421
7-2-81
file

2
B5449

OR-2791

ornl

ORNL/TM-7718

MASTER

OAK
RIDGE
NATIONAL
LABORATORY

Water-Related Constraints to the Development of Geothermal Electric Generating Stations

Roy C. Robertson
Alf D. Shepherd
Carey S. Rosemarin
Michael W. Mayfield

OPERATED BY
UNION CARBIDE CORPORATION
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A08 Microfiche A01

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

Contract No. W-7405-eng-26

Energy Division

WATER-RELATED CONSTRAINTS TO THE DEVELOPMENT OF
GEOTHERMAL ELECTRIC GENERATING STATIONS

Roy C. Robertson
Alf D. Shepherd
Carey S. Rosemarin*
Michael W. Mayfield†

Date Published: June 1981

* Formerly in the Energy Division, Oak Ridge National Laboratory;
currently an attorney for the U.S. Environmental Protection Agency,
Region V, Chicago, Illinois 60604.

† Formerly in the Geography Department, University of Tennessee,
Knoxville 37916; currently with Henningson, Durham and Richardson,
Sciences Division, Knoxville, Tennessee 37923

OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37830
operated by
UNION CARBIDE CORPORATION
for the
DEPARTMENT OF ENERGY

DISCLAIMER

This book was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MBW

CONTENTS

	<u>Page</u>
ACKNOWLEDGEMENTS	v
ABSTRACT	vii
1. EXECUTIVE SUMMARY	1-1
1.1 Introduction	1-1
1.2 Summary of Water Requirements	1-3
1.3 Summary of Resource Characteristics and Water Availability Analysis	1-4
1.4 Summary of Legal Issues Confronting Development	1-10
REFERENCES FOR SECTION 1	1-12
2. GEOTHERMAL POWER STATION WATER REQUIREMENTS	2-1
2.1 Introduction	2-1
2.2 Factors Influencing Makeup Water Requirements	2-4
2.2.1 Reinjection requirements	2-4
2.2.2 Temperature of the geothermal resource	2-5
2.2.3 Working fluid used in heat-power cycle	2-5
2.2.4 Quality of the makeup water	2-7
2.2.5 Climatology of the site	2-8
2.2.6 Type of cooling system	2-10
2.3 R. W. Beck Study of Heat Rejection from Geothermal Power Plants	2-11
2.4 Parametric Study of Makeup Water Requirements Using Simple Computer Models	2-12
2.5 Estimates of Makeup Water Flow Rates	2-14
2.6 Methods of Reducing Makeup Water Requirements	2-19
2.6.1 Dry towers	2-19
2.6.2 Deluge cooling of dry towers	2-20
2.6.3 Wet/dry cooling towers	2-21
2.6.4 Phased cooling	2-22
2.6.5 Variable, or floating, power	2-22
REFERENCES FOR SECTION 2	2-23
3. RESOURCES PROFILES AND WATER AVAILABILITY SITUATION	3-1
3.1 Introduction	3-1
3.2 Water Availability Overview	3-4
3.2.1 Uncertainty in water needs for geothermal development	3-4
3.2.2 Difficulties in quantifying water availability	3-6
3.2.3 Regional water supply and demand by assessment subareas	3-6
3.3 Imperial Valley of Southern California	3-14
3.3.1 Salton Sea	3-18
3.3.2 Westmorland	3-19

	<u>Page</u>
3.3.3 Heber	3-19
3.3.4 Brawley	3-20
3.3.5 East Mesa	3-21
3.4 Long Valley, California	3-23
3.5 Surprise Valley, California	3-24
3.6 Clear Lake Volcano, California	3-24
3.7 Coso Hot Springs, California	3-25
3.8 Morgan Springs-Growler Springs, California	3-26
3.9 Valles Caldera, New Mexico	3-26
3.10 Roosevelt Hot Springs, Utah	3-28
3.11 Cove Fort-Sulphurdale, Utah	3-29
3.12 Vale Hot Springs, Oregon	3-30
3.13 Newberry Caldera, Oregon	3-31
3.14 Mickey Hot Springs, Oregon	3-31
3.15 Desert Peak, Nevada	3-32
3.16 Stillwater Area and Soda Lake, Nevada	3-33
3.17 Steamboat Springs, Nevada	3-34
3.18 Brady Hot Springs, Nevada	3-35
3.19 Beowawe Hot Springs, Nevada	3-36
3.20 Crane Creek and Cove Creek, Idaho	3-37
3.21 Kamaili Homesteads (Puna District), Hawaii	3-38
3.22 Geyser Bight, Alaska	3-39
REFERENCES FOR SECTION 3	3-40
 4. LEGAL STRUCTURES GOVERNING THE DEVELOPMENT OF GEOTHERMAL RESOURCES	 4-1
4.1 Introduction	4-1
4.2 Legal Definition of Geothermal Resources	4-2
4.2.1 Extending the prior appropriation doctrine to geothermal resources	 4-4
4.2.2 Conflicts between state and federal law	4-7
4.3 California	4-10
4.4 New Mexico	4-19
4.5 Utah	4-25
4.6 Oregon	4-31
4.7 Nevada	4-38
4.8 Idaho	4-42
REFERENCES FOR SECTION 4	4-48
 APPENDIX A — METHOD OF ESTIMATING MAKEUP WATER REQUIREMENTS	 A-1
A.1 General	A-3
A.2 Mickley Method for Cooling Tower Analysis	A-13
REFERENCES FOR APPENDIX A	A-14
 APPENDIX B — EXAMPLE OF GEOTHERMAL PERMITTING PROCESS FOR NEW MEXICO	 B-1
 APPENDIX C — CONVERSION FACTORS USED IN THIS REPORT	 C-1

ACKNOWLEDGMENTS

The authors wish to gratefully acknowledge the assistance and cooperation of the numerous individuals in federal, state, and local agencies and offices who generously provided information, instructive comments, and reviews during the various phases of this study. Particular attention is directed to the cooperation and guidance of Clifton B. McFarland and Raymond J. LaSala of the Division of Geothermal Energy, Department of Energy, Washington, D.C.

Valuable support and assistance was also provided by our colleagues in the Energy Division, Oak Ridge National Laboratory, including William P. Staub and Garland Samuels, Jr., who provided constructive peer review of the report and made many valuable suggestions. Similar thanks go to Harry A. Arnold, Richard M. Davis, Jerome E. Dobson, and John W. Michel. Sandy M. Mitchum of the Geography Department, University of Tennessee, Knoxville, contributed significantly in helping prepare the graphic illustrations and assisted with numerous editorial tasks.

ABSTRACT

Geothermal power cycles typically reject three to four times more waste heat per unit of power output than do fossil- or nuclear-fueled power stations. Wet, mechanical-draft cooling towers are the most commonly used method of heat dissipation at geothermal power plants, but lack of water to make up for evaporation in the towers is a serious problem because most of the high-temperature, liquid-dominated geothermal resource regions in the western United States are located in areas in which existing water supplies are almost totally allocated. The water-related constraints, which may be among the most complex and variable of the issues facing commercialization of geothermal energy, are discussed under three headings: (1) water requirements of geothermal power stations, (2) resource characteristics of the most promising hydrothermal areas and regional and local water supply situations, and (3) legal issues confronting potential users of water at geothermal power plants in the states in which the resource areas are located.

