LOW-TEMPERATURE RESOURCE ASSESSMENT

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ABSTRACT

The U.S. Department of Energy - Geothermal Division (DOE/GD) recently sponsored the Low-Temperature Resource Assessment project to bring the inventory of the nation's low- and moderate-temperature geothermal resources up to date and to encourage development of the resources. A database of more than 9,278 thermal springs and wells that are in the temperature range of 20° to 150°C has been compiled for 10 western states, an increase of 85% compared to previous assessments. The databases include location, descriptive data, physical parameters, water chemistry and references for sources of data. Computer generated maps are also available for each state. State Teams have identified more than 50 high priority areas for near-term comprehensive resource studies and development. Geothermal energy cost evaluation software has been developed to quickly identify the cost of geothermal supplied heat to these areas in a similar fashion to that used for conventionally-fueled heat sources.

INTRODUCTION

Low- and moderate-temperature geothermal resources are widely distributed throughout the western and central United States. Numerous resources occur in the areas indicated in Figure 1, with individual reservoir areas one to ten square miles in extent. In the northern Great Plains, major aquifers with fluid temperatures exceeding 50°C extend in a continuous manner for thousands of square miles. Geothermal resources also occur at certain locations in the east.

The last major effort in assessing the national potential of low-temperature geothermal resources occurred in the early 1980s. Since that time, substantial resource information has been gained through drilling for hydrologic, environmental, petroleum and geothermal projects; but, there has been no significant effort to compile information on low-temperature geothermal resources.

While there has been a substantial increase in direct-heat utilization during the last decade, the large resource base is greatly under-utilized. Since the thermal energy extracted from these resources must be used near the reservoir, collocation of the resource and the user is required. Development of a user facility at the site of the hydrothermal resource is often economically feasible. Direct-heat resources are typically used by small businesses, various types of local industry, communities, and individuals. These users generally cannot afford to hire the technical expertise required to delineate and develop geothermal resources from scratch.

To expand utilization of the direct-heat resource, a current inventory of these resources is needed by potential users, together with the information necessary to evaluate the reservoirs and the economics of potential uses. To stimulate the development of an industry, it is necessary to reduce risks of development and this can be done by providing resource data and by cost-sharing of demonstration projects.

COMPILATION OF DATA ON HYDROTHERMAL RESOURCES

State geothermal resource teams (State Teams) reviewed and updated their geothermal resource inventories which were completed as part of the USGS-DOE national assessment from 1977-1983 (Muffler, 1979 and Reed, 1983). Each State Team prepared a comprehensive digital database in table format and a resource map at a scale of 1:1,000,000. ESRI and OIT have provided technical guidance

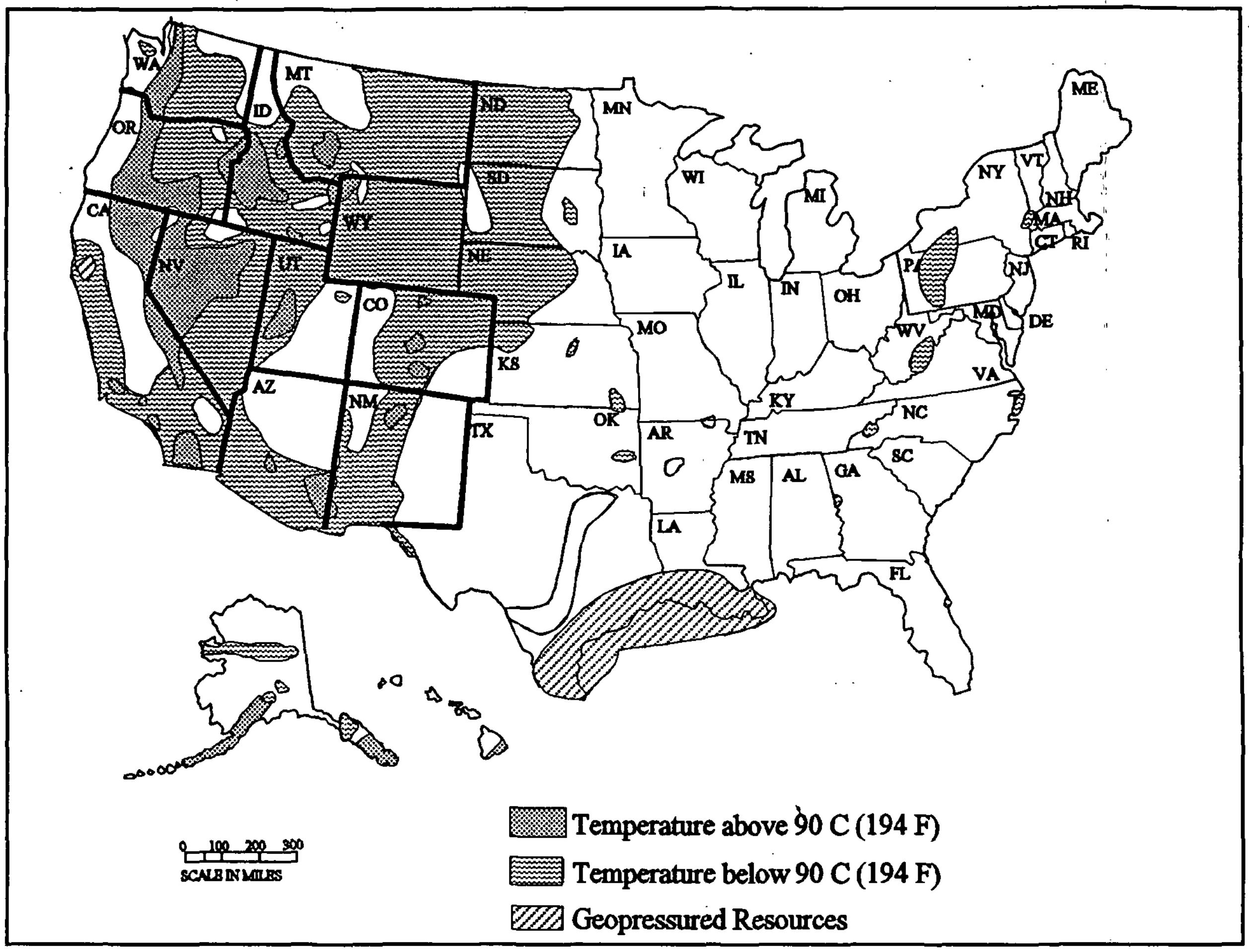

Figure 1. Geothermal resource areas of the United States with the 10 states involved in the new resource assessment identified in bold outlines.

and coordination. ESRI completed fluid chemistry analyses for participating states. Databases are designed to be readily accessible and maintained on PCs . Computer sorting, selection and comparison routines were employed to edit the new databases.

The compilations included resources in the temperature range of 20° to 150°C. Many of these resources have potential to supply energy to collocated cities within approximately 8 km of a resource as well as greenhouses, aquaculture, mining, and other process applications.

The State Teams reviewed drilling records and other information to identify new resources, verify temperatures and flow rates of springs and wells which may have changed substantially since the previous statewide geothermal resource inventory. The databases were organized into tables linked by common data-fields, using the preliminary database from the Utah Geological Survey as a model for uniformity in presentation (Blackett, 1994). Information in the tables included: Table 1 contains location data, descriptive data, and physical parameters of the thermal springs and wells; Table 2 contains data that relate to water chemistry and Table 3 repeats some data that are in Table 1, but primarily lists the source references from which the data were obtained.

Simultaneously, demographic and other data were collected and interpreted to evaluate potential heat loads, fossil-fuel displacement, utility electrical-demand reduction and load-leveling opportunities, and environmental benefits for potential geothermal direct-heat applications.

Table 1. State Geothermal Database Summary: 1992-94 Low-Temperature Assessment.

	State PGA	AZ 1982	CA 1980	CO 1980	ID 1980	MT 1981	NV 1983	NM 1980	OR 1982	UT 1980	WA 1981
Thermal Well/ Springs	**1994**	**1,003**	**989**	**157**	**1,537**	**267**	**1,100**	**265**	**2,193**	**792**	**975**
	PGA	501	635	125	899	68	796	312	998	315	368
Moderate Temp. Wells/Springs (100°C<T<150°C)	**1994**	**0**	**32**	**0**	**20**	**0**	**125**	**10**	**88**	**3**	**1**
	PGA	0	48	0	0	0	35	3	79	3	1
Low Temp. Wells/Springs (20°C<T<100°C)	**1994**	**1,003**	**957**	**157**	**1,517**	**267**	**975**	**255**	**2,105**	**789**	**974**
	PGA	501	587	125	899	58	761	309	925	312	367
Low Temp. Resource Areas (20°C<Tes<150°C)	**1994**	**35**	**58**	**93**	**28**	**16**	**300**	**30**	**200**	**161**	**17**
	PGA	29	56	56	28	15	300	24	151	64	10
Direct-Heat Utilization PGA Sites (Commercial, district, resorts)	**1994**	**5**	**78**	**35**	**41**	**24**	**26**	**7**	**41**	**16**	**5**
		0	54	24	20	2	8	0	23	9	0
Greenhouses, Aquaculture, Industrial Processes	**1994**	**5**	**17**	**6**	**17**	**4**	**8**	**6**	**7**	**6**	**0**
Areas, High Priority Resource Study	**1994**	**4**	**8**	**6**	**9**	**5**	**4**	**4**	**5**	**6**	**6**

Comments: PGA - Previous Geothermal Assessment. Tres = Estimated reservoir temperature.
The minimum low-temperature criteria is typically 20°C, but varies with climate.

RESULTS OF RESOURCE EVALUATION

State geothermal resource teams (State Teams) initiated their resource evaluation and database compilation efforts in late 1992 and early 1993, and have now updated their resource inventories. Table 1 summarizes the catalog of more than 9,278 thermal wells and springs for these 10 western states, an increase of 85% compared to the previous assessments in 1980 to1983. More than 900 low- to moderate-temperature resource areas are indicated, and perhaps a greater number of isolated (singular) thermal wells or springs. Direct-heat use of geothermal fluids is documented at more than 350 sites, including commercial and municipal buildings, rapidly expanding greenhouse and aquaculture industries, and major space-heating districts in California, Oregon, Nevada, Idaho, and Colorado. More than 50 high-priority resource study areas have been identified, along with high potential for near-term direct-heat utilization at 150 new sites. Previous estimates indicate that 254 cities in 10 western states could potentially displace 18,000 GWh per year (17 million BOE) with geothermal district heating (Allen, 1980). The number of commercial and residential direct-heat users and the total energy use has increased dramatically in one decade. Table 1 indicates the tremendous potential for expanded utilization of these resources. The new digital database reports are in most cases available as Open-File reports from each State Team listed in the references.

COLLOCATION OF RESOURCES

An important part of the assessment was to complete a collocation study of geothermal resources and communities in the western states in order to identify and encourage those communities to develop their geothermal resources. For example in

California, 56 communities were identified that are located within 8 km of a known geothermal resource with a temperature of at least 50°C (Youngs, 1994). The communities are shown on the state map on Figure 3.

Historically, most of the communities that were identified have experienced some development of their geothermal resources. However, depending on the characteristics of the resource, the potential exists for increased geothermal development for applications such as space and district heating, resort/spa facilities, aquaculture, industrial and greenhouse operations, and possible electrical generation in some areas.

GEOTHERMAL ENERGY COST EVALUATION

Each State Team has selected (partially based on population data and the need for more comprehensive resource studies) high priority areas for proposed near-term resource studies and development. It is important to characterize these energy sources in terms of cost, both capital and unit energy cost. Geothermal energy costs vary with depth and other characteristics of the resource, number of production and injection wells, and many other parameters. Software has been developed at the Geo-Heat Center to quickly identify the cost of geothermal supplied heat in a similar fashion to that used for conventionally fueled heat sources (Rafferty, 1995).

Using resource, financing and operating inputs, the spreadsheet calculates the capital costs for production well(s), well pump(s), wellhead equipment, injection well(s), and connecting pipelines. These capital costs are used along with the quantity of annual energy to be supplied and financing information to produce a unit cost of energy. Unit costs for operation (maintenance and electricity) are added to arrive at a total unit cost in $ per million Btu for geothermal heat. To put this value into perspective, similar costs for an equivalent sized boiler plant are also calculated. These values can then be compared to determine the relative economic merit of geothermal for any specific set of circumstances. This information is particularly useful at the conceptual stage of a project when decisions as to fuel source are typically made by the developers.

A general example of the use of the spreadsheet is illustrated in Figure 2. Consider a local economic development agency in an area of known geothermal resources. The economic development agency may wish to determine the relative economic merit of geothermal use for new industrial developments as a function of required well depth. Output from the spreadsheet can be used to develop the curve illustrated. This graph assumed a 3 MWt load at two different load factors: 20% representing greenhouse or multi-building district heating, and 30% representing an industrial process load. The basis for the cost competiveness graph is:

- Electric costs @ 0.07 $/kWh and 0.05 $/kW ;
- One production well/one injection well (where applicable);
- 20 year financing @ 8%;
- 60% hard drilling and 40% soft drilling;
- Open hole completion on production well;
- Lineshaft production well pumps;
- Full depth casing on injection wells; and
- Natural gas rate @ 0.43 $/therm and 75% efficiency.
- Based on geothermal system supplying 100% of peak

As illustrated in Figure 2, even for this relatively small load, conditions are favorable (simple payback less than 5 years) for geothermal for all applications up to a well depth of 610 m without

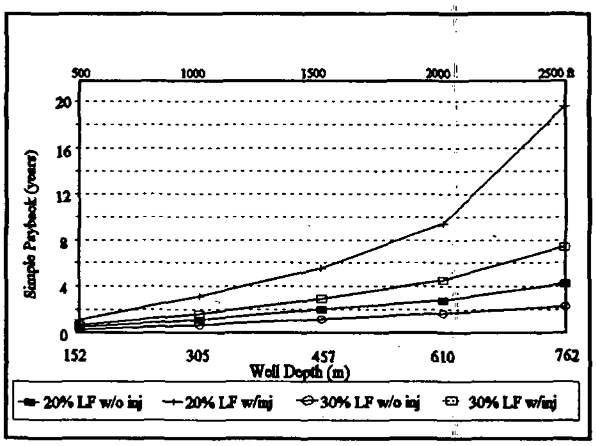

Figure 2. Cost effectiveness of geothermal versus natural gas - 3MW$_t$ system.

injection. For higher load factor applications, a well depth of up to 457 m with injection provides simple payback of less than 5 years.

CONCLUSIONS

Low- and moderate-temperature geothermal resources are widely distributed throughout the western and central United States. Since the last major effort in assessing the national potential of these resources in the early 1980s, there has been a substantial increase in direct-heat utilization. However, the large resource base is greatly under-utilized. To help expand utilization of the direct-heat resource base, a current inventory of these resource has been developed.

State geothermal resource teams (State Teams) evaluations and compilations have resulted in the cataloging of more than 9,278 thermal wells and springs for 10 western states, an increase of 85% over the previous geothermal assessment in 1980 to 1983. More than 50 high-priority resource study areas have been identified, along with high potential for near-term direct-heat utilization at 150 new sites.

Although the compilation of resource data by State Teams indicates the tremendous potential for expanded utilization of these resources, many high priority areas need comprehensive resource and preliminary engineering studies. More specifically, for over 50 sites these include:

- Geophysical exploration (10 sites)
- Confirmation drilling (12 sites)
- Hydrologic testing (11 sites)
- Comprehensive assessment (8 sites)
- District heating feasibility (12 sites)
- Industrial heating feasibility (7 sites)

These tasks are expected to pay off in further discoveries of resources and in better methods to evaluate reservoir production and ultimate development capacity at an earlier stage in the development cycle than is now possible.

ACKNOWLEDGMENT

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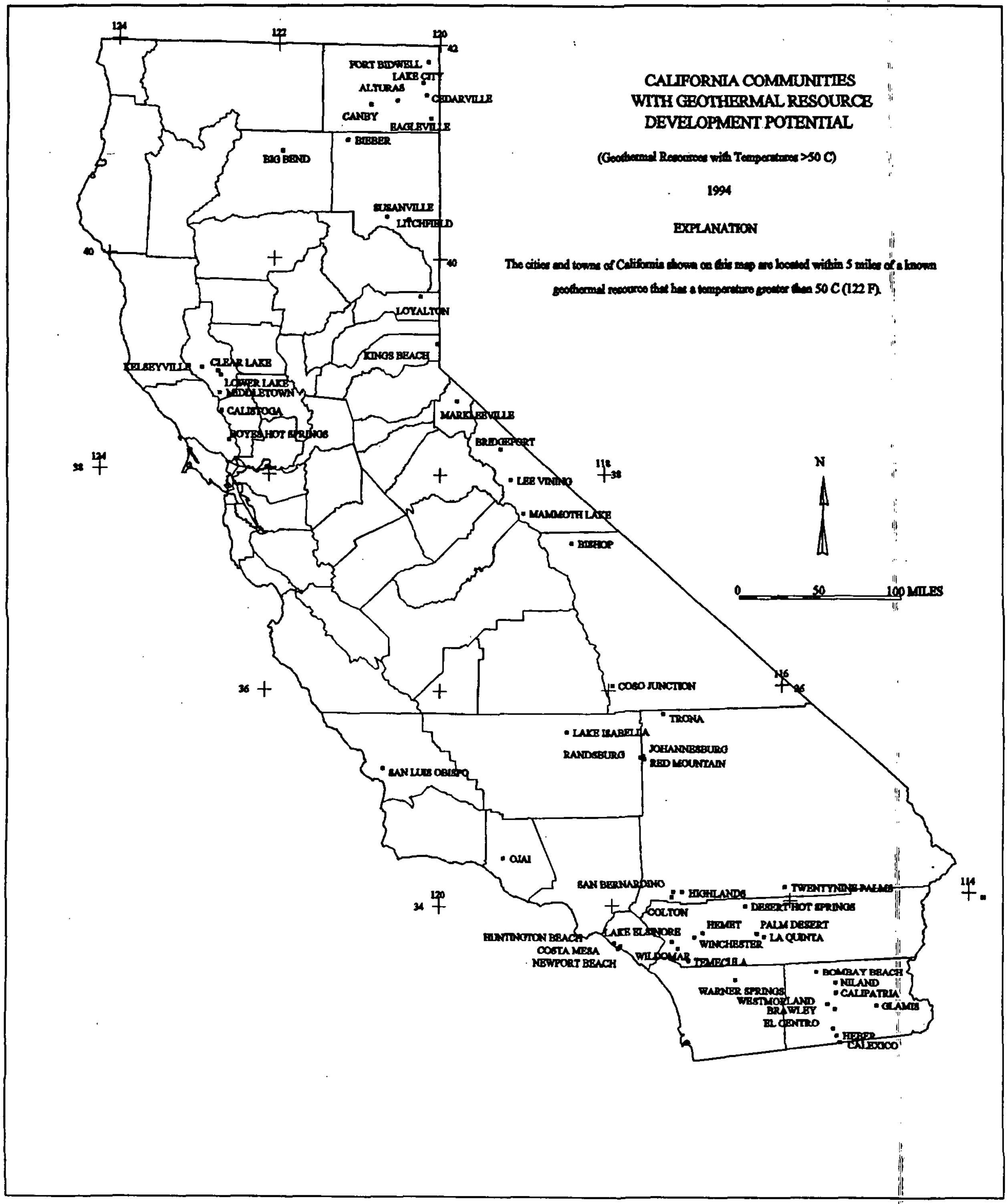

Figure 3. California communities with geothermal resource development potential.

LOW-TEMPERATURE RESOURCE ASSESSMENT

Ten Western States

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Earth Sciences and Resources Institute

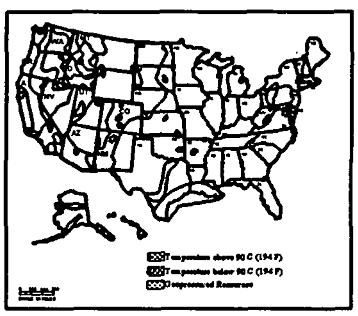
Low-Temperature Program

PARTICIPANTS

- Earth Sciences and Resources Institute
  - University of Utah
- Idaho Water Resources Research Institute
  - University of Idaho
- Geo-Heat Center
  - Oregon Institute of Technology
- State Resource Teams
  - Ten Western States

Low-Temperature Program

Known and Potential Hydrothermal Resources



Low-Temperature Program

HYDROTHERMAL RESOURCE DATABASES

- Resources in temperature range of 20° to 150°C
- Resource maps at a scale of 1:1,000,000
- ESRI completed 10 fluid chemistry analyses for each state
- Readily accessible and maintained on PCs
- Evaluate potential heat loads
- Prioritize resource sites
  - Highest potential for economic development

Low-Temperature Program

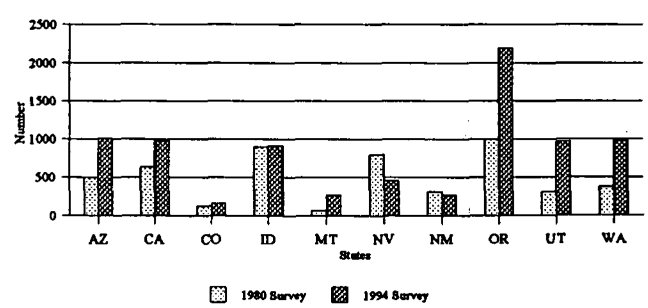
DATA SOURCES

- USGS GEOTHERM
- USGS WATSTORE
- EPA STORET water quality
- State drilling records
- Hydrologic studies
- Resource assessment reports
- Journals and GRC Transactions

Low-Temperature Program

STATE GEOTHERMAL DATABASES

Thermal Springs & Wells 20° to 150°C



Low-Temperature Program

TABLE 1. LOCATION

- ID number
- Source name
- County code
- Latitude and longitude
- References - source of data and relevant studies

Low-Temperature Program

TABLE 2. DESCRIPTION

- ID number
- Source name
- Type - spring or well
- Temperature (C)
- Flow rate (L/min)
- Depth of well (m)
- Drill date
- Operating status
- Current resource use

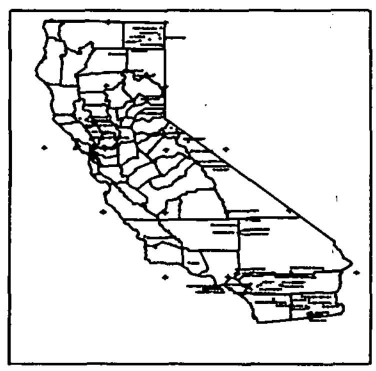
Low-Temperature Program

TABLE 3. WATER CHEMISTRY

- ID number
- Source name
- pH
- TDS
- Major cations
- Major anions
- Cation - anion balance
- Conductance
- Light stable isotopes

Low-Temperature Program

Collocated Communities



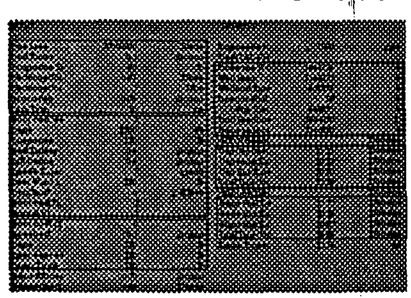
Low-Temperature Program

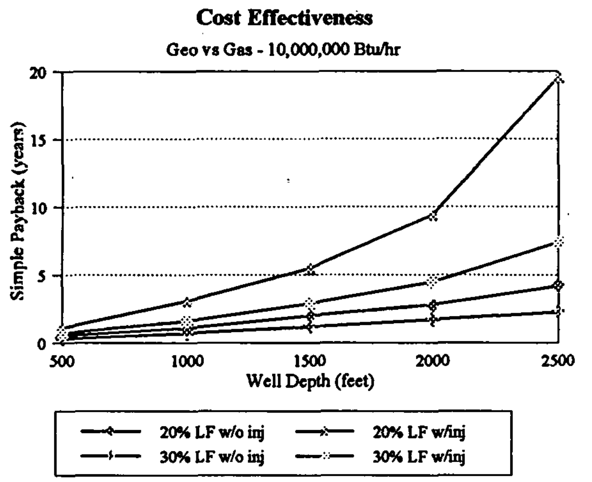
RESULTS FOR 10 WESTERN STATES

- More than 8,200 thermal springs & wells
  - Increase of 41% over previous assessment
- More than 900 resource areas
- Direct heat uses documented at more than 354 sites
  - Space heat, greenhouses, aquaculture and industrial uses
- More than 57 high priority resource areas identified

