity of new sewage will be continually dumped into the New River.

In addition to the international boundary information, a water quality analysis has been conducted at the New River outlet to the Salton Sea. TDS values which are about 5,000 ppm at the border are reduced to about 3,500 ppm as a result of the introduction of agricultural and municipal drain water from Imperial County. Water quality of the New River at the Salton Sea outlet resembles irrigation return water. Table I-14 shows water quality of the New River at the Salton Sea outlet.

TABLE I-13
NET INFLOW TO THE SALTON SEA, 1977

	Measured Pan Evaporation		Sea Evaporation ¹		River Inflow to Sea		Total Inflow to Sea ²		Difference Inflow Minus Evaporation	
	feet	meters	acre-feet	cubic hectometers	acre-feet	cubic hectometers	acre-feet	cubic hectometers	acre-feet	cubic hectometers
January	0.25	0.08	35,500	44	73,900	91	78,400	97	+ 42,900	+ 53
February	0.42	0.13	60,700	75	78,900	97	83,700	103	+ 23,000	+ 28
March	0.67	0.20	96,300	119	102,300	126	108,500	134	+ 12,200	+ 15
April	0.74	0.23	106,300	131	116,300	143	123,400	152	+ 17,100	+ 21
May	0.94	0.29	134,900	166	106,700	131	113,200	140	- 21,700	- 27
June	1.12	0.34	160,500	198	90,900	112	96,400	119	- 64,100	- 79
July	1.15	0.35	164,500	203	101,600	125	107,800	133	- 56,700	- 70
August	1.14	.035	162,500	200	149,200	184	158,300	195	- 4,200	- 5
September	0.92	0.28	131,800	162	83,700	103	88,800	109	- 43,000	- 53
October	0.63	0.19	90,200	111	82,800	102	87,900	108	- 2,300	- 3
November	0.53	0.16	75,300	93	73,800	91	78,300	96	+ 3,000	+ 4
December	0.37	0.11	52,200	64	70,100	86	74,400	92	+ 22,200	+ 27
TOTAL	8.88	2.71	1,270,700	1,567	1,130,200	1,394	1,199,100	1,479	- 71,600	- 88

Notes:

1 = 1×0.65 (pan factor) $\times$ 220,000 acres (Salton Sea surface area)

2 = 3×1.061 (estimated factor to include Coachella area inflows to sea)

Source: IID 1978 (p. 35)

TABLE I-14
WATER QUALITY OF NEW RIVER
AT THE SALTON SEA OUTLET

Parameter*	March 10, 1976	June 15, 1976	September 8, 1976	December 14, 1976
Na + K	728	825	798	811
C a	200	226	215	226
Mg	100	117	111	112
Cl	1,067	1,249	1,170	1,275
HCO ₃	293	311	311	216
SO ₄	719	790	790	782
Total Dissolved Solids (TDS)	3,120	3,540	3,484	3,528
Specific Conductance @ 24°C (K x 10 ⁶)	4,280	5,040	5,130	4,830
pH	7.1	7.4	7.8	7.4
Discharge in C.F.S. (C.M.S.)	764()	548()	601()	566()

*All readings are in mg/l (ppm) unless otherwise specified.

Source: IID 1977.

The Alamo River at the international border poses a lesser pollution problem due to a very small flow, and better inflowing water quality from Mexico (Table I-15). The Alamo River at the international border had fecal coliform of 6,000 MPN/150 ml on March 30, 1977, far exceeding the limit for water contact activities (less than 2,000 MPN/100 ml). Table I-16 shows total composition of water quality at the international boundary.

The TDS concentration of the Alamo River decreases from about 3,800 ppm at the border to about 2,700 ppm at the Salton Sea outlet. Due to more irrigation wastewater discharged into the Alamo River, its TDS is about 800 ppm less than that of the New River at the Salton Sea outlet. Table I-17 shows Alamo River water quality at the Salton Sea outlet.

4.4.2.5 Salton Sea

The Alamo River discharges in total approximately 1.047 maf into the Salton Sea annually. Crossing the international border, the total flow for both the Alamo and New Rivers is approximately 0.114 maf.

The water quality of New River at the international boundary has been monitored extensively because it is part of the National Stream Quality Accounting Network System. The New River is quite contaminated when it flows into California. Table I-18 shows water quality of New River at the international border.

The Salton Sea is estimated to contain 39,000 ppm of total dissolved solids. This water is unsuitable for either domestic or agricultural purposes. As a comparison this salinity is even greater than that of the ocean which is about 35,000 ppm. Littlefield (1966) indicated that the salinity in 1962 was 34,000 ppm. From 1962 to 1977, the average annual increase was about 250 ppm. According to the Regional Water Quality Board, the total dissolved solids content is increasing at an

TABLE I-15
WATER QUALITY OF THE ALAMO RIVER
AT THE INTERNATIONAL BOUNDARY

Parameter*	March 10, 1976	June 15, 1976	September 8, 1976	December 14, 1976
Na + K	773	700	380	654
Ca	198	192	154	185
Mg	113	100	70	106
Cl	1,000	897	447	866
HCO ₃	354	317	281	204
SO ₄	902	851	614	894
Total Dissolved Solids (TDS)	3,378	3,072	1,872	3,030
Specific Conductance @ 24°C (K x 10 ⁶)	4,520	4,250	2,680	4,100
pH	7.8	7.8	7.9	8.0
Discharge in C.F.S. (C.M.S.)	2	2	2	1

*All readings are in mg/l (ppm) unless otherwise specified.

Source: IID 1977.

TABLE I-16
POLLUTION IN THE ALAMO RIVER
AS IT FLOWS FROM MEXICO

Parameter	Date Sampled	
	March 30	April 30
Flow	2.54 cfs	2.54 cfs
20° BOD ₅	N.A.*	1.3 mg/l**
COD	N.A.*	47 mg/l
Suspended Solids	95 mg/l	N.A.*
Chloride	1,184 mg/l	1,214 mg/l
pH	8.1	7.9
Dissolved Oxygen	10.7 mg/l	8.3 mg/l
Ammonia	0.78 mg/l	0.78 mg/l
Total Coliform	23,000 MPN/100 ml	6,200 MPN/100 ml
Fecal Coliform	6,000 MPN/100 ml	1,300 MPN/100 ml
Specific Conductance	7,000 umhos/cm	7,296 umhos/cm
Temperature	N.A.	19°C
Settleable Solids (1 hr.)	0.3 ml/l	0.1 ml/l
Turbidity	N.A.	43 NTU
TDS	3,847 mg/l	N.A.

* Not available.

** Too low for reliable measurement.

Source: Swajian 1977.

TABLE I-17
WATER QUALITY OF THE ALAMO RIVER
AT THE SALTON SEA OUTLET

Parameter*	March 10, 1976	June 15, 1976	September 8, 1976	December 14, 1976
Na + K	480	495	577	546
Ca	182	192	204	218
Mg	91	113	118	124
Cl	618	661	744	772
HCO ₃	226	287	273	200
SO ₄	784	820	934	948
Total Dissolved Solids (TDS)	2,420	2,592	2,902	2,900
Specific Conductance @ 24°C (K x 10 ⁶)	3,300	3,510	4,020	3,910
pH	7.1	7.6	7.6	7.5
Discharge in C.F.S. (C.M.S.)	1,056	784	873	700

* All readings are in mg/l (ppm) unless otherwise specified.

Source: IID 1977.

TABLE I-18
WATER QUALITY DATA, NEW RIVER AT INTERNATIONAL BOUNDARY
CALEXICO, CALIFORNIA
FEBRUARY 1973 to SEPTEMBER 1976

<u>Parameters*</u>	<u>No. of Samples</u>	<u>Average</u>	<u>Standard Deviation</u>	<u>Coefficient of Variation %</u>
Instantaneous Discharge (CFS)	48	146.73	28.66	19.53
Ca	47	251.23	18.21	7.25
Mg	46	128.69	13.83	10.75
Na	47	1,090.85	115.66	10.60
K	46	57.62	21.77	37.77
HCO ₃	47	294.96	30.28	10.26
Alkalinity as CaCO ₃	47	242.00	24.88	10.28
SO ₄	47	807.02	62.92	7.80
Cl	47	1,813.83	191.99	10.58
F	47	.74	.18	24.70
Kjeldahl - N	39	5.95	2.76	46.31
Total - P	39	1.39	.38	27.49
Dissolved Residue at 180°C	47	4,533.40	416.80	9.19
Conductance (μmhos)	48	6,987.18	784.20	11.22
Ph (Scale)	47	7.63	.29	3.79
Temperature (°C)	48	24.19	6.30	26.04
Turbidity (NTU)	38	23.05	31.00	134.50
Phytoplankton (Cells/ml)	37	5.21 x 10 ⁴	5.237 x 10 ⁴	100.52
Fecal Coliform (Colonies/100 ml)	42	25.66 x 10 ⁵	24.454 x 10 ⁵	95.30
Streptococci (Colonies/100 ml)	45	3.835 x 10 ⁵	5.722 x 10 ⁵	149.22
Total Organic Carbon	11	24.91	9.03	36.24
Suspended Solids	31	126.10	74.91	59.41

*Dimension in mg/l except where specified.

Source: USG. Water Resources Data for California, 1973 - 1976.

average rate of about 550 ppm per year, due predominantly to an estimated 4.5 million tons of salt per year entering the Sea from all drainage water sources.

4.4.2.6 Crop Consumptive Uses of Water

The net volume of water delivered by IID to each acre of the farmed land has averaged about 5.19 acre-feet during the 1954 to 1977 period. (IID, 1978) If rainfall is added to this amount, a total of 5.38 acre-feet of water was used for the growth of each acre's crops. Of this total, 1.9 acre-feet per acre was discharged as irrigation return water. Thus, the consumptive use of the water is about 3.27 acre-feet per acre. The term "consumptive use" denotes water returned to the atmosphere by evaporation and transpiration, or incorporated in vegetation or industrial products. Table I-19 shows consumptive use analysis of water for IID. It should be noted here that this figure is lower than the IID estimation. This may reflect the success of the water conservation policy enforcement by the IID.

4.5 Ground Water

4.5.1 General Geology

The Imperial and Coachella Valleys of southeastern California are in a topographic and structural trough--the Salton Trough section of the Basin and Range physiographic province. The trough, which is about 130 miles long and as much as 70 miles wide, is a landward extension of the depression filled by the Gulf of California, from which it is separated by the broad fan-shaped subaerial delta of the Colorado River. Much of the land surface is below sea level. The lowest part of the trough is occupied by the Salton Sea, whose surface in 1968 was about 232 feet below mean sea level. (See Figure I-8)

TABLE I-19
CONSUMPTIVE USE OF WATER BY CROPS OF
THE IMPERIAL IRRIGATION DISTRICT, 1963-1977

Calendar Year	Total Quantity of water Delivered to Users - Acre-Feet	Total Inflow to Salton Sea From IID - Acre-Feet	Total Acreage Irrigated	Consumptive Use of Water by Crops	Net Acre-Feet per Acre Consumed	Rainfall - Feet	Total Consumption Feet Per Year
1963	2,284,666	1,153,827	430,222	1,130,839	2.63	0.20	2.83
1964	2,398,693	905,153	431,451	1,493,540	3.46	.08	3.54
1965	2,311,966	882,962	432,491	1,429,004	3.30	.27	3.57
1966	2,470,268	1,004,685	433,775	1,465,583	3.39	.13	3.52
1967	2,365,379	1,027,970	445,428	1,337,409	3.00	.35	3.35
1968	2,475,825	1,001,027	441,155	1,474,798	3.34	.17	3.51
1969	2,351,578	962,639	442,294	1,388,939	3.14	.29	3.43
1970	2,418,439	1,020,503	437,336	1,397,936	3.20	.14	3.34
1971	2,534,599	1,092,571	441,783	1,442,028	3.26	.11	3.37
1972	2,531,343	1,063,537	444,393	1,467,806	3.30	.18	3.48
1973	2,670,313	1,065,414	444,309	1,604,899	3.61	.11	3.72
1974	2,777,221	1,123,492	450,038	1,653,729	3.67	.17	3.84
1975	2,703,706	1,128,268	456,174	1,575,438	3.45	.10	3.55
1976	2,515,265	1,084,993	458,131	1,430,272	3.12	.42	3.54
1977	2,454,750	1,020,797	459,433	1,433,953	3.12	.43	3.55
Average	2,484,267	1,035,856	449,377	1,448,411	3.27	.21	3.48

Source: IID, 1978.

The Salton Trough is composed of a thick sequence of dominantly non-marine sedimentary rocks of Cenozoic age. The aggregate thickness in this sequence is many thousands of feet, both in exposures and beneath the Imperial Valley in the central part of the Salton Trough. Geophysical evidence indicates that the Cenozoic fill beneath south-central Imperial Valley probably is more than 20,000 feet thick.

The Cenozoic deposits are grouped in three broad categories: (1) a lower sequence comprising chiefly nonmarine sedimentary rocks of early to middle Tertiary age but including also volcanic rocks and minor marine sedimentary rocks; (2) a middle marine unit, the Imperial Formation, of late Tertiary (Miocene or Pliocene) age; and (3) an upper sequence composed of predominantly nonmarine deposits of late Tertiary (Pliocene) and Quaternary age. The upper sequence constitutes the main part of the ground water reservoir beneath the Imperial Valley (Loeltz, 1975).

4.5.2 Ground Water Hydrology

4.5.2.1 Introduction

The ground water reservoir in Imperial Valley consists of the upper Cenozoic valley-fill deposits, of which the upper few thousand feet is the ground water reservoir. Analysis of ground water has been limited to depths of less than two thousand feet because at greater depths the water is too saline for irrigation and most other uses and because the hydraulic connection between the water in the upper part of the ground water reservoir is poor.

4.5.2.2 Ground Water Movement

The general direction of movement of ground water is generally converging to the Salton Sea. The direction of ground water movement is at right angles, or normal, to the water level contour lines and toward

the next lower contour line. The contours were drawn on the basis of all known water-level altitudes provided useful information on the probably altitude of water levels in wells tapping the main water-bearing zones in 1965 (see Figure I-9).

The broad ground water mound that extends westward from Pilot Knob is the result of leakage from the All American and Coachella Canals. Between the canals, the direction of movement is principally westward, but south of the All American Canal the movement is southward toward Mexico.

The hydraulic gradients of two to five feet per mile that are common near the New River upstream contrast markedly with the gradients of 10 to 15 feet per mile that are common along the Alamo River at corresponding water-level altitudes.

In addition to moving toward the Alamo and New Rivers, appreciable quantities of ground water move upward to the extensive system of drains in the irrigated area. Most of the movement in the irrigated area, however, is downward to the drains. However, the contours may differ from the altitude of the drain water (Loeltz, 1975).

4.5.2.3 Ground Water Recharge

The important sources of ground water recharge in Imperial Valley are the Colorado River, imported irrigation water, and seepage through irrigation canals. Minor sources are underflow from tributary areas, precipitation and local runoff.

The Colorado River has been recharging the ground water reservoir of Imperial Valley since its delta is built sufficiently high to exclude the Salton Trough from the Gulf of California. However, the areas where the recharge has occurred have varied widely depending on whether the river was discharging to the Gulf of California or to the Salton Trough.

Figure I-9
GROUNDWATER LEVEL MAP OF SHALLOW AQUIFER,
IMPERIAL VALLEY, CALIFORNIA

When the Colorado River was flowing to the Gulf of California, recharge in Imperial Valley was principally underflow from Mexicali Valley and underflow through the alluvial section between the Cargo Muchacho Mountains and Pilot Knob.

Recharge to the shallow part of the ground water reservoir, as it occurred under natural conditions, was increased by the importation of Colorado River water to the Imperial Valley for irrigation beginning in 1901. Development of an agricultural economy based on irrigation was interrupted occasionally, notably by the uncontrolled flooding of the valley by the Colorado River in 1905-7, when the present Salton Sea was formed. However, irrigation agriculture continued to expand until, in the latter part of the 1960s, more than 430,000 acres of cropland was being irrigated. Much of the additional recharge in the irrigated area is due to leakage from the numerous conveyance channels and to the application of irrigation water in excess of crop requirements, the latter practice being necessary to prevent an excessive accumulation of salts in the root zone.

The completion of the All American Canal, which permitted the diversion of Colorado River water to Imperial Valley by an all United States route rather than through Mexicali Valley by the Alamo Canal, greatly increased the opportunity for recharge to the ground water system. In February 1942, the All American Canal became the sole means for diverting Colorado River water to the Imperial Valley. Six years later the Coachella Canal was completed and thereafter supplied water to the lower part of Coachella Valley.

The canals are major sources of recharge because (1) they are unlined; (2) they are up to 200 feet wide; (3) they flow across many miles of sandy terrain, especially in the easterly part of Imperial Valley; and (4) the water surface in the canals is much higher than the general ground water levels along their alignment. In the Sand Hill area of the East Mesa, the stage of the All American canal is about 80 feet

above pre-canal ground water levels; the difference between pre-canal levels and canal stage is similar at the head of the Coachella Canal and northward.

Recharge to the ground water reservoir by underflow from tributary areas is small compared with recharge that results from the importation of Colorado River water. The tributary areas that provide the major part of the underflow are the Mexicali Valley and the areas drained by Pinto and Coyote Washes and Carrizo and San Felipe Creeks. Of these, the two that contribute most of the recharge are the Mexicali Valley area drained by San Felipe Creek. Most of the ground water inflow from Mexicali Valley occurs through a section that extends westward from Calexico, California, to the mountains, a distance of about 23 miles and the average annual flow of ground water across this 23-mile section is about 7,000 acre-feet. A similar computation indicates that the underflow beneath San Felipe Creek is about 10,000 acre-feet per year. Underflow from the area drained by Coyote Wash is considerably smaller, and the underflow from areas drained by Pinto Wash is estimated to be hundreds rather than thousands of acre-feet per year (Loeltz, 1975).

Direct infiltration of precipitation to the groundwater reservoir is a minor source of recharge. Recharge also results from infiltration of runoff, mainly in washes and drainageways that discharge to the central part of the valley or to the Salton Sea. This recharge is estimated to average somewhat less than that from the tributary area of San Felipe Creek. Thus, the average annual recharge due to precipitation within the Imperial Valley area probably is less than 10,000 acre-feet (Loeltz, 1975).

4.5.2.4 Ground Water Discharge

In the Imperial Valley, ground water is discharged by springs, wells, irrigation drains and base flow contribution to rivers. Ground water is also discharged by numerous small springs and seeps. On the

northeast side of the Salton Sea these springs and seeps are fed by the Coachella Canal seepage. Springs and seeps southwest of the Salton Sea are less numerous and generally have smaller flows than those northeast of the Sea. The total discharge of springs and seeps, excluding the discharge due to seepage from the Coachella Canal, is estimated to be only a few thousand acre-feet per year.

Wells discharge only a small part of the groundwater in Imperial Valley. Although there are hundreds of wells in the area, most of them are small domestic or stock wells. The discharge from each of the several hundred wells in the valley averages about 10 gallons per minute, so the annual discharge is only a few thousand acre-feet.

Most of the ground water discharge in Imperial Valley is by an extensive network of drains that serve the irrigated land. The network discharges about one million acre-feet per year of ground water and agricultural waste water, most of which previously had been diverted to cropland for irrigation. Some of the discharge, however, is water that has moved upward to the drains from the deeper aquifers, principally near the east edge of the irrigated area.

The water level contours on Figure I-9 indicate upward leakage of water from the main groundwater body to the Alamo and New Rivers and in the vicinity of the Salton Sea. However, the amount of such leakage averages only a few tens of thousands of acre-feet per year (Loeltz, 1975).

4.5.2.5 Aquifer Characteristics

The term "aquifer" is applied to any water-bearing formation or rock unit that is capable of yielding an adequate water supply. The adjectives "excellent," "good," "fair," or "poor" may be used to denote the degree to which the yield from an aquifer is adequate, but they are not specific enough for a quantitative appraisal of an aquifer or

for comparing one aquifer with another. To be more specific, the productivity of an aquifer may be expressed in terms of the aquifer's transmissivity. Transmissivity is expressed as the rate of flow in gallons per day through a one-foot-wide vertical strip of the entire saturated thickness of the aquifer under a unit hydraulic gradient at the prevailing temperature of the water.

Transmissivities commonly are computed from the results of controlled pumping tests. They also can be computed on the basis of the width of a vertical section through which ground water is moving at a known rate under a known hydraulic gradient, or on the basis of the specific capacity, which is the rate of yield per unit drawdown of a well.

Short-term pumping tests were made at several widely scattered sites to obtain data for computing transmissivity. Although some of the short-term tests did not provide adequate data, most of the tests were satisfactory. The results of these pump tests are shown in Table I-20.

The data indicate that in the eastern and western parts of Imperial Valley, moderate to high yields can be obtained from wells that tap several hundred feet of the marginal alluvial deposits or deposits of the Colorado River. Transmissivities of several hundred thousand gallons per day per foot are characteristic of these deposits, and wells with specific capacities of as much as 50 gallons per minute (gpm) per foot of drawdown or more may be attainable in the more favorable areas.

In the East Mesa area the exceptionally high transmissivity and hydraulic conductivity computed for deposits at well LCRP 6 indicate that some of the Colorado River deposits at the site are very permeable. The values are similar to those obtained from pumping tests of large-yielding wells in the Mexicali and Yuma Valleys. The lower transmissivities and hydraulic conductivities at wells LCRP 11, 12 and 18

TABLE I-20

RESULTS OF PUMPING TESTS, IMPERIAL VALLEY, CALIFORNIA

Well Location	Owner or Name of Well	Date of Test	Interval Tested (ft. below land surface)	Yield (GPM)	Draw-down (feet)	Specific Capacity (GPM/ft)	Transmissivity (GPD/Ft)	Hydraulic Conductivity (GPD/Ft ²)
T12S/R9E-22AZ	T.M. Jacobs	7-29-63	285-667	1,450	14	100	290,000	760
T12S/R11E-18J1	LCRP19	5-20-64	310-650	150	4	38	100,000	300
T12S/R11E-18J2	LCRP19A	5-20-64	35-55	45	8.5	5	37,000	1,800
T14S/R11E-32R	LCRP8	5-11-62	135-165 218-258 310-354 390-416 430-560	250	13	19	130,000	480
T12S/R16E-9A	Southern Pacific Co.	7-9-63	150-1,000	975	43	23	62,000	73
T12S/R16E-9A	Southern Pacific Co.	7-9-63	150-1,000	675	27	25	47,000	55
T15S/R18E-15M	LCRP11	5-10-63	309-894	1,000	20	50	220,000	380
T15S/R18E-15M	LCRP11	5-10-63	309-894	1,000	20	50	220,000	380
T16S/R18E-32R	LCRP18	6-29-64	140-630	900	21	43	140,000	240
T16S/R19E-11D	LCRP12	5-14-63	300-610	990	24	41	240,000	770
T16S/R20E-31K	LCRP6	5-2-62	340-410 510-520	1,035	12	85	850,000	10,000
T16S/R20E-31K	LCRP6	5-2-62	340-410 510-520	1,035	12	85	880,000	10,000
T16S/R21E-16B	R.G. Winder	12-4-62	598-806	1,550	36	43	630,000	3,000
T16S/R21E-16B	R.G. Winder	12-4-62	598-806	1,550	36	43	590,000	2,800

Adapted From: Geohydrologic Reconnaissance of the Imperial Valley, California,
U.S.G.S. Professional Paper 486-K, O.J. Loeltz, et. al, 1975.

indicate that the permeability of the deposits decreases westward and northwestward from well LCRP 6. The eastward extent from well LCRP 6 of the region of high transmissivity is not known, but consideration of possible past courses of the Colorado River suggests that it probably is several miles (Loeltz, 1975). See Table I-20.

Pump test data on the central part of the Imperial Valley are not discussed in this study because most of the area is under irrigation and any major ground water development in the area may induce land subsidence which may damage the tile drain system.

4.5.2.6 Ground Water Quality

The geographic and geologic controls that govern the occurrence, movement and chemical quality of the ground water of the Salton Trough vary widely. The variability of the chemical quality of the water contained in the rocks is due to differences in location with respect to the water table and opportunities for recharge, to compositional differences in sources of recharge, and to the high evaporation rate in the hot arid climate.

Some of the deeper ground water may be moderately altered connate ocean water. At shallower depths, the water in the deltaic deposits probably consists of evaporation residuals of water from prehistoric Lake Cahuilla or earlier fresh-water lakes. Some of the residual water may be nearly fresh, and some, moderately saline. Locally, the ground water may have become saline because storm runoff has leached soluble evaporites from sedimentary rocks now above the water table. Some small lenses of fresh ground water may have resulted from impoundment of runoff from the ephemeral desert washes against sand dunes, as along the northeast margin of the Sand Hills.

Ground water quality analysis from selected wells in eastern Imperial Valley was reviewed. The total dissolved solids ranges from 360 to

7280 mg/l. Most of the readings indicating poorer quality water (greater than 2500 mg/l) are from wells less than 150 feet deep. Wells penetrating to a depth of 1000 feet will generally yield water containing less than 2500 mg/l of TDS. Appendix E lists ground water quality data from wells in eastern Imperial Valley.

Wells in central Imperial Valley were also analyzed for ground water quality. The total dissolved solids in this area range from 663 to 15,700 mg/l. The ground water quality is generally poor in the central Imperial Valley area due to the general fine grain nature of the alluvial deposit and occurrences of lacustrine or lake bed deposits. Wells penetrated to a depth of 1000 feet located between west of the East Highline Canal and east of the Alamo River generally yield water containing less than 3000 mg/l. Wells located west of the Alamo River of central Imperial Valley generally yield water unfit for most uses. Appendix E shows ground water quality data for wells in central Imperial Valley.

The last major area, western Imperial Valley, indicated total dissolved solids ranges from 262 to 13,000 mg/l. Wells located in the Coyote Valley yield the best quality water in the Imperial Valley. Wells in San Felipe Creek and West Mesa area generally will yield water containing less than 250 mg/l between depths of 150 to 1000 feet. Appendix E is a listing of ground water quality data from selected wells in western Imperial Valley.

4.6 Water Budget Analysis

4.6.1 Introduction

The purpose of water budget analysis is to determine the quantity of water resources in an area. For Imperial Valley, the input and output of the water resources components are in dynamic balance. The actual quantity of input and output may vary with time, however, all

in-going and out-going water components must be balanced for sound irrigation practices in the Valley. The major water resources components that apply to the Imperial Valley are:

- river inflows of the New and Alamo Rivers across the international border
- import waters of the Coachella and the All American Canals
- canal export water through the Coachella Canal to Coachella Valley
- river outflows of the New and Alamo Rivers to the Salton Sea
- consumptive use of irrigation water for crops in the Valley
- ground water outflow to the Salton Sea
- ground water recharge through canal seepage loss

Water derived from precipitation as natural runoff and recharge to ground water is considered to be negligible because of high evaporation rate and lack of precipitation in the area. For purposes of analysis, it is assumed that deep ground water inflow into the Valley equals its outflow and the interaction between the shallow and deep ground water system is minimal.

Therefore, the sum of components (a) and (b) shall be equivalent to the sum of components (c), (d), (e), (f) and (g). The water budget analysis conducted in this manner should reflect quantitatively the adequacy of the water resources in the Imperial Valley for geothermal energy development. The water budget for 1977 was selected for the analysis to reflect the most recent data. Moreover, this should be

a conservative quantitative analysis since 1977 was a relatively dry year. Most of the data were derived from the Imperial Irrigation District 1978 Water Report and other appropriate data sources. Figure I-6 shows the general location of canals and rivers in the Imperial Valley.

4.6.2 Water Resources System Input

4.6.2.1 River Inflow

There are two rivers that flow into the Imperial Valley, the New and Alamo Rivers (see Figure I-6). Both of these rivers flow across the international boundary from Mexico and north to the Salton Sea. For the year 1977, the flow across the international boundary for the New River was 108,000 acre-feet and 1,400 acre-feet for the Alamo River.

4.6.2.2 Canal Water Import

There are two major irrigation canals that flow into the Imperial Valley, the Coachella and All American Canals (see Figure I-6). They imported a total of 3.220 maf for the year 1977. The Coachella Canal delivers irrigation water to the Coachella Valley. The All American Canal water is for users in the Imperial Valley and is under the jurisdiction of the Imperial Irrigation District. The All American subdivides into three major north-flowing canals: the East Highline Canal, the Central Main Canal and the West Side Main Canal. The three canals form the major arteries of the irrigation water system in the Imperial Valley.

4.6.2.3 Total Water Resources Input

The quantity of water from both rivers and the three canals that flow into the Imperial Valley for the year 1977 was about 3.329 maf. (Approximately 108,000 acre feet from the New River, 1400 acre feet from the Alamo River and 3,220,000 acre feet from the canal system.)

4.6.3 Water Resources System Output

4.6.3.1 River Outflow

For the year 1977, the floww of the New River into the Salton Sea was measured to be .413 maf and .615 maf for the Alamo River. A majority of this volume was contributed from irrigation return water and a minor portion from municipal waste discharges.

4.6.3.2 Canal Water Export

The Coachella Canal, which delivers irrigation water to the Coachella Valley, leaves the Imperial Valley at an amount of approximately .387 maf for 1977. Substantial seepage loss to the groundwater system occurs along the Coachella Canal.

4.6.3.3 Irrigation Crop Consumptive Use

The Imperial Valley is a major area of irrigation farming in the United States. Much of the water is used by the crops through transpiration, consumptive use, and an additional amount is needed to leach the soil for proper salt balance. The actual water required for the crops is the consumptive use and is estimated to be about 3.27 feet of water per irrigated acre. Based on this analysis with a total irrigation acreage of about 460,000 acres, the consumptive use by irrigated crops in the Imperial Valley is estimated to be 1.504 maf. IID has developed a conservation plan to decrease this amount of use.

4.6.3.4 Ground Water Outflow to Salton Sea

The general direction of ground water movement is from southeast to northwest. This movement has the effect of contributing ground water to the Salton Sea from shallow aquifers to the south. The amount of ground water outflow to the Salton Sea is estimated at 50,000 acre-feet per year (Loeltz, 1975).

4.6.3.5 Ground Water Recharge through Canal Seepage Loss

Canal Seepage Loss Since 1941, the All American Canal has been diverting water from the Colorado River into the Imperial Valley area. In 1948, the Coachella Canal began diverting water north to the Coachella Valley. These canals are a major source of ground water recharge since they are (1) not lined; (2) are up to 200 feet wide; (3) flow across many miles of sandy terrain in the Imperial Valley, and (4) are at a higher level than the surrounding ground water levels. This leakage has caused ground water ridges to form adjacent to the canals.

The amount of recharge due to seepage has been decreasing since the canals are handling lower maximum volumes of water. The cumulative amount of water in ground water storage, however, is currently increasing (Loeltz, 1975).

For the year 1977, the Coachella Canal had a seepage loss of about 104,000 acre-feet. Along the All American Canal, from Drop 1 to East Highline Canal, seepage loss is estimated to be 22,000 acre-feet. Between East Highline Canal and Central Main Canal, the seepage loss was about 12,000 acre-feet. Between the Central Main Canal and the West Side Main Canal, the seepage loss was about 6,000 acre-feet. The seepage loss of the section of canal that is west of Drop 1 is estimated at about 29,000 acre-feet. The combined seepage loss along the East Highline, Central Main and West Side Main Canal irrigation system is estimated to be 88,000 acre-feet. Thus, the estimated ground water recharge from the canal system in 1977 was 261,000 acre-feet. (IID, 1978)

4.6.4 Water Budget Balance

This water budget balance should address the magnitude of water resources entering, leaving, and staying in storage in an area. If all components are estimated accurately, the water budget should be in

balance. Note, the water budget balance does not account for water quality and temperature parameters, critical considerations in geothermal power plant cooling considerations. Table I-21 shows the various components of the water budget for the Imperial Valley. For the Imperial Valley, the total water resources system input was about 3.329 maf for the year 1977. The total water resource system output was about 3.23 maf. This left approximately 99,4000 acre-feet of water unaccounted for, which is about 3% of the input value. Most of this is probably due to possible errors of estimating consumptive use or errors of measurement of the flows in the canals and rivers.

4.6.5 Results of Water Budget Analysis

The significant findings of this water budget analysis are:

- (a) Irrigation water importation is a dominating element in the water budget, accounting for 97% of the total budget volume.
- (b) Crop consumptive use of water is a significant quantity of non-recoverable water, about 45% of the total budget volume.
- (c) Uncommitted recoverable surface water resources are the river discharges to the Salton Sea at a total volume of about 1,028,000 acre-feet, or 31% of the total.
- (d) Uncommitted and possibly recoverable groundwater resources are ground water outflow to Salton Sea and recharge from canal seepage. This has a combined volume of about 311,000 acre-feet.

TABLE I-21

**WATER BUDGET BALANCE OF THE YEAR 1977
IMPERIAL VALLEY, CALIFORNIA**

WATER RESOURCES SYSTEM INPUT

Source	Acre Feet
NEW RIVER	108,000
ALAMO RIVER	1,400
COACHELLA CANAL AND ALL AMERICAN CANAL	3,220,000
TOTAL INPUT	3,329,400

WATER RESOURCES SYSTEM OUTPUT

Source	Acre Feet
NEW RIVER DISCHARGE TO SALTON SEA	413,000
ALAMO RIVER DISCHARGE TO SALTON SEA	615,000
COACHELLA CANAL EXPORT	387,000
CROP CONSUMPTIVE USE	1,504,000
GROUND WATER OUTFLOW TO SALTON SEA	50,000
GROUND WATER RECHARGE BY CANAL SEEPAGE	261,000
TOTAL OUTPUT	3,230,000
UNACCOUNTED FOR	99,400

Source: VTN Estimates, 1978.