Most geothermal power plants, regardless of type or location, will have cooling tower makeup water requirements of 50 to 100 m³/year per net kilowatt (electric) of generated output [40 to 80 acre-ft/year per net megawatt (electric)]. In flashed-steam systems this makeup water can be supplied from the steam condensate provided that reinjection is not required to help control ground-level subsidence or disturbances of groundwater quantities or quality due to the geofluid withdrawal. Binary power cycles, in which the geofluid is totally reinjected, will require a source of makeup water. Other types of cooling towers, such as the wet/dry or dry types, can be considered as a means of mitigating the water supply problems, but cost penalties currently discourage their use.

A total of 25 geothermal resource areas in California, New Mexico, Oregon, Idaho, Utah, Nevada, Hawaii, and Alaska were studied. Each had a hydrothermal resource temperature in excess of 150°C (300°F) and an estimated 30-year potential of greater than 100-MW(e) capacity. The study is handicapped by the fact that definitive evaluation of the water supply in each resource area would require expenditures for site-specific engineering studies that are well beyond the funding levels for this report. It is clear, however, that many of the potential sites will need water for cooling tower makeup and that in these cases, the availability of the water may be the most prominent of the problems facing developers of the geothermal power resource.

The water laws in the western states are not uniform as to the interpretation of water-rights doctrines nor as to the distinctions made between geothermal and conventional groundwater as to ownership and to the jurisdiction of the various governing bodies. The water-related legal issues are complex and highly site-specific. In making water available to geothermal power plants, many conflicts can be expected to arise.

1. EXECUTIVE SUMMARY

Alf D. Shepherd
Roy C. Robertson

1.1 Introduction

Water-related constraints to the development of geothermal electric power stations in the western portion of the United States are among the most complex and variable issues facing large-scale commercialization of this technology. Most of the high-temperature geothermal resource areas suitable for generating electricity are located in semiarid regions in which existing water supplies are almost totally allocated. If the development of the geothermal resources in a water-short area will require a supplemental source of water for cooling tower makeup or reinjection, some degree of conflict concerning water availability and its most beneficial uses can be expected to arise.

The stated near-term goal of the U.S. Department of Energy's (DOE) Geothermal Energy Program is to encourage and assist industry or municipal utilities to discover and exploit geothermal resources. DOE has estimated that this action could result in electric and thermal power equivalents that could replace one million barrels of oil per day by the year 2020.¹ Potential water use conflicts have been identified among the environmental concerns upon which the attainment of these goals is critically dependent and, furthermore, have been judged as one of the concerns with the greatest likelihood of having research findings adverse to commercialization.

One of the more serious barriers to the large-scale expansion of the use of geothermal energy is competition for available resources, such as water for heat rejection systems. If injection of most of the withdrawn water is required, then a supplementary source of cooling water will be required. As many hydrothermal reservoirs are in regions of limited water availability, this lack of water resources could result in a delay or could halt further development The likelihood of water conflicts is very site-specific and ranges from high to low (ref. 1, Vol. 7, No. 10, p. 47).

The purpose of this study is to provide a better overall understanding of water resources and the potential for water-related problems surrounding the most promising high-temperature, liquid-dominated geothermal reserves. This report is organized into three topical areas of study which address (1) the water requirements of geothermal power stations and the factors that influence the amount of water needed, (2) the resource characteristics of the geothermal areas having the greatest promise and the regional water availability situation in those areas, and (3) the water-related legal issues that may confront the development of geothermal resources. This topical framework was adopted to enable desired variations within the text of the report that would reflect the specializations of the analysts involved in specific areas of investigation and thus make the study's results more directly relevant to an audience engaged in geothermal development. Hence, the discussion of water requirements (Sect. 2) assumes an engineering approach, the resources characterizations (Sect. 3) a geographic perspective, and the legal issues (Sect. 4) an attorney's outline.

This study is limited by the fact that definitive treatment of each of these areas of investigation would involve highly site-specific analyses. DOE has estimated that these studies could require a greater level of effort for each potential site than the total allocated for this survey study (ref. 1, p. 44). In most cases, more definitive conclusions than those contained in this report regarding potential water-related constraints would be premature until accompanied by a judgment for each site on the specific power cycle to be employed and the amount of reinjection or other water that will be required. Even then, for example, if water rights needed to be purchased from existing appropriators, the feasibility of development might balance on the opportunity costs to be paid for the water required, versus the cost and availability of water-conserving technologies. In the end, much could still depend upon political factors, not to mention the individual negotiating skills and ingenuity of the developer.

1.2 Summary of Water Requirements

All power cycles must reject a portion of the supplied heat energy to the environment. Of the methods of heat dissipation available to geothermal power plants in the western United States, wet mechanical-draft cooling towers are of most importance at this time. Flashed-steam power cycles can produce sufficient condensate to make up for the evaporation, blowdown, and drift losses from the towers. Other power cycles, such as the binary, will need a supplementary source of water to make up for the cooling tower losses. A supply of water may be needed for the flashed-steam systems as well, however, because reinjection of essentially 100% of the fluids taken from the ground may be required to mitigate ground-level subsidence problems or effects of drawdown on the capacity of the geothermal resource. Further, hydraulic interconnection of aquifers can possibly cause geothermal fluid withdrawal at some locations to have measurable effects on ground- and surface-water quality and abundance. It may be necessary for the power plant owners to supply water of suitable quality to the users of groundwater whose supplies have been affected.

The calculation of makeup water needs for operation of high-temperature hydrothermal reservoirs at their estimated 30-year electric generating potential are based on the resource evaluations published by the U.S. Geological Survey.² The evaluations of the potentials rely on judgment of such factors as the breadth and depth dimensions of the resource volume, the specific heat and subterranean temperature distribution, and the percent of the heat that is recoverable. The major factors influencing the amount of makeup water needed per unit of capacity are the temperature of the geothermal resource, the working fluid used in the power cycle, the purity of the makeup water as it affects the cycles of concentration in the cooling towers, the water conservation measures employed in the tower design, and the meteorology of the site. Many of these factors require optimization studies to establish and are highly site-specific.

Several aspects were considered in establishing a representative range of values for the makeup water needed at geothermal power plants. Published studies were examined, makeup rates of some planned and existing geothermal stations were noted, and parametric studies were made of simplified, nonoptimized flashed steam and binary cycles using conventional wet, mechanical-draft cooling towers. Essentially all geothermal power plants, regardless of type or location, had makeup requirements falling within the range of 50 to 100 m³/year·kW(e) [40 to 80 acre-ft/year·MW(e)] of net generated output when taken on an annual average basis and at about 90% plant capacity factor. Other types of cooling towers, such as the wet/dry or dry types, can be considered as a means of mitigating the water supply problems, but cost penalties currently discourage their use.

1.3 Summary of Resource Characteristics and Water Availability Analysis

The geothermal resource areas included in this study were those hydrothermal (liquid-dominated) reservoirs having a source temperature greater than 150°C (300°F) and an estimated electric generating capacity of greater than 100 MW(e) for 30 years.² A total of 25 geothermal development areas located in California, New Mexico, Oregon, Idaho, Utah, Nevada, Hawaii, and Alaska meet these criteria.* The location of the major geothermal areas is illustrated in Fig. 1.1, and summary results regarding the resource characteristics and probable supplementary water sources at the sites studied are presented in Table 1.1.

