*Surface Water Supply for the
Clearlake, California
Hot Dry Rock Geothermal Project*

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*Alan R. Jager**

**Consultant at Los Alamos
P.O. Box 4754
Santa Fe, New Mexico 87502
(505) 984-0904*

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SURFACE WATER SUPPLY FOR THE CLEARLAKE, CALIFORNIA HOT DRY ROCK GEOTHERMAL PROJECT

by

Alan R. Jager

ABSTRACT

It is proposed to construct a demonstration Hot Dry Rock (HDR) geothermal plant in the vicinity of the City of Clearlake. An interim evaluation has been made of the availability of surface water to supply the plant. The evaluation has required consideration of the likely water consumption of such a plant. It has also required consideration of population, land, and water uses in the drainage basins adjacent to Clear Lake, where the HDR demonstration project is likely to be located. Five sources were identified that appear to be able to supply water of suitable quality in adequate quantity for initial filling of the reservoir, and on a continuing basis, as makeup for water losses during operation. Those sources are California Cities Water Company, a municipal supplier to the City of Clearlake; Clear Lake, controlled by Yolo County Flood Control and Water Conservation District; Borax Lake, controlled by a local developer; Southeast Regional Wastewater Treatment Plant, controlled by Lake County; and wells, ponds, and streams on private land. The evaluation involved the water uses, water rights, stream flows, precipitation, evaporation, a water balance, and water quality. In spite of California's prolonged drought, the interim conclusion is that adequate water is available at a reasonable cost to supply the proposed HDR demonstration project.

I. Introduction

The Warren-Alquist Act, Public Resources Code, Section 2500 et seq., 1974, requires the California Energy Commission (CEC) to promote needed energy development and provide for environmental resource protection. To achieve this mandate the CEC encourages the development of California's alternative and renewable energy sources, including geothermal energy (Bohrer, 1983). The present investigation of the Geothermal Regimes for Hot Dry Rock (HDR), Phase 2, by the City of Clearlake, has been funded by a grant from the CEC Geothermal Grant and Loan Program for Local Jurisdictions, managed by Roger Peake, Geothermal Energy Specialist, CEC, Sacramento.

Several local, state, and federal agencies share limited authority over water rights and uses. Water appropriation and use is permitted by the California Water Resources Control Board (CRWRCB), Division of Water Rights. Water quality control is decided by the California Regional Water Quality Control Board (CRWQCB), Central Valley Region. Several court decisions control the quantity of water allowed to be taken from Clear Lake.

This report identifies, describes, and quantifies potential sources of water for the proposed Clearlake HDR project, as to both quantity and quality. Existing water use was determined from various state and county reports and interviews with authorities involved.

This report is an assembly of factual, on-site data relevant to water supply to a demonstration HDR plant. This work was done in the period March–April 1991. At that time there were ongoing plans and studies, particularly at the county level, for which the outcome could have an effect on water availability. Also, scientific studies were continuing at the Fenton Hill site, New Mexico, on the water consumption of HDR plants, and these results would have an effect on estimates of water consumption. The effect of these concurrent developments on the conclusions reached here, will be assessed in a later report.

A. Background

A potential HDR plant site will be located approximately 110 miles north of San Francisco in the north central California Coast Ranges. It will lie within The Geysers-Calistoga Known Geothermal Resource Area (KGRA) (Fig. 1).

Fig. 1. Outline of The Geysers-Calistoga KGRA (modified from Bohrer, 1983, Fig. 1, p. 6).

Townships are CA=Calistoga, CD=Cloverdale, GS=Geyserville, HD=Healdsburg, HP=Hopland, LP=Lakeport, MD=Middletown, NP=Napa, SO=Sonoma, SR=Santa Rosa, UK=Ukiah, VJ=Vallejo, WHS=Wilbur Hot Springs, MSH=Mount St. Helena

The study area was selected during a CEC funded Phase 1 resource assessment phase in 1986. Subsequent investigations have centered around the Borax Lake 7-11 and Audrey A-1 deep wells that were drilled by Phillips Petroleum Co. in search of geothermal steam (Fig. 2).

The Borax Lake well is located on the north shore of Borax Lake about two miles northwest of the City of Clearlake and the Audrey well is about the same

distance due north. A final site for the demonstration HDR project has not been selected. The site will presumably be close enough to benefit the city economically.

B. Task

The purpose of this report is to provide a detailed evaluation of surface and near surface water sources available to fill and maintain proper fluid composition in a HDR reservoir.

Fig. 2. Clearlake area geothermal test wells.

II. Population, Land, and Water Use in the Clear Lake Area

A. General Description

Lake County is situated in the Coast Range mountains of California which consist of a series of northwest-southeast trending mountains that are interspersed by alluvial valleys and stream channels. These valleys influence the location of the residential population, the water availability, and thus the land use. Most of the land is basically undeveloped and inhabited by a sparse rural population. Approximately 50% of the land is owned by the United States government and managed by the U.S. Forest Service or the Bureau of Land Management. Most of the private land and population are along the shores of Clear Lake or in the alluvial valleys. The lake has drawn people for recreation and its waters, used for agriculture, for over 80 years.

The major water developers are the Yolo County Flood Control District, which owns and operates the Clear Lake Dam and the Indian Valley Dam; the Pacific Gas and Electric Company, which owns and operates the Pillsbury Project; and the U.S. Bureau of Reclamation, which owns and operates the Monticello Dam.

Topography divides Lake County into three major river systems (Fig. 3): Eel River, which flows northerly away from Clear Lake, and its related population; Cache Creek, which drains the Clear Lake area toward the southeast; and Putah Creek, which drains the area south of the Clear Lake and also flows toward the southeast.

Of the three systems, this report will be concerned only with the Cache Creek major basin which is subdivided into the Clear Lake, Lower Lake, Big Valley, Scotts Valley, Upper Lake, Indian Valley, and Cache Creek sub-basins. Flows from Indian Valley and Cache Creek sub-basins enter Cache Creek below the Clear Lake dam, and are not considered to be practical sources for an HDR demonstration project. Economic constraints will most likely dictate taking water from the Clear Lake or Lower Lake sub-basins for the proposed HDR demonstration project.

Lake County typically has mild, wet winters and hot, dry summers. Local topography and elevation

Fig. 3. Basin outlines (modified from Ott Water Engineers, 1987, Fig. 2, after p. 12).

influence the precipitation patterns. Mean annual precipitation ranges from 22 in. per year at Clear Lake to over 65 in. on Cobb Mountain just nine miles south of Clear Lake. Precipitation at the Southeast Treatment Plant, 1.5 miles north of the City of Clearlake, had an eight-year average of 31.9 in. Approximately 85% of the annual precipitation occurs from November through March with great variations from year to year. Drought years can have as low as 40% of normal precipitation while extremely wet years can have 200% of normal. Typical minimum and maximum mean temperatures for January are 31°F and 55°F, while July ranges from 56°F to 94°F.

Lake County has virtually no snow pack for developing natural storage for later release. Therefore, surface water is primarily associated with rainfall during the winter wet-weather periods. Groundwater and near-surface sources are recharged during the

winter storms. The period of greatest demand corresponds to the period of lowest available surface water supply. The evapotranspiration of agricultural crops varies from 3.0 acre-ft per year for pasture to 1.2 acre-ft per year for wine grapes. Domestic water use varies from 90 gallons per day per capita during winter months to 250 gallons per day in the summer.

B. Population Size and Projected Growth

Any discussion about water by necessity involves the population and projected population growth. From 1970 to 1980 the population on the margins of Clear Lake increased from 8,000 to approximately 18,000. County residents increased from 19,500 to over 36,300 during the same period. Obviously, this placed a great strain on water supplies and sewage treatment facilities.

Projected population growth to the year 2000 varies from a total Lake County estimate of 72,000 residents to a high of 86,000. The potential range for the year 2020 is 107,300 to 140,000 residents. Of the projected 140,000 residents, 70,212 or 50% will live in the Clear Lake basin and 6,125 or 4% will inhabit the Lower Lake sub-basin, which includes the Borax Lake and Thurston Lake closed basins. It appears certain that most of the future residential development will occur on the margins of Clear Lake. Approximately 50% of the entire county population resides in this area.

Lake County covers 850,000 acres with 407,000 acres or 50% managed by the U.S. Forest Service or Bureau of Land Management. Approximately two-thirds, or 300,000 acres of the remaining 443,000 acres, consist of unimproved barren land, areas of native vegetation, or bodies of water. The total acreage in agricultural production is approximately 36,000 acres. Of this, approximately 23,900 acres are irrigated. The remaining nonirrigated acreage consists of barley, wheat, and oat fields, and pasture. Irrigated crops include pears, wine grapes, and walnuts. Projections indicate that agricultural production will not significantly expand in the foreseeable future since approximately 95% of the prime agricultural lands are presently being cultivated.