PART II

COSO

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PART II

COSO

1.0 SUMMARY

The objective of this report was to assess the following for the Coso, California, Known Geothermal Resource Area (KGRA):

- water resources that are available for geothermal electric power plant development
- power plant make-up water requirements
- the developable megawatts as a function of the available make-up water
- the need for additional water resource data

The availability of outside sources of make-up water for power plant operations is a major consideration in developing geothermal resources in the Coso area. The quality, quantity and availability of both surface and ground water for use in geothermal power plants were examined. The demand for water was based upon the previously conducted geothermal power plant water utilization case study. These investigations and analyses yielded an estimate of the total megawatts that can be developed at the Coso KGRA: 1,500 MWe if 100% reinjection is mandated, and 2,000 MWe if neither rejection nor waste water disposal quality requirements exist. Given the prevailing constraints, 1,500 MWe are achievable.

1.1 Surface Water Quality

Analysis of the surface water resources for the Coso area indicate the following:

- There are less than 10 inches of precipitation per year.
- The total estimated surface runoff for the Rose Valley and Coso Wash watershed is approximately 3,000 acre-feet per year.
- The streams are either intermittent or ephemeral.
- The Haiwee Reservoir with a storage capacity of 510,000 acre-feet , part of the Los Angeles Department of Water and Power Aqueduct System, is the only surface water body in the area, and it is not available for geothermal power plant cooling purposes.
- Surface water is not available in sufficient quantity for geothermal power plant cooling.

1.2 Ground Water Supply

Findings related to ground water are:

- The only major source of aquifer recharge is approximately 11,000 acre-feet of seepage from the Haiwee Reservoir.
- The latest available data indicate that ground water is being pumped from the deep aquifer at a rate of approximately 15,000 acre-feet per year.

- On balance, the deep aquifer recharge and pumping rates in the vicinity of China Lake, Inyokern, and Ridgecrest indicate that the ground water is being depleted.
- The estimated ground water stored in the area is approximately 1.9 million acre-feet for $\leq 1,000$ mg/l TDS water and 2.1 million acre-feet for water of $\leq 4,000$ mg/l TDS, but $> 1,000$ TDS.
- Access to the ground water for use in geothermal power plant cooling may be limited, since this is the primary source of water for China Lake, the Naval Weapons Station, Ridgecrest and Inyokern.

1.3 Power Plant Water Requirements

Based on data developed in the case study, the following are the estimated total make-up water requirements for a 50 MWe power plant at Coso, where the geothermal resource temperature is 220°C:

<u>Type of Plant</u>	<u>Water Requirements (1)</u> <u>(Acre-Feet/Year)</u>
Flashed Steam (direct contact)	2,890
Flashed Steam (indirect contact)	3,700 (2)
Flashed Steam (indirect contact)	9,500 (3)
Binary Cycle	6,700 (2)
Binary Cycle	17,000 (3)

(1) Blow-down discharge of 4,000 ppm TDS

(2) Make-up water 1,000 mg/l TDS

(3) Make-up water 4,000 mg/l TDS

Access to the ground water for use in geothermal power plant cooling may be limited, since this is the primary source of water for China Lake, the Naval Weapons Station, Ridgecrest and Inyokern.

2.0 CONCLUSIONS

Analysis of the supply of water resources and the demand for water by the various types of geothermal power plants provides a method for identifying constraints on power development at Coso. This analysis of constraints is a function of four key factors:

- estimated ultimate capacity of the geothermal reservoir
- specific characteristics of the geothermal reservoir, primarily the resource temperature
- type of power plant conversion cycle utilized
- the scheduled on-line date of the power plants
- blow-down discharge requirements

The interaction of these variables determines the quantity and quality of water demanded for geothermal development.

2.1 Cooling Water Availability

To assess the availability of cooling water in the Coso area, certain parameters were assumed. These included the following:

- The policy of the Water Quality Control Board for this district is to not allow discharge on the surface into streams.
- Discharge is allowed only into evaporative ponds; however, this may not be allowed, as there are concerns about contamination of the ground water.

- Any blow-down would have to be injected back into the geothermal reservoir.

2.1.1 Surface Water

The only potential runoff from the rainfall in the area is estimated to be approximately 3,100 acre-feet per year. This limited amount of runoff occurs over the entire area, thus there are no perennial streams which can provide a source of power plant cooling water. The only other source of surface water is the Haiwee Reservoir which is under the control of the LADWP. Water from this source would not be available for geothermal power plant cooling purposes.

2.1.2 Ground Water

Delineations of the ground water basins within the vicinity of the Coso KGRA are limited. The predominance of data available is for the Indian Wells Valley. There are shallow and deep aquifers within the Indian Wells Valley. The deep aquifer has the potential to supply water suitable for power plant cooling. The physical and chemical data collected in these aquifers are confined to the ground water in the Indian Wells Valley.

The objective of the aquifer assessment was to determine the volume of ground water in storage which would potentially be available for geothermal power plant cooling requirements. To assess the extent of the aquifer, certain parameters were chosen. The parameters used were: (1) temperature less than 100°F (37.8°C), (2) minimum thickness of alluvium of 1,000 feet, and (3) less than 4,000 mg/l TDS. Item 3 was broken down further into (1) less than 1,000 mg/l TDS and (2) less than 4,000 mg/l TDS but greater than 1,000 mg/l.

To fully develop the aquifer, wells should penetrate at least 1,000 feet of the alluvium to ensure a substantial quantity of water. Based on seismic refraction done in Indian Wells Valley (Zbur, 1963), areas where alluvium exceeded 1,000 feet can be located (Figure II-1). For the area, the saturated sand thickness to a depth of 1,000 feet was estimated to be 550 feet. The estimated volume of ground water in storage for the area (Figure II-1) with less than 1,000 mg/l TDS is 1.935×10^6 acre-feet, and 2.140×10^6 acre-feet for areas with less than 4,000 mg/l TDS (Table II-1). These areas are located 10 to 12 miles from the geothermal area. Notwithstanding the presence of this ground water, accessibility to this water may be limited, as this is the primary source of water for domestic and industrial uses. Appendix D contains additional ground water data.

2.2 Developable MWe

Analysis in the case study indicated the relationship between the various power plant conversion cycles and the water requirements. For the Coso area, the analysis of constraints on geothermal power plant development were evaluated under various conditions relative to conversion cycle, source and quality of make-up water. The basis for the analysis was the implementation plans from the utilities and producer/developers. These plans were completed through 1990. Beyond 1990, the on-line schedule was developed to approximate the data developed by JPL. The ultimate reservoir capacity was based on USGS, EPRI and JPL developed estimates.

2.2.1 Case A: Flashed Steam--Complete Injection Not Required

Given these considerations, the analysis indicated for flashed steam power plant conversion cycles using direct contact condensers and the steam condensate for cooling water purposes would provide the best case conditions. With this situation, an outside source of cooling water is not required. Potentially, if all of the geothermal plants to be

TABLE II-1
ESTIMATED GROUNDWATER IN STORAGE

Water Quality Parameters	Approximate Surface Area (acres)	Approximate Alluvium Thickness (feet)	Total Estimated Groundwater in Storage (acre-feet)
1,000 mg/l TDS	29,000	1,000	$1,935 \times 10^6$
4,000 mg/l TDS	36,500	1,000	2.140×10^6

Source: VTN Estimates, 1978.

developed at Coso were to use this power conversion cycle, and if complete injection of the geothermal fluid were not required, there would be no constraint on geothermal development as a result of make-up water requirements.

2.2.2 Case B: Flashed Steam--Complete Injection

If complete injection into the geothermal reservoir is necessary, flashed steam power plant conversion cycles using direct contact condensers for cooling purposes would require an outside source of water to replace any evaporative losses from the cooling process. Potentially, water of any source and quality could be used for injection purposes. The water used, however, will have to be compatible with the geothermal fluid in order to minimize any potential problems in the injection system.

To develop constraints on developable MWe at Coso, for purposes of analysis, it is assumed that only surface water would be used. The use of ground water for injection purposes was not considered viable. Given these constraints and the lack of surface water in the Coso area, no geothermal power plant development could be undertaken.

2.2.3 Cases C, D and E: Flashed Steam--Indirect Contact Condenser

Using this system, an outside source of make-up water would be required to replace blow-down and evaporative losses. If surface water were to be used for this purpose, no geothermal power plant development could occur (Case C).

With this constraint on power plant development resulting from lack of surface water, ground water could be an alternative source of cooling water. Given the identified sources of ground water, the recharge and outflow rates, the estimated developable MWe using ground water of 4,000 mg/l TDS is approximately 500 MWe (Case D) and 1,500 MWe (Case E) with 1,000 mg/l TDS water.

2.2.4 Cases F, G and H: Binary Cycle

Binary cycle geothermal power plants present the worst-case conditions (i.e., greatest amount of water required) in terms of water requirements for cooling purposes. As with indirect contact condenser-type power plants, specific make-up and blow-down discharge requirements are applicable. Based on these considerations, if binary cycle power plants are developed and surface water is used, no development could occur (Case F).

As an alternative to surface water, ground water could be used for make-up purposes. Given the identified source of ground water quality, and if all the power plants use the binary cycle, an estimated developable MWe can be shown. If ground water of 4,000 mg/l TDS is used for cooling purposes, approximately 350 MWe are developable (Case G). If ground water of 1,000 mg/l TDS is used, an estimated 700 MWe (Case H) of power could be developed at Coso. Figure II-2 summarizes the developable MWe for Coso.

2.3 Procurement Specifications

Ground water resource information for the area was limited but adequate for assessment purposes; thus procurement specifications are not required.

Surface water data for the Coso area was generally not available. The extremely small precipitation levels, however, indicate even though data were available, the findings would not substantially change the estimated surface runoff developed in this analysis. Data collection through a procurement specification would most likely not materially change the estimates of the availability of surface water for power plant cooling purposes. Based on these considerations, procurement specifications for surface water data are not recommended.

FIGURE II-2
SUMMARY OF DEVELOPABLE MWe

TOTAL CAPACITY: 2000 MWe

- A: FLASHED STEAM -- ZERO MAKE-UP WATER**
- B: FLASHED STEAM -- COMPLETE INJECTION, SURFACE WATER**
- C: FLASHED STEAM -- INDIRECT CONTACT CONDENSER, SURFACE WATER**
- D: FLASHED STEAM -- INDIRECT CONTACT CONDENSER GROUNDWATER (< 4,000 ppm TDS)**
- E: FLASHED STEAM -- INDIRECT CONTACT CONDENSER, GROUNDWATER (< 1,000 ppm TDS)**
- F: BINARY CYCLE -- SURFACE WATER**
- G: BINARY CYCLE -- GROUNDWATER (< 4,000 ppm TDS)**
- H: BINARY CYCLE -- GROUNDWATER (< 1,000 ppm TDS)**

Source: VTN Estimates, 1978.

3.0 RECOMMENDATIONS

3.1 Initiatives and Activities

3.1.1 Federal

The primary recommendations for federal activities are:

1. Determine the legal/institutional aspects of using ground water from the Indian Wells area for use in geothermal power plant cooling. If an outside source of water is required for make-up or injection purposes, access to this source of ground water will be a key consideration in order for geothermal development to occur. If access to this water is to be limited by legal/institutional constraints, a timely determination should be made to provide a basis for developing plans for power plant cooling.
2. Determine the engineering/economic aspects of ground water pumping and distribution. The key factor in this analysis will be to determine the engineering feasibility of distribution and its related cost in terms of the sales price of the power developed. The final price of electrical output from geothermal plants will have to be competitive with other energy sources. The acquisition and distribution costs of ground water needs to be established in order to ensure competitively priced power from the Coso area.
3. Coordinate plans for development of the geothermal field with the U.S. Navy in all aspects of the planning process. Commercial development at Coso will, most likely, require some degree of participation from the U.S. Navy.

3.1.2 State

State activities should also involve the legal/institutional aspects of access to ground water resources. The institutional aspects of surface water diversion will also involve state activities. State initiatives on the water use for power plant cooling and other beneficial uses will be required to establish priorities for the Coso area.

3.1.3 Counties and Local

The coordinated development of the geothermal resources, and hence the outside water requirements, will require initiatives by Inyo County. Inyo County should coordinate access to the limited ground water in the area to ensure orderly development of the county and the geothermal resources. The cities of China Lake, Ridgecrest and Inyokern should also participate in this planning effort.

3.2 Site Specific

3.2.1 Plant Siting

Analysis of constraints indicate geothermal development could not occur if surface water were to be used as a source of cooling water. The ground water basins identified are approximately 10 to 12 miles from the geothermal resource areas, thus plants should be sited to minimize this distance. The engineering/economic aspects of the water distribution system will require consideration in power plant siting.

4.0 TECHNICAL DISCUSSION

4.1 Methodology

A general method of approach was established to accomplish the major objectives of the study. The initial step of this methodology was to determine the objectives of the study. A comprehensive literature search was conducted to collect all published water resources literature required for the evaluation. Sources of data were various government agencies, institutions, and private organizations. A systematic literature review by technical key words was then conducted to ascertain the extent of the data collected. Field investigations were then conducted among these groups to ascertain unpublished data and reports and also to confirm findings of previously published materials.

For surface water, major surface water bodies were identified, their physical and chemical characteristics evaluated, and their capacities determined based on these evaluations.

In the ground water evaluation, aquifers in the area were identified; their physical and chemical characteristics evaluated, and their capacity and productivity assessed. A water budget balance was not calculated because of lack of sufficient surface water.

Once the water availability was determined, cooling water requirements by quantity and quality based on case studies were determined. The water resources in the area were then classified by quantity and quality in accordance with the cooling water criteria. Finally, based on these evaluations, the geothermal energy growth with respect to cooling water availability was determined.

Figure II-3 indicates the major steps of the methodology.

FIGURE II-3 FLOW DIAGRAM OF METHOD OF APPROACH

4.2 Survey of Existing Information

The purpose of the literature search is to screen published reports and materials that are pertinent to the water resources evaluation. The initial step of this literature search was to contact various government agencies and private organizations to collect the required data.

All the literature collected are recorded on card catalogue under a specific format. For example,

Author:	Dutcher, L.C. and W. R. Moyle, Jr.
Report Title:	Geologic and Hydrologic Features of Indian Wells Valley, California
Source:	USGS Water Supply Paper 2007
Date or Year of Publication:	1973
Index Number:	D1-C

The index number identifies the first alphabet of the principal author's last name, the number of publication listed under the alphabet, and the study area of concern. The letter C indicates Coso scenario. Each report is then labeled by the index number.

Appendix A contains a listing of all pertinent literature collected for this study area with the appropriate index numbers. Notation of figure, table and page number of the report relative to the specific key word were recorded during the review (see Appendix B).

During the literature review process, twelve key literatures were identified and were used to provide a major input into the water resources evaluation of Coso KGRA, California. They are listed as follows:

Bloyd, Jr., R. M. and S. G. Robson
1971 "Mathematical ground water model of Indian Wells Valley, California." USGS Open File Report (Ref. No. B4-C)

- Dutcher, L.C. and W. R. Moyle, Jr.
1973 "Geologic and hydrologic features of Indian Wells Valley, California." USGS resources in the Imperial Valley area, California. USGS Water Supply Paper 2007 (Ref. No. D1-C)
- Kunkel, F. and G. H. Chase
1955 "Geology and groundwater of Inyokern Naval Ordinance Test Station and vicinity, China Lake, California." USGS Open File Report (Ref. No. K3-C)
- McClelland, E. J.
1964 "Aquifer test compilation for the Mojave Desert Region, California." USGS Open File Report (Ref. No. M2-C)
- Moyle, Jr., W. R.
1963 "Data on water wells in Indian Wells Valley area, Inyo, Kern and San Bernardino Counties, California." California Department of Water Resources Bulletin 91-9 (Ref. No. M4-C)
- Zbur, R. T.
1963 "A geophysical investigation of Indian Wells Valley, California." U.S. Naval Ordinance Test Station, China Lake, California (Ref. No. Z1-C)

In addition to the literature search, it was necessary to search for any unpublished literature or any new developments in the water resources of the Coso KGRA vicinity. Telephone contacts and visits were made to various government agencies and private organizations to validate and search for additional water resources data.

Appendix C contains a list of persons, agencies, addresses and date of visits and telephone contacts.

4.3 Location of the Study Area

The Coso KGRA is located in the central portion of Inyo County, California. Approximately 80% of the area is within the U.S. Naval Weapons Center. The actual study area was delineated as a function of the hydrologic considerations and availability of data rather than by political or jurisdictional boundaries. Although some types of data for this KGRA are sparse, the water resources generally could be estimated. Figure II-4 indicates the Coso study area.

The Coso KGRA covers Rose Valley and Coso Basin in the southwestern corner of Inyo County, California. The Rose Valley encompasses an area of 175 square miles. The southern part of the Sierra Nevada Mountains is west of Rose Valley, the Coso Range is to the east, the Haiwee Dam is north, and Little Lake is to the south. Coso Basin covers 275 square miles and consists of a drainage basin of almost entirely mountain slopes that culminate in peaks 6,000 to 8,000 feet above sea level. Sugarloaf Mountain (5,126 feet) and Cactus peak (5,415 feet) of the Coso Range separate Rose Valley from Coso Basin. Only part of the Coso Basin (the Coso Wash watershed and Rose Valley) is within the KGRA.

4.4 Surface Water

No official climatic station records have been kept for the Rose Valley and Coso Wash watershed areas. However, estimates for the area have been developed. Based on this analysis, precipitation varies from two to five inches on the valley floor to 25 inches in the Sierra Nevada Mountains and approximately 10 inches in the eastern mountains (California State Water Resources Control Board, 1971, 1974). Based on interpretations from the isopluvial map, the annual precipitation of Rose and Coso Hot Springs basins is approximately 10 inches (California Region Framework Study Committee, 1970).

No official gaging station records can be found in this region. Based on estimates for precipitation, it is, however, possible to develop approximations of the surface water runoff for the Rose Valley and Coso Wash watershed areas. These estimates indicate an annual runoff of approximately 2,300 acre-feet for the Rose Valley watershed and 830 acre-feet for the Coso watershed. Figure II-5 indicates the watershed for the Coso area.

The only other surface water in the area is from the Los Angeles Aqueduct system operated by the Los Angeles Department of Water and

FIGURE II-5
MONO-LONG VALLEY
AND COSO AREAS
WATERSHED MAP

VICINITY MAP

Power. This aqueduct system traverses Rose Valley longitudinally and carries water from Haiwee Reservoir in the Mono/Long/Owens Valley areas to the City of Los Angeles for domestic and industrial uses. Water from the aqueduct system or Haiwee Reservoir is not available for geothermal power plant cooling purposes. Thus, for the Coso area, surface water is not available in sufficient quantity to supply make-up water for geothermal power plant cooling purposes.

4.5 Ground Water

There are four basins of importance in and around the study area. These are: 1) Rose Valley to the west, partially enclosed in the KGRA; 2) Coso Basin to the southwest, partially enclosed in the KGRA; 3) Indian Wells Valley to the south, and 4) Owens Valley to the north. The area is characterized by roughly parallel faultblock basins and ranges.

For the purpose of the ground water summary, the geologic units in the study area can be considered in two groups: 1) non-water-bearing rocks, and 2) the water-bearing deposits. The non-water-bearing rocks, which form the bordering mountains and highland areas of the valley, are generally impermeable, except where fractured. Although small quantities of ground water probably could be obtained from such fractured zones, the consolidated rocks are not a practical source of ground water in the valley. Although the valley is up to 6,500 feet, the main hydrologic concerns are with the unconsolidated alluvial deposits in the upper 1,000 feet.

The water-bearing deposits, which overlie the non-water-bearing rocks in the valleys, consist of interbedded layers of clay, sand and gravel. These deposits are in part very permeable with the saturated deposits below the water table constituting the aquifers of the ground water basins.

Most of the wells draw from the unconfined part of the deep aquifer and penetrate only from 50 to 400 feet. Wells perforated in these deposits yield as much as 3,800 gpm (gallons per minute), with specific capacities up to 445 gpm per foot of drawdown (Moyle, 1963 and Banta, 1973). Information on the aquifer characteristics for the ground water basins is deficient except for portions of the Indian Wells Valley. Figure II-4 shows the water bearing areas near Coso.

4.5.1 Ground Water Movement

In general, the direction of ground water movement in the Coso is from north to south from the Owens Valley to northern Indian Wells Valley and west to east in Indian Wells Valley. Water level maps for the lower Owens and Rose Valley were not available, but water levels just north of Owens Lake indicated a north to south direction of ground water movement. The general direction of movement of ground water can be inferred from the water level contour lines on Figure II-11.

A ground water divide is considered to stop ground water movement from Owens Valley into Rose Valley except for seepage lost from the Haiwee Reservoir. Calculated subsurface outflow at this boundary was approximated at 11,000 acre-feet per year (Los Angeles Department of Water and Power, 1972). Both Rose Valley and Coso Basin have subsurface flow southward into Indian Wells Valley (Thompson, 1929).

In Indian Wells Valley there is a deep and a shallow aquifer (Figure II-1). The deep aquifer is a water table aquifer in western and northern Indian Wells Valley extending into Coso Basin and Rose Valley. A shallow aquifer overlies clay zones which confine the deep aquifer in the eastern part of Indian Wells Valley.

4.5.2 Ground Water Recharge

Under natural conditions, ground water moves through the deep aquifer from the areas of recharge along the southwest, west, north and northeast toward China Lake playa in the east-central part of the basin (Figure II-6). Near the China Lake playa the deep aquifer discharges into the shallow aquifer. This discharge is the only significant source of natural discharge from the deep aquifer and is the only significant source of natural recharge to the shallow aquifer. Evaporation from the playa surfaces and transpiration from local phreatophyte growth are the only significant sources of natural discharge from the shallow aquifer (Bloyd and Robson, 1971).

The principal source of ground water recharge is runoff from the mountains surrounding the valleys. Very little recharge is derived from rain on the valley floor. Local rainfall is generally exceeded by evapotranspiration, and only a small quantity penetrates below the root zone of the vegetation. Part of the Naval Weapons Center's treated sewage water recharges the shallow water body in the areas of the sewage ponds and golf course. This recharge occurs north of the City of China Lake. The rest is lost to the atmosphere. Part of Ridgecrest's treated sewage is used to irrigate alfalfa, and the rest is discharged to spreading ponds near the treatment plant which is located south of the city. Only a small part of this treated sewage is returned to the ground water basin.

The largest increment of recharge for Indian Wells Valley is derived from the east slopes of the Sierra Nevadas, west and southwest of Inyokern, where the heaviest precipitation within the area occurs. Second in importance are the steep fans and escarpment of the Sierra Nevada northwest of Inyokern, where the catchment area is smaller and the quantity of precipitation is less. A third increment, probably small, is derived from Rose Valley through a narrow channel at Little Lake. A very small quantity of recharge reaches the main water body

from the Argus Range, but the quantity is small because of the small amount of precipitation in that area. Other very minor quantities are derived from Coso Basin and the El Paso Mountains.

Figure II-5 shows recharge values for the deep aquifer as calculated in a mathematical ground water model for Indian Wells Valley (Bloyd and Robson, 1971). Recharge to the deep aquifer occurs as groundwater underflow from the permeable materials in canyons of the Sierra Nevada and the Coso and Argus Ranges and as deep percolation of some of the streamflow from Rose Valley and Freeman Gulch. Total recharge was estimated at 9,850 acre-feet per year.

Most of the water level changes in the shallow water body during the period 1953-65 were positive; the net recovery was due to recharging sewage and irrigating the golf course. The maximum water level rise was about six feet (Moyle, 1973).

North of the KGRA boundary, the Owens and Rose Valleys are separated by a topographic drainage divide. The Haiwee Reservoir is located on the Rose Valley side of the topographic divide. This topographic divide overlies a ground water divide and therefore a general subsurface movement of ground water would not occur across this boundary. However, evidence in the area south of Haiwee Reservoir indicates the existence of subsurface outflows. It is felt that these flows develop primarily from seepage loss out of Haiwee Reservoir.

Based on an estimated hydraulic gradient between Haiwee Reservoir and the ground water table in the region south of the study area and an estimated cross-sectional area of saturated alluvium, the calculated subsurface outflow across the southern boundary is approximately 11,000 acre-feet per year or 15 cfs (Los Angeles Department of Water and Power, 1972).

4.5.3 Ground Water Discharge

The total ground water discharge from the valleys is the sum of evapotranspiration, ground water outflow, and net draft from pumping. The natural discharge under conditions of virtually no pumping is equal to evapotranspiration and ground water outflow. Ground water that was earlier lost by natural discharge at the playa as in eastern Indian Wells Valley is now being captured by pumping in the vicinity of China Lake, Inyokern and Ridgecrest. This pumping has caused a net decline of water levels in the deep aquifer in these areas. During the 1953-65 period, there was a measured net decline in water levels in the deep aquifer ranging from a maximum of more than 20 feet northwest of Ridgecrest to a minimum of about 8 feet near Inyokern. In most of the marginal areas, however, the changes were negligible where known, and in the area of natural groundwater discharge near the China Lake playa, the changes in the deep aquifer were less than one foot or undetectable (Moyle, 1973).

Most wells penetrate the unconfined part of the main water body from depths less than 400 feet (Moyle, 1963). Table II-2 shows the estimated pumpage in Indian Wells Valley from 1962 to 1972.

In the northern portion of Rose Valley, there is one water user, a farmer, pumping an estimated 5,163 acre-feet per year with wells 675 and 724 feet below land surface (Los Angeles Department of Water and Power, 1978). Subsurface flow from Rose Valley into Indian Wells Valley occurs below Little Lake at about 45 acre-feet per year. The Coso Basin discharges into Indian Wells Valley through Coso Wash, Petroglyph Canyon, Renegade Canyon and Mountain Springs Canyon at about 2,750 acre-feet per year (Bloyd and Robson, 1971).

TABLE II-2

**ESTIMATED PUMPAGE FOR CALENDAR YEARS
1966-1972 IN INDIAN WELLS VALLEY
(IN ACRE-FEET)**

Year	Pumpage
1963	11,000
1964	11,600
1965	11,600
1966	12,400
1967	12,300
1968	13,000
1969	13,500
1970	14,000
1971	14,300
1972	15,200

Sources: Banta, R.L., Groundwater Conditions during 1971 and 1972 in Indian Wells Valley, California, USGS Open-File Report, 1972-73.

4.5.4 Ground Water Quality

The geographic and geologic controls govern the occurrence, movement and chemical quality of the ground water in the area. The variability of the chemical quality of the water contained in the aquifers is due to differences in location with respect to the water table, opportunities for recharge and to the high evaporation rate in the hot arid climate. The water quality data available is for Indian Wells Valley. Water quality diminishes as it approaches the China Lake playa. The shallow aquifer contains water that has greater than 1,000 mg/l of total dissolved solids (Moyle, 1973). (Appendix E contains information on water quality.)

Water in the unconfined part of the deep aquifer is generally of good quality, but locally, in the area southeast of Ridgecrest, some unconfined zones in the main water body are brackish to highly saline. In the area of confinement, the water is generally of poor quality; in the deepest part, penetrated by well 22P1, located at T. 26 S., R. 40 E., below 850 feet, the water, as inferred from an electric log, is extremely saline (Kunkel and Chase, 1969).

Water in the confined portion of the deep aquifer is generally in poor hydraulic connection with the shallow aquifer except where it is discharging into the China Lake playa.

For Indian Wells Valley, the temperature of ground water normally fluctuates very little during the course of a year. The fluctuation is normally greatest in shallow wells and least in deep wells. The temperature of water in wells tapping deposits 50 to 150 feet below the land surface usually is constant and approximately equal to the mean annual temperature of the region. In the main water body in Indian Wells Valley, this temperature is generally 68° to 70°F. In wells 400 to 452 feet deep, the temperature is 76° to 83°F, which is above the normal geothermal gradient of 1° to 2°F for approximately each 100 feet of depth (Kunkel and Chase, 1969). Appendix E shows a selected listing of ground water quality analyses.

PART III
MONO-LONG VALLEY

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CHAPTER III

MONO-LONG VALLEY

1.0 SUMMARY

The objective of this report was to assess the following for the Mono-Long Valley, California, Known Geothermal Resource Area (KGRA):

- water resources that are available for geothermal electric power plant development
- power plant make-up water requirements
- the developable megawatts based on available make-up water
- the need for additional water resource data

The availability of outside sources of make-up water for power plant operations is a major consideration in developing geothermal resources in the Mono-Long Valley area. The quality, quantity and availability of both surface and ground water for use in geothermal power plants was examined. The demand for water was based upon the previously conducted geothermal power plant water utilization case study (Part X). Although certain data are available for water resources in the area, complete information is lacking for ground water resources. This lack of complete data preclude projections of developable megawatts of geothermal power plant output. Procurement specifications have been prepared to acquire the requisite data to determine water available for geothermal power plant in the Mono-Long Valley geothermal area.

1.1 Surface Water Supply

Analysis of surface water resources in the Mono-Long Valley area indicate the following:

- **There are two primary watershed areas in the Mono-Long Valley area.**
- **The northern area, Mono Basin, receives approximately 216,000 acre-feet (296 cfs) of runoff annually.**
- **The southern area, including both the Long Valley and Mammoth Basins, receives approximately 280,500 acre-feet (384 cfs) of annual runoff.**
- **Major streams in the Mono Basin include Rush Creek, 61,400 acre-feet of annual runoff, Lee Vining Creek, 48,300 acre-feet of annual runoff, and Mill Creek, 21,200 acre-feet of annual runoff.**
- **In the Long Valley Basin, major streams include the Owens River, 132,600 acre-feet annual runoff, Hot Creek, 46,700 acre-feet annual runoff, McGee Creek, 24,700 acre-feet annual runoff.**
- **Major surface water bodies include Mono Lake and Lake Crowley.**
- **Water quality in Mono Lake is extremely poor, in excess of 60,000 ppm TDS in 1975.**
- **Lake Crowley water is dedicated for use by the City of Los Angeles Department of Water and Power (LADWP).**

- Both Mono and Long Valley basins serve as watershed areas for the LADWP.
- Use of surface water in the Mono-Long Valley will require coordination and agreement with the LADWP.

1.2 Ground Water Supply

Analysis of ground water resources in Mono-Long Valley indicate the following:

- Both shallow and deep aquifers exist in the Long Valley Basin.
- A shallow aquifer exists above the Bishop tuff and contains water which meets quality and temperature requirements for power plant cooling purposes.
- The deep aquifer, below 3,200 feet, contains water with temperatures exceeding the requirements for power plant cooling.
- Ground water data on Mono Basin is generally not available.
- Given the above, complete analysis of the ground water resources in the Mono-Long Valley cannot be developed.

1.3 Power Plant Water Requirements

Based on data developed in the case study, the following are the estimated total make-up water requirements for a 50 MWe power plant in the Mono-Long Valley KGRA, where the geothermal resource temperature is 220°C:

<u>Type of Plant</u>	<u>Water Requirements (1) (Acre-Feet/Year)</u>
Flashed Steam (direct contact)	2,890
Flashed Steam (indirect contact)	3,700
Binary Cycle	6,700 (2)

(1) Based on blow-down discharge of 4,000 ppm TDS, and (2) Make-up water 1,000 mg/l TDS

2.0 CONCLUSION

Surface water in the Mono-Long Valley area is available in sufficient quantity to provide a source of make-up water for geothermal power plant cooling purposes. The surface water in the area is, however, under the control of the LADWP and would, most likely, not be available for use in geothermal power plants. The surface water in the area is exported by the LADWP to the City of Los Angeles for domestic and industrial uses. Potentially water from Mono Lake could be used as a source of make-up water. Based on current design technology, Mono Lake may not, however, be a source of make-up water.

Ground water resources in the area were also examined. A certain amount of information was available on storage capacity of the shallow aquifer (depths to 220 feet), however, data were not available on the deeper aquifer. The existing data indicate the aquifer extends to greater depths, thus the estimates of storage capacity are less than the actual amount of ground water in-storage. To determine the ground water quality, temperature, aquifer productivity and storage, procurement specifications have been developed.

2.1 Make-Up Water Availability

Given the constraints on the use of surface water for power plant cooling purposes, ground water resources are the only alternative. Based on available data, the estimated ground water in-storage in the shallow aquifer is estimated to be 3.4 million acre-feet in the Mono Basin and 1.6 million acre-feet in the Long Valley Basin. Table III-1 indicates the estimated ground water in-storage in Mono and Long Valley IV-1 Basins.

2.2 Developable MWe

The lack of sufficient data on ground water precludes an analysis of geothermal power plant development in the Mono-Long Valley area. The USGS and JPL estimates for the capacity of the resource in the area is 2,000 MWe. The latest available data from the utilities indicate a 32 MWe co-generation facility is planned to be on-line in 1985. Southern California Edison is the utility involved in this project (see Task 1).

2.3 Procurement Specifications

Data on surface water in the Mono and Mammoth Basins was sufficient to assess the availability of this source of water. Groundwater data, however, were lacking in the Mono Basin area; thus a complete analysis of the source of water was not possible. Given the lack of complete data, procurement specifications have been prepared. The specifications, in general, delineate the area involved, the data to be collected and the methodology to be used in the collection of the data. The procurement specifications are shown in Appendix F.

TABLE III-1**ESTIMATED GROUNDWATER IN STORAGE**

Basin	Estimated Groundwater Storage (acre-feet)	Depth Zone (feet)
Mono Basin	3.40×10^6	20 - 220
Long Valley	1.60×10^5	20 - 120

Source: California Department of Water Resources, Reconnaissance
of Mono and Inyo Counties, California, 1960.