Although there is some lack of confidence in the preciseness of the estimated potentials of the geothermal reserve areas listed in Table 1.1, this study nevertheless indicates that there are a significant number of

*The recent volcanic activity at Mount St. Helens in Washington has drawn attention to the possible geothermal potential of the Cascade Range and the need to regularly update the information in U.S. Geological Survey Circular 790² (see Fig. 3.1).

MAJOR POTENTIAL GEOTHERMAL RESOURCE AREAS IN THE WESTERN UNITED STATES

* OR = $>150^{\circ}\text{C}$ AND $>100\text{ MW(e)}$ X 30 YEARS ELECTRICAL POTENTIAL
 + = $>100^{\circ}\text{C}$ AND $>0.75 \times 10^{12}\text{ J}$ WELLHEAD THERMAL ENERGY

Fig. 1.1. Locations of major potential geothermal resource areas in the western portion of the United States.

Table 1.1. Geothermal resource characteristics and cooling tower makeup water availability at 25 western geothermal areas of the United States^a

Resource area	Resource temperature		30-year potential [MW(e)]	Geothermal fluid (TDS)	Area size		Probable makeup water source ^b (other than condensate)
	°C	°F			Hectares	Acres	
California							
Imperial Valley							
Salton Sea area	323	613	3,400	250,000-350,000	38,779	95,824	Saline water from Salton Sea or poor quality water from New or Alamo rivers
Westmorland	217	423	1,710	37,000	(Not a KGRA) ^c		Same as Salton Sea area
Heber	175	347	650	14,000-20,000	23,677	58,508	Same as Salton Sea area (use of New River water has been protested)
Brawley	253	487	640	70,000-100,000	11,690	28,885	Same as Salton Sea area
East Mesa	182	360	360	2,000-50,000	15,526	38,365	Same as Salton Sea area but small amount of ground water may be available
Long Valley Caldera	230	446	2,100	1,000-2,000	184,236	455,256	Small amount of surface water
Surprise Valley	152	306	1,490	1,500	29,318	72,446	Very little available
Clear Lake Volcano	190	374	900				Very little available
Coso Hot Springs	230	446	650	2,000	20,947	51,760	Small amount of groundwater
Morgan Springs — Growler	230	446	116		(Not a KGRA)		Small amount from lakes and rivers
New Mexico							
Valles Caldera	273	523	2,700	6,000	68,295	168,761	Purchase of water rights
Utah							
Roosevelt Hot Springs	265	509	970	7,000	12,056	29,791	Very little available
Cove Fort — Sulphurdale	170	338	330		9,742	24,074	Purchase of water rights
Oregon							
Vale Hot Springs	160	320	870		9,303	22,988	Purchase of water rights
Newberry Caldera	230	446	740		12,660	31,284	Abundant surface water and groundwater
Mickey Hot Springs	205	401	160				Low-quality groundwater

Table 1.1 (continued)

Resource area	Resource temperature		30-year potential [MW(e)]	Geothermal fluid (TDS)	Area size		Probable makeup water source ^b (other than condensate)
	°C	°F			Hectares	Acres	
Nevada							
Desert Peak Area	221	430	750	7,500			Low-quality groundwater
Stillwater	159	318	450	7,000	91,159	225,260	Purchase of water rights, low-quality groundwater
Steamboat Springs	200	392	350	1,000-4,000	3,606	8,911	Purchase of water rights
Brady Hot Springs	155	311	157	1,000-2,600	39,864	98,508	Purchase of water rights, low-quality groundwater
Soda Lake Area	157	315	146		91,159	225,260	Purchase of water rights, low-quality groundwater
Beowawe Hot Springs	229	444	127	1,000	13,446	33,225	Purchase of water rights from Humboldt River
Idaho							
Crane Creek — Cove Creek	171	340	340		1,757	4,342	Weiser River, groundwater
Hawaii							
Kamaili Homesteads	273	523	210	2,000			Groundwater, rainwater, or ocean
Alaska							
Geyser Bight	208	406	136		8,482	20,960	Ocean

^aResource temperatures and 30-year potentials taken from L. J. P. Muffler (ed.), *Assessment of Geothermal Resources of the United States — 1978*, Geological Survey Circular 790 (1979).

^bProbable sources only if the water can be legally obtained and there are no technical or societal restraints to its use.

^cKGRA = Known Geothermal Resource Area.

areas in which lack of water of sufficient quality could constrain development of a geothermal power industry, if a supplementary source of water for cooling tower makeup water or reinjection is required. Water may be present at many of the locations but currently appropriated for agricultural, industrial, municipal, and other uses and, therefore, difficult to obtain in the amounts needed by a geothermal power station. Of the 25 sites studied, nine are in areas that the respective state water engineers have designated as critical water resource regions, indicating that all available supplies have been appropriated. These areas include

Steamboat Springs, Nevada
Desert Peak, Nevada
Brady Hot Springs, Nevada
Beowawe Hot Springs, Nevada
Coso Hot Springs, California

Mono-Long Valley, California
Surprise Valley, California
Valles Caldera, New Mexico
Roosevelt Hot Springs, Utah

Any supplementary water needs in these areas would have to be acquired from current appropriators.

The cost of obtaining water rights tends less to be a function of the marginal value of the water for alternate uses, such as agriculture, than of the monopoly rents imposed by the sellers. For example, the Intermountain Power Project has contracted to pay \$1.42/m³ (\$1750/acre-ft, or \$5.37/1000 gal) for water rights from local agricultural users in the Sevier River Basin in western Utah. This price is many times higher than the market value for alternate uses and reflects both the high value of the water to the utility and the strong monopoly position of the prior appropriators.

Alternatives to purchasing water rights from existing users (if available and if permitted) are to transport water over long distances, to install water treatment systems to make use of waste or high-salinity water, or to use dry cooling towers. In most cases, past experiences have shown these arrangements can be prohibitively expensive and require detailed investigation. For example, in transporting water for relatively long distances, the cost of the conduit itself is more or less linear with distance, and the cost of the conduit per unit volume of

water transported will decrease as the volume increases. In-place costs, however, can be highly site-specific in that such factors as the character of the terrain, distance from roads, amount of rock displaced, right-of-way costs, whether rural or metropolitan routing, season of the year, and elevation changes requiring pumping, all have to be taken into consideration. Also, while the in-place total costs per mile of similar water conveyance systems extending for long distances tend to have similar average costs per mile, application of such an average to shorter distances and site-specific situations could produce misleading results.

The complicated situation existing in the Imperial Valley of Southern California is of particular interest, because this area may be capable of producing over 6000 MW(e) and any technological, physical, and/or institutional solution(s) may have significant positive implications. In this highly productive agricultural region, all the water that is not highly saline is appropriated, and probabilities are against its transfer. The saline waters of the Salton Sea and the New and Alamo rivers, which consist primarily of agricultural runoff, are possible sources of water. However, the pretreatment which may be necessary to improve the quality of this water, and/or the costs of transporting the water over the distances required, may inhibit development.³ Further, the California Department of Fish and Game has opposed the use of water from the New and Alamo rivers because its withdrawal would tend to increase the salinity of the Salton Sea. Two special cases in the Imperial Valley are Heber, where the flow in the New River may not be adequate during low-flow periods, and East Mesa, which is not bordered by any return-flow channels. An integrated assessment of geothermal development problems in the Imperial Valley has recently been completed by Lawrence Livermore National Laboratory, but no definitive answers are yet apparent.⁴

This ORNL study provides an overview of the water supply situation for geothermal power stations in the western United States, with emphasis on the types of problems that may constrain development. The notation of these constraints, however, should not be interpreted as a definitive statement that development of geothermal resources will be prohibited or

impractical in any given area. Indeed, the nation's energy supply would benefit greatly from the power-generating potential of the western geothermal resources. The 25 sites studied in this report have an estimated total potential of over 20,000 MW(e). It may be noted that the Imperial Valley and the nine other geothermal areas listed as being closed to further water appropriation contribute approximately 16,000 MW(e) of this total.