C. Geothermal Effects on Water Supply

As of 1983, The Geysers stream field was producing 908 MWe and consuming 39,000 acre-ft of water per year. With reinjection running at 20%, the net consumption was approximately 31,200 acre-ft per year. At that time, facilities were under construction to raise production to 1700 MWe, which would be expected to increase water consumption to 58,500 acre-ft per year assuming the same reinjection rate of 20% (Bohrer, 1983).

In 1983, it was thought that development of the hydrothermal resources could lead to the installation of as much as 195 MWe of generating capacity in the Kelsey Creek watershed on the eastern side of The Geysers. The Kelsey Creek drainage comprises a major part of the Big Valley sub-basin and flows into the Clear Lake sub-basin. Development to this level was expected to create a net depletion of 9,000 acre-ft of water per year with an unknown amount of surface water reinjected. This would have heavily affected water supplies into the Clear Lake sub-basin. Anxiety on this account led to the study by the CEC staff (Bohrer, 1983).

As of 1991, the geothermal industry in this part of the basin was contracting, not expanding. If new production comes on line, it is not likely to require such an extravagant user of water. Accordingly, the concerns of 1983 no longer apply.

D. Water Rights in California

A water right is a legal entitlement authorizing water to be diverted from a specified source and put to beneficial, nonwasteful use. Water rights are property rights, but their holders do not own the water itself—they possess the right to use it. The owner of land that is contiguous to or borders a natural stream or lake is entitled to take water from that source for "reasonable and beneficial" use upon his adjacent land. These riparian rights do not require permits, licenses, or government approval, and remain with the property regardless of ownership.

However, riparian users must file a statement of water diversion and use with the Water Rights Division of the State Water Resources Control Board. This is a filing requirement only, the Board has no decision

authority. Water in a stream that is not put to beneficial use by a land owner can be appropriated and used elsewhere by another user as long as the "first in time, first in right" user's water is not diminished and quantities remain reasonable and beneficial. Beneficial uses commonly include municipal, industrial, irrigation, hydro-electric generation and livestock watering. The concept has recently been broadened to include recreational use, fish and wildlife protection, and "aesthetic enjoyment."

Riparian rights have a higher priority than appropriative rights. Natural flows can be diverted without a permit unless water is to be stored from one season to the next. Storing requires a permit. Riparian rights generally carry equal priorities requiring all users to share the shortage during a drought.

Records of water appropriation and use are maintained by the State Water Resources Control Board, Division of Water Rights. Permits spell out the amounts, conditions, and construction timetables for a proposed project. The Board considers prior rights, and the availability and flows needed to maintain recreation, fish, and wildlife. When the project is completed under the terms of the permit and the largest volume of water permitted is put to beneficial use, the Board issues a license that remains in effect as long as its conditions are met and beneficial use continues. A prescriptive right is not as common. It applies when a claimant uses water subject to the rights of another party for five continuous years without being contested.

The Board issues permits and licenses for appropriating underground water if the water is in "subterranean streams flowing through known and definite channels." A permit application is required if the water is to be used on land not overlying the channel. Only a Statement of Water Diversion and Use is required if the water is used on overlying land. Water unrelated to a subterranean stream, such as an aquifer in a ground water basin, is not subject to the Board's jurisdiction. Similar to riparian rights, the overlying land owners have the first right to draw from a ground water basin for reasonable beneficial use on the overlying land. Each owner's right is correlative to the others and the available supply. Such rights are called "correlative."

As is the case for holders of riparian rights and groundwater users, permits are not required for users of purchased water or those using water from springs or standing pools that have no natural outlet if used on adjacent land.

There are two classes of use under the riparian doctrine:

1. Natural or Ordinary Use, which means the water is necessary to maintain the lives of the occupants of the riparian land. This includes human consumption and watering of domestic animals and has priority during shortages.
2. Artificial or Extraordinary Use, which includes agricultural, commercial, or industrial uses, i.e., crop irrigation, large herds of livestock, manufacturing, and geothermal projects. During shortages industrial users must yield to domestic and agricultural users.

Between 1982 and 1983, Union Oil Company used a riparian right to inject Big Sulphur Creek water into The Geysers steam reservoir in an attempt to reduce the decline in reservoir pressure. Since 1957, a total of 280,000 acre-ft of water have been vented and lost from The Geysers.

During 1980 alone, 39,000 acre-ft were extracted from The Geysers. Celati (1981) estimated that reinjection of 100% of the extracted fluid might eventually be required to maintain pressure in deep geothermal wells. Because of losses due to non-condensable gases and leakages, this would require supplementary feed, or make-up water.

E. Streamflows in the Clear Lake Area

Flows measured at the Cache Creek gaging station include all flows from the Cache Creek Basin. The area of the sub-basins contributing to the Cache Creek gage is 528 mi². Since the lake surface area is 68.4 mi² and the drainage area associated with streams entering Cache Creek downstream from the lake outlet

but upstream from the gage is 38.7 mi², the area of the Clear Lake drainage is 420.9 mi². However, Thurston Lake and Borax Lake are sinks with no outlet. Their combined area is 20.9 mi² leaving a land area tributary to Clear Lake of 400 mi². About 86.8 mi² of this drainage is the Upper Lake (Fig. 4). This figure also shows the location of gaging, precipitation, and evaporation stations.

Fig. 4. Location of streamflow, lake stage, precipitation, and evaporation stations in and near Clear Lake watershed and contiguous sub-basins (modified from Chamberlin et al., 1990, Fig. IV- 4, p. 54).

The lake basin is equivalent to 256,000 acres, so that one inch of rain would generate 21,350 acre-ft of water. Since 1915, releases from Clear Lake have been controlled by the Clear Lake dam east of the township of Lower Lake on lower Cache Creek.

A series of decrees regulate releases from the dam:

1920 - The Gopcevic Decree (Appendix A) established maximum and minimum water levels for the lake at 0.00 and 7.56 ft (320,000 acre-ft) on the Rumsey gage at Lakeport. It also provided an operating schedule while filling the lake during the rainy season.

1940 - The Bemmerly Decree prohibited any enlargement of the Cache Creek channel which limits the amount of water that can be released during flood stages.

1978 - The Solano Decree (Appendix A) limits summer releases according to the water level prior to the release. It prohibits releases that would lower the lake level to below 0.12 on the Rumsey gage before October 31.

The Rumsey gage is 1318.26 ft elevation. Normal high water level is considered to be 7.56 ft on the Rumsey gage or approximately 1326 ft above sea level.

The level or "stage" of Clear Lake is measured at Lakeport, Lucern, and Clearlake Highlands. Figure 5 shows the annual maximum and minimum stages recorded at Lakeport and the associated ranges.

Lake levels above 9.0 ft on the Rumsey gage cause flooding around the lake. The lowest level recorded in 50 years was 3.4 during the 1976–77 drought. The average annual range in lake level is approximately 6 ft with variations from 3 to 9 ft.

Fig. 5a. Historical record of lake stage at Lakeport; **5b.** Annual range in lake stage (modified from Chamberlin et al., 1990, Fig. IV-5, p. 55).

The major streams flowing into the Upper (north) Arm of the Clear Lake sub-basin are Clover, Middle, Scotts, Manning, Adobe, Kelsey, and Cole Creeks. Schindler Creek flows into the Oaks Arm and Burns Valley Creek flows into the Highlands (south) Arm of Clear Lake. The surface outlet for the Clear Lake sub-basin is at the east end of Clear Lake, flowing into Cache Creek. Siegler and Copsey Creeks enter Cache Creek downstream from the lake outlet. All but Kelsey Creek are ephemeral with no flows recorded for up to four months during the year. Figure 6 shows the seasonal variation of major stream flows into Clear Lake and the effect of regulating the outflow into Cache Creek.

Table 1 shows the maximum, minimum, and average flows of major streams.

Fig. 6. Seasonal variation in streamflow at Clear Lake. The unit cfs/mi² is cusecs per square mile, where a cusec is a cubic foot/sec (modified from Chamberlin et al., 1990, Fig. IV-7, p. 58).