3.0 RECOMMENDATIONS

3.1 Initiatives and Activities

3.1.1 Federal

The primary recommendations for further analysis for the availability of water resources in Mono-Long Valley are:

- Proposals should be solicited to develop the groundwater data described in the procurement specifications (see Appendix F). Complete data are necessary to fully analyze the water resources situation.
- Long range planning and discussions should be initiated with the Los Angeles Department of Water and Power relative to the use of surface water in the Mono-Long Valley area. Notwithstanding further data on groundwater resources, considerations relative to utilization of surface water should be examined.
- In addition to these considerations, initiatives should include long range planning and discussions with the U.S. Forest Service relative to developments in the Inyo National Forest. The Primary area of geothermal interest, Casa Diablo, is located on USFS land.

3.1.2 State

State activities should involve primarily working with the utilities and developers relative to surface water discharge. Potentially, requirements which are too stringent would act to discourage geothermal development within the area. Proper analysis of surface water discharge requirements and appropriate mitigation measures to offset adverse environmental effects could act to maintain or potentially increase interest for geothermal development in the area.

3.1.3 Local and Counties

As geothermal development activities in the area increase, coordination of surface and ground water uses will be required. Since the Mono-Long Valley area has variations in water requirements as a result of fluctuations in the permanent and temporary pollution, geothermal development activities will require local and county input to develop any long-range plans. The county should act as lead on these planning activities to ensure proper coordination.

4.0 TECHNICAL DISCUSSION

4.1 Methodology

A general method of approach was established to accomplish the major objectives of the study. The initial step of this methodology was to determine the objectives of the study. A comprehensive literature search was conducted to collect all published water resources literature required for the evaluation. Sources of data were various government agencies, institutions, and private organizations. A systematic literature review by technical key words was then conducted. Field investigations were then conducted among these groups to ascertain unpublished data and reports and also to confirm findings of previously published materials.

For surface water, major surface water bodies were identified, their physical and chemical characteristics evaluated, and their capacities determined based on these evaluations. In the ground water evaluation, aquifers in the area were identified; their physical and chemical characteristics evaluated, and their capacity and productivity assessed.

Figure III-1 indicates the major steps of the methodology.

Figure III-1 FLOW DIAGRAM OF METHOD OF APPROACH

4.2 Survey of Existing Information

The purpose of the literature search is to screen published reports and materials that are pertinent to the water resources evaluation. The initial step of this literature search was to contact various government agencies and private organizations to collect the required data.

All the literature collected are recorded on card catalogue under a specific format. For example,

Author: Lewis, R. E.
Report Title: Data on Wells, Springs and Thermal Springs in
Long Valley, Mono County, California
Source: USGS Open File Report
Date or Year
of Publication: 1974
Index Number: L1-ML

The index number identifies the first alphabet of the principal author's last name, the number of publication listed under the alphabet, and the study area of concern. The letters ML indicate Mono-Long Valley scenarios. Each report is then labeled by the index number.

Appendix A contains a listing of all pertinent literature collected for this study area with the appropriate index numbers. Notation of figure, table and page number of the report relative to the specific keyword were recorded during the review.

During the literature review process, six key data sources were identified and were used to provide a major input into the water resources evaluation of Mono-Long Valley, California. They are listed as follows:

- California Department of Water Resources
1960 "Reconnaissance investigation of water resources of Mono and Inyo Counties." (Ref. No. C3-ML)
- California Department of Water Resources
1967 "Investigation of geothermal waters in the Long Valley area, Mono County." (Ref. No. C2-ML)
- California Regional Water Quality Control Board
1975 "Water quality control plan report, South Lahoutan Basin 6B." (Ref. No. C4-GEN)
- California Region Framework Study Committee
1970 "Comprehensive framework study, California region, Appendix V, water resources." Prepared for Pacific Southwest Inter-Agency Committee Water Resources Council. (Ref. No. C3-GEN)
- Los Angeles Department of Water and Power
"Los Angeles water rights in the Mono basin and impact of the department's operations on Mono Lake." (Ref. No. L2-ML)
- Pakiser, L. C. et al.
1964 "Structural geology volcanism of Owens Valley region, California geophysical study." USGS Professional Paper 438 (Ref. No. P1-ML).

In addition to the literature search, it was necessary to search for any unpublished literature or any new developments in the water resources of the Mono-Long Valley area. Telephone contacts and visits were made to various government agencies and private organizations to validate and search for additional water resources data.

Appendix C contains a list of persons, agencies, addresses and date of visits and telephone contacts.

4.3 Location of Study Area

The Mono-Long Valley KGRA is located in the east central part of California and in the general Mono Lake area. The KGRA covers approximately 455,000 acres and is located in Mono County. The actual study area was delineated as a function of the hydrologic considerations and availability of data rather than on a political or jurisdictional boundary. Figure III-2 shows the location of the Mono-Long Valley KGRA.

The KGRA is located within two major hydrological basins, Mono and Long Valley. Mono Basin is a northeast-trending rectangular depression at the base of the steep east-facing Sierra Nevada escarpment. The basin is nearly 50 miles in length and over 20 miles in width, and has a total area of 801 square miles. Land surface elevations vary from approximately 6,400 feet at the surface of Mono Lake to over 13,000 feet along the peaks of the Sierra Nevada. The Long Valley basin covers an area of 370 square miles and is bordered on the west by the Sierra Nevada range and on the east by the Benton range.

4.4 Surface Water

4.4.1 Mono Basin

Mono Basin is an internal basin in that all surface runoff drains into a central depression within the basin and evaporates. This central depression, Mono Lake, is a prominent topographic feature having a surface area of 70 square miles and a maximum depth of approximately 110 feet, and it currently contains about 2.5 million acre-feet of water (LADWP, n.d.). However, because water loss from the reservoir occurs only through evaporation, water within the Lake contains total dissolved solids of 60,000 parts per million, just slightly less than twice the concentration of sea water.

Discharge into Mono Lake from streams in the area is both intermittent and perennial. The streams on the east side of Mono Lake are intermittent or ephemeral--flowing only after intense rainstorms. The major streams to the west of Mono Lake, Mill, Lee Vining, Walker, Parker and Rush Creeks are perennial. Figure III-3 shows the watershed for the Mono Lake area.

The streams along the western edge of Mono Basin contain several small reservoirs in and along the Sierra Nevada. Grant Lake, on Rush Creek, is operated by the City of Los Angeles as part of their Owens River

Figure III-3
MONO-LONG VALLEY
AND COSO AREAS
WATERSHED MAP

aqueduct. Other small reservoirs located on Rush, Lee Vining and Mill Creeks and their tributaries are used for hydroelectric power production by the Southern California Edison Company. These reservoirs have a total storage capacity of 90,000 acre-feet.

The major water diversion in Mono Basin is the 11-mile-long Mono Crater Tunnel. The capacity of the extension varies from 300 cubic feet per second (cfs) at the Lee Vining intake to 380 cfs at Mono Crater Tunnel. (One cfs equals 1.98 acre-feet per day.)

Surface runoff in the Mono Basin occurs largely from the melting snow pack during the spring and summer. The primary stream flows originate from the west on the easterly slopes of the snow-laden Sierra Nevada. The total estimated mean seasonal runoff in Mono Basin is 216,000 acre-feet, of which 189,800 acre-feet comes from east Sierra Nevada drainage area, and 26,200 acre-feet from the rest of the basin. The estimated total inflow into Mono Lake is 137,000 acre feet per year (DWR, 1960). Estimated runoff data for Mono Basin are shown in Table III-2.

The consumptive use of water for domestic and irrigation practices is about 7,000 acre-feet in the Mono Basin (WQCB, 1975). The City of Los Angeles leases out 2,000 acres of land as irrigated pasture, and 13,000 acres for dry grazing. The water diverted for use on this land amounts to an average of about 10 to 12 cfs per year (LADWP, 1974).

In addition to local water use, water is exported from Mono Basin to Long Valley by the City of Los Angeles for its aqueduct operation. Normally this diversion is limited so that the flow to the Owens Basin does not discharge into Owens Lake. The mean annual export of water from the Mono Basin has increased from 78 cfs (56,940 acre-feet) in 1965-70 to approximately 140 cfs (102,200 acre-feet) in 1974. Based on

TABLE III-2

**ESTIMATED MEAN SEASONAL NATURAL RUNOFF
IN MONO BASIN
(IN ACRE-FEET)**

Stream	Annual Runoff (1894-95 through 1958-59)
Walker Creek at Walker Lake	5,220
Rush Creek below Silver Lake	61,440
Parker Creek below Parker Lake	8,130
Lee Vining Creek at Power Plant No. 3	48,280
Mill Creek at Sandy Lake	21,230
Remainder of East Sierra drainage	45,500
Sub-total, East Sierra drainage to Mono Lake	189,800
Remainder of Mono Basin	26,200
Total, Mono Basin	216,000

Source: DWR 1960.

this data, water from Mono Basin provides nearly 20% of the City of Los Angeles' water supply (Georgeson, 1978). It should be noted that the State Water Resources Control Board has issued the City of Los Angeles a permanent license for a maximum diversion of 167,800 acre-feet (232 cfs) per year from Mono Basin (see Table III-3).

The position of the City of Los Angeles is a key consideration in the development of geothermal resources in the Mono-Long Valley area. The City of Los Angeles has been granted a license to export 232 cfs per year of water from Mono Basin. Currently, the City is withdrawing 140 cfs per year of water from this Basin, leaving approximately 113,800 acre-feet. If the City claims all of its rights, only 46,640 acre-feet of water will remain for other uses. Most of the federal lands in the Mono Basin have been withdrawn from entry in order to protect the Los Angeles city water supply. Thus, no water can be obtained for geothermal power plant cooling purposes from the Mono Basin without infringing upon the City of Los Angeles' water rights (Gewe, 1978).

The Lahontan Regional Water Quality Control Board (No. 6) has prescribed certain water quality objectives for surface water in the Mono Basin. The overall objective of this policy is not to degrade the surface water quality in the Mono Basin. Thus, any surface discharge into existing streams and rivers which might create degradation would, most likely, not be permitted. Thus, any power plant discharge would have to be injected in order to meet these requirements.

4.4.2 Long Valley Basin

The Long Valley watershed is situated south of Mono Basin in Mono County and contains an area of 370 square miles. The Valley is bordered on the west by the Sierra Nevada Range and on the east by the Benton Range. Nearly all of this area, except for approximately 68 square miles around Lake Crowley, which is owned by the City of Los Angeles, lies within the confines of the Inyo National Forest. As in

TABLE III-3

SUMMARY OF WATER UTILIZATION IN THE MONO BASIN

Surface runoff	216,000 AF/Yr.
Water utilization	
Urban and irrigation	7,300 AF/Yr.
Export	102,200 AF/Yr.
Evaporation from Mono Lake	106,500 AF/Yr.
Sub-Total	216,500 AF/Yr.
Evaporation from Grant Lake	2,400 AF/Yr.
TOTAL	218,000 AF/Yr.

the case of Mono Basin, almost all federal land in the area is withdrawn from public entry in order to protect the water resources of the City of Los Angeles (California DWR, 1967). Figure III-3 shows the watershed area for Long Valley Basin.

The headwaters of the Owens River are located in the northwesterly portion of the basin. The Owens River flows southeasterly across Long Valley into Long Valley Reservoir (Lake Crowley, a man-made lake with a maximum capacity of 183,456 acre-feet). Approximately 50% of the flow from the Los Angeles Aqueduct is supplied by Lake Crowley. Major streams contributing to Lake Crowley are the Owens River, Mammoth Creek (Hot Creek), Convict Creek, McGee Creek and Hilton Creek.

Most of the surface runoff for the area originates in the Sierra Nevada Mountains along the western and southern end of the basin. As part of their aqueduct system, the Los Angeles Department of Water and Power has conducted extensive stream monitoring in the Mono Basin. Based on these data, Sorrey, Lewis and Olmstead (1977) estimated the total inflow into Lake Crowley from the various streams in the area to be 378.3 cfs (276,160 acre-feet/year). Figure III-4 shows the drainage areas and streamflow measuring stations in the Long Valley Basin.

Additional runoff, all which has not been measured, is generated from three major areas. The first area is from 10,900 acres along the lower edge of the Sierra Nevada south of the caldera. Secondly, an area of 49 square miles between Bald Mountain and Blass Mountain Ridge north of the caldera and around to Long Valley Dam on the east is a source of additional runoff. The third major source occurs from a 21-square-mile area near the resurgent dome.

Precipitation is also a source of additional flow into Lake Crowley. Based on the latest data, Lake Crowley has a surface area of 5,190 acres. If an average precipitation of 10 inches per year is assumed (low for this area), the annual precipitation falling on Lake Crowley

▲ STREAM GAUGING STATION

Figure III-4

**TRIBUTARY DRAINAGE AREAS AND STREAMFLOW-MEASURING
STATIONS IN THE LONG VALLEY BASIN**

is equivalent to 5.92 cfs (4.130 acre-feet). Adding this precipitation to the total flow from streams discharging into Lake Crowley, the annual surface water budget input is 384 cfs (280,490 acre-feet). Table III-4 shows the surface runoff into Lake Crowley.

The Long Valley watershed provides approximately one-half of the water which is exported to Los Angeles via the aqueduct. To ensure the future availability of water, most of the federal land within the basin has been withdrawn to protect the water supply for the City of Los Angeles. Therefore, cooperation with the Los Angeles Department of Water and Power is essential for the provision of cooling water for any power plants which may be constructed in the area. Given the long-term demands for water, it is doubtful that any additional water will be available in the Long Valley area for geothermal power plants (Geuser, 1978, pers. comm.).

Other legal issues have arisen over attempts to obtain additional water rights within the Long Valley Basin. The Mammoth County Water District submitted a proposal for augmenting an additional 3 cfs (2,190 acre-feet) from the Mammoth Lakes Basin. The Forest Service prepared an environmental analysis for the plan (Sapsek and Withers, 1977). The principle alternative for obtaining additional water was to pump it from Lake Crowley. However, this alternative was found infeasible because of both environmental constraints and legal constraints on the withdrawal of water from the reservoir.

Water quality standards passed by the Lahontan Regional Water Quality Control Board may also affect geothermal development within Long Valley. These standards prescribe waste discharge requirements for the geothermal wells at Casa Diablo Hot Springs area of Long Valley. Geothermal energy developers could not meet these discharge requirements, thus exploration was curtailed. These standards essentially indicated no degradation of surface water quality in the area. Strict enforcement of these water quality standards could, potentially, act to constrain future geothermal power plant development.

TABLE III-4
SURFACE RUNOFF INTO LAKE CROWLEY
FOR WATER YEAR 1964-1974

Streams	Discharge	
	(CFS)	(AF)
Owens River below East Portal	181.6	132,570
Hot Creek at the Gorge	64.0	46,720
McGee Creek	33.8	24,670
Convict Creek	28.4	20,730
Hilton Creek	12.2	8,900
Rock Creek Diversion	10.4	7,590
Laurel Creek	5.9	4,310
Crooked Creek	4.0	2,920
Ungauged inflow	38.0	27,740
SUB-TOTAL	378.3	276,160
Precipitation on Lake Crowley	5.9	4,130
TOTAL	384.2	280,470

4.5 Ground Water

The geologic units in the study area are divided into two groups: 1) non-water bearing deposits, and 2) water-bearing deposits. The contact between these two groups is approximately the area shown on Figure III-3. Potential areas for ground water are the Mono and Long Valleys which are underlain by thick alluvium deposits. With respect to ground water resources, unconsolidated alluvium in the upper 1000 feet of these deposits are the main areas of concern. Determination of the extent of these deposits will require a ground water procurement program. The extent of available ground water resources in Bridgeport Valley may not be significant due to the relatively small storage capacity and its location outside of the KGRA boundary.

4.5.1 Ground Water Movement

The general direction of ground water movement can be interpreted from water level contours. However, adequate water level data is not available to produce a map of the ground water movement in the entire area. In general, the ground water in Mono Basin moves from areas of recharge on the eastern slopes of the Sierra Nevada to areas of discharge at Mono Lake. A part of the aquifer near the edges of Mono Lake are overlain by an aquiclude which confines vertical movement of the ground water as evidenced by artesian wells found north of the Lake; however, the aquifer apparently outcrops below the surface of the Lake.

The ground water system in Long Valley is comprised of both shallow and deep aquifers. The two aquifers are not sharply delineated. Generally, the shallow aquifer is contained in the fill above the densely welded Bishop tuff which underlies most of the Long Valley caldera. Ground water in the shallow subsystem circulates through the relatively coarse-grained, more permeable sediments and, locally, through brecciated or faulted zones in the volcanic flows. Much of the material,

however, is of clay, tuffaceous, or altered sedimentary deposits or dense flows of extremely low permeability. Such material forms confining layers which form separate aquifers within a large shallow aquifer. More significantly, a zone of low permeability separates the shallow and deep aquifers from each other except locally where high-angle normal faults provide interconnecting channelways for upward or downward flowing ground water (Sorey, 1977). Figure III-5 shows the thickness of the Valley fill above the Bishop tuff.

The direction of ground water movement is at right angles to the water level contour lines and toward the next lower contour line. Ground water movement is from west to east beginning in the areas of surface runoff recharge in the Sierra Nevada (Deadmen Creek and Hot Creek) and flowing eastward toward the Owens River and Lake Crowley. Figure III-6 shows the direction of ground water movement for the Long Valley area.

4.5.2 Ground Water Recharge

Ground water in Mono and Long Valley originates primarily from percolation into underground strata of precipitation falling directly on alluvial fill material and of water flowing in streams or over the ground surface as runoff from the Sierra Nevada and other surrounding mountains. Recharge to the Mono ground water basin occurs in alluvial fans, and to some extent in the glacial moraines which fringe the basin. Ground water moves from the recharge areas toward Mono Lake. A major portion of the ground water apparently discharges into Mono Lake below the lake surface from the open end of the confined aquifer. Depth to water level varies from 300-400 feet in the recharge areas to artesian in areas of discharge. In the Long Valley area recharge is received from Deadman Creek and Hot Creek on the west. The map of water levels (Figure III-6) indicates that the Owens River is recharging the aquifer.

Figure III-5

THICKNESS MAP OF FILL ABOVE BISHOP TUFF
IN LONG VALLEY CALDERA, CALIFORNIA

Source: M.L. Sorey, et al, the Hydrothermal System of Long Valley Caldera, California U.S.G.S. Open-File Report 77-347, 1977.

Figure III-6

GROUNDWATER LEVEL MAP OF SHALLOW AQUIFER
IN LONG VALLEY CALDERA, CALIFORNIA

Adapted from:

M.L. Sorey, et. al, the Hydrothermal System of Long Valley Caldera, California, U.S.G.S. Open-File Report 77-347, 1977.

4.5.3 Ground Water Discharge

Ground water discharge occurs as the ground water moves at a very slow rate through the permeable underground strata toward the low points of the valleys. As the ground water accumulates in the basins, the water table rises until, at the low valley points, it discharges through springs into streams and lakes. A major portion of ground water discharge in the Mono Basin is into Mono Lake below the lake surface from the open end of the aquifer. Within Long Valley it is believed that subsurface outflow occurs into Owens Valley through and under the Bishop tuff. There is also discharge of hot water springs into Lake Crowley.

4.5.4 Groundwater Quality

Geographic and geologic controls determine the occurrence, movement and chemical quality of the ground water in Mono and Long Valleys. The variability of the chemical quality of the ground water is due to differences in location with respect to the water table and opportunities for recharge. Ground water to the west receives runoff from the Sierra Nevada and is generally excellent in mineral quality. Total dissolved solids (TDS) generally range from 60 to 400 mg/l. In the area northeast of Mono Lake ground water is of inferior quality with a TDS content of 2,600 mg/l. A few small isolated sources, such as hot springs, produce water of poor quality (CDWR, 1964).

Water quality in the areas of recharge into Mono Lake will have a tendency to be of higher TDS potential. Ground water pumpage in the alluvium surrounding Mono Lake could lower water levels and induce movement of water high in TDS from Mono Lake into the aquifer.

Ground water quality data are of limited extent in the study area. Appendix E contains a selected list of ground water quality for Long Valley. Good quality water is available from meteoric waters off the

slopes of the Sierra Nevadas. Significant concentrations of boron, fluoride and arsenic occur in ground waters above the periphery and near the central portions of the caldera as well as in hot springs, alkali lakes and geothermal wells (CDWR, 1967). The quality of ground water diminishes with increasing depth into the alluvium. Appendix E contains additional ground water data.

PART IV
GEYSERS-CALISTOGA

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PART IV

GEYSERS-CALISTOGA

1.0 SUMMARY

The objective of this report was to assess the following for the Geysers-Calistoga, California, Known Geothermal Resource Area (KGRA):

- water resources that are available for geothermal electric power plant development
- power plant make-up water requirements
- the developable megawatts as a function of the available make-up water
- the need for additional water resource data

The availability of outside sources of make-up water for power plant operations is a major consideration in developing geothermal resources in the Geysers-Calistoga area. The quality, quantity and availability of both surface and ground water for use in geothermal power plants were examined. The demand for water was based upon the previously conducted geothermal power plant water utilization case study. These investigations and analyses yielded an estimate of the total megawatts that can be developed at the Geysers-Calistoga KGRA. Under current technology, power plants in the Geysers-Calistoga area which use dry steam as a fuel source do not use an outside source of make-up water, thus development to the full potential could occur. In the hot water field, where an outside source of water may be required, sufficient surface and ground water sources are available to fully develop the geothermal resource. This water would, however, require storage and distribution in order to be usable in any power plant development.

1.1 Surface Water Supply

Analysis of the surface water resources for the Geysers area indicate the following:

- The Geysers area receives relatively heavy precipitation (22 to 80 inches of rainfall per year).
- The surface hydrologic considerations of The Geysers area is complex because of the four major watersheds (Cache and Putah Creeks, Napa, and Russian Rivers) in the area.
- The major surface water bodies in the area and their storage capacities are Clear Lake, (1,000,000 AF), Lake Mendocino (122,900 AF), Lake Hennessey (31,000 AF).
- The primary source of surface water which would be available for geothermal power plant cooling is spill-over from these surface water bodies.
- Based on the latest data available, the spill-over from Clear Lake (Cache Creek Basin) is approximately 107,600 acre-feet per year and from Lake Berryessa (Putah Creek Basin) 61,600 acre-feet per year. In the Russian River Basin and Napa Valley Basin, unappropriated water is not available.
- The water quality in the various rivers, streams and lakes in the area is relatively high with TDS normally below 1,000 ppm.

1.2 Ground Water Supply

Findings related to ground water in The Geysers area indicate the following:

- Five major ground water basins (Clear Lake, Russian River, Sonoma Valley, Napa and Petaluma) are in the area of the Geysers Calistoga geothermal area
- Within these major basins, there are 20 significant ground water basins

- The total estimated ground water in-storage in the area is 14,660,000 acre feet, composed of the following, Clear Lake 200,000 acre-feet, Russian River 9,300,000 acre-feet, Sonoma Valley 2,760,000 acre-feet, Napa Valley 300,000 acre-feet, and Petalume 2,100,000 acre-feet.
- Each of the separate ground water basins have varying potential for further development without exceeding the safe yield limits.
- In the Clear Lake area, only two of the basins, Coyote and Collayomi Valleys, have the potential for further development without exceeding safe yield limits
- For the Russian River Valley area, Santa Rosa, Healdsburg, Alexander and Knights Valley, can be further developed
- The Sonoma, Napa and Petaluma Valley areas all have the potential for additional development without exceeding the safe yield limits
- Although yields from wells in the area vary, most of the well data indicate yields of from 500 to 1,500 gpm.

1.3 Power Plant Water Requirements

Based on data developed in the case study, the following are the estimated water requirements for a 50 MWe power plant in The Geysers hot water geothermal field:

<u>Type of Plant</u>	<u>Annual Water Requirement*</u>
Flashed Steam (direct contact)	3,160 acre feet
Flashed Steam (indirect contact)	4,250 acre feet
Binary Cycle	7,100 acre feet

*Based on blow-down discharge of 4,000 ppm TDS and make-up water of 1,000 mg/l TDS

Note: the temperature of the geothermal resources is 200°C

2.0 CONCLUSIONS

Analysis of the supply of water resources and the demand for water by the various types of geothermal power plants provides a method for identifying constraints on power development at The Geysers. This analysis of constraints is a function of five key factors:

- (a) estimated ultimate capacity of the geothermal reservoir
- (b) specific characteristics of the geothermal reservoir, primarily the resource temperature
- (c) type of power plant conversion cycle utilized
- (d) the scheduled on-line date of the power plants
- (e) blow-down discharge requirements

The interaction of these variables determines the quantity and quality of water demanded for geothermal development.

2.1 Make-up Water Availability

2.1.1 Surface Water

The largest potential source of surface water would be from the runoff of the drainage areas. This runoff would, however, have to be collected, stored and distributed to the various power plant sites. The major surface water bodies in the area would be the next most likely source of water. The water available from these bodies would be the result of any spill-over from these sources. The latest available data for Clear Lake indicate approximately 107,600 acre-feet of spill-over is unappropriated and could potentially be used for geothermal power plant cooling purposes. Lake Berryessa in the Putah Creek Basin currently has an estimated annual spillover of 61,600 acre-feet annually. The Corps of Engineers has indicated no excess supply of water in the Russian River Basin. The Napa Valley Basin similarly does not have a supply of surface water which could potentially be used for power plant cooling purposes.

Notwithstanding the availability of these sources of water, most of the spillover occurs during the rainy season--October through March--and very little is available during the summer months. Thus, adequate storage and distribution facilities will have to be developed if use is to be made of these sources of water.

2.1.2 Ground Water

The total storage capacity of the five major ground water basins in the area of The Geysers-Calistoga KGRA has been developed by the California Department of Water Resources (CDWR). Based on 1975 data, the latest available, the total storage capacity of these five ground water basins is estimated to be approximately 14,600,000 acre-feet. A summary of the ground water in storage and potential for development follows:

- Clear Lake Area

The total ground water storage capacity of the eight ground water basins in the Clear Lake area is estimated to be about 200,000 acre-feet. Usable capacity, estimated by CDWR (1975), is about 85,800 acre-feet for all users in the area. The ground water is of good quality and suitable for geothermal power plant cooling purposes. Only the Coyote and Collayomi valleys have potential for additional ground water development without exceeding safe yield limits for the ground basin.

- Russian River Valley Area

The total ground water storage capacity of the nine ground water basins in the Russian River Valley area is estimated to be about 9.3×10^6 acre-feet. Usable capacity, estimated by CDWR (1975), is about 1.2×10^6 acre-feet for all users in the area. The groundwater is of good quality and suitable for geothermal power plant cooling purposes. Only the Santa Rosa, Healdsburg, Alexander, and Knights Valley areas have

potential for additional ground water development without exceeding safe yield limits for the ground water basins.

- Sonoma Valley Area

The total ground water storage capacity of the Sonoma Valley area is estimated to be about 2.7×10^6 acre-feet. No usable capacity was estimated by CDWR but the ground water is of good quality and has a high potential for further development.

- Napa Valley Area

The total ground water storage capacity of the Napa Valley area is estimated to be about 300,000 acre-feet. No usable capacity was estimated by CDWR but the ground water is of good quality and has a high potential for further development. It is, however, mentioned that if current use or pumpage increase to 24,000 acre-feet there will not be any significant decline of the water level (CDWR 1975).

- Petaluma Valley Area

The total ground water storage capacity of the Petaluma Valley area is estimated to be about 2.1×10^6 acre-feet. No usable capacity was estimated by CDWR but the ground water is not good quality and has a high potential for further development.

2.2 Developable MWe

Analysis in the case study indicated the relationship between the various power plant conversion cycles and the water requirements. Under current practices at The Geysers dry steam field, an outside source of make-up water is not required for power plant cooling purposes. Based on this analysis, development of the Geysers dry steam area should not be constrained by water availability considerations.

The main environmental constraint on power plant development in the dry steam field is from air pollution emission problems.

Specific plans for developing power plants in The Geysers hot water field have not yet been formulated by developers or utilities. Potentially, development in the dry steam field will occur first and then additional activity will occur in the hot water field. Thus, the power on-line schedule for the hot water area was developed to approximate the data developed by JPL. The ultimate reservoir capacity, 2000 MWe, was based on USGS, EPRI and JPL-developed estimates.

Given these considerations and the available supply of water from both surface and ground water sources, potentially full development of The Geysers hot water field could occur. The available sources of water would meet the cooling water requirements even under the worst case conditions of development of all binary cycle power plants. The key consideration in this analysis would involve a viable system of storage and distribution of the water to the location of the power plant. To fully develop the hot water resources at The Geysers, the engineering/economic factors for the storage and distribution of either surface or ground water will have to permit the generation of competitively priced electrical energy.

2.3 Procurement Specifications

Data on surface and ground water in The Geysers-Calistoga area was sufficient for assesment purposes, thus procurement specifications are not recommended.

3.0 RECOMMENDATIONS

3.1 Initiatives and Activities

3.1.1 Federal

The primary recommendations for federal activities of water resources in The Geysers area are:

- Determine the engineering/economic aspects of surface and ground water distribution. The key factor in this analysis will be to determine the engineering feasibility of water distribution and its related costs in terms of the sale price of power. The final price of electrical output from geothermal plants will have to be competitive with other energy source. The location of The Geysers geothermal area in the mountainous region makes the engineering distribution analysis a critical factor.
- In addition to the distribution aspects, storage of available surface water will require analysis. The surface water in the area is available for use during the winter months (approximately October to March) and is not in supply during the summer months. Thus, surface storage of the available water will be required.
- Develop a long-range plan for acquisition of surface water from the appropriate water management agency. Each of the agencies with responsibility for surface water management in the area will require a long-range planning and discussion to ensure the required supply of cooling water.

3.1.2 State

State activities would involve coordination of the agencies in The Geysers area which have surface water management responsibilities. These agencies would potentially include the Department of Water Resources, the Water Resources Control Board and the Water Quality Control Board. The timely determination of specific policies on management of available surface water will be required to fully develop the hot water geothermal resources in The Geysers area.

3.1.3 Counties and Local

The coordinated development of the geothermal resources, and hence the outside water requirements, will require initiatives by the counties affected, Lake, Napa, Sonoma and Mendocino. These counties should develop coordinated plans for the use of available surface and ground water in the area. Since access to a source of outside water may be required to develop the hot water resource, these local activities should be directed toward the long-range development of plans.

3.2 Site Specific

3.2.1 Plant Siting

Analysis of surface and ground water availability indicates that development of the hot water geothermal resource could occur without constraints. The available water should be of sufficient quantity to support the development of the hot water field. Site specific recommendations would involve location of power plants to minimize any distribution system which might be required. Potentially, this would keep the cost of distribution at a minimum.

4.0 TECHNICAL DISCUSSION

4.1 Methodology

A general methodology was established to accomplish the major objectives of the study. The initial step of this methodology involved a comprehensive literature search to collect all published water resources literature required for the evaluation. Sources of data were various government agencies, institutions, and private organizations. A systematic literature review by technical key words was then conducted. Field investigations were then conducted among these groups to ascertain unpublished data and reports and also to confirm findings of previously published materials.

For surface water, major surface water bodies were identified, their physical and chemical characteristics evaluated, and their capacities determined based on these evaluations. In the ground water evaluation, aquifers in the area were identified, their physical and chemical characteristics evaluated, and their capacity and productivity assessed. A water budget balance was not calculated. Figure IV-1 indicates the major steps of the methodology.

4.2 Survey of Existing Information

The purpose of the literature search was to screen published reports and materials that are pertinent to the water resources evaluation. The initial step of this literature search was to contact various government agencies and private organizations to collect the required data.

All the literature collected are recorded on card catalogue under a specific format. For example,

Author:	California Department of Water Resources
Report Title:	Lake County Investigation, Bulletin No. 14
Source:	California Department of Water Resources
Date or Year of Publication:	1957
Index Number:	C10-G

FIGURE IV-1

FLOW DIAGRAM OF METHOD OF APPROACH

The index number identifies the first alphabet of the principal author's last name, the number of publication listed under the alphabet, and the study area of concern. The letters G indicate Geysers-Calistoga scenarios. Each report is then labeled by the index number.

Appendix A contains a listing of all pertinent literature collected for this study area with the appropriate index numbers. Notation of figure, table and page number of the report relative to the specific key word were recorded during the review (see Appendix B).

During the literature review process, six key data sources were identified and were used to provide a major input into the water resources evaluation of Geysers-Calistoga KGRA California. They are listed as follows:

Bureau of Reclamation, U.S. Dept. of Interior

1968 "Feasibility Studies of the North Coast Project--Eel River Division, English Ridge Unit, California, Groundwater Geology and Resources Appendix". (Ref. No. B2-6)

Cardwell, G.T.,

1965 "Geology and Groundwater in the Russian River Valley Areas in Round, Laybonville and Little Lake Valley, Sonoma and Mendocino Counties." USGS Water Supply Paper 1548. (Ref. No. C1-6)

California Department of Water Resources

1966 "Clean Lake Water Quality Investigation." Bulletin 143-2. (Ref. No. C2-6)

California Department of Water Resources

1957 "Lake County Investigation." Bulletin 14. (ref. No. C10-6)

California Department of Water Resources

1965 "Land and Water Use in Putah-Cache Creeks Hydrographic unit, Volume I". Bulletin 94-13. (Ref No C8-6)

Kunkel, F. and J.E. Upson

1959 "Geology and Groundwater of Napa and Sonoma Valleys, Calif." USGS Water Supply Paper 1495. (Ref, No. K1-G)

In addition, it was necessary to search for any unpublished literature or any new developments in the water resources of The Geysers-Calistoga KGRA area. Telephone contacts and visits were made to various government agencies and private organizations to validate and search for additional water resources data.

Appendix C contains a list of persons, agencies, addresses and date of visits and telephone contacts.

4.3 Location of Study Area

The Geysers-Calistoga KGRA is located in Lake, Mendocino, Sonoma and Napa Counties in the general area of Clear Lake. The KGRA covers 378,700 acres, with the primary area being in Lake and Sonoma Counties. The actual study area was delineated as a function of hydrologic considerations and availability of data rather than on a political or jurisdictional boundary. Figure IV-2 is a location map of The Geysers-Calistoga KGRA.