Low-Temperature Program

GEOTHERMAL ENERGY COST





Low-Temperature Program

BASIS FOR COST COMPETITIVENESS

- Electric costs @ 0.07 $/kWh and 0.05 $/kW
- One production well/one injection well (where applicable)
- 20 year financing @ 8%
- 60% hard drilling and 40% soft drilling
- Open hole completion on production well
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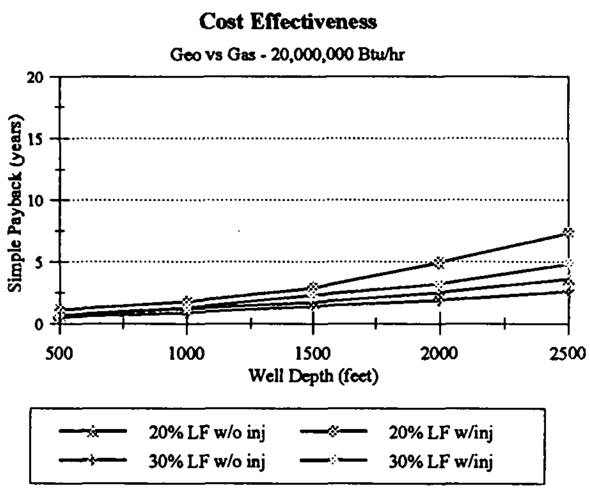


Low-Temperature Program

EXAMPLE: Greenhouse Load Factor

- 4 acre greenhouse
  - 10 x 10^6 Btu/hr peak load (0°F outside)
- Heating load factor = 0.24
- If Geothermal meets 60% of peak (6 x 10^6 Btu/hr)
  - Conventional meets 40% of peak (4 x 10^6 Btu/hr)
- Geothermal could supply 95% of annual energy
- **Geothermal load factor increases to 0.36**

Low-Temperature Program

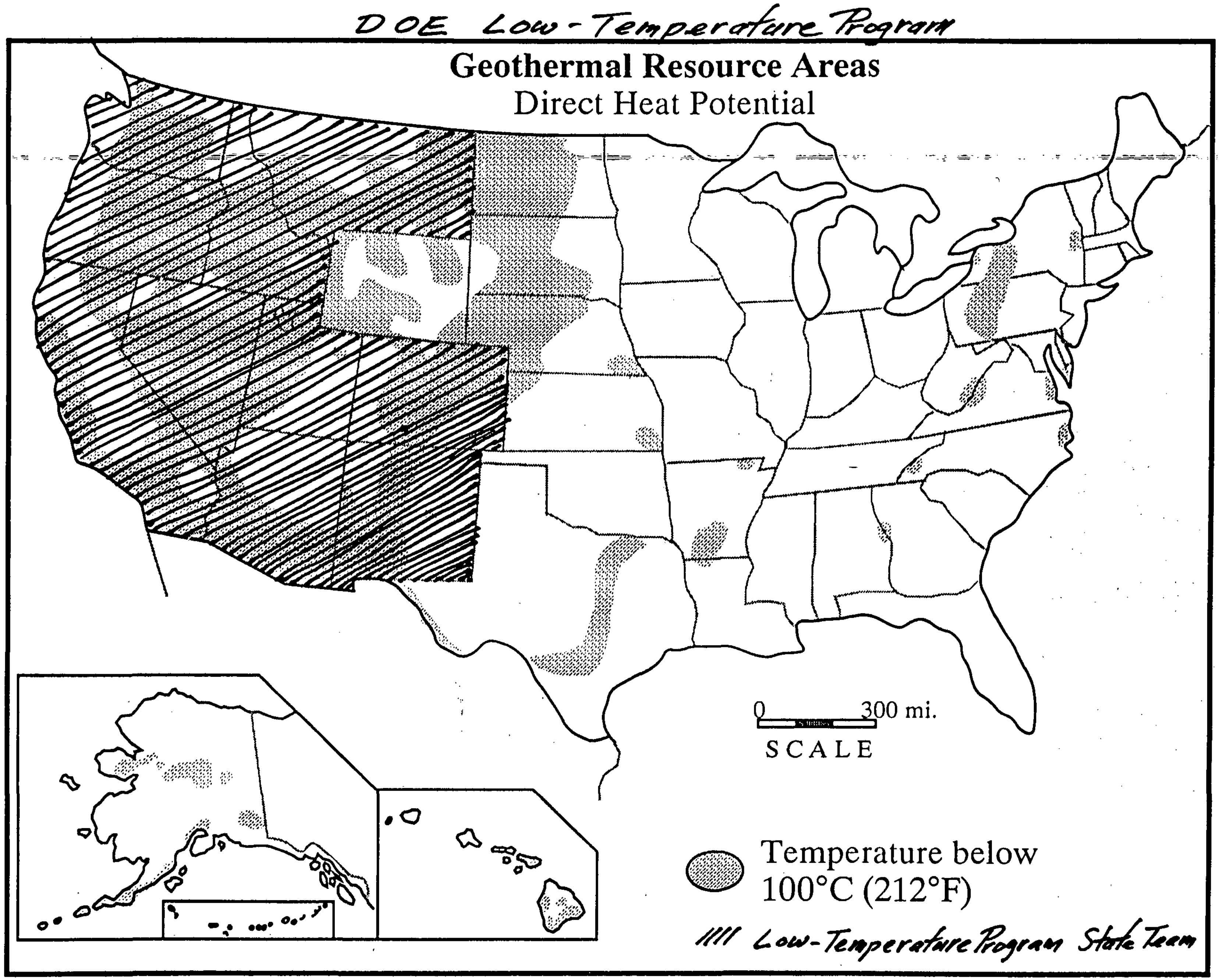
CONCLUSIONS

- Current inventory of resources will help expand utilization in 10 western states
- State Teams compiled data on more than 8,200 thermal wells and springs
- New State resource maps are available
- Databases are readily accessible and maintained on PCs
- More than 50 high priority resource study areas have been identified

Low-Temperature Program

FUTURE WORK PROPOSED ON HIGH PRIORITY AREAS

- Geophysical exploration (10 sites)
- Confirmation drilling (12 sites)
- Hydrologic testing (11 sites)
- Comprehensive assessment (8 sites)
- District heating feasibility (12 sites)
- Industrial heating feasibility (7 sites)


DOE Low-Temperature Program
Geothermal Resource Areas
Direct Heat Potential
0
300 mi.
SCALE
Temperature below 100°C (212°F)
//// Low-Temperature Program State Team

A NEW U.S. LOW-TEMPERATURE RESOURCE ASSESSMENT PROGRAM

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Keywords: Direct Use, Resource Assessment, Geochemistry, USA

ABSTRACT

In Fiscal Year 1991, the United States Congress appropriated money for the Department of Energy to begin a new program in the evaluation and use of low- and moderate-temperature (20° to 150°C) geothermal resources. The objective of this program is to promote accelerated development of these resources to offset fossil-fuel use and help improve the environment.

The assessment program has resulted in digital databases reporting on 8,170 thermal wells and springs for 10 western states, an increase of 40% compared to the previous assessment in 1980. More than 900 resource areas were indicated and 45 of these have been identified as high-riority study areas for 150 near-term direct-heat utilization sits.

INTRODUCTION

Low- and moderate-temperature geothermal resources are widely distributed throughout the western and central United States. Numerous resources occur in the areas indicated in Figure 1, with individual reservoir areas 1 to 10 square miles in extent. In the northern Great Plains, major aquifers with fluid temperatures exceeding 50°C extend in a continuous manner for thousands of square miles. Geothermal resources also occur at certain locations in the East.

The last major effort in assessing the national potential of low-temperature geothermal resources occurred in the early 1980s (Reed, 1983). Since that time, substantial resource information has been gained through drilling for hydrologic, environmental, petroleum and geothermal projects, but there has been no significant effort to compile information on low- and moderate-temperature geothermal resources.

While there has been a substantial increase in direct-heat utilization during the last decade, the large resource base is greatly under-utilized. Since the thermal energy extracted from these resources must be used near the reservoir, collocation of the resource and the user is required. Development of a user facility at the site of the hydrothermal resource is often economically feasible. Direct-heat resources are typically used by small businesses, various types of local industry, communities, and individuals. These users generally cannot afford to hire the technical expertise required to delineate and develop geothermal resources from scratch.

To expand utilization of the direct-heat resource, a current inventory of these resources is needed by potential users, together with the information necessary to evaluate the reservoirs and the economics of potential uses. To stimulate the development of an industry, it is necessary to reduce risks of development and this can be done by providing resource data and by cost-sharing of demonstration projects.

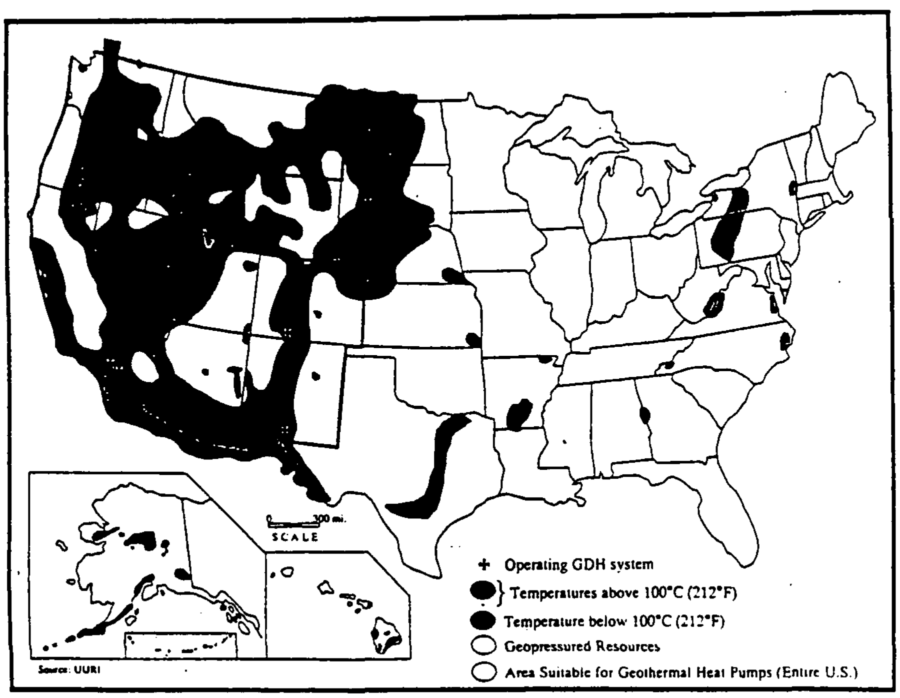

Figure 1. Geothermal Resource Areas of the United States.

LOW-TEMPERATURE PROGRAM

The program is a cooperative effort among a number of academic and state institutions working with potential direct-heat developers. The three principal institutions are the Geo-Heat Center at the Oregon Institute of Technology (OIT), the Idaho Water Resources Research Institute at the University of Idaho (IWRRI), and the Earth Science Laboratory of the University of Utah Research Institute (UURI). State geothermal resource teams (State Teams) compiling data for ten states in the west are also participating. The tasks for this project are discussed below.

Compilation of Data on Hydrothermal Resources

State Teams reviewed and updated their geothermal resource inventories which were completed as part of the USGS-DOE national assessment from 1977-1983 (Reed, 1983). Each state prepared a comprehensive digital database in table format and a resource map at a scale of 1:1,000,000. UURI and OIT have provided technical guidance and coordination, and UURI completed fluid chemistry analyses for participating states. Table 1 identifies the state agencies and principal investigators involved with the project.

The compilations included resources in the temperature range of 20° to 150°C. Many of these resources have the potential to supply energy to collocated cities within approximately 8 km of a resource as well as greenhouses, aquaculture, mining, and other process applications.

The State Teams, under subcontract to OIT and with guidance from UURI, reviewed drilling records and other information to identify new resources and verify temperatures and flow rates of springs and wells which may have changed substantially since the previous statewide geothermal resource inventory. The databases were organized into tables linked by common data-fields, using the preliminary database from the Utah Geological Survey as a model for uniformity in presentation (Blackett, 1993). Information contained in the tables includes: location (ID number, source name, county code, latitude and longitude); description (ID number, source name, type of source, temperature (°C), flow rate (L/min), depth of wells (m), current resource use, and references to relevant studies of geology, geophysics, geochemistry, hydrology completed for the site), and geochemistry (ID number, source name, pH, TDS, major cations, major anions, cation-anion balance, chemical species that may cause scale and corrosion products, and light stable isotopes).

Simultaneously, demographic and other data were collected and interpreted to evaluate potential heat loads, fossil-fuel displacement, utility electrical-demand reduction and load-leveling opportunities, and environmental benefits for potential geothermal direct-heat applications.

Preliminary Results - Resource Evaluation

State Teams for 10 western states initiated their resource evaluation and database compilation efforts in late 1992 and early 1993, and have now updated their resource inventories. Table 2 summarizes the catalog of 8,170 thermal wells and springs for these 10 western states; an increase of 40% compared to the previous assessment in 1983. More than 900 low- to moderate-temperature resource areas are indicated, and perhaps a greater number of isolated (singular) thermal wells or springs. Direct-heat use of geothermal fluids is documented at more than 250 sites, including commercial and municipal buildings, rapidly expanding greenhouse and aquaculture industries, and major space-heating districts in California, Oregon, Nevada, Idaho, and Colorado. More than 40 high-priority resource study areas have been identified, together with high potential for near-term direct-heat utilization at 150 new sites. Preliminary estimates indicate that 254 cities in 10 western state could potentially displace 18,000 GWh per year (17 million BOE) with geothermal district heating. The number of commercial and residential direct-heat users and the total energy use have increased dramatically in one decade. Some highlights from the participating follow.

Arizona. The 1992-1993 assessment shows a 100% increase in the number of thermal wells and springs. These wells and springs are delined as 35 low-temperature resource areas and an additional 205 singular thermal wells and springs. Arizona leads the nation in the use of geothermal fluids for aquaculture (Witcher, 1994).

California. The California Division of Mines and Geology reports 979 thermal wells and springs. Some 58 low-temperature resource areas have been identified with an additional 194 "singular" thermal occurrences. The 72 commercial direct-heat users include six district-heating systems, 48 resorts/spas, and 17 greenhouse, aquaculture or industrial concerns (Youngs, 1994).

Colorado. The 1992-1993 assessment reports that there are 93 goethermal areas (usually less than 8 km^2 in size) in Colorado, up from the 56 reported in 1978, there are 157 geothermal sites compared to the 125 reported in 1980. Six goethermal areas are recommended for further investigation: Trimble Hot Springs,

Table 1. State Resource Assessment Teams

State	Agency	Principal Investigator
California	Division of Mines and Geology	Leslie Youngs
Colorado	Colorado Geological Survey	James Cappa
Idaho	Idaho Water Resources Research Institute	Leland Mink William Dansart
Montana	Bureau of Mines and Geology	Wayne Van Voast John Metesh
New Mexico and Arizona	New Mexico State University- Southwest Technology Development Institute	James Witcher and Rudi Schoenmackers
Nevada	Bureau of Mines and Geology	Larry Garside
Oregon	Dept. of Geology and Mineral Industries	George Priest Gerald Black
Utah	Utah Geological Survey	Robert Blackett
Washington	Division of Geology and Earth Science	Eric Schuster

Table 2. State Geothermal Database Summary: 1992-93 Low-Temperature Program.

	State PGA	AZ 1982	CA 1980	CO 1980	ID 1980	MT 1981	NV 1983	NM 1980	OR 1982	UT 1980	WA 1981
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Low Temp.	1993	35	58	93	28	16	300	30	200	161	17
Resource Areas (20°C < Tes < 150°C)	PGA	29	56	56	28	15	300	24	151	64	10
Direct-Heat	1993	2	72	28	29	15	21	7	29	16	4
Utilization Sites (Commercial, district, resorts)	PGA	0	54	24	20	2	8	0	23	9	0
Greenhouses, Aquaculture, Industrial Processes	1993	5	17	4	17	4	8	6	7	6	0
Areas, Potential Near-Term Direct Heat Utilization	1993	4	2	4	51	2	2	4	25	7	24
Areas, High Priority Resource Study	1993	3	4	6	5	4	4	4	5	4	6

Comments: PGA - Previous Geothermal Assessment. Tres = Estimated reservoir temperature. The minimum low-temperature criteria is typically 20°C, but varies with climate.

Orvis Hot Springs, an area southeast of Pagosa Springs, the eastern San Luis Valley, Rico and Dunton area, and Cottonwood Hot Springs (Cappa, 1994).

Idaho. The Idaho Water Resources Research Institute lists 912 thermal wells and springs, more than the 899 reported in the 1980 inventory, but only half the total number of well and spring entries reviewed. Although district heating is well established at Twin Falls and Boise, there is high potential at about 50 sites for new direct-heat utilization, as well as some potential for electrical power development.

Montana. The Montana Bureau of Mines and Geology database contains information on location, flow, water chemistry, and estimated reservoir temperatures for 267 geothermal wells and springs. Low- and moderate-temperature wells and springs can be found in nearly all areas of Montana, but most are in the western third of the state. Five areas of Montana were chosen for future investigations of geothermal development based on the potential of the resource and its proximity to population centers. The areas identified are those near Bozeman, Ennis, Butte, Boulder, and Camas Prairie (Metesh, 1994).

Nevada. The Nevada Bureau of Mines and Geology includes 453 entries in a database which represents more than 3,000 wells and springs. More than 300 separate resource areas may be present in Nevada. Direct heat is utilized at 21 areas, including the Moana and Elko district-heating systems and the Duckwater (Big Warm) Springs aquaculture facility (Garside, 1994).

New Mexico. The Southwest Technology Development Institute reports 265 thermal wells and springs. Thirty low-temperature resource areas and perhaps 158 isolated thermal occurrences have been identified. New Mexico currently leads the nation with the largest acreage of geothermally-heated greenhouses on line, and expansion continues (Witcher, 1994).

Oregon. The new Oregon Department of Geology and Mineral Industries study identified 2,193 geothermal sites. More than 200 thermal areas have been identified. Geothermal fluids are used for heating over 625 buildings by businesses, organizations, and home-owners. Several greenhouses, aquaculture sites and industrial processes also use geothermal energy. Five high-priority resources study areas have been identified by DOGAMI and perhaps 25 businesses or organizations could utilize geothermal heating in the near term (Black, 1994).

Utah. The Utah Geological Survey compiled a database consisting of over 964 records on thermal wells and springs with temperatures of 20°C or greater; 300% of the previous geothermal assessment. Areas for future exploration and development interest include: southern Sevier Desert, where evidence suggests the possiblity of an undiscovered moderate to high-temperature system, and the eastern Escalante Desert, where high near-surface temperatures indicate a concealed geothermal system. Other direct-use opportunities for low-temperature geothermal resources are apparent within populated areas along the Wasatch Front (Blackett, 1993).

Washington. A detailed study by the Washington State Department of Natural Resources team has identified 971 thermal wells/ springs, 264% of the 1981 inventory, and several newly recognized low-temperature resources areas. Geothermal resource utilization is currently very low, but six counties are regarded as priority study areas, and as many as 49 potential users (commercial, private, or municipal) are collocated with promising resources (Schuster, 1994).

CONCLUSIONS

Low- and moderate- temperature geothermal resources are widely distributed throughout the western and central United States. Since the last major effort in assessing the national potential of these resources in the early 1980s, there has been a substantial increase in direct-heat utiliztion. However, the large resource base is greatly under-utilized. To expand utilization of the direct-heat resource base, a current inventory of these resource has been developed.

State Teams evaluations and compilations have resulted in the catalogging of 8,170 thermal wells and springs for 10 western states, an increase of 40% over the previous geothermal assessment in 1983. More than 40 high-priority resource study areas have been identified, together with high potential for near-term direct-heat utilization at 150 new sites.

In the future we hope to continue R&D on more cost effective methods for locating low-and moderate-temperature geothermal resources and on siting successful test and production wells. Part of this work will encompass development of improved well-testing methods and better hydrologic models of these hydrothermal resources. These tasks are expected to pay off in further discoveries of resources and in better methods to evaluate reservoir production and ultimate-development capacity at an earlier stage in the development cycle than is now possible.

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No. of pages 10, inclusive of this cover sheet.

Special Instructions: Info. on USGS ≤90°C database including 1st pg. of the three tables.

SELECTED DATA FOR LOW-TEMPERATURE (LESS THAN 90C) GEOTHERMAL SYSTEMS IN THE UNITED STATES; REFERENCE DATA FOR U. S. GEOLOGICAL SURVEY CIRCULAR 892

by

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U. S. Geological Survey
Open-File Report
83-250

This report is preliminary and has not been reviewed for conformity with U. S. Geological Survey editorial standards and stratigraphic nomenclature

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ABSTRACT

Supporting data are presented for the 1982 low-temperature geothermal resource assessment of the United States. Data are presented for 2072 geothermal sites which are representative of 1168 low-temperature geothermal systems identified in 26 States. The low-temperature geothermal systems consist of 978 isolated hydrothermal-convection systems, 148 delineated-area hydrothermal-convection systems, and 42 delineated-area conduction-dominated systems. The basic data and estimates of reservoir conditions are presented for each geothermal system, and energy estimates are given for the accessible resource base, resource, and beneficial heat for each isolated system.

INTRODUCTION

This report presents the compilation of data used in the 1982 assessment of low-temperature geothermal resources of the United States (Reed, 1983a). The assessment provides the estimated thermal energy available from the identified geothermal systems with mean reservoir temperatures less than 90C. Data for these geothermal systems were obtained from a large number of published and unpublished sources and stored in the computer-based GEOTHERM information system of the U.S. Geological Survey (Teshin and others, 1979). The computer information system is no longer active and this printed record is intended to preserve the specific data set used in the assessment. The original sources for the data are cited. Low-temperature geothermal sites were selected for assessment on the basis of surface and subsurface temperatures and evidence for permeable formations at depth. The minimum-temperature criterion used for this assessment is presented in Reed (1983b). Decisions to include or reject a system were based on the measured subsurface temperature at equlibrium conditions or on the subsurface temperature calculated from water chemistry (Mariner and others, 1983), on geologic evidence that a permeable zone existed in the rock, and on the depth measured in wells or infered from heat-flow and temperature-gradient data (Nathenson and others, 1983).

USE OF THE TABLES

The three tables present the basic data used for this assessment, the estimates of geothermal reservoir conditions, and the energies calculated for each isolated system. These tables are organized by State and county, and the tables in the assessment are organized by region, State, and geologic province. To make comparisons between the two reports easier, the geologic province is given for each geothermal system. In the process of assessment, the basic information in table 1 was used to identify low-temperature geothermal sites and to group sites that were related by geochemistry and structure into a single system. The data in table 1 was then combined with other available information to estimate the reservoir parameters: temperature, area, thickness, and the area needed for each producing well. For isolated systems, the reservoir volume was estimated to be 1 km3 and the recovery factor was estimated to be 25 percent (Sorey, Nathenson, and Smith, 1983). Table 2 gives the estimated range in reservoir temperature and the calculated energies for isolated systems. These isolated systems are summarized by geologic province in the assessment. For delineated-area systems, ranges for each reservoir parameter are given in table 3; the means of these ranges and the calculated energies for each delineated-area system are presented in the assessment.

The data for low-temperature geothermal systems are listed alphabetically by state and county. For systems that are in two or more counties, the information is cross-referenced in the tables. The geologic provinces given in the tables were used to group geothermal systems with major geologic affinities.

Table 1

The first table presents the available information on location, temperature, flow rate, and chemical composition for the low-temperature geothermal sites selected for this resource assessment. The location data were checked with available maps and reports. Names used in this table are generally those used on the state geothermal resource maps. If the site is unnamed, a nearby feature is usually given for reference. The site is identified as a spring or well, and alternate names are sometimes given in parentheses. The location is given by latitude and longitude in degrees, minutes, and hundredths of a minute. The surface temperature (Temp), in degrees Celsius, and the pH are presented with the accuracy of the original reference. The composite flow rate (Flow) of the entire spring system or set of wells is given in liters per minute (L/min). Water chemistry is presented as the concentration of dissolved constituents in milligrams per liter (mg/L).