Table 1
Variability of Annual Streamflow in Clear Lake Drainage

Station Name	Station ID No.	Ave. Annual Flow (cfs)	Max. Annual Flow (cfs)	Min. Annual Flow (cfs)	Ave. Annual Flow (gpm)
<u>USGS Streamflow Stations</u>					
Adobe Creek near Kelseyville	11448500	12.0	24.0	0.38	5,386
Highland Creek near Kelseyville	11449000	20.0	43.0	9.7	8,977
Highland Creek above Dam	11448900	21.0	45.0	0.88	9,425
Highland Creek below Dam	11449010	22.0	46.0	0.27	9,874
Kelsey Creek near Kelseyville	11449500	76.0	206.0	4.8	34,111
Scotts Creek near Lakeport	11449100	79.0	156.0	0.10	35,458
Burns Valley Creek near Clearlake Highlands	11449350	1.5	2.5	0.15	673
Copsey Creek near Lower Lake	11449450	14.0	26.0	2.9	6,284
Siegler Creek at Lower Lake	11449460	11.0	17.0	2.3	4,937
Cache Creek at Lower Lake	11450500	495.0	1003.0	68.0	222,171
Cache Creek near Lower Lake	11451000	381.0	1342.0	0.70	171,005
<u>Dept. of Water Resources Stations</u>					
Clover Creek at Upper Lake*	A81790	30.0	64.0	10.3	13,465
Clover Creek Bypass near Upper Lake	A81940				
Middle Creek near Upper Lake	A81810	91.0	237.0	13.3	40,844
Scotts Creek at Eickhoff Road near Lakeport	A81845	99.0	259.0	0.1	44,434

NOTE: * Discharges for Clover Creek and Clover Creek Bypass are combined.

From Chamberlin et al., 1990, Table IV-3, p. 59.

F. Precipitation in the Clear Lake Area

Approximately 85% of the precipitation occurs between November and March (Fig. 7).

Fig. 7. Seasonal variation in precipitation at Clear Lake (modified from Chamberlin et al., Fig. IV-10, p. 63).

Table 2 shows the maximum, minimum, and average precipitation measured throughout the Clear Lake drainage.

Annual precipitation averages 35–43 in. per year near Upper Lake, 26–30 in. per year near Kelseyville and Lakeport, and 23–26 in. per year near the City of Clearlake. Precipitation is greatly influenced by the NW/SE ridges and elevations. Table 3 shows average monthly precipitation and evapotranspiration at Lakeport compared with the 1977 drought year.

Table 2
Variability of Annual Precipitation in or Near Clear Lake Drainage

Station Name	Station ID No.	Mean Annual Precip. (in./yr)	Max Annual Precip. (in./yr)	Min. Annual Precip. (in./yr)
Clearlake 4SE	1806	25.5	61.8	8.1
Clearlake Park	1807	23.2	30.7	15.7
Kelseyville	4488	26.0	36.5	14.9
Lakeport	4701	29.8	44.5	9.9
Upper Lake 7W	9167	43.0	91.9	17.9
Upper Lake RS	9173	35.0	44.8	19.3

Chamberlin et al., 1990, Table IV-5; p. 65

Table 3
Monthly Precipitation
and Evapotranspiration for Lakeport

Month	Average Precip. (in.)	Drought Year 1977 Precip. (in.)	Potential Evapotran- spiration (in.)
October	1.71	0.50	2.7
November	3.52	1.91	1.2
December	5.99	0.40	0.7
January	5.95	2.40	0.8
February	4.57	2.46	1.2
March	3.17	2.23	2.4
April	2.04	0.18	3.4
May	0.70	1.57	5.0
June	0.34	0.00	5.9
July	0.02	0.05	7.1
August	0.08	0.05	6.2
September	0.22	1.41	4.6
Total	28.31	13.16	41.2

From Ott Water Eng., 1987, Table 1, p. 15

G. Evaporation, Pumping, Groundwater, and Springs in the Clear Lake Area

Five pan-type evaporation stations within the Clear Lake drainage are listed in Table 4.

Average annual evaporation rates vary from 46.77 in. per year at Lakeport to 79.41 in. per year at Lower Lake.

Evaporation varies with the season and peaks in July and August (Fig. 8).

Fig. 8. Seasonal variation in evaporation (modified from Chamberlin et al., 1990, Fig. IV-13, p. 68).

Table 4
Average Annual Evaporation in or Near Clear Lake Drainage

Station Name	Station ID No.	Pan Type*	Start Year	End Year	Record Length (yrs)	Elevation (ft-amsl)	Ave. Ann. Evap. (in./yr)
Finley 1 SSE	A80305600	A	1964	1979+	16	1377	54.25
Finley 2SW	A80305650	A	1971	1974	4	1365	68.31
Lakeport	A80470100	Q	1901	1906	6	1319±	36.50
		M	1902	1906	5	1343	41.38
		A	1948	1952	(combined with '64-'70)		
		A	1964	1970	12	1343	46.77
Lower Lake 1W	A80516100	A	1970	1973	4	1450	79.41
Upper Lake 1 SE	A80916440	A	1970	1972	3	1330	59.80

Note:* Pan Types: A = 47.5 in. diameter, 10 in. deep, off ground
(Weather Bureau Class A pan)
M = 36 in. diameter, 18 in. deep, buried 14 in.
Q = 36 in. diameter, 10 in. deep, floating

From Chamberlin et al., 1990, Table IV.

Pumping from the lake for irrigation amounts to approximately 38,000 acre-ft per year and municipal/industrial demand requires about 3,700 acre-ft per year for a total of 41,700 acre-ft per year.

The non-water-bearing Franciscan formation underlies most of the Clear Lake area. The Cache-Anderson formations are the primary sources of groundwater with average depths of 75 ft. These alluvial aquifers and formations have low yields and

are of little consequence in a water balance. Gaseous hot springs in the area and under the lake have minor flows and are not considered in a water balance.

H. Water Balance for the Clear Lake Area

Since approximately 50% of the Clear Lake drainage is not gaged, flows for the remainder must be estimated by areas and rainfall. The adjusted estimates of average annual streamflows are shown in Table 5.

Table 5
Estimated Average Annual Tributary Streamflow by Lake Section

Section	Tributary	Drainage Area		Average Annual Streamflow		
		(mi ²)	(%) ¹	(cfs)	(cfs/mi ²)	(10 ³ ac-ft/yr)
Upper Arm	Clover Creek	25.2	7.3	30	1.2	—
	Middle Creek	48.5	14.0	91	1.9	—
	Scotts Creek ²	55.2	15.9	89	1.6	—
	Highland Creek ³	14.2	4.1	22	1.5	—
	Adobe Creek	6.4	1.8	12	1.9	—
	Kelsey Creek	36.6	10.5	76	2.1	—
	ungaged	161.3	46.4	129	0.84	—
Narrows	Total	347.4	100.0	449	325.0	—
	ungaged	3.7	100.0	3	0.8 ⁴	—
Oaks Arm	Total	3.7	100.0	3	---	2
	ungaged	20.2	100.0	16	0.8 ⁴	—
Lower Arm	Total	20.2	100.0	16.0	---	12
	Burns Valley	4.4	15.2	1.5	0.34	—
	ungaged	24.3	84.8	8.0	0.34 ⁵	—
Clear Lake	Total	28.7	100.0	9.5	---	7
	gaged	190.5	47.6	321.5	---	—
	ungaged	209.5	52.4	156.0	---	—
All Sub-basins	Total	400.0	100.0	477.5	---	346
Downstream ⁶	Siegler Creek	13.2	34.1	11.0	0.83	—
	Copsey Creek	12.5	32.3	14.0	1.1	—
	ungaged	13.0	33.0	12.0	0.96 ⁷	—
Cache Creek Dam	Total	38.7	100.0	37.0	---	27
	Total	438.7 ⁸	100.0	381.0	---	276

Notes:

1. Percent of the total sub-basin drainage area.
2. Average of USGS Station 11449100 and DWR Station A81845.
3. Highland Creek below Highland Creek Dam (USGS Station 11449010).
4. Adjusted to correct storage discrepancy in water balance.
5. Based on the unit streamflow in the Burns Valley Creek sub-basin.

6. Watershed drainage area contribution to flow at Cache Creek gage but entering downstream of the Clear Lake outlet.
7. Based on area weighted average of the unit streamflows for Siegler and Copsey Creek sub-basins.
8. Includes the drainage areas of all the above sub-basins but excludes the surface area of lake and drainage areas of the terminal watersheds of Lake Thurston and Borax Lake.

From Chamberlin et al., 1990, Table IV-10, p. 74.

Direct precipitation onto the lake and stream-flows within the Clear Lake drainage make up the major inflow while evaporation and releases from the dam are the major outflows. These adjusted flows reduce the change in storage in this analysis virtually to zero (Table 6).

The outflow from Clear Lake is estimated at 249,000 acre-ft per year by subtracting the flows into Cache Creek below the Clear Lake sub-basin from the releases from the dam.

Table 6
Adjusted Long-Term, Annual Water Balance for Clear Lake

Component	Annual Contribution*	
	(10 ³ ac-ft /yr)	(ft/yr)**
Streamflow within Clear Lake-Lower Lake Sub-basins	+346	+7.9
Tributaries Downstream from Clear Lake-Lower Lake Sub-basins	+27	+0.6
Direct Precipitation on Clear Lake	+120	+2.7
Releases from Dam	-276	-6.3
Evaporation	-219	-5.0
Pumped from Lake	-2	-0.1
Groundwater	0	0.0
Change in Storage	-4	-0.2

Notes: * Positive values are inputs and negative values are outputs.