1.4 Summary of Legal Issues Confronting Development

Committing water sources to power production in the geothermal resource areas studied is governed by western water law, which has developed in the form of the prior appropriation doctrine. A main objective of this system is to apply water to the maximum economic good. This goal involves some use of the marketplace. However, water is a vital resource, and society has imposed rules governing its use which the market alone cannot enforce. For example, in most instances a water right may not be transferred without assurance of noninjury to junior appropriators. This ensures the security of all water rights. Ecological considerations may impose further limitations. The amount of water that may be appropriated from a given source may be restricted, or a groundwater reservoir may be closed to further appropriation to prevent groundwater mining. Such conventions have been devised to provide stability to traditional economic uses of water.

Barring highly inefficient uses of water, it is likely that geothermal electric generation will be classified as a beneficial use. Public interest considerations are determined on a case-by-case basis, but there appear to be no universal adverse effects which would obstruct a developer's acquisition of a water use permit in the name of the public interest. Therefore, geothermal developers should not occupy a position that is significantly different from other applicants for the use of water. The greater problem is likely to be the extent to which water law is applicable to geothermal fluid.

Regulatory devices developed for conventional water may apply to geothermal fluid without producing the benefits for which they were

designed. The current stage of development of the law in this area has resulted in inadequate mechanisms to distinguish between conventional and geothermal water. This lack of clarity can manifest itself in uncertainty about a range of particular issues and serve to delay development.

Of immediate importance is uncertainty about ownership. If the definition of the geothermal resource includes water, then geothermal fluid may be considered as such, and according to western water law, ownership will reside in the state. However, in defining geothermal resources broadly enough to include water, the legislature may have only wanted geothermal resources to be regulated as water, but in other respects, such as ownership, treated as minerals (which are subject to different legal structures). In this case the surface owner prevails. Further problems may arise if different persons own the surface and mineral estates of a single parcel of land.

Uncertainty in regulation, as a matter separate from ownership, presents additional problems. Unclear boundaries between the respective jurisdictions of state water and mineral agencies have the potential to produce duplicative and unnecessary requirements which can result in delay. Even if it is decided that geothermal resources are to be regulated as either water or mineral, the problem is not necessarily solved. It may still be unclear whether the entire body of the established law or only parts of it apply to geothermal resources.

An incomplete definition of rights can also manifest itself during conflicts between conventional and geothermal users, such as when hydraulic connections exist between aquifers. The question of whether an aggrieved water user should be able to prohibit a geothermal driller from pumping (as if the latter were a conventional user) or merely demand monetary damages, has also been raised. Situations have apparently already arisen in which one scheme of water law (prior appropriation) governs in conflicts between geothermal developers and water users, and another (correlative rights, which is essentially proportionate sharing) controls in conflicts among geothermal developers themselves.

It can therefore be seen that legal problems related to water use by geothermal steam electric generation plants are complex. The uncertainty that they present can indeed serve to constrain geothermal energy development. On the other hand, there appears to be room for optimism, because law as a reflection of social desires may be expected to develop in a manner that will promote use of the resource.

REFERENCES FOR SECTION 1

1. U.S. Department of Energy, Assistant Secretary for Environment, "Hydrothermal Electric and Direct Heat Commercialization Phase III Planning," *Geotherm. Energy*, 7(10), 38-47 (October 1979) [Part I of two parts; Part II in *Geotherm. Energy* 7(11) (November 1979)].
2. L. J. P. Muffler (ed.), *Assessment of Geothermal Resources of the United States - 1978*, Geological Survey Circular 790 (1979).
3. Salton Sea Study Group, "What are Current Costs and Feasibility of Using Salton Sea Water for ReInjection into Geothermal Reservoirs?" (unpublished document), Sacramento, Calif. (1980).
4. David Layton (ed.), *An Assessment of Geothermal Development in the Imperial Valley of California*, DOE/EV-0092 (July 1980).

2. GEOTHERMAL POWER STATION WATER REQUIREMENTS

Roy C. Robertson

2.1 Introduction

Almost all the water required for operation of a geothermal power plant is used by the cooling towers to replace, or make up, the amount of water lost from the towers by evaporation, blowdown, and drift. In judging the amount of water needed for this purpose, it should be noted that the makeup water flow rates at fossil- and nuclear-fueled power stations are not a good guide. Because of the relatively low temperature of geothermal heat sources, geothermal power plants usually have low efficiencies in the 10 to 15% range, and they thus demand three to five times more makeup water per kilowatt of power output than do the conventional steam-electric stations. To determine the water requirements of potential geothermal power plants, this report examines design studies and performances of planned and existing geothermal power stations and mathematically analyzes the thermodynamic performances of hypothetical geothermal power systems under various meteorological conditions.

Two basic types of power cycles can be used for converting the heat in hot-water-dominated geothermal reserves to electricity: (1) a flashed-steam system or (2) a binary power system. In the flashed-steam system, the geothermal fluid is allowed to flash, and the steam is separated from the liquid, passed through a turbine, and condensed.* The condensate may be used for cooling tower makeup, reinjected, or used for other purposes, since it is water of relatively high quality. The underflow from the flash tank, containing the dissolved and suspended solids, may be reinjected into the ground or otherwise discarded. In a

* If the total of the cooling tower water losses in a flashed-steam system is expressed as a percentage of the mass flow rate of the geothermal fluid taken from the ground, the percentage will vary with the temperature of the geothermal resource. At a 690-kPa (100-psia) turbine throttle pressure, the cooling tower water losses would be roughly 9% of the geofluid mass flow rate for a resource temperature of 204°C (400°F), about 21% for a temperature of 260°C (500°F), and about 36% for a 316°C (600°F) resource temperature.

binary system, the geofluid is circulated through a heat exchanger without flashing and is reinjected into the ground. The heat is utilized to vaporize a second fluid, such as isobutane or isopentane, which is expanded through a turbine, condensed, and returned to the boiler to provide a closed cycle. This report considers the performance of both the basic flashed-steam and binary cycles, since they yield somewhat different thermodynamic efficiencies, but the distinction between these two basic types is not great when viewed in the context of the limited degree of refinement possible without detailed design studies.

The major factors influencing the amount of makeup water needed are the efficiency of the heat-power cycle (as influenced by the temperature of the resource and the type of working fluid used in the cycle), the purity of the makeup water and the method of blowdown disposal (as they affect the cycles of concentration in the cooling towers), the water conservation measures incorporated into the tower design (such as use of wet/dry towers), and the meteorology of the site. To establish these factors it is necessary to make optimization studies that are highly site-specific. Close estimates of the water requirements at geothermal power plants, therefore, cannot be made within the scope of general, nonoptimized studies of the type reported here. A range of probable makeup rates must suffice.