The chemical analyses selected for this assessment were chosen on the basis of completeness, charge balance of ions, and most recent date of collection. If the calculated ionic charges did not balance within 10 percent, the analysis was considered inaccurate or incomplete and a better analysis was sought. The degree of precision in the original analytical data was preserved in the calculations, but in the table, formating constraints have placed zeros following decimal points in some values. The total concentration of dissolved solids (TDS) is corrected for partial loss of carbonate species on evaporation. The total alkalinity (Alk) is expressed as bicarbonate ion (HCO3-). References for the information given for each sample site are identified by a code number (Ref No.) that is keyed to the list of references at the end of table 1. Information that has not been previously published is identified in the list of references. Most delineated-area systems and a some isolated systems have more than one representative sample site listed to indicate the variability in temperature and water chemistry.

Table 2

The second table provides information for the isolated low-temperature geothermal systems identified in the assessment. The temperature range, calculated energies, and geologic province are presented for each system. The estimated values for minimum, maximum, and most likely temperatures and the calculated mean temperature are given in degrees Celsius. Temperature values were estimated through the use of chemical geothermometer calculations (Mariner and others, 1983) and from information on flow rate, temperature gradient, and geologic environment. The three temperature values were used to form a triangular density distribution for calculation of the energies for each system (Sorey, Nathenson, and Smith, 1983). The geologic province is given for each system to provide a key to the summarized values for isolated systems in the tables of the assessment Circular (Mariner and others, 1983; Sorey, Reed, Foley, and Renner, 1983).

Table 3

The third table provides information for the identified delineated-area low-temperature geothermal systems. Minimum, maximum, and most likely values are given for temperature, area, and thickness of the geothermal reservoir and for the spacing of producing wells on the surface. The three values of each parameter were used to form a triangular density distribution for calculation of the energies for each system, and the mean and standard deviation for each parameter are reported in the Circular (Sorey, Nathenson, and Smith, 1983). The mean transmissivity and geologic province for these systems are given in this table to aid in comparisions with the assessment.

The evaluations of some delineated-area systems were based on data compilations which could not be presented in table 1. The regional aquifers in the Central region of the United States were assessed primarily on the basis of data compliations presented as maps of temperature, water chemistry, depth, thickness, and permeablity which are referenced in the assessment (Sorey, Reed, Foley, and Renner, 1983). To obtain a more refined assessment of the thermal energy available, some large systems were divided into sub-systems with smaller ranges in temperature, area, thickness, or other characteristics, and the energy values calculated for the sub-systems were added together to determine the energy for the total system. The locations and characteristics of the smaller areas are not unique, and the intermediate energy values have little significance in this assessment. Only the ranges in characteristics for the significant systems are presented in this table.

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Table 1. Location, temperature, flow rate, water chemistry, and references for low-temperature geothermal sites in the United States

(Delineated-area systems are identified the same as in the assessment, and reperesentative sites follow the area listing. Cross reference is provided when areas occur in more than one county. Some isolated systems have more than one representative sample listed. Total alkalinity (Alk*) is calculated as bicarbonate ion. References are identified by Ref No. for the bibliography at the end of this table.)

Name	Latitude north	Longitude west	Temp C	Flow L/min	pH	TDS mg/L	Concentration (mg/L) Na	K	Ca	Mg	Cl	F	Alk*	SO4	B	SiO2	H2S	Ref No.
							ALASKA											
Baranof Hot Spring	57Ç 5.10'	134Ç50.34'	51.0		9.6	249	51	1.2	2.5	0.1	11	1.2	68	68	0.2	70.0		159
Battleship Mountain Spring	64Ç48.00'	162Ç55.00'	17.		9.2	334	120	1.2	4.8	0.1	120	9.0	53	16	0.7	56.0		161
Chena Hot Springs	65Ç 3.25'	146Ç 3.33'	57.0	840	9.1	380	110	3.3	1.3	0.1	29	18.6	131	68	0.2	85.0		159
Craig Hot Springs	55Ç20.04'	133Ç38.46'	43.5			149	30		3.9	1.5	8		56	20		57.0		254
Division BM Hot Springs	66Ç22.02'	156Ç46.02'	55.															161
"Farms - Red Shirt Lake 1" well	61Ç38.53'	150Ç 5.72'	76.7															167
Gas Rocks Hot Spring	57Ç51.90'	156Ç29.94'	52.8	57	5.9	53300	17700	450.0	1500.0	460.0	32000	0.1	1240	140	360.0	120.0	1.7	006
Granite Mountain (Sweepstakes)	65Ç22.02'	161Ç15.00'	49.		9.55	241	67	1.9	1.8		6		90	50	0.2	69.0		161
Gulkana Airfield well	62Ç 9.00'	145Ç28.00'	10.		6.6	23900	2630	82.0	4780.0	984.0	15400		84	5				083
Hawk River Spring	66Ç13.98'	157Ç34.98'	50.															161
Horner Hot Springs	64Ç55.33'	154Ç50.23'	47.0	95		292	58		10.0	3.0	39		87	45		29.0		256
Hutlinana Hot Spring	65Ç12.96'	149Ç59.58'	43.	190	7.66	590	180	7.9	20.2	6.6	40	0.8	488	55	0.3	40.0		161
Kenai High School well	60Ç33.72'	151Ç12.67'	20.0		8.0	306	108	4.7	0.5	0.7	6	1.2	308	2		32.0		244
Kilo Hot Springs	65Ç48.60'	151Ç14.22'	66.															161
Kwiniuk Spring	64Ç42.00'	162Ç28.00'	45.		7.3	1610	500	9.0	130.0	0.1	912	5.8	10		1.0	45.0		161
Lava Creek Spring	65Ç13.00'	162Ç54.00'	50.		9.1	215	75	1.4	2.0		8	9.0	100		0.8	70.0		161
Lower Klawasi, Drum Group	62Ç 8.75'	145Ç 1.55'	27.7	30	8.2	26100	9390	275.0	94.0	502.0	12000	0.4	7350		120.0	65.0		180
Lower Klawasi, Drum Group, west	62Ç 3.48'	145Ç13.32'	21.	28	7.7	27500	10080	271.0	31.0	136.0	12100	0.3	7230	664	169.0	123.0		083
Lower Klawasi, Drum Group, west	62Ç 3.48'	145Ç13.32'	27.	13	7.7	28000	10400	433.0	119.0	130.0	12500		7290	666		132.0		180
Lower Ray River Hot Springs	65Ç59.00'	150Ç35.00'	66.		9.04	224	95	2.0	11.0	0.1	25		136	23	1.6			161
Manley Hot Springs	65Ç 0.36'	150Ç37.98'	56.0	560	7.7	446	130	4.5	4.0	1.0	134	8.5	90	54	1.3	65.0		161
Nylen Hot Springs	57Ç38.64'	135Ç19.98'	49.	30	8.7	91			90.0	0.5								167
Okpilak Hot Spring	69Ç19.80'	144Ç 2.64'	48.5			379	120	4.5	9.8	0.1	31	14.0		200				244
Peril Strait Hot Spring	57Ç46.26'	135Ç49.20'	38.3			786	206	3.8	37.0	11.0	133		35	329		40.0		254
Port Moller Hot Springs	55Ç51.78'	160Ç29.58'	71.0	252	8.24	2830	792	12.3	228.0	0.2	1615	2.7	71	17	13.0	63.0	1.5	168
Ray River Hot Spring	65Ç57.78'	150Ç55.14'	45.		9.16	166	71	1.4	5.6	0.7	9		119	19	0.6			161
Red Hill Spring	69Ç37.62'	146Ç 1.62'	29.		8.2	569	120	5.8	55.0	21.0	130	1.0	322	50		27.0		036
Red Hill Spring	69Ç37.62'	146Ç 1.62'	32.8	1440	7.0	452	130	5.9			150	1.1	93	90		29.0		036
Richardson Highway well	62Ç25.00'	145Ç27.00'	10.		7.3	1530	233	11.0	167.0	111.0	800		337	3		36.0		083
Sadlerochit Spring	69Ç39.38'	144Ç23.62'	13.0	63500	7.3	223	8	1.0	47.0	18.0	4	0.6	140	66		10.0		036
South Spring	66Ç 9.00'	157Ç 7.02'	50.			284	83	2.1	5.9		6			122		65.0		161
Surprise Lake Hot Spring	56Ç55.68'	158Ç 7.20'	23.0			576	99	9.8	45.0	31.0	86	0.7	388	23	3.8	87.0		160
Tenakee Hot Springs	57Ç46.86'	135Ç13.02'	42.5		9.0	736	190	3.3	28.0	0.8	95	5.0	55	322	4.4	60.0		159
Tolsona Group, Tolsona 1 south	62Ç 6.50'	145Ç57.10'	10.		7.1	14600	4660	60.0	787.0	111.0	8870	0.3	143		35.0	16.0		180
Tolsona Group, Tolsona 2 north	62Ç 7.20'	145Ç56.60'	15.		6.3	15200	4000	26.0	1580.0	94.0	9450		48	6		7.1		180

Table 2. Temperature range, calculated energies, and geologic province for isolated low-temperature geothermal systems in the United States

[Systems in National Parks have been excluded from calculations of resource and beneficial heat (indicated by *) because they are not available for development. A standard reservoir volume of 1 km^3 was used to calculate the energy in each system. All means and standard deviations were calculated analytically.]

System	Reservoir temperature (°C) minimum	maximum	most likely	mean	Mean accessible resource base (10^{18} J)	Mean resource (10^{18} J)	Beneficial heat (MWt for 30 yr)	Geologic province
					ALASKA			
Baranof Hot Spring	51	70	65	62	0.123 ± 0.051	0.031	15.30	Southeastern Alaska
Battleship Mountain Spring	17	96	63	59	0.114 ± 0.065	0.028	13.92	Central Alaska
Chena Hot Springs	57	107	98	87	0.189 ± 0.082	0.047	25.77	Central Alaska
Craig Hot Springs	44	108	79	77	0.162 ± 0.075	0.040	21.50	Southeastern Alaska
Division BN Hot Springs	55	55	55	55	0.104 ± 0.042	0.026	12.40	Central Alaska

Table 3. Range of values for reservoir parameters and the mean transmissivity for delineated-area low-temperature geothermal systems in the United States.

[The geologic province is given to aid comparison with the assessment. Minimum (min), maximum (max), and most likely values for the reservoir parameters were used to calculate the means presented in the assessment (Reed, 1983).]

Area	Temperature (°C) min	Temperature (°C) max	Temperature (°C) most likely	Area (km^2) min	Area (km^2) max	Area (km^2) most likely	Thickness (km) min	Thickness (km) max	Thickness (km) most likely	Area per well (km^2) min	Area per well (km^2) max	Area per well (km^2) most likely	Transmissivity (m^2/s)	Geologic province
							ARIZONA							
Arizona, Cochise County														
Bowie	30	55	40	20	170	150	0.05	0.20	0.10	1.00	2.50	1.50	0.01	Basin and Range
Sulphur Springs Valley	40	80	45	50	150	100	0.05	0.20	0.10	1.00	2.50	1.50	0.01	Basin and Range
Arizona, Graham County														
Cactus Flat	35	80	45	15	50	35	0.05	0.20	0.10	0.75	1.25	1.00	0.01	Basin and Range
Arizona, Maricopa County														
Agua Caliente	35	65	45	15	30	20	0.05	0.20	0.10	0.75	1.25	1.00	0.01	Basin and Range
Buckeye Valley	30	50	40	100	200	150	0.05	0.20	0.10	1.00	2.00	1.80	0.01	Basin and Range
Buckhorn	40	75	50	10	100	50	0.05	0.20	0.10	0.75	1.25	1.00	0.01	Basin and Range
Gila Bend	35	80	50	10	50	20	0.05	0.20	0.10	0.75	1.25	1.00	0.01	Basin and Range
Harquahala Plain	35	75	40	20	140	140	0.05	0.20	0.10	1.00	2.50	1.50	0.01	Basin and Range
Rainbow Valley	30	80	35	20	140	140	0.05	0.20	0.10	1.00	2.50	1.50	0.01	Basin and Range
Arizona, Maricopa and Yuma Counties														
Hyder Valley	35	75	50	50	300	250	0.05	0.20	0.10	1.20	3.60	2.10	0.01	Basin and Range
Arizona, Pinal County														
Chandler	45	75	55	100	300	250	0.05	0.20	0.10	1.20	3.60	2.10	0.01	Basin and Range
Arizona, Maricopa County														

Table 3. State Geothermal Database Summary: 1992-95 Low-Temperature Program

	State PGA	AZ 1982	CA 1980	CO 1980	ID 1980	MT 1981	NV 1983	NM 1980	OR 1982	UT 1980	WA 1981
1. Thermal Well/ Springs	1995	1,251	989	157	1,537	267	457	359	2,193	792	975
	PGA	501	635	125	899	68	796	312	912	315	368
2. Moderate Temp. Wells/Springs (100°C<T<150°C)	1995	0	32	0	20	0	16	10	88	3	1
	PGA	0	48	0	0	0	35	3	79	3	1
3. Low Temp. Wells/Springs (20°C<T<100°C)	1995	1,251	957	157	1,517	267	441	349	2,105	789	974
	PGA	501	587	125	899	58	761	309	925	312	367
4. Low Temp. Resource Areas (20°C<Tes<150°C)	1995	35	58	93	54	33	300	30	200	161	17
	PGA	29	56	56	28	15	300	24	151	64	10
5. Space and District Heating Sites	1995	2	23	16	16	9	11	2	44	2	-
6. Industrial Appl. Sites (Dehydration, Greenhouses, Aquaculture, etc.)	1995	4	15	6	17	4	9	5	6	7	-
7. Resort/Spa Sites	1995	4	55	18	17	15	15	6	17	9	5
8. Areas, Collocated Communities	1995	14	70	15	51	18	30	12	32	23	6
9. Areas, High-Priority Resource Study	1995	3	7	6	5	4	4	4	5	4	6

Comments: PGA - Previous Geothermal Assessment. Tres = Estimated reservoir temperature.
The minimum low-temperature criteria is typically 20°C, but varies with climate.

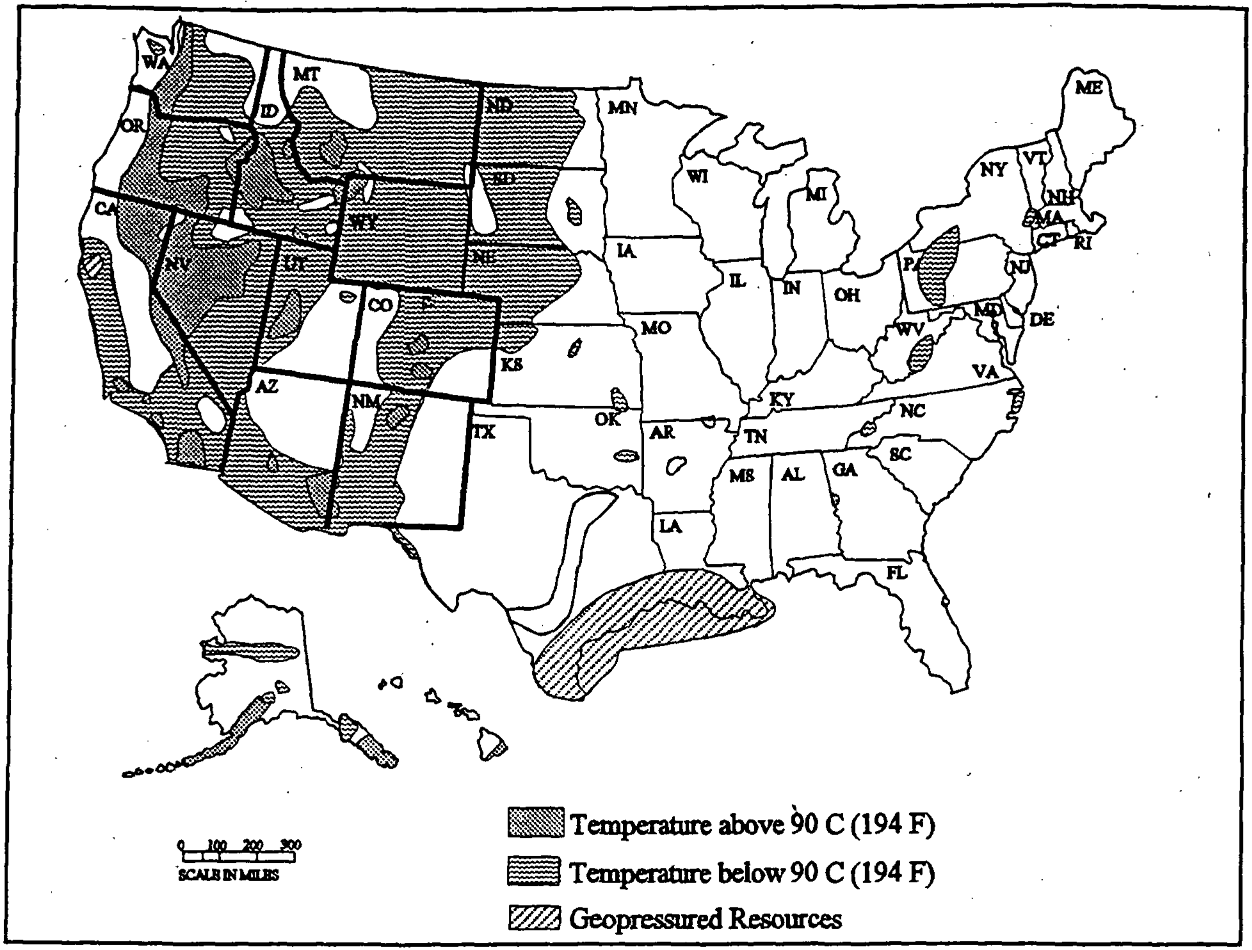

Figure 1. Geothermal resource areas of the United States with the 10 states involved in the new resource assessment identified in bold outlines.

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The U.S. Geothermal Industry: Three Decades of Growth

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Abstract *Over the last three decades the U.S. geothermal power-generation industry has grown to be the largest in the world, with over 2700 MW of installed electrical capacity. Growth during the first two decades (1960–1980) was characterized by a single utility's development of one dry-steam resource. After 1983, growth shifted toward independent power producers, and development of water-dominated geothermal resources at several locations. In the absence of significant changes in demand, incentives, or the regulatory process, new geothermal generating capacity, through 1995, will probably not exceed 500 MW. The U.S. geothermal industry must increase its inventory of characterized geothermal reservoirs in order to meet the expected demand for rapid geothermal development before the year 2000.*

Keywords Dry steam, geothermal, water-dominated.

Introduction

Geothermal energy plays a small but important role in the mix of energy sources for electric power generation in the United States. Each year, the electricity generated from geothermal resources accounts for approximately 1 billion[1] dollars of revenue and displaces over 30 million[2] barrels of imported oil. In California, about 7%[3] of the electricity consumed is supplied by geothermal resources.

Geothermal developers and researchers make a distinction between two main types of geothermal reservoirs. Two well-known geothermal systems, The Geysers in California and Larderello in Italy, are classified as dry-steam geothermal fields. In these two low-pressure, single-phase systems, dry steam is the pressure-controlling medium filling the fractured rocks. The pressure increases slightly with depth due to the density of the steam. Initial conditions in The Geysers reservoir at a depth of 1.5 km included temperatures near 250 °C and pressures near 3.3 MPa.

Much more common are the water-dominated geothermal fields, where liquid water

[1]Calculated estimate based on 2400 MW, 85% capacity and 6 cents/kWh.
[2]Calculated estimate based on 2400 MW, 85% capacity, and 540 kWh/bbl.
[3]Calculated estimate based on 2200 MW, 85% capacity, and 1990 total state consumption of 210 billion kWh (2% annual growth factor was applied to California Energy Commission 88 Electricity Report data for 1985 consumption to estimate 1990 consumption).

at high temperature, but also under high (hydrostatic) pressure, is the pressure-controlling medium filling the fractured and porous rocks. The pressure increases along a hydrostatic gradient in the water-dominated reservoirs. Some water-dominated systems may have a small steam cap at the top, and below any steam cap the temperature will often increase along the boiling-point curve with depth.

In dry-steam systems, only steam is produced at the surface, and after the steam is cleaned of rock particles it can go directly to the turbines. This ease of handling led to the early development of Larderello for electrical generation in 1904. The Geysers became the first U.S. geothermal, electrical development in 1960. In water-dominated geothermal systems, water comes into the wells from the reservoir; and the pressure decreases as the water moves toward the surface, allowing the water to boil. Only part of the water boils to steam, and a separator is installed between the wells and the power plant to separate the steam and water. The steam goes into the turbine, and the water is injected back into the reservoir. The greater capital expense required for separators and injection wells in water-dominated geothermal systems initially delayed their development because they could not compete with lower-cost alternatives such as coal, oil, and gas generation facilities.

Some water-dominated reservoirs, particularly those at temperatures below 175 °C, are pumped to produce the water, and also to keep it from boiling. The produced water is circulated through heat exchangers to heat a secondary liquid, usually an organic compound with a low temperature of boiling. The resulting organic vapor then drives a turbine to produce electricity. This type of turbine, where a secondary compound is used, is called a binary power system. Many small binary geothermal plants are installed in the United States.

Begun in 1960 in The Geysers of California, the United States geothermal electric-power industry has grown to be the largest in the world, with over 2700 MW of installed electrical-generating capacity (in this article MW only refers to electrical energy). Development in the United States is followed by the Philippines with 890 MW, Mexico with 700 MW, Italy with 545 MW, and New Zealand with 460 MW. The steady growth of geothermal development in the United States from 1960 through 1979 was led by activities at The Geysers, where the field developments of the partnership of Union Oil Company of California, Magma Energy Company, and Thermal Power Company were greatly expanded to provide steam to the Pacific Gas and Electric Company (PG&E) electrical-generation system. This construction made The Geysers field the largest geothermal development in the world. Production from The Geysers peaked in 1988, and pressure declines in the reservoir have limited any further expansion of the field.

Considerable resource exploration and research in areas outside The Geysers between 1972 and 1984 led to explosive growth in geothermal-generation capacity after 1985. Sixty-nine generating facilities are now operating at 18 resource sites in California, Nevada, and Utah. Figure 1 shows the locations of the geothermal power plants in the United States, and Table 1 provides information on the individual generating facilities.

Dry-Steam Resource Development

The Geysers fumarole area in northern California was discovered in 1847, and within a few years it became a recreation area for residents of San Francisco. In the first attempt at electrical production, two small generators (a few kilowatts) were powered by steam at The Geysers between 1924 and 1938, and several geothermal wells were drilled by

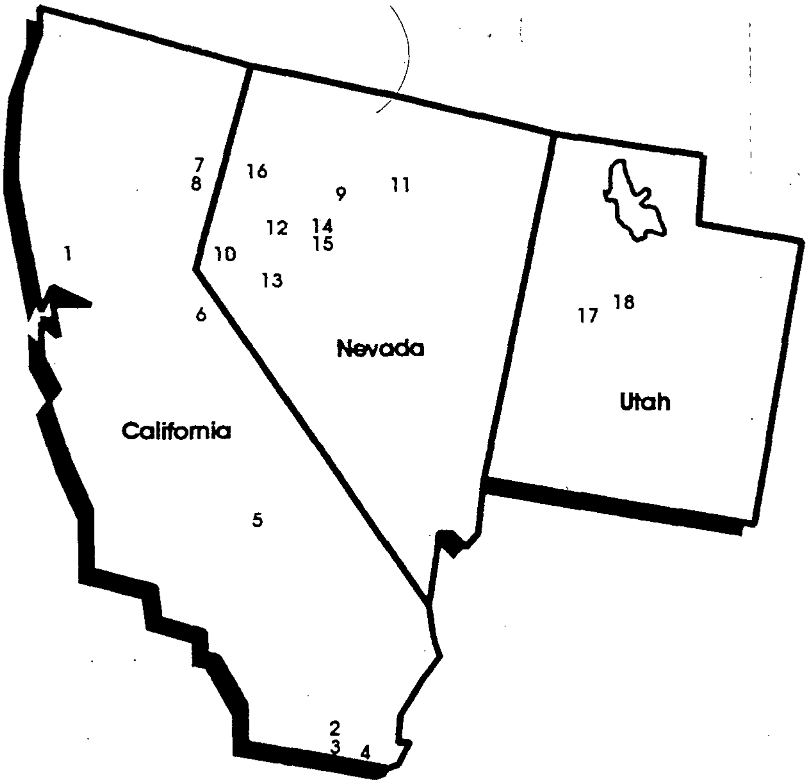

Figure 1. U.S. Geothermal power plant locations: 1, The Geysers; 2, Salton Sea; 3, Heber; 4, East Mesa; 5, Coso; 6, Casa Diablo; 7, Amedee; 8, Wendel; 9, Dixie Valley; 10, Steamboat Hot Springs; 11, Beowawe Hot Springs; 12, Desert Peak; 13, Wabuska Hot Springs; 14, Soda Lake; 15, Stillwater; 16, Empire and San Emidio; 17, Roosevelt Hot Springs; 18, Cove Fort.

the Geysers Development Company and its predecessors from 1924 through 1929 (Anderson and Hall 1973). This early attempt at commercial electrical production was discontinued, because steam generation was not competitive with other available power sources.