** Based on a surface area of 68.4 mi² = 43,776 ac.

From Chamberlin et al., 1990, Table IV-9, p. 72.

I. Water Quality in the Clear Lake Area

Groundwater resources in Lake County have several water quality limitations, such as high turbidity, high coliform, hydrogen sulfide and methane gas, and high TDS (total dissolved solids), boron, barium, iron, and manganese. Water quality problems are generally due to poor soil conditions, shallow and poorly constructed wells, high water tables and contamination from septic systems. Representative wells and the quality standards are shown in Table 7.

Surface waters in Lake County have high concentrations of algae, boron, coliform, and other microbiological contaminants. Agricultural and urban storm runoff, poor septic systems, and overflows from inadequate wastewater treatment plants create water quality problems in Clear Lake. Water taken from the lake by suppliers of municipal water is treated by sedimentation, coagulation, filtration, and disinfection (chlorination). Typical analyses of Clear Lake water are shown in Tables 8 and 9. Based on these analyses the waters of Clear Lake are classified as a magnesium-calcium carbonate type.

Table 7
Lake County Groundwater Quality

Parameter	Standards		Upper Lake (14 wells) Typ/Max	Scotts Valley (17 wells) Typ/Max	Big Valley (17 wells) Typ/Max	Lower Lake (16 wells) Typ/Max
	Drinking Water	Irrigation				
Conductivity ($\mu\text{mho/cm}$)	1,600	1,500	350/1,500	200/500	700/1,400	750/4,000
pH (units)*	5.0-9.0	4.5-9.0	6.4/8.1	6.8/7.2	6.5/7.3	5.6/7.3
Alkalinity (mg/l)	500.0	—	150/346	100/189	350/643	200/395
Hardness (mg/l)	120.0	—	150/615	100/216	450/620	200/1,540
Flouride (mg/l)	1.4	1.0	—	—	0.2/0.4	0.3/0.7
Arsenic (mg/l)	0.05	0.1	0/—	0/—	0/0	0/0
Boron (mg/l)	5.0	2.0	0.2/1.2	0.15/0.5	0.3/4.4	0.6/1.1
Copper (mg/l)	1.0	0.2	0/—	0/—	0/0.14	0.01/—
Iron (mg/l)	0.3	5.0	0.02/0.2	0.04/—	0.2/0.4	0.05/—
Manganese (mg/l)	0.05	0.2	0/0.6	0/—	0.1/0.9	0/—
Lead (mg/l)	0.05	5.0	0.01/0.01	0.01/—	0.01/0.02	0.01/—
Zinc (mg/l)	5.0	2.0	0.02/0.03	0.04/—	0.02/2.2	0.08/—
Selenium (mg/l)	0.01	0.02	0/0.01	0/—	0/0	0/—
Nitrate (mg/l)	45.0	—	1/15	1/9	15/41	10/84

*pH is minimum and maximum

Modified from Ott Water Engineers, 1987, Table 6A, p. 36.

Table 8
Clear Lake Water Quality at Lakeport

Mineral Constituents	Date mo/yr	Clear Lake at Lakeport
Calcium (mg/l)	5/60	20.0
	9/60	22.0
Magnesium (mg/l)	5/60	13.0
	9/60	15.0
Sodium (mg/l)	5/60	7.8
	9/60	11.0
Potassium (mg/l)	5/60	2.2
	9/60	1.7
Bicarbonate (mg/l)	5/60	138.0
	9/60	158.0
Sulfate (mg/l)	5/60	6.0
	9/60	6.0
Chloride (mg/l)	5/60	4.9
	9/60	6.8
Nitrate (mg/l)	5/60	0.9
	9/60	4.6
Boron (mg/l)	5/60	1.2
	9/60	0.8
TDS	5/60	138.0
	9/60	156.0
CaCO ₃	5/60	103.0
	9/60	118.0
Conductivity (µmho/cm)	5/60	235.0
	9/60	276.0

Note: pH varies from 7.2 to 9.7 depending on seasonal algae activity. Values remain below 8.0 during winter months but rise to between 8.0 and 9.0 during the summer.

From California Dept. of Water Resources 1966, Table 6, p. 33.

Table 9
Clear Lake Water Quality

Parameter	Drinking Water Standard	Irrigation Water Standard	Clear Lake	
			Typical	Max
Conductivity ($\mu\text{mho/cm}$)	1,600	1,500	250	385
pH (units)*	5.0-9.9	4.5-9.0	7.2	8.3
Hardness (mg/l)	120	—	115.0	158.0
Arsenic (mg/l)	0.05	0.1	0.00	—
Boron (mg/l)	5.0	2.0	0.9	2.6
Copper (mg/l)	1.0	0.2	0.00	—
Flouride (mg/l)	1.4	1.0	0.1	0.4
Iron (mg/l)	0.3	5.0	0.1	1.8
Lead (mg/l)	0.05	5.0	0.00	0.1
Manganese (gm/l)	0.05	0.2	0.04	—
Nitrate (mg/l)	45.0	—	2.0	5.0
Zinc (mg/l)	5.0	2.0	0.00	0.01
Suspended Sediment (mg/l)	0.0	—	—	—
Turbidity (NTU)**	0.5 (FTU)***	—	30.0	90.0

*pH is minimum and maximum.

**NTU is Nethelometric turbidity units.

***FTU is forward-scattering turbidity units.

From Ott Water Eng., 1987, Table 6B, after p. 37.

III. Anticipated Water Requirements for a Hot Dry Rock (HDR) Demonstration Plant

During discussions with Kerry Burns and other staff members of the Division of Earth and Environmental Sciences, Los Alamos National Laboratory (LANL), it became apparent that water requirements for a demonstration/commercial HDR project must be defined, as clearly as possible, before any attempt is made to secure or determine the availability of such water. The current near panic over the prolonged drought in California makes it imperative that the water requirements for the HDR project be as restricted and supportable as possible.

In a LANL memo dated February 8, 1991, K. Burns concluded that water requirements for a pilot or demonstration HDR unit, using the Fenton Hill, New Mexico, experience as a model, can be well documented. However, another isolated demonstration unit in the Clear Lake area has no practical value unless it can be scaled up to commercial proportions. Therefore, a quantity of water of suitable quality will be sought to eventually expand the demonstration unit to commercial size.

The size of a "commercial" HDR producer depends upon all the many factors that govern an economic feasibility study. Burns and Potter (1990) used a Net-Present Value model to calculate the break-even size at 2.4 MWe (12 MWt)* for a reservoir at 300°C (572°F) near Clearlake. Kerry MacDonald (personal communication) felt that a commercial generating plant should be greater than 35 MWe and preferably greater than 50 MWe (250 MWt). This was based largely on project financing considerations. Tester and Herzog (1990, p. 33) based their economic studies on a nominal 50 MWe plant. Taking these factors into consideration, we envisage a demonstration plant at 2.5 MWe which, if successful, would be enlarged for commercial operation to about 50 MWe. We therefore need to identify sources of water for a 50 MWe plant. Water is needed for drilling, for hydraulic stimulation and filling the artificially created reservoir, and to make up the water that leaks off due to permeability at the far-field boundary of the reservoir.

Drawing upon *in situ* leach mining experiences for copper and uranium, it is not reliable to scale up from bench tests in the laboratory to full-scale operations; therefore, a pilot plant or test site is utilized.

The pilot plant for the Clear Lake project is the Fenton Hill Experiment—the world's first hot dry rock geothermal energy system. By using a building block or "cell" approach (also referred to as a parallel configuration) the original unit can be reproduced to cover an area limited only by available water and physical features. Developing and operating the test cell provides valuable information for the subsequent up scaling. The initial cell would have one injection well feeding one production well for minimum capital expenditures (Fig. 9). The next step would be to one injection and two production wells, the configuration used by Tester and Herzog (1990) for their economic feasibility studies. This configuration may be necessary to achieve their production cost of 5 cents/kWhe.

Fig. 9. Hot Dry Rock (HDR) geothermal system concept for low permeability formations. (From Tester et al., 1989.) This is the test configuration. A commercial producer would have more than one production well.

Obviously, as the well field is developed by adding more cells, some injection fluids will migrate to adjacent production holes depending on how extensive the stimulation or fracturing. The well field evolves into a five-spot pattern (Fig. 10) which is used extensively in uranium *in situ* leach mining and experimentally in copper leach mining.

Fig. 10. Well field development for a "parallel" HDR configuration.

Test cells for *in situ* mining generally consist of one injection hole and four recovery or production holes for maximum control of potentially toxic solutions. HDR systems do not utilize toxic solutions and depths are much greater.