This section discusses the water needs of a typical geothermal station without regard for the source of the makeup water, whether it be from local surface- or groundwater supplies, or from the geofluids themselves. With respect to the latter, it is possible in flashed-steam systems to use the turbine condenser condensate as a source of makeup water, but it should be noted that this consumptive use of the subterranean fluid could, at some sites, cause subsidence of the ground level or affect the quantity and quality of groundwater or geothermal fluid supply. Although the regulations existing at the present time at a particular site may not require reinjection of the condensate, its use as makeup water may not be a long-term arrangement because problems could develop which would cause the regulations to change.

The makeup water rates estimated in this study are on an annual average basis. The range of rates given is the spread of annual average rates that could reasonably be expected. The water requirements during peak-load periods could be 50% or more greater than the annual average values. This situation is exacerbated by the fact that the peak electric loads in semiarid regions tend to occur during the air conditioning season — a time when water supplies are at their lowest. The economic feasibility of constructing a particular geothermal power plant will be strongly influenced by the ability to handle the peak as well as average loads, but, again, these aspects could not be investigated in a generalized study of this type.

The literature contains occasional references to the makeup water needs at geothermal power stations and these can serve as a basis for preliminary estimates. Almost all of these references, however, cite the water requirement without adequate explanation for the basis of the estimate, nor do they suggest a reasonable range of uncertainty. An exception, and probably the most definitive work published to date, is the 1979 study made by R. W. Beck and Associates for the Electric Power Research Institute (EPRI).¹ The Beck study, reviewed in detail in Sect. 2.4, used proprietary construction and operating cost data, assumed ranges of water costs, worths of electricity, etc., in a computer program to arrive at makeup water flow rates for cost-optimized flashed-steam and binary power cycles for four sets of meteorological conditions representing different climates in the western states.

Various methods have been proposed for reducing the water consumption rates of cooling towers during the peak periods or when water supplies are low. These methods, such as use of wet/dry towers, deluge cooling of dry towers, etc., are discussed in Sect. 2.6. To date, these special arrangements have generally not been sufficiently developed or economically attractive enough to make them competitive with conventional wet, mechanical-draft cooling towers. As the economic picture shifts, however, the special tower designs may take on added importance and have an impact on the water requirements of geothermal stations.

Research in water-conserving heat rejection technology is likely to continue because the escalating worth of electricity and the growing

scarcity and cost of water makes such measures increasingly attractive. It is not expected, however, that major technological breakthroughs will drastically lower water requirements and greatly reduce the problem of water availability at geothermal power stations.

2.2 Factors Influencing Makeup Water Requirements

2.2.1 Reinjection requirements

As previously mentioned in Sect. 1.2, flashed-steam systems generate steam condensate in sufficient quantity to satisfy the makeup water requirements of the cooling towers. A geothermal power plant operating on this cycle would not need an outside source of water provided that: (1) there is no requirement to reinject into the ground an amount of water equivalent to that lost in the cooling towers due to evaporation, blowdown, and drift or (2) no water is required to compensate for effects of geofluid removal on local ground- and surface-water quality or quantity due to interconnection of aquifers. It should also be noted that the steam condensate made available in flashed-steam systems is of relatively high quality, and there may be economic or other reasons inhibiting its use as cooling tower makeup water. A source of other water would then be needed. Water of a lower quality might be reinjected into the ground, when this is required, although this may be in conflict with local water quality regulations as well as practical limits on the quality and temperature of the water that can be reinjected without causing precipitation of solids and plugging of the reinjection system. At the Brawley geothermal development area in California, (see Sect. 3.3.4), only 80% of the removed geofluid must be reinjected under current regulations. Because the cooling tower losses could amount to less than 20% of the geofluid flow rate in a flashed-steam cycle at this location, no outside source of water would then be required. Other sections of the Imperial Valley require 100% reinjection. These complexities, particularly the percent of reinjection that may be required, thus have a major influence on the amount of water that must be furnished to a geothermal power station.

2.2.2 Temperature of the geothermal resource

The thermodynamic efficiency of a heat-power cycle, and therefore the amount of heat rejected from it, is a function of the boiler temperature. The heat rejected from the cycle can be expressed as

$$Q_{\text{rej.}} = (\text{Work output}) \times (1 - \eta)/\eta ,$$

where η is the thermal efficiency of the cycle. As shown in Fig. 2.1, the heat rejection rate mounts rapidly as the overall thermal efficiency falls into the low range of less than 15%, which is typical of most geothermal power plants.

It is not always clear when citing geothermal resource temperatures whether reference is being made to the temperature at the bottom of the well, or at the point of supply of the geothermal fluid to the boiler or heat exchanger, and whether the temperature is the low, maximum, or median value. In any event, the boiling temperature of the working fluid determines the cycle thermal efficiency, and this temperature is often 28 to 56C° (50 to 100F°) below the temperature of the geothermal fluid supplied to the boiler. Direct-contact boilers, in which the working fluid is boiled by direct mixing with the geothermal fluid, may more nearly approach the resource temperature. The most economical boiler temperature must be determined from optimization studies that take into account the capital cost of equipment, worth of electricity, geothermal and working fluid characteristics, and the cost of the geothermal fluid delivered to the boiler. Because such optimization studies are beyond the scope of this study, an approximate relationship between boiler and resource temperatures was assumed, as shown in Fig. 2.2.

2.2.3 Working fluid used in heat-power cycle

The efficiency of a turbine depends on the temperature and the properties of the fluid being expanded through it. The working fluids most commonly considered in geothermal power systems are steam, isobutane, isopentane, and the Freons with each having advantages under particular circumstances. The critical-point temperatures of isobutane and isopentane

Fig. 2.1. Effect of thermal efficiency of cycle on heat rejection rate.

Fig. 2.2. Relationship of boiler temperature to resource temperatures assumed in this study. Source: Randy D. Horsak, R. W. Beck and Associates, *Heat Rejection from Geothermal Power Plants*, prepared for California Energy Commission and Electric Power Research Institute, Palo Alto, Calif., EPRI ER-1216 (November 1979).

are 135°C (275°F) and 187.8°C (370.1°F), respectively. The thermodynamic properties of isobutane provide better thermal efficiencies than do those of isopentane at the lower temperatures, but isobutane imposes the penalty of a higher working pressure.

For a given resource temperature, binary systems tend to operate at lower average boiler temperatures than do flashed-steam systems, require a boiler feedpump not needed in the steam system, and thus may have a lower net thermal efficiency for the cycle. This is not to say, however, that the thermal efficiency of a binary cycle is always less than that of a flashed-steam system, but this is often the case. It is important to note, however, that even though the net efficiency of the binary cycle in converting a given amount of heat to power may be lower than that of a steam cycle, by operating at the lower average boiler temperature, more heat may be extracted from a given mass flow rate of brine circulated.

In any event, isopentane, isobutane, single-flash, and dual-flash steam heat-power cycles all have makeup water requirements falling in the same general range, and the distinction as to the working fluid used need not be made for the purposes of this study.

2.2.4 Quality of the makeup water

Water treatment and blowdown disposal costs must be balanced against the cycles of concentration, or concentration factor, in the cooling tower. The chemistry of the circulating water has an important influence on corrosion and fouling in the cooling water system. The amount of makeup water needed, M , is directly related to the concentration factor, F , and the evaporation rate, E , by

$$M = (F \times E) / (F - 1) .$$

Letting B equal the blowdown rate and D the drift rate (usually neglected), other useful relationships are

$$F = M/(B + D) ,$$

$$B = E/(F - 1) - D ,$$

$$E = (F - 1)(B + D) .$$

When the quality of the makeup water is low, as it is at many geothermal installations, concentration factors of less than 5 may be required, and, as indicated in Fig. 2.3, the amount of makeup water needed may be relatively high.