The Geysers Known Geothermal Resources Area comprises approximately 400 square miles of land 75 to 90 miles north of San Francisco on the Coast Range. The western part of the area is dominated by the rugged, northwest-trending Mayacmas Mountains which reach elevations of over 4000 feet; the eastern part of the area is characterized by volcanic domes, cones, and flows. There are no geysers in the Geysers KGRA, but numerous fumeroles and hot springs. A still-heated magma chamber southwest of Clear Lake, is believed to supply the heat for geothermal phenomena throughout the Geysers steam field.

4.4 Surface Water

The Geysers KGRA covers four major watersheds Cache Creek, Putah Creek, Napa River and Russian River watersheds. In addition, since the upper Eel River diverts most of its annual flow at Van Arsdale Dam to Potter

Valley over the upper East Fork of the Russian River, it is considered as part of the drainage system related to the Geysers KGRA. These watersheds are dominated by northwest-trending, linear ridges separated by narrow, V-shaped valleys. Major streams have cut trenches across this northwest-oriented grain. However, most of the streams run parallel to the grain.

The Mayacmas Range forms the highest range in this region, with ridge crests commonly above 3000 feet in elevation, and highest peaks above 4000 feet. Slopes are steep and often unstable and landslide prone. Ridge crest are flat to gently rolling. Geomorphically, therefore, the Mayacmas Range exhibits an uplifted submature landscape, incised by youthful, still-downcutting streams.

To the west of Mayacmas Range is the Russian River watershed which occupies 1,485 square miles of Sonoma and Mendocino Counties. West of the drainage area, the Mendocino Range, with elevations reaching 3,000 feet, is generally heavily forested.

Clear Lake (Cache Creek) basin has considerably lower average elevation and relief than the Mayacmas Range on the west. The area is generally mountainous with several large valleys suitable for cultivation. Elevations vary from 1,318 feet at zero on the Rumsey gage to 4,840 feet at High Glade Lookout in the Bartlett Mountains to the east of the Clear Lake. Most of the valley areas are adjacent to Clear Lake, though some mountains rise abruptly from the lake shore.

Putah Creek watershed in the south eastern KGRA is much like the Cache Creek watershed in terms of overall geomorphic appearance and elevation. The two basins are separated by a sinuous low divide; which trends southwesterly from Seigler Mountain. Average elevation in Putah Creek basin is somewhat lower, with flat floored valleys at about 1000 feet. Figure IV-3 shows the watershed areas.

4.4.1 Cache Creek Basin

The major surface water feature of the Cache Creek watershed basin is Clear Lake, which has a surface area of 68.5 square miles. The total drainage area of streams feeding Clear Lake is about 457 square miles (CDWR, 1966). The principal streams contributing to Clear Lake are to the north and west of the Lake and include the following creeks: Scott, Middle, Adobe, Highland and Kelsey. None of the major streams on the east side of Clear Lake discharge into it. The Mayacamas Mountains contribute most of the surface water flowing into Clear Lake.

Clear Lake is about 18 miles long and is 8 miles wide at its widest part. The Lake is divided limnologically into three parts, the upper lake, the lower lake, and the Oak Arm, by the "Narrows". Clear Lake has an average depth of about 26 feet and has a total capacity of approximately 1.053 million acre-feet.

The Lake is not fed by perennial streams, thus its level is determined by runoff from precipitation. The level of Clear Lake is controlled by a dam that was constructed at the Cache Creek outlet in 1915 by the Yolo Water & Power Company. Clear Lake is operated primarily as an irrigation water supply facility for Yolo County. The Yolo County Flood Control and Water Conservation District has the right to water stored in Clear Lake between 0 and 7.56 feet on the Rumsey gage at Lakeport or up to 314,000 acre-feet.

The remaining portion of the watershed basin consists of Cache Creek and its tributary system. Cache Creek has three sources, Clear Lake, the North Fork of Cache Creek and Bear Creek. Water discharged from Clear Lake flows east then turns northeast, where it is joined by the North Fork of Cache Creek. The Creek then flows southeast toward Rumsey, in Yolo County. Before leaving the Blue Ridge Mountains, Cache Creek is joined by Bear Valley, which is flowing from the north. Cache Creek has a discharge area of 955 square miles above Rumsey.

The estimated average yaerly inflow to Clear Lake from surface runoff has been estimated at 445,000 acre-feet. More than 70% of the total drainage area contributing to this volume of inflows is from tributaries to the Upper Arm of the Lake. This area is drained by six major creeks: Kelsey, Adobe, Scott, Middle and Clover (DWR, 1966).

Gaging stations have been established on all these creeks. These six major gaging stations measure the runoff from approximately 155 square miles of drainage area, about 30% of the total drainage area. This area contributes approximately 45% to 50% of the total inflows into Clear Lake (DWR, 1966). The streams in the Upper Clear Lake area, Scott Valley and Big Valley discharge directly into Clear Lake. The total annual discharge from these streams into Clear Lake is about 184,260 acre-feet. The streams in the Lower Lake area discharge into Cache Creek below Clear Lake. These include Seigler Creek with 7,800 acre-feet of annual runoff and North Fork with 130,300 acre-feet. The annual average discharge of Cache Creek above Rumsey is 560,000 acre-feet. Table IV-1 shows the runoff characteristics of the Cache Creek watershed. Appendix F shows the mean monthly and annual discharges from these streams.

Legal considerations on surface water use are crucial in the Clear Lake area. The Yolo County Flood Control and Water Conservation District (FCWCD) has the right to water stored in Clear Lake between 0 and 7.56 feet on the Rumsey gage at Lakeport, or up to 314,000 acre-feet. The Yolo County FCWCD has the obligation to provide municipal water, as needed, to the communities around Clear Lake.

In addition to the appropriated water, a certain amount of water from Clear Lake is unappropriated. The unappropriated water of Clear Lake is the amount of water that is released from Clear Lake Dam from October 1 to April 1 of the following year. Historically, this spill-over flow from Clear Lake Dam has amounted to approximately 107,600

TABLE IV-1

RUNOFF CHARACTERISTICS OF PRINCIPAL STREAM OF CACHE CREEK WATERSHED

Hydrographic Area	Stream	Drainage Area (acres)	Average Annual Runoff (acre-feet)	Average Unit Runoff (acre-feet/acre)
Upper Lake	Clover Creek	8,960	10,500	1.2
	Middle Creek	31,040	61,400	2.0
Scotts Valley	Scotts Creek	33,020	44,800	1.4
Big Valley	Highlands Creek	8,130	11,780	1.5
	Adobe Creek	4,100	7,080	1.7
	Kelsey Creek	23,420	48,700	2.1
Lower Lake	Siegler Creek	8,000	7,800	1.0
Indian Valley	North Fork	129,920	130,300	1.0
Cache Creek	Cache Creek at Clear Lake Dam	338,180	226,390	0.7
	Cache Creek above Rumsey	611,200	560,000	0.9

Source: Development and Resources Corporation
Lake County Resource Management Plan, January 1976.

acre-feet annually. If the distribution and storage of this surface water could be developed, this water could potentially be used for power plant cooling purposes.

In addition to this source of water, completion of the Tehama-Colusa Canal could provide a source of water. Potentially, an exchange of water from Clear Lake to Yolo and Solano Counties could be developed after the Canal is completed. The volume of water that could be exchanged has yet to be defined.

Water quality is controlled by the Regional Water Quality Control Board. The main policy of the Board is non-degradation of surface and ground water. Resolution No. 75-58 was adopted as the policy for the discharge of power plant waste water. This resolution is shown in Appendix G.

4.4.2 Putah Creek Basin

The Putah Creek Basin has a drainage area of 569 square miles and lies within the northern portion of Napa County and the southern portion of Lake County. It is a generally mountainous area, about 20 miles wide at the widest point and extends about 50 miles in a northwest to southeast direction. Putah Creek flows in a southeasterly direction from its headwater near Whispering Pines to Monticello Dam near Winters. The major tributaries of Putah Creek are Etecuera, Hunting, Soda, St. Helena, Butte, and Pope Creeks (Figure IV-2). Lake Berryessa, which is formed behind Monticello Dam, has a storage of 1.6 million acre-feet and a maximum surface area of 22,000 acres (DWR, 1965). Normally, the average surface area of Lake Berryessa is 19,000 acres.

The water resources in the Putah Creek basin originate from precipitation occurring during the winter. Therefore, the flow regimen in the streams in the area resembles precipitation regimen with peak discharge occurring in winter. The two gaging stations above Lake Berryessa

measure the primary stream flow in the area. One is located on Pope Creek near Pope Valley. This drainage area is 78.3 square miles. Annual discharge is 81.4 cfs and coefficient of variation is 52% for Pope Creek for the years 1962 through 1968. Total surface discharge from Pope Creek and Putah Creek near Guenoc totals 278.5 cfs. Ungaged streams such as Eticuera, Capel and Sage Creeks also contribute some flow into Lake Berryessa. According to 1977 published water data, the average discharge for Putah Creek near Guenoc over a 48-year period was 208 cfs, and 88.9 cfs for Pope Creek. Including some smaller streams, the total gaged discharge for Lake Berryessa is about 331 cfs per year (DWR, 1965).

All of the water samples collected by the USGS near Winters indicate TDS values below 200 ppm (USGS, 1977). The water quality of all streams discharging into Lake Berryessa is believed to be as excellent.

The temperature of the water in Putah Creek near Guenoc is 24°C in August and 10°C in January. All of the streams in this basin should have a temperature regimen similar to that of the Putah Creek.

The U.S. Bureau of Reclamation has the right to store and utilize up to 1,600,000 acre-feet annually of water which originates upstream of Lake Berryessa. This right is subject to a depletion for beneficial use within the Putah Creek watershed not to exceed 33,000 acre-feet annually. According to the U.S. Bureau of Reclamation, applications against the 33,000 acre-feet total about 40,000 acre-feet. Licenses have been issued on 10,000 acre-feet thus far, therefore 23,000 acre-feet remain uncommitted. This 23,000 acre-feet will, however, be completely utilized if the Solano project, which is presently in the feasibility study stage, is implemented. Thus, power plant cooling water may not be available from this watershed area.

4.4.3 Russian River Basin

The Russian River drains a 1,485-square-mile area that is approximately 100 miles long and from 12 to 32 miles wide. From its sources, about 16 miles north of Ukiah, the river flows southward for 90 miles through Redwood, Ukiah, Hopeland, and Alexander Valleys, and the northwestern part of the Santa Rosa Plains. The river then turns abruptly westward at Mirabel Park and flows for 22 miles through a canyon in the mountains before entering the Pacific Ocean at Jenner. The Mendocino Range lies to the west of the drainage area and the Mayacmas Mountains to the east. The principal tributaries of the Russian River are East Fork, Sulphur Creek, Mayacma Creek, Dry Creek, and Mark West Creek.

There are several major water developments in the Russian River basin. The Pacific Gas and Electric Company (PG&E) annually diverts about 150,00 acre-feet of Eel River water into the East Fork of the Russian River through the Potter Valley diversion tunnel. The capacity of this tunnel is 345 cfs. The diversion, which began in 1908, is now regulated by storage in Lake Mendocino (capacity 122,900 acre-feet). The releases from Lake Mendocino maintain a minimum flow of 125 cfs in the Russian River near Guerneville. Another reservoir, Warm Springs Reservoir on Dry Creek near Geyserville, is under construction (CDWR, 1976).

The Geysers KGRA occupies the west side of Russian River Basin, mainly in the headwaters of Big Sulfur, Redwood, Brigg and Franz Creeks. The area of the Sulfur Creek subwatershed has been developed by PG&E for geothermal power generation (Bedrossian, 1978).

The runoff pattern for the Russian River drainage basin generally reflects the wet winters and dry summers in the area. Nearly 90% of the annual runoff occurs in the six-month period from November through April.

Lake Mendocino, formed by Coyote Dam on the east fork of the Russian River near Ukiah, is the only sizable reservoir in the watershed. This 122,900 acre-foot reservoir was constructed by the United States Army Corps of Engineers in 1958 as a multi-purpose facility. The Corps of Engineers operates it for the purposes of flood control, water conservation and recreation. Coyote Dam must release enough water during the summer to maintain a flow of 125 cfs at Guerneville, about 20 miles down below Healdsburg (CDWR 1968). Lake Mendocino has a safe yield of 60,000 acre-feet annually and with a surface area of 1,700 acres.

Based on historical data, approximately 203 cfs of Eel River water is imported annually through PG&E's Potter Valley power house. This water is discharged to the East Fork of the Russian River and is regulated by Coyote Dam.

Complex legal considerations in the Russian River Basin hold the key to available water. The California Wild and Scenic Rivers Act of 1972 precludes the development of any major water impoundment facility on the Eel River from 100 yards below Van Arsdale Dam to the Pacific Ocean before 1985. At that time, the Department of Water Resources will reassess the water supply needs for the state and could potentially change this position.

The 50-year license by the Federal Power Commission issued to the Pacific Gas and Electric Company for the Potter Valley Project expired in April 1972. Renewal of this license is presently under review. To assure that all interests would be fairly considered, the Department of Water Resources together with the Eel River Water Council is organizing an interagency study committee to oversee the conduct of the study. Lake County is represented by the Eel River Water Council, whose duties were assumed by the North Coast County Supervisors Association, and Lake County representative.

Numerous conflicts exist relative to the Potter Valley Project and its future operation. Major conflicts have been noted by the DWR in a recent draft report on the "Eel Russian Rivers Streamflow Augmentation Study"; these include the desire of Humboldt and Mendocino Counties and the Department of Fish and Game to increase flows in the Eel River; PG&E's requirements to maximize power production at the Potter Valley Powerhouse and thus maximize diversions; the Sonoma County Water Agency, North Muni County Water District, and the Mendocino County-Russian River Flood Control and Water Conservation Improvement District desires to maximize diversions from the Eel River. Contrary to these positions, the U.S. Forest Service wishes to maintain high levels in Lake Pillsbury during the summer months, and, similarly, the U.S. Corps of Engineers wants to maintain high summer water levels in Lake Mendocino.

The Sonoma County Water Agency and the Mendocino County Flood Control and Water Conservation Improvement District (FCWCI) have been granted direct diversion and storage permits for waters of the East Branch of the Russian River and the Russian River. At the present time, the Mendocino County FCWID has a permit from the State Water Resources Control Board to use up to 8,000 acre-feet annually from the Russian River. The Sonoma County Water Agency has established water rights for a diversion of 37,544 acre-feet annually at Wohler and Mirabel Park on the Russian River. Part of this diversion has been contracted for use in Marin County. Permits for an additional 10,000 acre-feet of Sonoma County Water Agency project water from Lake Mendocino will be granted by the State Board directly to individual diverters from the Russian River. The Sonoma County Water Agency has recently petitioned the Board to have the 37,544 acre-feet entitlement increased to 75,000 acre-feet. The Sonoma County petition has been protested by several individuals and agencies, including Mendocino County and various environmental groups (CDWR 1978).

In 1959 the Sonoma County Water Agency and the Mendocino County Russian River Flood Control and Water Conservation Improvement District applied

for water right permits to cover the water diverted from the Eel River by the Potter Valley Project. These applications were made to insure the continuation of the diversion in the event the Federal Power Commission should reject the application for a new license for the project. The applications from these agencies were denied by the State Board in 1972.

Should the power license not be granted, it would appear that the water presently appropriated for power purposes would become subject to appropriation by any agency that could put it to beneficial use. Allocating that water among conflicting applications would then be within the jurisdiction of the State Water Resources Control Board.

4.4.4 Napa River Basin

The Napa River originates on the south flank of Mt. Helena, flows southeastward for about 45 miles, and empties into San Pablo Bay. Its principal tributaries are Conn, Dry, Milliken, and Redwood Creeks, all of which enter the river in a 10 miles reach upstream from the City of Napa. The Napa River Basin includes Napa Valley and is about 30 miles long and ranges in width from less than one mile at the north end to nearly four miles just north of Napa. The Geysers-Calistoga KGRA extends from the Mayacamas Mountains into the Napa Valley and covers Calistoga and St. Helena area. The Napa River near St. Helena has a drainage area of 81.4 square miles and near Napa, 218 square miles.

The principal use of water in the Napa River Basin is for municipal and domestic purposes and for the irrigation of about 1,500 acres of agricultural land in Napa Valley above St. Helena. Prior to 1945, almost all water was obtained from individual wells in the area. The major surface water bodies are Kimball Creek Reservoir (capacity 344 acre-feet), Bell Canyon Reservoir (capacity 2,530 acre-feet) and Lake Hennessey (capacity 31,000 acre-feet). Lake Hennessey is the chief water source of the City of Napa.

All of the tributary streams of the Napa River go dry in summer. The Napa River is perennial at the St. Helena gaging station but is usually dry at the Napa gaging station for one or more months during the summer (Rantz and Thompson 1967). This loss in stream flow between the two gaging stations is attributed to pumping for irrigation purposes from both the stream and the ground water reservoir.

The mean annual discharge for Napa River near St. Helena averages about 94 cfs. Most of the runoff occurs during the wet season from December to April. Ninety-four percent of the annual runoff is discharged in this five-month period. Both precipitation and runoff drop to an insignificant amount by May and completely disappear during the summer. Even though there was considerable amount of rainfall in October and November, runoff was not different from summer flow, principally due to the depletion of antecedent soil moisture content. Appendix F contains additional data for this area.

The quality of water in the Napa River is generally excellent, and is suitable for domestic and irrigation purposes. The water is bicarbonate in type with calcium and sodium as other chemical contents. pH ranged from 7.1 to 8.2. Total dissolved solids ranged from 200 to 300 ppm. Dissolved boron as high as 1.8 mg/l has been recorded near St. Helena and 0.9 mg/l near Napa.

4.5 Ground Water

In the vicinity of The Geysers-Calistoga KGRA, there are 20 significant ground water basins. Figure IV-4 shows the general location of these ground water basins. Geographically, the basins can be divided into 5 areas; Clear Lake, Russian River, Sonoma Valley, Napa Valley, and Petaluma Valley. In the Clear Lake area, there are eight significant ground water basins; Upper Lake Valley, Scott Valley, Kelseyville Valley, High Valley, Burns Valley, Coyote Valley, Collayomi Valley, and Lower Lake Valley respectively. In the Russian River area, there are

nine significant ground water basin, Potter Valley, Ukiah Valley, Sanel Valley, Alexander area, Cloverdale area, Santa Rosa Plain, Healdsburg area, Rincon Valley, and Knights Valley respectively. The Sonoma Valley, Napa Valley, and Petaluma Valley are the other ground water basins.

4.5.1 Ground Water Hydrology of the Clear Lake Area

4.5.1.1 Upper Lake Valley

The Upper Lake Valley is located just north of Clear Lake. It covers an area of approximately 15 square miles. The aquifer is composed mainly of young river alluvium. The aquifer is recharged by percolation of Middle Creek. The ground water movement is generally from north to south in the direction to Clear Lake (see Figure IV-4). The thickness of the aquifer is generally less than 200 feet. Analyses of water samples by the California Department of Water Resources (CDWR) indicate ground water in the area of present pumpage to be of excellent quality. The specific conductance is low in all instances and usually between 200 and 300 micromhos and none exceeding 500 micromhos (USBR 1968). The storage capacity of the aquifer is on the order of about 10,900 acre-feet and with well yields generally in the range of 300 to 900 gpm (see Table IV-2).

4.5.1.2 Scott Valley

Scott Valley is located on the west side of Clear Lake and covers an area of about 4 square miles. The aquifer is composed of mainly young river alluvium and its thickness generally range from 100 to 130 feet. This aquifer receives little recharge because of the presence of a confining layer located between 60 to 90 feet below the ground surface. The ground water movement in Scott Valley is generally northerly and follows the surface topography (see Figure IV-4).

TABLE IV-2
SUMMARY OF GROUND WATER DATA
CLEAR LAKE AREA

Basin name, county	Well yields in gpm		Depth zone in feet	Storage capacity in acre-feet	Usable capacity in acre-feet
	Max.	Aver.			
Upper Lake Valley, Lake County	900	300	10-100	10,900	5,000
Scott Valley, Lake County	700	500	10-100	5,900	4,500
Kelseyville Valley, (Big Valley) Lake County	1,350	450	10-100	115,600	60,000
High Valley, Lake County	1,000	100	10-100	9,000	900
Burns Valley, Lake County	300	200	10-60	4,000	1,400
Coyote Valley, Lake County	1,200	500	10-100	27,000	7,000
Collevoni Valley, Lake County	1,200	500	10-100	29,000	7,000
Lower Lake Valley, Lake County	300	Unknown	0-75	4,000	Unknown

Source: California Department of Water Resources
Bulletin #118

Analyses of samples collected by the California Department of Water Resources indicate that ground waters in the Scotts Valley Basin are of a calcium-bicarbonate type and are of very good quality, low in all mineral constituents. The analyses from eight wells averaged a specific conductance ($K \times 10^6$ at 25°C.) of 280 micromhos, with a range between 200 to 600 micromhos. Only one well of the eight exceeded 300 micromhos. Boron in all cases was under 0.3 parts per million (USBR 1968).

The storage capacity of the aquifer is on the order of about 5,900 acre-feet and well yield generally range from 500 to 700 gpm (see Table IV-2).

4.5.1.3 Kelseyville Valley

The Kelseyville Valley is the largest of the several small valleys surrounding Clear Lake. It is located adjacent to the south shore of the western portion of Clear Lake and is bounded by the Mayacmas Mountains to the west and Koncti Mountain to the east. The aquifer is composed mainly of recent river alluvium volcanic ash and older terrace deposits and is generally less than 200 feet in thickness. Percolation from Kelsey and Adobe Creeks furnishes most of the ground water recharge. The ground water movement in the valley is generally northerly towards Clear Lake.

Over 100 wells have been analyzed by the CDWR and the California Agriculture Extension Service. The summation of these data indicates the ground water is suitable for most uses with a few exceptions where wells produce boron in toxic quantities. Specific conductance averages about 500 micromhos, with ranges from 200 to 1,200 micromhos. Magnesium and calcium are the predominant cations and bicarbonate the predominant anion in these waters. Generally, boron runs under 0.6 parts per million, but a few wells contain concentrations ranging from 0.6 to 3.3 parts per million. The resulting high boron concentration

occurs in individual wells and there appears to be no general stratum or horizon of high boron water (USBR 1968).

The storage capacity of the aquifer is in the order of about 115,600 acre-feet and the well yields range from 450 to 1350 gpm (see Table IV-2).

4.5.1.4 High Valley

High Valley is located east of Clear Lake and covers an area of about 3 square miles. The aquifer is composed of alluvium and volcanic rocks and its thickness is at about 100 feet. There is little recharge to the aquifer system because the surface alluvium is generally tight and fine grained. The groundwater movement is generally easterly.

From the standpoint of mineral analyses the water was generally within permissible limits for irrigation water. Specific conductance range from 700 to 1,000 micromhos. Boron in one DWR sample was 2.1 parts per million and 1.2 parts per million for a USBR sample. Other samplings indicated water of acceptable boron content (USBR 1968).

The storage capacity of the aquifer is estimated to be 9000 acre-feet and well yields range from 100 to 1000 gpm (see Table IV-2).

4.5.1.5 Burns Valley

Burns Valley is located along the southeasterly edge of Clear Lake and covers an area of about 2 square miles. In Burns Valley, the alluvium and Cache formation are the principal water bearing deposits. The thickness of the aquifer is between 200 to 250 feet. The recharge potential to this aquifer system is not known. The movement of the ground water is generally southwesterly toward Clear Lake.

Ground water analyses from seven well samples, three of which were obtained in the summer of 1967 by the USBR, showed a generally acceptable quality of water from the standpoint of mineral content. Specific conductance averaged about 500 micromhos. One well showed a boron content of 1.2 parts per million which is slightly high for sensitive plants. Other analyses indicated a low boron content.

Several local residents interviewed during the USBR investigation said they objected to the unpleasant taste of the ground water and would use other sources (lake water) if at all available. It has been reported that several wells drilled within a few hundred feet of Clear Lake have been destroyed because the water obtained had a strong "soda" taste (USBR 1968).

The storage capacity of this aquifer is estimated to be 4000 acre-feet and well yields range from 200 to 300 gpm.

4.5.1.6 Coyote Valley

The Coyote Valley is located in the southeastern portion of Lake County. It covers an area of about six square miles. The aquifer is composed of recent alluvium and its thickness is estimated to be 200 to 300 feet. The major source of ground water recharge to the aquifer is from Putah Creek. Ground water movement is in a southeasterly direction, away from Clear Lake. Ground water in Coyote Valley is generally of good quality but localized areas may contain some boron above desirable limits. The Ground water is of a bicarbonate type and magnesium is the dominant cation. Specific conductance of all analyses averaged about 300 micromhos with only one well slightly exceeding 500 micromhos (USBR 1968). The storage capacity of the aquifer is estimated to be about 27,000 acre-feet and well yields range from 500 to 1200 gpm (see Table IV-2).

4.5.1.7 Collayomi Valley

The Collayomi Valley is located in the southern portion of Lake County. It covers an area of about 7 square miles. The aquifer is composed of recent alluvium and believe to be about 200 to 300 feet thick. The aquifer is recharged by Putah Creek. The ground water movement is believed to be in a southeasterly direction. The storage capacity of the aquifer is estimated to be 29,000 acre-feet and well yields range from 500 to 1200 gpm (see Table IV-2).

4.5.1.8 Lower Lake Valley

The Lower Lake Valley is located at the southeast end of Clear Lake and covers an area of about 5 square miles. The principal water-bearing formation is the alluvium with a thickness of about 75 feet. The ground water system is recharged by precipitation and natural runoff, however the extent and rate of replenishment are not entirely known. Two partial analyses by the U.S. Geological Survey and two complete analyses by the Bureau of Reclamation have been made from wells in the Lower Lake area. Specific conductance averaged 550 micromhos, with a range from 370 to 660 micromhos. One sample showed a boron concentration of 2.2 parts per million (USBR 1968).

The storage capacity of the aquifer is estimated to be 4,000 acre-feet and well yields are not expected to exceed 300 gpm (see Table IV-2).

4.5.2 Ground Water Hydrology of the Russian River Area

4.5.2.1 Potter Valley

The Potter Valley ground water basin, the northern-most basin in the Russian River area, is situated approximately 11 miles northeast of Ukiah (see Figure IV-4). It is approximately seven miles in length, varies from about 1-1/2 miles to 2 miles in width, and encompasses an

area of approximately 13 square miles. The basin is situated in a depression that is structurally controlled by folding and faulting. Non-water-bearing consolidated rocks form the boundaries of the ground water basin and underlie the water-bearing materials at depth. Water-bearing deposits include uplifted, undifferentiated, Tertiary and Quaternary continental sediments of low permeability which are discontinuously exposed along the margins of the basin, and Recent alluvial deposits which form the valley floor area. The continental deposits underlie the alluvium to some extent beneath the valley and directly overlie non-water-bearing consolidated rocks.

The uplifted, older continental deposits consist principally of sandy silt and clay with some gravel and sand. Cementation, compaction, and the abundance of fine-grained materials result in these deposits having low permeabilities. The Recent alluvium also consists principally of clay and silt with thin lenses of sand and gravel. Although more permeable than the underlying continental deposits, the abundance of fine-grained materials and the thin, poorly connected lenses of sand and gravel result in this unit also being of moderately low permeability. Yield to wells penetrating alluvium varies from 50 to 75 gpm with specific capacities of from 1 to 5 gpm per foot of drawdown. The maximum thickness of the older continental deposits is probably several hundred feet and that of the alluvium about 60 feet. The undifferentiated continental deposits exposed along the flanks of the ground water basin locally yield minor quantities of water for domestic and stockwatering purposes and probably, to some extent, act as recharge areas for the younger Recent alluvial deposits overlying them in Potter Valley. The Recent alluvium, however, is the principal water-producing unit. There are limited data regarding the occurrence of ground water in the continental deposits; however, it is probably largely confined. Ground water in the alluvium is also confined except at shallow depths and near the apex of alluvial fans on the valley's margin. Groundwater moves from the recharge areas along the valley margins toward the river in the central part of Potter Valley. Re-

charge is by infiltration and percolation of precipitation and stream-flow, and by infiltration of unconsumed irrigation water in Potter Valley.

As shown in Table IV-3 the usable ground water storage capacity of the Potter Valley ground water basin is estimated to be 9,000 acre-feet. Approximately 60,000 acre-feet of storage are in the older continental deposits; however, this storage is probably not usable for short-term cyclic storage because of the low permeability of the sediments (CDWR 1965). The groundwater quality is generally good (see Appendix F).

4.5.2.2 Ukiah Valley

The Ukiah Valley ground water basin is the northernmost basin along the Russian River. It is approximately 22 miles in length, averages 3 miles in width, and underlies an area of approximately 61 square miles. The basin is situated in a depression caused by faulting and folding. Non-water-bearing consolidated rocks form the boundaries of the ground water basin and underlie the waterbearing materials at depth. Water-bearing deposits in the basin include uplifted, undifferentiated Tertiary-Quaternary continental sediments of low permeability which are discontinuously exposed along the basin margins, and Recent alluvial sediments in the relatively flat floor of the valley. The alluvium is underlain in part by the Tertiary-Quaternary continental deposits, and in part by consolidated rocks.

The undifferentiated continental deposits consist principally of semiconsolidated, poorly sorted deposits of clayey and sandy gravel, clayey sand, and sandy clay. Cementation, compaction, and the abundance of fine-grained materials in these deposits cause them to be of low permeability. Most wells in this material yield less than 1 gpm per foot of drawdown.

**SUMMARY OF GROUND WATER DATA
RUSSIAN RIVER AREA**

Basin name, county	Well yields in gpm		Depth zone in feet	Storage capacity in acre-feet	Usable capacity in acre-feet
	Max.	Aver.			
Potter Valley, Mendocino County	70	30	0-200	71,000	9,000
Ukiah Valley, Mendocino County	1,600	400	0-200	369,000	35,000
Senel Valley, Mendocino County	1,200	500	0-100	51,700	20,000
Alexander Valley Alexander Area, Sonoma County	450	130	0-470	445,000	60,000
Cloverdale Area, Sonoma County	450	130	0-100	50,000	15,000
Santa Rosa Valley Santa Rosa Plain, Sonoma County	1,500	90	0-1000	7,100,000	950,000
Healdsburg Area, Sonoma County	1,000	180	0-250	930,000	67,000
Rincon Valley, Sonoma County	Unknown	Unknown	0-1000	290,000	18,000
Knights Valley, Sonoma County	Unknown	Unknown	10-110	17,000	17,000
Sonoma Valley, Sonoma County.	400	Unknown	0-1,000	2,660,000	Unknown
Napa Valley, Napa and Solano Counties.	3,000	200	10-200	300,000	Unknown
Petaluma Valley, Marin and Sonoma Counties.	650	40	0-900	2,100,000	Unknown

Source: California Department of Water Resources
Bulletin #118

The overlying Recent alluvium consists of unconsolidated deposits of gravel, sand, and silt with some clay. The alluvium is relatively permeable and is the most important ground water-producing unit in the basin. Wells producing from it yield up to 1,200 gpm with specific capacities generally varying from 0.5 to 7 gpm per foot of drawdown. Locally, specific capacities may exceed 100 gpm per foot of drawdown.

Thickness of the undifferentiated continental deposits is variable; however, the maximum thickness is probably about 2,000 feet. Maximum thickness of the Recent alluvium is probably about 80 feet.

Undifferentiated older continental deposits exposed along the flanks of the groundwater basin locally yield minor quantities of water for domestic and stockwatering purposes. These continental deposits also act as recharge areas for the more prolific water-producing Recent alluvial deposits.

There are limited data regarding the occurrence of groundwater in the older continental deposits; however, it is probably locally confined. Ground water in the Recent alluvium is essentially unconfined. Depth to ground water in the continental deposits on the margins of the basin varies from near the ground surface to over 60 feet, while depth to water in the alluvium of the valley floor ranges from a few feet to 20 feet. The general ground water movement is in the direction of the topographic slope toward the Russian River and then southward down the valley. Recharge is by infiltration and percolation of rainfall and streamflow in recharge areas along the margins of the basin, and by deep percolation of unconsumed irrigation water in the valley floor areas. Some recharge to the water-bearing deposits occurs by ground water movement from fractures, shears, etc., in the underlying and adjacent consolidated bedrock surrounding the basin.

Ground water is used extensively in the Ukiah Valley ground water basin for irrigation, domestic, and industrial purposes. An estimated 10,000

acre-feet of groundwater was used in 1954. Mineral quality of groundwater is generally good. Water in the undifferentiated continental deposits generally contains more dissolved solids than that in the Recent alluvial deposits (CDWR 1965).

As shown in Table IV-3 the usable groundwater storage capacity of the Ukiah Valley ground water basin is estimated to be about 45,000 acre-feet. About 324,000 acre-feet of storage exists in the older continental deposits; however, this is probably not usable for short-term cyclic storage because of the low transmissivity of the sediments (see Table IV-4).

4.5.2.3 Sanel Valley

The Sanel Valley ground water basin is located along the Russian River approximately 12 miles south of Ukiah. It is about eight miles long, has a maximum width of about six miles, and includes an area of approximately nine square miles. McDowell Valley ground water basin, located immediately east of Sanel Valley, is about three miles long and 1.5 miles wide. It includes an area of about 2 square miles. Although the ground waters of these two basins are not in hydraulic connection, they are discussed together because of their proximity and similarity of geologic conditions (CDWR 1965).

The major source of ground water is unconsolidated alluvium which underlies the valley floor. This unconsolidated alluvium, which was deposited by the Russian River, varies in thickness from a few inches to 170 feet and overlies consolidated bedrock. Wells pumping from the alluvium yield from 500 to 1,200 gpm, with specific capacities ranging from 20 to more than 100 gpm per foot of drawdown.