An analysis by Plains Electric (1981) for the U.S. DOE concluded: "The size of the fracture required to provide enough heat to operate a base loaded 10 MW unit is about 2,000 ft in diameter assuming a circular fracture and a rock temperature of 600°F. The useful life of a 2,000-ft diameter fracture is estimated to be about 15 years at a 10 MW base-loaded production rate. The long term loss of water to the formation is predicted to be about 1.5% of the average flow as observed during extended operation of the first prototype reservoir system (Fenton Hill, N.M.). A trend was established which showed the loss to be declining slowly with time as the rock around the fracture became saturated. The average water flow at the injection well is estimated to be 1542 gpm (gal./min). The 1.5% water loss (23.1 gpm) is based on a 365 day year and amounts to 37 acre-ft annually. At this point there is uncertainty as to how much water will be required to fill the reservoir. The assumption at this time is 5 million gallons." Losses in the generation

system are estimated at 1% or 15 gpm for a total of 38 gpm in the power-producing system. An estimate of 0.62 gpm for sanitary requirements makes a total system requirement of 38.62 gpm or 62 acre-ft per year (Fig. 11).

Fig. 11. HDR water requirements (modified from Plains Electric, 1981, Fig. 2, p. 22).

The reservoir loss will be dependent upon the porosity of the bedrock, the degree of thermal cracking, accumulation of precipitates, and the operating pressure of the subterranean system. The system would be operated without reservoir growth as monitored by seismic activity.

In 1986, LANL conducted a 30-day closed-loop circulation test of the Phase II, Hot Dry Rock reservoir at Fenton Hill, New Mexico (Los Alamos National Laboratory, LA-11498-HDR). In summary: "A total of 9.76 million gallons of water was injected while 6.15 million gallons of hot water was produced. The injection rates at the surface ranged up to 420 gpm, although most of the pumping was done at rates of 168 gpm and 294 gpm, with surface pressures around

3900 psi and 4400 psi, respectively. The production well surface pressure was controlled at around 500 psi, resulting in surface production flow rates from 100 gpm to 220 gpm. The EE-2 production temperature increased throughout the test, reaching a maximum of 192°C (378°F) at the surface and 232°C (450°F) at the bottom of the well by the end of the test. The production flow rate also increased throughout the test. This increase was related to the significant amount of time required to inflate the reservoir to a pseudo-steady-state volume. A slight reduction in the production wellbore impedance was observed. As a result of the temperature and production increases, there was a corresponding increase in power production which reached a maximum of 10 MWt after 28 days. The rate of water loss decreased throughout the test starting at 70% after 4 days of pumping and falling to 26% after 30 days. The apparently high water-loss rate

during the early portion of the test was caused primarily by the water required to inflate or fill the fractures that make up the reservoir. Of the total injected water, 66% was recovered during the test and an additional 20% was recovered during a subsequent "vent-down." Seismic data indicated that the reservoir was growing throughout the test.

Don Brown (personal communication) estimates that a Fenton Hill-sized reservoir of 706M ft³ (20M m³) would measure approximately 1000 x 1000 x 700 ft. This reservoir appears to be able to produce 7 MWt (1.4 MWe) at 446°F (230°C) on a sustained basis.

The diffusional water loss at the reservoir boundary was estimated at 2.5 gpm under stable conditions without reservoir growth (Fig. 12).

Fig. 12. Temporal variation in the Phase II reservoir. Water loss rate at a pressure of 2250 psi (15 MPa) (from Brown, 1991).

Figure 13 indicates that during the initial closed-loop flow test (ICFT) when the injection pressure was increased on June 4, 1986, the reservoir was growing and obviously taking on additional fluids.

Fig. 13. ICFT seismology histogram (from Dash et al., 1989, Fig. VI-3, p. 86).

The power production (Fig. 14) reached the 7 MWt level on the same date.

Fig. 14. Thermal production during the ICFT estimated using heat exchanger flow rates (from Dash et al., 1989, Fig. III-16, p. 45).

Present thinking would limit a Clear Lake HDR reservoir to an initial seismically inactive size. Empirically, the Fenton Hill HDR reservoir, with its present borehole spacing of about 120 meters at the heat extraction depth, can produce 7 MWt without requiring large amounts of make-up water to fill an expanding reservoir.

If similar production temperatures are encountered in the Clear Lake area approximately 35 cells would be required to produce 50 MWe (250 MWt) of commercial power. Since higher temperatures of 572°F (300°C) are expected, only 20 cells would be required.

Using the Fenton Hill ICFT it appears that each cell would require the following water to bring one cell on line:

	Volume (x 10 ⁶ gal.)
Drilling water	1.0 mil. gal
Reservoir fill water	9.8 mil. gal
Spills, venting, accidents	0.2 mil. gal
Total	11.0 mil. gal

The total of 11 million gallons is equal to 33.8 acre-ft. An additional 2.5 gpm would be required perpetually to make-up for permeation losses that leak off at the reservoir boundary. This amounts to an additional annual requirement of 4 acre-ft.

The Plains Electric reports estimated that an injection flow of 1542 gpm was required to produce 10 MWe. This is roughly 5 to 7 times the 294 gpm injection rate during LANL's subsequent tests that produced 10 MWt. This is consistent since it takes 5 MWt to produce 1 MWe. Also, a recovery of 66% of the 9.8 million gallons injected means that only 3.3 million gallons remained in the reservoir before vent-down to ambient pressures. It appears that the Plains Electric earlier estimate of 5 million gallons is more than adequate for a 10 MWt reservoir and probably sufficient for their proposed 10 MWe reservoir.

The diffusional water loss at the reservoir boundary was observed by D. Brown (1991) to be 2.5 gpm for a reservoir roughly the same size as that assumed in the Plains Electric report. Even though these observations were at less-than-projected operating pressures, it appears that the losses of 23 gpm at the reservoir boundary assumed by Plains Electric are more than adequate.

It is not certain how much water is required to fill a 10 MWe reservoir when extrapolating from the Fenton Hill experience because of the numerous phases while developing the Fenton Hill reservoir.

However, this author is assuming that 5 million gallons are required for hydraulic fracturing and filling in addition to about one million gallons for the drilling operation (D. Dreesen, verbal communication). Since most power plant experts feel that 50 MWe is a minimum size for a commercial plant, a fully developed field would require the equivalent of five demonstration units. Each newly created reservoir would require 6 million gallons of water unless a thermally exhausted unit is abandoned. In this case approximately 50% of the fill water is recovered for reuse as pressures becomes ambient. Storage for approximately 5 million gallons of water in two separate membrane-lined ponds would be required (J. Skalski, 1991, verbal communication).

The requirements for the quality of fluids to be injected into the HDR reservoir are not onerous. The fluid should be settled or filtered to remove suspended solids in order to avoid plugging the microfractures created by hydraulic fracturing. Slightly contaminated sewage treatment plant effluent would be suitable since downhole temperatures far exceed the pasturization temperature of 180°F. Brackish water or contaminated water, such as in Borax Lake, would be suitable provided clay minerals in the fractured rock did not swell when the ions exchange. Also, hot chloride solutions can be very corrosive. Table 10 shows the typical ion concentrations in production fluids in the ICFT system at Fenton Hill.

Grigsby et al. (1983) found that the two primary causes of dissolved species were displacement of downhole pore fluids and dissolution of minerals. Current thinking suggests a continuous extraction of original pore fluid from the fractured rock mass over a long period of time. The best support for this theory is the presence and continued supply of chemically inert species of boron and chloride, which were not found in the reservoir granite and not supplied by a dissolution reaction. A bleedstream could be required if concentrations built up to excessive levels in a closed-loop and mineral scale accumulates.

It is concluded that the demonstration plant (7 MWt) would require 34 acre-ft for construction, and thereafter 2.5 gpm for makeup. The commercial system (50 MWe), using linear scaling, would require about 700 acre-ft during construction, and thereafter 50 gpm during operations.

Table 10
Typical Ion Concentrations, HDR-Fenton Hill
Sample collected on day 6 after quasi-steady-state operation

Component	Concentration (ppm)
As	0.6
B	48.0
Br	11.5
Ca	42.0
Cl	1814.0
F	10.4
Fe	2.1
HCO ₃	408.0
K	114.0
Li	23.4
Na	1180.0
pH	5.79
SiO ₂	452.0
SO ₄	183.0
TDS	4300.0

*From Los Alamos National Laboratory, 1986,
Table V-1, p. 65.*

**Note: In the process of energy conversion in a power plant, MWt is the rate of heat removal from geothermal fluid, and MWe is the power produced as electricity by the plant. The second Law of Thermodynamics determines power "availability," that is, the maximum amount of mechanical energy that can be extracted from a given flow of geothermal fluid, and this is further reduced by the cycle efficiency of the particular conversion process. (Armstead and Tester, 1987, p. 402.)*

IV. Sources of Water for the Clearlake Demonstration HDR Plant

Five sources of water have been identified for supplying the requirements for the proposed Clearlake HDR demonstration plant.