2.2.5 Climatology of the site

Ambient wet- and dry-bulb temperatures affect the amount of water that must be evaporated in cooling towers to dissipate the heat load. Typically, about 80% of the heat will be dissipated by evaporation of water in the tower and the remainder by sensible heating of the air flowing through the tower. The actual distribution changes as a function of the ambient temperatures, the cooling water temperature, and the circulation rates. A comparison is made in Fig. 2.4 between the makeup water rates under annual average 8.3°C (47°F) dry-bulb and 2.8°C (37°F) wet-bulb temperatures, typical of sites in the mountains of New Mexico, and the 22.8°C (73°F) dry-bulb and 13.9°C (57°F) wet-bulb temperatures typical of the climate near Heber, California. It may be noted that the difference in the makeup water requirements for these two extremes of climate is about 6 to 18 m³/year·kW(e) [5 to 15 acre-ft/year·MW(e)]* for the flashed-steam systems and about 18 to 25 m³/year·kWe [15 to 20 acre-ft/year·MW(e)] for the binary systems. The Beck study¹ of optimized systems found a difference of about 5 m³/year·kW(e) [4 acre-ft/year·MW(e)] for the flashed-steam systems and 9 m³/year·kW(e) [7 acre-ft/year·MW(e)] for the binary systems. It is probably more important to note that

* Conversion factors used in this report are given in Appendix C.

Fig. 2.3. Effect of cooling tower concentration factor on tower makeup rate required.

Fig. 2.4. Effect of climate on makeup water needed.

these annual average values may be only about 50% of the water needed to meet summertime peak demands for makeup water.

The temperature to which the circulating water can be cooled in a cooling tower is a function of the wet-bulb temperature and the tower approach temperature, a performance factor of the tower determined not only by its design but also as a function of the operating conditions. The temperature of the water leaving the tower and the range of the temperature rise in the water have an influence on the condensing temperature of the working fluid, and thus on the thermal efficiency of the cycle; however, within the range of reasonable approach temperatures, roughly between 6 and 11C° (10 and 20F°), the effect on makeup water requirements is probably less than 6 m³/year·kW(e) [5 acre-ft/year·MW(e)].

An aspect of the effect of climate on the operating efficiency of geothermal power plants is that hydrocarbon turbines can operate satisfactorily over a broader range of back pressures than can steam turbines. Binary systems can therefore be designed to take fuller advantage of the variations in condenser cooling water temperatures in locations having large diurnal or seasonal differences. Although this aspect was not investigated in this study, it is speculated that the effect on annual average makeup requirements would not be great.

2.2.6 Type of cooling system

It is not likely that once-through cooling systems can be considered for large geothermal power stations because of lack of sufficient water within transportable distances and because EPA regulations discourage their use.* Cooling lakes, spray ponds and canals, and similar methods involving water surfaces open to evaporation are used in water-short areas only under special circumstances. Cooling towers have been selected for the majority of the geothermal power plants now installed or planned in the United States. Evaporation rates are roughly the same in mechanical-draft towers as in natural-draft types, but the latter have limited

*In some special circumstances, approval might be obtained for a small pilot plant to use groundwater in a once-through cooling system with reinjection of the water into the ground.

usefulness in hot, dry climates where the ambient air may have its dry-bulb temperature lowered rather than raised in its passage through the tower. The towers may be of the wet type (depending largely on the evaporation of water), the dry type (which evaporates little or no water), or a wet/dry type which combines the features of both of the others and evaporates an amount of water somewhere between 0% and 100% of that of the wet tower, as selected by the designer. The type of tower used clearly has a major influence on the makeup water requirements of a power station. Unfortunately, the less the amount of water evaporated, the greater will generally be the capital cost of the towers. Optimization studies are thus required at a specific site to make the necessary design decisions. Cooling tower arrangements are discussed further in Sect. 2.6.

2.3 R. W. Beck Study of Heat Rejection from Geothermal Power Plants

In 1979, R. W. Beck and Associates studied the makeup water requirements and electricity production costs for wet and wet/dry peaking cooling towers for the California Energy Commission and for the Electric Power Research Institute.¹ Parametric economic analyses were performed for both dual-flash and binary conversion processes for various combinations of resource temperature, climate, hydrothermal fluid costs, and makeup water costs. In brief, the results show that use of wet/dry towers can reduce makeup water requirements by factors of about 2 to 4 at the expense of an additional 10 to 25% in the busbar price of the electricity generated. Cutting the water consumption to about one-fifth that used in conventional wet towers would add up to about 35% to the busbar cost of the electricity.

The Beck study found that with a 182°C (360°F) resource temperature, binary cycles required about 17% more makeup water than flashed-steam systems. The binary cycle used in the Beck study employs isobutane as the working fluid and an Elliott tandem-compounded turbine rated at 74 MW(e) and 586 kPa (85 psia) exhaust pressure. Constant turbine inlet conditions of 3792 kPa (550 psia) and 143°C (290°F) were assumed regardless of the resource temperature. Although the dual-flash steam system

was optimized for best operating conditions, the binary cycle conditions were not. The makeup water requirements of the binary systems, shown in Table 2.1, do not show a reduction with increased resource temperature for reasons that were not fully explained in the Beck study.

The study estimated the makeup requirements at four conditions considered to be representative of the climates in the Known Geothermal Resource Areas (KGRA's) in the western United States. The annual average conditions are given in the footnote to Table 2.1.

2.4 Parametric Study of Makeup Water Requirements Using Simple Computer Models

It is often difficult to isolate the effect of various operating and design parameters when studying heat dissipation systems because in optimized systems a change in one parameter often dictates the changing of several others if the optimum arrangement is to be preserved. Altering a single parameter in an unoptimized system can lead to unrealistic situations, but if caution is exercised, parametric studies can give an appreciation of the importance of the factors affecting cooling water makeup rates. The values obtained are useful only for comparison purposes and should not be used for design.

This study assumes a single-flash steam system and a simple binary cycle using isopentane as the working fluid. The cycles are not optimized for either best efficiency or lowest costs. The thermodynamic properties of water and isopentane were approximated by correlations spanning a short segment of the published tables of properties.²⁻⁴ An efficiency of 70% was assumed for the steam turbine and an efficiency of 83% for the hydrocarbon turbine. The temperature of the working fluids supplied to the turbine was taken as a function of the resource temperature, as shown in Fig. 2.2. It was assumed that the auxiliary power requirements of the flashed-steam system would be about 10% of the gross output and for the binary system would be about 20% of the gross output. (The binary system would require a boiler feedpump and would also probably need more power for the circulating water pump and the cooling tower fan.) Even though these and other assumptions have a direct effect on

Table 2.1. Annual average makeup water requirements of geothermal power plants estimated by R. W. Beck and Associates

Climatological area ^a	Resource temperature		Makeup water required			
			Flashed system		Binary system ^b	
	°C	°F	m ³ /year·KW(e)	acre-ft/year·MW(e)	m ³ /year·KW(e)	acre-ft/year·MW(e)
Basin	149	300	77.8	63.1	73.4	59.5
	182	360	61.6	49.9	72.3	58.6
	206	475	47.9	38.8	72.3	58.6
High mountain	149	300	80.1	64.9	74.9	60.7
	187	360	63.2	51.2	74.1	60.1
	246	360	49.2	39.9	74.1	60.1
Hot desert	149	300	85.0	68.9	83.8	67.9
	182	360	68.5	55.5	82.8	67.1
	246	475	52.7	42.7	82.8	67.1
Pacific northwest	149	300	76.2	61.8	71.9	58.2
	182	360	60.6	49.1	70.8	57.4
	246	475	47.1	38.2	70.8	57.4

^aThe annual average wet- and dry-bulb temperatures used in the estimates were as follow:

Area	Data base	Dry-bulb temp./wet-bulb temp.	
		°C	°F
Basin	Reno, Nevada	10.0/4.4	(50/40)
High mountain	Valles Caldera, New Mexico	8.3/2.8	(47/37)
Hot desert	Heber, California	22.8/13.9	(73/57)
Pacific northwest	Medford, Oregon	11.7/7.8	(53/46)

^bThe binary system analyses were optimized only for the 182°C (360°F) resource temperature case.