The Magma Power Company began the recent, successful well drilling and steam developing operations at The Geysers in 1955; in 1960, PG&E began operating the first large-scale, geothermal, electric-generation plant (Unit 1) in the United States. This turbine was a 1924 vintage, 12.5-MW, General Electric machine modified to use geothermal steam. The unit produced 11 MW of net power and operated successfully for more than 30 years.

Confidence in The Geysers resource grew, and PG&E added additional generating units to the field. For several years, each addition of new turbines had a considerable increase in size (see Table 1). The turbine size reached a maximum with the 134-MW turbine of Unit 13, which began operating in May 1980. Increasing the turbine size created some problems. The larger turbines required the drilling of more wells, increased the delay in return on investment capital, needed more expensive steam gathering lines, and caused a greater loss of income during maintenance. As of 1990, PG&E's

Table 1
U.S. Geothermal Power Plants

Steam Supplier	Plant Name	Start Date	Generating Capacity Gross (MW)	Net (MW)	Turbine Type	Notes
The Geysers Geothermal Field (Dry-Steam), California, 38°48′N Lat. 122°48′W Long. (Center of Field)						
Unocal Geothermal Division and partners	PG&E Unit 1	Sept. 1960	12.5	11	Steam	Retired
	PG&E Unit 2	March 1963	14.1	13	Steam	Retired
	PG&E Unit 3	April 1967	28.8	27	Steam	Retired
	PG&E Unit 4	Nov. 1968	28.8	27	Steam	Retired
	PG&E Unit 5	Dec. 1971	55	53	Steam	
	PG&E Unit 6	Dec. 1971	55	53	Steam	
	PG&E Unit 7	Aug. 1972	55	53	Steam	
	PG&E Unit 8	Nov. 1972	55	53	Steam	
	PG&E Unit 9	Oct. 1973	55	53	Steam	
	PG&E Unit 10	Nov. 1973	55	53	Steam	
	PG&E Unit 11	May 1975	110	106	Steam	
	PG&E Unit 12	March 1979	110	106	Steam	
	PG&E Unit 14	Sept. 1980	114	109	Steam	
	PG&E Unit 17	Dec. 1982	119	113	Steam	
	PG&E Unit 18	Feb. 1983	119	113	Steam	
	PG&E Unit 20	Oct. 1985	119	113	Steam	
Calpine Corporation	PG&E Unit 13	May 1980	138	133	Steam	
	PG&E Unit 16	Oct. 1985	78	72	Steam	
	SMUD GEO #1	Dec. 1983	78	72	Steam	
	Bear Canyon	Oct. 1988	24.4	22	Steam	SO-4
	West Ford Flat	Dec. 1988	30.5	28.7	Steam	SO-4
Coldwater Creek Operating Company	CCPA Unit 1	June 1988	66	62	Steam	
	CCPA Unite 2	July 1988	66	62	Steam	
Mission Energy	Aidlin Plant	May 1989	23.4	20	Steam	SO-4
Santa Fe Geothermal	Santa Fe Unit 1	April 1984	97	95	Steam	SO-4
Northern California Power Association	NCPA Unit 2	Jan. 1983	115	110	Steam	
	NCPA Unit 3	Oct. 1985	115	110	Steam	
R. C. Dick	PG&E Unit 15	June 1979	64	59	Steam	Deactivated
California Department of Water Resources	Bottle Rock Plant	Oct. 1984	59	55	Steam	Deactivated

Table 1
U.S. Geothermal Power Plants (*Continued*)

Steam Supplier	Plant Name	Start Date	Generating Capacity		Turbine Type	Notes
			Gross (MW)	Net (MW)		
Salton Sea Geothermal Field (Water-Dominated), California, 33°11′N Lat. 115°37′W Long.						
Unocal Geothermal	Salton Sea Unit 1	June 1982	12	10	Single Flash	
	Salton Sea Unit 2	March 1990	19	17.7	Multi Flash	SO-4
	Salton Sea Unit 3	Feb. 1989	53.9	50.8	Dual Flash	SO-4
Magma Power Company	Vulcan Plant	Dec. 1985	39.7	32.4	2 Single Flash	
	Del Ranch Plant	Dec. 1988	38.2	32.4	2 Single Flash	SO-4
	J. J. Elmore Plant	Dec. 1988	38.2	35.8	Dual Flash	SO-4
	Leathers Plant	Dec. 1989	38.2	35.8	Dual Flash	SO-4
Heber Geothermal Field (Water-Dominated), California, 32°43′N Lat. 115°32′W Long.						
Chevron Resources	Heber Flash Plant	Aug. 1985	52	47	Dual Flash	SO-4
East Mesa Geothermal Field (Water-Dominated), California, 32°47′N Lat. 115°15′W Long.						
East Mesa Operator Corporation[a]	B.C. McCabe	Nov. 1979	13.4	12.5	Binary, isobutane	
	East Mesa Unit 1	May 1989	21.7	18.5	Dual Flash	SO-4
	East Mesa Unit 1	June 1989	21.7	18.5	Dual Flash	SO-4
Ormat Energy Systems[a]	Ormesa 1	Dec. 1986	29.7	24	30 Binary units	SO-4
	Ormesa 2	June 1987	24	18.5	20 Binary units	SO-4
	Ormesa 1E	Dec. 1988	12.8	8	10 Binary units	SO-4
	Ormesa 1H	Dec. 1989	8.5	6	12 Binary units	SO-4
Coso Hot Springs Geothermal Field (Water-Dominated), California, 36°02′N Lat. 117°48′W Long.						
California Energy Company	Navy 1, Unit 1	July 1987	30	27.5	Double Flash	SO-4
	Navy 1, Unit 2	Nov. 1988	30	27.5	Double Flash	SO-4
	Navy 1, Unit 3	Nov. 1988	30	27.5	Double Flash	SO-4
	Navy 2, Unit 4	Nov. 1989	30	27.5	Double Flash	SO-4
	Navy 2, Unit 5	Dec. 1989	30	27.5	Double Flash	SO-4
	Navy 2, Unit 6	Dec. 1989	30	27.5	Double Flash	SO-4
	BLM East, Unit 7	Dec. 1988	30	27.5	Double Flash	SO-4
	BLM East, Unit 8	Dec. 1988	30	27.5	Double Flash	SO-4
	BLM East, Unit 9	Aug. 1989	30	27.5	Double Flash	SO-4

Table 1
U.S. Geothermal Power Plants (*Continued*)

Steam Supplier	Plant Name	Start Date	Generating Capacity		Turbine Type	Notes
			Gross (MW)	Net (MW)		
Casa Diablo Geothermal Field (Water-Dominated), California, 37°39′N Lat. 118°55′W Long.						
Pacific Enterprises[a]	MP #1 Plant	Feb. 1985	12 (max)[b]	10 (max)	2 Binary units	
	MP #2 Plant	Dec. 1990	15 (max)	12 (max)	3 Binary units	SO-4
	PLES #1 Plant	Dec. 1990	15 (max)	12 (max)	3 Binary units	SO-4
Amedee Hot Springs Geothermal Field (Water-Dominated), California, 40°18′N Lat. 120°12′W Long.						
Trans-Pacific Geothermal Corp.[a]	Amedee #1	Nov. 1988	3.2	2	2 Binary units	SO-4
Wendel Hot Springs Geothermal Field (Water-Dominated), California, 40°21′N Lat. 120°15′W Long.						
Barber-Nichols Co.[a]	Wineagle	Sept. 1985	0.8	0.7	Binary Unit	
Dixie Valley Geothermal Field (Water-Dominated), Nevada, 39°38′N Lat. 118°06′W Long.						
Oxbow Geothermal Corporation	Dixie Valley	Feb. 1988	62	57	Dual flash	SO-4
Steamboat Hot Springs Geothermal Field (Water-Dominated), Nevada, 39°23′N Lat. 119°45≈′W Long.						
Caithness Corporation[a]	Caithness Plant	Feb. 1988	13.2	12.5	Single flash	
Far West Electric Energy Fund, Ltd.[a]	Far West Plant	Oct. 1986	9.4	6.8	9 Binary, pentane	
Beowawe Hot Springs Geothermal Field (Water-Dominated), Nevada, 40°34′N Lat. 116°35′W Long.						
California Energy Company	Oxbow Beowawe	Dec. 1985	17	16.7	Dual flash	SO-4
Desert Peak Geothermal Field (Water-Dominated), Nevada, 39°45′N Lat. 118°57′W Long.						
California Energy Company	Desert Peak	Dec. 1985	10	9	Dual flash	

Table 1
U.S. Geothermal Power Plants (*Continued*)

Steam Supplier	Plant Name	Start Date	Generating Capacity Gross (MW)	Generating Capacity Net (MW)	Turbine Type	Notes
Wabuska Hot Springs Geothermal Field (Water-Dominated), Nevada, 39°09′N Lat. 119°11′W Long.						
Tad's Enterprises[a]	Wabuska	Sept. 1984	2.5	1.7	2 Binary units	
Soda Lake Geothermal Field (Water-Dominated), Nevada, 39°34′N Lat. 118°51′W Long.						
Ormat Energy Systems[a]	Soda Lake 1	Dec. 1987	3.6	2.7	3 Binary units	
	Soda Lake 2	Sept. 1990	18	13	7 Binary units	
Stillwater Geothermal Field (Water-Dominated), Nevada, 39°31′N Lat. 118°33′W Long.						
Ormat Energy Systems[a]	Stillwater Plant	April 1989	17	12.5	14 Binary units	
San Emidio Geothermal Field (Water-Dominated), Nevada, 40°24′N Lat. 119°25′W Long.						
Ormat Energy Systems[a]	Empire Project	Dec. 1987	4.8	3.2	4 Binary units	
Roosevelt Hot Springs Geothermal Field (Water-Dominated), Utah, 38°30′N Lat. 112°51′W Long.						
California Energy Company[a]	Blundell Plant	July 1984	23.5	20	Single Flash	
Cove Fort—Sulphurdale Geothermal Field (Water-Dominated), Utah, 38°36′N Lat. 112°33′W Long.						
Mother Earth Industries[a]	Sulphurdale Unit 1	Oct. 1985	2.6	1.8	4 Binary units	
	Sulphurdale Unit 2	Sept. 1988	2	1.8	Single flash atm. exhaust	
	Bud Bonnett Plant	Oct. 1991	10	8.5	Single flash	

[a]Supplies both brine and steam.
[b]max, Maximum.

geothermal capacity at The Geysers had grown to 1360 MW. In addition, other utilities have installed 459 MW at The Geysers, and independent power producers have installed 147 MW.

Delay in Water-Dominated Resource Development

Geothermal exploration in water-dominated systems of the western United States began shortly after the exploration in The Geysers. In 1925 and 1926, after drilling 2 wells at The Geysers, pioneer geothermal driller Fred Stone and his company drilled 12 geothermal wells (each less than 1000 ft deep) in the Hot Creek area just east of the present Casa Diablo geothermal field in eastern California (Anderson and Hall 1973). In 1927, the Pioneer Development Company used Fred Stone's company to drill 3 geothermal exploration wells (maximum depth 1473 ft) at Mullet Island, which is now at the northeast end of the Salton Sea geothermal field in the Imperial Valley of California (Rook and Williams 1943). Competing sources of electricity with better economic returns cooled the ambitions of the early geothermal pioneers.

From a global perspective, the first major electrical development of a water-dominated geothermal reservoir took place in 1950 at the Wairakei field of New Zealand. The success at Wairakei and the continued success of PG&E at The Geysers fueled interest in developing the water-dominated resources in the United States. During the period 1957 to 1965, the Magma Power Company and several partners drilled geothermal exploration wells in many areas that now produce electricity. Magma drilled several shallow wells at Casa Diablo, Wendel, and Amedee, California; and Brady Hot Springs, Steamboat, Beowawe, and Wabuska, Nevada; and at Puna, Hawaii. In 1967, both Earth Energy Corporation (later Unocal) and Morton Salt Company had small, experimental geothermal turbines operating at the Salton Sea field, but the silica scaling and high salt content prevented their commercial development of the resource at that time.

In 1975, the U.S. Geological Survey (USGS) conducted a geothermal-resource assessment (White and Williams 1975) that indicated that over 90% of the geothermal resources in the United States are water dominated; of these, 80% are between 100 and 200 °C. The USGS assessment documented what was known about the geothermal prospects at that time, and this report was instrumental in expanding interest in developing these resources. The higher degree of risk, greater cost, an adverse regulatory climate, and relative immaturity of the associated technology discouraged development of water-dominated resources through 1976. These impediments were mitigated significantly by actions taken by the federal government in response to the oil shock of 1973.

In order to encourage the development of indigenous resources and the associated technologies, the federal government provided large sums to support research and development (R&D) in these areas. The federal geothermal R&D program was initiated in 1972 by the actions of Congress: funding the National Science Foundation for energy research, giving the Atomic Energy Commission broad authority to conduct research on all types of energy resources, and increasing the research effort of the U.S. Geological Survey in the location of energy resources. After passage of the Geothermal Research, Development and Demonstration Act in 1974, the programs of the Atomic Energy Commission and the National Science Foundation (NSF) were placed in the Energy Research and Development Administration (ERDA), and then passed to the Department of Energy (DOE) in 1978. Federal R&D annual funding for geothermal energy at DOE reached a peak of $160 million in 1979. Two later geothermal resource assessments by the USGS documented the greatly expanded information base for geothermal systems in the United States that resulted from the research effort (Muffler 1979; Reed 1983).

During the same period, the federal government also encouraged development of geothermal resources by providing energy tax credits and loan guaranties and creating a more progressive regulatory climate through passage of the Public Utility Regulatory Policy Act (PURPA) of 1978. Sections 201 and 210 of PURPA were designed to encourage development of cogeneration and other small, independent-power projects by establishing a legal framework for the existence of independent (nonutility) power producers and requiring utilities to purchase power form qualifying facilities (QFs). Such producers were limited to a maximum net capacity of 80 MW.

In 1979, the Federal Energy Regulatory Commission (FERC) formulated the set of rules and regulations for implementation of PURPA. FERC directed state regulators to require that utilities purchase power from independent power producers (IPPs) at the utility's full avoided cost and to make the utility's transmission system available to deliver the power to markets. Of particular significance to the geothermal industry was the FERC decision that utilities could be required to pay the QF a capacity charge as well as an energy charge. The rationale for the capacity charge was that, because of the baseload nature of geothermal power, its sale to the utility directly displaced capacity that the utility would otherwise have to build in the future. This led to the California Energy Commission requiring utilities to issue Standard Offer Number Four (SO-4) contracts for purchase of power from independent producers. These long-term contracts (30 years) set prices at the utility's full avoided cost for new baseload capacity. The effect of these incentives on the geothermal industry has been a shift from utility development of a single dry-steam resource to independent development of water-dominated resources at multiple locations. This trend, evident in Figure 2, has resulted in the IPP segment of the industry increasing its capacity from zero to approximately one-third of the total. Production from water-dominated resources is also approximately one-third of total production.

Rapid Development of Water-Dominated Resources

The first electrical development of a water-dominated geothermal resource in the United States occurred in November 1979, at the East Mesa field in the Imperial Valley of California. The electrical generation facility, consisted of a binary application, a Borg Warner double-flow, three-stage turbine using isobutane as the working fluid to drive a 10-MW generator. Several production wells are pumped to produce 655,000 kg/h of brine (approximately 3.5 salt by weight). The brine is delivered at 1.86 MPa and 182 °C to the heat exchangers to transfer energy to the isobutane. Later turbine modifications increased the gross output to 13.4 MW of electricity. This plant is named after B. C. McCabe, the geothermal pioneer who, with his Magma Power Company, started the U.S. geothermal industry at The Geysers in 1955.

In June 1980, Southern California Edison (SCE) began operation of a 10-MW (gross) experimental power plant at the Brawley geothermal field with steam produced by Unocal (Cedillo and Yamasaki 1981). The high-salinity brines produced ranged between 5 and 25% salt by weight, and reservoir uncertainties led to abandonment of the field after only a few years of production. The turbine and generator were later installed at the Salton Sea geothermal field.

An experimental geothermal generator built by the Department of Energy (DOE) began continuous operation in March 1982, at the Puna geothermal field on the Island of

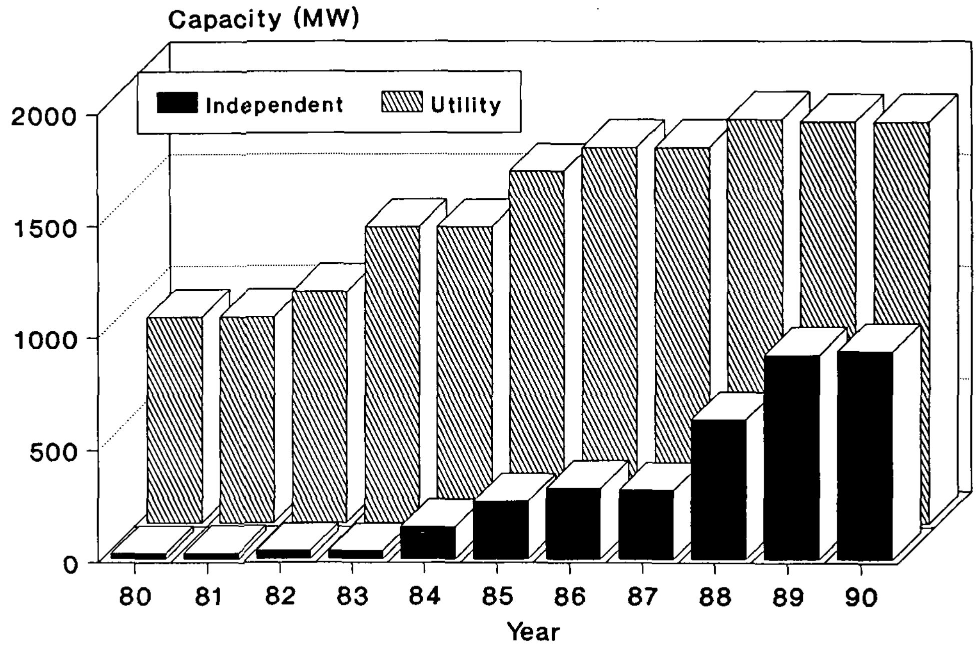

Figure 2. Geothermal electric plant ownership by utilities and independent power producers.

Hawaii (Thomas 1982). This plant produced a maximum of 2.5 MW from steam flashed from the hot water of a single well begun by NSF and completed by ERDA in 1976. Water in the reservoir has temperature above 360 °C at a depth of almost 2 km. Production from this well ceased when generation from the plant was discontinued in December 1989, after almost 7 years of operation.

The Geothermal-Loop Experimental Facility (GLEF) in the Salton Sea geothermal field of California is an example of a jointly funded, government and industry, geothermal research facility. Difficulty in handling the high-salinity brines (over 20% salt by weight) in the Salton Sea field was delaying commercial power generation from this high-energy, water-dominated resource. The facility, completed in 1976, was built to determine the technical feasibility of removing salt that formed when steam was flashed from the brine. The crystallizer-clarifier, brine-treatment process developed at the GLEF demonstrated that commercial power generation was technically and economically feasible.

Economic electrical generation from the Salton Sea geothermal field began in June 1982, when Unocal began production from its 12 MW (gross) turbine. Wells in this field produce from depths of about 1 km and reservoir temperatures of about 300 °C. The higher-temperature (up to 380 °C) brines from greater depths also have higher salinity. One well in this field produces over 1.5 million kg/h of brine, which is equivalent to the generation of 30 MW of electricity (Reed 1989). After 1982, Unocal added two additional generation units for a total gross electrical generation of 83 MW. In December 1985, Magma Power Company began continuous production from their first power plant in the Salton Sea field (40 MW, gross). Magma has since added 3 more generating units to bring their total electrical generation to 145 MW (gross).

After 1980, the United States experienced phenomenal growth in the water-dominated segment of the geothermal industry. Forty water-dominated geothermal generating units (839 MW) were commissioned, a 49% annual compound rate of growth. The industry annual compound growth rate (for both dry-steam and water-dominated capacity) from 1980 through 1990 was 15%. The sharp increase in the number of new water-dominated plants in 1988 and 1989 (see Fig. 3) resulted from developers rushing to complete projects before expiration of SO-4 contracts and available tax credits.

Current Industry Outlook

The Geysers geothermal field reached its maximum production rate in 1988 of about 2000 MW, and pressure and production rates have declined since then. The Geysers production decline has demonstrated the need for increased water injection to maintain reservoir pressure, and current research is directed toward determining the best method for water injection. Efforts being made to mitigate production decline include a search for additional sources of water to augment injection in this semi-arid area. Other research projects are investigating modifications to turbine operations to increase effi-

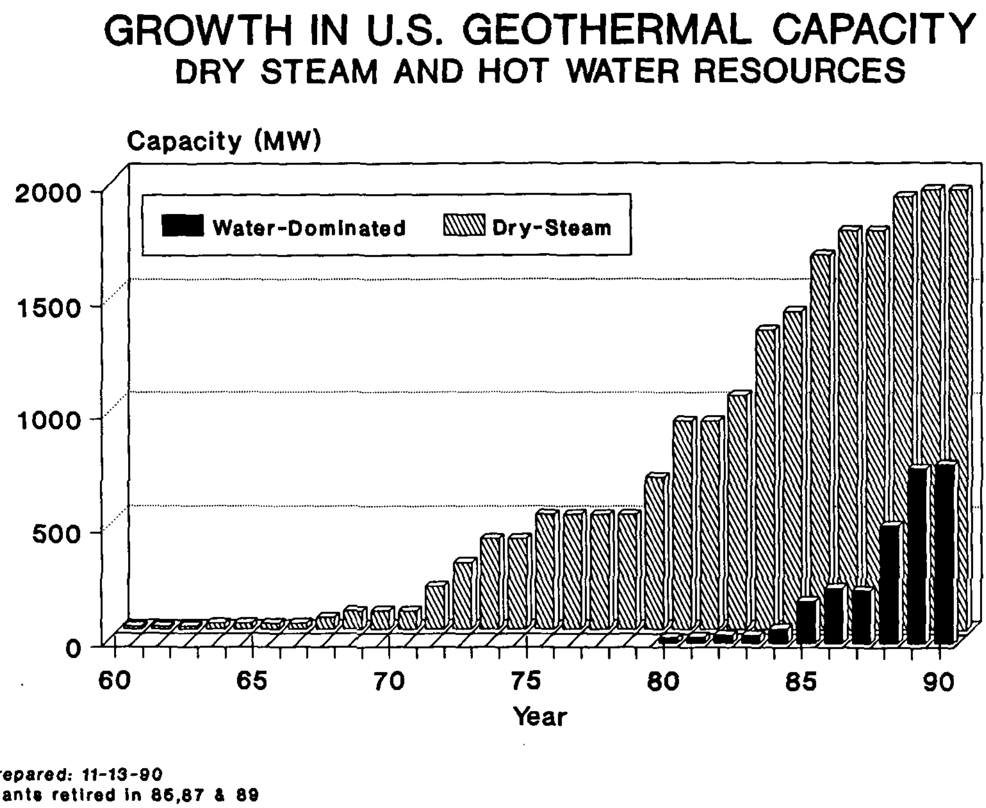

Figure 3. Growth in U.S. geothermal electric generation capacity by dry-stream and water-dominated resources.

ciency. Operations at some of the older, less efficient plants have been suspended, and the steam has been re-routed to more efficient units.