1. Municipal Water Suppliers
2. Clear Lake (Yolo County Flood Control & Water Conservation District)
3. Borax Lake
4. Southeast Regional Wastewater Treatment Plant (SERWTP)
5. Wells, Catchment Ponds, and Streams on Private Lands

A. Municipal Water Suppliers

There are four suppliers of public water in the immediate vicinity of Clearlake City that might be considered for supplying the needs of an HDR demonstration plant (Table 11).

Table 11
Water Suppliers in the Southeast Regional Wastewater System Service Area
October 1989

Supplier	Raw Water Source	Area Served Accounts	Number of Accounts	Approx. Flow (gal./day)
California Cities Water Company (private)	Clear Lake	Clearlake Highlands Clearlake Park N. to Monitor Point	2100	N/A
Highlands Water Company (private)	Clear Lake	Clearlake Highlands, City of Clearlake	2300	795,500
Konocti County Water District	Clear Lake	City of Clearlake, Area E. of Highway 53 South to Cache Creek	1600	195,000
Lower Lake County Water District No. 1	Wells	Lower Lake Area	696	54,000

Note: Each supplier provided figures for his service area as of October 1989.

From Dewante and Stowell, 1991, Table 4-1, p. 4-2.

However, only the California Cities Water Company is close enough to the Borax Lake or Audrey geothermal test wells to be considered economical (Fig. 15).

The Borax Lake well lies approximately 4,000 ft northwest of a California Cities water main that presently supplies the subdivision east of Country Club Drive and west of Eastlake Drive. Like the

California Cities Water Company, the Highlands Water Company and Konocti County Water District take their water from Clear Lake and treat the water by sedimentation, coagulation, filtration, and chlorination. The Lower Lake County Water District No. 1 water supplier draws water from wells near Lower Lake and only chlorinates the water. They are presently under a restraining order because of excessively high iron and manganese content.

Fig. 15. Part of area supplied by California Cities Water Co.

The author met with Donald K. Saddoris, Director of Operations, and James D. Carson, Senior Northern Division Engineer, both of Southern California Water Company, on March 27, 1991, to discuss the proposed HDR needs. California Cities is a subsidiary of Southern California Water Company and is managed locally by Fleming Jenson. I was told that the California Cities Water Company had been approached by the developers of the Borax Lake basin to supply water to their proposed golf course and housing development. Saddoris and Carson stated that an expanded water treatment plant would soon be completed and could easily supply up to about 300 gpm to the Borax Lake well site in the near future. The cost of an extended water main to service the housing development would be borne primarily by the developer but a contribution by the water company and geothermal users would be expected. An easement with the developer would also be required. If limited to about 300 gpm, a membrane-lined storage pond at the well site would be essential before drilling and hydraulic fracturing. There is ample water for developing a commercial operation. This municipal water meets EPA drinking water standards (Ott Water Engineers, 1987, p. 36) and should present no problem when injected into the reservoir.

The cost of this treated water is \$2.06/100 cu. ft. (748 gallons) plus a monthly service charge of \$24.60. Six million gallons would cost approximately \$16,500 plus the monthly service charge. Taking water from a municipal supplier could be an advantage in times of drought. Such suppliers have first priority for using Clear Lake waters.

B. Clear Lake Source

Water could be pumped from Clear Lake itself by constructing a 6,000-ft pipeline with a 320-ft lift. This would require pumps, pipelines, easements with property owners, and a purchase contract with the Yolo County Flood Control and Water Conservation District (the District). The District controls the lake water except for "reasonable" amounts used by property owners bordering the lake.

The author met with James F. Eagan, General Manager, and Christy Barton, Assistant General Manager of the District on March 14, 1991. They explained that through much litigation and the Solano decree, the District now controls approximately

320,000 acre-ft of water between zero and 7.56 ft on the Rumsey gage (approximately 1318 ft and 1326 ft elevation). Average annual evaporation is approximately 120,000 acre-ft for a net of 200,000 acre-ft. The District may take 150,000 acre-ft if the lake reaches 7.56 ft on the Rumsey gage on April 1. If starting at 7.56 ft, the October 31 level must be held above 1.25 ft on the Rumsey gage, instead of zero. If the April 1 level is 3.22 ft or less, then the District gets no water, with corresponding amounts in between. Only 61 years or 52% of the 117 years since 1873 have not had a "full" status of 7.56 ft on the Rumsey gage by April 1. The level by that date in eight of those years was below 3.22 ft, meaning that no lake water was available. It appears that the six million gallons required for a geothermal demonstration HDR plant would be reliably available. Water from the District, for geothermal use is classified as "measured non-agricultural" and costs \$30.30 per acre-ft (325,851 gal.) Six million gallons would cost only \$560.00. The costs for pumps, pipelines, and rights-of-way have not been estimated.

The Lake County Flood Control and Water Conservation District holds appropriate water rights to 41,000 acre-ft per year from Kelsey Creek for the Pomo Dam above Kelseyville. The right has not been perfected by putting it to beneficial use and the dam has not been built. This is not a part of the Clear Lake source but might be considered if the HDR demonstration site is located near Kelseyville.

C. Borax Lake Source

The Borax Lake geothermal well is located approximately 1,000 ft from the water's edge on the north shore of Borax Lake (Fig. 16).

The surface area of the lake varies greatly depending on rainfall within the closed Borax Lake basin. The lake has a maximum depth of five feet and almost dries up in drought years. Houses along Country Club Drive have been threatened in wet years. The fact that the lake never completely dries up

suggests to some observers that the lake is partially spring fed. Because of its proximity, Borax Lake would seem to be the obvious choice for supplying water if the Borax Lake well is selected for refurbishment as the Clearlake demonstration HDR well. However, the volume is not reliable and the very high mineral content could create precipitates and corrosion problems in the HDR system. Removal of salts from water is expensive and involves distillation or reverse osmosis. Treatment to extract dissolved minerals might be offset by producing a saleable product such as borax.

Fig. 16. Property owners for geothermal test wells.

The uncircled numbers are sections in Township 13N Range 7W MD Base and Meridian in the California land grid. The circled numbers are file numbers in the TRW REDI Property Database.

Table 12 shows values for samples collected in the 1970s and Tables 13 and 14 give analytical results by two different labs run on the same sample.

Table 12
Borax Lake Water Quality

Parameter	Units	Range	Average	Tolerance Range of Aquatic Organisms	Comments
Temperature	°C	4-25	16.0	8-27°C	Extremes for trout and channel catfish
Conductivity	µmho x 10 ⁶	27,175-69,679	47,081.0	—	—
Turbidity	ppm	0-55	—	—	—
Acidity	pH	9.55-9.80	9.68	6.5-9.0	Too alkaline
Carbonate	mg/l	4,102-11,994	7,697.0	Depends on cation	Not toxic per se, contributes to high pH
Bicarbonates	mg/l	890-2,735	1,657.0	<200	Good fish fauna
Chloride	mg/l	8,789-22,339	15,068.0	<4,000	Most warmwater Species
Sulphate	mg/l	21-40	30.0	<90	
Sodium	mg/l	8,971	15,446.0	<500	A problem
Calcium	mg/l	23-80	37.0	<300	Reduces metal toxicity
Magnesium	mg/l	93-324	163.0	<100	A potential problem
Potassium	mg/l	361-1,438	857.0	50-200	Toxic effects on fish
Boron	mg/l	440-850	589.0	<2000	Not a problem to fish

From: Technical Memorandum, K.P. Lindstrom & Assoc., May 1983, Table 4.

Table 13
Analysis of Borax Lake Surface Water Sample

Analysis		Results
23331-1 Borax Lake 1 Surface Water Sample, grab 4/24/89 by SRB		
pH	9.5	
Calcium	11.2	mg/l
Magnesium	120.0	mg/l
Sodium	3500.0	mg/l (rerun)
Potassium	159.0	mg/l
Iron	0.11	mg/l
Manganese	<0.03	mg/l
Boron	170.0	mg/l
Chloride	3125.0	mg/l (rerun)
Sulfate	<2.5	mg/l (rerun)
Alkalinity, carbonate	2400	mg/l
Alkalinity, bicarbonate	1000	mg/l
Lithium	0.06	mg/l
Nitrate-N	0.84	mg/l
Aluminum	<0.5	mg/l
Nickel	<0.05	mg/l
Specific conductance	9700	µmho/cm
Total dissolved solids	9635.00	mg/l
Cations	166.636	93.7%
Anions	156.080	

Source: Sierra Foothill Laboratory Report, to State of California
CRWQCB-CVR, 6/29/89, supersedes report issued 5/31/89.