Ground water is generally unconfined, with the exception of local pressure effects. Recharge is by percolation of streamflow, precipitation, and irrigation water. Ground water movement is from the margins of the valley toward and into the Russian River.

TABLE IV-4

RANGE OF YIELD CHARACTERISTICS OF WELLS, RUSSIAN RIVER AREA

Area	Geologic Formation ^{1/}	Number Of Wells	Depth (feet)	Yield (gpm)	Specific Capacity (gpm/ft)	Transmissibility ^{2/} (gal/day/ft)
Santa Rosa	Tsv	3	200-1,018	290-485	1.10-5.75	2,200-11,500
	TQm	8	132-1,204	125-1,620	0.96-5.56	1,920-11,120
	TQge	13	80-914.	100-550	1.25-7.16	2,500-14,320
	Qal	3	154-161	100-545	2.38-6.25	4,760-12,500
Healdsburg	TQge	1	209	200	7.15	14,300
	Qt	2	111-151	20-400	0.45-4.65	900- 9,300
	Qsc	4	31-66	350-1,000	62.5 -200.0	125,000-400,000
Alexander Valley	Kc	1	122	6	0.086	172
	TQge	4	105-454	40-400	0.50-8.00	1,000- 16,000
	Qt	1	180	435	4.35	8,700
	Qal	1	180	150	1.36	2,720
Cloverdale Valley	Qsc	1	35	500	250.0	500,000
Sanel Valley	TQc	2	187-220	70-155	1.07-3.53	2,140- 7,060
	Qal	2	61-220	100-550	3.55-20.0	7,100- 40,000
	Qsc	1	47	950	238.0	476,000
Ukiah Valley	TQc	2	64-199	18-246	1.1 -14.5	2,200- 29,000
	Qt	1	93	30	0.38	720
	Qal	4	108-215	230-892	3.11-15.4	6,220- 30,800
	Qsc	2	22-34	525-1,350	65.5 -450.0	131,000-900,000

1/ Qsc: Stream channel deposits; Qal: Alluvium; Qt: Terraces; TQc: Plio-Pleistocene sediments; TQge: Glen Ellen Formation; Tm: Merced Formation; Kc: Cretaceous conglomerate.

2/ Transmissibility determined by the modified Thiem equilibrium formula where $T = 2,000^* \times \text{specific capacity}$. $2,000^*$ actually 1,990, is a factor for confined aquifer conditions.

Source: California Department of Water Resources Bulletin #143-4

Mineral analysis of water from nine wells, samples in 1964 and 1965, indicated bicarbonate water with the calcium and magnesium the predominant cations. The water was excellent in quality (see Appendix F).

Ground water in McDowell Valley occurs in uplifted differential Tertiary-Quaternary continental sediments and Recent alluvium. The major source is the alluvium. Recharge is by direct infiltration of rainfall and streamflow. Wells pumping from the alluvium yield from 500 to 1,200 gpm, with specific capacities ranging from 20 to more than 100 gpm per foot of drawdown. Yields in the continental deposits are as low as 7 gpm with capacities of less than 1 gpm per foot of drawdown.

Water quality data available for McDowell Valley are limited. However, water quality is believed to be excellent with low total dissolved solids and no high concentrations of individual constituents. The water is probably bicarbonate in type with calcium and magnesium the predominant cations (CDWR 1968).

As shown in Table IV-3, the usable ground water storage capacity of Sanel Valley ground water basin is estimated to be approximately 20,000 acre-feet. Capacity of the older continental deposits in McDowell and Sanel Valleys' ground water basins is about 27,000 acre-feet. The storage in these older sediments is probably not usable because of low permeability (CDWR 1965).

4.5.2.4 Alexander Valley

Alexander Valley is situated in faulted synclinal structures that have the same trend as the structures of the Cloverdale Valley. It is located along the Russian River immediately south of Cloverdale Valley and about 5 miles east of Healdsburg. It is a narrow valley, approximately 14 miles in length, and includes an area of about 33 square miles.

Major sources of ground water are the Tertiary-Aquaternary Glen Ellen Formation and Recent alluvium. The Glen Ellen Formation yields substantial quantities of water (up to 400 gpm with specific capacities from 3 to 8 gpm per foot of drawdown) to deep wells and acts as a forebay for the alluvium in the valley. The alluvium yields 200 to 500 gpm with specific capacities of 10 to 100 gpm per foot of drawdown in shallow wells near the Russian River. Further from the river, yields in alluvium are less than 200 gpm with specific capacities of 2 to 5 gpm per foot of drawdown.

Ground water recharge is from precipitation and percolation from streams tributary to the Russian River. The Russian River provides some recharge during high flows. Groundwater moves from the margins of the valley towards the Russian River where it appears as effluent at normal and low stages.

Mineral analysis of samples taken in 1964 and 1965 from five wells indicated that the ground water was bicarbonate in type with magnesium, calcium, and sodium the predominant cations (see Appendix F). The water was generally of good quality (CDWR 1968).

As shown in Table IV-3, usable ground water storage capacity of the Alexander Valley ground water basin has been estimated to be 60,000 acre-feet. Capacity of the uplifted continental deposits is about 160,000 acre-feet, but it probably is not usable for short-term cyclic storage (CDWR 1965).

4.5.2.5 Cloverdale Valley

Cloverdale Valley is situated along the Russian River immediately south of the Mendocino County line and approximately 10 miles south of Sanel Valley. It is a narrow valley, approximately 6 miles long, and encompasses an area of about eight square miles. The basin occupies a fault-complicated structural trough. At the southern end of the

valley, a narrow section of alluvium forms a hydraulic link with the Alexander Valley ground water basin.

The major source of ground water is Recent alluvium. Wells yield up to 1,000 gpm with specific capacities of up to 250 gpm per foot of drawdown.

Major sources of recharge to ground water are infiltration and percolation of precipitation and streamflow. When the Russian River is at high stages it also provides recharge. Ground water movement is from recharge areas on the margins of the basin to the center of the valley and then southward.

Although the ground water is hard, the mineral quality is generally good. During dry seasons, some wells produce poor quality water from underlying rock (CDWR 1968).

As shown in Table IV-3, the usable ground water storage capacity of Cloverdale Valley ground water basin is estimated to be 15,000 acre-feet. Capacity of the continental deposits is about 5,000 acre-feet; however, it probably is not usable for short-term cyclic storage (CDWR 1965).

4.5.2.6 Knights Valley

Knights Valley is situated in faulted synclinal structures similar to those of Alexander Valley. It is located about 3 miles southeast of Alexander Valley and has a total area of about 4.5 square miles. The valley includes two alluviated areas known as the North Basin and the South Basin, which are separated by a narrow strip of non-water-bearing consolidated rock. Although they may be considered as two separate ground water basins, they are discussed as one in this report.

The major source of ground water in Knights Valley is Recent alluvium deposits. Well yields are similar to those of Alexander Valley. Ground water is probably unconfined, and the depth to ground water is unknown. Movement of ground water is probably toward the streams in the central portion of the alluviated areas, and then downstream.

There are only limited data regarding ground water quality. However, groundwater is believed to be calcium-magnesium bicarbonate type containing low total dissolved solids (CDWR 1968).

The estimated reservoir capacity of Knights Valley area as shown in Table IV-3 is 17,000 acre-feet (CDWR 1965).

4.5.2.7 Santa Rosa Valley

The Santa Rosa Valley area includes Santa Rosa Valley and its minor tributaries, that portion of the Russian River flood plain bordering it on the northwest, and Bennett Valley, Rincon Valley, Kenwood Valley and the Healdsburg area to the northeast. It covers an area of about 130 square miles. The principal water-bearing deposits underlying Santa Rosa Valley are the Glen Ellen and Merced Formations; beneath the Russian River flood plain, the younger alluvium; and beneath the small valleys east of Santa Rosa Valley, the younger and the older alluvium, the Glen Ellen Formation, and the Sonoma volcanics.

In the Santa Rosa Plain area, the aquifer thickness is estimated to be 1,000 feet and similarly for the Rincon Valley area. In the Healdsburg area, it is estimated to be 250 feet (see Table IV-3).

The source of most ground water in the Santa Rosa Valley area is rainfall and seepage from streams that infiltrate the soil zone and permeable zones beneath the stream beds and percolates downward to the ground water body. Because the water levels are close to the land surface, there is little opportunity for recharge seepage from streams.

If water levels were drawn down substantially, recharge from streams probably would increase greatly. In general, surface conditions permit recharge of the ground water body by rainfall in much of the Santa Rosa Valley area, but the rate of recharge is likely to be low at most times and places (Cardwell 1958).

The general ground water movement in these areas is shown on Figure IV-4. The direction of movement follows the Russian River drainage pattern. The water quality in these areas are generally fit for domestic and irrigation users. Appendix F shows the water quality analyses results summary of the Santa Rosa Valley area. The aquifer storage capacity for the Santa Rosa Plain, Healdsburg, and Rincon Valley areas are 7,100,000 acre-feet, 930,000 acre-feet and 290,000 acre-feet respectively. The well yields in these areas range from 90 to 1500 gpm (see Table IV-3).

4.5.3 Ground Water Hydrology of the Sonoma Valley

The Sonoma Valley is located in the southeastern portion of Sonoma County and covers an area of about 50 square miles. Ground water in the Sonoma Valley occurs in several of the described formations and perhaps in several hydrologically distinct bodies. In this report two water bodies are recognized. One of these is a main body, chiefly in the younger and older alluvium; the water is mostly unconfined, but that in the lower part is semiconfined in some areas. The other is in the Huichica and Glen Ellen formations and in the Sonoma volcanics and the water is mainly confined.

In the younger and older alluvium, the water constitutes a continuous body lying beneath the alluvial plain and extending northward from San Pablo Bay to the northern edge of the plain, about 1 mile south of Glen Ellen. This water is mostly unconfined, but locally the water at depth has a head higher than the water table, probably because of the inter-fingering of the water-yielding lenses with beds of clay. The ground

water discharges into Sonoma Creek and into the tidal sloughs tributary to San Pablo Bay. The source of the water is seepage from small streams draining the surrounding hilly areas, and infiltration of rainfall on the outcrop area of the water-bearing deposits. Some water probably enters the unconfined water body by upward movement from the deeper confined water where the confinement is not complete.

In Sonoma Valley, the water in the unconfined water body in the younger and older alluvium, generally north of the zero water-level contour is hard bicarbonate water, low in sulfate, chloride, and dissolved solids. The water is generally satisfactory for irrigation and, except for hardness, for domestic uses.

Water in the Huichica and Glen Ellen formations and the Sonoma volcanics occurs as a body more or less coextensive with these deposits. It thus occupies a large area, including that adjacent to the alluvial plain and that within the plain, where it underlies the unconfined water. The semiconfined water extends to depths of several hundred feet, and beneath the main part of the valley and the tidal marshes it may extend to depths of more than 1,000 feet. Within the area of the younger and older alluvium it underlies the unconfined water without any clear-cut separation.

The source of water in the Huichica and Glen Ellen formations and the Sonoma volcanics is precipitation on the outcrop area; infiltration of water from streams that flow over the outcrop area, and probably, in some places where the head is low and confinement is not complete, downward seepage of water from the overlying formations.

The confined water in Sonoma Valley occurs mostly in the older consolidated deposits. In general these waters are soft and of the bicarbonate type, low in sulfate, and generally higher in dissolved solids than the unconfined water in the younger and older alluvium.

Water in the Huichica and Glen Ellen formations at most places is usable for domestic needs and irrigation but may be unsatisfactory locally. Water from some wells has a chloride concentration as high as 400 ppm, which is generally above acceptable limits for irrigation and domestic use in Napa and Sonoma Valleys. Water from other wells has a boron concentration as high as 7.7 ppm, which makes it unsuitable for irrigation of all but very tolerant plants. Few analyses of water from the Sonoma volcanics in Sonoma valley are available but water from these rocks is generally reported to be satisfactory for all uses.

Table IV-5 shows the general range of ground water chemistry analysis done on the younger and older alluvium. A comprehensive listing of ground water chemistry analyses done in the Sonoma Valley including water from various aquifers is included in Appendix F. The storage capacity of the aquifer system in Sonoma Valley is estimated at 2,660,000 acre-feet based on 1000 ft. of saturated thickness and the maximum well yield is about 400 gpm (see Table IV-3).

4.5.4 Ground Water Hydrology of Napa Valley

The Napa Valley is located in the northwestern portion of Napa County and covers an area of approximately 230 square miles.

The characteristics of ground water occurrence and availability in Napa Valley are sufficiently different in the several formations that it is desirable to consider the ground water as divided into several bodies that are for the most part hydrologically distinct. They are the younger and older alluvium, Sonoma volcanics and Huichica formation.

Ground water in the younger and older alluvium constitutes a continuous body coextensive with these formations in Napa Valley. This water body extends from San Pablo Bay, on the south, northward to the edge of the alluvial plain north of Calistoga. Water of this body occurs also in the minor arms of alluvium that extent up the stream valleys tributary

TABLE IV-5
GROUND WATER CHEMISTRY, SONOMA VALLEY

Geologic Formation	Area	Water Types	Range of Specific Conductance (micromhos)	Range of Total Hardness (mg/l)	Range of Total Dissolved Solids (mg/l)	Range of Constituents (mg/l)						Range of Sodium Percentage	Remarks
						Na ⁺	Ca ²⁺	Mg ²⁺	Fe ²⁺	NO ₃ ⁻	Cl ⁻		
Tranquil Alluvium	Sonoma Valley	Sodium and Magnesium Bicarbonate	401-923	20-276	217-574	20-211	204-480	1.5-71	0.1-0.5	0-1.5	0.21-4.4	16-94	Fe=0.10; Al=0.02; Zn=0.005
	Petaluma Valley	Sodium, Magnesium, and Calcium Bicarbonate	340-927	24-355	232-570	17-205	104-407	13-76	0-0.32	0.4-13	0-2.2	21-95	Fe = 0.02
Alluvial Fans	Petaluma Valley	Sodium, Magnesium, and Calcium Bicarbonate	422-732	0-170	170-462	25-102	104-391	20-63	0-0.7	0-1	0-0.81	24-98	Fe: 0-0.1
Ridge Alluvium	Sonoma Valley	Sodium, Magnesium, and Calcium Bicarbonate	310-1040	30-202	109-670	16-172	170-200	2.4-139	0-1.2	0-47	0-1.4	29-87	As=0; Fe: 0-0.1; Pb=0.05; Li=0.06
Merced Formation	Petaluma	Calcium Bicarbonate	305-978	135-390	250-592	11-40	163-240	9-130	0.2	1-27	0-0.12	14-10	Fe = 0.01-2.9
Petaluma Formation	Petaluma Valley	Sodium Bicarbonate and Sodium Chloride	601-1490	90-201	395-826	95-256	245-494	48-204	0.1-0.4	0.1-16.0	0.13-0.79	58-79	As: 0.0-0.03; Li: 0.03-0.06
Franciscan Formation and Great Valley Sequence	Petaluma	Sodium Bicarbonate	040	5	497	105	310	60	1.7	0.4	0.0	99	Li = 0.05

to Napa Valley, but these do not constitute a major part of the body. The terrace and older alluvial-fan deposits are thin, are ordinarily above the water table, and are not a source of water.

Most of the water from the younger and older alluvium is apparently of satisfactory quality--generally good for most uses. Most of the samples analyzed are from the part of the valley north of Napa. These show that the water is somewhat hard and of the bicarbonate type. It has small concentrations of sulfate, chloride, and dissolved solids (Kunkel & Upson 1960).

In Napa Valley, three distinct ground water bodies are recognized in the Sonoma volcanics. One is in the area of Milliken and Tulucay Creeks east of Napa, another is in the area south of Napa and north of Suscol, and the third is in the vicinity of Calistoga. These bodies are distinguished from the water in the younger and older alluvium largely by the water levels in wells.

Ground water in the Sonoma volcanics is of good quality at most places. Complete chemical analyses of uncontaminated waters indicate that they are relatively low in sulfate (SO_4), calcium (Ca), and magnesium (Mg) and are satisfactory for most uses.

Water occurs in the Huichica formation in two areas: near Milliken Creek east of Napa and in the Carneros area west of Napa. The water in the Huichica formation itself is apparently unconfined, but the fine silt and clay composing the formation locally confine water in the underlying Sonoma volcanics.

The source of the water in the Huichica formation is precipitation that falls on the outcrop area and infiltration from streams where they cross the formation. However, the permeability of the formation is low and movement of water through the formation is very slow.

Water in the Huichica formation generally is usable for domestic purposes and for irrigation but is not so good as most water from the younger and older alluvium.

Comprehensive ground water quality analyses and pump test data for the Napa Valley area are included in Appendix F.

The storage capacity of the aquifer system in Napa Valley is estimated to be 300,000 acre-feet based on a saturated thickness of 190 feet and well yields range from 200 to 3000 gpm (see Table IV-3).

4.5.5 Ground Water Hydrology of Petaluma Valley

The Petaluma Valley is located in the south central portion of Sonoma County and covers an area of about 41 square miles.

The Petaluma Valley area of this report comprises Petaluma Valley; the small tributary valleys; and contiguous areas, which include the small alluvial valley southeast of Penngrove, upland areas adjoining the valley--especially areas underlain by deposits of the Merced formation in the northwestern and southeastern parts of the valley--and Novato Valley.

The principal water-bearing deposits are the younger and the older alluvium and the Merced formation. Locally, water occurs in the Petaluma formation and in the Sonoma volcanics; in a few places minor amounts of water are obtained from Cretaceous and Jurassic rocks.

In much of the Petaluma Valley area, the ground water reservoir has limited vertical extent, owing to faulting. East of Petaluma on the southwestern side of the Tolay fault the Franciscan group is penetrated at depths of only 400-800 feet. Northeast of the fault the Petaluma formation lies at the surface, or is encountered at shallow depth, and extends to a considerable depth, but the water-bearing beds it contains has low permeability.

The younger alluvium has a considerable thickness in Petaluma Valley, especially in the southeastern (lower) part. However, because most of the southern part of the valley is tidal, not everywhere does the younger alluvium form a usable part of the ground water reservoir. The maximum thickness of the younger alluvium in the northern part of Petaluma Valley has not been definitely ascertained, but on the basis of well logs it is believed to be as much as 200 feet. In the extreme northern part the thickness is much less, decreasing to a feathered edge at the margins of the alluvial plain.

In the southern or downstream part of Petaluma Valley the thickness of the younger alluvium may be as much as 300 feet, depending on the gradient of the pre-alluvial trench cut by ancestral Petaluma Creek.

The older alluvium makes up a principal part of the deposits comprising the groundwater reservoir in the Petaluma Valley area. The unconsolidated deposits of silty or sandy clay, sand, and gravel crop out only locally on the northeastern side of the valley but extend across the valley beneath the younger alluvium, where they overlap deposits of the Merced formation. Logs of wells that penetrate the older alluvium indicate a possible maximum thickness of about 200 feet.

The Merced formation is the principal aquifer in the upland area northwest of the city of Petaluma, in the northwestern part of the valley, and on the northeastern flank of the lower valley, and the Merced is tapped by deeper wells near the center of the valley and near the bay.

The Sonoma volcanics form only a small part of the ground water reservoir in Petaluma Valley, but locally they supply moderate yields to a few wells, probably from tuff and fractured lava. South of Penngrove and southwest of Petaluma are the two principal areas in the Petaluma Valley area where wells penetrate volcanic rocks. Except in the immediate vicinity of outcrops, volcanic rocks are not encountered in

wells beneath the alluvial plain. The quality of water obtained from the Sonoma volcanics is generally satisfactory.

The ground water in the Petaluma Valley area is recharged in large part by the deep infiltration of rainfall but also in part by seepage loss from streams that cross permeable deposits that lie above the water table. However, seepage gain occurs along the main stem of Petaluma Creek upstream from the tidal reach. Tributaries draining the Sonoma Mountains along the northeastern side of the valley supply recharge where their courses cross permeable beds. Some of this recharge is from lows sustained by ground water discharge from the Sonoma volcanics and Petaluma formation in the Sonoma Mountains. Along the course of Adobe Creek across the valley floor, water levels in wells are lower than the stream bed during most years, indicating that the creek is generally influent with respect to the ground water where the channel is permeable. Streams draining terrane of the Merced formation are mainly effluent, those draining the Sonoma Mountains are locally and intermittently influent. Rainfall records show that less rain falls in Santa Rosa Valley than in Petaluma Valley. Hence, the unit recharge available in the Petaluma Valley area is also less than that in the Santa Rosa Valley area, and the amount decreases in the direction of San Francisco Bay.

The quality of the ground water varies widely from place to place. In general the quality of water obtained from wells tapping the principal water body in the northern part of Petaluma Valley is good. The water normally is of the calcium magnesium bicarbonate or sodium bicarbonate type, and generally contains between 250 and 500 ppm of dissolved solids. In the central part of Petaluma Valley, commencing a short distance southeast of Petaluma and continuing downstream, many wells tap water which seems to be contaminated by intrusion of brackish bay water or unflushed connate water of similar chemical character. This water is of the sodium chloride type, and the content of dissolved solids is greater than in the water farther up the valley (Cardwell 1958).

A summary of ground water chemistry analyses of the Petaluma Valley area is shown in Table IV-5. The storage capacity of the aquifer system in Petaluma Valley is estimated to be about 2,100,000 acre-feet based on a 900 feet saturated thickness and the well yields range from 40 - 650 gpm (see Table IV-3).

PART V
SURPRISE VALLEY

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PART V

SURPRISE VALLEY

1.0 SUMMARY

The objective of this report was to assess the following for the Surprise Valley, California, Known Geothermal Resource Area (KGRA):

- water resources that are available for geothermal electric power plant development
- power plant make-up water requirements
- the developable megawatts based on available make-up water
- the need for additional water resource data

The availability of outside sources of make-up water for power plant operations is a major consideration in developing geothermal resources in the Surprise Valley area. The quality, quantity and availability of both surface and ground water for use in geothermal power plants was examined. The demand for water was based upon the previously conducted geothermal power plant water utilization case study (Part X). Although certain data are available for water resources in the area, complete information is lacking for ground water resources. Data on ground water in storage are available, however, the usable capacity from this source is not known. This lack of complete data preclude projections of developable megawatts of geothermal power plant output. Procurement specifications have been prepared to acquire the requisite data to determine water available for geothermal power plant in the Surprise Valley geothermal area.

1.1 Surface Water Supply

Analysis of the surface water resources for the Surprise Valley area indicate the following:

- Three shallow, intermittent dry lakes are the major surface water feature of the area.
- These lakes, Upper, Middle and Lower Alkali, are at depths of less than six inches of water and are dry at the end of summer.
- Water quality in the lakes are poor with TDS ranging from 305 to 17,500 ppm, with an average of 9,000 ppm
- Almost all of the surface water in the area is diverted for irrigation purposes by individual land owners.
- On balance, a significant amount of surface water is not available for geothermal power plant cooling purposes.

1.2 Ground Water Supply

The following is summary of ground water findings:

- Three major ground water basins, Surprise Valley, Alturas Basin and Goose Lake Valley, are in the Surprise Valley area.
- Estimates of ground water in storage have been developed for each of these basins (Surprise Valley 4.0 million acre-feet, Alturas Basin 6.7 million acre-feet, Goose Lake Valley 1.0 million acre-feet).
- Data on usable capacity is not available for any of the ground water basins.
- Available data indicate there are variations in water quality within each of the ground water basins, with only certain areas suitable for power plant cooling purposes.
- Procurement specifications have been developed to acquire the requisite data to determine usable capacities in each basin.

1.3 Power Plant Water Requirements

Based on data developed in the case study, the make-up water requirements for a 50 MWe power plant at Surprise Valley are estimated to be:

Type of Plant	Water Requirements (1) <u>(acre-feet/yr)</u>
Flashed Steam (Direct Contact)	3,600
Flashed Steam (Indirect Contact)	5,150
Binary Cycle	8,750

(1) Based on blow-down discharge of 4,000 ppm TDS, make-up water of 1,000 ppm and geothermal resource temperature of 175°C.

2.0 CONCLUSIONS

Surface water in the Surprise Valley area is not available in quantities necessary for geothermal power plant development. Given this analysis, complete data on ground water will be required to assess constraints on geothermal power plant development due to limitations on water resources. Thus, procurement specifications have been prepared to obtain the requisite data on usable capabilities in each ground water basin. Upon completion of the tasks contained in the procurement specifications, an analysis of ground water resources in the Surprise Valley can be completed.

2.1 Make-up Water Availability

Surface water in the area is limited to two primary sources: the three alkali lakes in the valley and from surface runoff of streams in the area. The alkali lakes are shallow and intermittently dry, and they contain water with average TDS of 9,000 ppm. Thus they are not suitable as a source of make-up water. Streams in the area are diverted by individual users for irrigation purposes, thus are not a suitable source of make-up water.

The data on ground water storage indicates a quantity which potentially could be sufficient for geothermal power plant development. Since irrigation from ground water is necessary, usable capacity must be known to determine the make-up water availability. The lack of complete data precludes this determination.

2.2 Developable MWe

The lack of sufficient data on ground water precludes an analysis of geothermal power plant development in the Surprise Valley area. The USGS estimate for the capacity of the resource in the area is 2100 MWe, while JPL uses 2000 MWe for planning purposes.

No geothermal power plants are currently planned for the Surprise Valley area (see Task 1).

2.3 Procurement Specifications

A complete analysis of data on both surface and ground water is necessary to provide a basis for estimating constraints on geothermal power plant development. Sufficient data were available to assess the availability of surface water in the area. Ground water data, however, were not sufficient for developing an estimate of available make-up water. Ground water storage data have been developed, however, information on usable capacity is not known.

Procurement specifications are in Appendix G.

3.0 RECOMMENDATIONS

3.1 Initiatives and Activities

3.1.1 Federal

Until further water resources data are developed and specific constraints can be identified and quantified, specific initiatives or activities which are applicable to Surprise Valley will be federal. The initial federal activity recommended is the acquisition of the specific ground water data identified in the procurement specifications. Once data acquisition and analysis is complete, constraints on geothermal power plant development can be identified and further federal recommendations can be developed.

3.1.2 State

State activities would involve primarily access to the requisite data for determination of usable capacity of ground water. The California Division of Oil and Gas and the California Department of Water Resources would be the two primary agencies involved in this portion of the procurement specification.

3.1.3 Counties and Local

Data from Modoc County will be required to complete the analysis of ground water in the Surprise Valley area. Due to the lack of surface water, data on ground water resources will be a critical element of analysis.

As geothermal development activities increase, coordination of surface and ground water uses will be required. The formation of a local irrigation district would potentially be required to coordinate this development. Local initiatives in this area to accomplish the formation of an irrigation district are recommended.

3.2 Site Specific

3.2.1 Plant Siting

Specific plant siting recommendations can be developed once geothermal power plant development constraints are known.

4.0 TECHNICAL DISCUSSION

4.1 Methodology

A general methodology was established to accomplish the major objectives of the study. The initial step of this methodology involved a comprehensive literature search to collect all published water resources literature required for the evaluation. Sources of data were various government agencies, institutions, and private organizations. A systematic literature review by technical key words was conducted to ascertain the extent of the data collected. Field investigations were then conducted among these groups to ascertain unpublished data and reports and also to confirm findings of previously published materials.

For surface water, major water bodies were identified, their physical and chemical characteristics evaluated, and their capacities determined based on these evaluations.

In the ground water evaluation, aquifers in the area were identified, their physical and chemical characteristics evaluated, and their capacity and productivity assessed. A water budget balance was not calculated because of the lack of sufficient data.

Figure V-1 indicates the major steps of the methodology.

4.2 Survey of Existing Information

The purpose of the literature search was to screen published reports and materials that were pertinent to the water resources evaluation. The initial step of this literature search was to contact various government agencies and private organizations to collect the required data.

FIGURE V-1

FLOW DIAGRAM OF METHOD OF APPROACH

All the data collected were recorded on card catalogue under a specific format. For example,

Author:	California Department of Water Resources
Report Title:	Northeastern Counties Groundwater Investigation, Bulletin No. 8
Source:	California Department of Water Resources
Date or Year of Publication:	1963
Index Number:	CS-GEN

The index number identifies the first alphabet of the principal author's last name, the number of publication listed under the alphabet, and the study area of concern. The letter S indicates Surprise Valley scenarios. Each report is then labeled by the index number.

Appendix A contains a listing of all pertinent literature collected for this study area with the appropriate index numbers. Notation of figure, table and page number of the report relative to the specific keyword were recorded during the review (see Appendix B).

During the literature review process, three key data sources were identified and were used to provide a major input into the water resources evaluation of the Surprise Valley KGRA. They are listed as follows:

California Department of Water Resources
1963 "Northeastern Counties Ground Water Investigation,"
Bulletin 98 Volume 1 (Ref. No. C5-GEN)

California Department of Water Resources
1960 "Northeastern Counties Investigation,"
Bulletin 58 (Ref. No. C2-GEN)

United States Department of Agriculture
1975 "Water and Related Land Resources, Central Lahontan Region,"
(Ref. NO. C2-GEN)

In addition to the literature search, it was necessary to search for any unpublished data or any new developments in the water resources of the Surprise Valley KGRA area. Telephone contacts and visits were made to various government agencies and private organizations to validate and search for additional water resources data.

Appendix C contains a list of persons, agencies, addresses and date of visits and telephone contacts.

4.3 Location of the Study Area

The Surprise Valley KGRA is located in the northeastern corner of California, bordered by Nevada on the east and Oregon on the north. The KGRA covers 66,251 acres and is located within Modoc County. The actual study area for the water resources evaluation was, however, delineated as a function of hydrologic considerations and availability of data rather than by political or jurisdictional boundaries. Figure V-2 indicates the Surprise Valley study area.

The altitude on the basin floor of Surprise Valley is around 4,500 feet. The Warner Mountains bordering the west side of the Surprise Valley have several peaks above 8,000 feet. The Warner Peak and the Eagle Peak reach an elevation of 9,710 and 9,892 feet, respectively. The Hays Canyon Range on the Nevada side borders the east side of the Surprise Valley. Peaks of the Hays Canyon Range range from 6,600 feet to 7,600 feet. The presence of the high mountains on the western side of the Valley produces a rain shadow effect causing variations in rainfall from 30 inches in the mountains to 4 inches on the basin.

4.4 Surface Water

The Surprise Valley basin, the main watershed in the area, is a closed basin trending north-south. The basin is approximately 65 miles in length and 20 miles in maximum width. The drainage area enclosed is

Figure V-2

LOCATION MAP OF SURPRISE VALLEY KGRA

	WATER BEARING STRATIGRAPHIC UNITS		NON-WATER BEARING UNITS
	DIRECTION OF GROUNDWATER MOVEMENT		

ADAPTED FROM: CALIFORNIA DIVISION OF MINES AND GEOLOGY,
BOUGER GRAVITY MAP OF CALIFORNIA-
ALTURAS SHEET.

0 5 10
SCALE IN MILES

approximately 800 square miles (see Figure V-3). All surface runoff drains to three shallow, intermittent lakes--Upper Alkali Lake, Middle Alkali Lake and Lower Alkali Lake. The water is lost from these lakes by evaporation. Major perennial gaged streams are Bidwell Creek, Cedar Creek and Eagle Creek. All of these streams drain from the Warner Mountains. Table V-1 shows discharge and drainage area.

The estimated mean annual natural runoff for the entire basin is 170,000 acre-feet. The streams originating in the Warner Mountains contribute approximately 130,000 acre-feet of the total for the basin (Calif. Water Resources Control Board 1971).

All runoff from the perennial and ephemeral streams in the basin drain to Upper, Middle and Lower Alkali Lakes. These lakes are extremely shallow (less than six inches in total depth) and are frequently dry during the late summer months due to irrigation in upper streams and evaporation from the lakes.

The water quality of the perennial and ephemeral streams is generally good. The water is a calcium bicarbonate type with concentration of total dissolved solids ranging from 47 to 332 ppm with an average value of 87 ppm. Values of pH range from 7.2 to 8.5 (CDWR 1960).

The water quality of the three Alkali Lakes is generally poor due to extremely high salinity. The water is sodium chloride in nature. The concentration of total dissolved solids ranges from 305 to 17,500 ppm with an average value of 8,990 ppm. The value of pH ranges from 8.4 to 9.5 (CDWR 1960).

Irrigation is a major consumptive use of water in the Surprise Valley basin. At the present time the consumptive use is estimated to be approximately 50,000 acre-feet of water for 33,000 acres under irrigation (Soil Conservation Service in Cedarville 1978).

Figure V-3
SURPRISE VALLEY WATERSHED

TABLE V-1**MEAN ANNUAL DISCHARGE AND DRAINAGE AREA
FOR GAGING STATIONS
IN SURPRISE VALLEY BASIN**

Gaging Station	Drainage Area (sq.mi.)	Mean Annual Discharge (acre-feet)	Years of Record
Bidwell Creek below Mill Creek near Fort Bidwell, USGS St.No. 10360900	25.6	16,370	1961-1976
Cedar Creek at Cedarville, USGS Sta.No. 10360320	25	5,260	1967-1975
Eagle Creek at Eagleville, USGS Sta.No. 10360230	--	5,960	1967-1970

**Source: California Dept. of Water Resources, Bull.No. 130, 1967-1975,
USGS Water Data Report CA 76-4, 1976**

Currently, there is no organized irrigation district in Surprise Valley. All of the surface water is diverted by individuals for irrigation purposes. Streams discharge into the three Alkali Lakes only during flood periods or after the other requirements have been fulfilled. Ground water is used to supplement this surface water irrigation system.

