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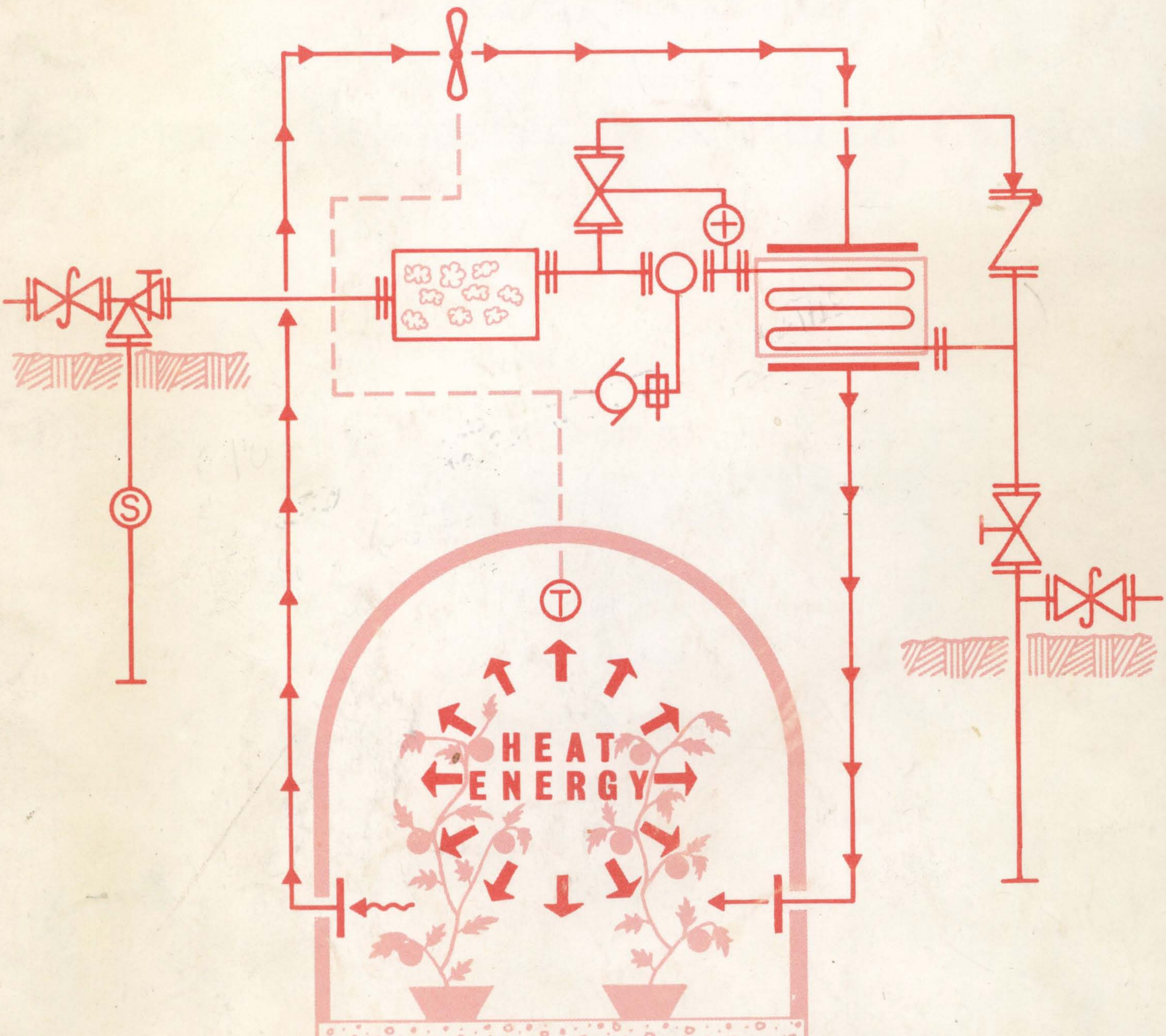

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LOW-TEMPERATURE

Geothermal Resources in Northern California

by
Judith L. Hannah

A Publication of the

CALIFORNIA DIVISION OF OIL & GAS

Sacramento

1975

FOREWORD

The primary purpose of this report is to bring to the attention of the public the existence of a potential, but virtually unused, energy source -- low-temperature geothermal energy. Due to the scant information available on this subject, a general background section covering the present use of geothermal energy is included to demonstrate the existence of a utilization technology.

The field work was done during the summer and early fall of 1973. The hot spring data reflect the conditions present at that time. Although hot springs and well temperatures and flow rates vary during the year, past records indicate the data presented are representative of the normal conditions present at the sampled sites.

The measurement units are in the metric system. A set of simplified metric-English conversion tables is included in Appendix B.

The author extends her gratitude to David N. Anderson of the California Division of Oil and Gas for his guidance and editorial assistance throughout the project. The technical assistance of Glen E. Campbell and Marshall J. Reed, also of the California Division of Oil and Gas, is gratefully acknowledged. She also wishes to extend her gratitude to Norman V. Peterson of the Oregon Department of Geology and Mineral Industries, and to Professors Harry C. Kohl, Jr., and Cordell Durrell of the University of California, Davis, for their information on particular geothermal areas. In addition, she is grateful for the help of many individuals in the areas studied who generously shared their time and knowledge.

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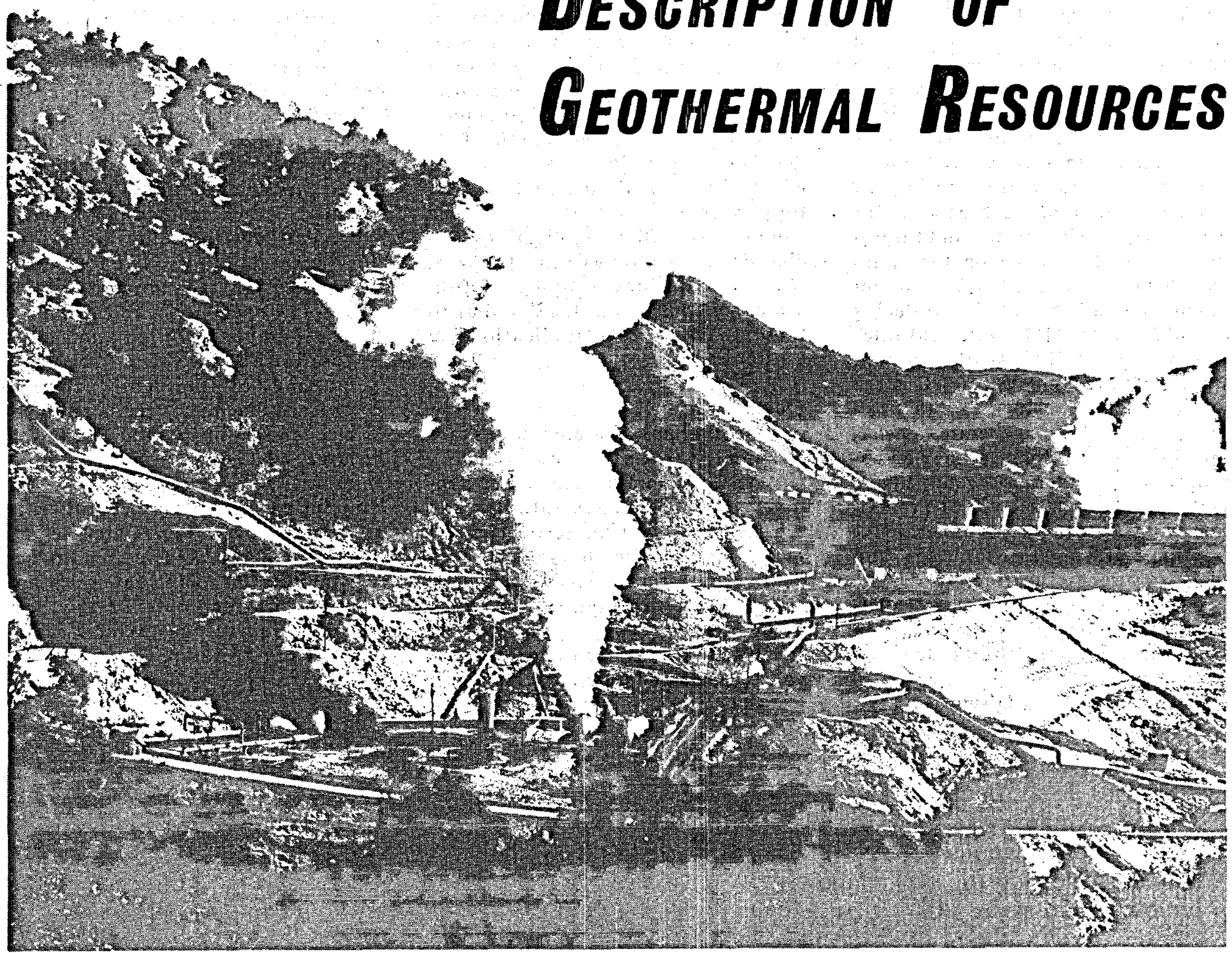
INTRODUCTION

Geothermal resources represent a significant, but little used, energy source. Most emphasis is being placed on the development of high-temperature geothermal resources for the generation of electrical power. With present technology, geothermal fluids below a temperature of 160°C cannot be utilized economically to generate power. The objective of this study is to delineate economically feasible uses for geothermal heat at temperatures too low for conventional electrical power generation at present. In support of this objective, several geothermal resource areas in northern California that have development potential are described, and applications of the heat found in each area are suggested. The field study areas (Plate I) include the east side of the Sierra-Cascade Range north of Bishop, and the northern Coast Range from San Francisco Bay to Clear Lake. The counties included in the study area are Modoc, Lassen, Sierra, Plumas, Placer, Alpine, Mono, Mendocino, Lake and Sonoma.

Assuming a base temperature equal to the mean ambient air temperature, the total power available from the hot water from springs and shallow wells in the project areas is 5.18×10^{15} J/yr. Heating this water in a steam boiler with 80% efficiency would require over one million barrels of crude oil per year -- enough to meet the total energy requirements of a town with a population of 20,000. Drilling additional wells to tap underground hot-water reservoirs can greatly increase the flow of hot water. For example, shallow wells in and near the city of Calistoga now produce 250 times the energy released by the original spring.

Current use of geothermal energy in northern California, other than for power generation, is limited to hot mineral baths, and heating of swimming pools, three small greenhouse operations, and a few private homes, apartments, and hotels. These developments use less than 1% of the total surface flow, and use the hot water very inefficiently. The total economic utilization of low-temperature geothermal areas in northern California is restricted by the following factors: (1) remote geographic locations; (2) all the heat above ambient air temperature cannot be extracted economically; (3) the heat cannot be used with 100% efficiency. However, if 50% of the areas are developed, if flow is increased 100 times by drilling wells, and if the heat is used with 50% efficiency, the energy provided would still be enough to meet the demands of a city with a population of 500,000.

Description of Geothermal Resources



Classification

The earth is a tremendous reservoir of heat, but most of the energy is far too diffuse for economic use. However, about 500 sq km of known hot spring regions have an average heat flow of 4 x 10^{-4}cal/cm^{2}sec, almost 300 times the earth's average (White, 1965). Heat from these areas can be extracted economically.

Hot springs occur where there is a combination of the following:

(1) A heat source--either molten rock in an area of young volcanism, or mantle material where the crust is relatively thin.

(2) A reservoir rock--either permeable or fractured sedimentary rock, volcanic rock, or metamorphic rocks.

(3) Sufficient water or steam to transfer the heat from the rocks to the earth's surface.

The type of practical use for a given geothermal system is dependent upon the enthalpy* of the fluid; therefore, systems are classified according to temperature and phase, such as dry steam or hot water.

A geothermal system includes the reservoir, the contained fluid, the heat source, and the interaction of these essential units. There are two major types of geothermal systems: (1) vapor dominated or "dry steam," and (2) hot water (White and others, 1971). Hot-water geothermal systems are further divided into two temperature ranges: (1) those above 160°C (capable of being used to produce electrical power), and (2) those from 50 to 160°C (discussed in this report). Heat can seldom be extracted economically from water below 50°C.

Vapor dominated systems are relatively rare; the only known systems of this type occur at Larderello, Italy; Matsukawa, Japan; and The Geysers, California (White, 1973). Dry steam is ideal for electrical generation and has been developed mainly for that purpose.

Hot-water geothermal systems above 160°C are economical for power production with present technology. Pressure from confinement by an impermeable cap rock allows the temperature in deep hot-water reservoirs to exceed the surface boiling point. When the fluid flows to the surface through a well bore, the hydrostatic pressure is reduced, and a certain percentage of the fluid flashes to steam. The steam is separated and used to turn a turbine which turns a generator to produce electrical energy. Several plants of this type are in operation, including one at Wairakei, New Zealand (reservoir temperature of

*Enthalpy is the amount of energy in a given mass. Units may be J/kg, Btu/lb, etc.

270°C) producing 160 MW,* and one at Cerro Prieto, Mexico (reservoir temperature above 300°C) producing 75 MW (Koenig, 1973).

If the thermal water is not hot enough to produce enough steam to be used directly, or if surface and atmospheric pollution is a definite problem, a binary-cycle system may be practical. In this type of system the heat is transferred to a low boiling point fluid, such as freon or isobutane, which expands and turns a turbine. At Paratunka on the Kamchatka Penninsula, U.S.S.R., a freon-based generating unit is producing 0.7 MW using 81°C water (Muffler and White, 1972). At the present stage of the technology, 160°C is the lowest practical temperature that can be used to generate power. Multiple-use development may be appropriate for thermal water above 160°C, combining electrical production with desalination, mineral extraction, greenhouse farming, and space or process heating.

Geothermal fluids below 160°C have tremendous potential for use in space heating, agricultural development, product processing, refrigeration, air conditioning, and drying. Iceland has shown how significant the development of geothermal energy can be to a small nation deficient in conventional energy-producing natural resources. Geothermal energy provides domestic heat for almost half of its 200,000 population, and heat for greenhouses which supply most of the fresh vegetables for Reykjavik, the capital city. Other applications, including production of salt, drying of seaweed, and freeze-drying of fish, are being considered. Uses similar to these have great application in California.

*1 MW (megawatt) = 1,000 kW (kilowatts)

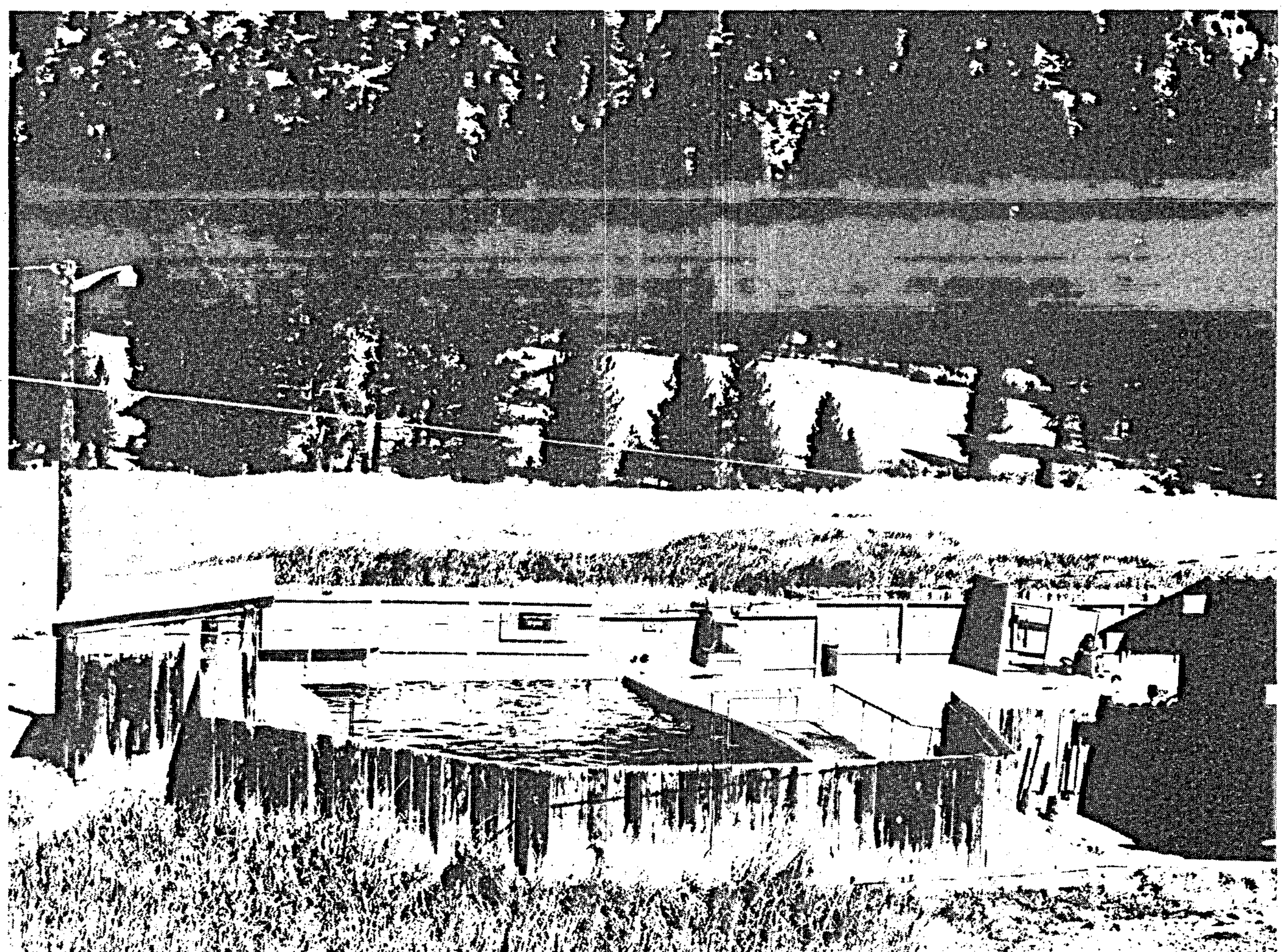
Occurrence

Geothermal resource areas are commonly associated with rift zones or young mountain belts along tectonic plate boundaries (Muffler and White, 1972). Characteristics of plate margins include high conductive heat flow, recent volcanism, high seismic activity, and in some cases, shallow depths to the mantle. In California, areas of recent volcanism include the northern Coast Range between Napa and Clear Lake, the Modoc Plateau, the east side of the Sierra Nevada, and the Imperial Valley. These localities contain most of California's potential geothermal areas.

Frequent microearthquakes and nearly continuous high-amplitude seismic tremors (geothermal ground noise) have been observed near many geothermal areas. Ward (1972) documents the relationship between seismicity and geothermal activity and points out the following:

> "Active faulting is one important way of forming and keeping open permeable channels suitable for circulation of geothermal fluids. Active faulting of the chill zone around magma is a possible mechanism for maintaining the large heat fluxes observed in geothermal areas."

Hot springs in northern California are almost invariably related to active faults. Fractures related to active faulting in competent rocks apparently provide most of the permeability for the geothermal reservoirs in the northern Coast Range.



ADVANTAGES AND DISADVANTAGES

Cost Savings

Comparison of costs of different energy sources show geothermal energy to be less expensive in almost every case (Koenig, 1973). Generation of electricity from a plant at The Geysers Geothermal field, California, costs 5 mills/kWhr* (including plant costs), 2 mills/kWhr less than other fuels. The heating and air-conditioning system in a hotel in Rotorua, New Zealand, costs $0.12 per Gcal** using geothermal power, compared to $2.40 per Gcal for a similar system using fuel oil. The Reykjavik Municipal District Heating Service in Iceland provides geothermal heating for the equivalent of $4.00 per Gcal, rather than the average of $6.70 per Gcal for other fuels. Heating costs at Oregon Technical Institute in Klamath Falls were cut from $94,000 to $18,000 per year by changing to geothermal energy.

When the enthalpy of geothermal water is not sufficient, the available heat can still reduce energy costs significantly. A lumber mill in Susanville, California, is currently pumping 2,300 l/min of water at 25°C to provide steam for electrical generators, steam-driven drying kilns, and log handling equipment. But nearby wells produce water at 50°C that could be used to produce steam at a 4% savings in fuel energy. This seemingly small savings in fuel energy would represent a savings of $6,700 per year in energy costs. A dairy in Klamath Falls, Oregon, has reduced energy expenditures for pasteurization 13% by using geothermal water at 99°C (5°C above boiling at that altitude) instead of using municipal water at 20°C. In addition, the geothermal water is used for space heating in the dairy and for cleaning equipment without additional energy input.

Environmental Advantages

Geothermal power has fewer adverse effects on the environment than other power sources. There is no associated mining, refining, or storage as in the utilization of other energy sources. Wellheads and pipelines occupy small areas, allowing the remaining land to be used for other purposes. Water pollution hazards due to high mineral concentrations in geothermal fluids may be overcome by the use of closed systems with produced fluids reinjected after the heat has been withdrawn.

Limitations

Although geothermal energy is cleaner and less expensive than other energy sources, it does have

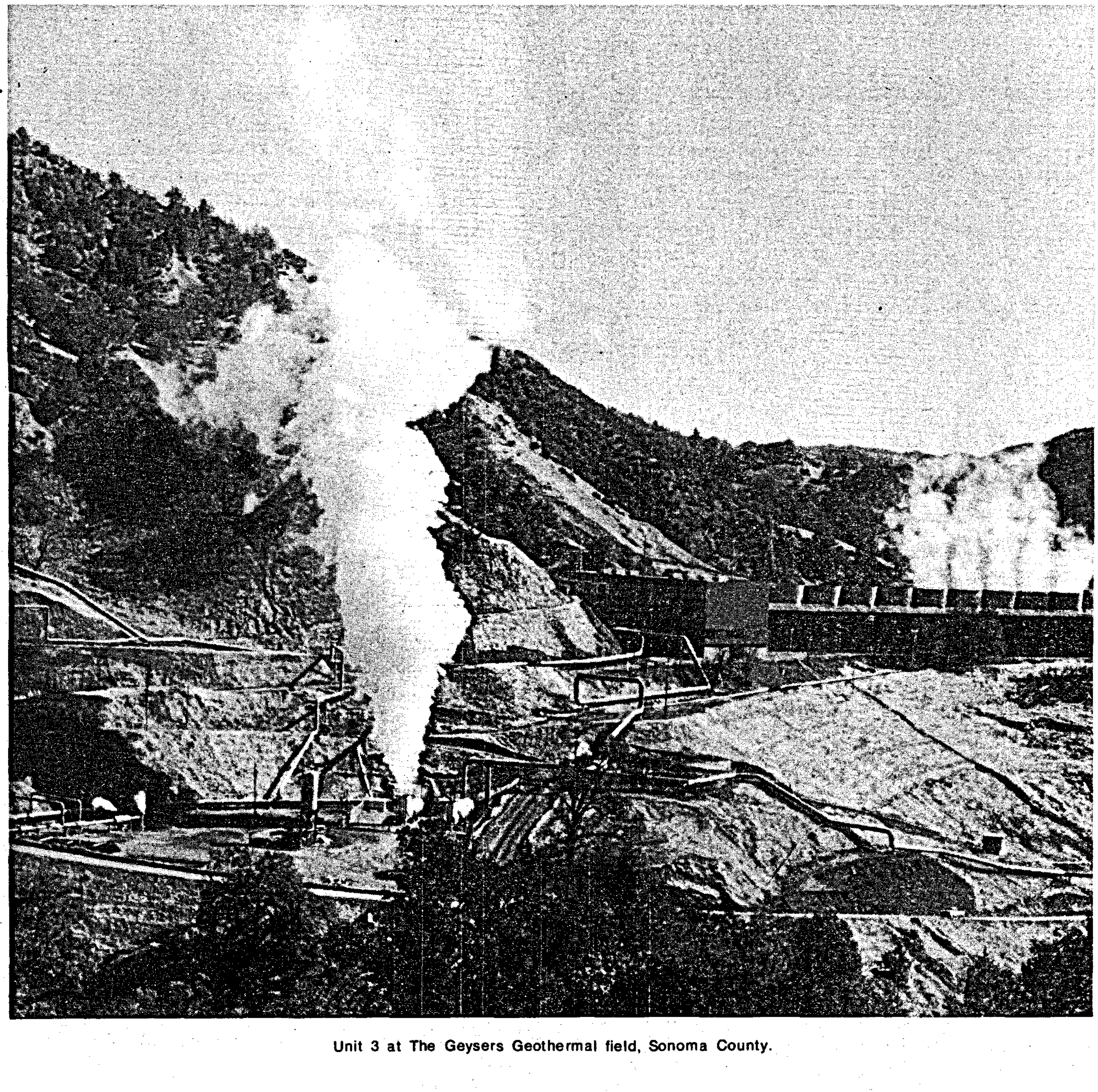
*1 mill = 0.1 cent

**See miscellaneous equivalents in Appendix B.

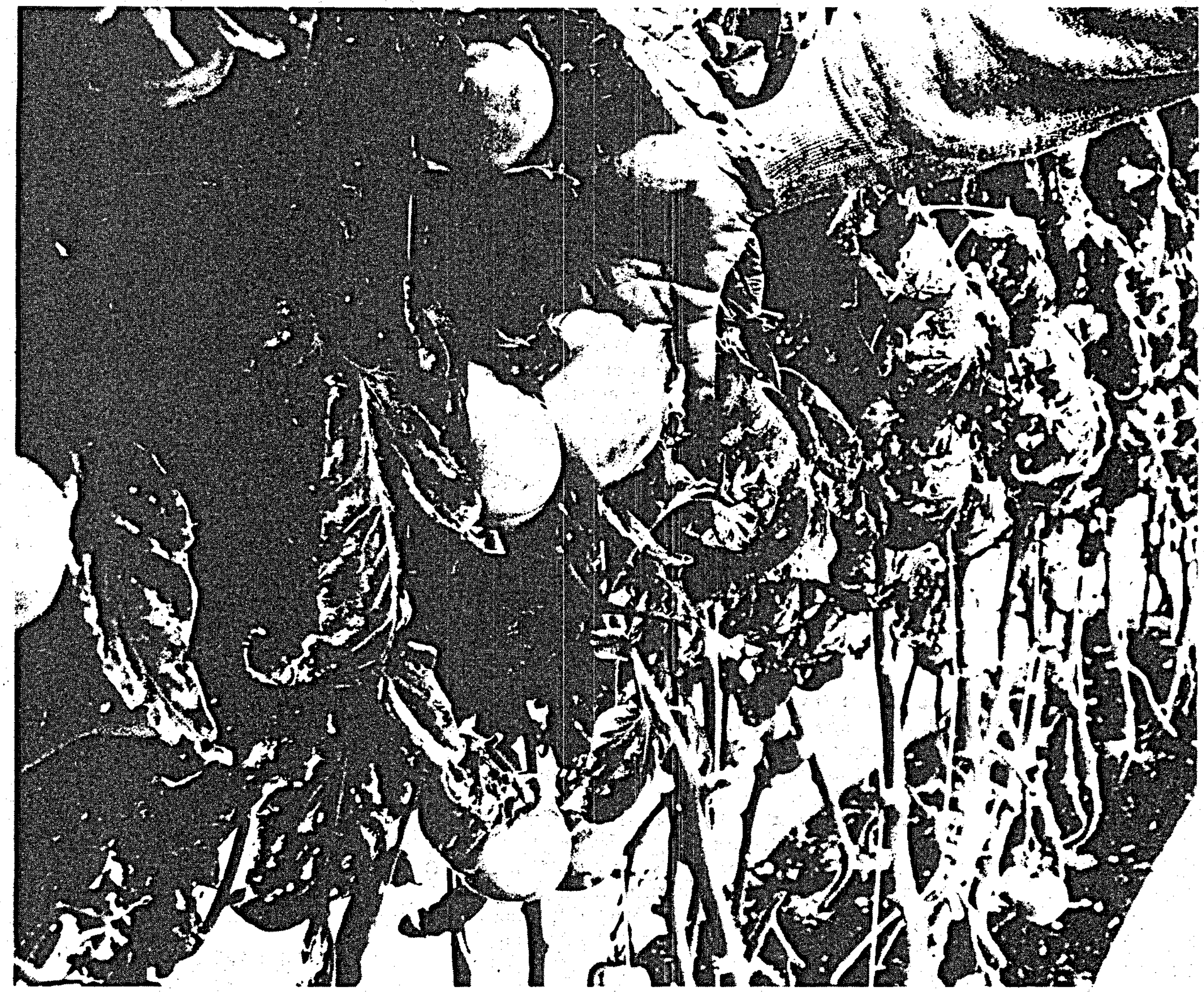
limitations. Geothermal fluids cannot be transported long distances because the heat dissipates rapidly. In Reykjavik, Iceland, hot water for space heating is moved at distances up to 18 km in 353 cm diameter steel pipelines encased in concrete. The water temperature drops about 5°C during transport and is delivered at 80°C to the users. Greater distances, with corresponding greater heat loss, may prove uneconomical. Where temperatures are above 160°C, the energy is converted into electricity which can be transported over great distances without temperature loss; however, the thermal efficiency of geothermoelectric generating plants is low. For example, in units 3 and 4 at the Geysers, only 14.3% of the energy supplied to the generators is converted to electricity (Bruce, 1971). This compares with 34.5% for the average fossil fuel fired plant.

Because geothermal resources must be utilized on site, developments cannot always be near large labor forces, near convenient transportation systems for raw materials or processed goods, or near major markets.