Before the year 2000, a major exploration effort is needed to rebuild the inventory of undeveloped geothermal sites that can be developed rapidly when the economic need occurs. A major period of geothermal exploration culminated in 1979 and 1980, with the DOE cost-shared program for Industry-Coupled Drilling. In that program, DOE used federal funds to share the risk of exploratory drilling (with industry) in 15 prospect areas of Utah and Nevada. The program was highly successful, and eight of those geothermal prospects are now producing electricity. The rapid expansion after 1980 was made possibly by earlier characterization of several geothermal reservoirs, and future development requires that a new selection of geothermal reservoirs be characterized soon.

The availability of SO-4 contracts from California utilities provided the needed economic incentive for development of many previously characterized geothermal sites in California and Nevada. Unfortunately, geothermal exploration has not kept pace with development, and there are now very few geothermal sites that are well characterized for rapid development in the future. To sustain a pace of development similar to that from 1980 through 1990, a major exploration effort is needed to build the inventory of geothermal areas.

The most promising new areas for geothermal exploration are in Hawaii and the Cascade Mountains of Washington, Oregon, and northern California. An area with extensive geothermal exploration, the Basin and Range of Nevada and Utah, still holds the promise of large quantities of undiscovered geothermal resources. Developers have begun construction of a 25-MW geothermal plant in the Puna field of Hawaii and expect to begin electrical generation before the end of 1992. Some developers have speculated that the rift system on Hawaii could yield up to 500 MW. The Glass Mountain field of northern California (southern Cascades) is another area believed to have significant potential. Unocal plans to construct a small plant there and is seeking a power-sales agreement. Other areas of the Cascades are being explored slowly and may eventually provide new areas for geothermal development.

Future Growth

A strong market for geothermal electrical generation is anticipated as a result of the Clean Air Act of 1990 and because of the growing concern about global warming. Geothermal development will benefit from the growing need for energy sources with low atmospheric emissions and proven environmental safety. It will not be easy for the geothermal industry to continue a high growth rate of electrical generating capacity from 1990 to the end of the millennium. Most of the easily located geothermal systems, those with hot springs, fumaroles, and geysers at the surface, are already known and many have been developed. In order to locate and characterize hidden geothermal systems that do not reach the surface, new approaches to exploration are needed. The high economic risk of drilling in frontier areas has limited geothermal exploration in recent years.

The economic risk of exploratory drilling may be reduced, researchers believe, through the development of new core hole evaluation technologies. Core drilling became an important method of geothermal exploration after 1980, because the cost is only half that of a large-diameter well to the same depth. Core drilling provides an excellent set of rock samples and fine temperature-gradient information, but it is still necessary to drill a more expensive, large-diameter well for reservoir testing and evaluation. To take full advantage of the lower cost of core drilling, it will be necessary to develop the methodology and equipment to conduct reservoir testing and evaluation during core drilling.

The demand for electric power has finally caught up with the supply in the western United States, and state regulatory agencies are reinterpreting PURPA to require independent power producers to bid competitively on a cost-only basis. Experts estimate that demand for new capacity will grow again during the next decade, but the current low prices for natural gas make it difficult for geothermal power to compete with gas-fired generation on a cost-only basis.

State regulatory actions under consideration may enhance the competitive position of geothermal IPP projects. Several states are considering requiring weighted cost factors for generation bids, based on environmental and fuel diversity considerations. Other states are expected to follow this trend. California has adopted a renewable "set-aside" of 286 MW, as a temporary measure while the state promulgates rules for the weighted cost factors. Approximately 60% of the new generating capacity added from 1980 through 1990 was at The Geysers (Rannels and McLarty 1990). With further development there unlikely, significant growth in geothermal generating capacity during the next decade will rely on the discovery and production of several new water-dominated geothermal fields.

In the absence of significant changes in demand, incentives, or the regulatory process, new geothermal generating capacity during the next 5 years will probably not exceed 500 MW. Growth in the longer term is difficult to predict, but with large estimates of untapped resources (Muffler 1979) and an excellent reputation for rapid and cost-effective development, the geothermal industry has the potential for significant growth.

Acknowledgment

This analysis was sponsored by the Geothermal Division of the U.S. Department of Energy through a contract to Meridian Corporation.

References

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not on UGS tables

COMPILED BY............. LEE, LINDA
COMPILER AFFILIATION... IDAHO DEPT. WATER RESOURCES

RECORD 00004

GEOTHERM SAMPLE FILE
NAME OF SAMPLE SOURCE... BEARD WELL
WELL/SPRING NUMBER...... 3N 2E 11ABC1

GEOTHERM FILE ID: 0015265

LOCATION
COUNTRY............. UNITED STATES
STATE............... IDAHO
COUNTY.............. ADA
(?) GEOLOGIC PROVINCE..
(?) MAP REFERENCE...... BOISE NORTH 1:24000

TOWNSHIP-RANGE
03N 02E 11 NW OF NE

COORDINATES
LAT/LONG... 43-37.01 N 116-11.40 W
UTM ZONE... +11
NORTHING... 4829420.
EASTING.... 565359.

SAMPLE DESCRIPTION AND CONDITIONS
DATE/COLLECTOR....... 1977/10/21 MITCHELL, JOHN
SAMPLE NUMBER........ 3N 2E 11ABC1
POINT OF COLLECTION.. WELL DISCHARGE PIPE
TEMPERATURE (C)...... 76.0
DISCHARGE............ 0.09 L/MIN
WATER TREATMENT............ 7 BOTTLE SAMPLE 3FA FU FD RU RC

WATER ANALYSIS
PH..................... 8.5 AT(C) 25.
SPECIFIC CONDUCTANCE.... 420.
ALKALINITY.............. 126. AS CACO3
TOTAL DISSOLVED SOLIDS... 295.

ANALYSIS IN MG/L

AG....		CO3.....	19.	LI...	0.05		
AL....		CR......		MG...	N		
AS....	0.007						
AU....		CU......		MO...		SIO2.	80.
B.....		F.......	17.	NA...	89.		
BA....		FE+3....		NA+K.		SO4..	21.
CA....	5.5	HCO3....	120.				
CA+MG.		HG......	N				
CD....		H2S.....		PO4..	0.01		
CL....	3.1						
CO....		K.......	1.4				

ISOTOPES (0/00)

REFERENCE AND IDENTIFICATION
Ref COMPILED BY............. LEE, LINDA
COMPILER AFFILIATION... IDAHO DEPT. WATER RESOURCES

RECORD 00005

GEOTHERM SAMPLE FILE
NAME OF SAMPLE SOURCE... FERD KOCH WELL
WELL/SPRING NUMBER...... 3N 2E 2CBD1

GEOTHERM FILE ID: 0015260

LOCATION
COUNTRY............. UNITED STATES
STATE............... IDAHO

TOWNSHIP-RANGE
03N 02E 02 NW OF SW

COORDINATES
LAT/LONG... 43-37.28 N 116-11.?? W

```
    CA....   1.5       HCO3....   86.
    CA+MG.             HG......   0.0005     PB...  L 0.06
    CD.... L 0.01      H2S.....              PO4..    0.092
    CL....   17.       I.......   0.007      RB...  L 0.02
    CO.... L 0.05      K.......   1.1
REFERENCE AND IDENTIFICATION
  COMPILED BY............  SANFORD, LINDA
  COMPILER AFFILIATION...  U.S. GEOLOGICAL SURVEY
  COMPILER CROSS INDEX...  01
  REFERENCE..............  MARINER AND OTHERS, 1974; MARINER AND OTHERS, 1975
```

RECORD 00004

```
GEOTHERM SAMPLE FILE                                                          GEOTHERM FILE ID:  0002206
  NAME OF SAMPLE SOURCE... RADIUM HOT SPRINGS
  WARING NUMBER........... 17A
LOCATION                                TOWNSHIP-RANGE                    COORDINATES
  COUNTRY............  UNITED STATES     07S 039E  28 NE                    LAT/LONG...  44-55.82 N 117-56.36 W
  STATE..............  OREGON                                               UTM ZONE...  +11
  COUNTY.............  BAKER                                                NORTHING...  4975423.
  GEOLOGIC PROVINCE..                                                       EASTING....  425874.
  MAP REFERENCE......  HAINES 1:24000
  OTHER LOCALITY INFORMATION:  1 MI. NORTH OF HAINES
SAMPLE DESCRIPTION AND CONDITIONS
  DATE/COLLECTOR.......  1955/05/01
  TEMPERATURE (C)......    57.2
   DISCHARGE...........    871.   L/MIN
  PERTINENT LITHOLOGY...... JURASSIC OR CRETACEOUS QUARTZ DIORITE
WATER ANALYSIS
  PH......................     9.7
  SPECIFIC CONDUCTANCE.....    290.
  TOTAL DISSOLVED SOLIDS...    244.
  ANALYSIS IN PPM                                                        ISOTOPES (0/00)
    AG....             CO3.....   47.
    AL.... N           CR......              MG...  N
    AS....             CS......              MN...  N
    AU....             CU......              MO...             SIO2.    80.
    B.....             F.......   1.0        NA...    63.
    BA....             FE+3....              NA+K.             SO4..    31.
    BE....             FE(TOT). N
    CA....   1.6       HCO3....   5.         NO3..    0.2      U....  L 0.0001
    CD....             H2S.....              PO4..  N
    CL....   17.
    CO....             K.......   2.0
REFERENCE AND IDENTIFICATION
  COMPILED BY............  SANFORD, LINDA
```

CHEM

UGS Table 3 Chemistry

ID	SOURCE	pH	TDSc	TDSm	Na	K	Ca	Mg	Fe	Al	SiO2	B	Li	HCO3	SO4	Cl
1	St. George City Aqueduct	8.4	103	108	5	0	18	5	0	0	25	0	0	90	3	2
2	Vevo Hot Springs	7.5	395	408	32	4	56	28	0	0	38	0	0	245	86	30
3	Green Spring	7.0	1239	1248	274	24	104	23	0	0	22	0	0	234	404	270
4	Toquerville Spring	7.7	459	480	21	3	74	31	0	0	44	0	0	219	160	18
5	Pah Tempe Hot Springs	5.9	7214	7388	1587	120	740	130	0	0	27	2	2	1104	1802	2250
6	Pahcoon Spring	7.5	386	107	25	2	57	27	0	0	45	0	0	203	77	48
7	Berry Spring	7.9	1349	1490	73	12	192	97	0	0	26	0	0	196	768	81
8	Washington Hot Pot	7.7	311	338	9	3	62	22	0	0	18	0	0	189	86	17
9	Stratton Turf Farm	7.8	1177	1284	71	8	161	90	0	0	23	0	0	202	636	86
10	Stratton Turf Farm	8.2	325	318	29	0	52	23	0	0	15	0	0	154	62	68
11	W. Hafen	8.0	3081	3140	847	21	79	47	0	0	9	1	0	536	1640	170
12	O. Gregorson	7.1	4109	4398	484	7	637	154	0	0	25	1	0	341	1930	694
13	W. Cooper	7.7	353	382	37	2	46	27	0	0	15	0	0	154	106	44
14	St. George City, Creek#2	7.0	928	952	176	19	90	18	0	0	20	1	0	197	462	41
15	Stucki Farms	7.8	2492	2646	501	12	155	125	0	0	17	1	0	167	1164	430
16	P. Foremaster	6.6	2588	2740	442	19	260	102	0	0	16	1	0	380	1138	416
18	EV-111	9.1			446	148	3	5	0	0	54	5	0	259	40	26
19	EV-118	7.2		1760	405	34	140	18	0		49	1	1	376	367	447
20	EV-119	7.1		1730	395	34	145	14	0		52	1	1	351	376	402
21	EV-130	7.1			482	51	0	95	17	0	42	0	0	367	24	60
22	EV-131	7.1			724	60	0	123	27	0	33	0	0	159	219	321
23	EV-140	7.9			304	25	7	41	11	0	58	0	0	292	26	37
24	EV-141	7.6			672	54	8	96	34	0	46	0	0	167	188	46
24	EV-141	7.6	5847		1900	65	155	60	0	0	17	1		265	60	3400
25	EV-150	7.1		1556	376	24	145	14	2		44	1	1	476	359	366
26	Thermo Hot Springs EV-151	6.6		1524	378	51	77	10	0		87	1	1	392	474	222
27	Thermo Hot Springs EV-152	6.8		1564	378	52	78	10	0		87	1	1	401	476	222
28	Thermo Hot Springs EV-153	7.4		1518	379	51	85	10	0		89	1	1	401	475	220
29	Thermo Hot Springs EV-154	7.0		1495	371	50	69	10	0		84	1	1	401	460	222
30	Christensen Bros., NC-10	7.6		1120	270	21	58	0	0	0	99	1	0	64	580	52
31	Wood Ranch	7.4	1812	1796	445	41	146	17	0	0	65	1	1	452	400	468
32	Hatton Hot Springs	7.1	4783	4848	1041	137	438	86	0	0	48	4	3	425	1018	1790
33	Saratoga Hot Springs-1	6.8		1428	225	23	193	48	0	0	25	0	0	376	422	339
34	Saratoga Hot Springs-2	6.7		1436	225	23	186	48	0		25	0	0	367	424	329
35	Saratoga Hot Springs-3	6.8		1446	223	24	234	49	0		25	0	0	351	417	325
36	P-10	7.9			260	14	7	38	25	0	49	0	0	259	28	15
37	P-12	8.0		1040	216	21	49	59	0		25	0	0	284	239	280
38	P-16	7.9			580	76	24	56	27	1	68	0	0	234	25	180
39	P-39	7.7			500	83	7	55	28	0	20	0	0	493	28	55
40	G-14	7.4			300	42	11	34	17	0	63	0	0	284	27	15
41	G-24	6.7		1724	464	32	88	33	0		46	1	0	476	182	680
42	C-3	7.4			740	125	18	55	27	0	60	0	0	242	34	300
43	C-11	7.3			776	125	11	78	36	0	11	0	0	334	94	210
44	C-15	7.3		1790	260	26	236	59	0		17	1	1	351	499	460
45	Thistle Hot Spring	6.7		3094	1117	22	79	13	0		42	1	0	426	425	1300
46	Castilla Hot Spring(East)	6.6		3640	970	70	262	43	0		31	1	1	509	1516	2580
47	Castilla Hot Spring(West)	6.5		7112	1950	117	533	81	0		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

UGS Table 1. Location

ID	SOURCE	CO	TSP	RNG	SEC	SUB	LAT	LONG	UTM.N	UTM.E
2	Veyo Hot Springs	WA	40S	16W	06	dbc	37.3183	113.6900	4135219	261945
3	Green Spring	WA	42S	15W	15	bba	37.1383	113.5277	4113076	275631
4	Toquerville Spring	WA	40S	13W	35	acd				
5	Pah Tempe Hot Springs	WA	41S	13W	25	cca	37.1900	113.2683	4118497	298339
6	Pahcoon Spring	WA	41S	18W	02	ddc				
7	Berry Spring	WA	42S	14W	01	bcb	37.1660	113.3830	4115743	288410
8	Washington Hot Pot	WA	42S	15W	11	ccc	37.1383	113.5117	4112937	276694
9	Stratton Turf Farm	WA	42S	14W	15	aba			4113000	286050
10	Stratton Turf Farm	WA	42S	14W	15	bbc			4112300	286600
11	W. Hafen	WA	42S	17W	01	aac			4116200	260100
12	O. Gregorson	WA	43S	15W	10	cca			4103750	275100
13	W. Cooper	WA	42S	13W	07	cdb			4113450	290400
14	St. George City, Creek#2	WA	42S	15W	06	ddb			4114900	271300
15	Stucki Farms	WA	43S	15W	12	ccc			4103400	278250
16	P. Foremaster	WA	42S	15W	33	cbc			4107400	273550
17	Phillips Petroleum TG6	WA	40S	16W	08	bbc			4134300	262650
18	EV-111	IR	34S	16W	22	baa	37.8450	113.6283	4191668	268731
19	EV-118	IR	33S	16W	11	cdc	37.9403	113.6144	4202210	270251
20	EV-119	IR	33S	16W	14	dcb	37.9456	113.6367	4202853	268308
21	EV-130	IR	31S	14W	09	bdb	38.1233	113.4031	4222018	289348
22	EV-131	IR	31S	14W	29	aac	38.0050	113.4392	4208972	285838
23	EV-140	IR	33S	18W	20	bdd	37.8753	113.8211	4195526	251865
24	EV-141	IR	33S	17W	20	cbb	37.9250	113.7839	4200944	255302
25	EV-150	IR	33S	16W	10	ccc	38.1703	113.3256	4227060	296273
26	Thermo Hot Springs EV-151	BE	30S	12W	21	add	38.1730	113.2050	4227102	306846
27	Thermo Hot Springs EV-152	BE	30S	12W	21	add	38.1730	113.2050	4227102	306846
28	Thermo Hot Springs EV-153	BE	30S	12W	21	add	38.1860	113.1950	4228523	307757
29	Thermo Hot Springs EV-154	BE	30S	12W	21	add	38.1860	113.1950	4228523	307757
30	Christensen Bros., NC-10	IR	36S	15W	20	bbd	37.6595	113.5628	4170985	273651
31	Wood Ranch	IR	33S	16W	11	cdc	37.9403	113.6144	4202210	270251
32	Hatton Hot Springs	MI	22S	06W	35	ddc	38.8530	112.4900	4301311	370705
33	Saratoga Hot Springs-1	UT	05S	01W	25	ccc	40.3489	111.9053	4466665	423116
34	Saratoga Hot Springs-2	UT	05S	01W	25	ccc	40.3494	111.9047	4466720	423168
35	Saratoga Hot Springs-3	UT	05S	01W	25	ccc	40.3611	111.9036	4468018	423274
36	P-10	UT	08S	02W	18	ccc	40.1281	111.7675	4442047	434607
37	P-12	UT	08S	01W	10	bcb	40.1381	111.8231	4443200	429880
38	P-16	UT	08S	02W	32	dda	40.0728	111.7322	4435884	500000
39	P-39	UT	08S	02W	25	bca	40.0956	111.6689	4438372	442981
40	G-14	UT	08S	02W	29	aaa	40.1581	111.7308	4445351	437761
41	G-24	UT	08S	02W	31	cdb	40.0725	111.7679	4435876	434520
42	C-3	UT	10S	01W	28	adb	39.9186	111.9392	4418935	419732
43	C-11	UT	08S	03W	03	dca	40.1481	111.5872	4444150	449984
44	C-15	UT	06S	01E	30	baa	40.2744	111.8883	4458382	424477
45	Thistle Hot Spring	UT	09S	04E	28	bcb	40.0300	111.5117	4431002	456339
46	Castilla Hot Spring(East)	UT	09S	04E	18	baa	40.0383	111.5333	4431934	454502
47	Castilla Hot Spring(West)	UT	09S	04E	18	baa	40.0383	111.5333	4431934	454502
48	Goshen Warm Springs	UT	10S	01E	08	cab	39.9583	111.8550	4423269	426971
49	unnamed well	UT	05S	02E	27	baa	40.3587	111.7059	4467599	440059
50	Bird Island Warm Spring	UT	07S	01E	26	c	40.1755	111.7842	4447321	433230
51	Lincoln Point Warm Spring	UT	08S	01E	03	dda	40.1445	111.8051	4443896	431420
52	unnamed well	UT	10S	01W	32	ccc	39.8933	111.9707	4416156	417010
53	unnamed well	UT	10S	01W	33	aba	39.9690	111.9398	4424529	419740
54	Burgin Mine	UT	10S	02W	15	ddd	39.9381	112.0355	4421190	411527

Table 1. State Geothermal Database Summary: 1992-93 Low Temperature Program

	State	AZ	CA	CO	ID	MT	NV	NM	OR	UT	WA
Database Result	YPGA	82	80	80	80	81	83	80	82	80	81
Total Database Entries	**1993**	**543**	**979+**	**170**	**1,935**	**346**	**3,300**	**247**	**2,135**	**713**	**971**
(thermal wells, springs)	YPGA	501	635	120	899	68	1,376	312	998	315	368
Moderate Temp. Wells	**1993**	**0**	**73**	**0**	**20**	**0**	**50**	**10**	**88**	**3**	**1**
(100°C<T< 150°C)	YPGA	0	48	0	0	0	35	3	79	3	1
Low Temp. Wells/Springs	**1993**	**543**	**906**	**170**	**1,915**	**97**	**1,000**	**237**	**2,047**	**710**	**970**
(20°C<T<100°C)	YPGA	501	587	120	899	58	700	309	925	312	367
Low Temp. Resource Areas	**1993**	**29**	**58**	**27**	**28**	**16**	**400**	**29**	**275**	**161**	**17**
(20°C<Tres.<150°C)	YPGA	29	56	27	28	15	400	24	151	64	10
Direct Heat Utilization	**1993**	**0**	**71**	**24**	**29**	**1**	**20**	**2**	**39**	**16**	**3**
(Commercial or district)	YPGA	0	54	24	20	2	8	0	33	9	0
Greenhouses, Aquaculture,	**1993**	**5**	**17**	**4**	**17**	**2**	**5**	**6**	**9**	**6**	**0**
Industrial Processes	YPGA	1	8	4	10	0	3	1	6	1	0
(Number separate businesses)											
Areas, Multiple Residence Heating (not a district)	1993	2	18	0	52	1	2	5	10	1	0
Areas, Potential Near-Term Direct Heat Utilization (Commercial Buildings)	1993	4	2	4	51	2	2	4	25	7	49+
Areas, Possible New Binary Power Development (110°C<Tres<150°C)	1993	1	3	0	2	0	2	3	0	7	0
Areas, High Priority Resource Study	1993	3	4	7	5	4	4	4	5	8	3

Comments: YPGA = Year of Previous Geothermal Assessment. Total Database Entries may include several representative wells in a single resource area. The minimum low-temperature criteria, typically 20°C, is higher (10°C above mean annual temperature) for low-elevation areas in some states (AZ, CA, NM) and lower in some cold regions (i.e. MT).
Direct Heat Utilization = Total number of commercial space heating systems, etc.
Areas, Multiple Residence Heating = 1 or more residences.
Tres = Estimated reservoir temperature

Geothermal Resources Council, TRANSACTIONS, Vol. 1 May 1977

GEOTHERM Data File

James R. Swanson

U.S. Geological Survey, Reston, Virginia

GEOTHERM is a computerized geothermal resources file developed by the U.S. Geological Survey. The file is a part of the International Geothermal Information Exchange Program (IGIEP) which was initiated at the First Geothermal Implementation Conference in New Zealand in 1974.

GEOTHERM contains data on the physical characteristics, geology, geochemistry, and hydrology of geothermal resources. The file is org three subtopics: geothermal fields, g wells, and chemical analyses.

The file will be used in an asses geothermal resources of the United Sta as part of the USGS Geothermal Program of Geothermal Energy (DGE) within the and Development Administration (ERDA) an effort to collect and contribute lo geothermal data to GEOTHERM. These da used to assist ERDA in evaluating geot for non-electric uses.

The information in the file is av public in the form of computer printou reports, formatted records for extened and maps.

GEOTHERM computer file, USGS

✓ Swanson, J.R., 1977a GEOTHERM data file, in Geothermal--State of the art: GRC Trans, v. 1, p. 285-~~86~~.

Swanson, J.R., 1977b, GEOTHERM users guide: USGS-Open File Rept 77-504, 53p.