4.5 Ground Water Hydrology

Three ground water basins are in the vicinity of the Surprise Valley KGRA. The identified basins include Surprise Valley, Alturas Basin and Goose Lake Valley. Surprise Valley, the main ground water basin in the area, consists of water bearing sediments of near shore deposits, recent valley sediments and lake deposits. The near shore and recent valley sediments underlie the margins of the Valley floor and constitute the aquifer under Surprise Valley. The lake deposits in the central part of the Valley, although extensive and saturated, are not sufficiently permeable to yield large quantities of water to wells. Of the recent valley sediments, only the deposits in the alluvial fans on the western margin of the Valley are sufficiently extensive and permeable to yield significant quantities of water to wells.

Shallow ground water under water table conditions overlies deeper, confined ground water throughout Surprise Valley. The limited thickness of the aquifer, however, precludes development of large capacity wells. Both the shallow and deeper confined ground water in the Valley move toward the three alkali lakes where discharge occurs in the form of evaporation. Figure V-4 shows the direction of ground water movement in the confined aquifer in Surprise Valley.

Ground water in Surprise Valley is generally of good quality and suitable for most uses. In the area which is highly mineralized, however, ground water occurs under artesian conditions and is generally unsuitable for agriculture or domestic uses. Appendix F shows the

LOCATION MAP OF SURPRISE VALLEY KGRA Figure V-4

results of selected water quality analyses of ground water in Surprise Valley.

Estimates of the ground water in storage in the upper 400 feet of sediments in areas of Surprise Valley have been made on the basis of drillers logs and logs of test wells. Estimates are available for four areas within Surprise Valley, Ford Bidwell, Lake City to Eagleville, Bare Branch and Sand Creek. Based on these data, it is estimated that the upper 400 feet of sediments in these areas contain approximately 4,000,000 acre-feet of ground water (see Table V-2).

The Alturas Basin is located approximately 25 miles southwest of Surprise Valley. It is comprised of the north-south trending valleys of the upper forks of the Pit River and the westward trending Warm Springs Valley. Ground water in the aquifer under the valleys of the upper forks of the Pit River is under conditions ranging from unconfined to confined. Although the thickness of the aquifer has not been investigated extensively, available data from measured sections and well logs indicate that the maximum thickness of the aquifer is 2000 to 3000 feet.

Recharge of the aquifer in the Surprise Valley basin results from the infiltration of precipitation into permeable basalt flows in upland areas surrounding the basin. Ground water moves toward the center of the valleys and along the central portion of the valleys. Ground water movement in the valleys of the upper forks of the Pit River is shown in Figure V-4.

Using data from well logs and test wells, an estimate of ground storage for the upper forks of the Pit River has been developed. These estimates for the upper 800 feet of water bearing basalts and sediments under the valleys indicate the area to contain approximately 6,700,000 acre-feet of ground water in storage.

TABLE V-2
SUMMARY OF GROUNDWATER BASINS NEAR SURPRISE VALLEY KGRA

Basin name, county	Well yields in gpm		Depth zone in feet	Storage capacity in acre-feet	Usable capacity in acre-feet
	Max.	Aver.			
Surprise Valley, Lassen and Modoc Counties	2,800	900	0-400	4,000,000	Unknown
Goose Lake Valley, Modoc County	2,500	1,500	0-500	1,000,000	Unknown
Alturas Basin--South Fork Pit River and Alturas area	1,000	400	0-800	6,700,000	Unknown

Source: California Department of Water Resources, Bulletin No. 118
1975

Goose Lake Valley, the third major ground water basin in the vicinity of the Surprise Valley KGRA, is located about 20 miles west of the geothermal area. Extensive lake deposits under the central portions of the valley floor are saturated but not sufficiently permeable to yield large quantities of water to wells. Small bodies of alluvium which occur along the eastern margin of the valley are generally too limited in size and recharge to sustain long-term discharge of large quantities of water to wells.

Recharge of the aquifer along the eastern side of Goose Lake Valley results from infiltration of precipitation into basalts in upland areas west of the valley and from infiltration of precipitation. Recharge also occurs in the upland basalts and alluvium on the eastern side of the valley. The direction of ground water movement along the eastern side of Goose Valley are shown in Figure V-4.

Based on the aquifer characteristics and well log data, ground water in eastern Goose Lake Valley has been determined. This estimate indicates the upper 500 feet of water bearing materials in the eastern Goose Lake Valley to contain 1,000,000 acre-feet of ground water.

PART VI
WENDELL AMEDEE

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PART VI

WENDELL AMEDEE

1.0 SUMMARY

The objective of this report was to assess the following for the Wendell-Amedee, California, Known Geothermal Resource Area (KGRA):

- water resources that are available for geothermal electric power plant development
- power plant make-up water requirements
- the developable megawatts based on the available make-up water
- the need for additional water resource data

The availability of outside sources of make-up water for power plant operations is a major consideration in developing geothermal resources in the Wendell-Amedee area. The quality, quantity and availability of both surface and ground water for use in geothermal power plants was examined. The demand for water was based upon the previously conducted geothermal power plant water utilization case study (Part X). The lack of complete data on ground water in storage and an inventory of usage in the pertinent water basins preclude projections of developable megawatts of geothermal power plant output. Procurement specifications have been prepared to acquire the requisite data to determine water available for geothermal power plant development.

1.1 Surface Water Supply

Analysis of the surface water resources for the Wendell-Amedee area indicate the following:

- Annual precipitation varies from 40 inches on the western portion of Honey Lake to less than 10 inches on the eastern portion.
- Honey Lake, the only major surface water body in the area, has an average storage capacity of 300,000 acre-feet.
- Total surface runoff discharged into Honey Lake is estimated to be approximately 100,000 acre-feet per year.
- Water quality in the streams and lakes is generally good, with TDS less than 300 ppm and pH ranging from 7.0 to 9.0.
- Water in Honey Lake has TDS of 5,000 ppm.
- If engineering/economics of distribution are favorable, water from Honey Lake could potentially be used for geothermal power plant development.

1.2 Ground Water Supply

Analysis of ground water related to the Wendell-Amedee area indicates:

- Three major ground water basins, Honey Lake Valley, Willow Creek Valley and Secret Valley, are in the area.
- Ground water in storage in the Honey Lake Valley is estimated to be approximately 16 million acre-feet.
- Ground water in storage for Willow Creek and Secret Valley is not known.
- Usable capacity (recharge and inflow less current usage) is not known for any of the ground water basins.
- Procurement specifications have been developed to acquire the requisite data to determine the amount of ground water available for geothermal power plant development.

1.3 Power Plant Requirements

Based on data developed in the case study, the make-up water requirements for a 50 MWe power plant at Wendell-Amedee are estimated to be:

<u>Type of Plant</u>	<u>Water Requirements (1)</u> <u>(Acre-Feet/Yr)</u>
Flashed Steam (Direct Contact)	3,600
Flashed Steam (Indirect Contact)	5,150
Binary Cycle	8,750

(1) based on blow-down discharge of 4,000 ppm TDS, make-up water of 1,000 ppm and geothermal resource temperature of 175°C.

2.0 CONCLUSIONS

The lack of sufficient data to completely assess ground water resources in the Wendell-Amedee geothermal area precludes an analysis of constraints on geothermal power plant development, due to limitations on water resources. Thus, procurement specifications have been prepared to obtain the requisite data. Upon completion of the tasks contained in the procurement specifications, an analysis of ground water resources in the Wendell-Amedee area can be completed.

These data, along with surface water information, should provide a basis for estimating any constraints on geothermal development due to limitations on water resources.

2.1 Make-up Water Availability

Data on surface water for the Wendell-Amedee geothermal area indicate that Honey Lake is the only major surface water body. The remaining surface water bodies are not of sufficient size to be a source of make-up water for geothermal power plant cooling purposes. Honey Lake could potentially be used as a source of make-up water for power plant development.

Data are not sufficient to develop estimates of the amount of ground water in storage and usable capacities. The lack of complete data for the three ground water basins precludes estimates of make-up water availability.

2.2 Developable MWe

The lack of sufficient data on ground water precludes analysis of geothermal power plant development for the Wendell-Amedee area. Although USGS has not yet developed an estimate of resource potential for Wendell-Amedee, for planning purposes JPL has indicated a 500 MWe potential.

Current implementation plans for Wendell Amedee indicate that a 55 MWe geothermal power plant is being considered for startup in 1983. Geoproducts will be the developers, with the California Department of Water Resources taking the power (see Task 1).

2.3 Procurement Specifications

A complete analysis of data on both surface and ground water are necessary to provide a basis for estimating constraints on geothermal power plant development. Surface water data for the Wendell-Amedee area was sufficient to estimate the availability for make-up water purposes. Ground water data, however, was not sufficient for developing an estimate of available make-up water. To be sufficient, data on both ground water in-storage and usable capacity must be known. Usable capacity is defined as recharge plus inflow into the ground water basin less current usage. Procurement specifications are in Appendix G.

3.0 RECOMMENDATIONS

3.1 Initiatives and Activities

3.1.1 Federal

Until further water resources are developed and specific constraints can be identified and quantified, the specific initiatives and activities which are applicable to the Wendell-Amedee area will be primarily federal. The initial activity recommended is the acquisition of specific ground water data identified in the procurement specifications. Once data acquisition and analysis is complete, constraints on geothermal power plant development can be identified.

Ground water is of critical importance. Potentially, once the ground water in storage and usable capacity are known, if warranted, an engineering/economic study on the viability of distribution of ground water will also be necessary.

3.1.2 State Agencies

The requisite data from the water management agencies in the Wendell-Amedee area should be made available for determination of ground water in storage and usable capacity. The primary agencies involved will be the California Division of Oil and Gas and the California Department of Water Resources. Since discharge requirements will be involved, the California Water Quality Control Board should also be involved in any discussions of water resource data and geothermal power plant development.

3.1.3 County and Local Agencies

Information on Lassen County and other local data will be required for complete analysis of ground water. Complete data acquisition from

Lassen County is critical to assess ground water resources in the Wendell-Amedee area.

3.2 Site Specific

3.2.1 Plant Siting

Specific plant siting recommendations can be developed once the geothermal power plant development constraints are known. Identifying the development constraints will be dependent upon the acquisition of the requisite ground water data.

3.2.2 Technological and Design Innovations

Specific recommendations related to technological and design innovations can also be developed when development constraints are established.

4.0 TECHNICAL DISCUSSION

4.1 Methodology

A general methodology was established to accomplish the major objectives of the study. The initial step of this methodology involved a comprehensive literature search to collect all published water resources literature required for the evaluation. Sources of data were various government agencies, institutions, and private organizations. A systematic literature review by technical key words was conducted to ascertain the extent of the data collected. Field investigations were then conducted among these groups to ascertain unpublished data and reports and also to confirm findings of previously published materials.

For surface water, major surface water bodies were identified, their physical and chemical characteristics evaluated, and their capacities determined based on these evaluations.

In the ground water evaluation, aquifers in the area were identified, their physical and chemical characteristics evaluated, and their capacity and productivity assessed. A water budget was not calculated because of the lack of sufficient data.

Figure VI-1 indicates the major steps of the methodology.

4.2 Survey of Existing Information

The purpose of the literature search was to screen published reports and materials that were pertinent to the water resources evaluation. The initial step of this literature search was to contact various government agencies and private organizations to collect the required data.

FIGURE VI-1

FLOW DIAGRAM OF METHOD OF APPROACH

All the data collected were recorded on card catalogue under a specific format. For example,

Author:	California Department of Water Resources
Report Title:	Northeastern Counties Groundwater Investigation, Bulletin No. 8
Source:	California Department of Water Resources
Date or Year of Publication:	1963
Index Number:	CS-GEN

The index number identifies the first alphabet of the principal author's last name, the number of publication listed under the alphabet, and the study area of concern. The letters WA indicate Wendell-Amedee scenarios. Each report is then labeled by the index number.

Appendix A contains a listing of all pertinent literature collected for this study area with the appropriate index numbers. Notation of figure, table and page number of the report relative to the specific keyword were recorded during the review (Appendix B).

During the literature review process, three key data sources were identified and were used to provide a major input into the water resources evaluation of the Wendell-Amedee KGRA. They are listed as follows:

California Department of Water Resources
1963 "Northeastern Counties Ground Water Investigation,"
Bulletin 98 Volume 1 (Ref. No. C5-GEN)

California Department of Water Resources
1960 "Northeastern Counties Investigation,"
Bulletin 58 (Ref. No. C2-GEN)

United States Department of Agriculture
1975 "Water and Related Land Resources, Central Lahontan Region,"
(Ref. NO. C2-GEN)

In addition to the literature search it was necessary to search for any unpublished data or any new developments in the water resources of the Wendell-Amedee KGRA area. Telephone contacts and visits were made to various government agencies and private organizations to validate and search for additional water resources data. Appendix C contains a list of persons, agencies, addresses and date of visits and telephone contacts.

4.3 Location of the Study Area

The Wendell-Amedee KGRA is located in Lassen County, California, near the California/Nevada border. The KGRA covers 17,292 acres and is located on the northeastern shore of Honey Lake. The actual study for the water resources evaluation was, however, delineated as a function of hydrologic considerations and availability of data rather than by political or jurisdictional boundaries. Figure VI-2 indicates the study area.

The Wendell-Amedee and Island study areas are situated in the Honey Lake Valley, in the basin and range physiographic province. Honey Lake Valley is a northwest/southeast trending topographic feature bound to the northeast by the Amedee, Shaffer and Skedaddle Mountains, and to the southwest by the Diamond Mountains. The Fort Sage Mountains are located at the southeast terminus of the valley.

The Honey Lake Valley is situated in a graben, bound by the Litchfield and Honey Lake faults to the northeast and southwest. The central part of the valley is occupied by Honey Lake (intermittently dry) which covers an area of approximately 75 square miles. The lake bed is at an elevation of 4,000 feet.

LOCATION MAP OF WENDEL-AMEDEE KGRA Figure VI-2

4.4 Surface Water

The climate of the Honey Lake basin is transitional between the mountain climate in the west to the desert climate in the east. The annual precipitation over the western mountain divide is around 30 inches. But south of the Wendell-Amedee KGRA, in the Sierra Army Depot, the annual precipitation is four inches or less. The shadow effect of the surrounding mountains is probably the major factor influencing the Honey Lake basin climate.

The Honey Lake basin is a closed basin approximately 100 miles in length and 35 miles in width. The drainage area enclosed is approximately 2200 square miles. All surface runoff drains to Honey Lake, from which it is lost by evaporation and ground water recharge. The major perennial streams are the Susan River, Willow Creek, and Long Valley Creek. The Susan River and Willow Creek have their sources in the mountains to the west and northwest of Honey Lake. Long Valley Creek has its source to the southeast of Honey Lake. Major storage reservoirs located within the Susan River drainage are McCoy Flat Reservoir, Hog Flat Reservoir and Lake Leavitt. Horse Lake is an intermittent lake located within the Willow Creek-Secret Valley drainage.

The Eagle Lake basin is not within the Honey Lake watershed, but it does contribute water to Willow Creek by percolation through an abandoned and blocked tunnel when the water surface level of Eagle Lake reaches 5100 feet elevation (California Water Resources Control Board 1971). Figure VI-3 shows the Honey Lake and Eagle Lake watersheds.

Drainage area and annual runoff for the drainages and the gaging stations within the drainages are shown in Table VI-1. The monthly distributions of runoff at the gaging stations on the Susan River and Willow Creek are shown in Appendix F. The runoff pattern of the gaging station on the Susan River reflects snowmelt runoff characteristics,

TABLE VI-1

**DRAINAGE AREA AND ANNUAL RUNOFF
FOR DRAINAGES AND GAGING STATIONS
WITHIN HONEY LAKE BASIN**

Drainage	Drainage Area (sq.mi.)	Estimated Annual Runoff (acre-feet)	Gaging Station	Drainage Area (sq.mi.)	Mean Annual Runoff (acre-feet)
Susan River	568	100,000	Susan River at Susanville USGS #10356500	184	71,290
Willow Creek- Secret Valley	666	60,000	Willow Creek near Susanville, USGS #10358500	90	25,210
Herlong	935	30,000	Long Valley Creek near Hallelujah DWR #G61705	100	10,720
TOTAL	2,169	190,000		374	107,220

Sources: California Dept. of Water Resources, Bull.No. 130, 1970-1975; USGS Water Data Report CA 76-4, 1976; Calif. DWR Bull. No. 58, 1960

while the gaging station on Willow Creek reflects baseflow characteristics (CDWR #58 1960). During the summer crop irrigation season (June through October) only small quantities of irrigation waste water reach Honey Lake.

Storage capacity and surface area of the major lakes and reservoirs within the Honey Lake basin are shown in Table VI-2. Honey Lake is extremely shallow. It has dried up completely three times since 1900 (Bureau of Land Management 1978). McCoy Flat and Hog Flat Reservoirs regulate the flow of the Susan River for irrigation purposes. Lake Leavitt is also used for irrigation. Horse Lake is a shallow intermittent lake.

The estimated mean annual flow from Eagle Lake to Willow Creek by the percolation through the tunnel is 5800 acre-feet (USDA 1975).

The water quality of the small lakes and ephemeral and perennial streams is good in general. The water is generally a calcium-bicarbonate type with total dissolved solids less than 300 ppm, and pH ranging from 7.0 to 9.0. Long Valley Creek is an exception to the generally good water quality of the streams originating in the Sierra Nevada. The water from Long Valley Creek has total dissolved solid levels that are less than 500 ppm (CDWR 1960).

The water quality of Honey Lake is poor because of its extremely high salinity. Its water is a sodium bicarbonate-sulfate type with an extremely high sodium content, i.e. greater than 90 percent sodium, (CDWR 1960). The concentration of total dissolved solids is 5000 ppm (CDWR #204 1977).

Irrigation is a major consumptive use of water in the Honey Lake basin. For the 1973 crop irrigation season, the consumptive use was estimated to be 87,350 acre-feet for 58,659 acres under irrigation. The irrigation within the basin is limited by the available water supply (USDA 1975).

**STORAGE CAPACITY AND SURFACE AREA
OF LAKES AND RESERVOIRS
WITHIN HONEY LAKE BASIN**

Lake or Reservoir	Storage Capacity (acre-feet)	Surface Area (acres)
Honey Lake	300,000 (average)	60,000 (average)
McCoy Flat Reservoir	17,290	1,800
Hog Flat Reservoir	8,000	1,000
Lake Leavitt	14,000	2,560
Horse Lake	13,200	2,840

**Sources: California Dept. of Water Resources Bull.No. 204, 1977;
California Dept. of Water Resources Bull.No. 17-76, 1976;
U. S. Dept. of Agriculture, 1975**

Irrigation in the Honey Lake basin is essential. Presently there are about 72,592 acres being irrigated from both surface and underground sources in the California part of the Calvada Subbasin. Honey Lake basin is part of the Calvada Subbasin and has 58,659 acres of irrigated land. Included in this total for the Calvada Subbasin are 13,354 acres semi-irrigated pasture and mountain meadows, which may or may not have water rights. The 65,400 acres in the Calvada Subbasin have surface water rights (USDA 1975).

Summary of Findings for the Wendell-Amedee area are:

- The Honey Lake watershed is a closed basin, having a drainage area of 2,200 square miles. The major streams are the Susan River, Willow Creek, and Long Valley Creek.
- Honey Lake, the major surface water body in the area, has a surface area of approximately 59,198 acres (1973). The only other surface water bodies in the area are several irrigation reservoirs, ranging from a few acres to 2560 acres.
- Annual precipitation varies from 40 inches at the western portion to less than 10 inches along the eastern side of Honey Lake. Most of the precipitation occurs in winter, from October through March.
- Total surface runoff discharged to Honey Lake reported by Water and Related Land Resources, Central Lahontan Basin is 100,000 acre-feet per year. The measured annual discharge at gaging stations within the Honey Lake basin is 107,220 acre-feet. To the south of the Honey Lake, Long Creek has an average annual discharge of 10,720 acre-feet. To the west of Honey Lake, the Susan River and the Willow Creek-Secret Valley have 71,290 acre-feet and 25,210 acre-feet, respectively. The estimated total annual runoff based on area proportion is 190,000 acre-feet for the Honey Lake basin.

- Most of the streams have insignificant amounts of flow discharging into Honey Lake because of the irrigation diversion in the upper stretches.
- The water quality of the lakes and streams is generally good, with total dissolved solid less than 300 ppm and pH ranging from 7.0 to 9.0. The water from Long Valley Creek has TDS less than 500 ppm.
- Honey Lake has an average storage of 300,000 acre-feet but it has dried up completely three times since 1900. Evaporation from lake surface varies from 10,000 acre-feet to 200,000 acre-feet annually. The estimated annual evaporation in 1970 was 66,300 acre-feet. The average pan evaporation near KGRA was 41.2 inches from May through September. Honey Lake has 5,000 ppm of the total dissolved solids.
- Consumptive use of water by irrigated crop land was estimated to be 87,350 acre-feet for 58,659 acres. Domestic use of water is discrete and negligible and is supplied by ground water.
- Potentially, the 300,000 acre-feet of Honey Lake water could be considered as cooling water. Because the streams run nearly dry in summer, storage facilities and transmission conduits are necessary to tap surface water for cooling purposes.
- Discharge should be in compliance with the California State Water Resources Control Board's water quality control policy for power plant cooling. The Region 6 Water Quality Control Board, Lahontan Region, issues discharge permits.

Surface water data are shown in Appendix D.

4.5 Ground Water

The ground water basins of importance in the vicinity of the KGRA are Honey Lake Valley, Willow Creek Valley, and Secret Valley. The physiographic setting of the KGRA is illustrated in Figure VI-4. Elevations in the area vary from 7574 feet in the Amedee Mountains to about 4000 feet at Honey Lake (Hilton 1963).

Aquifers within these basins are both confined and unconfined. Water levels in general are within several tens of feet of the ground surface. The characteristics of each of these basins will be discussed separately in the following study.

Honey Lake Valley is located within the KGRA, and Honey Lake is located therein. The California portion of the valley is about 45 miles in length and 10 to 15 miles in width, having an area of 490 square miles. Honey Lake Valley is a closed basin with no surface or subsurface outflow, and ground water movement is controlled by topography. The general direction of ground water is toward Honey Lake from all areas in the Valley. Figure VI-5 shows ground water movement.

The storage capacity of the ground water basin is approximately 16 million acre-feet for a depth zone of 0 to 750 feet. The amount of this ground water which is of usable quality and the usable storage below 750 is not presently known. Well yields are as high as 2200 gpm with an average of 900 gpm (CDWR #118). Figure VI-5 indicates two zones of ground water development potential. Wells properly constructed in Zone A should have yields in excess of 500 gpm (Phil Lorens, phone conversation). Zone B should produce wells in excess of 100 gpm.

Figure Physiographic setting of Wendel-Amedee KGRA

FIGURE VI-4

LOCATION MAP OF WENDEL-AMEDEE KGRA Figure VI-5

ADAPTED FROM: CALIFORNIA DIVISION OF MINES AND GEOLOGY,
GEOLOGIC MAP OF CALIFORNIA, WESTWOOD SHEET.

Willow Creek Valley is northwest of the Wendell-Amedee KGRA about 17 miles. It is approximately seven miles long and four miles wide, with a total area of approximately 20 square miles (CDWR, #98 1963). Ground water movement is not impaired by faulting in the valley, and the general direction of movement is southeast toward Willow Creek. Storage capacity and usable capacity of the Willow Creek area is not known.

Secret Valley, the third ground water basin for the Wendell-Amedee geothermal area, is located five miles north of the KGRA. The Valley, covering an area of about 65 square miles, is approximately nine miles long and six miles wide. Ground water movement is to the southwest toward Secret Creek, eventually discharging from the Valley by way of Balls Canyon. Storage usable capacities for the area have not been determined. Data on water quality, water levels and well yields is limited.

Secret Valley is located approximately five miles north of the KGRA. It is an erosionally formed valley with very little modification by faulting. Thickness of valley fill sediment range up to 400 feet. The valley is nine miles long and six miles wide, with an area of about 65 square miles. Basin deposits of silt and clay are generally thin with less than 150 feet of thickness. These deposits are only locally productive but in general are of low permeability. Pliocene basalt and lake deposits interbedded under the valley are the principal aquifers in the valley, and they may yield large amounts of confined water to wells locally. Plio-Pleistocene and Pleistocene basalts border the valley and are the recharge areas for the valley. Ground water movement is to the southwest toward Secret Creek, eventually discharging from the valley by way of Balls Canyon. The storage capacity of the valley is unknown. Data on the water quality, water levels and well yields is limited.

Appendix E contains a summary of the ground water hydrology for Honey Lake Valley, Willow Creek Valley and Secret Valley.

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GLASS MOUNTAIN
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PART VII

GLASS MOUNTAIN

1.0 SUMMARY

The objective of this report was to assess the following for the Glass Mountain, California, Known Geothermal Resource Area (KGRA):

- water resources that are available for geothermal electric power plant development
- power plant make-up water requirements
- the developable megawatts based on the available make-up water
- the need for additional water resource data

The availability of outside sources of make-up water for power plant operations is a major consideration in developing geothermal resources in the Glass Mountain area. The quality, quantity and availability of both surface and ground water for use in geothermal power plants was examined. The demand for water was based upon the previously conducted geothermal power plant water utilization case study (Part X). The lack of complete data on ground water in-storage and an inventory of usage in the pertinent water basins preclude projections of developable megawatts of geothermal power plant output. Procurement specifications have been prepared to acquire the requisite data to determine water available for geothermal power plant development in the Glass Mountain geothermal area.

1.1 Surface Water Supply

Analysis of the surface water resources for the Glass Mountain area indicate the following:

- Annual precipitation is approximately 50 inches in the Glass Mountain area.
- Due to the highly permeable volcanic soils, there is no surface drainage system in the watershed areas.
- Medicine Lake is the only surface water body in the area that could potentially be used for geothermal power plant development.
- Other surface water bodies (Clear Lake Reservoir, Tule Lake Sump and Lower Klamath Lake) are not available for geothermal power plant development as they have been designated as national wildlife refuges.

1.2 Ground Water Supply

Analysis of ground water related to the Glass Mountain area indicate:

- Four major ground water basins, Butte Valley, Red Rock Valley, Lower Klamath Lake and Tule Lake, are in the area.
- Although some well data are available, ground water storage capacity for each of the ground water basins is now known.
- Data on usable capacity is also not available for any of the areas.
- Available data on water quality from wells in the area indicate ground water of suitable quality for geothermal power plant cooling purposes.
- Procurement specifications have been developed to acquire the requisite data to determine the amount of ground water available for geothermal power plant development.

1.3 Power Plant Water Requirements

Based on data developed in the case study, the make-up water requirements for a 50 MWe power plant at Glass Mountain are estimated to be:

<u>Type of Plant</u>	<u>Water Requirements (1)</u> <u>(acre-feet/yr)</u>
Flashed Steam (Direct Contact)	3,100
Flashed Steam (Indirect Contact)	4,250
Binary Cycle	7,400

- (1) Based on blow-down discharge of 4,000 ppm TDS, make-up water of 1,000 ppm and geothermal resource temperature of 200°C.

2.0 CONCLUSIONS

Surface water in the Glass Mountain area is not available in quantities necessary for geothermal power plant development. In addition, the lack of sufficient data to completely assess ground water resources in the Glass Mountain area precludes an analysis of constraints on geothermal power plant development due to limitations on water resources. Thus, procurement specifications have been prepared to obtain the requisite data. Upon completion of the tasks contained in the procurement specifications, an analysis of ground water resources in the Glass Mountain area can be completed. These data, along with surface water information, should provide a basis for estimating any constraints on geothermal development due to limitations on water resources.

2.1 Make-up Water Availability

Data indicate Medicine Lake is the only surface water body near the Glass Mountain geothermal area. The USFS's Land Management Plan indicates the maintenance of Medicine Lake as part of a wilderness area is an objective of the plan. Given this consideration, use of water from Medicine Lake for geothermal power plant development will require coordination with the USFS.

Data are not sufficient to develop estimates of the amount of ground water in-storage and usable capacities. The lack of complete data for the four ground water basins precludes estimates of make-up water availability.

2.2 Developable MWe

The lack of sufficient data on ground water precludes complete analysis of geothermal power plant development in the Glass Mountain area. Although the USGS has not yet developed an estimate of resource potential for Glass Mountain, for planning purposes, JPL has indicated a 1000 MWe potential.

No geothermal power plants are currently being planned for the Glass Mountain area (see Task 1).

2.3 Procurement Specifications

A complete analysis of data on both surface and ground water is necessary to provide a basis for estimating constraints on geothermal power plant development. Sufficient data were available to assess the availability of surface water in the area. Ground water data, however, were not sufficient for developing an estimate of available make-up water. To be sufficient, data on both ground water in-storage and usable capacity must be known.

Procurement specifications are in Appendix G.

3.0 RECOMMENDATIONS

3.1 Initiatives and Activities

3.1.1 Federal

When further water resources data are developed and specific constraints can be identified and quantified, the specific initiatives and activities which are applicable to the Glass Mountain area will be primarily federal. The initial activity recommended is the acquisition of specific ground water data identified in the procurement specification. Once data acquisition and analysis is complete, constraints on geothermal power plant development can be identified.

Since a surface water discharge system does not exist in the area and the other sources of water are limited, determination of ground water information is of critical importance. Potentially, once the ground water in storage and the usable capacity are known, if warranted, an engineering/economic study on the viability of distribution of ground water will also be necessary.

The position of the USFS in the Glass Mountain KGRA is important. Development of geothermal power plants on USFS land will require coordination with the field developer and utility involved. As specific projects are identified, coordination planning and informational meetings should be undertaken to facilitate orderly development of the geothermal resource.

3.1.2 State

The requisite data from the water management agencies in the Glass Mountain area should be made available for determination of ground water in storage and usable capacity. The primary agencies involved will be the California Division of Oil and Gas and the California

Department of Water Resources. Since discharge requirements will be involved, the California Water Quality Control Board should also be involved in any discussions of water resource data and geothermal power plant development.

3.1.3 Counties and Local

Siskiyou County and other local data will be required for complete analysis of ground water, thus this information should be provided, where available. Complete data acquisition from Siskiyou County is critical to completely assess ground water resources in the Galss Mountain area.

3.2 Site Specific

3.2.1 Plant Siting

Specific plant siting recommendations can be developed once the geothermal power plant development constraints are known. Identifying the development constraints will be dependent upon the acquisition of the requisite ground water data.

3.2.2 Technological and Design Innovations

Specific recommendations related to technological and design innovations can also be developed when development constraints are established.

4.0 TECHNICAL DISCUSSION

4.1 Methodology

A general methodology was established to accomplish the major objectives of the study. The initial step of this methodology involved a comprehensive literature search to collect all published water resources literature required for the evaluation. Sources of data were various government agencies, institutions, and private organizations. A systematic literature review by technical key words was conducted to ascertain the extent of the data collected. Field investigations were then conducted among these groups to ascertain unpublished data and reports and also to confirm findings of previously published materials.

For surface water, major surface water bodies were identified, their physical and chemical characteristics evaluated, and their capacities determined based on these evaluations.

In the ground water evaluation, aquifers in the area were identified, their physical and chemical characteristics evaluated, and their capacity and productivity assessed. A water budget balance was not calculated because of the lack of sufficient data.

Figure VII-1 indicates the major steps of the methodology.

4.2 Survey of Existing Information

The purpose of the literature search was to screen published reports and materials that were pertinent to the water resources evaluation. The initial step of this literature search was to contact various government agencies and private organizations to collect the required data.

FIGURE VII-1

FLOW DIAGRAM OF METHOD OF APPROACH

All the data collected were recorded on card catalogue under a specific format. For example,

Author: California Department of Water Resources
Report Title: Northeastern Counties Groundwater Investigation, Bulletin No. 8
Source: California Department of Water Resources
Date or Year of Publication: 1963
Index Number: C5-GEN

The index number identifies the first alphabet of the principal author's last name, the number of publication listed under the alphabet, and the study area of concern. The letters GM indicate Glass Mountain scenarios. Each report is then labeled by the index number.

Appendix A contains a listing of all pertinent literature collected for this study area with the appropriate index numbers. Notation of figure, table and page number of the report relative to the specific key word were recorded during the review (Appendix B).

During the literature review process, three key data sources were identified and were used to provide a major input into the water resources evaluation of the Glass Mountain KGRA. They are listed as follows:

California Department of Water Resources
1963 "Northeastern Counties Groundwater Investigation,"
Bulletin 98 Volume 1 (Ref. No. C5-GEN)

California Department of Water Resources
1960 "Northeastern Counties Investigation,"
Bulletin 58 (Ref. No. C2-GEN)

United States Department of Agriculture
1975 "Water and Related Land Resources, Central Lahontan Region,"
(Ref. NO. C2-GEN)

In addition to the literature search, it was necessary to search for any unpublished data or any new developments in the water resources of the Surprise Valley KGRA area. Telephone contacts and visits were made to various government agencies and private organizations to validate and search for additional water resources data.

Appendix C contains a list of persons, agencies, addresses and date of visits and telephone contacts.

4.3 Location of the Study Area

The Glass Mountain KGRA is located on the eastern side of Siskiyou County, California, and lies within the western boundary of the Modoc National Forest. The KGRA covers approximately 33,500 acres. The actual study area for the water resources evaluation was, however, delineated as a function of hydrologic considerations and availability of data rather than by political or jurisdictional boundaries. Figure VII-2 indicates the Glass Mountain study area.

The Glass Mountain KGRA situated in the transitional zone between the Cascade and the Madoc Plateau geomorphic provinces. Most of the KGRA lies at an altitude above 6,000 feet. The area consists of a thick accumulation of lava flows and tuff beds with a one square mile surface area crater lake--Medicine Lake. The surface drainage pattern is poorly developed because the highly permeable volcanic rock allows ready infiltration of precipitation and snowmelt.

4.4 Surface Water

The annual precipitation at the Glass Mountain KGRA is above 40 inches. Average January and July temperatures are 20°F and 60°F respectively (California Region Framework Study Committee 1970).