Problems also arise from the generally high mineral content of geothermal fluids. Corrosion and scaling in pipe have slowed development in some areas, particularly in the Imperial Valley, California, where salts in one area compose more than 25% by weight of the geothermal fluids. High concentrations of toxic constituents present serious waste disposal problems if reinjection is not feasible. For example, at the Sulfur Bank Mine near Clear Lake, California, boron concentrations in thermal waters exceed 100 ppm (parts per million by weight). Boron in concentrations above 2 ppm is harmful to some plants. These difficulties increase costs, thus restricting utilization of geothermal resources.



Unit 3 at The Geysers Geothermal field, Sonoma County.



Potential Uses for Geothermal Resources Below 160°C (320°F)

Bathing

Throughout history, the most common use of natural hot water has been for bathing. Many persons extolled the therapeutic value of the mineralized thermal water, and spas grew up around hot springs. Although bathing is still popular in a few other countries, notably Japan and Hungary, the hot spring resorts of California are declining in popularity. Resorts sprang up around hot springs throughout California in the early 1900's, particularly in the mountains between Clear Lake and the Napa and Sonoma Valleys. Today, only in Calistoga are spas economically maintained for hot spring enthusiasts. A few of the old hotels in this area are still operated for hot springs users; some have been converted to summer camps or communes. Today's private resorts within the area covered by this report are limited to the hotels in Calistoga, the Hot Springs Hotel near Cedarville in Surprise Valley, and McLear's Resort near Clio in Mohawk Valley (Appendix A). Only two springs are open to the general public: Grover Hot Springs near Markleeville, now a state park; and Hot Creek near Mammoth Lakes, maintained by the U.S. Forest Service.

Space Heating

General space heating is the most versatile use for the heat from natural hot water. Unlike the more exotic uses, steam or high-temperature water is not required, nor is the technology complicated. In Olafsjordur, Iceland, water at only 48 to 56°C is being used for space heating by circulating it through very large radiators (Einarsson, 1970). Geothermal energy is being used extensively for space heatng in Reykjavik and other towns in Iceland, Rotarua, New Zealand, Boise, Idaho, Klamath Falls, Oregon, and various towns in Hungary and in the U.S.S.R. In several areas, hot water is piped under sidewalks or driveways to melt snow and ice. The use of space heating for agriculture will be discussed later in this report.

The practicality of geothermal energy for space heating has been best demonstrated in Iceland. About half of the 200,000 population uses geothermal energy for heating. The Reykjavik Municipal District Heating Service (R.M.D.H.S.) supplies geothermal water to 9 out of 10 homes in Reykjavik. The R.M.D.H.S. pipes the hot water from the Reykir and Reykjavik geothermal fields at distances up to 18 km to a çontrol distribution system in the city. Much of the water is distributed by a single pipe system which does not allow recirculation, and excess heat is wasted. A new section of the system is constructed with double pipelines in which return water is mixed with the 119°C water from Reykjavik field to reduce it to the 80°C distribution temperature. Costs are estimated at \$4.00 per Gcal, considerably less than the \$6.70 Gcal for imported oil. Use of the geothermal energy saves the import of 190,000 metric tons (1,273,000 bbl) of fuel oil each year. Details of the heating system are given in Table 1. A complete description of Iceland's geothermal developments was given by Palmason and Zöega (1970).

Municipal heating systems have also been established for several towns in Hungary (Boldizsar, 1970). An average geothermal well producing 1,300 to 1,500 l/min of water at 85 to 95°C can supply 1,200 flats (generally four rooms, including a kitchen and a bath). The system provides not only domestic hot water and space heat for flats, but also for associated municipal buildings, pools, and schools. With auxiliary oil and gas heating units to meet peak demands (during about two weeks each year), an average well can heat 1,800 flats. The cost for the geothermal energy is about \$3.00 per Gcal as opposed to \$11.00 per Gcal for coal.

In Klamath Falls, Oregon, geothermal water from 350 wells

TABLE 1
System Data for Reykjavik District Heating System (compiled from data by Zöega and Kristinsson 1970)*

1.	**CLIMATIC DATA**	
1.1	Mean temperature for the year	+ 5°C
1.2	Mean temperature for the warmest month (July)	+ 11.2°C
1.3	Mean temperature for the coldest month (Jan.)	- 0.4°C
2.	**AVAILABLE HEAT RESOURCES (Dec. 1969)**	
2.1	Reykir geothermal area 1,000 m^3/hr at 80°C	40 Gcal/hr
2.2	Reykajavik geothermal area 1,700 m^3/hr at 119°C	135 Gcal/hr
2.3	Own peak power boiler plants (oil fired)	30 Gcal/hr
2.4	National Power Co. peak power boiler plant (available at electrical off-peak hours only)	20 Gcal/hr
		Total 225 Gcal/hr
3.	**HEAT LOAD**	
3.1	Volume of houses connected	10.3×10^6 m^3
3.2	Number of houses connected	8,700
3.3	Heat load at - 10°C outside and + 20°C inside	190 Gcal/hr
3.4	Specific load at - 10°C outside and + 20°C inside	19 kcal/hr m^3
4.	**SYSTEM DATA**	
4.1	Installed horsepower in pumping plants	5,115 hp = 3.800 kW
4.2	Area served by distribution system	11.2 km^2
4.3	Length of pipe lines	
	4.31 collecting mains	14.2 km
	4.32 supply mains	29.1 km
	4.33 street mains	125.2 km
	4.34 house connections	120.2 km
4.4	Average density of population	643 inhabitants/km^2
4.5	Average load density	17 Gcal/hr km^2
5.	**YEARLY HEAT PRODUCTION**	
5.1	Geothermal energy (1968)	960 Tcal/yr
5.2	Peak power stations (1968)	60 Tcal/yr
NOTE:	See Appendix B for equivalents	Total 1,040 Tcal/yr

* From Einarsson, 1970

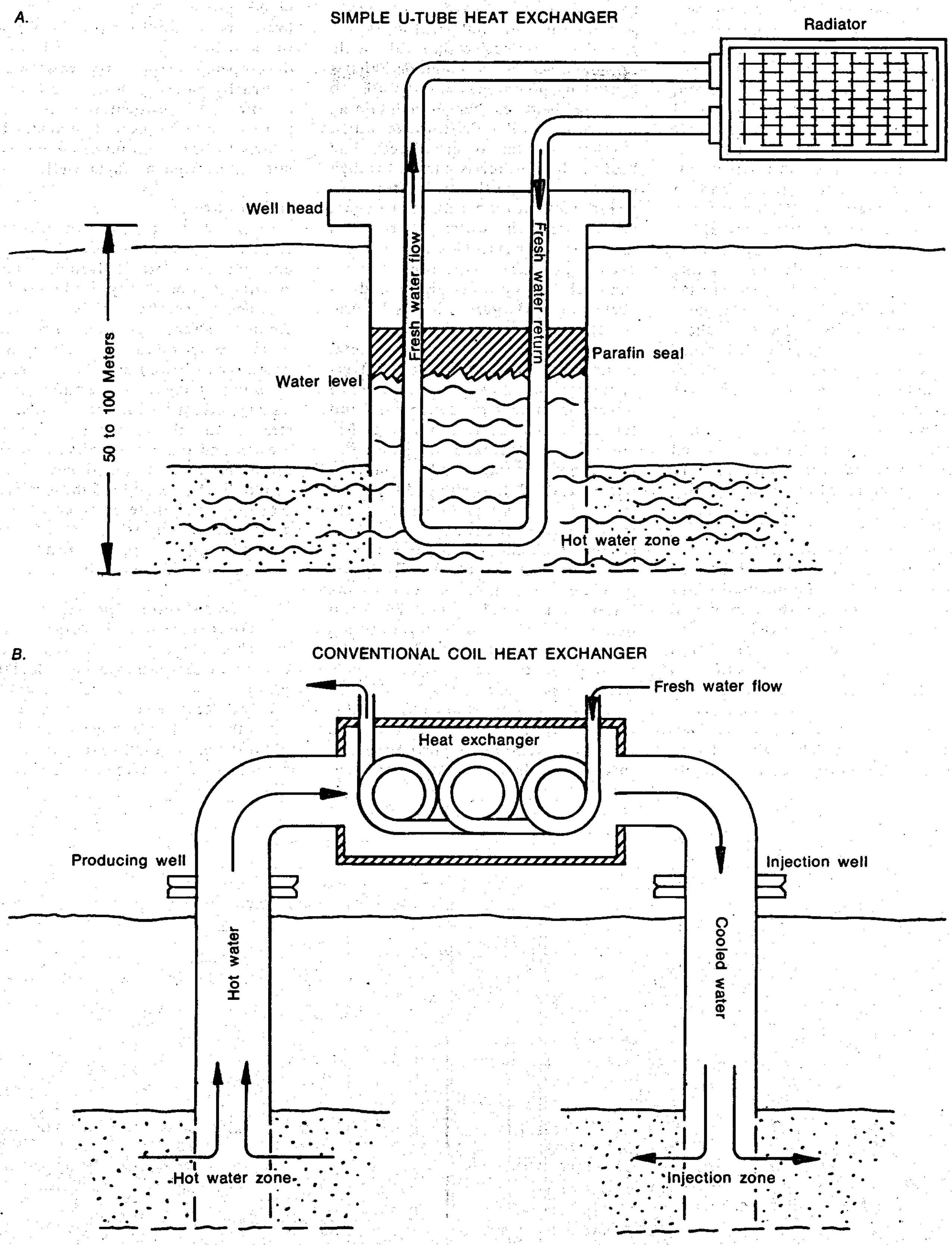


Figure 1
Typical heat exchange systems in use in Klamath Falls, Oregon

ranging from 60 to 114°C is being used to heat at least 450 homes, several apartments, commercial establishments, and schools, including the Oregon Institute of Technology (Peterson and Groh, 1967). Natural hot water circulated through underground pipe systems also melts ice and snow from a number of private walks and driveways, gas station pump areas, and a railroad underpass. Unfortunately, development has been piecemeal, so that each well generally supplies only one building. City-wide systems like those in Iceland and Hungary are far more economical. In spite of its inefficient use in Klamath Falls, geothermal energy is competitive with other sources of heat, and may become increasingly attractive as oil and gas prices rise.

To avoid problems of scaling, corrosion, or waste disposal, closed water circulation systems are generally employed in Klamath Falls. In most cases, wells are drilled to depths of 70 to 120 m and a simple U-pipe is lowered into the casing, extending to near the bottom of the well (Figure 1(A)). Clean municipal water is circulated through the closed coil and radiator system. Heat is received by water in the coil and transferred to the air as the water passes through the radiators. Corrosion can still be a problem at the air-water interface in the well. Because of this, it is common practice in Klamath Falls to float paraffin on the water surface to separate it from the air. The heat of the thermal water prevents solidification of the paraffin, which provides an effective, movable seal.

Each school in Klamath Falls is heated by pumping thermal water to a large heat exchanger containing numerous small coils through which municipal water is circulated. The heated clean water is passed through radiators and the thermal water is injected back into the ground through a second well; the water never leaves the closed system. This type of heat exchange system is more efficient than the simple U-pipe, and is preferred for larger buildings (Figure 1 (B)).

At Oregon Technical Institute, natural hot water heats 968,213 m^2 of floor area, and supplies all the hot water for student residence halls and the physical education building. The hot water is obtained from a well 523 m deep, pumping 1,325 l/min of water at 89°C. It is pumped to a central radiator and fan system. Waste fresh-water at about 50°C is run to a cooling pond and eventually is flowed into Upper Klamath Lake. Corrosion problems are minimal because the water is relatively pure. To avoid depletion of the reservoir, reinjection is being considered. Geothermal heating of the campus costs only $18,000 per year.

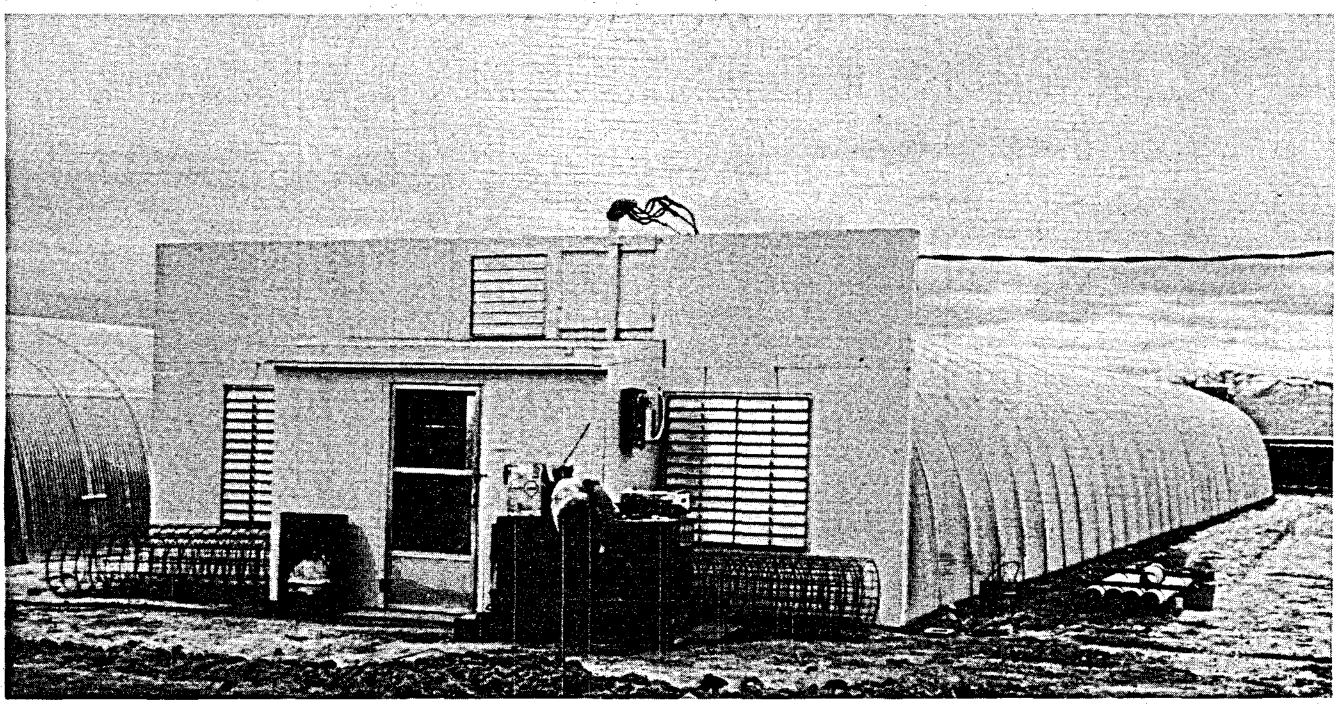
Because natural hot water at any temperature above 50°C can be used for space heating, opportunities for this type of development are tremendous. Surface thermal water can be piped into nearby buildings for very low costs. An additional loop of pipes in another type of geothermal development could carry waste water to nearby buildings for space heating at low cost. Residential heating expenses can be reduced by cooperative efforts to heat a group of homes with hot water from a single well.

Agriculture

Artificial heating can increase yield in a variety of agricultural endeavors. Controlled-environment greenhouse operations can be used to produce specialty crops, increase yields, decrease growing time, and permit year-round production. Soil heating can increase yields, decrease growing time, or reduce frost damage. Heating in cattle stalls, pig sties, and chicken houses speeds growth and increases weight gain per given amount of food. Aquaculture is economically feasible if the heat can be supplied at little or no cost. Thus, geothermal heating may have widespread applications in agriculture and aquaculture.

Greenhouse Operations

Geothermal heating for greenhouse operations has been successful in several locations. Iceland produces most of the fresh vegetables for the Reykjavik market in about 100,000 m^2 of greenhouses heated by natural hot water. In Hungary, large greenhouses are heated with thermal

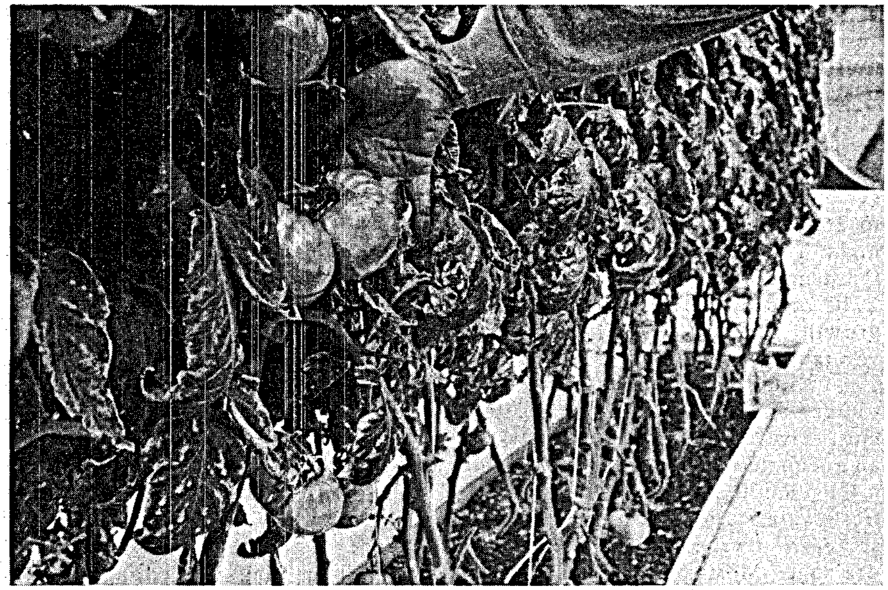


Quonset hut-type greenhouse, Hobo Wells, Inc., Wendel Hot Springs, Lassen County.

water. Geothermal greenhouse operations in Japan produce melons and flowers for cutting. The Agri-Technology Corporation of Reno, Nevada, is developing 20 acres at Wabuska, Nevada, 12 miles north of Yerrington, for hydroponic greenhouses. Three artesian geothermal wells at 97°C supply heat for the operation.

Within the study area shown on Plate VI, Hobo Wells Hydroponics, Inc. is the only commercial greenhouse development. The company built two greenhouses in the semiarid Honey Lake Basin, 40 km east of Susanville, Lassen County, at an elevation of about 1,220 m. The technique called hydroponics is used to grow tomato plants without the use of soil. The roots of the plants are held in sterile gravel and periodically flooded with a nutrient solution. As tomato plants will not tolerate the highly alkaline soil near Wendel Hot Springs, hydroponics is an attractive alternative.

Both greenhouses are of the Quonset hut type and are covered with translucent fiberglass. Each encloses an area of 8 by 43 m and costs about $14,000 to construct. In each house, about 1,200 tomato plants are grown in 5 gravel beds separated by concrete walkways. The first crop, grown during the exceptionally cold winter and spring of 1973, averaged 5.9 kg per plant for a total of 7,020 kg. These were sold in Susanville for $.93 per kg, or $6,500. The high yield far surpassed expectations and an average crop of 6,000 to 7,000 kg may be more realistic. However, the second crop, just maturing at the time of this writing, promises to be as successful as the first. The rapid growth rate allows two crops per year, assuring an annual gross sales of at least $20,000 per greenhouse. The second greenhouse was completed during the summer of 1973, and was producing tomatoes by November of that year. As of December 1973, construction had been started on four additional greenhouses.



Tomatoes grown with geothermal energy. Hobo Wells, Inc., Wendel Hot Springs, Lassen County.

The geothermal heating system at Wendel Hot Springs eliminates gas or oil heating costs that would average $6 per week per greenhouse. The key to the operation is Wendel Hot Spring, discharging 1,200 l/min of water at 96°C. The greenhouse heating system involves pumping water at 90.5°C from the outflow channel about 100 m downstream from the main spring into a 38,000-liter holding tank. The water flows from the tank through a 4-cm diameter galvanized pipe to a radiator at one end of the greenhouse. The air blown across the radiator passes into a 50-cm diameter clear plastic tube running the length of the building. The tube is perforated with a series of 5-cm diameter holes along its entire length to distribute the heated air evenly. The thermal water drains from the radiator and flows through several 2-cm diameter plastic pipes embedded in the concrete walks between the gravel beds, thus providing extra radiant heat. The warm water leaving the greenhouse either flows into a 19,000-liter nutrient tank or is disposed of in the hot spring's outlfow stream. The specially treated water in the nutrient tank is used to flood the gravel several times a day, providing both nutrients and water for the plants. The high boron concentration of the thermal water (5.3 ppm) has not been detrimental to the first two crops. The nutrient solution is changed weekly, and the excess is used to irrigate a small area near the greenhouse. The treated water has partially overcome the high alkalinity of the soil.

Tomato plants and concrete walkway inside greenhouse operated by Hobo Wells, Inc., Wendel Hot Springs, Lassen County.

To overcome the summer heat, each greenhouse is equipped with an evaporating pad at one end and two fans at the other. Water trickles over the pad and the fans draw air through it to cool the greenhouse. The geothermal heat and the cooling system maintain temperatures of 24 to 26°C during the day and 18°C at night. To avoid damage to the plants, the temperature must never exceed 27°C or drop below 10°C. Optimum growth temperatures for several vegetables are shown in Figure 2.

In addition to a dependable heat source, a good greenhouse location must have access to a good market, an adequate labor supply (1 man/650 m^2 or 6,000 ft^2), a good supply of fresh water, a high incidence of sunshine, a level site and good air drainage. Most plants with a high yield per square meter and high market value are suitable for geothermal greenhouses. Recommended crops include salad vegetables, cut flowers, bedding plants, potted plants, and seedling conifers.

Geothermal heat application to the cut flower business is particularly attractive because the large wholesale market for cut flowers simplifies marketing of the greenhouse product. However, a minimum of about 10,000 m^2 of greenhouse area is required to compete in the cut flower market. If the flowers must be transported long distances, much larger areas may be necessary for an economical operation. For example, Calistoga, 120 km north of San Francisco, should be an excellent location for a geothermal greenhouse operation producing cut flowers. In contrast, Surprise Valley meets all of the physical needs for greenhouses, but it is 400 km from Reno, the nearest sizable market and shipping center. Thus, transportation costs would require up to 1,500 m^2 of greenhouses, and the time required for transport might prohibit raising of fragile varieties.

The raising of seedling conifers has high potential for geothermal greenhouse operations. The California State Division of Forestry currently operates three large nurseries that produce 5 million seedlings annually. Recent production has fallen short of demand by as much as 50%. A pilot gas heated greenhouse in Davis, California, operated by the Division of Forestry, covers 360 m^2 and is currently producing 300,000 seedlings per year. A greenhouse of this size, complete with a geothermal heating system (excluding the cost of a well), costs about $20,000. The trees sell for $30 per 1,000, or about $9,000 per year per greenhouse.

The main advantage of controlling the environment in a greenhouse is the considerable reduction in growing time: Nursery seedlings normally require one to two years to mature, whereas the greenhouse crops mature in about six months (oral communication, Brian Bennett, California State Division of Forestry). Reduced growing time eliminates the need for long range estimates of demand and therefore reduces waste. A major market for seedling conifers arises from reforestation of logged or burned areas. Several geothermal areas--in particular Calistoga and Susanville--are located near heavily cut forest areas. Heating costs for seedling conifer greenhouse operations could be reduced by locating such operations in these areas.

Greenhouse plants must have a high survival rate to offset large investment and operating costs.

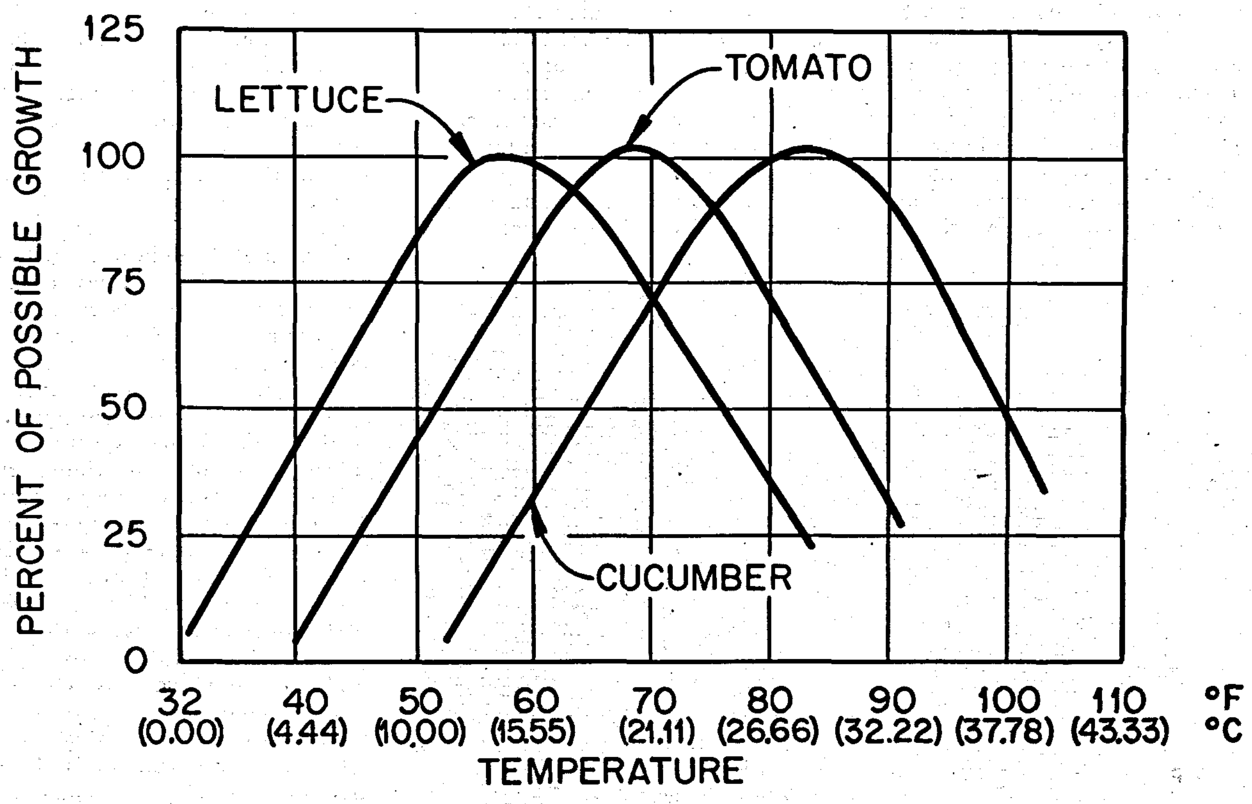


FIGURE 2
Beall (1973)
IDEALIZED GROWTH CURVES FOR SEVERAL CROPS
(Ontario Department of Agriculture And Food - Publication 526)

Sterilization of the soil or hydroponic medium by geothermal steam treatment reduces the threat of disease. The steam is needed only for short periods between plantings (for cut flowers, every 10 to 14 weeks), and for large operations a small steam supply could meet all needs on a rotating basis.

Water Quality Criteria

In many geothermal areas, sufficient fresh water for agricultural uses is not readily available. Generally, the suitability of the thermal water for irrigation can be estimated from four criteria: electrical conductivity, boron concentration, chloride concentration, and percent sodium (Table 2).

TABLE 2
Water Quality Criteria

Factor	Excellent to Good	Good to Injurious	Injurious to Unsatisfactory
Electrical conductivity at 25°C µmho/cm	<1,000	1,000-3,000	> 3,000
Boron (B), ppm	<0.5	0.5-2.0	> 2.0
Chloride (Cl), ppm	<175	175-350	> 350
Percent sodium of total cations	<60	60-75	> 75

Another useful check on water quality is the sodium adsorption ratio (SAR). The SAR is a comparison of sodium (Na), Calcium (Ca), and Magnesium (Mg) concentrations given in equivalents per million (milliequivalents per liter). Equivalents per million (EPM) can be derived from concentrations in parts per million (PPM):

$$EPM = \text{Atomic Weight}/(PPM)(\text{Valence})$$

The sodium adsorption ratio is given by:

$$SAR = Na^{+}/\sqrt{(Ca^{++} + Mg^{++})/2}$$

Water with a SAR value less than 10, electrical conductivity less than 750 micromhos, and less than 2 ppm boron, is considered safe for most purposes.

Soil Heating

Soil heating is a secondary use of thermal water in agriculture. Initial costs are high because of the large amounts of pipe required and the labor costs for installation. An inexpensive heat source reduces operating costs, possibly offsetting the high capital investment. The greatest advantages of increased soil temperatures are a longer growing season and increased growth rate. Plants may be able to withstand fall and winter air temperatures, but the cold soil slows growth. The combination of increased growth rate and a longer growing season may allow the planting of an additional crop each year, or may increase yields from perennial plants.

For low-growing plants, heat rising from the soil may be sufficient to prevent freezing, again, lengthening the growing season. Soil heating is most economical in cool climates where small temperature increases can have a significant effect. Low-growing, high-return crops, such as onions, strawberries, cucumbers, or melons, are best suited for soil-heating.

Animal Husbandry

Heat from geothermal water has been used effectively to increase winter production in a variety of commercial animals.

Figure 3 shows the relationship between growth rate and temperatures. For example, in Taupo, New Zealand, water and steam at a pressure of 2 bars is employed in a multiple-use system (Boldizsar, 1970). A steam cooker treats garbage from several hotels and restaurants, which is used for pig feed. The floors of the piggery are held at 30°C. The hot water is also used for cleaning the animal houses. Manure and butchering wastes are processed in a steam-heated tank and used as fertilizer in a heated greenhouse.