Table 14
Analysis of Sample from the South Side of Borax Lake

Constituent	Method/Date/Analyst	Detection Limit (mg/l)	Total Level Found (mg/l)	Duplicate (mg/l)	Spiked AT* (mg/l)	Level Found W/Spike (mg/l)	Spike Recovery (%)
Aluminum	7020 05/11/89 MM	0.2	0.2	0.2	10.0	11.7	106
Antimony	6010 05/18/89 MM	3.0	<3.0	<3.0	4.0	4.8	120
Arsenic	7060 05/23/89 KM	2.0	<0.005	---	4.0	5.06	101
Barium	6010 05/16/89 MM	0.01	0.18	---	1.0	1.21	103
Beryllium	6010 05/16/89 MM	0.01	0.10	---	1.0	1.05	95
Boron	6010 05/16/89 MM	0.1	150.0	---	10.0	164.0	140
Cadmium	6010 05/16/89 MM	0.2	1.0	---	5.0	5.91	98
Calcium	6010 05/16/89 MM	1.0	16.0	---	10.0	25.7	97
Chromium	6010 05/16/89 MM	0.05	0.41	---	5.0	5.27	97
Cobalt	6010 05/16/89 MM	0.05	0.36	---	1.0	1.05	69
Copper	6010 05/16/89 MM	0.05	0.13	---	1.0	1.02	89
Iron	6010 05/16/89 MM	0.05	0.88	---	10.0	11.5	106
Lead	7421 05/12/89 RJ	1.0	0.009	---	---	---	---
Lithium	303A 05/16/89 KM	0.01	0.97	0.93	0.194	1.16	108
Magnesium	6010 05/16/89 MM	1.00	110.0	---	10.0	126.0	160
Manganese	6010 05/16/89 MM	0.02	0.13	---	5.0	5.29	103
Mercury	7471 05/17/89 RJ	0.0002	0.001	---	---	---	---
Molybdenum	6010 05/16/89 MM	5.0	<5.0	---	10.0	12.0	120
Nickel	6010 05/16/89 MM	0.05	0.41	---	1.0	1.10	69
Potassium	6010 05/16/89 MM	3.0	160.0	---	10.0	166.0	60
Selenium	7741 05/18/89 MM	0.005	<0.005	<0.005	---	---	---
Silver	6010 05/18/89 MM	0.2	<0.2	<0.2	2.0	1.97	99
Sodium	6010 05/23/89 MM	0.1	3300.0	---	10.0	---	---
Tin	6010 05/11/89 MM	1.0	<0.05	---	4.0	13.8	320
Titanium	6010 05/11/89 MM	0.05	<0.05	---	---	---	---
Thallium	7840 05/18/89 KRW	0.05	<0.05	---	1.0	1.03	103
Vanadium	6010 05/16/89 MM	0.02	0.75	---	0.5	0.783	7
Zinc	6010 05/16/89 MM	0.05	0.19	---	1.0	0.827	64

*AT = Analyte Total

Source: Central Coast Analytical Services to State of California
CRWQCB-CVR, 5/30/89.

Temperatures and mineral content are extremes for most fish and plant life but water fowl have been observed on the lake in great numbers (Lindstrom, 1983).

The flat basin bottom has been proposed for development by Montross Barber Investments (Dumont Enterprises) to include a golf course and housing (Fig. 16, Table 15).

Their proposal involves a dike across the basin to confine the mineral waters to the west end of the basin. Presumably fresh water would flush the east end so that grasses could grow. Their proposal needs more study. In any event the developers have expressed an interest in disposing of the water by HDR injection. The developers own the water since they own the land adjacent to water in a closed basin as described in the section on water rights.

Table 15
Property Owners for Geothermal Test Wells

Parcel List* Parcel No.	TRA	Owner Address	Zip Code	Date	Document No.	Assessed Values
010 002 54 01	60087	Clear Lake Hotel P.O. Box 71287 Los Angeles, CA. #14995 Hwy 20 Clearlake Oaks, CA	90071	—	0603-030-00	\$182,205 LND
010 022 54 02	60087	Weger Audrey, et al., 8310 Hwy 29 Lakeport, CA	95453	1980	1071-687-80	LND
010 002 60 01	60087	Clear Lake Hotel Resort Co. P.O. Box 71287 ARCO Plz. Los Angeles, CA	90071	—	0603-052-00	\$65,716 LND
010 002 60 02	60087	Weger Audrey, et al., 8310 Hwy 29 Lakeport, CA	95453	—	1071-687-00	LND
010 002 61 01	2013	Dumont Enterprises 351 Rosedale Rd. Calistoga, CA	94515	1985	1254-114-85	\$198,084 LND
010 002 61 02	2013	Dumont Enterprises 351 Rosedale Rd. 2455 Old Hwy 53 Clearlake, CA	94515	1985	1254-114-85	LND
010 002 62 02	2013	Dumont Enterprises (See above for address)	94515	1985	1254-114-85	\$71,439 LND
010 002 62 02	2013	Dumont Enterprises (See above for address)	94515	1985	1254-114-85	LND

From TRW Real Estate Information Services, 1991.

Wastewater flows in the system have exceeded treatment and disposal capabilities in recent years, prompting the LCSD to initiate expansion improvements to eliminate overflows into Clear Lake. Treatment methods are effective, the treatment plant is in excellent condition, and present plans are to add to existing facilities. The most serious deficiencies are the lack of adequate storage and disposal facilities for excess effluent during wet seasons. A 1984 study

recommended disposal into a tributary of the North Fork of Cache Creek (Fig. 18).

Several disadvantages postponed action and prompted a study of alternative disposal methods (Table 16). Lake County, and especially the Clearlake area, have been and are expected to continue to be among the fastest growing areas of California (Table 17).

Fig. 18. Surface and deep injection disposal alternatives (from Dewante and Stowell, 1991, Figs. 7-4, p. 7-36).

Table 16
Overview of Disposal Alternatives

		Costs in Millions				
Disposal Option	Treatment Level and Extra Cost*	Disposal Costs	Total Disposal		Advantages	Disadvantages
1. Discharge to Cache Creek Effluent pumped to Cache Creek or North Fork of Cache Creek for year-round disposal	Advanced Secondary or Tertiary \$3.0-5.5	Phipps Crk \$2.7 Cache Crk \$3.7-4.6	\$6.7-12.6		<ul style="list-style-type: none"> • No storage reservoir req'd • Proven reliable technology • Reliable disposal capacity • Tertiary treatment allows variety of reclamation options 	<ul style="list-style-type: none"> • Potential litigation over discharge • High operation and maintenance costs
2. Discharge to Borax Lake Excess effluent above current capacity discharged to Borax Lake, year-round for evaporation in dry months	Secondary No extra cost	Pipeline-\$2.7 Diking and storm water diversion \$3.7+	\$6.4		<ul style="list-style-type: none"> • No storage reservoir req'd • Short piping and pumping dist. • Potential to alleviate certain water quality problems 	<ul style="list-style-type: none"> • Storm water needs to be diverted to Clear Lake • Complex operation of system • High hydrologic uncertainty • Uncertain status of Borax Lake before and after discharge
3. Deep Geological Injection Effluent is injected into deep, high-temperature strata for disposal or geothermal energy production	Secondary No extra cost	Pipeline-\$2.7 Well-devel. \$1.1	\$3.8?		<ul style="list-style-type: none"> • Low environmental impact • Potential for energy production • Unobtrusive disp. facilities 	<ul style="list-style-type: none"> • Uncertain capacity-short and long term • Uncertain long term geologic impacts
4. Reinjection at geysers Effluent is piped to Geysers area and disposed of in existing reinjection wells operated by geothermal energy producers	Secondary Cost	Pipeline-\$10-\$15	\$10-\$15		<ul style="list-style-type: none"> • Beneficial use of wastewater • Low environmental impact • Potential for purchase of WW as valuable resource 	<ul style="list-style-type: none"> • Organization and operation very complex • Backup needed in case of pipeline shutdown • Energy use in pumping effluent
5. Land Disposal Excess effluent is stored in new reservoir for irrigation on additional disposal land during dry months	Secondary No extra cost	Storage and disposal \$19	\$19		<ul style="list-style-type: none"> • Proven, acceptable technology • Reclamation of wastewater 	<ul style="list-style-type: none"> • Requires large land acquisition • Land required may interfere with development of City of Clearlake

Note: (*) Extra costs for treatment above expansion of existing secondary treatment facilities which is \$4.04 million for each alternative.

From Dewante and Stowell, 1991.