Mariner et al., 1978

Mariner, R.H., Brook, C.A., Swanson, J.R., and Mabey, D.R., 1978, Selected data for hydrothermal convection systems in the United States with estimated temperatures ≥ 90°C; USGS Open-File Rept. 78-858

lowt.pri
7/18/95

STATE TEAM
LOW-TEMPERATURE RESOURCE ASSESSMENT
PRIORITY AREAS FOR PHASE TWO FUNDING

Colorado

1. Archuleta Antiform, Archuleta County (communities of Pagosa Springs, Chromo, Edith)

   * Res. Temp: 40-80 C
   * Potential Utilization: space heating, resorts, recreational community
   * R & D Activities: regional geological mapping, compile and interpret existing geophysics, well data

2. Eastern San Luis Valley, Saguache and Alamosa Counties (communities of Mineral Hot Springs, Moffatt, Hooper, Alamosa, Henry)

   * Res. Temp: 40-100 C
   * Potential Utilization: greenhouses, fish farming, food drying, resorts, space heating
   * R & D Activities: Compile oil and water well data, available geophysical data; thermal gradient drilling

3. Rico and Dunton Hot Springs, Dolores County

   * Res. Temp: 50-70 C
   * Potential Utilization: resort complex
   * R & D Activities: geological mapping, geophysical surveys, water sampling and chemistry

4. Trimble Hot Springs, La Plata County

   * Res. Temp: 45-70 C
   * Potential Utilization: resort, space heating
   * R & D Activities: geological mapping, geophysical surveys, shallow gradient drilling

5. Orvis Hot Springs, Ouray County

   * Res. Temp: 41-50 C
   * Potential Utilization: greenhouses, fish farming
   * R & D Activities: geological mapping, geophysics, shallow gradient drilling

6. Cottonwood Hot Springs, Chaffee County

   * Res. Temp: 150-200 C
   * Potential Utilization: resort, space heating, greenhouses
   * R & D Activities: geological mapping, geophysics, geochemistry

Montana

1. Bozeman Area, Gallatin County

   * Res. Temp: 80 C
   * Potential Utilization: space heating, swimming pool
   * R & D Activities: geophysical surveys, temp. gradient drilling, feasibility study

2. Butte Area, Silver Bow Coounty

   * Res. Temp. 50-80 C
   * Potential Utilization: space heating
   * R & D Activities: general geothermal assessment, inventory of existing holes, gradient drilling, heat pump feasibility studies

3. Ennis Area, Madison County

   * Res. Temp: 90-100 C
   * Potential Utilization: space heating, resort
   * R & D Activities: geoscience data integration, temperature gradient hole, feasibility study

4. Boulder Hot Springs, Jefferson County
   * Res. Temp: 110-130 C
   * Potential Utilization: space heating, resort
   * R & D Activities: inventory wells and springs, log temperatures, drill deep hole

5. Camas Prairie, Sanders County

   * Res. Temp: 50-80 C
   * Potential Utilization: space heating, greenhouses
   * R & D Activities: inventory wells and springs, measure temperatures, water chemistry, resource model, feasibility study

Nevada

1. Hawthorne Area, Mineral County

   * Res. Temp: 80-100 C
   * Potential Utilization: space heating, district heating
   * R & D Activities: compile existing geoscience data, feasibility study

2. Fallon Naval Air Station, Churchill County

   * Res. Temp: 50-100 C
   * Potential Utilization: space and industrial heating
   * R & D Activities: compile existing data on shallow resource, feasibility study

3. East Elko, Elko County

* Res. TEmp: 60-90 C
* Potential Utilization: space and district heating
* R & D Activities: geological study, geophysical surveys, feasibility study

4. Caliente, Lincoln County

* Res. Temp: 50-70 C
* Potential Utilization: space and industrial heating
* R & D Activities: update existing feasibility study

5. South Truckee Meadows, Washoe County

* Res. Temp: 80-100 C
* Potential Utilization: district and industrial space heating
* R & D Activities: compile and interpret existing data, geophysical surveys, water chemistry, reservoir modeling

Utah

1. Newcastle Area, Iron County

* Res. Temp: 130-150 C
* Potential Utilization: greenhouses, binary power
* R & D Activities: drill observation wells, monitoring program, modeling

2. Monroe Area, Sevier County

* Res. Temp: 77-110 C
* Potential Utilization: resort, fish farming, space heat
* R & D Activities: reservoir evaluation, drill production well, well test, feasibility study

3. Thermo Hot Springs, Beaver County

* Res. Temp: 120-174 C
* Potential Utilization: binary power, greenhouses
* R & D Activities: resource evaluation of existing database, geophysical survey, drill shallow gradient holes

4. Midway Area, Wasatch County

* Res. Temp: 45-70 C
* Potential Utilization: resorts, space heating
* R & D Activities: well inventory, hydrologic assessment

5. Meadow-Hatton Area, Millard County

   * Res. Temp: 85-114 C
   * Potential Utilization: greenhouses, food drying
   * R & D Activities: geophysical survey, shallow gradient drilling

6. Woods Ranch, Iron County

   * Res. Temp: 110-115 C
   * Potential Utilization: greenhouses, crop processing
   * R & D Activities: geophysical survey, gradient drilling, feasibility study

7. Crystal Hot Springs Area, Salt Lake County

   * Res. Temp: 88-115 C
   * Potential Utilization: greenhouses, fish farming
   * R & D Activities: hydrologic study, monitoring

GEO-HEAT CENTER

Oregon Institute of Technology
Klamath Falls, Oregon 97601
(503) 885-1750
Fax: (503) 885-1754

FAX TRANSMISSION COVER SHEET

Date:	*July 17, 1995*
To:	*Howard Ross*
Fax:	*801-534-4453*
Re:	*Proposal for Low-Temp.*
Sender:	*Paul J. Lienau*

YOU SHOULD RECEIVE 15 PAGE(S), INCLUDING THIS COVER SHEET. IF YOU DO NOT RECEIVE ALL THE PAGES, PLEASE CALL (503) 885-1750.

Dear Howard:

Here is a draft of a proposed program for continuation of the State Resource Assessment Teams. Please mark up and add your 4 states.

Thanks,

Paul

STATE TEAM
LOW-TEMPERATURE GEOTHERMAL RESOURCE ASSESSMENT
PRIORITY AREAS FOR PHASE II FUNDING

Paul J. Lienau
Geo-Heat Center
Oregon Institute of Technology

Howard Ross
Earth Sciences and Resources Institute
University of Utah

Proposed Program

The low-temperature resource assessment program has been ~~concentrated~~ conducted in 10 states having high potential: Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah and Washington. Resource inventories have identified some 9,278 thermal wells and springs in these 10 states. The new databases give an indication of the enormous potential for development of clean, domestic geothermal-heat resources.

Collocated sites of cities and resources of greater than 50°C and within a distance of 8 km have been identified (Figures 1-8) for 257 cities in 8 of the states (data are not yet available for Arizona and New Mexico), representing a population of over 6.4 million.

State resource assessment teams have recommended high priority areas for resource assessment studies. These Second Phase Studies are essential to provide potential developers with basic resource information, local governments with data for planning purposes and serve to increase public awareness of their local geothermal resources. The following list of proposed high priority study areas identify potential utilization and resource assessment tasks and are based on new geothermal development, local interest, cost shared funding, and probability of resource use:

bold → California

1. Coachella Valley (communities of La Quinta, Palm Desert and Palm Springs)

   - Res. Temp: 75°C
   - Potential Utilization: space heating, fish farming and food drying processes.
   - R & D Activities: comprehensive study of the resource

2. Alturas, Modoc County

   - Res. Temp: 86°C
   - Potential Utilization: space heating to other structures in the community
   - R & D Activities: geophysical surveys

3. Lake Elsinore, Riverside County

- Res. Temp: 54°C
- Potential Utilization: space heating
- R & D Activities: detailed assessment study

4. Ojai, Ventura County

- Res. Temp: 51°C
- Potential Utilization: space heating
- R & D Activities: detailed study of resource assessment

5. Lake Isabella, Kern County

- Res. Temp: 54°C
- Potential Utilization: space heating, expand resort
- R & D Activities: comprehensive study - geophysics, SP

6. Huntington Beach/Los Angeles Basin, Orange and Los Angeles Counties

- Res. Temp: 82°C
- Potential Utilization: space heating and industrial
- R & D Activities: compile and distribute well temperature data

7. Hemet/Winchester, Riverside County

- Res. Temp: 59°C
- Potential Utilization: space heating
- R & D Activities: comprehensive assessment - geologic, water chemistry

8. Kelley Hot Springs, Modoc County

- Res. Temp: 92°C
- Potential Utilization: greenhouses, fish farming, space heating in Canby
- R & D Activities: geophysical surveys, shallow gradient drilling

bold → Idaho

1. Boise area, Ada County

- Res. Temp: 81°C
- Potential Utilization: space heating, greenhouses
- R & D Activities: hydrologic, geophysical and geochemical investigations - effects of development and longevity

2. Pocatello-Tyhee and Lava Hot Springs, Bannock County

- Res. Temp: 41-80°C
- Potential Utilization: space heating
- R & D Activities: flow tests to determine sustainable yield, seismic and electrical ~~prospecting~~ surveys, monitoring holes drilled and aquifer tests and isotopic ratios determined

3. Garden Valley area, Boise County

- Res. Temp: 81°C
- Potential Utilization: space heating and/or process heating
- R & D Activities: well inventory, water level measurements and determination of historic water level decline. Aquifer tests and ~~heat hole~~ temperature gradient drilling

4. Camas Prairie area, Camas County

- Res. Temp: 30-40°C
- Potential Utilization: space heating, greenhouses
- R & D Activities: geophysical surveys to pinpoint the ~~existence~~ location and attitude of faults in the valley down into the granitic basement

5. Nampa-Caldwell area, Canyon County

- Res. Temp: 24-38°C
- Potential Utilization: space heating, greenhouses
- R & D Activities: well drilling on the thermal permeable zones, geochemical sampling program, determine deep water isotope and geochemical characteristics, investigate recharge of the thermal aquifers, monitoring of potentiometric surfaces, stable isotope analysis, seismic net (3 stations) should be set up to obtain background data before large scale withdrawal of geothermal water begins, detailed petrographic and geochemical studies, geophysical data purchased and interpreted to help determine the boundaries of the geothermal system, and detailed geologic mapping. } too long

6. Greys Lake and Blackfoot Reservoir area, Caribou County

- Res. Temp: high temperature (150°C) at a depths greater than 2 km
- Potential Utilization: electric power generation
- R & D Activities: detailed delineation of fault zones combined with limited shallow test drilling should be conducted to evaluate this resource.

7. Big Creek Hot Springs, Lemhi County

- Res. Temp: surface of 93°C, geothermometer estimates of 137° to 179°C
- Potential Utilization: electric power generation

- R & D Activities: thermal gradient measurements, mapping to define the nature of the Hot Springs Fault, shallow (50 to 160 m) temperature gradient hole drilling, resistivity survey, deeper drilling and flow testing.

8. Twin Falls area, Twin Falls County

- Res. Temp: 70-80°C
- Potential Utilization: space heating
- R & D Activities: compile existing geologic, hydrologic and geothermal information, develop a conceptual model of the reservoir, and provide information for resource management decisions.

bold → Oregon

1. Paisley, Lake County

- Res. Temp: 112°C
- Potential Utilization: electric power generation, greenhouses, industrial process - lumber drying
- R & D Activities: update ~~feasibility of~~ lumber drying feasibility study, reservoir engineering for electric power generation possibilities.

2. Lakeview, Lake County

- Res. Temp: 102°C
- Potential Utilization: space heating, greenhouses
- R & D Activities: geophysics to define faults, district heating feasibility study

3. Burns/Hines, Harney County

- Res. Temp: 68°C
- Potential Utilization: kiln drying of lumber, greenhouses and space heating
- R & D Activities: none feasibility study

4. LaGrande/Hot Lake, Union County

- Res. Temp: 80°C
- Potential Utilization: greenhouses, fish farming and space heating
- R & D Activities: feasibility for greenhouse and fish farming projects

5. Vale, Malheur County

- Res. Temp: 100°C+
- Potential Utilization: space heating (district heating feasibility study) and food

processing

- R & D Activities: reservoir engineering and feasibility for food processing.

bold → Washington

Insert A ~~Washington has identified the following three recommendations in order of rank:~~

1. Top recommendation: (1) match existing thermal wells with proposed new construction or remodeling of public buildings, (2) determine which projects could make advantageous use of geothermal resources, (3) encourage and facilitate such applications.

2. Second recommendation is to station an investigator in the Columbia Basin to find and visit new wells to: (1) measure downhole temperature gradients, (2) obtain well-test data, (3) obtain drill cuttings for measurement of thermal conductivity and geochemistry, and (4) collect water samples for chemical analysis.

3. Third recommendation is to institute a long-term effort to: (1) inform the people of the state about uses of low-temperature geothermal resources, (2) work with public policy makers to make certain that the legal and institutional framework encourages wise use, and (3) advocate for use of geothermal resources in place of fossil fuels.

Funding Needs

This program needs to be continued and strengthened. Funding would be used to stimulate development of low- and moderate-temperature resources through cost-sharing of demonstration projects to spur infrastructure development and bring costs down. Funding would also help support state resource teams whose geothermal knowledge and contacts with developers is essential to expanding geothermal use.

FUNDING NEEDED ($millions)

FY 1996	FY 1997	FY 1998	FY 1999	FY 2000
5.0	5.0	4.5	3.0	2.0

Anticipated Results

At the conclusion of this program, we anticipate being able to increase the amount of direct-heat geothermal power on line from 470 thermal megawatts to 3,700 thermal megawatts. With displacement of fossil fuels, this would save the emissions of about 1,550,000 tons of carbon dioxide, 30 tons of sulfur dioxide and 1,400 tons of nitrogen oxides per year (emissions reductions are dependent on the fuel mix replaced and other factors. See EPA 430-R-93-004 "Space Conditioning: The Next Frontier" by M. L'Ecuyer, C. Zoi, and J.S. Hoffman, April 1993).

Insert A: Washington state investigators have identified laterally extensive low-temperature resources in a six-county area within the Columbia Basin. Rather than prioritize limited areas within this region for detailed studies, they make three recommendations for greatly expanding geothermal use in the state of Washington.