The Yoshizawa Poultry Yard in Minami-Izu-Machi, Japan, uses 100 l/min of geothermal water at 125°C to heat four chicken houses with a total floor area of 528 m² (Komagata and others, 1970). The water is pumped through 1,456 m of 50.8 mm diameter steel pipe embedded in the floors of the chicken houses, and is discharged at 85 to 87°C. The floors are maintained at 12 to 18°C by controlling the flow through the pipes. Throughout the year, the chickens produce about 2.5 kg of meat for 3 kg of feed, compared with a normal winter production of 1 kg of meat for 3 kg of feed. In addition, the heated floors dry the droppings, preparing them for sale as fertilizer and reducing odor and sanitation problems. About 40,000 chickens are raised annually. Geothermal heating of chicken houses may also increase egg laying in winter months, and could certainly be used for incubating eggs.

The experience of ranchers in Surprise Valley indicates that warm drinking water for stock increases production during the winter. The water intake for cattle during cold weather is greatly reduced. With a lower water intake, the cattle naturally consume and utilize less feed. Furthermore, very cold drinking water tends to inhibit metabolic processes. Thus, winter weight gain is minimal for stock raised in a cold climate. Natural warm water as used for stock watering in Surprise Valley has increased winter weight gain. In addition, the ranchers are spared the chore of breaking ice in the watering troughs.

Multiple-use agricultural operations such as those in New Zealand could be developed in northern California. Again, the remote locations of most geothermal areas call for large, efficient developments to offset transportation costs.

Aquaculture

Aquaculture, the cultivation of plants and animals in water, is another possible application of geothermal energy. Aquaculture today is most commonly considered for raising shrimp, oysters, channel catfish, and other warm-water fish and shellfish. Geothermal heat has been used successfully in Japan for breeding alligators for zoos, and eels and carp for food. An aquaculture development on Long Island Sound, New York, uses warm waste water from a power plant for raising oysters.

Aquaculture requires large amounts of water, and to be economical, the heat source must be very inexpensive. In northern California, geothermal resources are inland

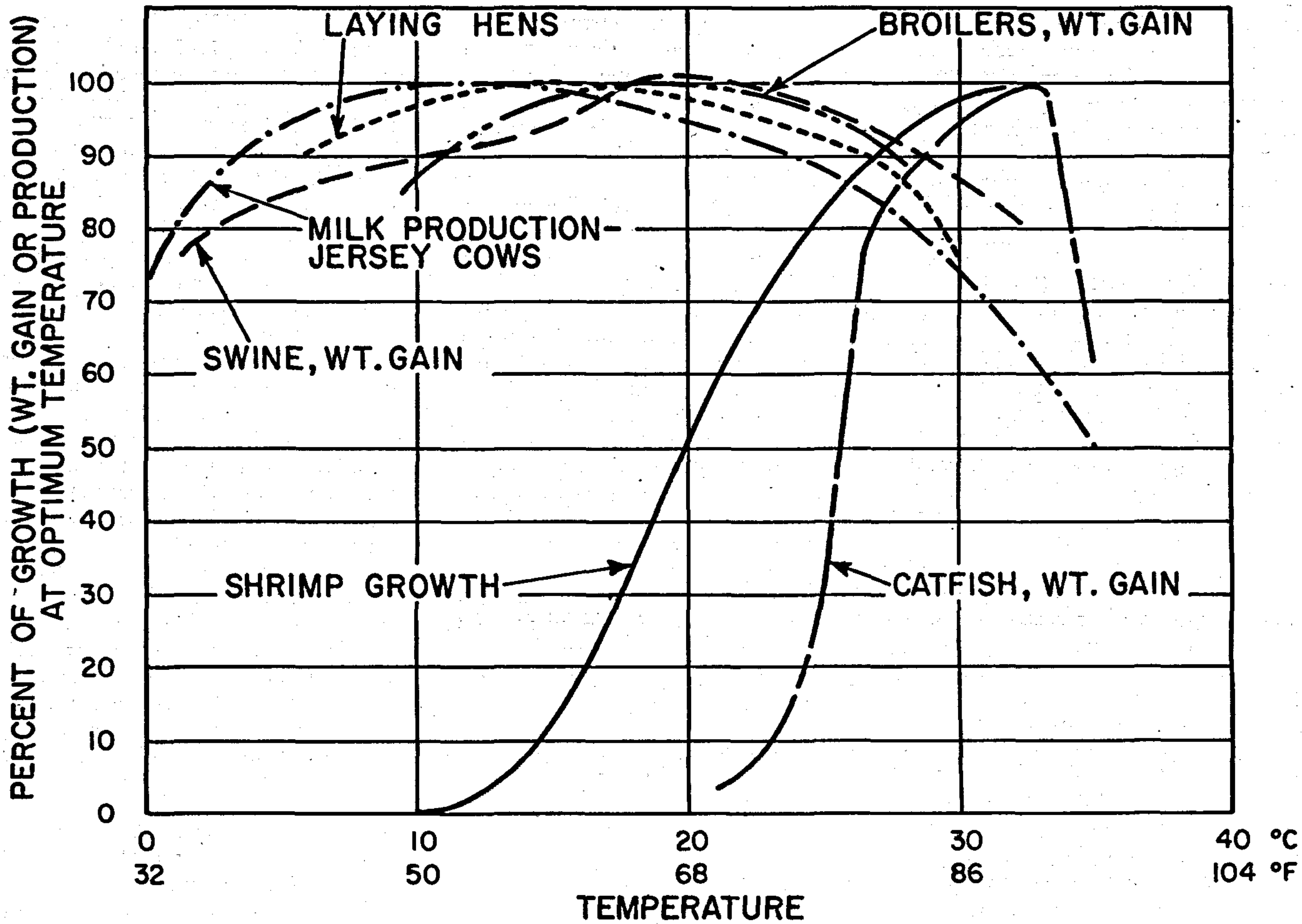


FIGURE 3
Beall (1973)
The effects of temperature on growth rates.

in semiarid areas. Thus, neither ocean water nor large amounts of fresh water are available.

Aquaculture would be most feasible where the salinity of the geothermal water is suitable for the fish. Because heating costs must be low for economical operation, the best sources would be water from a flowing hot spring, excess water from a geothermal well drilled for other purposes, or warm waste water from another geothermal development. Commercial geothermal aquaculture operations have not been attempted in California; however, the outflow from the artesian wells at the Hot Springs Hotel near Cedarville, Modoc County, has been stocked successfully with bluegill and catfish.

Refrigeration

Geothermal steam is used for air-conditioning as well as space heating, and for domestic hot water at the Rotorua International Hotel, New Zealand. A central cooling unit chills fresh water which is then circulated throughout the building for air conditioning. The cooling unit consists of two separate water circulation systems: (1) the cooling water pumped throughout the building, and (2) the heated water which effects cooling by vaporization. The cooling water is pumped through closed coils within a chamber held at a partial vacuum. The heated water is introduced into the chamber and expands rapidly, extracting heat from the coils as it evaporates. Circulation of the heated water is controlled by an absorbent lithium bromide, which has a strong affinity for water vapor. The water vapor is absorbed by the lithium bromide at moderate temperatures in the vacuum chamber. When heated (by geothermal steam), the water vapor is released by the lithium bromide solution. The water vapor is then condensed and returned to the vacuum chamber.

Modern gas refrigerators and freezers, and large industrial cooling or refrigerating units often operate on similar water and lithium bromide cycles. Geothermal steam can be substituted easily for natural gas, and variation in design specifications would allow use of natural hot water as a heat source.

Drying and Other Industrial Uses

Geothermal heat has great potential for any processing operation requiring drying. Iceland has made widespread use of geothermal heat for drying. Warm waste water from the Reykjavik Municipal District Heating Service maintains a temperature of 25°C in fish drying rooms. The dried fish are the major export of the country. Geothermal water at 100°C provides heat for drying seaweed for recovery of alginates. Diatomite from Lake Myvatn in northern Iceland is dried with steam from the Namafjall field.

The use of geothermal energy for drying is a simple process similar to space heating. For drying on racks or in large drying rooms, the hot fluid is pumped through a radiator, and a blower system transfers the heat to the air and into the drying room. For drying of loose, fine-grained material, a rotary steam dryer similar to an ordinary clothes dryer is used. Heat from steam tubes encircling the dryer warms the air circulated through a rotating drum.

Geothermal heat for drying has several potential applications in northern California. The greatest potential exists for the drying of various agricultural products, such as fruit, seed, grains, and hay. Because geothermal heat cannot be economically transported long distances, the produce must be dried at or near the heat source, and freight costs require that the growers locate near the heat source. Since cattle ranching is a major part of the economy in many of northern California's geothermal areas, drying of processed cattle feed with geothermal heat could be economical.

Lumber mills use large amounts of steam for drying timber. A lumber mill in Susanville, Lassen County, pumps 1,400 l/min of water into a boiler to produce the steam for drying 2.83 million m^3 of lumber each year. An additional 900 l/min is converted to steam for log handling equipment and a generator. The boiler is heated by burning scrap wood from the mill; however, this does not provide enough heat for all the energy needs. The mill still purchases half of its electrical power at a cost of $14,000 per month. Using natural steam directly or using natural hot water in the boiler could eliminate the need to purchase additional power.

The lumber industry, a major employer in parts of Modoc, Lassen, and Sierra Counties, has several mills near geothermal resources. It is essential to dry the timber at the mill because the large weight loss from removal of the water greatly reduces transportation costs. In some areas, such as Bieber, Lassen County; Susanville, Lassen County; and Sattley, Sierra County, new mills or expansions could be located near geothermal sites and utilize the inexpensive heat.

Another potentially widespread application of geothermal drying in northern California is in mineral processing. Diatomaceous earth, sand, and kaolinite are common in the Pleistocene lake and basin deposits found on the east side of the Sierra-Cascade Mountains, and most of the geothermal areas are in these basins. In Long Valley, Mono County, kaolinite is a product of widespread hydrothermal alteration. It is currently being quarried and processed. The processing of these materials generally requires heat for drying or pelletizing. Use of geothermal energy could reduce costs.

Minor industrial uses of low-temperature geothermal water may represent significant savings in some cases. Such uses are extremely varied. CPI Cement Company in Klamath Falls uses low-temperature geothermal water to mix cement in the winter. A dairy in Klamath Falls and Miller's Custom Work in Susanville use natural hot water for cleaning equipment. About 50 years ago, managers of a lumber mill in Susanville drilled and abandoned several geothermal wells in search of cold water to cool equipment. Eventually a new mill manager realized that pumping the hot water into the mill pond would keep it ice-free during the winter months and extend the mill operation season. A cold storage company in Klamath Falls runs geothermal water through pipes under the buildings to prevent frost heaving.

The Tasman Pulp and Paper Co. at Kawerau, New Zealand, produces newsprint, kraft pulp, and sawn timber with the aid of natural steam. Applications include timber drying, powering of log handling equipment, recovery boiler shatter sprays and liquor heaters, electric power generation, and generation of clean steam for milling processes (Smith, 1970).

At Lake Myvatn in northern Iceland, natural steam from the Namafjall field (temperatures up to 280°C) makes diatomite mining economically feasible (Lindal, 1970). Diatomaceous earth dredged from the lake contains 88% water, much higher than the 55 to 65% water found in the material from the usual dry diatomite quarries. The extra cost of fuel for drying the wet diatomite would normally prohibit its production. The diatomite is piped to the processing plant from Lake Myvatn in a slurry. At the plant, the slurry is filtered, producing a mixture of 74% water and 26% diatomite. The resulting cake is fed into rotary steam-tube dryers and discharged with a moisture content of 2 to 6%. Steam at 6 to 7 bars gauge pressure is supplied to the steam tubes. Iceland's diatomite plant is presently the only application of this type. Assuming a cost of $2.75 per 1,000 kg of steam and $26 per 1,000 kg of fuel oil (1970 figures), heating costs for production of 1,000 kg of diatomite are $2 using geothermal energy, and $12 using fuel oil. Diatomite drying may not be economical using water temperatures below 160°C. Geothermal energy is also used for de-icing around the dredge, heating of the slurry, and space heating.

Food Processing

Food processing, such as canning, preserving, or freeze-drying, requires low-temperature heat application. Canning and preserving use temperatures around 100°C. Thermal water under pressure and at temperatures of 130 to 160°C could be pumped through coils of pipe in boilers to provide the heat. If dry heat is required, systems like those used in drying could be employed. Freeze-drying is a high energy-consuming process calling for both heating and refrigeration. Energy demands may account for 45% of the processing costs (Einarsson, 1970). It is economical only for specialty items, such as instant coffee and specially packaged, light-weight meals. Geothermal systems like those used in drying and refrigeration could be installed in freeze-drying plants, significantly reducing energy costs. Reduced costs could allow construction of freeze-drying plants near geothermal resources in spite of increased transportation costs. Where transportation costs do not offset saving in energy expenditures, the freeze-drying process could be extended to less specialized products. It may also be possible in certain areas to use geothermal heat to dry fruit.

Multiple-Use Systems

It is obvious that different uses of geothermal heat require different temperatures. Combining several operations allows utilization of waste heat from higher temperature uses. "Total energy" systems have been designed to utilize as much heat as possible from the energy sources (Beall, 1973). The results are conservation of fuel, decreased expenses because of shared capital investments, elimination of thermal pollution, and reduction of other types of pollution.

Boersma (1971) outlines an integrated water system utilizing heated waste water from a steam electric generating plant. In his model, the hot water is used for fish ponds, single-cell protein production, greenhouse heating, soil warming, and recreation. Beall (1973) describes a plan in which waste heat from a power plant is used in vegetable greenhouses, swine houses, chicken houses, and fish ponds. All wastes from the agricultural operations are used for fertilizer and feed preparation. Similar systems could be designed for utilization of geothermal water.

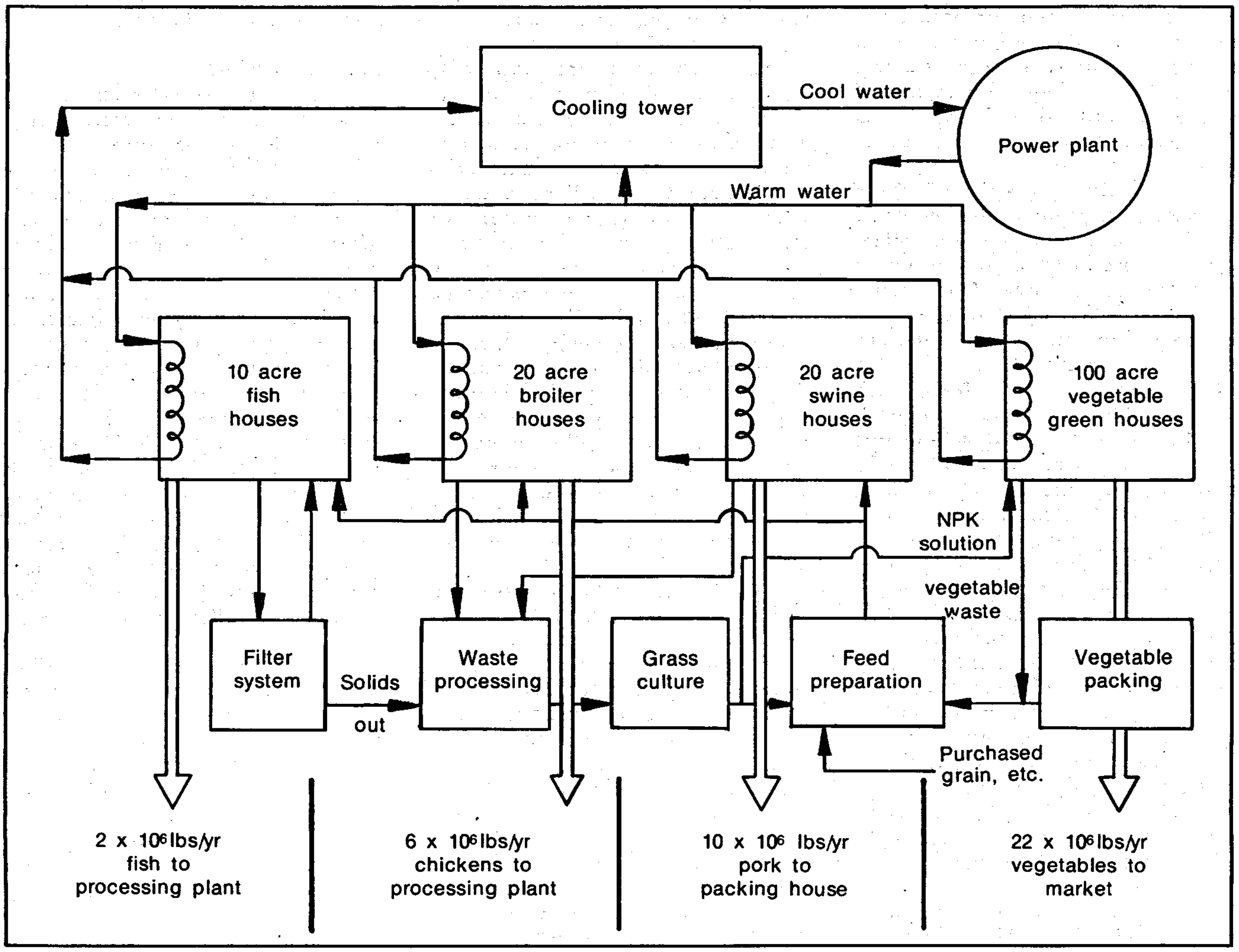
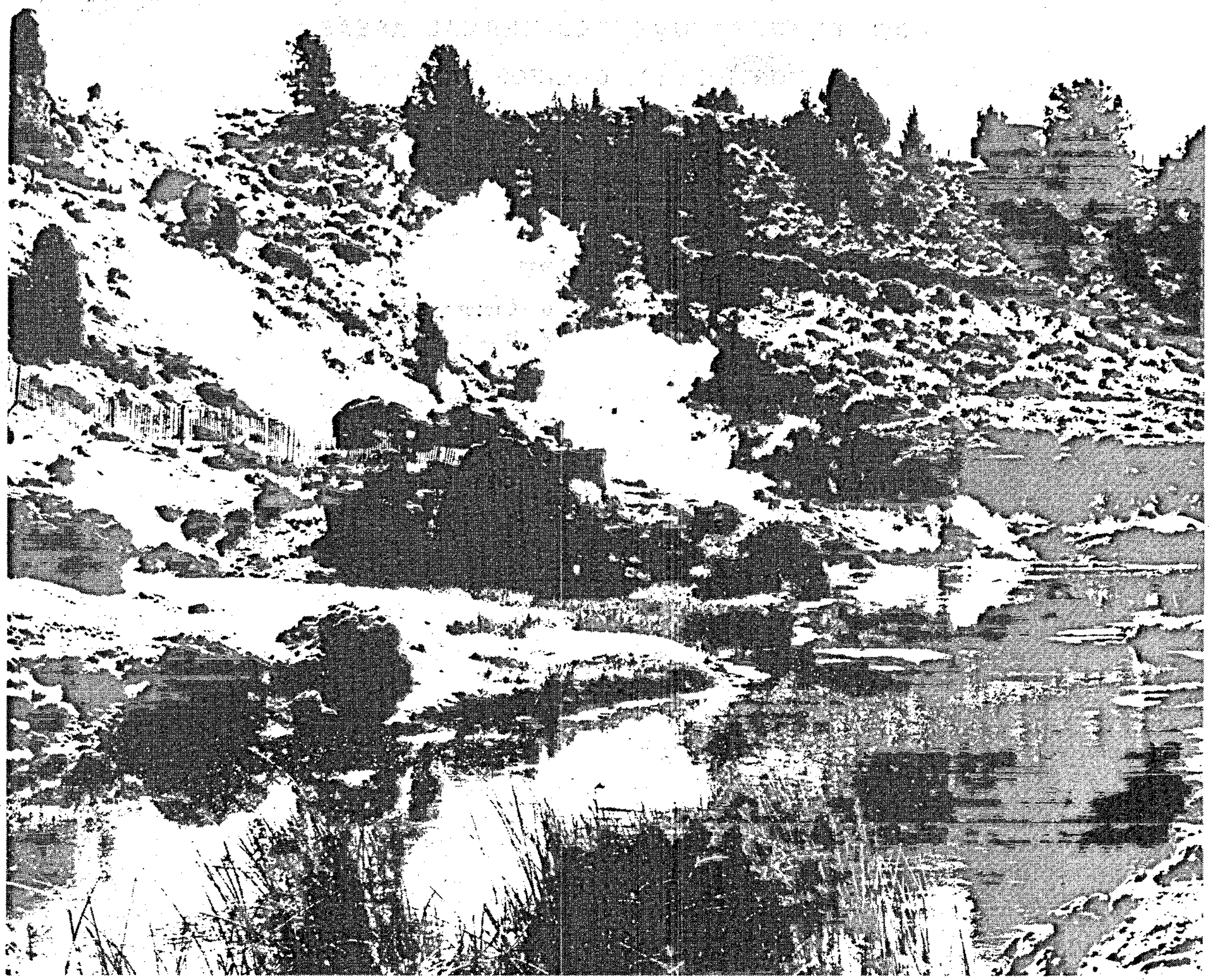


Figure 4
Multiple-use system for utilization of heated waste water (after Beall, 1973)



Descriptions of Northern California Low Temperature Geothermal Resource Areas

Surprise Valley

Surprise Valley is a north-south trending basin, approximately 80 km long and 20 km wide, in Modoc County at the extreme northeast corner of California (Plate II). The valley floor is about 1,400 m above sea level; the Hays Canyon Range on the east exceeds 2,000 m altitude, and the Warner Mountains on the west reach an altitude of 2,998 m at Eagle Peak. The valley has internal drainage and contains three large lakes -- Upper, Middle, and Lower Alkali Lakes. The lakes are extremely saline, seldom more than 1.5 m deep, and often are dry in the summer. State Highway 299 goes through Cedar Pass, providing easy access from Alturas to Cedarville, Surprise Valley's largest town. The remainder of the valley's small population is scattered in three villages and on ranches along the western edge.

Climate

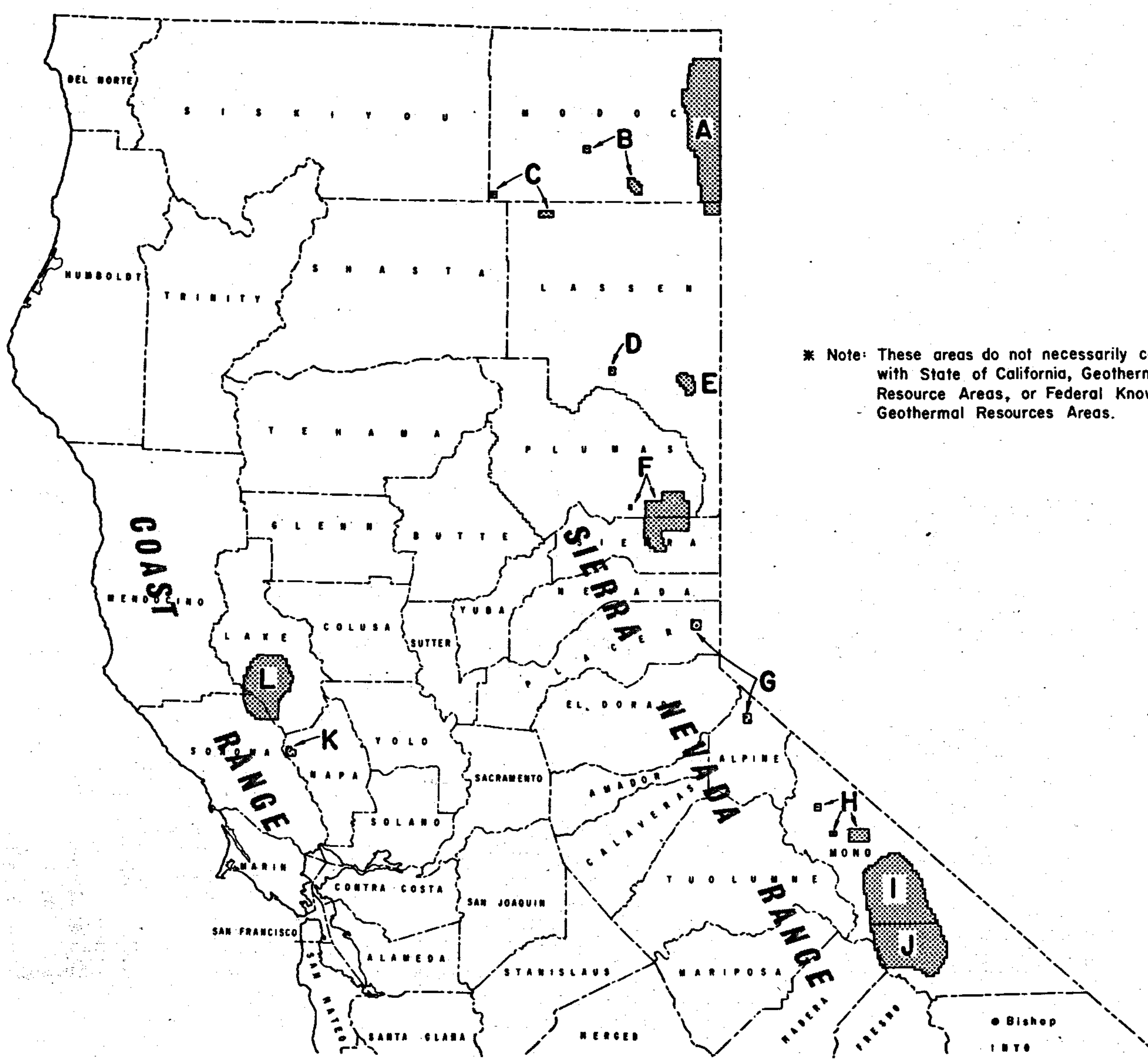
Surprise Valley has a climate typical of high-altitude deserts. Average temperatures are -1°C in January and 22.1°C in July. The maximum and minimum temperatures recorded over a 40-year period are 44°C and -29°C. The valley receives an annual average precipitation of 31.1 cm, with a January average of 4.6 cm and a July

LOW TEMPERATURE GEOTHERMAL AREAS *
NORTHERN CALIFORNIA

SCALE
0 20 40 60 80 100 KILOMETERS

Geothermal Areas

A Surprise Valley
B Alturas Area
C Big Valley and Little Hot Spring Valley
D Susanville
E Wendel - Amedee
F Sierra Valley
G Eastern Sierra Springs
H Bridgeport Valley
I Mono Lake Basin
J Long Valley
K Northern Napa Valley
L The Geysers and Clear Lake



* Note: These areas do not necessarily coincide with State of California, Geothermal Resource Areas, or Federal Known Geothermal Resources Areas.


NEVADA
CALIFORNIA
OREGON
CALIFORNIA
T 47 N
T 46 N
T 45 N
T 44 N
T 43 N
T 42 N
T 41 N
T 40 N
T 39 N
R 17 E
R 16 E
R 15 E
R 14 E
HAYS CANYON RANGE
LARKSPUR HILLS
UPPER ALKALI LAKE
MIDDLE ALKALI LAKE
LOWER ALKALI LAKE
GOOSE LAKE
SURPRISE VALLEY FAULT ZONE
LAKE CITY FAULT
SURPRISE VALLEY RD.
WARNER MOUNTAINS
Fort Bidwell
Lake City
Cedarville
Eagleville
MODOC COUNTY
LASSEN COUNTY
299
395
ALTURAS 185 KM
Sectionized Township
PLATE II
SURPRISE VALLEY GEOTHERMAL AREA
LEGEND
FAULTS
KNOWN
INFERRED
CONCEALED
STUDY AREA BOUNDARY
GEOTHERMAL OR WARM WATER WELL
HOT SPRINGS
MOUNTAINS
SCALE IN KILOMETERS
0
5
10
1:125000

average of 0.4 cm. Precipitation is higher in the Warner Mountains on the west, exceeding 50 cm/yr. The average growing season of 126 days could easily be extended by the use of greenhouses because of the high annual percentage of sunshine. The average period of daily sunshine ranges from 5 hours in the winter to 13 hours in the summer.