Source: Randy D. Horsak, R. W. Beck and Associates, *Heat Rejection from Geothermal Power Plants*, prepared for California Energy Commission and Electric Power Research Institute, Palo Alto, Calif., EPRI ER-1216 (November 1979).

the estimated makeup water rates and are primarily a matter of judgment, varying the assumptions over a reasonable range of values does not alter the general conclusion that makeup rates will probably fall in the 50 to 100 m³/year·kW(e) [40 to 80 acre-ft/year·MW(e)] range.

The method of calculation used in the parametric study is described in more detail in Appendix A. In brief, the cycles were first analyzed to determine the amount of heat rejected in the condensers per MW(e) of net generated output at the various resource temperatures and ambient air conditions. The amount of water that must be evaporated in the cooling tower to dissipate this amount of heat was then estimated. The condition of the air-water-vapor mixture leaving the cooling tower was estimated using the Mickley method,⁵ which breaks up the cooling process into discrete steps, as indicated in Fig. A.1. (The size of the steps is unimportant as long as they are small.) This method, originally devised for graphical solution, gives a better representation of the cooling tower exit conditions than to simply assume a saturated mixture, but it would probably have been sufficiently accurate for the purposes of this report to have assumed saturation. In the event the initial calculation of the exit air temperature is equal to or greater than the entering water temperature, the approach temperature of the cooling tower is increased by 0.56C° (1F°) and the calculation repeated until the exit temperature is less than the entering water temperature by about 1.7C° (3F°).

2.5 Estimates of Makeup Water Flow Rates

To establish a representative range of values for the makeup water needed at geothermal power plants, published studies were examined, makeup rates of some planned and existing geothermal stations were noted, and parametric studies were made of simplified, nonoptimized flashed-steam and binary cycles using conventional wet, mechanical-draft cooling towers, as mentioned above. These rates, plotted in Fig. 2.5, represent a broad range of geothermal resource temperatures and meteorological conditions. Essentially all the points fall within the range of

Fig. 2.5. Annual average makeup water needed for cooling towers at geothermal electric generating stations. Sources: Δ from Randy D. Horsak, R. W. Beck and Associates, *Heat Rejection from Geothermal Power Plants*, prepared for California Energy Commission and Electric Power Research Institute, Palo Alto, Calif., EPRI ER-1216 (November 1979); $\square$ from Ben Holt and Ed. L. Ghormley, Ben Holt Company, *Energy Conversion and Economics for Geothermal Power Generation at Heber, California, Valles Caldera, New Mexico, and Raft River, Idaho - Case Studies*, prepared for Electric Power Research Institute, Palo Alto, Calif., EPRI ER-301 (November 1976); ∇ from John L. Sakaguchi, VTN Consolidated, Inc., *Water Resources Evaluation*, Topical Report, Task 3, prepared for System Development Corp., Santa Monica, Calif., and the Department of Energy, DOE/ET/28432-3/1 (Mar. 19, 1979); $\circ$ from estimates calculated in this study.

50 to 100 $\text{m}^3/\text{year} \cdot \text{kW(e)}$ [40 to 80 $\text{acre-ft}/\text{year} \cdot \text{MW(e)}$] of net generated output when taken on an annual average basis for a station operating at about 90% plant factor and using conventional wet, mechanical-draft cooling towers.

At higher resource temperatures, flashed-steam systems may require about 15% less makeup water than do binary systems, but this depends on the working fluid used in the binary cycle. In any event, determining the optimum thermal power cycle to be employed at each particular site

was too large an undertaking for this study, and the distinction between the water requirements of various types of cycles was not made.

The above-mentioned range is for a resource temperature of about 200°C (400°F); if the resource temperature is at about 150°C (300°F), the range might be about 6 m³/year·kW(e) [5 acre-ft/year·MW(e)] higher, and if at 260°C (500°F), might be about 6 m³/year·kW(e) [5 acre-ft/year·MW(e)] lower; however, this adjustment is overshadowed by the uncertainty in knowing other factors, such as the amount of geothermal fluid in the reserve. More importantly, it should be noted that summertime maximum rates can be almost 50% greater than annual average values and that the availability of sufficient water to meet peak electrical loads can have a major effect on the economic practicability of a geothermal power station.

In general, the highest makeup water rates shown in Fig. 2.5 are for locations in semiarid regions, such as at Heber, California. In such conditions the cooling tower heat dissipation depends almost entirely on the evaporation of water, and the dry-bulb temperature of the ambient air may at times even be lowered in its passage through the tower. Differences of the extremes of climate between the high mountains and the hot deserts of the southwest can make a difference of 6 to 18 m³/year·kW(e) [5 to 15 acre-ft/year·MW(e)] in the amount of makeup water required.

Estimates of the average cooling tower makeup water requirements of each geothermal reserve are given in Table 2.2. The principal basis for Table 2.2 is the 30-year-average electric-generating potential estimated for each reserve in U.S. Geological Survey Circular 790.⁶ In brief, the potentials estimated in Circular 790 were arrived at by (a) taking such geofluid temperature data as exists; (b) judging the area and thickness of the reserve by probability methods (stated to be the largest uncertainty in the procedure); (c) estimating the heat resource based on typical porosity and specific heat data and an assumed recovery factor of 0.25 for hot water reservoirs; (d) calculating the theoretical work available from the heat, based on an hourly mass flow rate of water judged to be capable of being sustained over 30 years, the well-head temperature, and an assumed heat sink temperature of 15°C (59°F); and (e) applying a utilization factor of 0.40 as

Table 2 2. Cooling tower makeup water requirements at 25
western geothermal areas of the United States^a

Resource area	Resource temperature		30-year potential MW(e)	Annual average use rate	
	°C	°F		m ³ /s	10 ³ acre-ft/year
California					
Imperial Valley					
Salton Sea Area	323	613	3,400	5.3-10.6	136-272
Westmorland	217	423	1,710	2.7-5.4	68-136
Heber	175	347	650	1.0-2.0	26-52
Brawley	253	487	640	1.0-2.0	26-52
East Mesa	182	360	360	0.6-1.2	14-28
Long Valley Caldera	230	446	2,100	3.3-6.6	84-168
Surprise Valley	152	306	1,490	2.3-4.6	60-120
Clear Lake Volcano	190	374	900	1.4-2.8	36-72
Coso Hot Springs	230	446	650	1.0-2.0	26-52
Morgan Springs — Growler	230	446	116	0.2-0.4	5-10
New Mexico					
Valles Caldera	273	523	2,700	4.2-8.4	108-216
Utah					
Roosevelt Hot Springs	265	509	970	1.5-3.0	39-78
Cove Fort — Sulphurdale	170	338	330	0.5-1.0	13-26
Oregon					
Vale Hot Springs	160	320	870	1.4-2.8	35-70
Newberry Caldera	230	446	740	1.2-2.4	30-60
Mickey Hot Springs	205	401	160	0.3-0.6	6-12