The Glass Mountain KGRA is located within five individual drainage basins. These are: Oklahoma, Lava Beds, Medicine Lake, McArthur and Big Valley. The Oklahoma and Lava Beds drainages are portions of the Lost River Basin and drain to the north. The McArthur and Big Valley drainages are portions of the Pit River basin and drain to the south. The Medicine Lake drainage is a small closed basin draining underground subsurface to a volcanic crater occupied by Medicine Lake. There are no perennial streams in the vicinity of the Glass Mountain KGRA.

The volcanic soils in the vicinity of the Glass Mountain KGRA absorb almost all precipitation. There are no perennial streams and very little drainage development (such as gullies) in this vicinity, which indicates that there is almost no surface runoff (M. Cleveland 1978).

Medicine Lake is located within a small closed drainage basin of approximately 23 square miles. The surface area of the lake is 425 acres and the volume is 7,000 acre-feet. The lake occupies a volcanic crater which is divided into two portions. The maximum depth of the western portion is 150 feet, and the maximum depth of the eastern portion is 55 feet (M. Cleveland 1978).

Lakes and reservoirs of significant size within the Glass Mountain area include Clear Lake Reservoir, Tule Lake Sump and Lower Klamath Lake. The storage capacity of Clear Lake Reservoir is 527,000 acre-feet and the surface area is 24,800 acres (CDWR #17-76 1976). Clear Lake Reservoir is designated as a national wildlife refuge, thus the water is not available for any other use. Tule Lake Sump and Lower Klamath Lake are extremely shallow and the surface areas (including marsh) are 13,000 and 18,000 acres, respectively (M. Roos 1978). Lower Klamath Lake is also designated as a national wildlife refuge (See Figure VII-3).

Summary of findings for Glass Mountain area are:

- The Medicine Lake watershed accounts for half of the land area of the Glass Mountain KGRA.

- Annually precipitation is approximately 50 inches in the vicinity of Medicine Lake. The winter precipitation is in the form of snow.
- Because of the highly permeable volcanic soils, the Glass Mountain area has no surface drainage system. All of the precipitation and snow melt seeps completely into volcanic soils and rocks.
- The Medicine Lake has a surface area of 425 acres, and a volume of 7,000 acre-feet. The Lake is sustained by base-flow and precipitation falling on the surface.
- The Medicine Lake watershed is within the jurisdiction of the Modoc National Forest.
- Any geothermal development will have to be compatible with the USFS's land management plan.

Surface water data are shown in Appendix D.

4.5 Ground Water Hydrology

Four ground water basins are located in the vicinity of the Glass Mountain KGRA. The identified basins are Butte Valley, Red Rock Valley, Tule Lake and Lower Klamath Lake. Butte Valley, Tule Lake and the Lower Klamath Lake area comprise the principal aquifers of the Glass Mountain area. The sedimentary rock structure of the Red Rock Valley are not sufficiently permeable to yield large quantities of water to wells.

Butte Valley is a closed basin located about 20 miles northwest of the Glass Mountain KGRA and covers an area of about 480 square miles. The lake deposits under the central and wester portion of the valley are not sufficiently permeable to yield large quantities of water to wells. The eastern portion of the valley comprise the aquifer in the Butte Valley.

Well yields up to 4,100 gpm have been mmeasured in Butte Valley, with an average of 2,000 gpm. Water quality in Butte Valley is generally

adequate for most uses with TDS values ranging from 150 to 500 mg/l in most areas (CDWR #118 1975). Estimates of ground water storage capacity in Butte Valley are not available.

Red Rock Valley is located approximately 12 miles northwest of Glass Mountain geothermal area and covers an area of about 20 square miles. The water bearing materials in the valley include up to 120 feet of core deposits and basalt. The deeper basalts which underlie Red Rock Valley are permeable and capable of large well yields. The lake deposits which overlie the basalt do not yield significant quantities of water to wells.

The lack of data precludes a determination of the ground water stored in the valley or the general pattern of its movement. Data on the quality of ground water are also lacking.

The Tule Lake area of the Klamath River Valley is located approximately 10 miles north of the Glass Mountain KGRA. Water bearing material in the area include lake deposits and basalt. The lake deposits have low permeability and do not yield large quantities of water to wells. The basalt is highly permeable and capable of large yields. Although yield data for wells located in the Tule Lake area is limited, some well information is available. This information indicates yields from wells in the lake deposits of 1,200 to 2,650 gpm at specific capacities of 16 to 62 gpm per foot of drawdown. Wells in the basalts west of the lake deposits produce up to 4,000 gpm at specific capacities up to 250 gpm per foot of drawdown. By contrast, the average yield of the lake deposits is 30 gpm at an average specific capacity of 2 gpm per foot of drawdown. The total ground water storage capacity for the area is unknown.

The Lower Klamath Lake area of the Klamath River Valley is located approximately 13 miles northwest of the Glass Mountain KGRA. Information is not sufficient to accurately describe the water bearing

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PART VIII

LASSEN

1.0 SUMMARY

The objective of this report was to assess the following for the Lassen, California, Known Geothermal Resource Area (KGRA):

- water resources that are available for geothermal electric power plant development
- power plant make-up water requirements
- the developable megawatts based on available make-up water
- the need for additional water resource data

The availability of outside sources of make-up water for power plant operations is a major consideration in developing geothermal resources in the Lassen area. The quality, quantity and availability of both surface and ground water for use in geothermal power plants was examined. The demand for water was based upon the previously conducted geothermal power plant water utilization case study (Part X). Although certain data are available for water resources in the area, complete information is lacking for ground water resources. Data on ground water in-storage is not complete for analysis purposes. Thus, constraints on geothermal power plant development cannot be developed. Procurement specifications have been prepared to acquire the requisite data to determine water available for geothermal power plant cooling purposes.

1.1 Surface Water Supply

Analysis of the surface water resources for the Lassen area indicates the following:

- Annual precipitation varies from 60 inches along the Plumas-Tehama County line to approximately 30 inches at Lake Almanor.
- The North Fork of the Feather and its tributaries drain the eastern slope of the KGRA. The North Fork of the Feather River discharges into Lake Almanor and Mountain Meadows Reservoir, which have storage capacities of up to 1,193,000 and 24,000 acre-feet, respectively.
- The North Fork of the Feather River has an annual adjusted discharge of approximately 665,800 acre-feet at the gaging station near Prattville.
- Use of this water from these reservoirs or from streams which discharge into them will, most likely, require agreements with Pacific Gas and Electric.
- The eastern portion of the KGRA includes the South Fork of Battle Creek, Mill Creek and Deer Creek.
- The annual stream flow along the western boundary of the KGRA is 28,000 acre-feet for the South Fork of Battle Creek, 81,000 acre-feet for Mill Creek and 100,000 acre-feet for Deer Creek.
- There are no major lakes within these watershed areas.

1.2 Ground Water Supply

Specific ground water findings in the Lassen area include:

- Three major ground water basins are in the area, Indian Valley, Lake Almanor Valley and Humbug Valley.
- Estimates of ground water in-storage have been developed for each of these areas, Indian Valley 100,000 acre-feet, Lake Almanor Valley 45,000 acre-feet, and Humbug Valley, 76,000 acre-feet.
- Data on usable capacity is not available for any of the ground water basins.
- Available data indicate the water quality in the ground water is high and is suitable for geothermal power plant cooling purposes.
- Procurement specifications have been developed to acquire the requisite data to determine usable capacities in each basin.

1.3 Power Plant Water Requirements

Based on data developed in the case study, the make-up water requirements for a 50 MWe power plant at Lassen are estimated to be:

<u>Type of Plant</u>	<u>Water Requirements (1)</u> <u>(acre-feet/yr)</u>
Flashed steam (direct contact)	2,890
Flashed steam (indirect contact)	3,700
Binary cycle	6,700

(1) Based on blow-down discharge of 4,000 ppm TDS, make-up water 1,000 ppm TDS and geothermal resource temperature of 220°C.

2.0 CONCLUSIONS

Surface water in the Lassen area exists in major reservoirs on the western portion of the KGRA. These reservoirs, Lake Almanor and Mountain Meadows Reservoir, are used by Pacific Gas and Electric (PG&E) for hydroelectric power generation. Potentially, significant withdrawal from these reservoirs, as would be required for extensive power geothermal plant development, would require agreement from PG&E. The use of any water from streams feeding these reservoirs would, most likely, also require agreements with PG&E.

Ground water data are not complete for the area, thus specific conclusions as to constraints on geothermal power plant development could not be estimated. The potential for constraints on the use of surface water may require the development of ground water if geothermal resources are to be developed. Once the data contained in the procurement specifications are available, the ground water analysis can be completed and constraints on power plant development can be identified.

2.1 Make-Up Water Availability

Surface water in the area is potentially available for power plant development. Since use of the surface water bodies would, most likely, require agreements with PG&E for any long-term significant withdrawal, this may not be a suitable source of make-up water. A similar condition applies to the use of other streams in the area since PG&E has a system of seven power plants located on the main surface drainage system.

The data on ground water storage indicates a source for some geothermal power plant development. Significant use of ground water for geothermal development would, most likely, create a situation in which the resource is being mined. To fully analyze the availability of make-up water from ground water resources, usable capacity data will be required.

2.2 Developable MWe

The lack of complete data on ground water precludes an analysis of geothermal power plant development in the Lassen area. The USGS estimate for the capacity of the resource in the area is 150 MWe, while JPL use 1,000 MWe for their purposes.

No geothermal power plants are currently planned for the Lassen area (see Task 1).

2.3 Procurement Specifications

Complete information on both surface and ground water are necessary to provide a basis for estimating constraints on geothermal power plant development. Sufficient data were available to assess the availability of surface water in the area. Ground water data were, however, not sufficient for developing an estimate of available make-up water. Ground water storage information has been developed; however, data on current usage are not available. Thus, procurement specifications have been developed to acquire the requisite data. Procurement specifications are in Appendix G.

3.0 RECOMMENDATIONS

3.1 Initiatives and Activities

3.1.1 Federal

Further water resources data will be required to identify specific constraints on geothermal development in the Lassen KGRA. The initial federal initiative should be to issue the procurement specifications to acquire the requisite ground water data. Acquisition of a complete data base will allow analysis of constraints on geothermal power plant development.

Additional federal initiatives in the Lassen area involve coordination with the USFS. Specific development plans of geothermal developers and utilities will have to be compatible with USFS requirements and plans. Early coordination between the USFS and developers/utilities will allow for orderly and timely development of geothermal resources in the Lassen KGRA.

3.1.2 State

State activities would involve primarily access to the requisite data for determination of usable capacity of ground water. The California Division of Oil and Gas and the California Department of Water Resources would be the two primary agencies involved in this portion of the procurement specification.

3.1.3 Counties and Local

Data from Plumas and Tehama County will be necessary to complete the tasks contained in the procurement specifications. The county records on well drilling activity in the geothermal area will be a critical element for completing this task.

3.2 Site Specific

3.2.1 Plant Siting

Specific plant siting recommendations will be dependent upon development of constraints. Certain general recommendations can, however, be developed based on the locale of surface water resources. Although agreements will, most likely, be required with PG&E, the plant siting in areas of available surface water should be considered.

4.0 TECHNICAL DISCUSSION

4.1 Methodology

A general methodology was established to accomplish the major objectives of the study. The initial step of this methodology involved a comprehensive literature search to collect all published water resources literature required for the evaluation. Sources of data were various government agencies, institutions, and private organizations. A systematic literature review by technical key words was conducted to ascertain the extent of the data collected. Field investigations were then conducted among these groups to ascertain unpublished data and reports and also to confirm findings of previously published materials. For surface water, major surface water bodies were identified, their physical and chemical characteristics evaluated, and their capacities determined based on these evaluations.

In the ground water evaluation, aquifers in the area were identified, their physical and chemical characteristics evaluated, and their capacity and productivity assessed. A water budget balance was not calculated because of the lack of sufficient data.

Figure VIII-1 indicates the major steps of the methodology.

4.2 Survey of Existing Literature

The purpose of the literature search was to screen published reports and materials that were pertinent to the water resources evaluation. The initial step of this literature search was to contact various government agencies and private organizations to collect the required data.

All the data collected were recorded on card catalogue under a specific format. For example,

Figure VIII-1

FLOW DIAGRAM OF METHOD OF APPROACH

Author: California Department of Water Resources
Report Title: Northeastern Counties Groundwater Investigation, Bulletin No. 8
Source: California Department of Water Resources
Date or Year: 1963
of Publication:
Index Number: C5-GEN

The index number identifies the first alphabet of the principal author's last name, the number of publication listed under the alphabet, and the study area of concern. The letter L indicates Lassen scenarios. Each report is then labeled by the index number.

Appendix A contains a listing of all pertinent literature collected for this study area with the appropriate index numbers. Notation of figure, table and page number of the report relative to the specific keyword were recorded during the review (see Appendix B).

During the literature review process, three key data sources were identified and were used to provide a major input into the water resources evaluation of the Lassen KGRA. They are listed as follows:

California Department of Water Resources
1963 "Northeastern Counties Ground Water Investigation,"
Bulletin 98 Volume 1 (Ref. No. C5-GEN)

California Department of Water Resources
1960 "Northeastern Counties Investigation,"
Bulletin 58 (Ref. No. C2-GEN)

United States Department of Agriculture
1975 "Water and Related Land Resources, Central Lahontan Region,"
(Ref. NO. C2-GEN)

In addition to the literature search, it was necessary to search for any unpublished data or any new developments in the water resources of the Lassen KGRA area. Telephone contacts and visits were made to various government agencies and private organizations to validate and search for additional water resources data.

Appendix C contains a list of persons, agencies, addresses and date of visits and telephone contacts.

4.3 Location of the Study Area

The Lassen KGRA is located within Plumas and Tehama Counties. Approximately 40% of the KGRA is within Tehama County, with the remainder in Plumas County. The KGRA is 78,642 acres and is entirely within the Lassen National Forest. The area studies for water resources were delineated as a function of hydrologic considerations and availability of data rather than by political or jurisdictional boundaries. Figure VIII-2 indicates the Lassen study area.

The Lassen KGRA lies in the southern portion of the Cascade Range geomorphic province. Lassen Peak, which is north of the KGRA, reaches 10,657 feet, and is the only active volcano in the continental United States. Other features of the area include Mount Harkness (8,045 feet), Sifford Mountain (7,408 feet), and Mount Diller (9,087 feet).

4.4 Surface Water

The Lassen KGRA is divided into two portions by a drainage divide trending in a north-south direction and generally following the Tehama-Plumas county line. The eastern portion of the Lassen KGRA, about three-fifths of the area, is within the North Fork Feather River drainage basin. This basin is the main drainage area for the Lassen KGRA.

Figure VIII-2

The watershed consists of the headwaters of the North Fork Feather River and its tributaries above Almanor Dam. The drainage area involved is 493 square miles. Major reservoirs and lakes in the basin include Mountain Meadows Reservoir (24,000 acre-feet storage) and Lake Almanor (1,193,000 acre-feet storage). Outflow from Lake Almanor is released to the North Fork Feather River at Almanor Dam, and through diversion to the Butt Valley powerhouse. Leakage through the abandoned Almanor-Butt Creek tunnel number 1 is also a source of outflow from Lake Almanor (USGS Water-Data Report CA76-4 1977).

The water level and volume of Lake Almanor has been measured by the USGS on the North Fork Feather River near Prattville, about one-half mile below Almanor Dam. These measurements indicate the mean annual adjusted discharge at the USGS station over 71 years has been 665,800 acre-feet (USGS Water Data Report CA76-4, 977).

The North Fork Feather River and its tributaries above Lake Almanor have relatively uniform flow characteristics. This is due to the fact that the predominantly volcanic soils readily absorb and store precipitation and snowmelt, and then yield runoff at a comparatively even rate of flow (CDWR #59-2 1960). The flow in the Hamilton Branch, in the eastern portion of the basin, is regulated by Mountain Meadows Reservoir. The outflow from the whole basin is regulated by Lake Almanor. The only unregulated part of the basin is the western portion.

The water quality of the surface streams, lakes, and reservoirs in the basin is relatively good. The water is calcium bicarbonate type. The concentration of total dissolved solids is less than 100 ppm (CDWR #58 1960). The monthly mean water temperatures for February and August are 3°C and 15°C, respectively (USGS-WRD 1971). These monthly mean water temperatures are the minimum and maximum for the year.

The western portion of the Lassen KGRA is within the Battle Creek, Mill Creek and Deer Creek drainage basins. The total drainage area in the

KGRA is 126 square miles. These streams flow to the west and are tributaries of the Sacramento River. Battle Creek, Mill Creek and Deer Creek all have gaging stations near their confluences with the Sacramento River. There are no major lakes or reservoirs within these watersheds.

The drainage area and mean annual discharge for the gaging stations of interest are shown in Table VIII-1. In addition, the drainage areas of South Fork Battle Creek and Mill Creek, as shown in Figure VIII-3, are 20.2 and 36.6 square miles, respectively.

The data for the gaging stations on Deer Creek indicate that the annual discharge at the upstream station is 43% of the annual discharge for the downstream station, and the drainage area of the downstream station is 33% of the drainage area of the downstream station. If this same relation is applied to the Battle Creek and Mill Creek drainages, then the annual discharge for the headwaters of South Fork Battle Creek and Mill Creek, as shown in Figure VIII-3, would be 28,000 and 81,000 acre-feet, respectively. There are no major lakes or reservoirs within the watersheds.

The water quality of the surface streams is relatively good, with total dissolved solids of less than 150 ppm (CDWR #58 1960). The monthly mean water temperatures for February and July are 2°C and 16°C, respectively (USGS-WRD 1971). These monthly mean water temperatures are the minimum and maximum for the year.

Water rights permits or licenses have been issued to the Pacific Gas and Electric Company to appropriate water on Feather River stream systems (CDWR 1960). One of the licenses is for 65 cfs (47,000 acre-feet per year) on the North Fork of the Feather River for the purpose of power generation. Although water could be withdrawn from this system on this basis of riparian rights, Pacific Gas and Electric Company may challenge any significant withdrawal of water upstream of Lake Almanor (Piro 1978).

Figure VII-3

TABLE VIII-1

DRAINAGE AREA AND MEAN ANNUAL DISCHARGE
FOR GAGING STATIONS IN BATTLE CREEK,
MILL CREEK, AND DEER CREEK BASINS

USGS GAGING STATION	Drainage Area (sq.mi.)	Years of Record	Mean Annual Discharge (acre-feet)
Battle Creek below Coleman Fish Hatchery, near Cottonwood, Sta.#11376550	357	15	382,500
Mill Creek near Los Molinos, Sta.#11381500	131	48	222,200
Deer Creek near Vina, Sta.#11383500	208	38	230,400
Deer Creek below Slate Creek near Deer Creek Meadows, Sta.#11382550	69.4	9	99,980

Source: USGS, Water Data Report CA-76-4, 1977

The other possible source is the unappropriated water, spilling over Almanor Dam. Because there is a chain of seven powerhouses (reservoirs) downstream from Lake Almanor, the unappropriated spill might be the appropriated. This will also require agreements with PG&E (Piro 1978).

The KGRA area within Tehama County is within the Lassen National Forest. Thus, any water development within the county will require cooperation with the USFS. Moreover, downstream water users in Sacramento Valley may challenge any sizable diversion in the Tehama County area.

4.5 Ground Water Hydrology

The available data indicates three potential areas for ground water development within the vicinity of the Lassen KGRA. These are: 1) Indian Valley, 2) Lake Almanor Valley and 3) Humbug Valley. Indian Valley is located approximately 16 miles southeast of the KGRA (see Figure VIII-3). It covers an area of approximately 20 square miles. The water-bearing sediments in the valley include unconsolidated, interbedded, and intermixed deposits of gravel, sand, silt and clay. Depth to water levels vary from 10 feet to artesian (Comprehensive Framework Study 1970). The thickness of these deposits extends to a depth of 210 feet. Recharge into the valley is received from percolating of precipitation and from stream tributaries entering the valley from the northwest and northeast. The amount of recharge to the ground water basin is limited by the high water table which causes swampy ground in some locations (CDWR #59-2).

Ground water flows into the Indian Creek and discharges from the valley to the southeast. Water quality in the basin is good to excellent and has a range of total dissolved solids (TDS) of 71 to 294 ppm (Comprehensive Framework Study 1970). The storage capacity of the aquifers is on the order of 100,000 acre-feet and well yields generally range from 150 to 500 gpm.

Lake Almanor Valley is located just southeast of the KGRA (see Figure VIII-3). It covers an area of about 7 square miles. The aquifer is composed of alluvial deposits of gravel, sand, silt and clay interbedded with layers of pyroclastic deposits and lava flows to a depth of about 210 feet. Ground water recharge is from percolation of surface waters, both rainfall and stream flow, and subsurface underflow from the volcanic rocks.

The general direction of ground water movement is towards Lake Almanor. Water in Lake Almanor Valley is of excellent quality with a range of TDS of 74 to 143 (Comprehensive Framework Study 1970). The storage capacity of the aquifer is on the order of 45,000 acre-feet and well yields generally range from 100 to 300 gpm.

Humbug Valley is located approximately 11 miles south of the KGRA and covers an area of about 14 square miles (see Figure VIII-3). Water bearing deposits are younger alluvium which extends to depths of 100 feet. Ground water recharge is from the percolation of surface water and subsurface underflow from volcanic flows west of the valley. Water quality is generally of excellent quality; however, the presence of mineralized springs which drain into the valley may cause a slight impairment of the surface water during low flow. Storage capacity of the aquifer is on the order of 76,000 acre-feet and well yields are unknown (see Table VIII-2).

TABLE VIII-2

SUMMARY OF GROUNDWATER BASINS NEAR LASSEN KGRA

Basin name, county	Well yields in gpm		Depth zone in feet	Storage capacity in acre-feet	Usable capacity in acre-feet
	Max.	Aver.			
Indian Valley, Plumas County	500	150	10-210	100,000	Unknown
Lake Almanor Valley, Plumas County	300	100	10-210	45,000	Unknown
Humbug Valley, Plumas County	Unknown	Unknown	0-100	76,000	Unknown

Source: California Department of Water Resources
Bulletin No. 18

PART IX

PUNA

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PART IX

PUNA

1.0 SUMMARY

The objective of this report was to assess the following for the Puna, Hawaii, Known Geothermal Resource Area (KGRA):

- water resources that are available for geothermal electric power plant development
- power plant make-up water requirements
- the developable megawatts based on the available make-up water
- the need for additional water resource data

The availability of outside sources of make-up water for power plant operations is a major consideration in developing geothermal resources in the Puna area. The quality, quantity and availability of both surface and ground water for use in geothermal power plants was examined. The demand for water was based upon the previously conducted geothermal power plant water utilization case study (Part X). Present plans are for development of a 5 MWe demonstration project at the Puna site. Beyond these plans, there are no other projects planned on the site.

1.1 Surface Water Supply

Analysis of the surface water resources for the Puna area indicate the following:

- There are three sources of surface water, rainfall catchments, streams and sea water.
- Precipitation in the Puna district averages approximately 120 inches annually.

- Rainfall catchments of reasonable size (up to 125 acres) would be sufficient to provide approximately 1,120 acre-feet/year.
- Volcanic soils in the Puna district are permeable; as a result, no streams are found in the Puna area.
- Use of surface water from the Hilo area would require inter-basin movement of water and would, most likely, face legal challenges.
- Sea water could potentially be used for power plant make-up water; however, the feasibility of using this source under current geothermal power plant technology is not known.

1.2 Ground Water Supply

Analyses of ground water in the Puna district indicate:

- Three basic ground water aquifers exist in the Puna area.
- These aquifers include perched water, dike-impounded and basal water deposits.
- Most of the rainfall in the Puna area percolates directly to the basal lens and could provide a source of geothermal power plant development.
- Water quality of the basal lens is high in salinity as a result of sea water infiltration.
- Extensive withdrawal from this source of ground water may create sea water encroachment into this basin.

1.3 Power Plant Requirements

Based on data developed in the case study, the following are the estimated total make-up water requirements for a 50 MWe power plant at Puna, where the geothermal resource temperature is 350°C+.

Water Requirements (1)
(Acre-Feet/Year)

Type of Plant	
Flashed Steam (direct contact)	1,650
Flashed Steam (indirect contact)	2,200
Binary Cycle	3,300
(1) Blow-down discharge of 4,000 ppm TDS and make-up water 1,000 mg/l TDS	

2.0 CONCLUSIONS

The only project being considered at the Puna site is the demonstration generator that is to be built at the HGP-A well at Puna. Current plans call for this project to be a single-flash type of power plant using steam condensate as a source of cooling water. Thus, make-up water will not be required for this demonstration project. Beyond this initial demonstration project, no other projects are being considered at the Puna site. Moreover, with the expected high resource temperature ($350^{\circ}\text{C}+$), the energy conversion cycle will, most likely, be the flash type, thus not requiring an outside source of make-up water.

2.1 Make-up Water Availability

2.1.1 Surface Water

Although the Puna district receives no surface water, due to the porosity of the soil and substrata. Transporting water from the streams north of Hilo is not considered as a viable alternative. The distance and terrain involved indicate that the engineering/economics of distributing any surface water would be a key consideration: moreover, the interbasin transfer of water may be an issue in transporting water from north of Hilo.

2.1.2 Ground Water

Analysis of the ground water resources indicated the Puna district is underlain by ground water aquifer which will be available for geothermal development. However, it is highly unlikely that make-up water will be required for geothermal development in the Puna district. Potentially, the availability of make-up water would not be a constraint on geothermal development at the Puna site.

2.2 Developable MWe

The lack of surface water in the Puna district would preclude any geothermal development if this source of water were to be used. Due to this constraint on the availability of surface water, if geothermal power plants were to require make-up water, ground water would be the alternative. Analysis indicates the presence of sufficient ground water to potentially develop the geothermal resource.

3.0 RECOMMENDATIONS

3.1 Initiatives and Activities

3.1.1 Federal

If an outside source of water is required, the data indicate sufficient ground water in the Puna district to develop the geothermal resource. Further initiatives or activities related to availability of water in the Puna district are not required at this time.

3.1.2 State

The recent revision to the State Constitution mandated the formation of a state water agency. The authorities and specific duties of this agency with regard to geothermal development have not been clearly defined. If the state is interested in further development of geothermal resources, this position should be represented when this agency begins to formulate policy. Potentially, input to the policies of this agency should also include federal and private geothermal interests. The unclear legal definition of the geothermal resource may become a more critical issue as development occurs.

3.1.3 Counties and Local

County interests in water resources in Hawaii center primarily around the available domestic water supply within its boundaries. Potentially, activities or initiatives involving water resources as it relates to geothermal development within the Puna area would not involve the local county. Thus, specific recommendations for the county relative to water resources for geothermal development at the Puna site are not required.

3.2 Site Specific

3.2.1 Plant Siting

The availability of ground water resources in the Puna District indicates that specific constraints on geothermal development should not occur. Thus, site-specific constraints on geothermal development are not pertinent. Potentially, geothermal development could occur without constraints from the availability of water resources.

4.0 TECHNICAL DISCUSSION

4.1 Methodology

A general methodology was established to accomplish the major objectives of the study. The initial step of this methodology involved a comprehensive literature search to collect all published water resources literature required for the evaluation. Sources of data were various government agencies, institutions, and private organizations. A systematic literature review by technical key words was then conducted to ascertain the extent of the data collected. Field investigations were then conducted among these groups to ascertain unpublished data and reports and also to confirm findings of previously published materials.

For surface water, major water bodies were identified, their physical and chemical characteristics evaluated, and their capacities determined based on these evaluations.

In the ground water evaluation, aquifers in the area were identified, their physical and chemical characteristics evaluated, and their capacity and productivity assessed. A water budget balance was not calculated because of the lack of sufficient data.

Figure IX-1 indicates the major steps of the methodology.

4.2 Survey of Existing Information

The purpose of the literature search was to screen published reports and materials that were pertinent to the water resources evaluation. The initial step of this literature search was to contact various government agencies and private organizations to collect the required data.

Figure IX-1

FLOW DIAGRAM OF METHOD OF APPROACH

All the data collected were recorded on card catalogue under a specific format. For example,.

Author:	State of Hawaii, Dept. Land and Natural Resources
Report Title:	An Inventory of Basic Water Resources Data: Island of Hawaii
Source:	State of Hawaii, Dept. Land and Natural Resources
Date or Year of Publication:	--
Index Number:	H-Gen

The index number identifies the first alphabet of the principal author's last name, the number of publication listed under the alphabet, and the study area of concern. The letter H indicates Hawaii scenarios. Each report is then labeled by the index number.

Appendix A contains a listing of all pertinent literature collected for this study area with the appropriate index numbers.

During the literature review process, three key data sources were identified and were used to provide a major input into the water resources evaluation of the Puna KGRA. They are listed as follows:

- Morahan, E. T. and H. Yamauchi
1972 "A Study of Water Institutions of Hawaii." Technical Report No. 58. Water Resources Center, University of Hawaii.
- Stearns, H. T., G. A. MacDonald
1947 "Geology and Ground Water Resources of the Island of Hawaii." (Hawaii Division of Hydrography)
- U.S. Geological Survey
1968 "The Water Resources of the Hilo-Puna Area, Hawaii." USGS Circular C45, prepared in cooperation with the State of Hawaii DLNR.

4.3 Location of the Study Area

The Puna geothermal area is located on the eastern portion of the Island of Hawaii. The main geothermal area has not been clearly defined but is believed to be extensive. Evaluation of water resources was delineated as a function of hydrologic considerations rather than by political boundaries. Figure IX-2 indicates the Puna study area.

4.4 Surface Water

Surface water in the Puna district is composed of the following: rainfall catchments, surface water from streams, and sea water. Rainfall in the Puna district north of the east rift zone of the Kilauea Volcano is quite heavy, with increasing amounts in the north direction. Total yearly amounts average about 120 inches/year at the HGP-A well, and increase to a maximum of over 300 inches/year around the 3,000 foot level west of Hilo (Figure IX-3).

South of the East Rift Zone of Kilauea, rainfall decreases markedly. For instance, the coastal area directly south of Kilauea Crater gets under 40"/year. Due to the high evaporation at these latitudes, this rainfall results in an arid zone (the Kau desert).

Monthly rainfall in the area is fairly uniform throughout the year, although lighter amounts fall in the summer season. Even in the driest month (June), the long term average rainfall exceeds 5". A similar seasonal distribution is found at stations along the windward (east) side of the island.

The Island of Hawaii is divided into five hydrographic regions, shown in Figure IX-3. The HGP-A well site is on the southern fringe of Region II, which receives a mean annual rainfall of 8.219 million

FIGURE IX-2
Location Map
HGP-A WELL

FIGURE IX-3

Source: An Inventory of Basic Water Resources Data, Island of Hawaii. Report R34. Prepared by UFGS and DOWALD, State of Hawaii

MEAN ANNUAL RAINFALL

acre-feet/year (52.2% of the total island rainfall). Only 23.5% of the Region II rainfall is lost to evapotranspiration. Of the remainder, 3.468 million acre-feet/year go into ground water recharge and 2.819 acre-feet/year becomes surface water discharge (rivers and streams).

A 1964 report (Water Feasibility Study, by L. Frederick Park Associates) recommended the construction of an asphalt-lined catchment for rain water collection to supply the Mountain View-Glenwood area, located approximately 15 miles from the HGP-A site in an area that receives over 150 inches of rain per year. This study estimated that a 125-acre lined catchment could deliver approximately one million gallons/day (1,120 acre-feet/year). A catchment located in the HGP-A area would need to be somewhat larger to deliver the same flow, since rainfall at the site is lower (120 inches/year).

The extremely porous nature of the volcanic soils in Hydrographic Region II causes rapid rainfall infiltration into the ground. As a result, no streams are found in the Puna district. However, near the City of Hilo, with mean annual rainfall of 150" a year, intermittent streams are present. Surface water in the Puna area is only found during period of intense rainfall over poorly-defined water courses. There are no gaging stations for any of these water courses.

The major streams in the Hilo area are the Wailuku River, Waiakea Stream and Wailou River. The discharge of these rivers constitutes only a minor percentage of the total rainfall falling on the area. Most precipitation is absorbed by the highly permeable ground surface and rapidly descends to the basalt water table. A small part of the rainfall is intercepted by poor permeable layers of ash or dense lava flows and returns to the ground surface as high level springs where the layers crop out.

Data on the Hilo area streams follow:

Wailuku River. Head waters of this river are at the 11,000-foot elevation near the summit of Maunakea, where it flows 23 miles to its discharge point at Hilo Bay. Average discharge into the bay is 537 acre-feet/day. Water temperatures fluctuate between 18.5°C and 23.5°C. The Hawaii Board of Water Supply presently diverts 12 acre-feet/day for use to its domestic water supply. Hawaiian Electric Company also generates hydroelectric power on Wailuku River.

Waiakea Stream. Waiakea Stream is an intermittent stream located on the east slope of Mauna Loa, southwest of Hilo. The flow of Waiakea Stream during dry weather begins at the 2,100-foot level. Flows along this stream average 23 acre-feet/day and range from zero to 599 acre-feet/day. The lower reaches of the stream are dry during most of the year and flow only during or shortly after heavy rains. This stream is the source of surface water located closest to the HGP-A site. The distance from this point to the HGP-A is approximately 25 miles.

Wailoa River. Waiakea Pond is the source of the Wailoa River, which is only 1/2 miles in length and is entirely within the City of Hilo. The discharge averages more than 307 acre-feet/day, but no detailed water quality or discharge information is available, as there is no gaging station located on the river. The discharge results mainly from large basalt springs that discharge into Waiakea Pond, while other basalt springs flow into the river below Waiakea Pond. The river is essentially an estuary and as such would be quite saline.