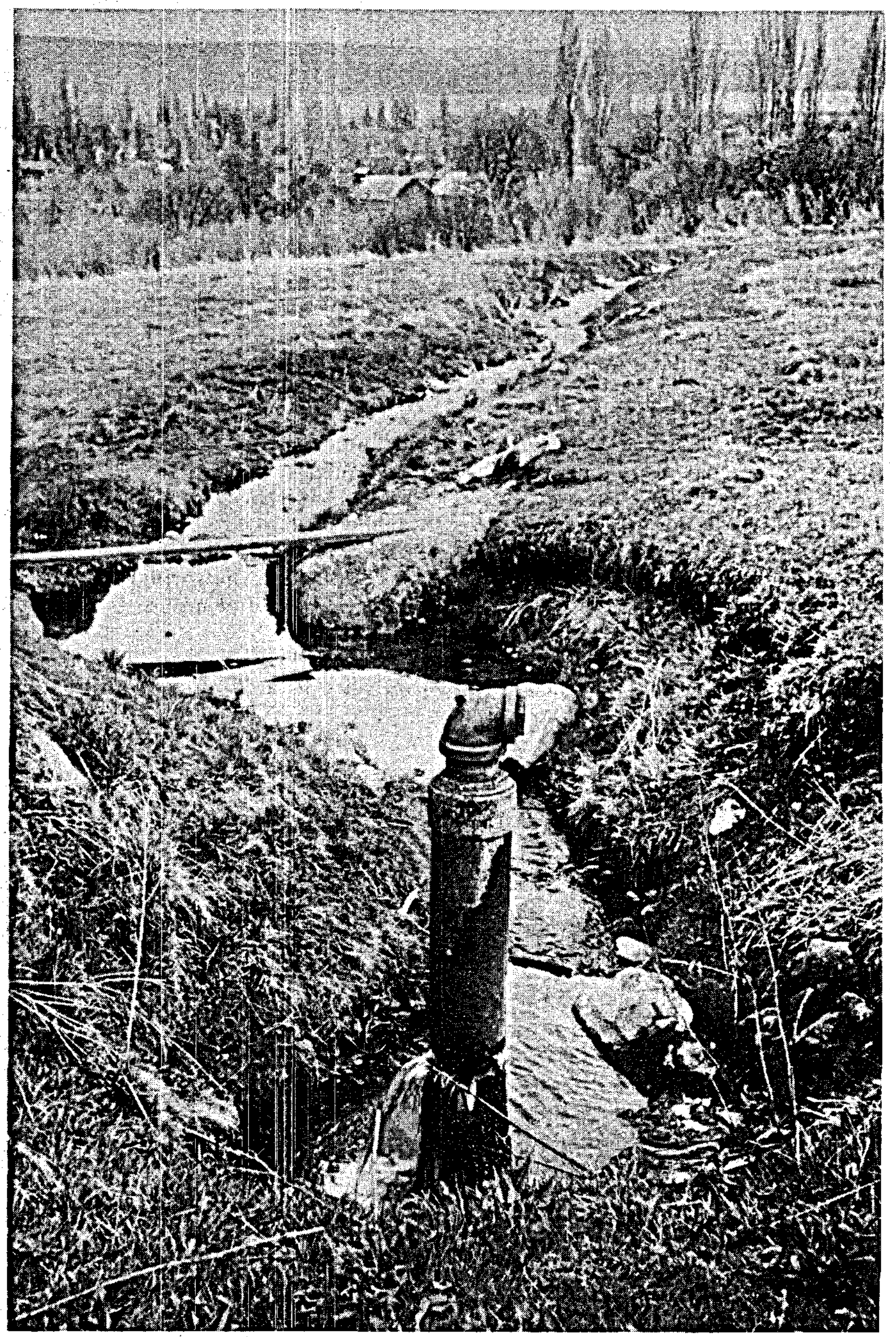
Geology

The mountains adjacent to Surprise Valley are composed of Oligocene to Pleistocene volcanic and associated sedimentary rocks. The Cedarville Series, which includes andesitic tuff, agglomerate, and intercalated andesite and basalt flows, crops out extensively in the Warner Mountains. These rocks probably underlie most of Surprise Valley. Extensive volcanism in the Warner Mountains from the Miocene through the Pleistocene left a thick sequence of pyroclastic rocks, andesite and basalt flows, rhyolite tuffs, and shallow intrusions. The Forty-Nine Camp Formation, a unit of tuffaceous sand and volcanic gravel, overlies the Cedarville Series east of the valley, but pinches out under the valley fill. The valley fill material consists of Pleistocene and Holocene lake deposits, and Holocene alluvial fan deposits. The thickness of the sediments ranges up to 1,525 m.

The dominant structural features of Surprise Valley are normal faults. The Surprise Valley fault zone defines the western boundary of the valley. The rapid formation of the valley as a result of faulting is evidenced by the large displacement of Plio-Pleistocene volcanic units. These rocks are found both high on the peaks of the Warner Mountains and deeply buried below the valley sediments. The less distinct eastern boundary of the valley consists of a series of parallel fault blocks that step upward and to the east. Clearly visible normal faults cut the Warner Mountains at nearly right angles to the Surprise Valley fault and extend beneath the valley fill. The inferred valley floor fault pattern is supported by geophysical studies which indicate that the bedrock beneath the sediments is broken into numerous tilted blocks. Hot springs are found along the entire length of the Surprise Valley fault. Other notable faults possibly related to thermal activity are: (1) two parallel faults extending north-south along the east side of Middle Alkali Lake, and (2) the Lake City fault trending northwesterly between Upper and Middle Alkali Lakes.

Hydrology

Numerous small creeks issuing from the Warner Mountains supply irrigation water for Surprise Valley. Because of generally low yields from wells, ground water is used mainly for stock-watering or domestic water supply. The major aquifers on the west side of the valley are the fan deposits; the volcanic rocks and lake deposits are largely impermeable. Therefore, ground water recharge is limited to infiltration of surface streams into alluvial fans at the base of the Warner Mountains. On the east side of the valley, the Forty-Nine Camp Formation is a good aquifer; however, the low rainfall in the Hays Canyon Range severely restricts recharge potential. In the central part of the valley, ground water may be of low quality. For example, a cold water well drilled in NW1/4, SW1/4, Sec. 5, T. 42N., R.17E. to a depth of 41 m produces water too highly mineralized for domestic use. In addition, wells drilled near thermal



Fort Bidwell Spring (artesian well) flows approximately 600 l/min at 37°C. The town, Fort Bidwell, can be seen in the background through the trees.

springs may produce water with excessive concentrations of sodium, boron, fluorine, or arsenic.

Known Springs and Wells

All of the wells and springs mentioned in this report are listed by geographical area in Appendix A. Numbers refer to the location on the map and the listing in the appendix.

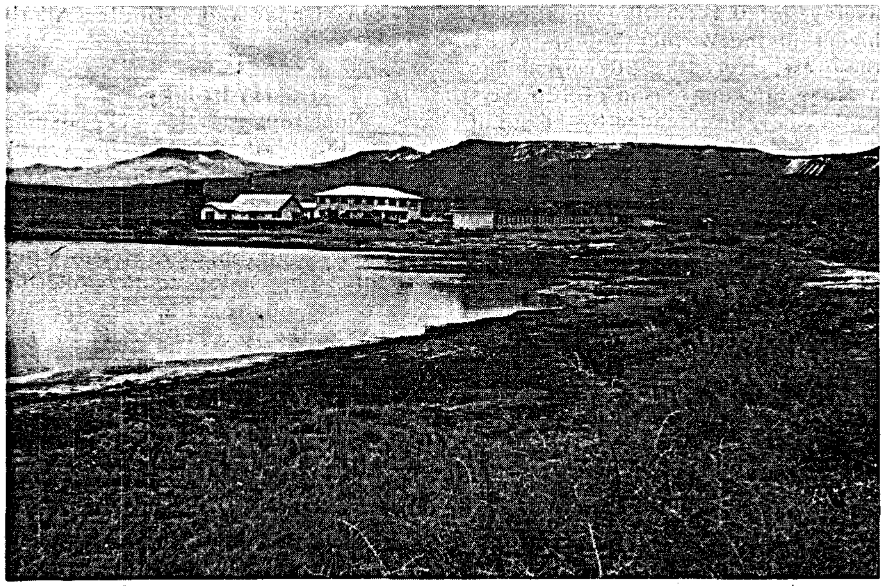
There are two warm springs near the town of Fort Bidwell. The Fort Bidwell Spring (actually a well) (3) flowing 600 l/min at 37°C, is on an Indian reservation just west of town. The Peterson's Ranch springs (1), flowing 400 l/min at 36 to 42°C, are used to fill a small swimming pool 2 km north of Fort Bidwell. A well (2) directly between the two springs yields water at 36°C. A pump test produced 8,300 l/min with a drawdown of 18.3 m. All three sources of hot water occur near the Surprise Valley fault zone at elevations slightly above the valley floor. Road access is good, but the rugged terrain on the Warner Mountains escarpment might limit development, since sizable areas of flat ground are not immediately available for large agricultural developments.

Several mudpots and hot springs 3 km north of Lake City mark the site of a spectacular mud volcano eruption in March 1951 (4). Prior to the eruption, the springs were inconspicuous and their temperatures and flow rates were not definitely known. The eruption began without warning at about 11:30 p.m. on March 1, 1951, and continued with decreasing vigor for about four days. Initially, large chunks of mud were thrown several hundred meters in the air, and strong winds carried frozen mud pellets up to 7 km from the site. D.E. White (1955) gives a complete account of the eruption. The area has been quiet since then, and the springs maintain fairly constant temperatures ranging from 48 to 97°C. Their total discharge is about 400 l/min. The ground around the springs is swampy and unstable, and no use is made of the hot water.

Several other warm springs and wells are located along the mountain front north and south of the Lake City mud volcanoes. For example, an artesian well on the Lyle Hill Ranch 12 km north of Lake City discharges water in excess of 60°C. Exploration wells (5) drilled 3 km north of Lake City to a maximum depth of 1,368 m produced hot water up to 160°C with some steam flashover. None of the heat from geothermal resources in the Lake City area is being used, but the area has potential. Fresh surface water, extensive areas of flat ground, and natural hot water at moderately high temperatures are all available. The major impediments to development are the long distances to sizable markets and the small labor force available.

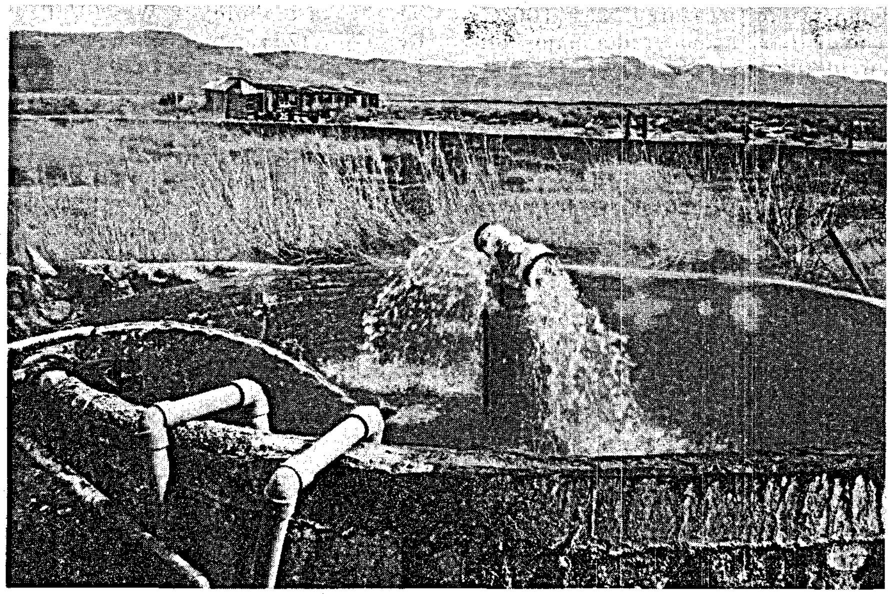
Hot water flows from 2 wells and 5 springs near the Hot Springs Motel about 8 km east of Cedarville. Two wells (13) near the hotel have temperatures of 98°C and 84°C and have flows of about 300 l/min each. These wells provide hot water for a 646 m^3 indoor pool, for domestic use, and for space heating in the motel units. Bluegill and catfish are raised in the outflow from the wells, but trout cannot survive the high temperature. Waste water from the heating system has been used successfully to irrigate a small vegetable garden.

Five springs (12, 14, 15) issue from alluvial deposits northeast and southwest of the hotel. They range in temperature from 50°C to 97°C. All these springs occur between two north-south trending faults (Calif. Dept. Water Resources, 1963). A shallow well drilled east of this block



Hot Springs Motel, which uses geothermal energy for space heating and heating of an indoor pool (8 km east of Cedarville, Modoc County).

Lake City mud volcano and hot spring area, 3 km north of Lake City, Modoc County. View toward the southwest. Note the sunken area with grove of trees in front of the Warner Mountains.



One of two artesian wells at Hot Springs Motel that have flow rates of 300 l/min with temperatures from 84 to 98°C.

produced cold mineralized water. It seems likely that the hot water is largely confined to a north-south zone within the fault block.

Three small groups of springs, Leonard Hot Springs (west) (10), Seyferth Hot Springs (9), and Leonard Hot Springs (east) (11), occur 8 to 10 km north of the Hot Springs Motel. These springs may be related to the Lake City fault. All have been used sporadically for bathing, irrigation, and stock watering. Development is limited to a few dilapidated wooden shacks at the Old Leonard Baths (Leonard Hot Springs). The terrain is nearly flat and access is provided by a good gravel road and fair dirt roads. Availability of good quality water may be limited; the thermal water has high electrical conductivity and may contain excessive concentrations of boron, fluoride, sodium, sulphate, or arsenic.

There are two hot springs along the highway south of Eagleville: Menlo Hot Springs (16), 6 km south of the town, discharging 1,000 l/min at 57°C; and Squaw Bath (17), 11 km south of the town, discharging 450 l/min at 49°C. Menlo Hot Spring was once used for bathing, but there are no improvements at the present time. Squaw Bath, once popular with Eagleville residents, was closed to the public in August of 1973 because of increasing vandalism. Several warm wells at nearby ranches indicate an extensive hot-water zone parallel to the Surprise Valley fault zone.

Summary

The greatest deterrents to development in Surprise Valley are its isolation and small population. Reno, the nearest large market and transportation center, is 400 km to the south. Cattle ranching is the predominant land use in the valley; related agricultural developments are therefore recommended for utilization of the geothermal heat. Thermal water could be used for processing of cattle feed and waste and for stock watering.

The exploration wells drilled at Lake City indicated reservoir temperatures marginally sufficient for electrical power generation. If the reservoir is developed, consideration should be given to a multiple-use project utilizing the waste heat for agriculture. All four towns in Surprise Valley are near geothermal resources; municipal heating services may be practical, particularly for any new developments.

Alturas Area

Alturas, with a population of about 3,000, is the county seat of Modoc County and the main service center for an extensive area. Most of the remaining population is clustered near the small farming communities of Likely (in South Fork Pit River Valley) and Canby (in Warm Springs Valley). The town of Alturas is located in central Modoc County near the confluence of the North and South Forks of the Pit River at an altitude of 1,336 m (Plate III). There are two areas of interest near Alturas: a small area within the South Fork Pit River Valley, 5 to 8 km northeast of Likely, and Warm Springs Valley in the vicinity of Kelly Hot Spring 3 km east of Canby. Warm springs outside these two areas include several at Hot Creek, 14 km west of Alturas on State Highway 299, and one on the east shore of West Valley Reservoir, 10 km east of Likely.

Climate

The Alturas area has a rigorous semiarid climate with an average growing season of only 77 days. Average temperatures are -2.9°C in January and 19.6°C in July. The maximum and minimum temperatures recorded over a 22-year period are 41°C and -36°C. Alturas receives an annual average precipitation of 32.0 cm, with a January average of 5.3 cm and a July average of 1.3 cm. Precipitation decreases somewhat in the South Fork Pit River Valley, but exceeds 50 cm in the surrounding mountains. The Alturas area is ideal for greenhouse agriculture because of the high percentage of sunshine, an average of 5 hours in midwinter and 13 hours in midsummer.

Geology

Warm Springs Valley and South Fork Pit River Valley are underlain to a depth of 290 to 450 m by the Plio-Pleistocene Alturas Formation. The formation includes similar upper and lower members composed of tuffs, sands and gravels, and diatomite which were deposited in a large ancient lake. These units are randomly separated by massive, scoriaceous olivine basalt flows, and the Warm Springs Tuff Member, which includes welded tuff, lapilli tuff, and ashy sandstone. The formation has been gently folded and extensively faulted in a northwesterly direction. Widespread highly jointed olivine basalt flows with interbedded scoriaceous zones overlie the Alturas Formation north of Alturas and on the sides of South Fork Pit River Valley. Coarse fan deposits and unconsolidated sandy alluvium flank both valleys, but the valley floors are blanketed with unconsolidated basin deposits of clay, silt, and very fine sand.

Numerous northwest-trending normal faults cut the Tertiary and Quaternary units. Major thermal activity occurs along the Likely fault and smaller associated faults. The Likely fault extends about 100 km from a point 18 km northwest of

Canby, to the Madeline Plains in T. 35 N., R. 15 E., and may be the path for deep circulation of meteoric water. The hot wells in South Fork Pit River Valley are found in a small downdropped block between two faults transecting the valley. Warm springs emanate along the faults where they meet the slope on the east side of the valley.

Hydrology

Water supply is not currently a problem in the Alturas area. Almost half of the irrigation water demand is met by surface water and a small number of irrigation wells supply the remainder. The greatest demand for groundwater comes from domestic and stock requirements. Groundwater development potential is sufficient over most of the area to meet near-future needs. However, because of limited recharge opportunity, local overdraft conditions may result from extensive agricultural development. Water in the central Warm Springs Valley between Kelly Hot Spring and Hot Creek has excessive sodium adsorption ratios making it hazardous for irrigation. Water from Kelly Hot Spring also contains fluoride and boron concentrations above recommended standards for domestic or irrigation use.

Known Springs and Wells

Kelly Hot Spring (19), located 3 km east of Canby on U.S. Highway 299, discharges 1,200 l/min of water at 92°C. The spring boils up into a circular pool about 4 m in diameter at the edge of the Warm Springs Valley. Two narrow creeks, 1 to 3 m apart, carry the hot water to a small reservoir about 0.5 km southeast of the spring, from which it is used for irrigation. The water is high in sodium, boron, and fluoride, and has been used successfully in raising only certain salt-tolerant grasses. At one time, tomatoes were grown between the two outlfow streams, taking advantage of the warm, moist air. This is the only known use of the heat. Two shallow wells, drilled about 200 m east of the hot spring, were for domestic use at the now abandoned Kelly Hot Springs Store. Both wells produced warm water, probably about 30°C (information from a local resident).

In 1969, Geothermal Resources International drilled and abandoned an exploratory well (20) just south of Kelly Hot Spring. The total depth was 977 m and the maximum temperature measured was 100°C. The drillers encountered a major lost circulation zone at 488 m.

Hot Creek, which carries about 2,600 l/min, is fed largely by warm springs along its 2 km course. The creek parallels a fault which cuts the moderately permeable Alturas Formation. One of the springs near Hot Creek (18) has a temperature of 33°C and supplies a swimming pool at Hot Creek Ranch. No well data is available in this area, but it is possible that higher temperatures exist at depth.

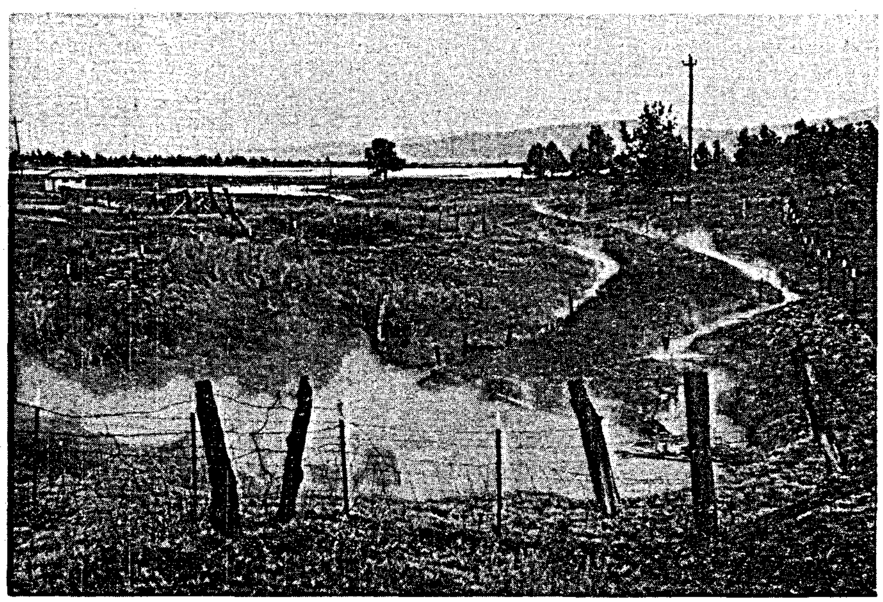
A well on the old Williams Ranch (22), 5 km northwest of Likely, discharges water at 44°C. For many years the well supplied a commercial pool, but the pool is no longer operated. The water currently supplies domestic and irrigation needs of the ranch. The water is apparently soft and poses no problems for domestic use. A 45-year-old iron pipe line to the swimming pool shows only slight scaling at the joints.

A 62-meter deep well on the new Williams Ranch (21), 1 km north of the original ranch, discharges about 150 l/min of water at 29°C. According to Mr. Williams, owner of the well, the producing aquifer is only 6 to 7 m thick. Several other wells have been drilled between the two mentioned above, and all yielded warm water. Numerous springs in the area never freeze and a few maintain temperatures of 25 to 30°C throughout the year.

An isolated cluster of hot pools on the east shore of West Valley Reservoir (23) contains water up to 74°C. The total flow from all the pools is only 1 l/min. About half of this flow is diverted into a dilapidated, wooden bathhouse enclosing a small concrete lined pool. Bubbles, probably CO_2, rise in most of the pools. Mineralization around the pools and the bathhouse is slight, but white mineral deposits (mostly $CaCO_3$) give evidence of former springs up to 20 m north of the present group. The springs issue along a fault in relatively impermeable mudflow deposits. No known aquifers underlie the mudflows, and the low flow of the springs suggests overall low permeability. Wells drilled in this area would probably yield only minimal volumes of hot water.

Summary

Because ranching is the predominant land use in the areas around the springs, agricultural developments are recommended for utilization of the heat. Greenhouse products would have a limited market in Alturas, major service center for Modoc County, but larger markets are only 300 to 400 km away (Reno, Nevada and Sacramento, California). Use of geothermal heat for production improvement in the cattle industry may be possible. Sufficient open, flat land is available for large greenhouse operations if the required labor force is available. In addition, mining and processing of local diatomite deposits may be



Looking south at Kelly Hot Spring, 3 km east of Canby, Modoc County. Kelly Hot Spring flows about 1,200 l/min of 92°C water.

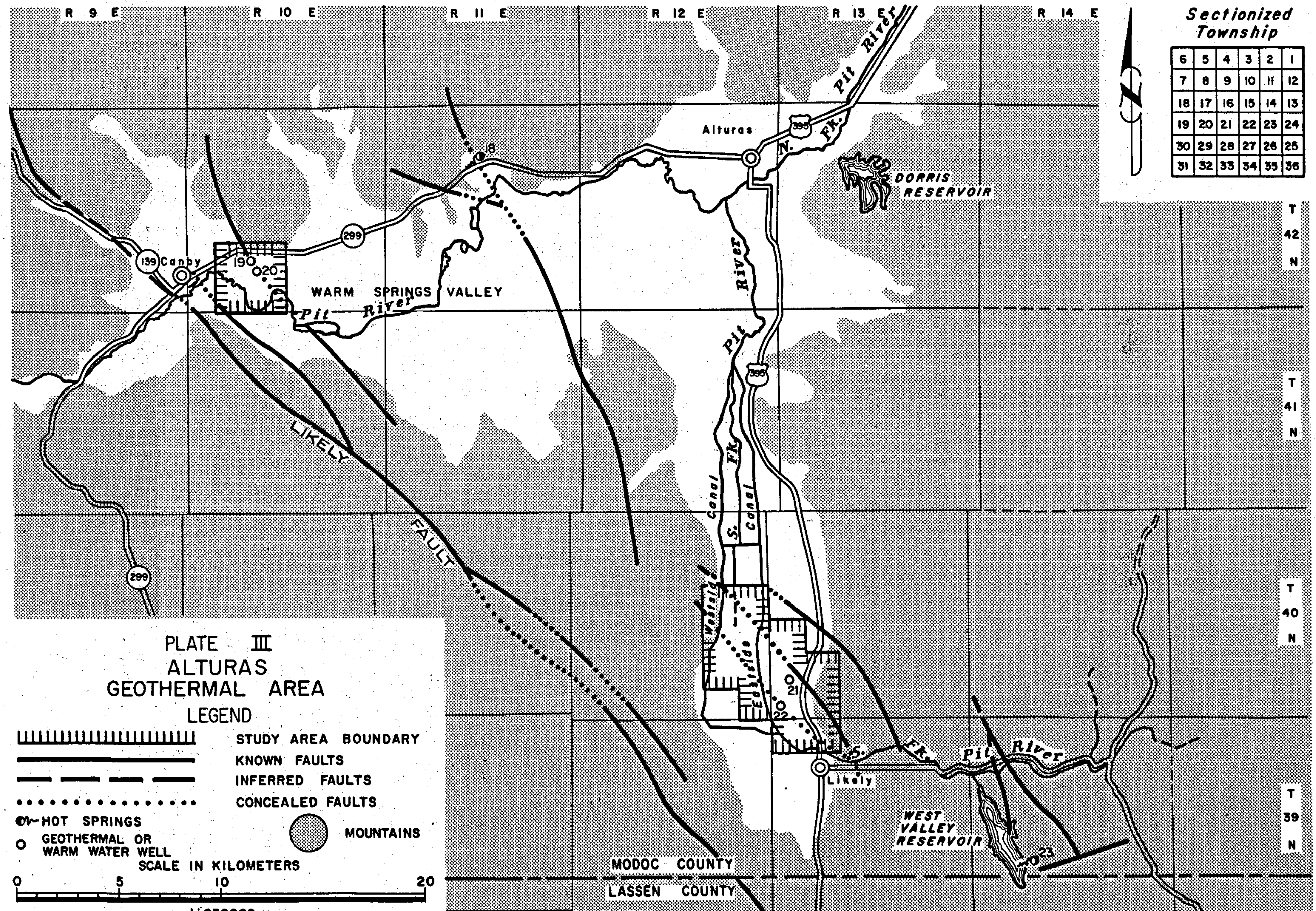


PLATE III
ALTURAS GEOTHERMAL AREA

economical if geothermal heat is used for processing. Exploration for increased geothermal development has been in the immediate vicinity of Kelly Hot Spring; the entire length of the Likely fault merits study.

Big Valley and Little Hot Spring Valley

Big Valley is a large plain about 21 km long from north to south and 18 km wide from east to west, straddling the boundary between Modoc and Lassen Counties. The elevation of the valley floor is about 1,218 m above sea level. It is surrounded by volcanic ridges including the Big Valley Mountains on the west and the Barber Ridge on the east. State Highway 299 crosses the valley from east to west passing through the towns of Adin, Bieber, and Nubieber. Little Hot Spring Valley extends about 7 km on the west side of the Big Valley Mountains as shown on Plate IV. It is bounded on the west by an extensive, recent basalt flow. The floor of Little Hot Spring Valley is hummocky and scattered with cobbles and mounds of basalt. The valley is accessible from the south via an excellent paved and gravel road. Both valleys are somewhat isolated and very sparsely populated.

Climate

Average temperatures are -2°C in January and 20°C in July. Maximum and minimum temperatures in 1971 were 37°C and -27°C. The valley receives an average annual precipitation of 50.6 cm, with a January average of 4.5 cm and a July average of 0.15 cm. The average daily number of hours of sunshine ranges from 5 in the winter to 13 in the summer.

Geology

The mountains surrounding Big Valley and Little Hot Spring Valley are composed of Tertiary and Quaternary volcanic and sedimentary rocks, basalt flows, andesite flows, rhyolite tuffs, and mudflows, locally interbedded with silt, sand, gravel, and diatomite. The well-bedded flows and sedimentary rocks of the Big Valley Mountains Volcanic Series dip gently to the east. The Big Valley fill consists of unconsolidated Tertiary lake and basin deposits, including diatomite, silt, sand, and some gravel. The lowest part of the valley is filled with very fine-grained basin deposits surrounded by slightly sandy alluvium, and minor coarse-grained fan deposits. Little Hot Spring Valley, underlain by Quaternary basalt, has accumulated only small amounts of sand and silt.

The Big Valley Mountains and the Barber Ridge are fault blocks that have been uplifted and tilted to the east. The trend of surface faulting is to the northwest, but geophysical studies (Calif. Dept. Water Resources, 1963) indicate a possible subordinate fault system trending to the northeast. A hot spring and several warm wells issue water at the point where the slope breaks on the east side of Little Hot Spring Valley. The warm water probably follows fractures in the fault zone which marks the western edge of the Big Valley Mountains. Two hot springs occur in the alluvium in Big Valley. These may be related to bedrock faulting below the valley fill.

Hydrology

Water from wells in Big Valley is used primarily for stock watering and domestic supply. Most irrigation water is diverted from unregulated streams and springs. The water table is very high in the spring and early summer, and crops must be able to withstand periodic inundation. In late summer and fall, springs and streams often run dry. Recharge to the groundwater reservoir results from seepage from upland porous basalt flows. These flows yield moderate to large quantities of water to wells. Unfortunately, the permeable units do not extend under the valley floor, and valley wells generally provide only small volumes of water. Large developments requiring significant quantities of water may have to pipe fresh water from wells in the upland areas. Water quality is excellent except around thermal springs where excessive concentrations of sodium, boron, fluoride, or arsenic may be found.

Known Springs and Wells

There are two hot springs in Big Valley near the town of Bieber: Bassett Hot Spring (24), 3 km north-east of Bieber on State Highway 299, discharging 200 l/min at 79°C, and Kellog Hot Spring (25), 11 km east of Bieber on Road A2, discharging 15 l/min at 78°C. The Packwood family once ran a commercial pool heated by the thermal water of Bassett Hot Spring, but no longer holds a license to operate it. At one time, Kellog Hot Spring was used to heat a bathhouse, several cabins, and a chicken house. The buildings were finally razed after a long history of vandalism.

Little Hot Springs (26), on the east side of Little Hot Spring Valley, discharge 300 l/min at 75 to 77°C. The hot water is not used. Two wells drilled south of the spring produce hot water. One is used successfully to irrigate alfalfa, indicating satisfactory water quality; however, cool groundwater is apparently difficult to find in the valley. Wells drilled south of the spring along the fault zone at the base of the Big Valley Mountains would probably produce hot water.