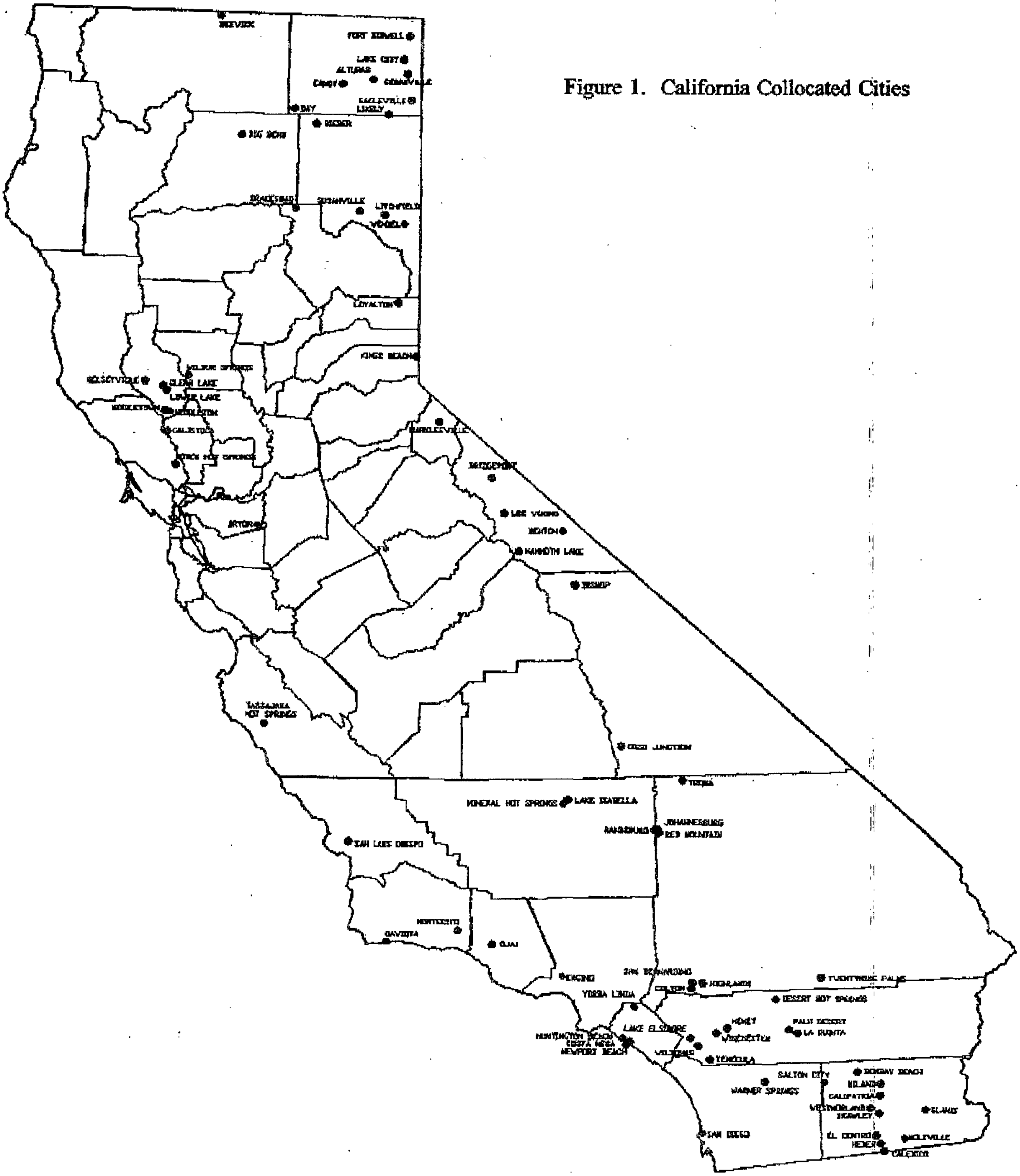


Figure 1. California Collocated Cities

Figure 2. Colorado Collocated Cities

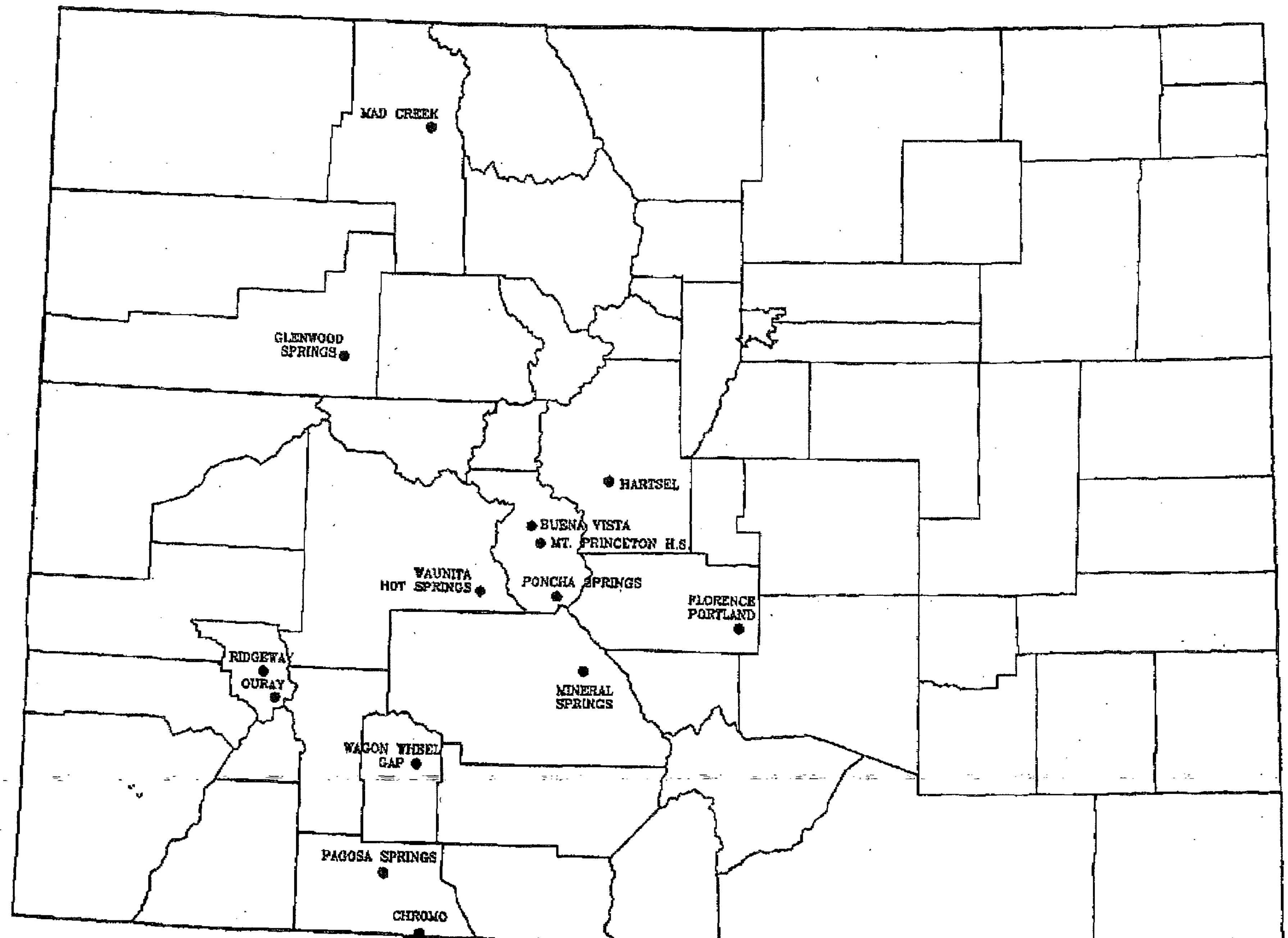


Figure 3. Idaho Collocated Cities

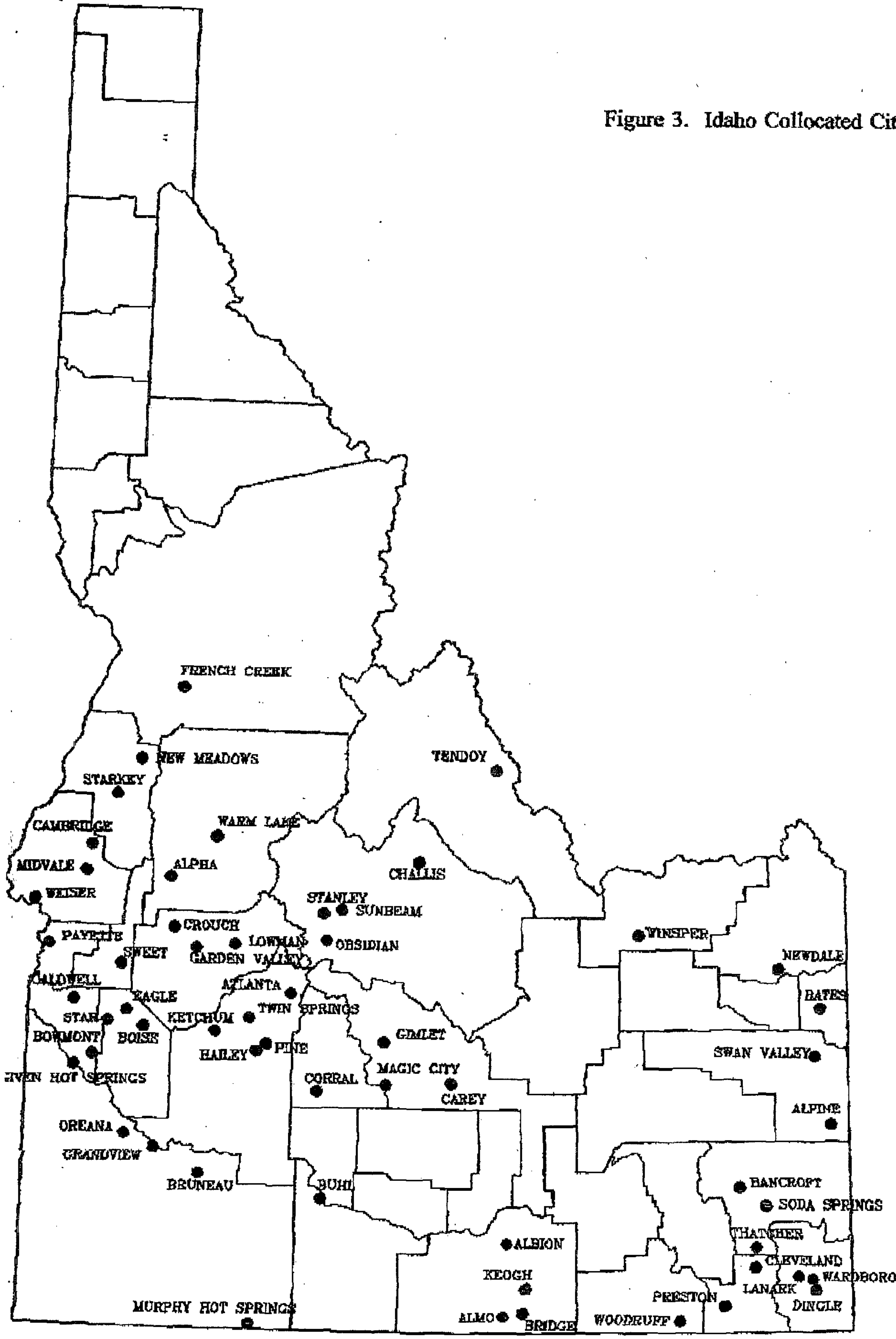
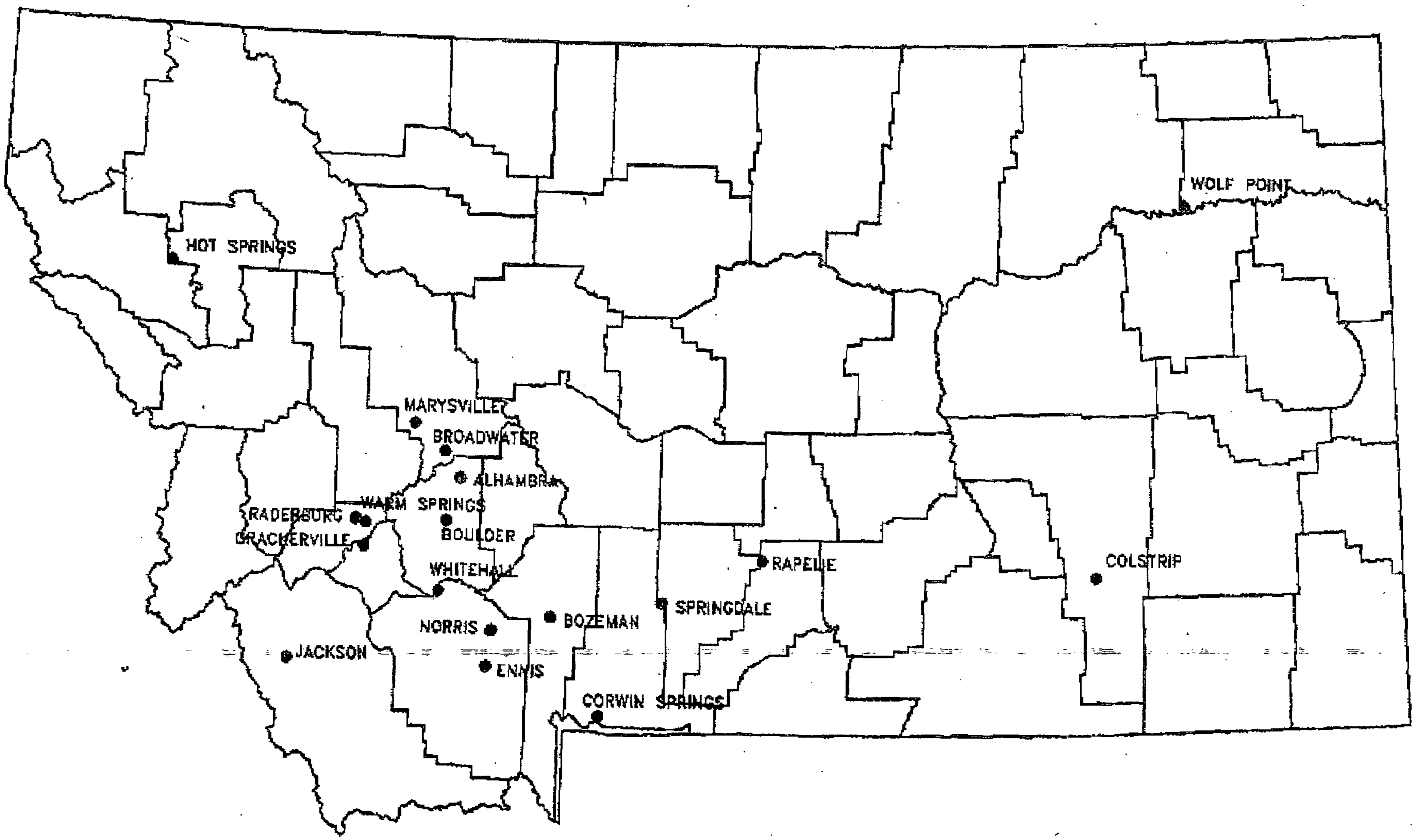


Figure 4. Montana Collocated Cities



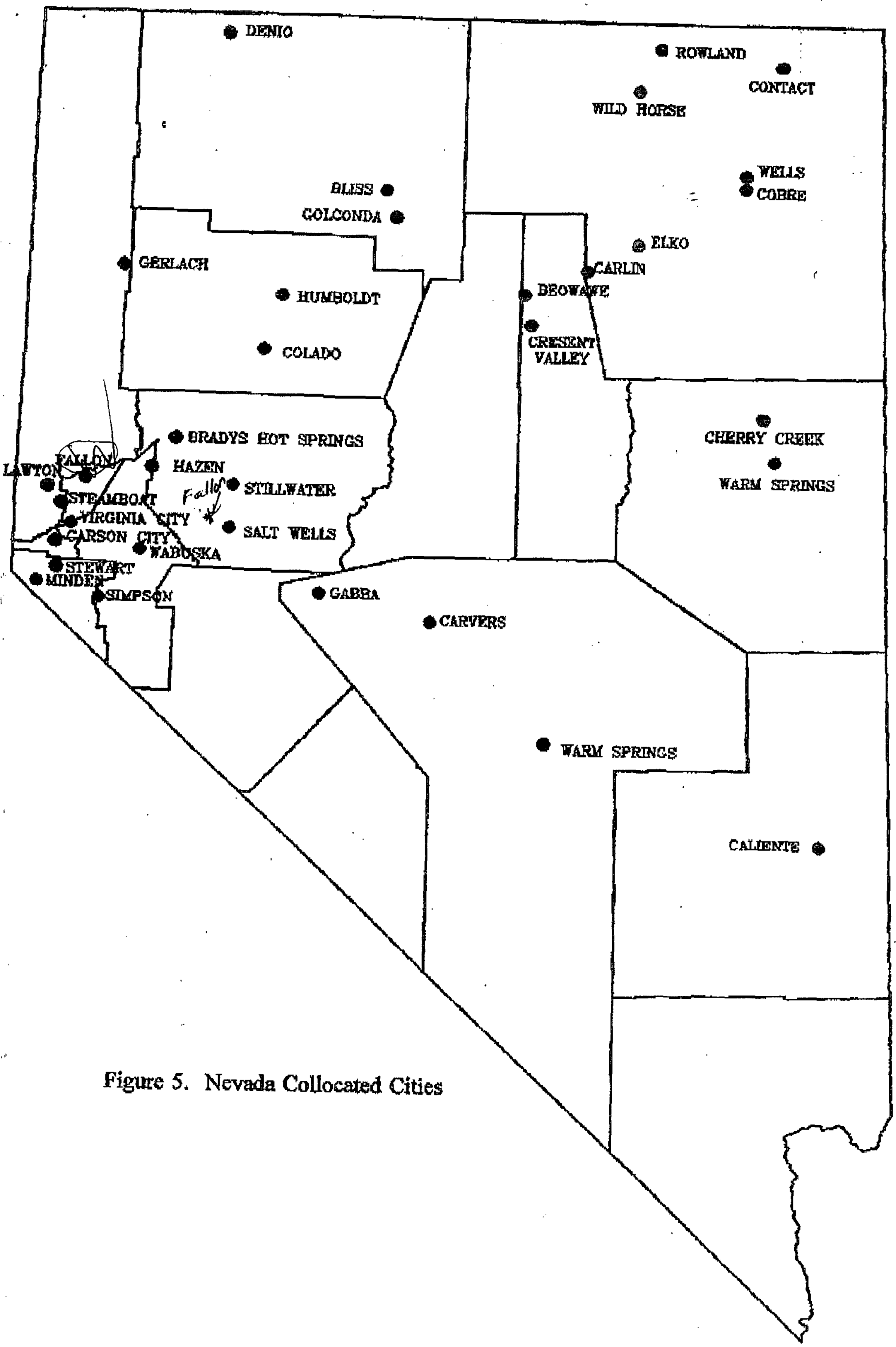
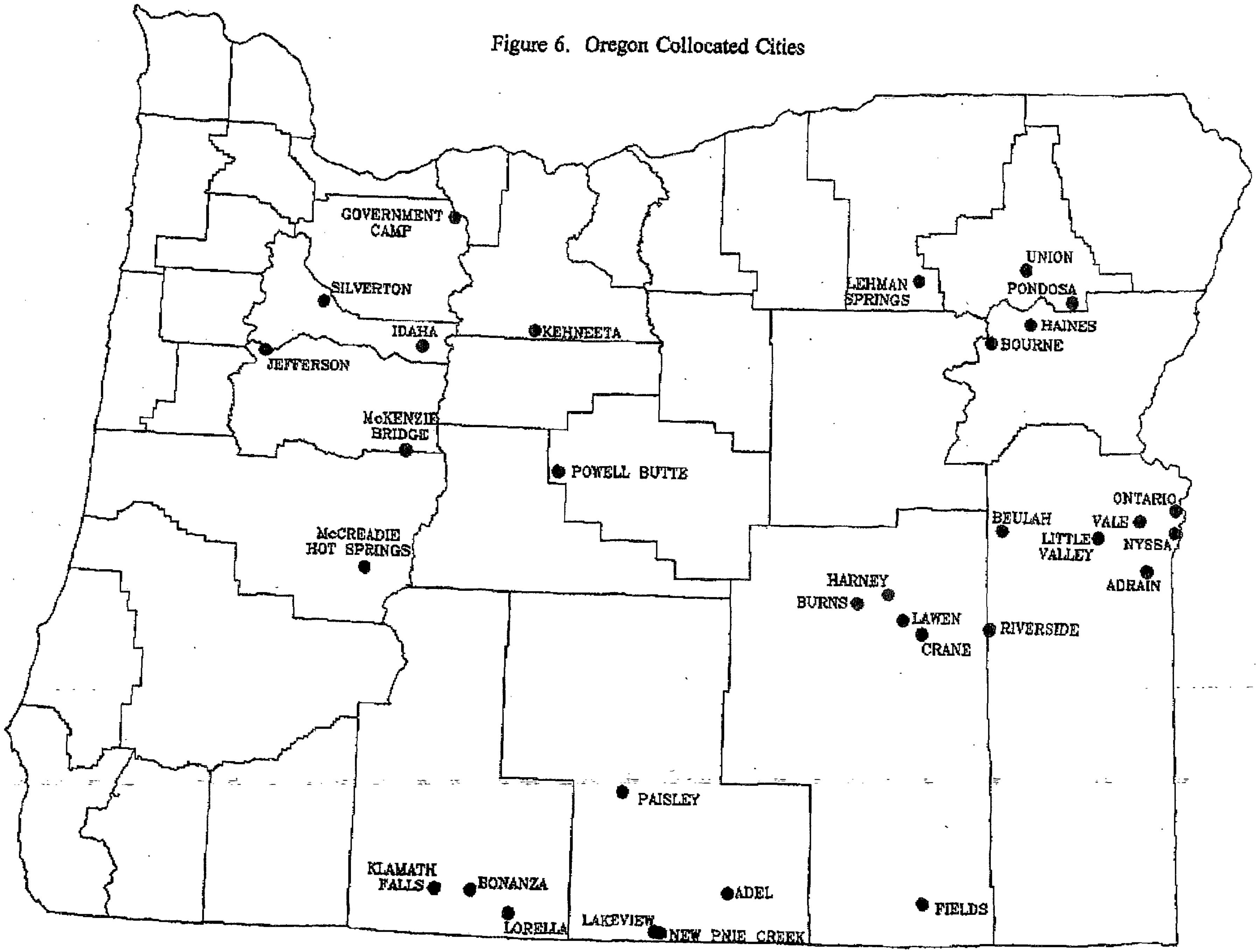


Figure 5. Nevada Collocated Cities

Fallon
Gabbs

Figure 6. Oregon Collocated Cities



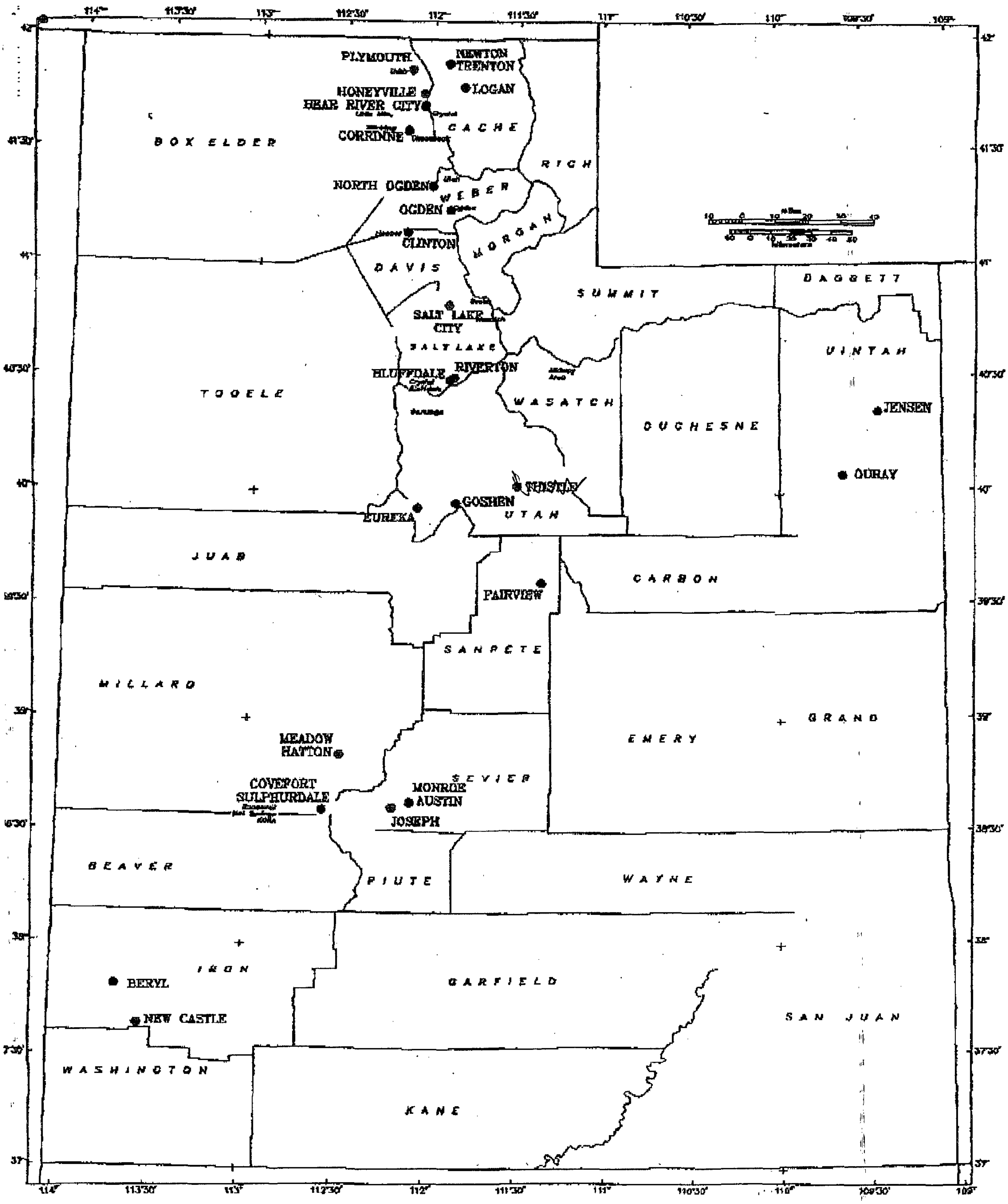
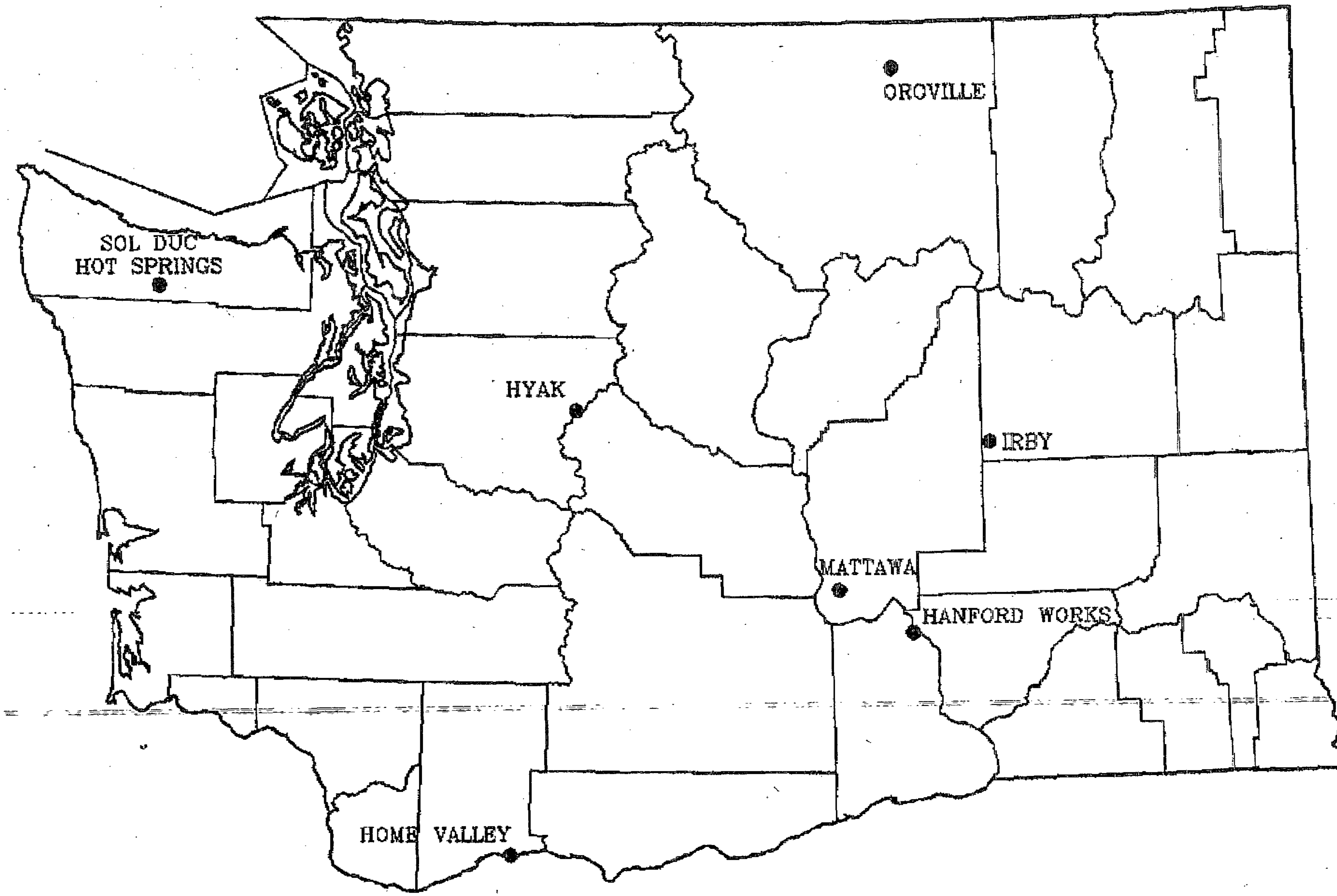


Figure 7. Utah Collocated Cities

Figure 8. Washington Collocated Cities



FINAL REPORT

LOW-TEMPERATURE GEOTHERMAL RESOURCE ASSESSMENT PROGRAM

EXECUTIVE SUMMARY

INTRODUCTION

General (Background)
Compilations
Fluid Chemistry

RESOURCE EVALUATION AND INVENTORY

State teams for 10 western states initiated their resource evaluation and database compilation efforts in late 1992 and early 1993 and completed these inventories and reports in 1994 and 1995. The state teams reviewed essentially all available sources of information on water wells and geothermal literature to arrive at the new inventory. The most productive sources of information included the USGS's on-line water information system known as the National Water Data Storage and Retrieval System, or WATSTORE, the 1983 USGS database file GEOTHERM, and previous state geothermal resource maps. State agency files of water well records submitted by drillers were key data sources for some states, as were open-file and published reports by state agencies. With very few exceptions, the databases do not include bottom-hole temperature (only) sites, and temperature gradient or heat flow sites. The data were checked for accuracy of site location, to the extent practical, and numerous corrections were made to previously published locations. Water analytical data were checked by evaluation of charge balance.

Table 2 summarizes the catalog of 8,976 thermal wells and springs for these 10 western states; an increase of more than ~~40%~~ 60% compared to the previous assessments of 1980 to 1983. Each data entry in the inventory is a separate thermal well or spring (w/s). For purposes of this inventory and report, State Team P.I.s have often selected a single well or spring to represent several (2 to 20) wells or springs within a small area (generally <1 km^2) within the same geothermal resource. Thus the true number of thermal wells and springs represented by this inventory is substantially greater than the numbers reported here.

To improve our reporting the State Teams were asked to identify the number of distinct hydrothermal resource areas represented by the wells and springs in the inventory. A distinct resource area may be less than 1 km^2 in areal extent, in the case of a few wells or springs in a small, fault-controlled resource, or more than 100 km^2 in the case of extensive thermal aquifers such as in the Snake River Plain or Columbia Plateau. More than 900 low- to moderate-temperature resource areas are indicated, and perhaps a greater number of isolated (singular) thermal wells or springs.

The State Teams and OIT Geo-Heat Center have documented direct-heat use of geothermal fluids at more than 250 sites, including commercial and municipal buildings, rapidly expanding greenhouse and aquaculture industries, and major space-heating districts in California, Oregon, Nevada, Idaho, and Colorado. More than 40 high-priority resource study areas have been identified, together with high potential for near-term direct-heat utilization at 150 new sites. Preliminary estimates indicate that 254 cities in 10 western states could potentially displace 18,000 GWh per year (17 million BOE) with geothermal district heating. The number of commercial and residential direct-heat users and the total energy use have increased dramatically in one decade. Even greater resource utilization would be expected without the competition of low-priced natural gas. With proper conservation and utilization of our geothermal resources, they will be there to serve us when natural gas and other fuel types are less competitive. Several problem areas have been identified however, where the heat or fluid content of these resources are largely wasted and additional monitoring, reservoir management, and possibly regulation is warranted.

The final reports, maps, and databases generated by the State Teams document the present knowledge of the resource base and its utilization and potential in some detail. A state-by-state summary of this information, and recommendations for high-priority resource studies follows.

ARIZONA

Witcher (1995a) in completing the new resource inventory for Arizona, notes that almost all wells and springs found at elevations below 5,000 feet (1,524 m) in elevation exceed 20 C. Accordingly the new database is restricted to wells and springs with discharge temperature greater than 30 C, except for a few sites at higher elevations and sites on the Colorado Plateau of northern Arizona. Sites based only on bottom-hole temperature and temperature gradient or heat flow measurements are also excluded. Even so this new geothermal database totals 1,251 discrete thermal wells or springs, 250 percent of the 1982 listings. The database also includes 2,650 chemical analyses for these 1,251 sites.

Low-temperature resources occur in all counties of Arizona, but many fewer in the Colorado Plateau of northwestern and northcentral Arizona and the Transition Zone in Yavapai and Gila Counties in central Arizona. Witcher (1995a) notes that most thermal well occurences are located along the trend of lower heat flow, where many irrigation wells tap deep-seated aquifers that are overlain by thermally-insulating, low thermal conductivity sediments in highly-developed agricultural areas. These resources occur in the Mohave, Sonoran Desert, and Mexican Highland Sections of the Southern Basin and Range Province (SBRP).