Table 17
Lake County Sanitation District Regional WWTP Expansion Study
Southeast Flow and Load Projections

Parameter	Year		
	1989	1994	2000
• Wastewater System Users (a)	16,250	19,000	23,000
• Average Dry Weather Flow (ADWF) mgd (b)	1.08	1.33	1.73
• Average Wet Weather Flow (AWWF), mgd (c)(d)	1.7(e)	2.0	2.6
• AWWF for 1 in. 10 year Rain Event, mgd (c)	—	2.9	3.7
• AWWF for 1 in. 100 year Rain Event, mgd (c)	3.7	3.8	3.9
• Average Annual Flow, mgd (f)	1.3	1.6	2.1
• Peak Wet Weather Flow, mgd (g)	4.5	4.5	4.5-5.0
• Peak Week By BO ₅ Load Per Capita, lbs/day (h)	0.14	0.19	0.20
Total, lbs/day	2,227	3,590	4,500

Notes:

(a) Based on Lake County, Special Districts Data 1989; 6,500 connections with 2.5 persons (users per connection). Includes AD1-6 residences. Projections for 1994, 2,000 based on 150 new connections per year for 1989-91 and 250 new unit connection/year from 1992-2000 with 2.5 users per unit connection. (b) Based on observed SETP inflows from 9/88 through 8/89, which produce a per capita flow of 67 gal./day. Projections for 1990 and year 2000 used 70 gpc/day and 75 gpc/day, respectively. (c) Average monthly flow for period December-April.	(d) Projections based on AWWF/ADWF differences in 1985-86, scaled to reflect increase in system users. (e) Assuming average weather conditions. Actual AWWF for water year 1988-89 was 1.15 mgd. (f) Time weighted sum of ADWF and AWWF (5 months of AWWF, 7 months of ADWF). (g) Limited by Pump Station No.1 output capacity (maximum is 4.3-4.5 mgd). Expect to increase capacity of Pump Station No.1 between 1994 and year 2000. (h) BOD is bio oxy demand.

From Dewante and Stowell, 1991, Table 4-2, p. 4-4.

The SERWTP facilities have been strained to the limit, prompting a Cease and Desist Order by the California Regional Water Quality Control Board, effective on March 22, 1991. No more sewer connections will be allowed until a facilities expansion plan is completed, at which time 50 new connections will be allowed. Another 100 new connections will be allowed for every foot of rise of the dam which retains the treated effluent.

The five disposal alternatives in Table 16 were presented to the Lake County Board of Supervisors on March 26, 1991, in Lakeport, by Charles Bunker and Dave Maciolek of Dewante and Stowell, Consulting Engineers. Briefly, the Board of Supervisors concluded that the land disposal alternative No. 5 reflected inflated land values in the area and it was ruled out on cost. There seems to be a lack of interest for participation in a costly pipeline by operators at The Geysers, therefore alternative No. 4 was ruled out. It is highly doubtful that the geologic formations in the vicinity would accept the volumes of wastewater required for disposal in deep wells even if water vapor is vented to the atmosphere. Therefore, the Deep Geologic Injection alternative No. 3 was ruled out. The Board was quite interested in the HDR geothermal possibilities and plan to follow progress of the Clearlake HDR demonstration project. The alternative No. 2 for discharging to Borax Lake for storage and evaporation is complicated by Dumont Enterprise's plans for a golf course and housing subdivision. Treated effluent would dilute and possibly improve the Borax Lake water quality but the system is complex and uncertain. The Board of Supervisors concluded that alternative No. 1, which discharges to Cache Creek for year-round disposal, was the most reliable and reasonable in cost. Discharging to Cache Creek would not require additional storage capacity but does have higher operating expenses and could invite litigation by downstream users.

The Board planned to take a wait-and-see attitude toward the Clearlake HDR demonstration project but would consider supplying treatment plant effluent in the future. If the Audrey A-1 well is selected, a two-mile pipeline and booster pump would be required between the present treatment plant and the well site (Fig. 18). Only one land owner, the Audrey Weger/Clear Lake Hotel & Resort consortium, would be involved in negotiations and they have no known plans

for development (Fig. 16, Table 15).

E. Wells, Catchment Ponds, and Streams on Private Land

Another source of water for the Clearlake HDR demonstration plant could be from private land. As explained in the section on water rights, unused water can be appropriated and put to "beneficial use" elsewhere if approved by the California State Water Resources Control Board, Division of Water Rights. The author has been told that minor appropriated rights can be found throughout Lake County but an exhaustive search for private water rights has not been conducted. The Yolo County Flood Control and Water Conservation District automatically challenges any attempts to appropriate unused water. Yolo County will cite the "first in time-first in right" doctrine and claim a diminished downstream flow in all cases where flows contribute to the Clear Lake-Cache Creek basin. Water in interior basins without outlets, such as Borax and Thurston Lakes, is owned by adjacent landowners and can be sold for use at other locations.

V. Agencies and Regulations Controlling HDR Injection

Several permits or approvals must be obtained before fluids may be injected into an HDR reservoir.

A. California Department of Conservation, Division of Oil and Gas (CDOG)

The CDOG has jurisdiction over the drilling, operation, maintenance, and abandonment of wells for geothermal injection and aquifer recharge where the injected fluids are nonhazardous, oil, gas, or geothermal wastes. These are Class V wells under the EPA's Underground Injection Control Program. California has a Memorandum of Agreement with the EPA for primacy over geothermal wells, including the injection of treatment plant wastewater into a geothermal reservoir. The EPA would be notified and approval granted through the CDOG. The California Regional Water Quality Control Board works with the CDOG in this case to insure water quality. The CDOG is notified before drilling a production or injection well or abandoning a well. Monthly injection reports are required.

B. California Regional Water Quality Control Board (CRWQCB)

The CRWQCB, Central Valley Region, issues Waste Discharge Requirements (WDRs) which control surface discharges. Permits are reviewed to be sure they conform to the California Environmental Quality Act (CEQA).

C. California Department of Health Services

The California Department of Health Services controls injection of toxic or hazardous materials and its approval would be required if wastewater was disposed of by geological injection.

D. County of Lake

Lake County requires a use permit to be reviewed publicly under the CEQA. Public sewage disposal requires a state license in addition to a Lake County Health Department Permit to Operate. The Lake County Sanitation District operates the Southeast Regional Wastewater Treatment Plant being considered as a source for HDR injection fluids and an

agreement must be negotiated. The Lake County Zoning Ordinance requires a use permit for geothermal projects. An operating contract that includes the owners of the land, the well, and the geothermal rights, and Lake County could be required.

E. Landowner and Owner of Geothermal Rights

Agreements with landowners would be necessary for access and for restoration of a drill site and roads. A geothermal lease would also be necessary if rights are held by the landowners. It is conceivable that geothermal rights, ownership of the well, and land surface rights could be held by separate parties, requiring a separate agreement with each.

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Appendix

A History of Yolo Water Rights, by H.C. Porter, Director, Lake County Flood Control and Water Conservation District. Internal memorandum, February 9, 1988.

In 1912, the Yolo Water and Power Company, a corporation, applied to the State to appropriate 300,000 miner's inches of water from Cache Creek. In appropriating this water it was necessary for the Yolo Water and Power Company to show that this water was available for appropriation and that it would be put to beneficial use, which in their case was the irrigation of lands in Yolo County.

The measure of this right to the water in the Clear Lake Basin has now been defined and refined by the following litigation:

(1920) *Gopcevic v. Yolo Water and Power Company*, Mendocino Superior Court. (Yolo Water and Power Company may not draw Clear Lake below zero Rumsey).

(1927) Yolo Water and Power Company was purchased by the Clear Lake Water Company.

(1964) *Clear Lake Water Company v. Highlands Water Company*. (Clear Lake Water Company has right to water above zero and below 7.56 on the Rumsey scale).

(1967) Clear Lake Water Company was purchased by Yolo County Flood Control and Water Conservation District.

(1972) *Yolo County Flood Control and Water Conservation District v. California Consolidated Water Company*, Lake County Superior Court. (Yolo County F.C. and W.C.D. has right to water above zero and below 7.56 on the Rumsey scale).

In effect the water rights from 1912 to the present have been perfected by the 1914 construction of Clear Lake Dam and the network of canals and irrigation structures in Yolo County.

There are approximately 320,000 acre-ft of water between zero and 7.56 ft Rumsey. Average annual precipitation is approximately 120,000 acre-ft, leaving 200,000 acre-ft for Yolo when the lake starts full. The construction of the Indian Valley Reservoir by Yolo County Flood Control and Water Conservation District prompted the following litigation:

(1978) *County of Lake v. Yolo County Flood Control and Water Conservation District*, Solano County Superior Court. (Yolo County Flood Control and Water Conservation District shall operate Clear Lake in accordance with an Operating Criteria established hereby).

This complex operation schedule says, in brief, if Clear Lake fills to 7.56 ft above the Rumsey gage by 1 April, Yolo gets 150,000 acre-ft. If the lake reaches 3.22 ft Rumsey or less, Yolo gets no water, with proportional amounts in between. (This "Solano Decree" provides that more water is left in Clear Lake. When the lake starts full, the October 31 level must be above 1.25 ft Rumsey instead of zero.)

Yolo County Flood Control and Water Conservation District's appropriated water right does not expire and cannot be revoked except for two reasons:

1. Improper exercise of right
2. Nonuse.

In summary, an Appropriative Water Right is based on the "first in time-first in right" doctrine, diligent pursuit, and beneficial use.

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