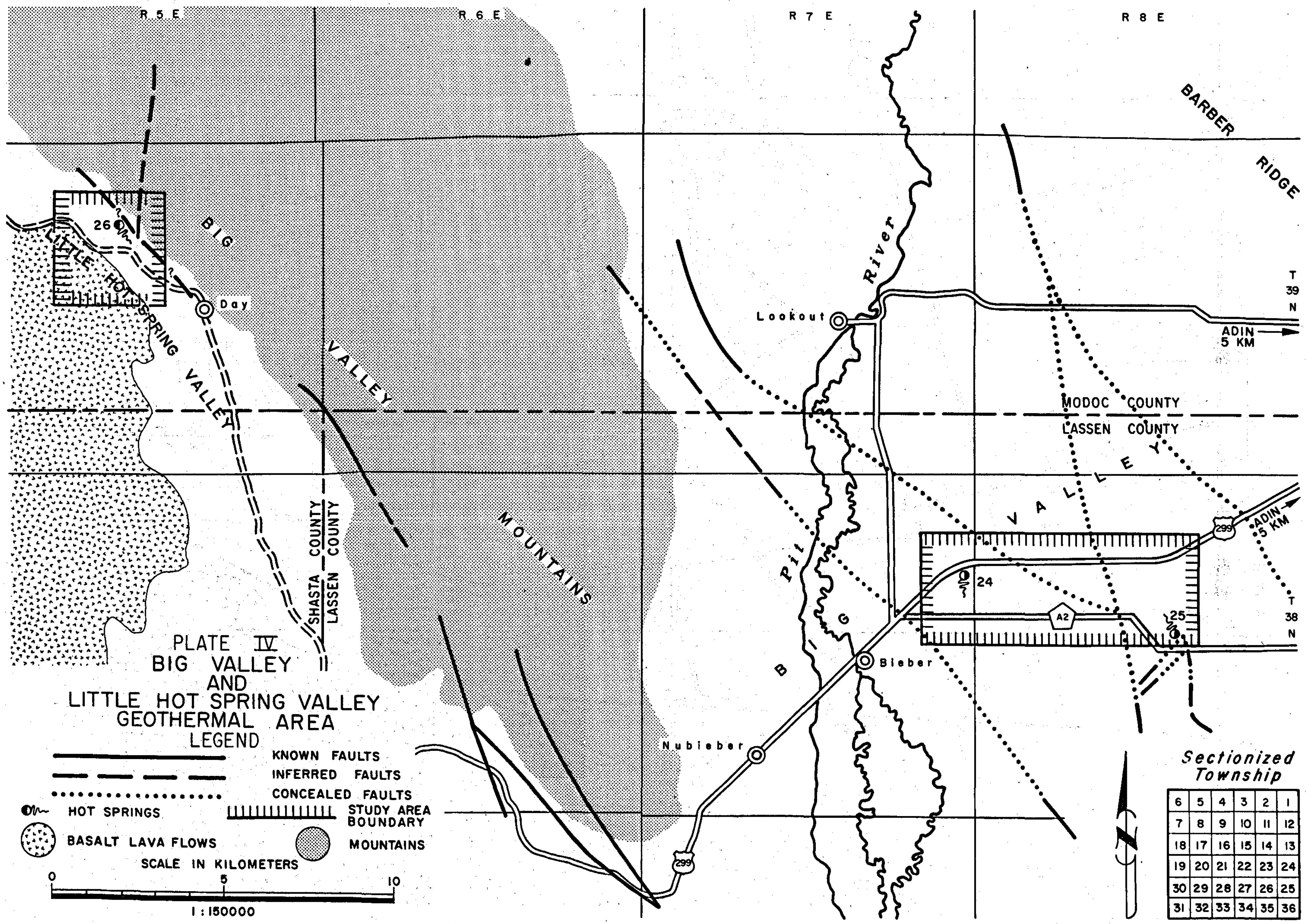
Summary

Although ranching is an important land use in Big Valley, it is limited by poor soils to the raising of feed. Ranching is also limited by marshes in the central part of the valley. Cattle grazing is restricted to the small, marginal pastures above the marshland. Thermal water could be used for greenhouse heating or other agricultural developments. Large operations would be necessary to outweigh the long distances to major markets. The only other major industry is a lumber mill in Bieber. The lumber company could reduce or eliminate fuel costs by piping geothermal water or steam to the boilers. There are extensive diatomaceous earth deposits west of Big Valley which have remained untouched. The prospect of using geothermal heat for drying, and other heat requirements should make these deposits more attractive, but the extent and temperature of the hot-water reservoir is not known. As in the case of the lumber industry, supplying hot water to steam boilers could significantly reduce fuel costs.

Little Hot Spring Valley is almost completely undeveloped; there are only a few houses with small pastures and one alfalfa field in the valley. Its isolation and small size make it impractical for most types of development.

Susanville

Susanville, seat of Lassen County, has a population of 6,600 (1970 census) and is the principal city of northeastern California. The town is at the extreme northwestern edge of the Honey Lake basin, at an altitude of about 1,300 m (Plate V). Major sources of employment include county, state, and federal organizations (particularly the U.S. Forest Service), tourism, farm trade, and several lumber mills. The Susan


R 5 E
R 6 E
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BARBER RIDGE
T 39 N
T 38 N
26
BIG VALLEY
LITTLE HOT SPRING VALLEY
Day
River
Pit
Lookout
ADIN 5 KM
MODOC COUNTY
LASSEN COUNTY
SHASTA COUNTY
LASSEN COUNTY
MOUNTAINS
24
25
A2
299
Bieber
Nubieber
PLATE IV
BIG VALLEY
AND
LITTLE HOT SPRING VALLEY
GEOTHERMAL AREA
LEGEND
KNOWN FAULTS
INFERRED FAULTS
CONCEALED FAULTS
HOT SPRINGS
STUDY AREA BOUNDARY
BASALT LAVA FLOWS
MOUNTAINS
SCALE IN KILOMETERS
0
5
10
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Sectionized Township
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19 20 21 22 23 24
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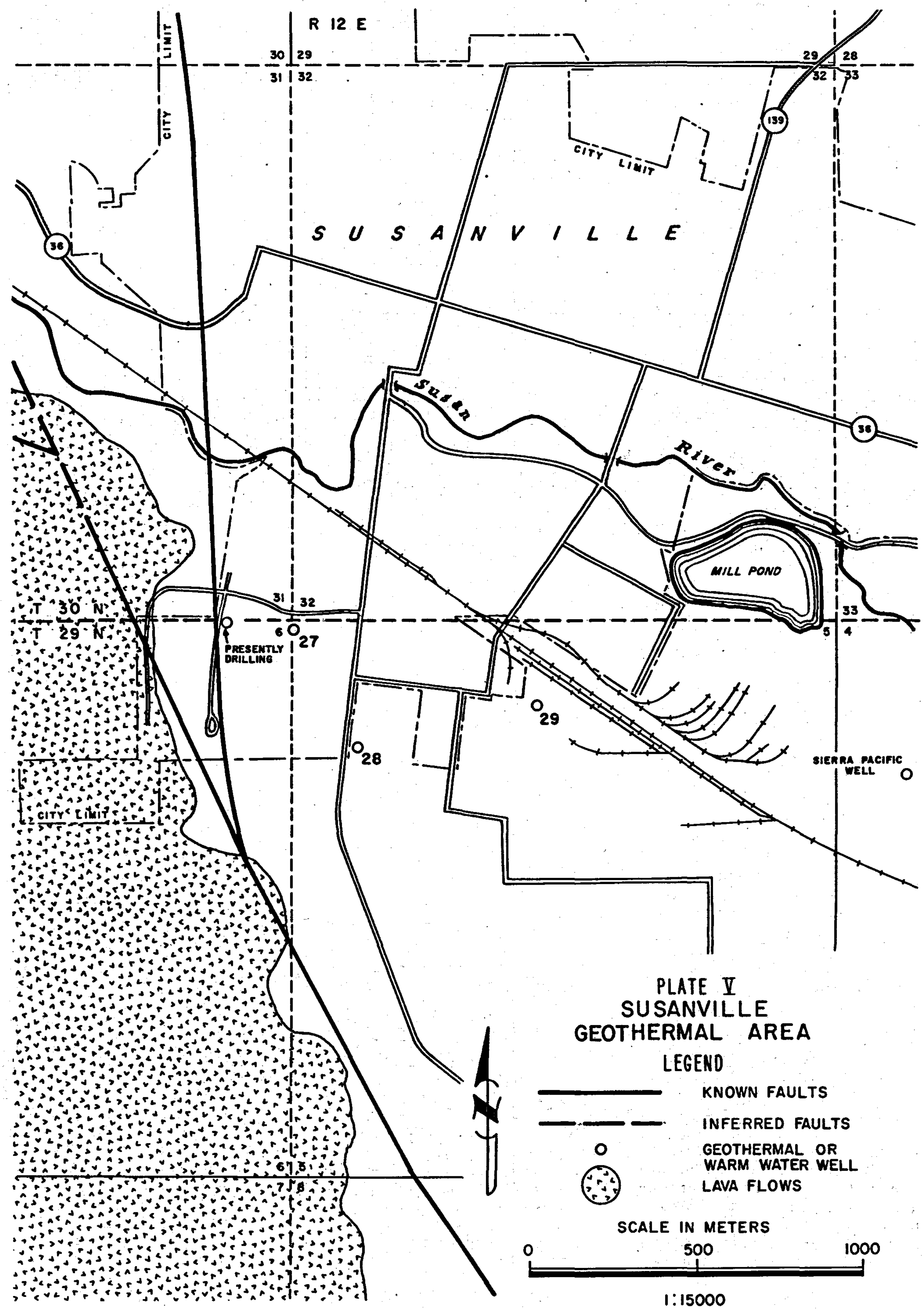
31 32 33 34 35 36


R 12 E
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33
CITY LIMIT
CITY LIMIT
139
36
S U S A N V I L L E
Susan
River
36
MILL POND
T 30 N
T 29 N
31
32
6
27
PRESENTLY DRILLING
33
5
4
29
28
SIERRA PACIFIC WELL
CITY LIMIT
6
5
7
8
PLATE V
SUSANVILLE
GEOTHERMAL AREA
LEGEND
KNOWN FAULTS
INFERRED FAULTS
GEOTHERMAL OR WARM WATER WELL
LAVA FLOWS
SCALE IN METERS
0
500
1000
1:15000

River divides the town just south of the central business district. A reservoir of warm water underlies part of the town between the foothills to the southwest and the Susan River. Much of this area is still used for cattle grazing, but it also includes Susanville's small industrial area, an elementary school, some county offices, a municipal swimming pool, the county hospital, and several small residential sections. There is no surface expression of thermal water; the hot water is found only in wells.

Climate

Average temperatures in Susanville are -1°C in January and 21°C in July. The maximum and minimum temperatures recorded over a 30-year period were 41°C and -27°C. The town receives an average annual precipitation of 45.2 cm, with a January average of 9.24 cm and a July average of 0.56 cm. The average daily number of hours of sunshine ranges from 5.5 in the winter to 13 in the summer.

Geology

Susanville is on the northwestern end of Honey Lake basin. The basin fill consists of Pleistocene and Holocene sediments. Much of the fill is fine- to medium-grained Pleistocene lake deposits. Toward the south and west there are coarse-grained near-shore deposits and recently deposited sandy alluvium. The upland areas consist mainly of jointed Quaternary basalt flows with interbedded scoriaceous zones. An extensive flow of Tertiary Sierran andesite crops out southwest of Susanville. Conjugate pairs of normal faults trending northwest and northeast cut these volcanic rocks and may extend under the valley sediments. One of these faults, which approximately follows the break in slope in the southeast edge of town, may be the southwest limit of the hot-water zone. No warm water has been found north of the Susan River. Hot water in shallow aquifers is apparently cooled by shallow ground water as it moves toward the river.

Hydrology

Susanville's municipal water supply comes in part from two cold springs in the foothills west of the town. The remainder is pumped from three wells on the east side of town just north of the Susan River. Most of the sediments have moderate to high permeability and readily yield water to wells. The jointed basalts form excellent forebays for groundwater recharge. The Susan River supplies much of the irrigation water for the Susanville area. Irrigation wells, usually with sufficient yield, supplement surface water supplies. Water quality is generally excellent, although water in the closed Honey Lake basin is increasing in salinity from use and re-use.

Known Wells

Utilization of natural hot water in Susanville began about 50 years ago when managers of a lumber mill began drilling for water to cool sawing operations. They drilled several wells, but subsequently abandoned them because the water was hot. Eventually, the thermal water was used to fill the mill pond, keeping it ice-free in the winter and thereby extending the mill operating season.

Three geothermal wells are currently in use: The Roosevelt Swimming Pool is heated with 36°C water from a geothermal well (27); the Church of Latter Day Saints (28) uses 49°C water to heat the buildings; and the Miller's Custom Work (29) uses 48°C water for cleaning equipment. In addition, the 26°C water (12°C above ambient) from Sierra-Pacific Industries' well near Susanville indicated an extensive reservoir of thermal water; the relatively low temperature may be the result of mixing with cool water near the Susan River.

Summary

The zone of hot water extends from the break in slope southwest of Susanville to the Susan River; its east-west extent is not known. The meager well data available indicate considerable variation of groundwater temperatures within the zone. The highest temperature found to date is 49°C. Because of the moderately low temperatures, space heating is probably the best application for the thermal water. In late August 1973, a well was being drilled near the Roosevelt Swimming Pool for natural hot water to heat a private home. The shop for a local moulding company has no central heating system; the workers use portable electric heaters in the winter. With increasing electricity costs, it may be practical to install a radiator system using geothermal heat. As pointed out earlier, Susanville's lumber mills could certainly benefit from the use of geothermal heat. Consideration should also be given to using heat from a single well in several buildings.

Any building already using a hot water heating system could be easily converted to geothermal heating. Before total development of the hot water zone takes place, plans could be made to avoid inefficient, piecemeal development of geothermal resources as in Klamath Falls.

Wendel-Amedee

The Wendel-Amedee area includes Wendel and Amedee Hot Springs and the small communities of Wendel and Amedee (Plate VI). The area, about 38 km east of Susanville in Lassen County, is bounded on the southwest by Honey Lake, and on the north and northeast by Shaffer Mountain and the Amedee and Skeedaddle Mountains. Honey Lake is a remnant of Pleistocene Lake Lahontan; it is an alkaline lake that is periodically dry in the summer. The main spur of the Southern Pacific Railroad crosses the Honey Lake basin on the east side, passing through Wendel. Other than the railroad, land use in the Wendel-Amedee area is largely confined to limited cattle grazing. Agriculture at lower elevations is restricted by the highly alkaline soils.

Climate

There are no meteorological stations within the Wendel-Amedee area. The nearest station is in Susanville (page 20). Because of its greater exposure, greater temperature extremes should be expected in Wendel than in Susanville, where the minimum temperature recorded during the winter of 1972-73 was -31°C.

Geology

The mountains northeast of the Wendel-Amedee area are composed of jointed and fractured Plio-Pleistocene vesicular basalt with some pyroclastic rocks. They have been uplifted along the Litchfield and Amedee faults. Up to 1,500 m of sandstone, tuffaceous siltstone, and diatomite accumulated in Pliocene lakes in the Honey Lake basin. These slightly consolidated deposits are overlain by Holocene fan deposits, sandy alluvium, silty basin deposits, and loose, wind-blown sands. The Litchfield, Amedee, and Wendel faults may provide paths for deep circulating meteoric waters which surface as hot springs.

Hydrology

The Susan River enters Honey Lake about 9 km west of Wendel.

Diversions from the river provide much of the irrigation water for the Honey Lake basin. Domestic water for Wendel is supplied by the Southern Pacific well, in NE 1/4, SW 1/4, Sec. 30, T. 29 N., R. 16 E., which is pumped at about 5,000 l/min. In parts of the Wendel-Amedee area, including the immediate vicinity of Amedee Hot Spring, groundwater contains excessive concentrations of total dissolved solids, boron, fluoride, and nitrate. Domestic water for the one residence at Amedee is carried in from the well at Wendel. Wells drilled near Wendel tap moderately permeable lake and near-shore deposits, and generally yield sufficient quantities of water. Limited recharge potential and less permeable deposits may limit yields from wells near Amedee; however, some shallow aquifers have been tapped at a depth of 100 m, 2 to 3 km north or east of Amedee Hot Springs.

Known Springs and Wells

Wendel Hot Springs (30), discharging 1,200 l/min at 96°C, is the site of Hobo Wells, Inc., currently northern California's only commercial geothermal agriculture development. The feasibility of geothermal greenhouses in Wendel's rigorous climate has been demonstrated by two successful tomato crops. A complete description of this operation is given on pages 9–10. The hot water issues from basin deposits near the intersection of the Litchfield and Wendel faults. A row of tufa mounds up to 10 m high marks the site of former hot springs along an approximate east-west line, possibly related to the Wendel fault.

Amedee Hot Springs (32) discharge 500 l/min at 95°C from basin deposits near the intersection of the Litchfield and Amedee faults. No use is made of the heat; the water is used only for bathing and stock watering.

Exploration wells (not shown on map) for thermal water were drilled in 1962 by Magma Power Co. near both Wendel and Amedee Hot Springs. A well (31) near Wendel, in Sec. 23, T. 29N., R. 15E., drilled to 189 m, produced water at 64°C. Three wells (33) were drilled in Sec. 4 and Sec. 8 of T. 28N., R. 16E., near Amedee. The maximum depth was 334 m, and the maximum temperature was 107°C. All four wells were abandoned. Also worthy of mention is a hot spring (34) with a temperature of 42°C near the town of Doyle (3 km south of the map border on U.S. Highway 395).

Summary

The shallow exploration wells drilled in the Wendel-Amedee area did not indicate temperatures substantially above boiling; however, temperatures at depth are not yet known. Sufficent quantities of water at 90 to 100°C are available for space heating, agricultural, and industrial uses. Plans for expansion have been made by Hobo Wells, Inc., to utilize more of the heat from Wendel Hot Springs. Other agricultural uses, particularly those related to the cattle industry, may be applicable in the Wendel-Amedee area. Raising seedling conifers in controlled environments using geothermal heat is already being considered. Extensive logging in nearby areas creates a large demand for seedlings for reforestation. Industrial uses are limited by the low population and the distance to a major trade center. The area has immediate access to the Southern Pacific Railroad and U. S. Highway 395, but Reno, the nearest sizable town, is 160 km to the southeast.

Sierra Valley

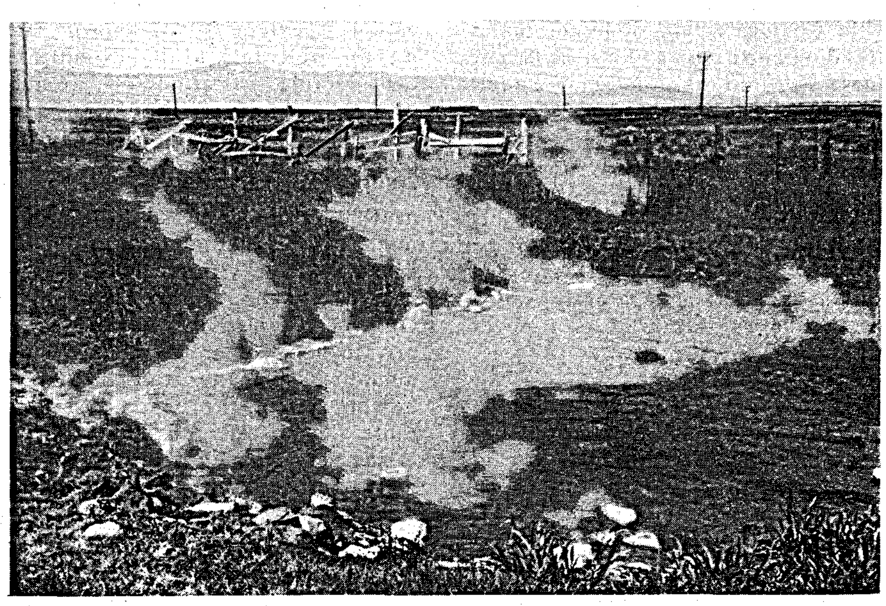
Sierra Valley is a large square basin, about 19 km on each side, straddling the boundary of Sierra and Plumas Counties, at an elevation of about 1,500 m (Plate VII). The Middle Fork of the Feather River passes through the valley and flows westerly across its northern edge between the towns of Vinton and Portola. An arm of the valley about 11 km long and 6 km wide extends south to the town of Sierraville. The valley floor is sparsely populated and used largely for cattle grazing. The lumber industry, including a mill at Sattley, is a major employer. Campbell Hot Springs (45) are the only natural hot springs in the valley; McLear's Warm springs (46) are near the town of Clio, about 10 km west of Sierra Valley. All other evidence of thermal water is from wells drilled in the central part of the valley.

Climate

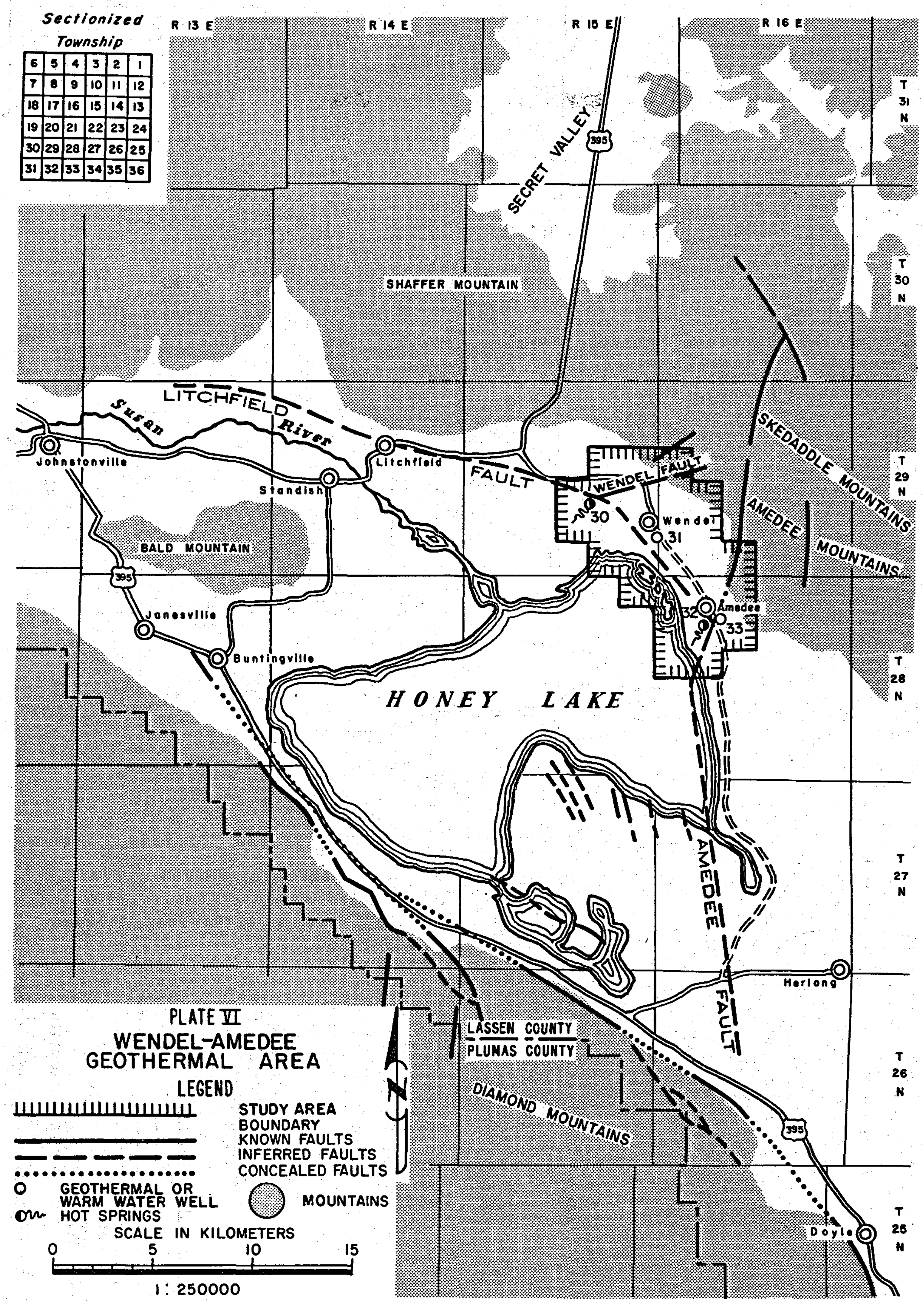
Average temperatures in Sierra Valley measured at Portola are -3°C in January and 17°C in July. The maximum and minimum temperatures recorded over a 28-year period were 40°C and -37°C. The town receives an average annual precipitation of 56.4 cm, with a January average of 11.1 cm and a July average of 0.89 cm. Most of the winter precipitation is snow. Average daily sunshine ranges from 5.5 hours in the winter to 13 hours in the summer.

Geology

Sierra Valley is underlain by slightly weathered granitic rocks that are impermeable except where they are cut by faults. Paleozoic metamorphic rocks crop out between Sierra Valley and the Mohawk Valley fault. Tertiary volcanic rocks overlie the basement complex over much of the area. Lakes occupied the valley



Amedee Hot Springs, flowing 95°C water at 500 l/min. Wendel-Amedee area, Lassen County.



Sectionized Township
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T 27 N
T 26 N
T 25 N
SECRET VALLEY
395
SHAFFER MOUNTAIN
LITCHFIELD
FAULT
Susan River
Johnstonville
Litchfield
Standish
WENDEL FAULT
30
Wendel
31
SKEDADDLE MOUNTAINS
AMEDEE MOUNTAINS
BALD MOUNTAIN
Janesville
Buntingville
Amedee
32
33
HONEY LAKE
AMEDEE
FAULT
Herlong
LASSEN COUNTY
PLUMAS COUNTY
DIAMOND MOUNTAINS
Doyle
N
PLATE VI
WENDEL-AMEDEE GEOTHERMAL AREA
LEGEND
STUDY AREA BOUNDARY
KNOWN FAULTS
INFERRED FAULTS
CONCEALED FAULTS
GEOTHERMAL OR WARM WATER WELL
HOT SPRINGS
MOUNTAINS
SCALE IN KILOMETERS
0 5 10 15
1: 250000

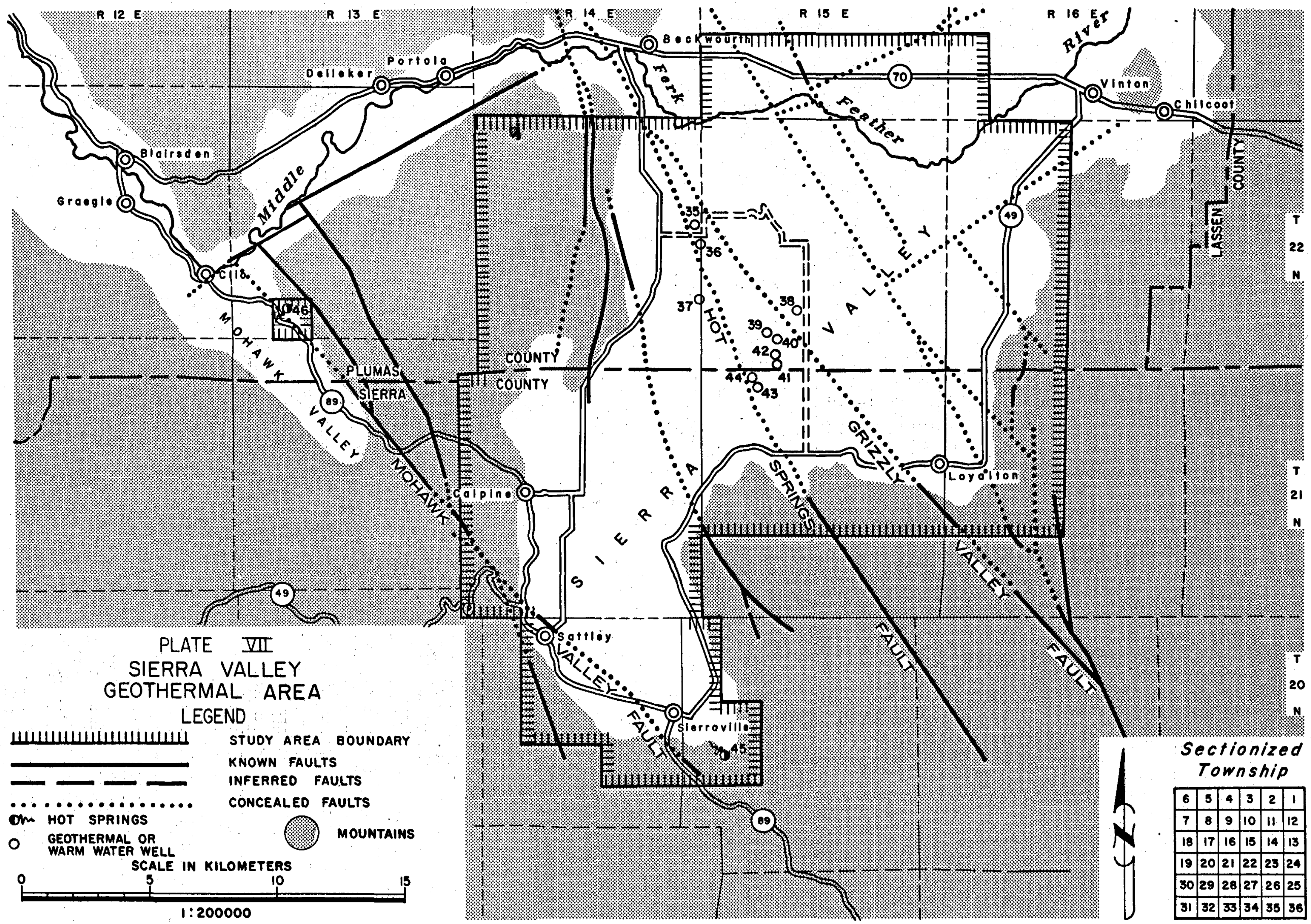


PLATE VII
SIERRA VALLEY
GEOTHERMAL AREA
LEGEND

during the Pleistocene, and up to 600 m of sand, silt, clay, and diatomite were deposited. The lake deposits are overlain by 15 m of Holocene, silty basin deposits. Since the Pleistocene, headward erosion by the Middle Fork of the Feather River has drained the lake, but only the extreme northwestern corner of the valley has been eroded.