Witcher (1995a) describes occurrence models for both convective and conductive resources in Arizona. He notes that in southeast Arizona and neighboring New Mexico nearly all convective systems occur where aquitards or confining units have been stripped by faulting or erosion from basement terranes which contain significant vertical fracture permeability, which he terms a 'hydrogeologic window model.'

Conductive resources occur in the SBRP where grabens and half-grabens may contain several thousand feet (>1,000 m) of Cenezoic sediments with low thermal conductivity and low vertical permeability. The potential of large-volume conductive resources is offset by the cost of deep wells. In the eastern Colorado Plateau, several areas of high heat flow are collocated with significant thickness of fine-grained Cenezoic and Mesozoic sediments are preserved over older, permaeable aquifers. The fine-grained sequences act as aquitards and thermal blankets to create a deep-seated conductive geothermal resource. The thermal fluids are often of high salinity, with few geological alternatives for fluid injection (Witcher, 1995a). The relatively low median temperature of about 36.6 C for all 1,251 sites is attributed to the predominance of conductive resources.

Witcher (1995a) provides considerable realistic insight regarding the future utilization of geothermal resources in Arizona. He notes that basins with most of the thermal (>30 C) wells have warm climates and space cooling is more needed than space heating. He notes that in Arizona the thermal fluids are more valued for irrigation of field crops, municipal water supply and industrial uses than for the heat carried by the waters. He sees some potential for space heating and district heating, but much more potential for direct-use utilization in the agricultural sector. Geothermal aquaculture is the only major direct-use application which has experienced noticable growth in recent years - Arizona leads the nation in the use of geothermal fluids for aquaculture.

Rather than identify specific sites for detailed study to advance geothermal utilization in Arizona, Whitcher offers several recommendations. A strong, in-state advocate for direct-use geothermal applications is required. Key parameters for successful aquaculture and greenhousing, specific to Arizona, need to be determined, and detailed feasibility studies completed for these uses.

CALIFORNIA

The new California low-temperature database lists 989 thermal wells and springs, an increase of 354 over the 635 data entries reported in 1980. In many areas one, or a few, wells have been selected to represent many thermal wells drilled to similar depths in a thermal aquifer. The database includes only a few representative high-temperature (>150 C) wells, especially from KGRAs. Youngs (1994) estimates that there may be 58 distinct low-temperature resource areas, and an additional 194 "singular" thermal occurrences.

Low-temperature resources occur in volcanic terrains in northern California, in the Basin and Range in the northeastern part of the state, within the Long Valley caldera, and along faults in the sedimentary basins in southern California. Low- to intermediate-temperature resources often occur as outflow areas peripherial to the state's many high-temperature resources.

The commercial application of low-temperature geothermal fluids is already well developed in California with a large district heating system in the City of San Bernardino, and smaller projects in several other communities. Geothermal greenhouse and aquaculture industries have expanded substantially in the last decade, and at least 48 commercial resort/spa facilities utilize geothermal fluids.

Youngs (1994) has identified 56 communities that are located within 8 kilometers of a geothermal resource that has a reported temperature of at least 50 C. The total population collocated with these resources exceeds 2 million people. Thus the potential for expanded use of these fluids in the near term is great, and this new low-temperature inventory is an important step in expanded use. Additional technical and feasibility studies will be required to prove the economic use of these fluids.

Youngs (1994) recommends seven areas for comprehensive resource studies, based in part on population considerations. The Coachella Valley (Riverside County) is a major agricultural area with a population around 200,000. A number of thermal wells and springs occur along a 20-30 km extent along the west side of the valley, but there is no comprehensive study of the resource. Potential applications may include aquaculture and food drying.

In Alturas (Modac County) the geothermal resource provides space heating for the local high school. The city would benefit from a comprehensive resource study which could provide the basis for expanding the space heating to other structures in the community. At Lake Elsinore, Riverside County, thermal wells and springs with temperatures to 54 C could provide space heating to community buildings. A detailed resource assessment study is recommended (Youngs, 1994).

Comprehensive resource assessments are recommended for geothermal resources collocated with Ojai, Ventura County; Lake Isabella, Kern County; and Hemet/Winchester, Riverside County. Each resource has measured temperatures greater than 50 C, but little or no resource utilization.

The Huntington Beach/Los Angeles Basin, Orange and Los Angeles Counties, is located in part over major oil fields that produce thermal waters as a waste product of petroleum production. There are at least 12 petroleum fields with very large quantities of associated thermal water, as characterized by the Venice Field of 21 million BTU/hour at 82 C. There is great local interest in utilizing the geothermal resource. Technical and feasibility studies may speed the beneficial use of this resource.

COLORADO

The new database for Colorado includes ~~167~~ 157 wells and springs (w/s) compared to the 125 reported in the 1980 assessment. Cappa (1993, 1995) identifies 93 geothermal areas (generally less than 8 km^2 in size), up from the 56 areas reported in 1980. A total of 382 geochemical analyses were compiled. The great majority of geothermal areas occur west of the Front Range within the Rocky Mountain Province. A grouping of seven areas occurs west of Trinidad in the south-central part of the state. The measured temperatures for most areas fall in the 25 to 40 C range, but fluid temperatures exceed 50 C at 15 geothermal areas, with a maximum temperature of 85 C at Mt. Princeton Springs in Chaffee County. Here subsurface reservoir temperatures of 150 to 200 C are indicated by a variety of geothermometers (Cappa, 1993, 1995).

The present level of direct-heat utilization in Colorado is substantial, totaling 32 sites. Distric heating systems are in service at Pagosa Springs and Ouray, and space heating is utilized at 15 additional motels, lodges, and resorts (Lienau et al., 1994). Two greenhouses utilized thermal fluids for heating, and aquaculture uses fluids at four additional sites. Spas and bathing spring resorts occur throughout western Colorado, and are a major part of the economy of communities such as Glenwood Springs, Pagosa Springs, Idaho Springs, Steamboat Springs, Mount Princeton, Durango, Gunnison, and Ouray.

Cappa (1993, 1995) identified six geothermal resource areas collocated with or near population centers which are on the fringe of geothermal development. The areas are:

1) Archuleta Antiform, Archuleta County
2) Eastern San Luis Valley, Saguache and Alamosa Counties
3) Rico and Dunton Hot Springs, Dolores County
4) Trimble Hot Springs, La Plata County
5) Orvis Hot Springs, Ouray County
6) Cottonwood Hot Springs, Chaffee County

The indicated reservoir temperatures range from 40 C to as much as 200 C (Cottonwood Hot Springs). Potential utilization of these resources include most common direct heat uses.

A variety of R&D activities are recommended to further the development of these resources. These include the compilation of oil and water well data; geological and geophysical studies; thermal gradient drilling; water sampling and fluid geochemistry.

Four other areas with promising hydrothermal resources, far from a population center were also identified:

1) Deganahl well, Routt County
2) Brands Ranch well, Jackson County
3) Craig warm water well, Moffatt County
4) Hartsel Hot Springs, Park County.

IDAHO

Extensive drilling in Idaho since the previous geothermal assessment (Mitchell et al., 1980) has resulted in a large increase in the known thermal water occurrences in Idaho. Dansart et al.(1994) have compiled a database of 1554 entries for 1537 individual wells and springs, compared to the 899 wells/springs of the earlier compilation. A bibliography of over 750 references on Idaho thermal water accompanies the report. Dansart et al. (1994) describe 54 resource areas, some of which may overlap, compared to 28 recognized areas identified previously. A large number of isolated thermal wells and springs occur throughout the state.

Geothermal resource areas occur throughout the state of Idaho, except the northernmost panhandle of the state. The geologic setting of the hydrothermal occurrences varies greatly, including fault and fracture-controlled resources of the Idaho batholith; fault-controlled reservoirs of the northern Basin and Range; the Island Park-Yellowstone caldera complex; and the extensive volcanic reservoirs of the Snake River Plain. The state's largest thermal reservoir area, Bruneau-Grand View, includes an area of perhaps 2850 km^2 (Dansart et al., 1994). Measured temperatures range as high as 149 C at Raft River, and geothermometers suggest some reservoir temperatures of 200 C. Clearly the geothermal potential of Idaho is very large, and it is greatly underutilized.

Lienau et al. (1994) report five district heating systems, including the Boise system which is the nation's oldest, operating since the 1890's. Ten other sites utilize space heating and 17 sites use thermal fluids for aquaculture or greenhouses. Thermal resorts and pools number 27.

Dansart et al. (1994) recommend site specific studies for nine geothermal resource areas, with the highest priority for study being the Twin Falls area. The large geothermal reservoir is collocated with the population center of Twin Falls and development of the geothermal reservoir has resulted in a recent decline of water levels in several wells being used for space heating, including the geothermal space heating system of the College of Southern Idaho. Unfortunately, the artesian pressure of the geothermal system has been used to generate electricity for sale of power to power companies, without beneficial use of the heat or water resource. Additional studies are needed to develop conceptual and numerical models of the reservoir which may provide a basis for resource management decisions. Similar studies and arguements apply to the Boise area geothermal resource.

Geologic, geophysical, drilling and feasibility studies are proposed for several other resource ares with good potential for benefical space heating, greenhousing, aquaculture, and possibly electric power development. Other high-priority areas identified by Dansart et al. (1994) are: Pocatello-Tyhee and Lava Hot Springs (Bannock County); the Garden Valley area (Boise County); Camas Praire area (Camas County); Nampa-Caldwell area (Canyon County); Greys Lake and Blackfoot Reservoir area (Caribou County); Island Park area (Fremnot County); and Big Creek Hot Springs (Lemhi County). Idaho clearly has extensive geothermal resources collocated with population centers, and many utilization of these resources may be quite economic at this time.

MONTANA

The 1994 Montana geothermal database includes 291 records from 267 distinct wells and springs (Metesh, 1994). For this northern state, a minimum observed temperature of 10 C above the mean annual air temperature (as low as 3 C) or 13 C could qualify as a thermal site. This is somewhat fewer than the 346 sites reported by Sonderegger et al. (1981) and reflects a strict elimination of "warm-day" sampling or improper purging of shallow well samples. Sixteen resource areas and more than 100 isolated thermal occurrences are indicated.

Thermal wells and springs occur throughout all areas of Montana but mainly (152 of 267) in the western third of the state (the Northern Rocky Mountains). The plains of the eastern two-thirds of the state host 115 of the 267 thermal sites (Metesh, 1994). About 77 percent of the geothermal sites have measured water temperatures less than 40 C, but 12 percent have temperatures greater than 50 C. Geothermometer temperatures calculated for more than 50 records with acceptable chemistry indicate several reservoir temperatures above 100 C. New fluid sampling and geothermometer results indicate reservoir temperatures of about 107 C (Green Springs), 120 C (Hot Springs Area), and 130 C at Boulder Hot Springs.

Geothermal resources are not fully utilized in Montana, due in part to the limited and scattered population. Lienau et al. (1994) document space heating at nine sites and limited greenhouse, aquaculture, and industrial utilization. Perhaps 15 resorts and spas make use of the thermal fluids. Metesh (1994) has identified five geothermal resource areas collocated with communities which have good potential for resource utilization, and these are recommended as priority study areas.

The Bozeman area has experienced steady population growth over the last decade. Bozeman Hot Springs, just west of the city of Bozeman, has surface temperatures of approximately 55 C and estimated reservoir temperatures of 80 C. Geophysical exploration and deep drilling are needed to better define the source and extent of the resource area. Detailed temperature, fluid chemistry and feasibility studies are needed to evaluate potential utilization of the low-temperature thermal waters (to 33 C) in the Butte area. The geothermal resource near Ennis (Madison County) is relatively well studied, but deep drilling and a feasibility study are needed to evaluate use of this >80 C resource. Boulder Hot Springs, with an estimated reservoir temperature of 110-130 C, is well located for space heating but requires additional resource studies. The Camas Prairie area, Sanders County, includes a number of thermal wells and springs, with reservoir temperatures of 50-80 C. Metesh (1994) suggests that additional studies in this area may accelerate the use of thermal waters for local recreation facilities and cottage-industries.

NEVADA

Nevada is well endowed with both high- and low-temperature geothermal resources. The latter are distributed rather uniformly throughout the entire state. Garside (1994a) made a careful selection of 457 thermal spring/well entries from a much larger (>2,000) candidate list to represent the geothermal rsources of Nevada. He notes that the mean annual air temperature varies from less than 7 C in northern parts of the state to over 18 C in the south, varying as a function of latitude and elevation. Seven high-temperature (>150 C) wells were included to represent thermal areas which also included lower-temperature (but poorly documented) resources. Perhaps 90 percent of the state has potential for the discovery of low- to moderate-temperature reources. Garside (1994b) believes the more than 1,000 thermal springs and wells represent several hundred resource areas.

Essentially all of Nevada lies within the Basin and Range province, an area of crustal extension which has remained active since the Tertiary. The thermal waters of most higher-temperature and many lower-temperature resources are believed to derive their heat from deep circulation of ground water along faults in an area of higher-than-average heat flow. In east-central and southern Nevada, the low- to moderate-temperature resources may be related to regional groundwater circulation in fractured carbonate-rock aquifers (Garside, 1994a).

In Nevada, as in many arid areas of the west, most water (whether thermal or nonthermal) has been put to use, and nonthermal applications require cooling before use (Garside, 1994a). Direct heat applications include district heating systems at Moana Hot Springs, in the southwestern part of Reno, and Elko, swimming pool and resort use, vegetable drying and aquaculture. There is great potential for expanded direct use of thermal fluids where communities or users are collocated with resource.

Many remotely located hydrothermal resource areas are not represented by the present inventory, but have been noted by private companies engaged in mineral and geothermal exploration. One priority recommendation for future studies is to try and obtain access to these data and thus improve the present database. Several communities collocated with geothermal resources have good potential for space heating, district heating, and industrial heating. These areas are: Hawthorne area, Mineral County; Fallon Naval Air Station, Churchill County; East Elko, Elko County; Caliente, Lincoln County; and South Truckee Meadows, Washoe County. Recommended studies to expedite geothermal utilization include data compilation, geological and geophysical surveys, water chemistry, and feasibility studies.

NEW MEXICO

The updated New Mexico resource inventory (Witcher, 1995) includes 360 discrete thermal wells and springs (w/s) compared to the 312 w/s reported by Swanberg (1980). This increase is more significant in view of the fact that all the sites of deep wells with bottom hole temperatures (BHT) included in the 1980 listing have been deleted, and that only sites with temperatures greater than 30 C are included for wells and springs below 1524 m (5000 ft.) elevation. The database includes 842 chemical analyses for the 360 discrete wells and springs. A median temperature for 308 w/s (excluding the high temperature wells and springs of the Jemex Mountains) is about 35 C. At least 29 different resource areas and perhaps 151 isolated thermal occurrences have been identified.

Almost all of the thermal occurrences occur in the western half of the state, within the Colorado Plateau, Basin and Range, and Rocky Mountains physiographic provinces (Witcher, 1995). Virtually all of the convective geothermal system in New Mexico, including the Jemez systems, occur over Laramide structural highs (Witcher, 1987 and 1988). Witcher (1995) believes that virtually all New Mexico convective occurrences occur where aquitards or confining units have been stripped by faulting or erosion from basement terranes which contain significant vertical fracture permeability - a model he refers to as a 'hydrogeologic window model.' Extensive conductive geothermal resources are present in the Basin and Range and Rio Grande Rift, and in the Colorado Plateau. Witcher notes that the cost of deep wells and fluids with high salinity are drawbacks to the utilization of these conductive resources.

New Mexico has had significant direct-use geothermal development since the early 1980s, with a large district heating system at New Mexico State University, and the largest acreage of geothermal greenhouses (more that 40 acres-161,900 m^2) in the nation. At present there is considerable interest in the use of geothermal heat for greenhousing, aquaculture, crop and food processing, and milk and cheese processing. The new database will certainly aid further direct-use geothermal development.

Witcher (1995) has identified eight resource areas with near-term utilization potential which need site-specific geologic and feasibility studies. The Rincon geothermal system, Dona Ana County, is well located to provide greenhouse heat, milk and cheese processing, chile processing, refrigerated warehousing and possibly binary electrical power. Detailed geologic mapping, drilling of a shallow production hole, and reservoir testing would speed the development of this promising resource. A phase 1 exploration program to define a resource north and west of Truth or Consequences (T or C) could encourage local support for space heating, district heating, geothermal greenhousing and aquaculture. An updated feasibility study for the Las Cruces East Mesa resource may encourage substantial additional use of this large resource which is collocated with one of the fastest growing medium-sized cities in the United States. Hydrogeologic studies are needed to support the extensive greenhouse development at Radium Springs and Lightning Dock.

OREGON

The Oregon Department of Geology and Mineral Industries (DOGAMI) compiled a database of 2,193 thermal well/spring sites, an increase of 1,281 over the 1982 compilation (Black,1994). These springs and wells may represent more than 200 resource areas. The study confirmed a conclusion from the earlier assessment (NOAA, 1982) that the entire state east of the Cascade Range, except for the crest of the Wallowa Mountains, was "favorable for the discovery at shallow depth (less than 1,000 m) of thermal water of sufficient temperature for direct heat applications". It appears that the entire Columbia Plateau Province appears to be underlain by large volumes of 20-25 C water at relatively shallow depth.

Thermal fluids of 89-99 C are used for a district heating system by the City of Klamath Falls (Lienau et al., 1994). Other uses include spac heating at a number of sites, greenhouse heating, aquaculture, and resorts and pools. Most of the state may be suitable for geothermal heat pump applications (Lienau et al., 1994).

Five areas have been recommended for high priority studies to support near-term utilization of the fluids. The Paisley area, Lake County has an estimated reeservoir temperature of 112 C, and may be appropriate for binary electric power generation, greenhouses, or industrial process heat (lumber drying). An earlier feasibility study for lumber drying needs to be updated, and reservoir studies would assist the evaluation of electric power generation possibilities. The Lakeview system in Lake County may be appropriate for space heating and greenhouses. Geophysical studies to define faults and a district heating feasibility study are recommended for high-priority studies.

Feasibility studies are recommended to assess the economics of space heating, greenhouse heating and aquaculture projects at three other areas: Burns/Hines, Harney County; LaGrande/Hot Lake, Union County; and Vale, Malheur County.

UTAH

Blackett (1994) lists 964 entries for 792 thermal wells and springs in the new Utah database. This compares to only 315 thermal wells and springs documented in the 1980 compilation. Blackett (Personal Communication) estimates 161 different hydrothermal resource areas.

Utah comprises parts of three major physiographic provinces as defined by Fenneman (1931). These include the Colorado Plateau, the Middle Rocky Mountains and the Basin and Range. Hydrothermal resources with temperatures greater than 50 C occur in each province, and in the Transition Zone between the Basin and Range and Colorado Plateau in central Utah. Most of the higher-temperature resources occur in the Basin and Range, an area of active east-west extension, and young (<1 Ma) volcanic rocks, and high average heat flow (80-120 mW/m^2). In central and western Utah most thermal areas are located in valleys near the margins of mountain blocks, and are thought to be controlled by active Basin and Range faults. Others occur in hydrologic discharge zones at the bottom of valleys. The most significant known occurrence of thermal waters in the Colorado Plateau of eastern Utah is from wells of the Ashley Valley oil field, which yield large volumes of nearly fresh water at temperatures between 43 and 55 C (Blackett, 1994).

Regional low energy costs (Wright et al., 1990) have contributed to the relatively low growth of geothermal energy in Utah. Presently, electric power is generated at two areas, Roosevelt Hot Springs and Cove Fort-Sulphurdal KGRAs. Commercial greenhouses use thermal water for space heat at Newcastle in Iron County, and at Crystal Hot Springs in Salt Lake County. Ten resorts use thermal waters for swimming pools, spas and baths (Blackett, 1994).

Seven geothermal areas in Utah are recommended for additional studies when funding becomes available. These studies would aid in expanded use and better management of resources currently in production, and could encourage development of previously unused resources. The Newcastle area, where rapid development of the resource for a growing greenhouse industry is taking place, is perhaps the highest priority. In order to adequately protect the geothermal aquifer and ensure a continued supply of energy to commercial users, geohydrologic studies and numerical modeling of fluid flow and heat transfer is needed. Slimhole drilling is also needed to evaluate the center of the geothermal system (Blackett, 1994).

The Midway geothermal system, with observed temperatures about 45 C and probable reservoir temperatures around 70 C, extends for several square miles around the community of Midway. Midway is a growing resort community located about 8 km from Heber City. Thermal water has been used for decades in pools and spas, and many new residences are using the waters for space heating. Drawdown of the resource has been observed, and water rights of established users may be compromised as development of the resource continues. Additional work is required to define the hydrologic controls of the system and to prvide a technical basis for management of the thermal system. The Monroe Hot Springs - Red Hill Hot Springs resource in Sevier County provides thermal fluids for a small resort which, as a result of a change in ownership, may become a much larger destination resort. Hydrologic and space heating feasibility studies should be completed to aid in managing the resource. Hydrologic studies are also needed to evaluate the Crystal Hot Springs area, in southern Salt Lake County. Here Utah Roses, a commercial greenhouse operator, produces thermal waters from wells for space heating.

Two other geothermal systems, Thermo Hot Springs and the Wood's Ranch geothermal area, are not located near major communities, but large agricultural areas occur to the east, north and south. Each area would benefit from a limited exploration program to determine resource potential (Blackett, 1994).

WASHINGTON

Shuster and Bloomquist (1994) have compiled a resource database which includes 1044 (?) entries with 941 thermal (>20 C) wells, 34 thermal springs, lakes, and fumaroles, and 238 chemical analyses. This compares with 368 thermal sites reported by Korosec et al. (1981). The new database includes every qualifying water well (>20 C) but only a few oil and gas wells selected for other databases. Chrisie (1994) provides an extensive bibliography and index of geothermal literature for the State of Washington.

Schuster and Bloomquist (1994) make several interesting observations concerning the distribution of thermal sites in Washington. Most thermal springs occur in the Cascade Range, and many are associated with stratovolcanoes. In contrast 97 percent of the thermal wells are located in the Columbia Basin of southeastern Washington, and 83.5 percent are located in an six county area. Yakima County with 259 thermal wells, has the most. Most of the thermal springs are associated with a stratovolcano or a fault, where the waters have circulated more deeply or in areas of higher geothermal gradients. The springs are much less dilute than the well waters, with major chemical species averaging a total of 1,570 ppm.

Thermal wells are strongly associated with the Columbia River Basalt Group and the Columbia Basin. The Columbia River

Basalt Group is a thich succession of theolitic basalts that was erupted from fissures in southeastern Washington, northeastern Oregon and western Idaho between about 17 million and 6 million years ago (Schuster and Bloomquist, 1994). More than 300 lava flows occurred and interflow sediments are present between many pairs of flows. The Yakima fold belt developed during and after vulcanism, and includes a series of sharply defined anticlines, faults and broad, flat synclinal basins. The flow tops and bottoms and interflow sediments are generally quite porous and permeable and make good aquifers. The Columbia Basin has a high regional temperature gradient at 41 C/km, and this accounts for most of the thermal wells, although many wells exhit higher temperatures indicative of temperature gradients to 77 C/km. Thermal waters can be resch, in many cases, by wells only 65 m deep.

Schuster and Bloomquist (1994) discuss a number of legal and instutional problems which need to be resolved before utilization of the thermal waters becomes widespread. At least 250 of Washington's thermal wells are publically owned, and many of these are located near public buildings that might be economically heated through the use of geothermal water-source heat pumps. The waters are quite dilute, averaging only 260 ppm total for eight major chemical species.

Washington state investigators have identified laterally extensive low-temperature resources in a six county area within the Columbia Basin. Rather than prioritize limited areas within this region for detailed studies, they make three recommendations for greatly expanding geothermal use in the state. The top recommendation is: to match existing thermal wells with proposed new construction or remodeling of public buildings; determine which projects could make advantageous use of geothermal resources; and then encourage and facilitate such applications.

A second recommendation is to station an investigator in the Columbia River Basin to find and visit new wells, measure temperature gradients, obtain well-test data and drill cuttings, and collect water samples for chemical analyses. A third recommendation is to inform state residents and policymakers about uses of geothermal energy, help policy maakers form a legal and institutional framework which encourages wise use, and advocate the use of geothermal resources in place of fossil fuels.

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