Surface Water North of Hilo. North of Hilo there are many streams which flow perennially to the sea from the slopes of Mauna Kea. Ground surface in this area is still very permeable, but rainfall on the slopes between the 2,000- to 4,000-foot altitude is so great that more water is available than can percolate into the ground. Most of this surface water is unused. Potentially, the area north of Hilo has an

abundant supply of untapped surface water which could be used as a source of outside make-up water for geothermal power plants. However, the cost of piping the water over a distance of 30 to 50 miles may make this alternative prohibitively expensive. Moreover, the legal, institutional and environmental implications of this action could prove to be significant barriers.

An unlimited source of water for geothermal development is the nearby ocean. The HGP-A site is located approximately three miles from the shore, at an altitude of 600 feet. The use of ocean water for cooling coastal power stations is quite common. In general, scaling has not been a problem in these stations (Lee Roberts, SCE, Rosemead, pers. comm.). The use of sea water as make-up water for geothermal power plants has not yet been fully developed. Compatibility with the condenser and cooling system will require further investigation and study.

4.5 Ground Water Hydrology

Ground water on the island of Hawaii is stored in three main water-bearing aquifers: perched water, dike-impounded deposits and basal water. Perched water deposits occur in thin discontinuous bodies. The underlying geology is a formation of soil from weather lava and on dense lava flows. These ground water deposits are trapped above ash beds and discharge at springs in high altitude areas. This source of water may discharge to the surface as springs. The water occurs in thin discontinuous reservoirs with discharge fluctuating with rainfall in the area. Thus, perched water is not an effective large-scale source of water for the Hilo-Puna area (Preliminary Report on the Water Resources of the Hilo-Puna Area, USGS and DOWALD, 1968).

Perched water does, however, have one advantage if make-up water is required for geothermal power plant cooling purposes. This source of water normally occurs at higher elevations, thus if perched water were

to be located and developed, it could be delivered to the Puna site by gravity flow. This advantage may be offset since the flow from this source would, most likely, be sporadic, closely corresponding to fluctuations in rainfall.

Dike-impounded water occurs as a result of impermeable volcanic dike structures at rift zones of volcanoes. The rift zones create an impermeable dike structure which intercepts water percolating down from the surface. Potentially large quantities of good quality dike impounded water are present in the east rift zone of Kilavea. There are no wells currently tapping this source.

Basal water deposits present the largest potential source of ground water for the Puna area. Basalt deposits are found near sea level over most of the Hawaiian Islands. Most of the rainfall in the Hilo-Puna area percolates directly to the basal lens. The result is a large body of fresh water floating on sea water.

Recharge from rainfall in the area below the 4,000-foot contour between Hilo and the East Rift Zone of Kilavea near the HGP-A well is estimated to be 3,920,000 acre-feet per year. The variable nature of the rainfall is shown by the fact that along the southern shore beyond the East Rift Zone, rainfall is so low that the basal water is brackish (Stearns and MacDonald, 1947). Brackish water also occurs near the coastline where mixing of the fresh basal water and sea water occurs. Under these conditions, the brackish water is of variable quality.

Basal water of variable quality underlies all of the Hilo-Puna area. Since the HGP-A well is located in the vicinity of the East Rift Zone of Kilavea Volcano, dikes may occur in the area, thus interrupting the basal lens. The result of this would be zones of impounded water and areas of high-salinity due to sea water infiltration where dikes prevent the seaward flow of fresh underground water. Figure IX-4 shows the areas where perched, dike-impounded and basal ground water are located in the vicinity of the Puna field.

The majority of the wells in the Puna area tap the basal ground water lens. Selected chemical analyses of water from these wells is shown in Table IX-1. It is interesting to note the greatly increased salinity of wells located south of the rift zone, indicating the rift zone acts as a barrier to the underwater flow of fresh water from areas with heavier rainfall to the north.

Ground water resources represent the most easily-available source of outside make-up water for geothermal power plant development. The largest source of ground water in the area is the basal lens. Since the HGP-A site is close to the edge of the fresh water/sea water interface of the basal lens, large scale withdrawal would probably entail increased sea water encroachment on the fresh water lens in the immediate vicinity of the HGP-A site.

Notwithstanding the availability of surface or ground water, access to use of water from either source is an issue in the State of Hawaii. Access to surface water is governed by ancient tradition and by recent court decisions. This litigation, if upheld, would establish that all surface water belongs to the state and that water rights are not transferrable. These rights would be applicable only to that particular parcel of land to which they were attached. The ability of the state to transfer water from one watershed to another has not been clearly established.

Ground water is based on the doctrine which holds that each overlying land owner has a coequal right to a reasonable use of the water with due regard to rights of other coworkers. Reasonable use has not been precisely defined.

The State of Hawaii has no administrative procedure for the acquisition of water rights. Water rights may only be acquired through original acquisition, a grant or lease from a private or public owner, or by prescription or condemnation.

TABLE IX-1

SELECTED CHEMICAL ANALYSES OF HAWAII GROUNDWATERS (Concentrations in PPM)

USGS Well No.	Name	SiO ₂	Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	HCO ₃ ⁻	SO ₄ ⁼	Cl ⁻	NO ₃ ⁻	pH	Dissolved Solids
9-11	Pahoa 1	54	5.0	4.2	20.0	2.6	51	6.8	20.0	0.1	7.7	137
9-5A,B	Pahoa 2	52	3.3	3.3	16.5	3.4	51	12.5	6.0	0.4	7.5	123
S11 9	Kapoho Cone	41	80	51	73	10.5	551	6.8	84	13	7.7	653
9-9	Malama-Ki	59	182	324	3090	----	262	681	5850	0.5	6.9	11700
9-7	Keallohana	41	6.6	3.3	54	3.8	42	22	70	0.0	7.3	221
9-10	Pulama	72	16	31	170	8.5	54	65	345	0.3	7.4	838
S11 7	Olaa Mill	40	6.0	2.7	5.8	2.4	38	5.5	4.0	2.8	7.0	88
9A,B	Olaa Mill	21	4.8	3.5	8.7	1.8	33	8.4	7.3	0.4	7.4	72
9-2	Keaau Orchard	33	6.5	5.9	39	3.7	44	12	58	3.6	7.3	183
9-12	Keaau Orchard	33	8.9	13.6	90	5.6	42	25	158	3.1	6.8	355

SOURCE: American Journal of Science, Vol. 277, April, 1977, P. 438-458
 CHEMICAL AND ISOTOPIC INVESTIGATIONS OF GROUNDWATER
 IN POTENTIAL GEOTHERMAL AREAS IN HAWAII
 Gary M. McMurtry, Pow-Foong Fan and Tyler B. Coplen.

Without administrative control over water rights, the State of Hawaii has little control over the use of water and cannot require permits as do most Western States. The State of Hawaii does have the authority to regulate the use of ground water if an aquifer is threatened by overdraft and to condemn water under eminent domain. County boards of water supply can issue regulations to prevent the waste of water supplies.

PART X

CASE STUDY - COOLING WATER REQUIREMENTS

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Appendix A Sample Problem

PART X

CASE STUDY - COOLING WATER REQUIREMENTS

1.0 CURRENT GEOTHERMAL ENERGY CONVERSION PROCESSES

1.1 Introduction

Geothermal energy resources occur in the form of steam, water-steam mixtures and hot water fluids. The energy conversion processing mode depends on the type and physical/chemical characteristics of the particular resource being developed. The occurrence of 100% quality steam at The Geysers in Northern California is unique, and because of the superiority of this energy source, the most advanced geothermal power generating facilities are located in this region. Thus, the dry steam total flow type of energy conversion cycle, representative of this KGRA region is addressed in the following section.

Hot water and water-steam resources, designated simply as hot water resources, lend themselves to the application of energy conversion cycles based on vapor flashing and liquid binary heat transfer systems. Power generating plants which utilize these processes, both in actual operation and advanced design status, are described for three specific plants.

1.2 Prototype Geothermal Power Generating Plants

1.2.1 Identification and Selection Rationale

Four prototype power generating plants for the conversion of geothermal resource energy to electric power have been identified. These are Unit #6, operated at The Geysers, California, by Pacific Gas and Electric Company (PG&E); the demonstration plant being designed by San Diego Gas

and Electric Company for location at Heber, California, in the Imperial Valley; the plant operated by Kyushi Electric Company at Hatchobaru, Japan; and the Cerro Prieto power plant in Mexicali Valley, Baja, California. Each of these systems is identified in Table X-1.

These four types of power plants represent the major energy recovery systems adopted by the geothermal power industries at the present time. The water requirements for each of these systems vary, being a function of the resource utilization process, the electric energy output, the heat content of the geothermal resource and the energy conversion efficiency. It should be noted the data developed in this study are based on the specific characteristics identified in Table X-1. Potentially, if any of the parameters involved in a particular plant vary from those shown, the water requirements for that plant will vary. The data developed are used to describe generalized conditions to project water requirements.

1.2.2 Process Description

1.2.2.1 Dry Steam Process; Ref: Figure X-1

In PG&E's Unit No. 6 at The Geysers, initially operated in 1971, dry steam from about eight wells is collected through a piping network and conveyed to the power plant. The temperature and pressure at the wells are 238°C (460°F) and 469 pounds per square inch absolute (psia), with both values being reduced to about 182°C (360°F) and 105 psia at the power plant because of pressure drop losses in the well-bore and steam transmission lines. Based on a steam flow equivalent of about 18,000 lb/hr per MWe, the total steam being provided for Unit No. 6, which has a generating capacity of 53 MW, would be 970,000 lb/hr. The steam is introduced into the turbine from where it is exhausted to a direct-contact condenser, located below the turbine, at a temperature and pressure of 51°C (124°F) and 1.9 psia. The non-condensable gases in the steam are withdrawn from the condenser and discharged to the

TABLE X-1

GEOHERMAL POWER PLANT DEFINITION

Operator	Location	Gross Generating Capacity (MW)	Geothermal Resource		Energy Conservation System	Plant Status
			Type	Temp.(°F)		
Pacific Gas & Electric Co.	The Geysers, California	53	Dry Steam	460°F	Total Flow	Operating
San Diego Gas & Electric Co.	Heber, California	65	Hot Water	360°F	Binary	Demonstration Plant Design
Mexican Government Comision Federal De Electricidad*	Cerro Prieto, Mexico	75	Hot Water	385°F	Single Flash	Operating
Kyushu Electric Co.	Hatchobaru, Japan	50	Hot Water	*574°F	Double Flash	Operating

REGIONAL SYSTEMS DEVELOPMENT FOR GEOTHERMAL ENERGY RESOURCES
(PACIFIC REGION)

FIGURE X-1

DRY STEAM PROCESS

Source: VTN 1978

atmosphere, passing through the gas ejector system comprised of two steam jet ejectors and heat exchangers. Steam is furnished to the ejectors at a flow rate of 58,000 lb/hr. The condensate from the heat exchangers is returned to the turbine condenser hot well.

The cooling water for the turbine condenser is pumped from the cooling towers at a flow rate of 42,600 gallons per minute (gpm) entering the condenser at 27°C (80°F). The combined steam condensate and cooling water is returned to the towers from the condenser hot well at a flow rate of 48,000 gpm and a temperature of about 120°F. Additional cooling water is required by the ejector heat exchangers being pumped from the cooling towers at a flow of 3,300 gpm and being returned to the towers via the condenser hot well.

The cooling tower evaporation rate is above 800,000 lb/hr. This value is less than the steam resource condensate, so that an excess of about 170,000 lb/hr is developed in the cycle. This effluent, representing about 21 percent of the steam flow from the production wells, is injected into the steam reservoir through a series of injection wells.

In this energy conversion cycle, the cooling water is provided by steam condensate so that there are "zero" water requirements from an outside source. However, environmental impacts are considerable. The steam contains such pollutants as hydrogen sulfide (H₂S), ammonia and several minerals which are released to the atmosphere from the cooling towers and non-condensable gas ejector system. Despite prolonged discussions between the power plant operators and the various air quality regulatory agencies, a serious problem of pollutant emissions still persists at the Geysers.

1.2.2.2 Hot Water Binary Cycle; Ref: Figure X-2

The hot water resource for the 65 MWe demonstration binary plant being proposed by the San Diego Gas and Electric Company, will be produced

REGIONAL SYSTEMS DEVELOPMENT FOR GEOTHERMAL ENERGY RESOURCES (PACIFIC REGION)

FIGURE X-2

BINARY CYCLE PROCESS

SOURCE:
SDG&E 1977

from about eleven wells, with two or three additional wells being maintained on a stand-by basis. Each well is fitted with a down-hole pump which transfers the geothermal fluid to the power plant while maintaining it at a sufficiently high pressure to prevent vaporization in the lines. The hot water from the producing wells, which is maintained completely in the liquid phase, enters the power plant at a total flow rate of about 7,600,000 lb/hr. The water enters the hydrocarbon fluids heat exchanger at about 182°C (360°F), transferring most of its heat to the isobutane-isopentane mixture, presently being considered for the working fluid. The vaporized hydrocarbon enters the heat exchanger as a liquid at about 109° F and 550 psia, leaving as a saturated vapor at 146°C (295°F). The spent geothermal liquid is discharged from the heat exchanger at about 38°C (200°F) and is returned to the reservoir via seven injection wells.

The hydrocarbon vapor enters the turbine at 146°C (295°F), where its energy content is converted to 65 MW of electrical energy. The hydrocarbons are exhausted from the turbine as a vapor at 75°C (166°F) and 72 psia and are then cooled and converted to a liquid at 40°C (104°F) and 7 psia in the condenser. The liquid hydrocarbon is then pressurized to 550 psia and returned to the heat exchanger at a temperature of 43°C (109°F) for completion of the cycle.

The cooling water for the turbine condenser is pumped from the cooling towers at a recirculation flow rate of about 136,000 gpm. The cooled water enters the condenser at 90°F where it will be heated to 42°C (108°F) as it extracts the heat from the condensing hydrocarbon. The warm water is returned to the forced draft cooling tower, where its temperature is reduced to 32°C (90°F), from where it is recirculated through the condenser. Based on worst-case conditions during the summer months, the evaporation rate from the towers will be 1,270,000 lb/hr. To prevent the formation of scale and the build-up of suspended solids in the recirculating cooling water circuit, a blow-down rate from the cooling tower has been estimated at about 430,000 lb/hr.,

based on average inlet and outlet solids content of 1000 ppm and 4000 ppm respectively. The make-up water to the system, which is to be withdrawn from the nearby irrigation canals must be sufficient to replace the evaporative and blowdown loadings, or 1,700,000 lb/hr. (3,400 gpm.).

In this energy conversion system, cooling water must be furnished from an outside source. However, since the geothermal hot water is withdrawn from, and returned to the reservoir in a closed system, there are essentially "zero" air pollution impacts from the contaminants in the geothermal resource.

1.2.2.3 Hot Water Single Flash; Ref: Figure X-3

The Cerro Prieto geothermal power generating plant is located approximately 20 miles from the U.S. Mexico border and was placed in service on April 1973. It presently produces 75 MWe of electrical energy from two steam turbine-generator units. A twin turbine-generator system is now being constructed which will bring the plant capacity up to 150 MWe.

The geothermal resource consisting of a water-steam mixture, at a temperature and pressure of 196°C (385°F) and 115 psia, flows from the 13 wells supplying the plant under its own pressure at a rate of 6,150,000 lb/hr. The mixture passes through a centrifugal separator, located at each of the wells, and the dry steam removed is directed to the power plant at a flow rate of 1,350,000 lb/hr. The separated hot water is forced through silencers and then discharged to the disposal pond at a flow of 4,800,000 lb/hr. Currently, this salt laden liquid effluent is not re-injected into the geothermal reservoir but is pumped to evaporation ponds for possible future minerals recovery.(see Fig.X-3)

The steam, entering the power plant, flows through a moisture separator where condensed steam droplets are removed. A small portion of the

high quality steam is diverted to the non-condensable gas ejector system (110,000 lb/hr), while the major flow continues to the turbine at a flow rate of 1,240,000 lb/hr and a temperature and pressure of 160°C (320°F) and 90 psia. The steam is exhausted from the turbine at 49°C (120°F) and 1.7 psia, passing through a jet-type condenser where it is directly contacted with circulating cooling water from the cooling towers. The inert gases are withdrawn from the condenser, flow through a two-stage steam ejector system and are discharged to the atmosphere. The condensed steam from the ejector hot well is pumped to the cooling tower from where it is recirculated to the turbine condenser and ejector system.

Cooling water from the towers enters the turbine condenser at a temperature and flow rate of 32°C (90°F) and 94,300 gpm. The condensed steam leaves with the heated water at a combined flow rate of 96,700 gpm and temperature of 47°C (117°F). Cooling water from the towers is also circulated through the ejector system at a rate of 3,300 gpm. The cooling tower evaporation rate is about 220,000 lb/hr. The overall plant water balance is shown in Table X-2

TABLE X-2

<u>OVERALL PLANT WATER BALANCE</u>		
(Values Expressed as 10 ³ lb/hr)		
(Single Flash System)		
	<u>IN</u>	<u>OUT</u>
Water/Steam Resource	6,150	
Separated Water		4,800
Evaporated Water		220
Cooling Tower Blowdown		<u>1,130</u>
TOTAL	6,150	6,150

Based on these values, the total water to be discharged into the evaporation pond would be that from the separator and the cooling water blowdown, for a total of 5,930,000 lb/hr. Similar to the dry-steam energy cycle, the cooling water is provided by the geothermal fluid, without reinjection of the spent resource into the reservoir. Again, the major disadvantage of this "zero" water requirement energy cycle is the H₂S emissions from the cooling towers and ejectors. At the Cerro Prieto Plant the odor of H₂S is very noticeable.

1.2.2.4 Hot Water Double Flash; Ref: Figure X-4

The Hatchobaru 50 MWe geothermal power generating plant, operated by Kyushu Electric Company, is located near Hatchobaru, Japan and was placed in service in June 1977. In the double flash energy recovery cycle, used at this plant, the water/steam mixture enters the separator and the discharged steam phase is introduced into the high pressure side of the turbine. The separated water is sent to a flash vessel to produce low pressure steam which is supplied to the intermediate stage of the turbine.

A steam-hot water mixture is furnished to the power plant from seven production wells at a flow rate of 2,420,000 lb/hr. The fluid mixture enters the centrifugal separator under its own pressure at 301°C (574°F) and 109 psia. The separated steam at this pressure flows to the turbine, at a flow rate of about 757,000 lb/hr, entering the high pressure end. The hot water from the separator is directed to the flash vessel, where its pressure is reduced to about 16.5 psia causing it to be converted into 189,000 lb/hr dry steam and 1,476,000 lb/hr hot water. The steam is introduced into the intermediate pressure stage of the turbine except for a small flow which is diverted to the non-condensable gas evacuation system. The hot water is injected into the reservoir. (See Figure X-4)

X-12

X-12

Both steam flows from the turbine, amounting to 946,000 lb/hr, are exhausted to a direct contact condenser located below the turbine. The steam pressure entering the condenser is 1.5 psia. The non-condensable gases are withdrawn from the condenser by an evacuation system comprising steam ejectors and a two-stage radial blower set. The blowers are steam driven with the exhaust steam being utilized in the ejectors. The non-condensable gases are discharged from the blowers directly into the atmosphere. The steam condensate is returned to the cooling tower pump.

The cooling water for the turbine condenser is pumped from the cooling towers at a flow rate of 54,200 gpm, entering the condenser at 26°C (79°F). The combined steam condensate and cooling water is returned to the cooling towers from the condenser hot well at a flow rate of 56,100 gpm and a temperature of about 43°C (110°F). Additional minimal cooling water is pumped to the ejector heat exchangers.

The cooling tower evaporation rate is 840,000 lb/hr. This is less than the geothermal fluid furnished by the production wells. The net flow of water discharged from the flash vessel and cooling towers is returned to the injection wells. The overall plant water balance is shown in Table X-3

TABLE X-3

OVERALL PLANT WATER BALANCE
(Values Expressed as 10^3 lb/hr)
(Double Flash System)

	<u>IN</u>	<u>OUT</u>
Water/Steam Resource	2,420	
Flashed Water		1,476
Evaporated Water		840
Cooling Tower Blowdown		104
TOTAL	2,420	2,420

Based on these values, the total water to be reinjected into the reservoir would be that from the flash vessel and the cooling towers for a total of 1,580,000 lb/hr. As in the case of the Single Flash System, the cooling water is provided by the geothermal fluid. Thus, the outside water requirement is zero, with the attendant potential air pollution impacts covered by the emission of H_2S from the ejector system and cooling towers.

1.3 Major Water Requirements

The major water needs for the four typical energy conversion cycles are to provide for the cooling tower heat exchange duty. The only plant type which is designed for outside make-up water requirements is the 65 MWe Binary System Demonstration Plant planned for construction by the San Diego Gas and Electric Company at Heber in Imperial Valley.

An overall water balance for each of the four power plant types previously described, is shown in Table X-4. It should be emphasized that these water quantities and sources are based on current practice and design concepts and may vary as a function of such environmental effects as air quality degradation and potential land subsidence. For example, the significant H_2S emissions accompanying the use of geothermal fluids as a cooling water source would encourage consideration of an outside water source with an indirect surface condenser. In the other direction, the severe limitations placed on the use of irrigation water as a cooling medium for the Heber Binary Plant could demand that geothermal fluid be used as a source of cooling water for future expanded capacity in that region.

Quantification of water requirements in this section of the report are based on the assumption that only the binary system has need for outside water and that the steam resource and hot water flash processes are self sufficient in terms of cooling water. Section 2.0 contains a discussion of conditions where outside water is required in flash steam plants.

TABLE X-4

SUMMARY OF WATER REQUIREMENTS FOR FOUR (4)
TYPICAL GEOTHERMAL POWER GENERATING PLANTS

Process	Location	Plant Status	Net Power Output (KWe)	Reservoir Conditions Flow (10 ³ lb/hr)	Temp. (° F)	Cooling Water Requirements			Water Source	Water Disposal
						Evaporation (10 ³ lb/hr)	Blowdown (10 ³ lb/hr)	Total (10 ³ lb/hr)		
Dry Steam Total Flow	The Geysers California	Operating	53	970	460	800	170	970	Geothermal Fluid	Reservoir Injection
Hot Water Binary	Heber California	Demonstration Plant Design	65	7,600	360	1,270	330	1,600	Irrigation Water	Irrigation System
Hot Water Single Flash	Cerro Prieto Mexico	Operating	75	6,150	385	220	1,130	1,350	Geothermal Fluid	Evaporation Pond
Hot Water Double Flash	Hatchobaru Japan	Operating	50	2,420	574	840	104	944	Geothermal Fluid	Reservoir Injection

Geothermal resource and total cooling make-up water requirements are expressed in a series of curves, Figure X-5 through X-9. An explanation of each of these follows.

Figure X-5

This curve, relating the geothermal reservoir temperature to the resource flow requirements for a binary plant, was based on VTN-source data. The Heber binary plant design fits this curve, although some extrapolation of the VTN data was necessary to include the Heber 65 MW resource temperature of about 182°C (360°F). From this curve, the Heber 65 MW binary power plant would require about 115 lb/hr-KW of hot water flow at 182°C (360°F), equivalent to about 7,480,000 lb/hr. The actual resource flow, according to the flow design in Figure VI-2, is 7,600,000 lb/hr.

Figure X-6

In this curve, the cooling tower evaporative load was related to the reservoir temperature. The VTN-source data, based on low temperature operating data, was found to be inadequate for the higher temperatures in the range of 200 to 350°C (392°F to 662°F).. Other data investigated was that of M. Goldsmith, Engineering Development of Geothermal Development in Imperial Valley; California Institute of Technology, December 1976 and D.L. Ermak, Potential Growth of Electric Power Production from Imperial Valley Geothermal Sources; Lawrence Livermore Laboratory, September 1977.

The evaporation water requirements cited by Ermak at a resource temperature of 190°C (374°F) of 75 acre-feet/yr-MW (26 lb/hr-KWe) compared with a VTN-extrapolated value of about 20 lb/hr-KWe. However, the data of Goldsmith is considerably higher, indicating the need for about 107 acre-feet/yr-MW for a binary plant at a resource temperature of 190°C. At the higher reservoir temperature range, the Ermak and Goldsmith

FIGURE X-5 RELATIONSHIP OF GEOTHERMAL RESERVOIR TEMPERATURES
AND BINARY POWER PLANT FLOW REQUIREMENTS

Source: VTN data, 1977.

values at 285°C (545°F) are 50 and 65 acre-feet/yr-MW, respectively. In this study, to show the most restrictive requirements, the more conservative values of Goldsmith were adopted as shown in Figure X-6.

Figure X-7

Based on the evaporation rate, a series of total make-up water flows was computed and plotted in Figure X-7, for various water quality levels. Make-up water solids concentrations in the range of 500 to 2,000 ppm were chosen as being representative of expected ground water and surface water contaminant levels. The blowdown flow rate, representing the make-up water flow less the evaporative losses, was assumed to be discharged at a solids content of 4,000 ppm. This value is predicated on the average value for effluent discharges specified by the Regional Water Quality Control Board. If the blowdown can be re-injected into the reservoir, then the discharge concentrations can be increased by an order of magnitude and the make-up water requirements reduced. The estimated temperature level of the blow-down flow which averages about 20% of the total make-up requirement would be in the range of 40°C to about 50°C (104°F to 122°F).

Figure X-8

In Figure X-8, the total make-up water requirements for a binary geothermal plant are related to the reservoir temperature. Because both evaporation losses and blow-down flows constitute the total make-up needs, this curve defines the total requirement as a function of the water solids content. The maximum permissible built-up solids content in the cooling water recirculation flow was assumed at 4,000 ppm.

For the Heber binary plant, with a reservoir temperature of about 182°C (360°F), a make-up water solids concentration of 1,000 ppm and a

FIGURE X-7 **MAKE-UP WATER REQUIREMENTS AT DIFFERENT SOLIDS CONTENTS**
AS A FUNCTION OF COOLING TOWER EVAPORATION RATES

**FIGURE X-8 COOLING TOWER MAKE-UP REQUIREMENTS AT DIFFERENT SOLIDS CONTENTS
AS A FUNCTION OF GEOTHERMAL RESERVOIR TEMPERATURES**

BASES:

- VALUES ARE FOR GEOTHERMAL BINARY POWER PLANT
- TOTAL MAKE-UP WATER INCLUDES EVAPORATION AND BLOWDOWN FLOWS
- BLOWDOWN SOLIDS CONTENTS ASSUMED AT 4000 ppm

discharge level of 4,000 ppm, the estimated total water requirements from Figure X-8 would be 65 lb/hr-KWe, equivalent to a total demand of about 4,200,000 lb/hr at the plant rating of 65 MW. From the power plant flow diagram, Figure X-2, the designed make-up water flow rate is 1,700,000, or about 40% of that predicted from the Goldsmith data. The conservative nature of the latter data was discussed under Figure X-6.

Figure X-9

The data plotted in Figure X-9 is an extension of the data developed in Figure X-8. It relates the total water requirements for a mix of binary and fluid flash plants at different reservoir temperatures. Because the total make-up flows, including blow-down, are involved, the solids content of the supply rate was assumed at 1,000 ppm with a discharge containing 4,000 ppm. The water requirement for the flash plants are considered to be zero.

Figure X-9 is the final working curve and its application to a specific water demand/supply problem is defined in the following steps.

1. A known KGRA region is identified, the temperature of the reservoir is defined, and the projected MW capacity of the field estimated.
2. The available water resources in the region are quantified and converted to acre-feet/MW-yr, based on the projected MW rating of the field.
3. Assuming a solids content of the water resource of 1,000 ppm, the value of acre-feet/yr-MW can be fixed on Figure VI-9 and projected parallel to the abscissa until it intersects the temperature of the KGRA.

AT DIFFERENT RESERVOIR TEMPERATURES FOR COMBINED BINARY AND FLASH-TYPE ENERGY CYCLES

BASES:

- TOTAL MAKE-UP WATER INCLUDES EVAPORATION PLUS BLOWDOWN FLOW
- SUPPLY WATER SOLIDS CONTENT = 1000 ppm
- BLOWDOWN SOLIDS CONTENT = 4000 ppm

4. A line dropped vertically from the intersection of the water availability value (acre-feet/MW-yr) and KGRA temperature ($^{\circ}\text{C}$) will indicate on the abscissa, the permissible mix of binary and flash plants to meet the water supply limitations.
5. Any corrections in the water resource solids content can be made by developing pro-rate factors from Figure X-8.

Although the methodology is valid, there is some uncertainty regarding the basic design data relating evaporation rate with the geothermal reservoir temperature. There is a spread of about 40% between the lowest and highest evaporation rate levels. The maximum values were applied in this report, to yield worst-case conditions. It is recommended that in the evaluation of water supply availability, a range of water requirements should be considered to reflect the difference in the original base data.

A sample problem showing the use of curves shown in Figures X-8 and X-9 is contained in Appendix A.

2.0 ALTERNATIVE ENVIRONMENTAL CONSIDERATIONS

2.1 Introduction

The analysis developed to this point indicates make-up water requirements for non-binary type geothermal power plants were "zero." This conclusion was based on actual operating practices adopted by the three power plant processes described. Under actual practice, these processes utilize the spent geothermal fluid in the cooling tower/direct condenser circuit, with a portion of the flow being evaporated in the cooling towers. The remainder of the fluid is injected into the geothermal reservoir, or in the case of Cerro Prieto, put into evaporative ponds.

Two major environmental consideration could, however, necessitate the use of make-up water for flash energy conversion processes. These considerations are potential ground level subsidence and air quality degradation. To minimize the potential of subsidence, up to 100% injection of the geothermal resource may be necessary. The other concern, pollution emissions control, could necessitate the use of an indirect turbine condenser. To meet both requirements it would be necessary to furnish outside make-up water for power plant cooling purposes.

2.1.2 Total Injection Requirements

The most simple approach to satisfy the need for 100% injection in flash systems is to furnish make-up water from an outside source to replace only the evaporation losses from the cooling towers. Referring to Figure X-4, the blowdown effluent from the cooling towers being charged to the injection wells at a rate of 104,000 lb/hr would be supplemented by a make-up flow of 840,000 lb/hr to replace the evaporative flow. In this system, there are negligible limitations on the solids content of the make-up water and the injection is compatible with the reservoir.

2.1.3 Air Pollution Emission Requirements

In an alternate system, an indirect shell and tube heat exchanger would replace the direct contact condenser shown in Figure VI-4. Thus, as shown in Figure X-10, the total steam flow from the turbine is condensed in the shell side and the condensate, together with the flash liquid effluent is charged to the injection well. Cooling water is recirculated through the condenser tubes, continuing to the cooling tower where evaporative cooling is effected. In this indirect condenser system, the make-up water required is that necessary to replace the cooling tower evaporation load and blowdown effluent. The same restrictions on the make-up water solids content as for the binary system, would be in effect for this system.

One of the major additional advantages accruing to the use of the indirect condenser is the reduction of pollutant emissions. In the direct condenser system hydrogen sulfide (H_2S) and particulate emissions from the geothermal fluid are discharged from the ejectors and cooling towers. Because of the considerable volumetric flow from the cooling towers and the configuration and number of discharge stacks, the application of effective control equipment is difficult. With the indirect condenser scheme, the total pollutant emissions are limited to the ejectors, thus facilitating the application of control equipment.

Using the data developed by Goldsmith, the cooling water requirements can be calculated. These data indicate that for flashed steam systems, the evaporation water requirements vary from 58% to 68% of that required for the binary system over the temperature range of 150 to 300°C. Because of the environmental advantages inherent in the indirect condensation system for the flashed steam power plant, the more conservative water make-up quantities for this type of plant were estimated as shown in Figure X-11. Should it be desired to adopt a direct condenser for the flashed steam plant, then it becomes necessary

**PROTOTYPE FLASH POWER GENERATION PROCESS
WITH 100% FLUID REINJECTION**

FIGURE X-10

**FIGURE X-11 COOLING TOWER MAKE-UP WATER REQUIREMENTS AT DIFFERENT SOLIDS CONTENTS
AS A FUNCTION OF GEOTHERMAL RESERVOIR TEMPERATURES**

to replace the evaporation losses only without any concern for the make-up water solids content. In Table X-5, there are summarized the evaporation and total make-up water requirements for the flashed steam power plant at different reservoir temperatures. Column "A" would replace water make-up requirements without any solids content restrictions, for the direct condenser design version. In Columns "B" the total make-up water for the indirect condenser alternate design, at various solids contents, has been developed.

Continuing the analysis, Figure X-12 has been computed, which shows the relationship of the geothermal total water requirements at different reservoir temperatures, with total reinjection of the spent geothermal fluid, or its equivalent, for both flash plants, using an indirect condenser, and binary cycle plants.

In summary, Figure X-9 is applicable when only a portion of the geothermal fluid from the flashed steam power plant is injected with the remainder being evaporated at the cooling towers; equivalent to a "zero" make-up water requirement. In Figure X-11, sufficient make-up water is provided for the flashed steam power plant with indirect condensation, to ensure 100% re-injection. In both curves the binary plant design incorporates 100% re-injection capabilities.

TABLE X-5

FLASHED STEAM PLANT WATER REQUIREMENTS, LB/HR KWe

Reservoir Temperature	Column "A"	Column "B"				
	Evaporation Rate	Total Water Make-Up Rate + Supply Solids Content				
		500	1000	1500	2000	2500
200 °C	24.5	28.8	33.	39.	49.2	65.4
250	19.2	22.1	26.	31.2	38.4	52.
300	16.0	19.0	22.4	25.8	31.3	43.5
350	12.6	15.3	17.2	20.7	25.4	34.0

* Blowdown Solids Content 4,000 ppm

Source: VTN Estimates, 1978.

FIGURE X-12

TOTAL MAKE-UP WATER REQUIREMENTS FOR BINARY AND FLASH TYPE POWER PLANT MIXES AT DIFFERENT GEOTHERMAL RESERVOIR TEMPERATURES