Extensive faulting accompanied the Tertiary volcanism, leaving the downdropped blocks that form the Sierra and Mohawk Valleys. The basement rocks underlying Sierra Valley are broken into tilted blocks and are bounded by normal faults. These faults may serve as passages for deep circulation of meteoric water. Extensive Tertiary volcanic rocks and local Pleistocene basalt flows indicate the possibility of a heat source at depth.

Hydrology

Most of the rock units in the upland areas surrounding Sierra Valley are of very low permeability. Recharge to groundwater comes mainly from water infiltrating alluvial fans and sandy lake shore deposits along the valley margins. Shallow wells (less than 30 m deep) tap an unconfined aquifer, which provides water mostly for domestic use. Deeper flowing wells intercept numerous confined aquifers within the lake sediments. Much of the central part of the valley has a poor potential for groundwater development because of the overall low permeability of the lake sediments. Sufficient quantities of groundwater for irrigation are available only in small areas near Loyalton and Sierraville, where thick alluvial fan and lake shore deposits are present.

A distinct mound in the piezometric surface of the confined groundwater in the vicinity of Marble Hot Springs (35, 36) may indicate upwelling thermal water. Water in this area may contain excessive concentrations of dissolved solids, boron, and fluoride. Soils immediately surrounding Marble Hot Springs are slightly saline, indicating the sodium chloride character of the thermal water. Mineralized thermal water may migrate from wells and springs into nearby cold-water aquifers.

Known Springs and Wells

Campbell Hot Springs (45), discharging 12 l/min at 37 to 44°C, are the only natural hot springs in Sierra Valley. They occur at the edge of the hills southeast of Sierraville, near the Mohawk Valley fault. The fault zone extends northwesterly through Mohawk Valley. McLear's warm springs (46), discharging 530 l/min at 30°C, issue along the fault zone near the town of Clio in Mohawk Valley.

A number of wells (35 through 44) tap a hot-water aquifer in the center of Sierra Valley. The hot water is largely confined to the block defined by the Grizzly Valley and Hot Springs faults. The most notable wells are the Marble Hot Springs wells (35 and 36) and Filipini well 1 (42). Marble Hot Springs are actually two old artesian wells discharging a total of 180 l/min at 70 to 73°C. The hot water is not used. Filipini well 1, the hottest well in the valley, discharges 50 l/min at 94°C. The remaining wells, all under 200 m deep, range in temperature from 39 to 55°C.

Summary

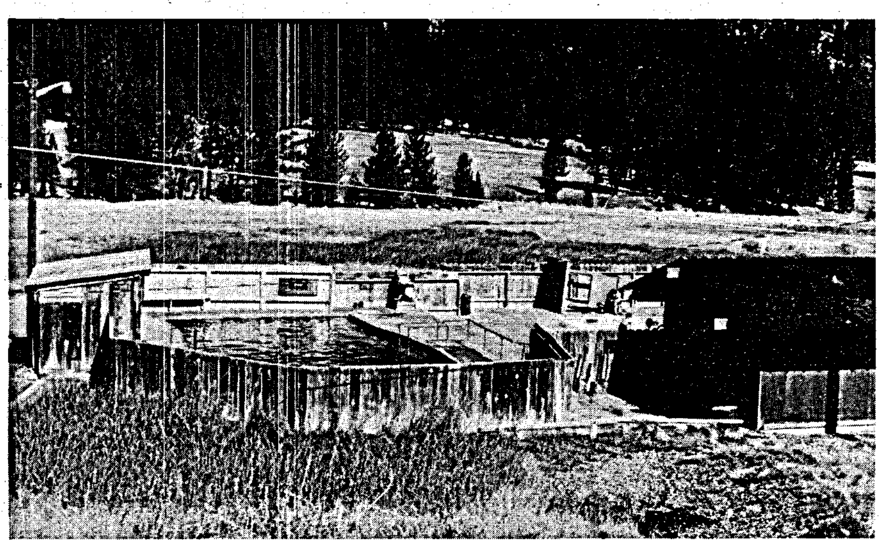
Significant quantities of hot water are available in central Sierra Valley and along the Mohawk Valley fault. The valley has potential for agricultural operations using geothermal heat, particularly operations related to the cattle industry, such as drying feed, heating feed lots, and heating drinking water. Because Sierra Valley is relatively close to the Tahoe and Reno markets, raising of poultry or swine in controlled environments heated by thermal water may be economical. The lumber mill in Sattley, near the Mohawk Valley fault, could reduce fuel costs by supplying natural hot water to the boilers. Homes and commercial establishments near hot-water zones could use the water for space heating. Sierra Valley's geothermal resources merit further exploration. The towns of Sattley, Sierraville, Loyalton, and Calpine could benefit from more precise mapping of hot-water zones.

Eastern Sierra Springs

Following are descriptions of two hot springs that are not shown on a map because of their relative unimportance; however, they are included here for the sake of completeness.

•Brockway Hot Springs (47) occur in a line along an east-west trending fault on the north shore of Lake Tahoe at King's Beach. Almost all the flow of 600 l/min of 55°C water comes from the largest spring, a few meters offshore. Since the earliest settlement around Lake Tahoe, the springs have been part of a resort. They are presently included in a group of condominiums named Brockway Springs. The springs are currently unused, but could be used, at least to heat the resort's swimming pool. Industrial development is unlikely because of the low temperatures and location in the Tahoe basin.

Grover Hot Springs (48) discharge 500 l/min of 64°C water at the south edge of a small valley 7 km east of the town of Markleeville, Alpine County. One main spring and several smaller springs and seeps issue near the break in slope, 5 to 10 m above the valley floor. Faulting along the edge of the valley may provide a pathway for deep-circulating meteoric water. There are no other springs or hot wells in the area.



Pool heated by geothermal waters at Grover Hot Spring State Park in Alpine County.

The springs are protected as the central attraction of Grover Hot Springs State Park. A small swimming pool and a hot bath are filled by the springs. Because the only known springs in the area are protected by the park, and because the temperatures are relatively low, potential for commercial development is limited.

Bridgeport Valley

Bridgeport Valley is a structural basin about 10 km wide and 12 km long, at an elevation of 2,000 m (Plate VIII). It is bounded by the Bodie Hills to the east and the east face of the Sierra Nevada to the west. U. S. Highway 395 traverses the valley from north to south, passing through the small town of Bridgeport, seat of Mono County. The valley floor, adjacent to the East Walker River, is used mainly for growing hay and for summer pasture for cattle. Because of the high elevation and consequent cold winters, the cattle are taken to lower winter pastures in Nevada. Hot Springs occur in three places near the Bridgeport Valley: above the valley floor about 8 km west of Bridgeport along Buckeye Creek, and in two locations on the edge of the Bodie Hills, 1 and 2 km south of Bridgeport.

Climate

Temperatures in the Bridgeport Valley range from a January average of -3°C to a July average of 17°C. The maximum and minimum temperatures over a 13-year period were 33°C and -37°C. The valley receives an average annual precipitation of 37.8 cm, with a January average of 4.9 cm and a July average of 1.2 cm. Much of the winter precipitation is snow; however, because of the semiarid conditions, snow does not accumulate to great depths. The area receives a high percentage of sunshine with a daily average of 6.5 hours of sunshine in the winter and 13 hours of sunshine in the summer.

Geology

Bridgeport Valley is an alluvium-filled basin between the Sierra Nevada and the Bodie Hills. In the Sierra Nevada, west of Bridgeport, a basement complex of granitic rocks and Mesozoic metamorphic rocks is overlain by Tertiary volcanic rocks. In the vicinity of Buckeye Hot Springs (50), Buckeye Creek has carved a deep canyon exposing coarse-grained granite. Cobbles of hornblende andesite and pre-Mesozoic metamorphic rocks dot the slope. The rocks are highly altered by hydrothermal activity, and mounds and sheets of tufa mark the site of past and present hot springs.

A distinct northeast-trending gravity low crossing the Bodie Hills may indicate a graben, partially filled with low-density Tertiary volcanic rocks and alluvium. The graben includes Bridgeport Valley, the two hot springs areas, and Big Alkali Flat. Big Alkali Flat, once the source of dacite pyroclastic debris and flows, is a collapsed caldera. Emplacement of dacite plugs, irregular rhyodacite dikes, and rhyolite plugs followed the collapse (Chesterman, 1968). Hydrothermal alteration is common around the caldera, particularly in the porous pyroclastic rocks. The impermeable dacite flows have been altered along contacts and fractures. Cinnabar is found in Cinnabar Canyon, south of the caldera. Evidence of continuing hydrothermal activity is found in the two hot spring systems near Bridgeport, warm springs east of the caldera and, perhaps, the alkaline springs within the caldera.

Hydrology

Ample fresh water is available in the Bridgeport Valley both from surface water and wells. A dam creating the Bridgeport Reservoir backs up the East Walker River as it flows out of the valley at the north end. The greatest groundwater problem in the valley is the high water table. Near the reservoir, a thin layer of impermeable clays confines the groundwater to shallow depths; wells tap aquifers only 1 or 2 m below the surface and produce water by artesian flow. Unlike many of California's eastern basins, neither water quantity nor quality is a problem in Bridgeport Valley.

Known Springs and Wells

Fales Hot Springs (49) is north of Bridgeport Valley on U. S. Highway 395, about 0.8 km west of Devil's Gate Pass, in a narrow fault-controlled valley at an elevation of about 2,300 m. Some of the springs' total flow of 1,050 l/min of 80°C water is diverted to a small swimming pool. A few cabins and a trailer camp surround the pool. Mounds of tufa up to 3 m high cover an area of about 100 m², north of the springs just across U. S. Highway 395. According to a local resident, the present spring is relatively new, and as little as 50 years ago, major springs occurred in the area of the tufa mounds. The mounds are presently dry at the surface.

Because the spring is in a narrow valley at a high elevation, with little flat land and few hours of sunlight, agricultural or industrial uses of the hot water are impractical. A resort, hotel, or trailer park, attracting skiers, hunters, or tourists, could use the hot water for domestic heating and extend use of the swimming pool.

Travertine Hot Springs (51) issue from fractures in otherwise impervious dacite flows. The springs have deposited travertine ($CaCO_3$) in an unusual cluster of five ridges along the fractures. The ridges are 10 to 20 m long and up to 3 m high, and have narrow crevices up to 1 m deep along their axes. Occasional small seeps are found in the crevices, and gurgling sounds can be heard in several places where no water is found on the surface. The main spring (flowing from the crevice at the west end of one ridge) is still depositing travertine. Gas, probably carbon dioxide, rises with the water. The springs and seeps discharge a total of 50 l/min at 50 to 65°C. The soil around the ridges is covered with white mineral deposits, mostly calcium carbonate. The soil is saturated with water; tire tracks and footprints fill with water even during the dry summer months. The travertine has been mined sporadically in the past, but there is currently no economic use of the land.

About 1 km south of Travertine Hot Springs, at the edge of the same dacite unit, a second group of hot springs (52) discharge a total of about 100 l/min at 35 to 45°C. Numerous pools of varying temperature and chemistry are scattered over a broad terrace.

The surrounding soil, as at Travertine Hot Springs, is saturated and covered with white salt deposits. Similar deposits mark the soils between the two groups of springs and in Big Alkali Flat.

Thermal and mineral water in these areas may have a common origin. The heat source is probably a slowly cooling body of molten rock underlying the volcanic rocks of the Bodie Hills. The location and temperature of each spring is controlled by fracture systems in the dacite flows and the permeability of rock units below the dacite.

Buckeye Hot Springs (50) are probably not related to the other hot spring areas. They occur near the

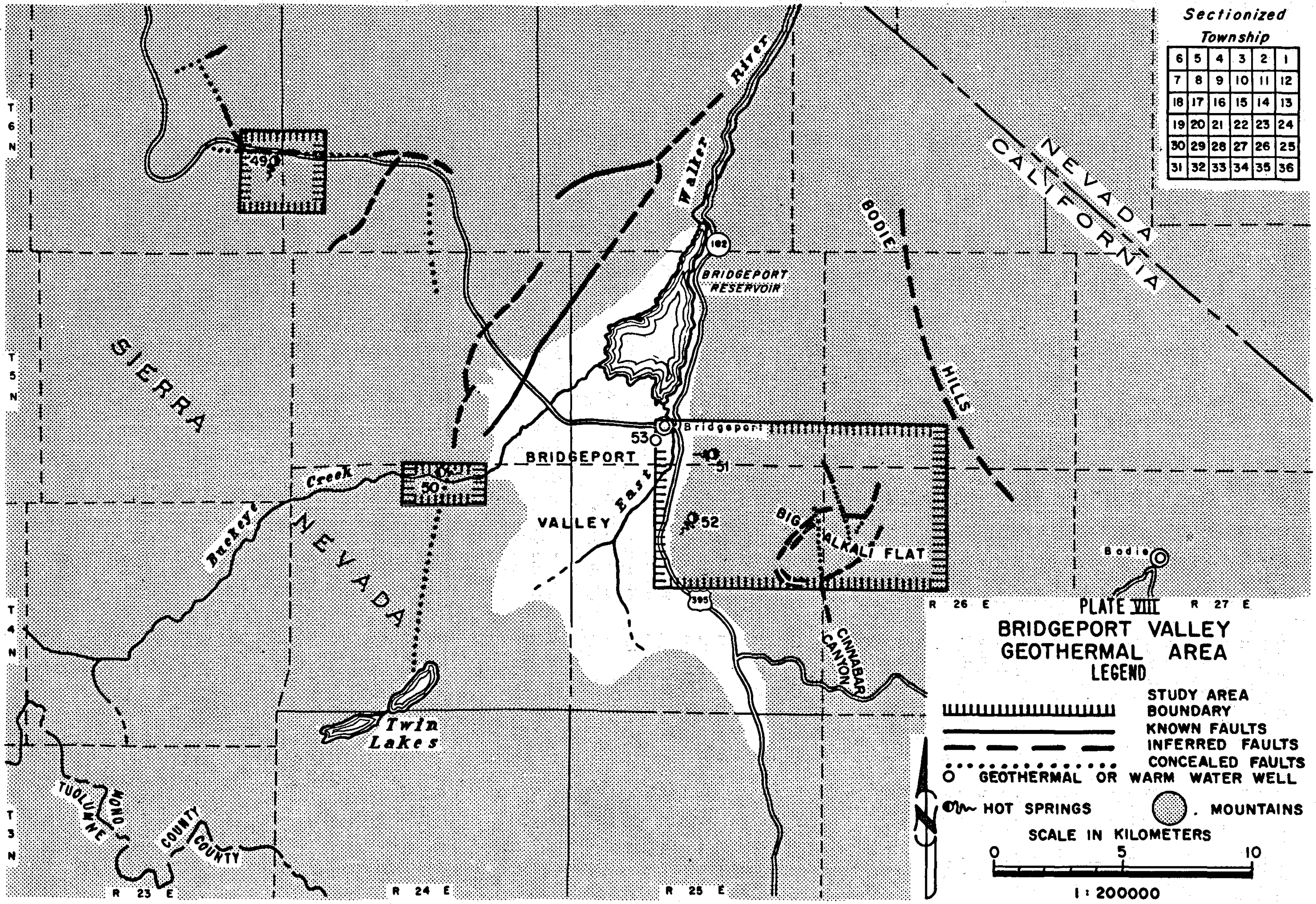


PLATE VIII
BRIDGEPORT VALLEY
GEOTHERMAL AREA
LEGEND
STUDY AREA BOUNDARY
KNOWN FAULTS
INFERRED FAULTS
CONCEALED FAULTS
GEOTHERMAL OR WARM WATER WELL
HOT SPRINGS
MOUNTAINS
SCALE IN KILOMETERS
0
5
10
1 : 200000
Sectionized Township
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36
NEVADA
CALIFORNIA
SIERRA NEVADA
BODIE HILLS
Walker River
East
Buckeye Creek
BRIDGEPORT RESERVOIR
Bridgeport
BRIDGEPORT VALLEY
BIG ALKALI FLAT
CINNABAR CANYON
Twin Lakes
Bodie
TUOLUMNE COUNTY
MONO COUNTY
182
395
49
50
51
52
53
T 6 N
T 5 N
T 4 N
T 3 N
R 23 E
R 24 E
R 25 E
R 26 E
R 27 E

base of the Sierra Nevada on the steep canyon wall of Buckeye Creek and discharge about 200 l/min at 60°C. The hot water has deposited tufa in several places, including a large sheet overhanging Buckeye Creek. The outflows from two smaller springs have been dammed with rock piles and plastic sheets to make small bathing pools. There is no economic use of the hot water. Development is restricted by the rugged terrain; the nearest level areas are 1 and 2 km from the springs.

Magma Power Company drilled a well (53) * near Bridgeport in 1962 to a depth of 280 m, and a maximum temperature of 50°C was recorded. The well was abandoned.

Summary

The two hot spring areas at the edge of the Bodie Hills near Bridgeport have potential for development if more successful wells can be drilled. Exploration may be limited by the lack of good roads to the springs or into the Bodie Hills in the direction of the heat source. The current temperatures and flows are not sufficient for economic use. Level ground and fresh water are available for small industry or agricultural developments. South Lake Tahoe, Carson City, and Reno, 120 to 150 km to the north, represent potential markets. Use of geothermal heat for processing or agriculture would probably be economical if raw materials were available locally. Recommended uses are for animal husbandry, greenhouse heating, drying or processing animal feed or wastes, or drying grain. Space heating would be economical (on a cooperative basis) for buildings near the geothermal source, such as the motels along Highway 395 south of Bridgeport.

Mono Lake Basin

The Mono Lake basin (Plate IX) has a barren, volcanic landscape. As a result, even grazing is limited. The major feature of the basin is Mono Lake, the remnant of a much larger Pleistocene lake. There is no present outlet from the lake and evaporation far exceeds inflow. Consequently, the lake volume is shrinking at a rate of about 500 million m^3 per year. Salts carried into the lake are left behind as the water evaporates, and the concentration of total dissolved solids in the lake water now exceeds 60,000 ppm. The lake currently covers about 330 km^2 at an elevation of about 1,922 m. The entire Mono Lake basin has a population of about 700 people, mostly concentrated in the town of Lee Vining near the juncture of U. S. Highway 395 and State Highway 120. The major source of income is from services and tourist facilities.

Climate

In general, the climate of the Mono Lake basin is similar to that of Bridgeport. Because of the slightly lower elevation, slightly higher temperatures occur. The very abrupt face of the Sierra Nevada accentuates the rain shadow effect, producing a dry climate.

Geology

A normal fault with large vertical offset forms the distinct southwestern boundary of the Mono Lake basin. Beyond this fault, the Sierra Nevada rise dramatically to peaks above 3,700 m. The remaining boundaries of the basin are formed by small uplifted fault blocks and low volcanic hills. The most outstanding volcanic feature is the arc of the Mono Craters, extending about 13 km from north to south. The steep sided Holocene cones, composed of rhyolite ash, lapilli, and pumice, and obsidian flows, reach a height of 2,800 m, some 850 m above the floor of the basin.

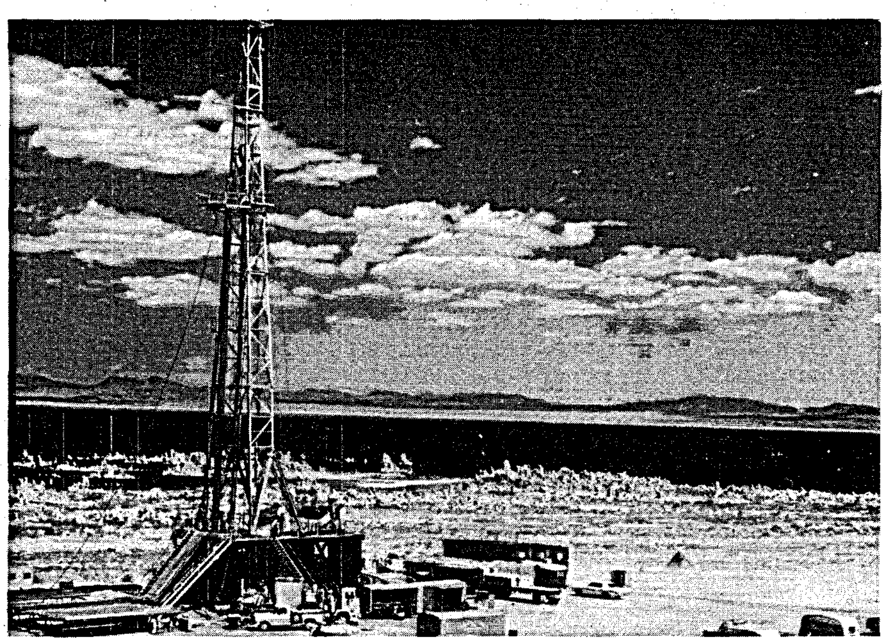
Lithologic columns from two geothermal exploration wells drilled on the shores of Mono Lake provide subsurface data on the geology of the basin (Axtell, 1972). On the north shore near Black Point, granite gneiss basement was reached at 1,217 m. On the south shore, weathered basement rock (biotite granodiorite) was encountered at 731 m. In both locations, the basement rocks are overlain by interbedded alluvium, lake deposits, tufa, and felsic pyroclastic rocks.

Hydrology

Because of the low population and lack of demand for irrigation water, fresh-water requirements in the Mono Lake basin are low. Surface runoff, mainly from the Sierra Nevada, contributes 2.7 billion m^3 of fresh water to the basin annually. Local demands require only 3% of this. The City of Los Angeles, the owner of the water rights, exports about one-third of the surface flow. Prior to the start of exportation, the level of Mono Lake was stable. Today, exportation of surface runoff is causing the lake level to drop. Fresh-water springs are common within Mono Lake itself and adjacent to the surrounding hills.

Known Springs and Wells

The most notable hot springs in the Mono Lake basin are on Paoha Island in Mono Lake. Waring (1965) reports steam vents and thermal springs (55) as hot as 95°C. A warm spring (54) on the east shore of the lake discharges about 40 l/min at 33°C. The spring once had facilities for bathing but is presently unused. There are reports of "numerous ther-



Drilling rig at Geothermal Resources International, Inc., Well No. "State PRC 4397.1" 1, on the south shore of Mono Lake, Mono County.

*Exact location not available, not shown on map.

mal springs in the basin" (Axtell, 1972), but locations are not given.

Two geothermal exploration wells were drilled in 1971 on the shores of Mono Lake. Geothermal Resources International, Inc., Well No. "State PRC 4397.1" 1, was drilled in SW 1/4, SW 1/4, Sec. 17, T. 1N., R. 27E. (57) to a depth of 1,250 m, and a maximum temperature of 54°C was recorded. The second well, No. "State PRC 4572.1" 23-1 (56) was drilled by Getty Oil Co. near the NW corner of Sec. 23, T. 2N., R. 26E., to a depth of 743 m and had a maximum temperature of 57°C. Both wells were abandoned.

Summary

The low temperatures in the two wildcat wells did not indicate an economic resource; however, the springs on Paoha Island indicate much higher temperatures. Further geophysical studies might aid in locating an economical geothermal system. Because of the low population and limited resources of the Mono Lake basin, and the long distances to major transportation centers, large industrial operations seem improbable.

Long Valley

Long Valley is a 14 by 30 km depression extending east from the Mammoth Lakes area of Mono County (Plate X). The irregular floor of the valley ranges in elevation from 2,030 to 2,400 m. A low mountain mass in the western half of the depression includes rhyolite domes reaching heights of 2,814 m. Mammoth Mountain, on the southwest rim of the depression, has an elevation of 3,316 m. Most of Long Valley's small population is clustered in the resort areas around Mammoth Lakes. The remaining land is utilized largely for cattle grazing. Other developments include a fish hatchery on Hot Creek, a gravel pit, and a kaolinite quarry.

Climate

There is no permanent meteorological station in Long Valley. Based on the nearest stations (Bridgeport and Bishop), temperatures range from a January average of about 0°C to a July average of about 20°C. Temperature extremes are about -30°C and 38°C. Average annual precipitation is 25 to 30 cm, falling mostly during the winter months as snow. The average hours of daily sunshine ranges from 6.5 in the winter to 13 in the summer.

Geology

The Long Valley depression is an oval-shaped collapsed caldera thought to have been brought about during the eruption of the Bishop Tuff about 700,000 years ago. Incipient resurgence is evidenced by the intrusion of rhyolite domes in the southwestern half of the caldera, and the quartz latite of Mammoth Mountain, 15,000 to 37,000 years ago (Sheridan, 1971). Recent and historic volcanic activity has occurred north of Long Valley at Inyo and Mono Craters. The hot springs in Long Valley are closely related to tectonic activity. Sheridan (1971) states that "(the caldera) shows incipient resurgence associated with hydrothermal activity in the southern ring-fracture zone." The low mountain mass within the caldera is cut by numerous high-angle north-to-northwest-trending faults. Almost all the hot springs occur along these faults or along their projected strikes.

Most of the volcanic units in Long Valley are interbedded with or overlain by deposits from the Pleistocene Long Valley Lake. The deposits are largely well-indurated tuffaceous sandstones grading locally into conglomerates. Opaline cement resulting from hydrothermal activity makes up as much as 20% of the rock (Rinehart and Ross, 1964). Clay and silt-sized sediments crop out in the center of Long Valley, and also occur interbedded with the sandstone at depth.

Extensive hydrothermal alteration, indicated by deposits of opal, tufa, travertine, and kaolinite, suggests a long history of thermal activity. Minor silica encrustations and cinnabar-bearing clay have been observed near Casa Diablo Hot Springs (58) (Rinehart and Ross, 1964). Tufa deposits clearly related to hydrothermal activity occur at numerous locations in Long Valley. Tufa caps a small hill northeast of Whitmore Hot Springs (64), but this larger mass may be the result of algal deposits from Long Valley Lake. However, the deposit is intersected by a fault and deposition by thermal springs has not been disproved.

Hydrology

Seasonal run-off from the Sierra Nevada into Long Valley has been estimated at 1.65 billion m^3 per year. Current local demands require only 2 to 3% of the available surface water. The remainder flows into the Owens River, which is impounded in Lake Crowley to supply water for Los Angeles. Although the water in Hot Creek near the hot springs is high in dissolved solids, it is diluted to acceptable standards as it mixes with other surface water.

The groundwater in Long Valley is generally of good quality, and many wells have artesian flow. Poor quality groundwater is found along an east-west trend from Casa Diablo Hot Springs to the thermal springs on Hot Creek. Water in this area contains excessive concentrations of fluoride, boron, and a high percentage of sodium.

Known Springs and Wells

Between 1959 and 1962, Magma Power Co. and Associates drilled 20 exploratory geothermal wells (60) near Casa Diablo Hot Springs and one near an adjacent hot spring (59). The wells reached a maximum depth of 323 m and a maximum temperature of 178°C. The wells produced hot water (maximum flow of 1,900 l/min) with about 5% steam flashover. Difficulties were encountered with scaling and waste disposal. High concentrations of arsenic (1.7 ppm), boron (14.3 ppm), fluoride (13.6 ppm), total dissolved solids (1,530 ppm), and high electrical conductivity (1.920 micromhos) preclude direct use for domestic or agricultural purposes. Although the prospects for geothermal electrical power production appear to be good, the wells have all been capped and no future plans have been divulged.

Casa Diablo Hot Springs (58) issue from Quaternary basalt on both sides of the old U. S. Highway 395 near the Mammoth Lakes turnoff. About 20 springs and fumaroles, ranging from 46 to 90°C, discharge a total of about 130 l/min. Hydrothermal alteration around the springs includes minor opal and siliceous sinter, and extensive kaolinite and tufa deposits. Most of Magma Power Co.'s wells were drilled near the springs. The two commercial enterprises are a Southern California Edison substation and a retail lumber company, neither of which utilize the geothermal heat.

The Casa Diablo Hot Pool (59), near Hot Creek Ranch, flows only intermittently but maintains a temperature of about 80°C. The pool occurs in tuffaceous lake deposits near faulted Tertiary rhyolite.

Several hot springs and an occasional geyser (62) flow into Hot Creek where it crosses the boundary of R. 28E. and R. 29E. According to Waring (1965), five main springs

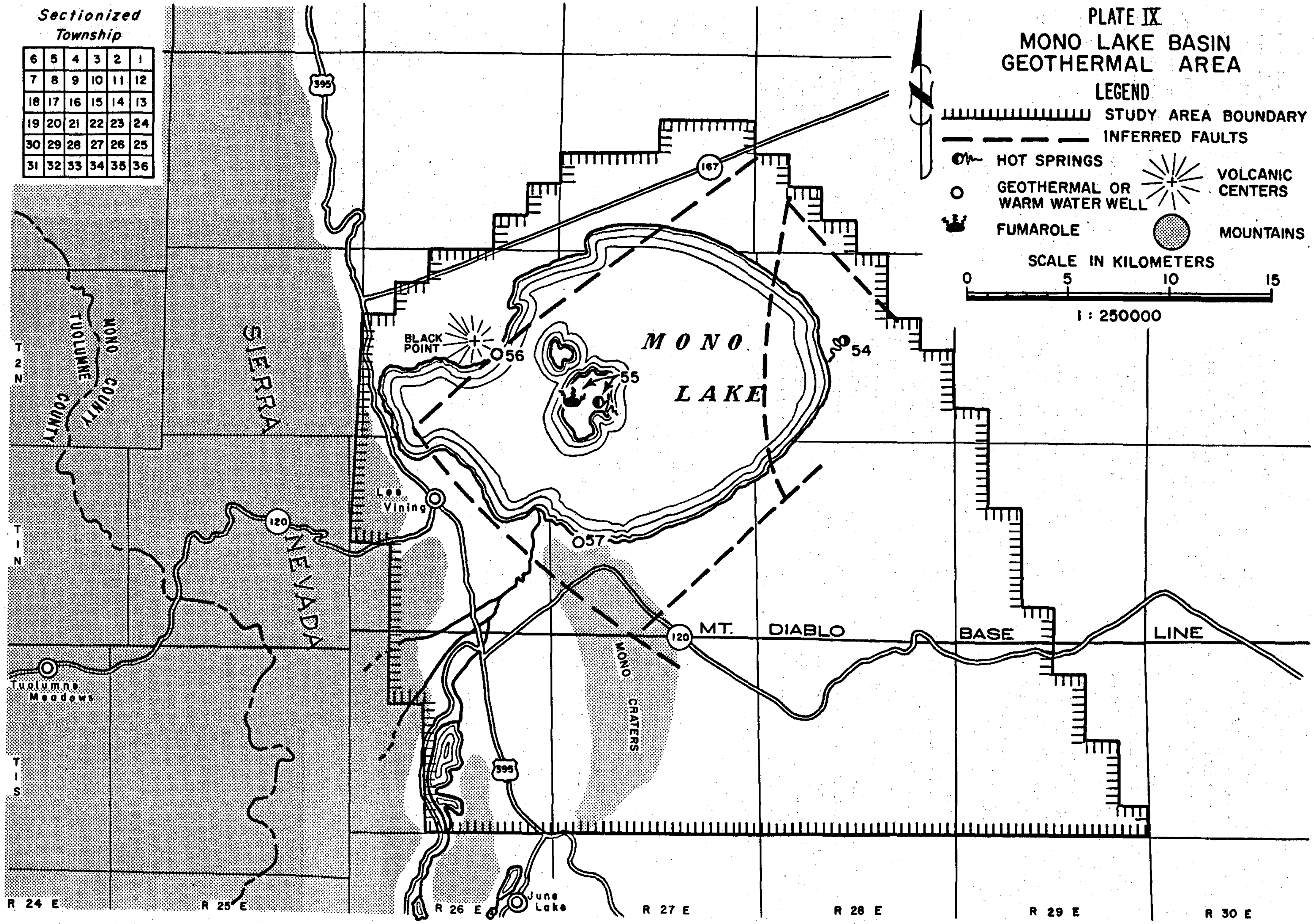


PLATE IX
MONO LAKE BASIN
GEOTHERMAL AREA
LEGEND
STUDY AREA BOUNDARY
INFERRED FAULTS
HOT SPRINGS
GEOTHERMAL OR WARM WATER WELL
FUMAROLE
VOLCANIC CENTERS
MOUNTAINS
SCALE IN KILOMETERS
0 5 10 15
1 : 250000
Sectionized Township
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36
MONO LAKE
BLACK POINT
56
55
54
57
Lee Vining
SIERRA
NEVADA
MONO COUNTY
TUOLUMNE COUNTY
MONO CRATERS
MT. DIABLO BASE LINE
Tuolumne Meadows
June Lake
395
167
120
T 2 N
T 1 N
T 1 S
R 24 E
R 25 E
R 26 E
R 27 E
R 28 E
R 29 E
R 30 E

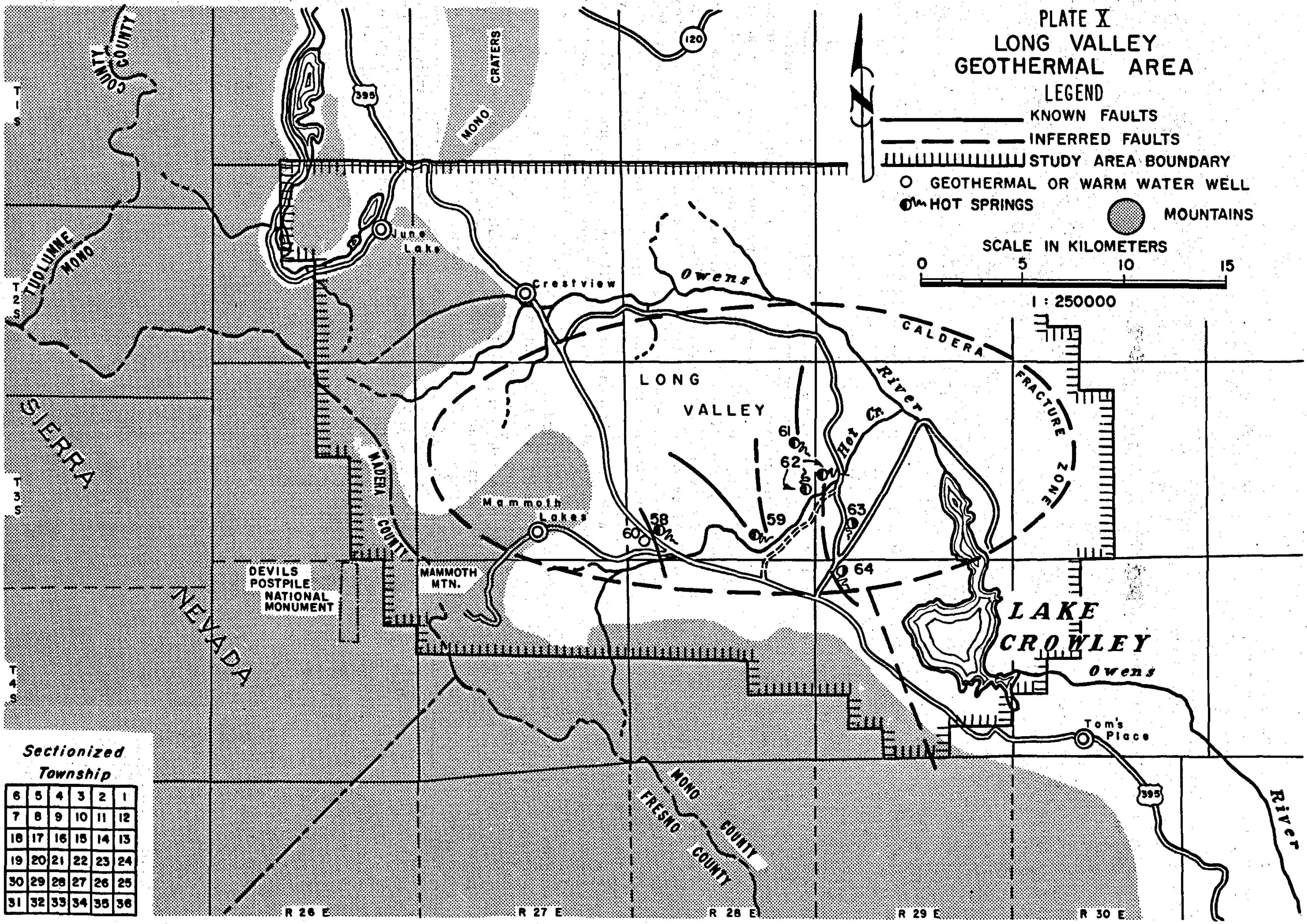


PLATE X
LONG VALLEY
GEOTHERMAL AREA
LEGEND
KNOWN FAULTS
INFERRED FAULTS
STUDY AREA BOUNDARY
GEOTHERMAL OR WARM WATER WELL
HOT SPRINGS
MOUNTAINS
SCALE IN KILOMETERS
0 5 10 15
1 : 250000
LONG VALLEY
CALDERA
FRACTURE ZONE
Owens River
Hot Cr.
LAKE CROWLEY
Owens River
Tom's Place
Crestview
June Lake
Mammoth Lakes
MAMMOTH MTN.
DEVILS POSTPILE NATIONAL MONUMENT
MONO CRATERS
SIERRA NEVADA
TUOLUMNE MONO
COUNTY COUNTY
MADERA COUNTY
MONO COUNTY
FRESNO COUNTY
58
59
60
61
62
63
64
120
395
T 1 S
T 2 S
T 3 S
T 4 S
R 26 E
R 27 E
R 28 E
R 29 E
R 30 E
Sectionized Township
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36

produce a total of 1,900 l/min of water at 90 to 95°C. At least three steam vents also occur along the stream bank. Since August 24, 1973, nine new springs, mudpots, and fumaroles have appeared about 100 m downstream from the original group. These range in temperature from 90 to 95°C and have an estimated total flow of 1,100 l/min. Most of the flow comes from one large geysering spring. Much of the rhyolite around Hot Creek has been altered to kaolinite, and extensive tufa deposits occur for about 300 m along the creek. The new springs flow over thick tufa deposits, indicating probable rejuvenation of older springs.

The U. S. Forest Service has improved the Hot Creek hot springs area for swimming. A good gravel road provides access to the plateau above the creek where there is a parking lot and changing rooms. A short, paved trail descends the cliff to the creek and a footbridge crosses the creek near the main springs. The area is popular for bathing, but no other use is made currently of the heat.

Whitmore Hot Springs (64) discharges about 1,150 l/min of water at 33°C. A resort was maintained at the springs for many years, but is not currently in operation. The present owners are hoping to reopen the resort in 1974.

In addition to the areas described, several other hot springs with temperatures up to 80°C occur in the low mountain mass of western Long Valley. Widespread deposits of kaolinite and tufa indicate inactive hot spring areas. Because the area is sparsely settled, and surface water is plentiful, only a few shallow wells have been drilled. Deposition of silica or calcium carbonate by rising hot water may have sealed the routes to the surface, concealing a boiling hot-water reservoir at depth. Subsurface exploration within the hot spring area might reveal large volumes of hot water. The reservoir temperature at the Casa Diablo wells is in excess of 188°C (Koenig, 1970).

Summary

The magnitude of Long Valley's geothermal resources makes a variety of applications practical. Several foreseeable uses of the heat are: space heating for the Mammoth School on Hot Creek and for homes and buildings at the fish hatchery, warming water in the fish hatchery, and drying kaolinite. Steam (if available) may also be used for running heavy equipment at the quarry. Other possibilities include greenhouse and aquaculture operations to provide fresh vegetables or warm-water fish for nearby resorts and the town of Bishop. Many of these operations could utilize waste heat from an electric generating plant if one is built. In general, Long Valley appears to be one of northern California's most promising geothermal resource areas.

U. S. Forest Service Recreation area on Hot Creek in Long Valley, Mono County.

Northern Napa Valley

Napa Valley is a long, narrow trough extending northwesterly for over 60 km from the San Pablo Bay to Mt. St. Helena (only the northern portion of Napa Valley has been shown on Plate XI). The valley averages 5 to 6 km in width, narrowing to 1 km at the northern end. Most of the natural hot water in the Napa Valley is found in and near Calistoga, the northernmost town in the valley. However, thermal springs and abnormally warm groundwaters are found as far south as Napa, 38 km from Calistoga. The northern end of the valley is devoted almost exclusively to viticulture.

Calistoga, with a population of about 2,000, has a long reputation as a health resort. The town has many hotels and spas advertising hot mineral baths, and despite the decline of other northern California spas, it has maintained a brisk business.

Climate

Temperatures in the northern Napa Valley range from a January average of 7.5°C to a July average of 21°C. The maximum and minimum temperatures recorded over a 31-year period are 46°C and -12°C. Average annual precipitation at St. Helena (13 km southwest of Calistoga) is 81 cm, with a January average of 19.2 cm and a July average of 1.0 cm. Rainfall increases toward the north end of the valley. The average daily number of hours of sunshine ranges from 5 in the winter to 9.5 in the summer.

Geology

The Napa Valley is a fault-controlled structural trough that is almost entirely surrounded by Pliocene volcanic rocks of the Sonoma Group. These overlie rocks of the Franciscan Complex of late Mesozoic age. The valley alluvium, which ranges in thickness from a few meters to over 300 m, can be separated into younger and older units. The younger alluvium unit is very thin in the northern part of the valley; however, to the south, it thickens and becomes an important aquifer. The older alluvial unit, often over 150 m thick, yields water from gravel lenses.

The Sonoma Group has been broken into three units (youngest to oldest) (Kunkel and Upson, 1960): (1) andesite and basalt flows, interbedded with tuffs, ash, pumice, mudflows, and agglomerates; (2) diatomaceous strata, water-laid ash and pumice, sand, gravel, and clay; and (3) the St. Helena Rhyolite, including flows, welded tuffs, some pumice, and perlitic obsidian.

Hydrology

Many of the rock units in and around the northern Napa Valley are impermeable. Good aquifers exist only in the thicker sections of the younger alluvium, gravel lenses in the older alluvium, and in some pyroclastic rocks of the Sonoma Group. High yield domestic water aquifers are difficult to locate in the Calistoga area. A lack of fresh ground water has been a problem for many years. A small reservoir north of town meets some demands, but it is generally dry by midsummer. Water from the Napa River and its tributaries is used for irrigation in the spring and early summer, but it also runs dry during the rainless summers. The town of Calistoga had two moderately deep wells drilled in search of a municipal water supply, but the wells reached warm water too highly mineralized for domestic use. Eventually, successful wells were drilled in the hills to the south of town. The major aquifers in the Calistoga area carry hot, mineralized water. Cold-water wells tap only small gravel lenses and seldom yield sufficient quantities of water for irrigation.

Known Springs and Wells

Calistoga Hot Spring (65) is the only known natural hot spring in the area. The spring has been almost obscured by a cluster of nearby artesian thermal wells. It discharges 30 l/min at 52 to 78°C.

Thermal water is found largely in two major areas in Calistoga: in the center of town, and near Tubbs Lane (1.5 km west of town). The latter area includes a geyser. Over 60 wells tap the hot water in the first area for use in health spas, for heating swimming pools, for domestic hot water, and for a water-bottling company. About 20 wells have been drilled in the second area for similar uses. Two of the wells are used sporadically for heating greenhouses. Calistoga's "Old Faithful" geyser (a 30-meter deep well), blowing steam and hot water up to 12 m above the ground every 35 to 50 minutes, is operated as a tourist attraction. Calistoga's wells have an average flow of about 80 l/min and range in temperature from 60 to 120°C. Interference between wells has not been a problem.

In 1960 and 1961, Calistoga Power Company drilled three exploratory geothermal wells (66). The maximum depth was over 600 m and the maximum temperature was 167°C. The wells produced hot water with minor steam flashover. Reservoir temperature was estimated to be about 170°C. Difficulties were encountered with scaling and waste disposal and the wells were abandoned.

Summary

Thermal water in the Napa Valley more than a few kilometers south of Calistoga is probably not hot enough for economical use; however, the Calistoga area has tremendous potential for geothermal development. Very inefficient use is made of the hot-water wells; many wells are temporarily or permanently out of use. Other high-temperature wells are being used a small percentage of the time to meet occasional low temperature heating needs. It would require almost 40,000 barrels of crude oil per year to heat cold water equal in volume to the water discharged by Calistoga's thermal wells. Substantial saving of fuel could be realized by the city if a more efficient central geothermal heating system were installed.

Unlike most of northern California's geothermal resource areas, Calistoga is close to a major urban center, 120 km north of San Francisco. Without unusually high transportation costs, a greater variety of geothermal heat applications may be considered. Raising flowers for cutting in geothermal greenhouses is an excellent possibility. If the geothermal wells have sufficiently high temperatures, the low-pressure steam could also be used for sterilizing soil. Raising seedling conifers in geothermal greenhouses also has potential in Calistoga because of the high local demand. Other greenhouse operations, soil heating, and space heating are all practical. A wide variety of industrial applications could be economical.

The Geysers and Clear Lake

The Geysers and Clear Lake area lies in the rugged northern Coast Ranges 120 to 160 kilometers north of San Francisco. The western part of the area is transected by the Mayacmas Mountains which have elevations of over 1,200 m (Plate XI). The eastern sector is dominated by several extinct volcanoes (sources of the Clear Lake Volcanics) including Mt. Konocti, Mt. Hannah, Boggs Mountain, and Cobb Mountain. Lake County, with its scenic beauty, has become a popular retirement and vacation home area; however, the county has suffered recently from a lack of new industry to provide a solid tax base. Recreation and agriculture form the economic base for the area.

The mountains surrounding The Geysers and Clear Lake have been a favorite recreation and retirement area for almost a century. Adding to the scenic attractions were the many hot mineral baths and the resorts that grew around them. Business at the hot springs resorts has dwindled in recent years; however, a valuable source of heat still exists.

Since the discovery of The Geysers by a hunter in 1847, interest in using this source of natural energy has been high. Between 1921 and 1925, eight steam wells were drilled for generating electricity, but the project failed for lack of a nearby market. In 1955, Magma Power Company began drilling for steam. In June 1960, Pacific Gas and Electric Company's first power plant to operate on geothermal steam went on the line with 12,500 kW. Since then, ten generating units with a total capacity of 404 MW have made The Geysers the world's largest producer of power from geothermal energy. Future plans call for an additional 110 MW each year until the field is fully developed.

Because of the rugged terrain, secondary uses of the geothermal heat at The Geysers are impractical. However, the untapped resources closer to the surrounding lowlands may prove useful. For the purposes of this report, areas of interest are Big Valley, Sulphur Bank, and the hills southwest of Lower Lake.

Climate

Extended climatological records have not been kept for the Clear Lake area. St. Helena provides the closest approximation. Temperatures in St. Helena range from a January average of 7.5°C to a July average of 21°C. Over a 31-year period, the maximum and minimum temperatures recorded were 46°C and -12°C. Average precipitation measured in Lakeport is 68 cm annually, falling almost exclusively during the winter months. The average number of hours of daily sunshine ranges from 5 in the winter to 9.5 in the summer. Microclimates dependent upon elevation and exposure are numerous.

Geology

The geology of the Clear Lake and The Geysers area consists of a complex assemblage of slightly metamorphosed Jurassic and Cretaceous rocks which are in part overlain by Cretaceous, Tertiary and Quaternary strata, and intruded and overlain by Quaternary volcanics (Plate XI).

The metamorphic assemblage, considered to be a mélange (rocks that are highly faulted, sheared, and mixed) by Hsü (1971), is present throughout the area, although it is locally overlain by unaltered rocks of the same age and by younger rocks. The mélange assemblage, including graywacke associated with shale, chert, basalt, diabase, and large, lenticular serpentine bodies, has been assigned to the Franciscan by Bailey and others (1964). McNitt (1968) divided these Upper Jurassic and Cretaceous metamorphic rocks into two units: "The younger unit consists of interbedded slightly metamorphosed sandstone and shale, and directly overlies the older unit, which is dense graywacke interbedded with chert and basalt, and intruded or interbedded with basic igneous rocks."

The primary permeability of the Franciscan rocks, which make up the geothermal reservoirs, is very low. The major zones of permeability in this formation occur along fault and fracture planes.

In the northeast portion of the area, Cretaceous and early Tertiary (Paleocene and Eocene) marine sedimentary rocks overlie the mélange assemblage. These sedimentary rocks are often referred to collectively as the Great Valley Sequence. They include shales, siltstones, sandstones, and conglomerates. On the northeastern edge of the study area, these rocks form continuous units; however, elsewhere within the area they exist only as disconnected folded and faulted blocks.

Big Valley, on the south shore of Clear Lake, and other areas adjacent to the south end of the lake, contain thick accumulations of slightly folded and faulted lake sediments of Pliocene or Pleistocene age (Cache Formation). These sediments were deposited in Clear Lake when it was at a higher stage. The higher portions of Big Valley are overlain by coarse-grained terrace deposits. These deposits are an important aquifer in an area otherwise poor in groundwater.

The Clear Lake Volcanics, Holocene in age, were produced from several distinct cones and plugs, and form extensive flows and ash falls. Dacite and andesite flows comprise the greatest bulk of the volcanic rocks. Rhyolite plugs, flows, and tuffs dominate in the area around Cobb Mountain. The lava flows of Mt. Konocti are overlain by poorly consolidated lapilli and tuff. Obsidian and minor olivine basalt flows are also found. Koenig (1968) suggests that "perhaps a molten or near-molten body underlies portions of the region." His suggestion is substantiated by a distinct negative gravity anomaly of about 50 milligals centered on Mt. Hannah.

Hydrology

In much of The Geysers and Clear Lake area, domestic water needs can be met with indigenous surface water. Population is sparse in the upland area and the land is far too rugged for agriculture. In the valleys, however, water is needed for irrigation as well as for domestic requirements. In the areas around Middletown and Lower Lake, shallow water wells can meet domestic needs, but yields are too low for irrigation water. The aquifers are thin and overlie essentially impermeable rock.

Big Valley, including the town of Kelseyville, is the major agricultural center in the area. The extensive natural terrace deposits provide a sizable recharge capability, and these aquifers are relatively thick; however, groundwater levels are dropping steadily. A dam on Kelsey Creek has been proposed to increase, recharge, and provide storage for irrigation water. Around Mt. Konocti, the very porous volcanic rocks hold almost no water. Wells drilled in this area are often dry.

Little is known about the groundwater hydrology of the upland areas, but the rock units found there are largely impermeable. Surface water is usually absent during the long, dry summers. In general, the prospects for discovering additional water supplies are limited.

Known Springs and Wells

Since about 1880, resorts and health spas have dotted the hills south of Clear Lake. Hot springs in the vicinity of Lower Lake, Middletown, and Cobb Valley were a major attraction. In recent years, however, business at hot spring resorts has declined, and none of the former resorts are open today.

A winding back road from Lower Lake to Middletown passes Siegler Springs (69), Howard Springs (70), and Harbin Springs (71), formerly the sites of large resorts. Each group of springs occurs in a small valley, and each issues from fractured serpentine and other metamorphic rocks at temperatures up to 52°C. Howard Springs Resort is idle, and the owner apparently has no plans for future use of the property. Siegler Springs and Harbin Springs and their rambling resort buildings are both occupied by communal living groups. The residents at Siegler Springs, renamed Yogaville West, are considering use of the thermal water for space heating in living quarters and greenhouses.

Anderson Springs (72) and Castle Rock Springs (73), 8 to 10 km northwest of Middletown, were both popular with hot spring enthusiasts at one time. The Anderson Springs area is now a vacation home and retirement community, and the springs are not being used. Castle Rock Springs is presently a summer camp. The Geysers Geothermal field extends at least as far south as Castle Rock Springs; the road to the springs passes several recently drilled steam wells. The full extent of this high-temperature geothermal resource is not known.

Extensive hydrothermal alteration produced economic deposits of sulphur and mercury at Sulphur Bank Mine, on the north side of a peninsula extending westerly into Clear Lake. Hot springs (67) up to 50°C, and water up to 80°C in the shafts at the Sulphur Bank Mine are evidence of continuing hydrothermal activity. Between 1961 and 1964, four wells (68) (not shown on map) were drilled by Magma Power Company and Earth Energy, Inc., in the Sulphur Bank Mine area. The maximum depth reached was about 1,520 m and the maximum temperature was 186°C. The wells produced hot water with 5% steam flashover. The water contained over 100 ppm boron, creating a serious waste disposal problem. The wells were abandoned.

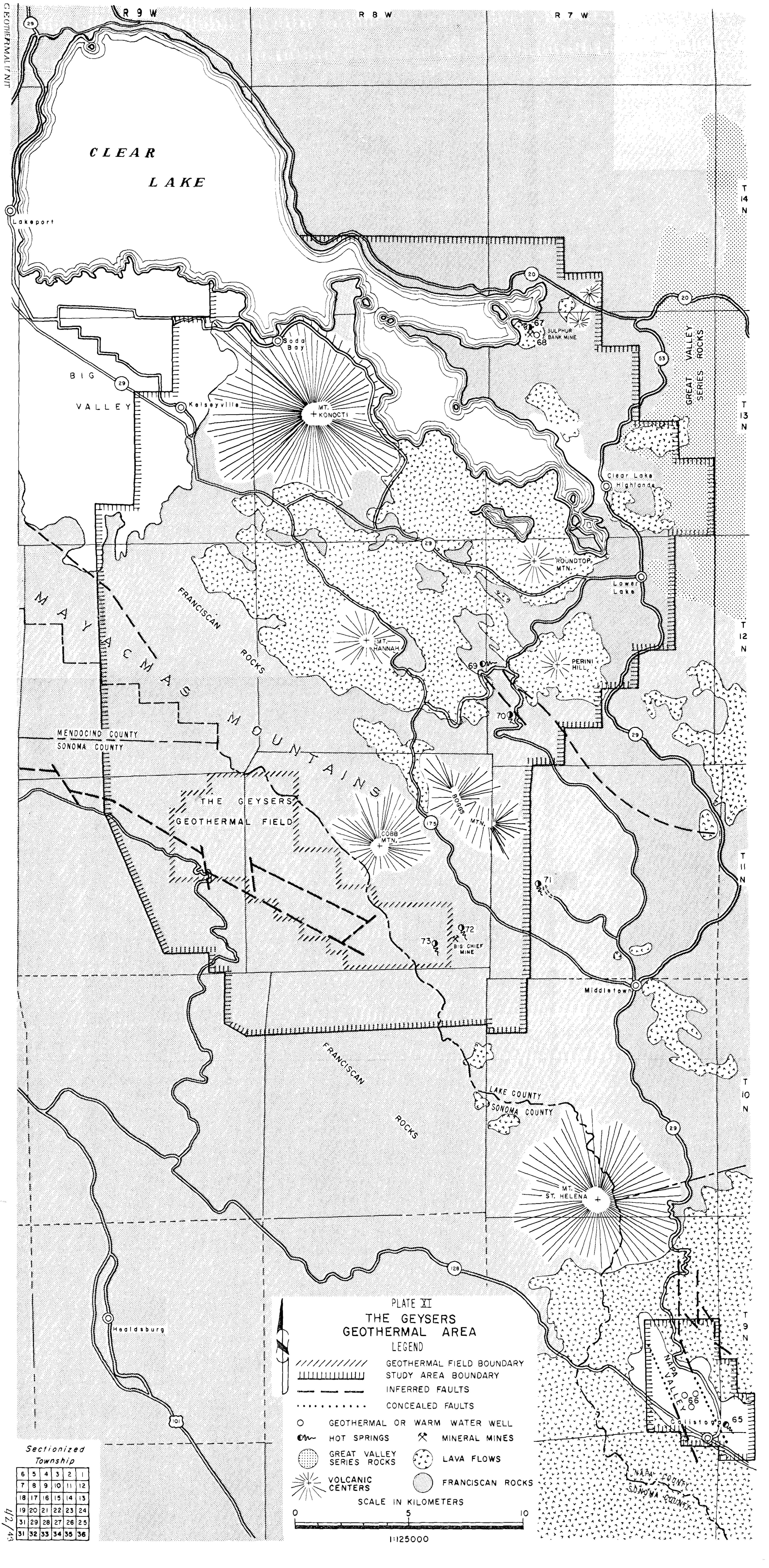
Many warm springs (not shown on map) surround Big Valley just south of the main part of Clear Lake including Highland Springs, Carlsbad Springs, Soda Bay Springs, and several springs on the shore of Dorn Bay. Highland Springs and Soda Bay Springs have been used sporadically for bathing. All of the springs have low temperatures and low flow rates. Soda Bay Springs issue into Clear Lake, and Highland Springs have been flooded by a new reservoir.

Carlsbad Spring is not easily accessible by car, and is in a steep, brush-covered canyon. Except for the cold-water aquifers within Big Valley, yields from wells are generally very low, and only a few have produced abnormally warm water.

Summary

Development of The Geysers Geothermal field for production of electrical power will be of primary importance in the western part of this area. Because of the rugged terrain, secondary uses of the thermal water will probably not be economical. Steam or high-temperature water may be available as far east as Cobb Valley, but rapid industrial development is unlikely because of the numerous resorts and vacation home developments. However, use of thermal water for recreation or space heating in new housing developments should be considered.

The hills between Lower Lake and Middletown have not been explored for geothermal resources. The rocks are generally impermeable, but wells intersecting major fracture systems or shear zones might yield some hot water. The widespread occurrence of hot springs around Clear Lake and the discovery of a 186°C hot-water reservoir at Sulphur Bank are good indications of economic geothermal resources. Further geological investigations are needed in this complex area to locate hot-water zones; however, sufficient fresh water may not be available for many low-temperature applications of geothermal heat. If the resource can be developed, uses most compatible with the present economy would be space heating, greenhouse heating, or soil heating.


R9W
R8W
R7W
CLEAR
LAKE
Lakeport
Soda Bay
Kelseyville
BIG
VALLEY
MT. KONOCTI
SULPHUR BANK MINE
67
68
GREAT VALLEY SERIES ROCKS
Clear Lake Highlands
ROUNDTOP MTN.
Lower Lake
MAYACMAS MOUNTAINS
FRANCISCAN ROCKS
MT. HANNAH
PERINI HILL
69
70
MENDOCINO COUNTY
SONOMA COUNTY
THE GEYSERS GEOTHERMAL FIELD
COBB MTN.
BOGGS MTN.
71
72
73
BIG CHIEF MINE
Middletown
FRANCISCAN ROCKS
LAKE COUNTY
SONOMA COUNTY
MT. ST. HELENA
Healdsburg
NAPA VALLEY
Calistoga
65
66
NAPA COUNTY
SONOMA COUNTY
T14N
T13N
T12N
T11N
T10N
T9N
29
20
53
175
128
101
PLATE XI
THE GEYSERS GEOTHERMAL AREA
LEGEND
GEOTHERMAL FIELD BOUNDARY
STUDY AREA BOUNDARY
INFERRED FAULTS
CONCEALED FAULTS
GEOTHERMAL OR WARM WATER WELL
HOT SPRINGS
MINERAL MINES
GREAT VALLEY SERIES ROCKS
LAVA FLOWS
VOLCANIC CENTERS
FRANCISCAN ROCKS
SCALE IN KILOMETERS
0
5
10
1:125000
Sectionized Township
6 5 4 3 2 1
7 8 9 10 11 12
18 17 16 15 14 13
19 20 21 22 23 24
30 29 28 27 26 25
31 32 33 34 35 36

42/43

SELECTED REFERENCES

Anderson, C. A., 1936, Volcanic history of the Clear Lake area, California: Geol. Soc. America Bull., v. 47, p. 629-664.

Anderson, D. N., and Axtell, L. H., 1972, Geothermal overviews of the western United States: Geothermal Resources Council, El Centro Conference, Feb. 16, 17, 18, 1972.

Anderson, J. H., 1973, The vaporturbine cycle for geothermal power generation, *in* Kruger, Paul, and Otte, Carel, eds., Geothermal energy: Stanford University Press, p. 163-175.

Axtell, L. H., 1972, Mono Lake geothermal wells abandoned: California Geology, v. 25, no. 3, March 1972, p. 66-67.

Bailey, E. H., Irwin, W. P., and Jones, D. L., 1964, Franciscan and related rocks and their significance in the geology of western California: Calif. Div. Mines and Geology, Bull. 183, 177 p.

Barnea, J., 1972, Geothermal power: Sci. American, v. 226, no. 1, p. 70-77.

Beall, S. E., Jr., 1973, New sources and methods - total energy - a key to conservation: Consulting Engineer, March 1973, p. 180-185.

Biehler, S., Kovach, R. L., and Allen, C. R., 1964, Geophysical framework of the northern end of the Gulf of California structural province: Am. Assoc. of Petrol. Geol. Mem. 3, p. 126-143.

Boersma, L., 1971, Using waste heat from steam electric plants: Agricultural Engineering, v. 52, no. 11, p. 586-588.

Boldizsar, T., 1970, Geothermal energy production from porous sediments in Hungary: Geothermics, Spec. Issue 2, v. 2, pt. 1, p. 99-109.

Brice, J. C., 1953, Geology of the Lower Lake quadrangle, California: Calif. Div. Mines, Bull. 166, 72 p.

Bruce, A. W., 1971, Geothermal power - on line: Proceedings of the First Northwest Conference on Geothermal Power, Olympia, Wash., Wash. Div. Mines and Geology.

California Department of Water Resources, 1963, Northeastern counties groundwater investigation: Calif. Dept. Water Resources Bull. 98, v. 1 and 2, 224, p., 32 pl.

——1964, Groundwater occurrence and quality - Lahontan Region: Calif. Dept. Water Resources, Bull. 106-1, 439 p.

Chesterman, C. W., 1968, Volcanic geology of the Bodie Hills, Mono County, California: Geol. Soc. America Mem. 116, p. 45-68.

Dragone, G., and Runi, O., 1970, Pilot greenhouse for the utilization of low-temperature waters: Geothermics, Spec. Issue 2, v. 2, p. 2.

Einarsson, S. S., 1970, Utilization of low enthalpy water for space heating, industrial, agricultural, and other uses, Rapporteur's Report: Geothermics, Spec. Issue 2, v. 1 (in press).

Garrison, L. E., 1972, Geothermal steam in The Geysers-Clear Lake Region, California: Geol. Soc. America Bull., v. 83 p. 1449-1468.

Hickel, W. J., 1972, Geothermal energy. A national proposal for geothermal resources research: Geothermal Resources Research Conference, Battelle Seattle Research Center, Seattle, Wash., Sept. 18-20, 1972, 95 p.

Hsü, J. K., 1971, Franciscan mélanges as a model for eugeosynclinal sedimentation and underthrusting tectonics: Jour. of Geophysical Research, v. 76, no. 5, Feb. 10, 1971.

Kerr, R. N., Bangma, R., Cooke, W. L., Furness, F. G., and Vamos, G., 1961, Recent development in New Zealand in the utilization of geothermal energy for heating purposes, *in* Proceeding of the U. N. conference on new sources of energy: Rome, v. 3, p. 456-468.

Koenig, J. B., 1968, Field trip to The Geysers, Sonoma County, California, Sept. 28, 1968: Northern California Geological Society.

——1970, Geothermal exploration in the western United States, *in* Proceedings of the U. N. Symposium on the development and utilization of geothermal resources; Geothermics: Pisa, Italy, Spec. Issue 2, v. 2, pt. 1, p. 1-13.

——1973, World-wide status of geothermal resources development, *in* Kruger, Paul, and Otte, Carel, eds., Geothermal energy: Stanford University Press, p. 15-58.

Komagata, S., Iga, H., Nakamura, H., and Minohara, Y., 1970, The status of geothermal utilization in Japan: Geothermics, Spec. Issue 2, v. 2, pt. 1, p. 185-196.

Kruger, Paul, and Otte, Carel, eds., 1973, Geothermal energy: Stanford University Press, 360 p.

Kunkel, Fred, and Upson, J. E., 1960, Geology and groundwater in Napa and Sonoma Counties, California: U. S. Geol. Survey Water-Supply Paper 1495, 252 p.

Laird, A. D. K., 1973, Water from geothermal resources, *in* Kruger, Paul, and Otte, Carel, eds., Geothermal energy: Stanford University Press, p. 177-196.

Lindal, B., 1961, The extraction of salt from sea water by multiple-effect evaporators using natural steam, *in* Proceedings of the U. N. Conference on New Sources of Energy, Rome, v. 3, p. 479-482.

———1970, The use of natural steam in a diatomite plant: Geothermics, Spec. Issue 2, v. 2, pt. 1, p. 921-924.

McNitt, J. R., 1968, Geology of the Kelseyville quadrangle, Sonoma, Lake and Mendocino Counties, California: Calif. Div. Mines and Geology, Map Sheet No. 9.

Mizutani, Yoshitaka, 1961, Salt production by geothermal energy in Japan, *in* Proceedings of the U. N. Conference on New Sources of Energy: Rome, v. 3, p. 483-485.

Muffler, L. J. P., 1973, Geothermal resources: U. S. Geol. Survey Prof. Paper 820, p. 251-261.

Muffler, L. J. P., and White, D. E., 1972, Geothermal energy: Sci. Teacher, v. 39, no. 3, p. 40-43.

Palmason, G., and Zöega, J., 1970, Geothermal energy developments in Iceland, 1960-1969: Geothermics, Spec. Issue 2, v. 2, pt. 1, p. 73-76.

Pessina, S., Rumi, O., Silvestri, M., and Sotgia, G., 1970, Gravimetric loop for the generation of electrical power from low-temperature water: Geothermics, Spec. Issue 2, v. 2, pt. 1, p. 901-909.

Peterson, N. V., and Groh, E. A., 1967, Geothermal potential of the Klamath Falls area, Oregon - a preliminary study: Ore Bin, v. 20, no. 11, p. 209-232.

Peterson, N. V., Groh, E. A., and McIntyre, R., Jr., 1970, The reconnaissance geology and mineral resources of eastern Klamath County and western Lake County, Oregon: Oregon Dept. Geol. and Mineral Industries Bull. 66, 70 p.

Proceedings of the U. N. Conference on New Sources of Energy, 1961, Solar energy, wind power, and geothermal energy: Rome, Italy, Aug. 21-31, 1961, v. 7.

Proceedings of the U.N. Symposium on the Development and Utilization of Geothermal Resources, 1970, Geothermics: Pisa, Italy, Sept. 22-Oct. 1, 1970, Spec. Issue 2, v. 1 and 2.

Rinehart, C. D., and Ross, D. C., 1964, Geology and mineral deposits of the Mount Morrison quadrangle, Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 385, 106 p.

Sheridan, M. F., 1971, Guidebook to the Quaternary geology of the east-central Sierra Nevada: XVI Field Conference, Rocky Mountain Section of the Friends of Pleistocene, Oct. 9-10, 1971, 60 p.

Smith, J. H., 1970, Geothermal development in New Zealand: Geothermics, Spec. Issue 2, v. 2, pt. 1, p. 232-247.

Smith, R. L., and Bailey, R. A., 1968, Resurgent cauldrons: Geol. Soc. America Mem. 116, p. 613-662.

Summers, W. K., 1971, Annotated and indexed bibliography of geothermal phenomena: New Mexico State Bureau of Mines and Mineral Resources.

U. S. Department of Agriculture, 1941, Climate and man, yearbook of agriculture, 1941: Government Printing Office, Washington, D. C.

Ward, P. L., 1972, Microearthquakes-prospecting tool and possible hazard in the development of geothermal resources: Geothermics, v. 1, p. 3-12.

Waring, G. A., 1915, Springs of California: U. S. Geol. Survey Water-Supply Paper 338, 410 p.

———1965, Thermal springs of the United States and other countries of the world - a summary: U. S. Geol. Survey Prof. Paper 492, 383 p.

White, D. E., 1955, Violent mud-volcano eruption of Lake City Hot Springs, north-eastern California: Geol. Soc. America Bull., v. 66, no. 9, p. 1109-1130.

———1965, Geothermal energy: U. S. Geol. Survey Circular 519, 17 p.

———1973, Characteristics of geothermal resources *in* Kruger, Paul, and Otte, Carel, eds., *Geothermal* energy: Stanford University Press, p. 69-94.

White, D. E., Muffler, L. J. P., and Truesdell, A. H., 1971, Vapor-dominated hydrothermal systems compared with hot-water systems: Econ. Geology, v. 66, no. 1, p. 75-97.

Zöega J., and Kristinsson, G., 1970, District heating for old and new town development: District Heating Convention, London.

APPENDIX A

HOT SPRINGS AND HOT-WATER WELLS IN NORTHERN CALIFORNIA

No.	Name of Spring or Well	Location	Temp (°C)	Temp (°F)	Flow (1/min)
	(A) Surprise Valley				
(1)	Peterson's Ranch	SE1/4,NW1/4,Sec. 8,T.46N.,R.16E.	36-42	97-108	400
(2)	Bucher's well	SW1/4,SE1/4,Sec. 8,T.46N.,R.16E.	36	97	8,300*
(3)	Ft. Bidwell well	NW1/4,NE1/4,Sec. 17,T.46N.,R.16E.	37	99	600
(4)	Lake City mud volcano and hot springs	Sec. 24,T.44N.,R.15E.	48-97	118-207	400
(5)	Wells (to 1,368 m)	near Lake City	160	320	N.A.
(6)	Hutchen's well (124 m)	SW1/4,NE1/4,Sec. 20,T.43N.,R.16E.	48	118	9,460*
(7)	Well (194 m)	SW1/4,NW1/4,Sec. 20,T.43N.,R.16E.	69	156	570*
(8)	Robison's well (77 m)	NE1/4,SW1/4,Sec.30,T.43N.,R.16E.	50	122	605*
(9)	Seyferth Hot Springs	NW1/4,NW1/4,Sec. 12,T.43N.,R.16E.	85	185	500
(10)	Leonard Hot Springs (west)	NW1/4,NE1/4,Sec. 13,T.43N.,R.17E.	65	149	200
(11)	Leonard Hot Springs (east)	NE1/4,NE1/4,Sec. 13,T.43N.,R.17E.	62	144	150
(12)	Hot Spring	NW1/4,SE1/4,Sec. 6,T.42N.,R.17E.	95	203	N.A.
(13)	Hot Springs Hotel wells	NE1/4,SW1/4,Sec. 6,T.42N.,R.17E.	84-98	183-208	300
(14)	Hot Springs Hotel springs	SE1/4,SW1/4,Sec. 6,T.42N.,R.17E.	50-54	122-129	1,800
(15)	Benmac Hot Springs	SW1/4,SW/4,Sec. 6,T.42N.,R.17E.	96-97	205-207	750
(16)	Menlo Hot Springs	NE1/4,NE1/4,Sec. 7,T.39N.,R.17E.	57	135	1,000
(17)	Squaw Bath	NE1/4,NW1/4,Sec. 29,T.38N.,R.17E.	49	120	450
	(B) Alturas Area				
(18)	Hot Creek Ranch	SE1/4,Sec.9,T.42N.,R.11E.	33	91	500
(19)	Kelly Hot Spring	NE1/4,Sec. 29,T.42N.,R.10E.	92	198	1,200
(20)	Well** (977 m)	Sec. 29,T.42N.,R.10E.	110	230	N.A.
(21)	New William's Ranch well (62m)	SE1/4,SW1/4,Sec. 30,T.40N.,R.13E.	29	84	150
(22)	Old William's Ranch well	SW1/4,NW1/4,Sec. 31,T.40N.,R.13E.	44	111	150
(23)	West Valley Res. Hot Spring	SW1/4,NE1/4,Sec.29,T.39N.,R.14E.	74	165	1
	(C) Big Valley and Little Hot Spring Valley				
(24)	Bassett Hot Spring	NW1/4,SE1/4,Sec.12,T.38N.,R.7E.	79	174	200
(25)	Kellog Hot Spring	SW1/4,SE1/4,Sec.15,T.38N.,R.8E.	78	172	15
(26)	Little Hot Springs	NW1/4,SW1/4,Sec. 9,T.39N.,R.5E.	75-77	167-171	300
	(D) Susanville				
(27)	Roosevelt Swimming Pool well (37 m)	NE1/4,NE1/4,Sec. 6,T.29N.,R.12E.	36	97	N.A.
(28)	L.D.S. Church well (181 m)	SW1/4,NW1/4,Sec. 5,T.29N.,R.12E.	49	120	N.A.
(29)	Miller's Custom Work well	NE1/4,NW1/4,Sec. 5,T.29N.,R.12E.	48	118	N.A.
	(E) Wendel-Amedee				
(30)	Wendel Hot Springs	SW1/4,SE1/4,Sec. 23,T.29N.,R.15E.	96	205	1,200
(31)	Well (189 m)	Sec. 23,T.29N.,R.15E.	64	147	N.A.
(32)	Amedee Hot Springs	NW1/4,NE1/4,Sec. 8,T.28N.,R.16E.	95	203	500
(33)	Wells (to 334 m)	Sec. 4 and Sec. 8, T.28N.,R.16E.	107	225	N.A.
(34)	Doyle Hot Spring**	SE1/4,NW1/4,Sec. 24,T.24N.,R.12E.	42	108	500

*Temperature and flow measured during pump test.
**Not located on maps.
N.A.—Not available.

APPENDIX A
(continued)

No. Name of Spring or Well	Location	Temp (°C)	Temp (°F)	Flow (l/min)
(F) Sierra Valley				
(35) Marble Hot Springs well 1 (104 m)	NW1/4,SE1/4,Sec. 13,T.22N.,R.14E.	73	163	100
(36) Marble Hot Springs well 2 (99 m)	SW1/4,SE1/4,Sec. 13,T.22N.,R.14E.	70	158	80
(37) Viscia well (7 m)	SE1/4,NE1/4,Sec. 25,T.22N.,R.14E	40	104	40
(38) Shallow well	NE1/4,SW1/4,Sec. 28,T.22N.,R.15E.	55	131	N.A.
(39) Hagge well 1	NW1/4,NE1/4,Sec. 32,T.22N.,R.15E.	40	104	2.5
(40) Hagge well 2	NW1/4,NE1/4,Sec. 32,T.22N.,R.15E.	39	102	2
(41) Hagge well 3 (300 m)	SE1/4,SE1/4,Sec. 32,T.22N.,R.15E	52	126	N.A.
(42) Filipini well 1 (334 m)	NE1/4,SE1/4,Sec. 32,T.22N.,R.15E.	94	201	50
(43) Filipini well 2 (122 m)	SW1/4,NW1/4,Sec. 5,T.21N.,R.15E.	51	124	8
(44) Filipini well 3 (182 m)	NW1/4,NW1/4,Sec. 5,T.21N.,R.15E.	44	111	10
(45) Campbell Hot Springs	NW1/4,NE1/4,Sec. 19,T.20N.,R.15E.	37-44	99-111	12
(46) McLear's Warm Springs	SW1/4,NW1/4,Sec. 32,T.22N.,R.13E.	30	86	530
(G) Eastern Sierra Springs				
(47) Brockway Hot Springs	north shore Lake Tahoe, near King's Beach	55	131	600
(48) Grover Hot Springs	State Park, off Hwy. 89, 7 km east of Markleeville	64	147	500
(H) Bridgeport Valley				
(49) Fale's Hot Springs	NW1/4,SE1/4,Sec. 24,T.6N.,R.24E.	80	176	1,050
(50) Buckeye Hot Springs	NE1/4,NE1/4,Sec. 4,T.4N.,R.24E.	60	140	200
(51) Travertine Hot Springs	SE1/4,SW1/4,Sec. 34,T.5N.,R.25E.	50-65	122-149	50
(52) The Hot Springs	NE1/4,Sec. 9,T.4N.,R.25E.	35-45	95-113	100
(53) Well (280 m)	near Bridgeport	50	122	N.A.
(I) Mono Lake Basin				
(54) Warm Spring	SE1/4,NE1/4,Sec. 16,T.2N.,R.28E.	33	91	40
(55) Springs and Steam Vents	Paoha Island	95	203	400
(56) Well (743 m)	NW1/4,NW1/4,Sec. 23,T.2N.,R.26E.	57	135	N.A.
(57) Well (1,250 m)	SW1/4,SW1/4,Sec. 17,T.1N.,R.27E.	54	129	N.A.
(J) Long Valley				
(58) Casa Diablo Hot Springs	SW1/4,NW1/4,Sec. 32,T.3S.,R.28E.	46-90	115-194	130
(59) Casa Diablo Hot Pool	SW1/4,NW1/4,Sec. 35,T.3S.,R.28E.	82	180	Intermittent
(60) Wells (maximum 323 m)	Sec. 32,T.3S.,R.28E.	178	352	N.A.
(61) Hot Spring	SW1/4,NW1/4,Sec. 13,T.3S.,R.28E.	79	174	20
(62) Hot Creek Geysers (Springs)	NE1/4,NE1/4,Sec. 25,T.3S.,R.28E.	90-95	194-203	1,900
(63) Hot Springs	NE1/4,NE1/4,Sec. 32,T.3S.,R.29E.	58	136	N.A.
(64) Whitmore Hot Springs	SE1/4,NE1/4,Sec. 6,T.4S.,R.29E.	33	91	1,150
(K) Northern Napa Valley				
(65) Calistoga Hot Spring	Calistoga	52-78	126-172	30
(66) 3 Wells (maximum over 600m)		167	333	N.A.

Numerous shallow wells up to 120°C (average 80 to 85°C) average flow 75-100 l/min with little or no interference between wells.

APPENDIX A
(continued)

No.	Name of Spring or Well	Location	Temp (°C)	Temp (°F)	Flow (l/min)
	(L) Clear Lake and The Geysers				
(67)	Sulphur Bank Mine	NW 1/4,SW1/4,Sec. 7,T.13N.,R.7W.	30-50	86-122	small
(68)	Sulphur Bank Wells (1,520m)	Sec. 7,T.13N.,R.7W.	186	367	N.A.
(69)	Siegler Springs	NE1/4,Sec. 24,T.12N.,R.8W.	40-52	104-126	400
(70)	Howard Springs	NW1/4,SE1/4,Sec. 30,T.12N.,R.7W.	35-45	95-113	700
(71)	Harbin Springs	NW1/4,SE1/4,Sec. 20,T.11N.,R.7W.	49	120	200
(72)	Anderson Springs	SW1/4,Sec. 25,T.11N.,R.8W.	52-63	126-113	100
(73)	Castle Rock Springs	NE1/4,NW1/4,Sec. 35,T.11N.,R.8W.	73	163	250

APPENDIX B
CONVERSION TABLES

The metric system of measure has been used in this publication to be consistent with worldwide geothermal literature. The basic metric units are:

Measure	Metric
length	meter (m)
mass	gram (g)
temperature	deg. Celcius (°C)
pressure	bar (bar)
energy	joule (J)
power	watt (W)
volume	liter (l)

The multiplication factors for metric units are the following:

Factor	Prefix
1 trillion (10^{12})	tera (T)
1 billion (10^{9})	giga (G)
1 million (10^{6})	mega (M)
1 thousand (10^{3})	kilo (k)
1 thousandth (10^{-3})	milli (m)

Thus, one megawatt (MW) equals 1 million watts.

Temperature

Celcius (C°) to Fahrenheit (F°)
(C° x 1.8 + 32 = F°)

0° = 32°	50° = 122.0°	140° = 284.0°	240° = 464.0°
1° = 33.8°	55° = 131.0°	145° = 293.0°	250° = 482.0°
2° = 35.6°	60° = 140.0°	150° = 302.0°	260° = 500.0°
3° = 37.4°	65° = 149.0°	155° = 311.0°	270° = 518.0°
4° = 39.2°	70° = 158.0°	160° = 320.0°	280° = 536.0°
5° = 41.0°	75° = 167.0°	165° = 329.0°	290° = 554.0°
6° = 42.8°	80° = 176.0°	170° = 338.0°	300° = 572.0°
7° = 44.6°	85° = 185.0°	175° = 347.0°	310° = 590.0°
8° = 46.4°	90° = 194.0°	180° = 356.0°	320° = 608.0°
9° = 48.2°	95° = 203.0°	185° = 365.0°	330° = 626.0°
10° = 50.0°	100° = 212.0°	190° = 374.0°	340° = 644.0°
15° = 59.0°	105° = 221.0°	195° = 383.0°	350° = 662.0°
20° = 68.0°	110° = 230.0°	200° = 392.0°	360° = 680.0°
25° = 77.0°	115° = 239.0°	205° = 401.0°	370° = 698.0°
30° = 86.0°	120° = 248.0°	210° = 410.0°	380° = 716.0°
35° = 95.0°	125° = 257.0°	215° = 419.0°	390° = 734.0°
40° = 104.0°	130° = 266.0°	220° = 428.0°	400° = 752.0°
45° = 113.0°	135° = 275.0°	230° = 446.0°	

APPENDIX B
(continued)

Distance

Centimeters (cm) to Inches
(cm x 0.39 = Inches)

1 = 0.39	16 = 6.30	40 = 15.75
2 = 0.78	17 = 6.69	50 = 19.68
3 = 1.18	18 = 7.08	60 = 23.62
4 = 1.57	19 = 7.48	70 = 27.56
5 = 1.96	20 = 7.87	80 = 31.49
6 = 2.36	21 = 8.26	90 = 35.43
7 = 2.75	22 = 8.66	100 = 39.37
8 = 3.15	23 = 9.05	110 = 43.30
9 = 3.54	24 = 9.45	120 = 47.24
10 = 3.93	25 = 9.84	130 = 51.18
11 = 4.33	26 = 10.24	140 = 55.12
12 = 4.72	27 = 10.63	150 = 59.05
13 = 5.12	28 = 11.02	160 = 62.99
14 = 5.51	29 = 11.42	170 = 66.93
15 = 5.90	30 = 11.81	180 = 70.87

Meters (m) to Feet
(m x 3.28 = Feet)

1 = 3.28	160 = 524.80
2 = 6.56	170 = 557.60
3 = 9.84	180 = 590.40
4 = 13.12	190 = 623.20
5 = 16.40	200 = 656.00
10 = 32.80	300 = 984.00
20 = 65.60	400 = 1,312.00
30 = 98.40	500 = 1,640.00
40 = 131.20	600 = 1,968.00
50 = 164.00	700 = 2,296.00
60 = 196.80	800 = 2,624.00
70 = 229.60	900 = 2,952.00
80 = 262.40	1,000 = 3,280.00
90 = 295.20	2,000 = 6,560.00
100 = 328.00	3,000 = 9,840.00
110 = 360.80	4,000 = 13,120.00
120 = 393.60	5,000 = 16,400.00
130 = 426.40	
140 = 459.20	
150 = 492.00	

Kilometers (km) to Miles
(km x 0.62 = Miles)

1 = 0.62	160 = 99.20
2 = 1.24	170 = 105.40
3 = 1.86	180 = 111.60
4 = 2.48	190 = 117.80
5 = 3.10	200 = 124.00
10 = 6.20	300 = 186.00
20 = 12.40	400 = 248.00
30 = 18.60	500 = 310.00
40 = 24.80	600 = 372.00
50 = 31.00	700 = 434.00
60 = 37.20	800 = 496.00
70 = 43.40	900 = 558.00
80 = 49.60	1,000 = 620.00
90 = 55.80	2,000 = 1,240.00
100 = 62.00	
110 = 68.20	
120 = 74.40	
130 = 80.60	
140 = 86.80	
150 = 93.00	

APPENDIX B
(continued)

Rate

Liters Per Minute (l/min) to Gallons Per Minute (G.P.M.)
(l/min x 0.26 = G.P.M.)

1 = 0.26	20 = 5.2	300 = 78.0
2 = 0.52	30 = 7.8	400 = 104.0
3 = 0.78	40 = 10.4	500 = 130.0
4 = 1.04	50 = 13.0	600 = 156.0
5 = 1.30	60 = 15.6	700 = 182.0
6 = 1.56	70 = 18.2	800 = 208.0
7 = 1.82	80 = 20.8	900 = 234.0
8 = 2.08	90 = 23.4	1,000 = 260.0
9 = 2.34	100 = 26.0	2,000 = 520.0
10 = 2.60	200 = 52.0	3,000 = 780.0

Square Measurement

Square Meters (m^2) to Square Feet
(m^2 x 10.76 = Square Feet)

1 = 10.76	6 = 64.56	20 = 215.20	70 = 753.20
2 = 21.52	7 = 75.32	30 = 322.80	80 = 860.80
3 = 32.28	8 = 86.08	40 = 430.40	90 = 968.40
4 = 43.04	9 = 96.84	50 = 538.00	100 = 1,076.00
5 = 53.80	10 = 107.60	60 = 645.60	

Square Kilometers (km^2) to Square Miles
(km^2 x 104 = Square Miles)

1 = 104	6 = 624	20 = 2,080	70 = 7,280
2 = 208	7 = 728	30 = 3,120	80 = 8,320
3 = 312	8 = 832	40 = 4,160	90 = 9,360
4 = 416	9 = 936	50 = 5,200	100 = 10,400
5 = 520	10 = 1,040	60 = 6,240	

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APPENDIX B
(continued)

Pressure

Kilograms per Centimeter Squared (kg/cm^2) to Pounds per Square Inch (lbs/in.^{2})
(kg/cm^2 x 14.22 = lbs/in.^{2})

1 = 14.22	6 = 85.32	20 = 284.40
2 = 28.44	7 = 99.54	30 = 426.60
3 = 42.66	8 = 113.76	40 = 568.80
4 = 56.88	9 = 127.98	50 = 711.00
5 = 71.10	10 = 142.20	

Weight

Kilograms (kg) to Pounds (lbs)
(kg x 2.20 = lbs)

1 = 2.20	11 = 24.20
2 = 4.40	12 = 26.40
3 = 6.60	13 = 28.60
4 = 8.80	14 = 30.80
5 = 11.00	15 = 33.00
6 = 13.20	16 = 35.20
7 = 15.40	17 = 37.40
8 = 17.60	18 = 39.60
9 = 19.80	19 = 41.80
10 = 22.00	20 = 44.00

Miscellaneous equivalents

1 Horsepower = 745.7 watts (W), 1,000 W = 1 kilowatt (kW), 1,000 (kW) = 1 megawatt (MW)
1 kcal = 10^3 calories = 10,000 calories
1 Gcal = 10^9 calories = 10,000,000,000 calories
1 Tcal = 10^{12} calories = 10,000,000,000,000 calories
1 Mill = 0.1 cent = $0.001
1 Barrel = 42 gallons
1 Average barrel of crude oil will yield 5.8 million Btu or 6.1 billion joules

REPORT NO. TR13
1975 EDITION

ERRATA SHEET

THE POTENTIAL OF LOW TEMPERATURE GEOTHERMAL RESOURCES IN CALIFORNIA

Page	
9	Line 11 of the second paragraph should read: ". . . almost 5.9 kg per plant for a total of . . ."
9	Line 23 of the second paragraph should read: ". . . $13,000 per greenhouse. The second . . ."
10	Line 18 of the fourth paragraph should read: ". . . $18,000 per year per greenhouse, based on a six-month growing period . . . ."
52	The third table should read:

Square Kilometers (km^2) to Square Miles
(km^2 x .39 = Square Miles)

1 = .39	6 = 2.34	20 = 7.80	70 = 27.30
2 = .78	7 = 2.73	30 = 11.70	80 = 31.20
3 = 1.17	8 = 3.12	40 = 15.60	90 = 35.10
4 = 1.56	9 = 3.51	50 = 19.50	100 = 39.00
5 = 1.95	10 = 3.90	60 = 23.40	

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