Table 2.2. (Continued)

Resource area	Resource temperature		30-year potential MW(e)	Annual average use rate	
	°C	°F		m ³ /s	10 ³ acre-ft/year
Nevada					
Desert Peak Area	221	430	750	1.2-2.4	30-60
Stillwater	159	318	450	0.7-1.4	18-36
Steamboat Springs	200	392	350	0.5-1.0	14-28
Brady Hot Springs	155	311	157	0.3-0.6	6-12
Soda Lake Area	157	315	146	0.2-0.4	6-12
Beowawe Hot Springs	229	444	127	0.2-0.4	5-10
Idaho					
Crane Creek — Cove Creek	171	340	340	0.5-1.0	14-28
Hawaii					
Kamaili Homesteads	273	523	210	0.3-0.6	8-16
Alaska					
Geyser Bight	208	406	136	0.2-0.4	5-10

^aResource temperatures and 30-year potentials taken from L. J. P. Muffler (ed.), *Assessment of Geothermal Resources of the United States — 1978*, Geological Survey Circular 790 (1979).

the amount of the theoretical work that could actually be converted to useful power.* The resulting average power, published in Circular 790, expressed in MW(e), was then multiplied by the 50 to 100 m³/year·kW(e) [40 to 80 acre-ft/year·MW(e)] estimated range of makeup water requirements developed in this section. The spread has thus been applied only in the range of makeup water requirements. Had the range of uncertainties in the estimates of the reserve potentials been known, the combined effect would have been far broader ranges of possible values. While one could point out areas in which the estimating procedure could be refined, such as use of a more realistic condensing temperature for hot climates, distinguishing between the performance of flash and binary systems, etc., it is apparent that these aspects are completely overshadowed by the uncertainties in estimating the extent of the geothermal reserve potentials.

2.6 Methods for Reducing Makeup Water Requirements

The shortage of water for power plant cooling tower makeup has directed much effort toward discovering ways to reduce the water requirement without imposing unacceptable penalties on the costs to produce electricity. Some of the approaches that have been investigated are very briefly described below. (There is no particular order of listing.)

2.6.1 Dry towers

In this concept, plant waste heat is dissipated by transfer through the walls of an extended-surface, air-cooled coil to raise the temperature of the air stream by sensible heating alone. In direct arrangements, the turbine exhausts directly into the coils with condensation taking place within the coils. In indirect systems a heat transport fluid, such as water or ammonia^{7,8} conveys the heat from the condenser to the

*Some geologists are skeptical of the sensitivity of the geo-thermometry techniques employed. Due to sparseness of down-hole data at some locations, they also believe it possible that the potentials listed in circular 790 could be overstated. (See Sect. 3.1 for further comments on the estimates of potentials listed in Circular 790.)

air-cooled coil. The heat transfer per unit mass of air moving through the tower is small in comparison to towers that evaporate water, and surface area requirements are high, leading to high capital costs for dry cooling towers. Turbine back pressures are also higher because the heat transfer is a function of the dry-bulb rather than the wet-bulb temperature, and special high-back-pressure turbines, which are not yet generally available, often must be specified.⁹ Performance is sensitive to wind and thermal inversion effects.¹⁰ Dry cooling towers may cost four to five times as much as conventional wet cooling towers of the same capacity.¹² These unfavorable aspects have led to little use to date of dry cooling towers in the United States.

The resistance to heat transfer is mainly the air-side film resistance so that little can be done to improve the overall heat transfer coefficient. Methods of extending the heat transfer area, such as through use of fins, have been explored. The remaining area offering promise of improvement in the outlook for dry cooling towers is in reducing the construction cost of the towers. Extruded shapes have been investigated⁷ as has the use of plastic surfaces. The rewards for developing a lower cost dry tower are so great that research and development in this area will undoubtedly continue. The most extensive series of studies on dry cooling towers are probably those published by Battelle Pacific Northwest Laboratories.¹² In general, however, it would be ill-advised for the geothermal power industry to count on "break-through" types of discoveries in this area to solve the problems of waste heat dissipation in water-short regions.

2.6.2 Deluge cooling of dry towers

At many power plant locations, the dry-bulb temperatures are low enough during much of the year to allow a dry cooling tower of more reasonable size to handle the load satisfactorily. Only during peak electric loads and high summertime ambient temperatures is its capacity overtaxed, resulting in higher turbine back pressures. (In this regard it should be noted that steam turbine performance drops off markedly at exhaust pressures greater than the design value but that the hydrocarbon turbines used in binary cycles are far less sensitive to this aspect.)

Since the capacity of a dry cooling coil can be more than doubled by evaporating water on the outside surface, studies have been made of so-called "deluge," or "water augmented," systems, which spray water on the coils to carry the plant through the peak load periods.¹³ The amount of water lost by evaporation is small when compared to the losses from conventional wet cooling towers. The evaporating water leaves behind deposits of dissolved and suspended solids, however, that foul the coil surfaces and are difficult to remove. Even though the water flow rate is kept high enough to allow runoff, the fouling and corrosion of the intermittently wetted surfaces causes problems that have not yet been fully resolved.¹⁴ The potential advantages of deluge cooling, however, such as initially specifying a smaller heat exchanger and maintaining lower turbine back pressures, are so great that there will be continued interest in the concept.

2.6.3 Wet/dry cooling towers

If a power plant were provided with both wet and dry cooling towers, the latter could be used during periods of low loads and low ambient temperatures, and the wet towers could be used to help meet peak loads and when ambient cooling conditions are unfavorable. The concept permits significant savings in the amount of water needed for cooling tower makeup when considered on an annual basis. By combining the tower types into one structure and sharing air-moving equipment, some savings can be made, but wet/dry towers still cost two to three times more than conventional wet cooling towers of the same capacity.¹⁵ A further argument for using the wet/dry concept to conserve water is that water resources are often not restricted during the winter months when the dry cooling is most likely to be used but are in short supply when needed in the hot summer months for the wet cooling tower makeup water.

Since wet/dry cooling towers may make a geothermal power station feasible at a water-restricted site when it would otherwise be impractical, it can be expected that DOE and the geothermal power industry will have a continued interest in them. As in dry cooling towers, one of the few options available for improvement is in devising methods of lowering the

construction costs. Numerous studies of the economics of use of wet/dry towers have been made by Battelle Pacific Northwest Laboratories.^{16,17}

2.6.4 Phased cooling

At power stations having significant diurnal differences in cooling capability, as is typical of many geothermal sites, significant reductions in water consumption may be possible by storing a portion of the warmed circulating water for nighttime heat dissipation.¹⁸ This arrangement has been termed "phased cooling." Essentially the same amount of heat must eventually be dissipated, however, and by postponing the heat release the capacity of the heat dissipation equipment must be increased accordingly. Costs are not necessarily increased in direct proportion to size, however, because of the size factor and the more advantageous nighttime cooling conditions. Depending on the availability of land, on construction costs for water storage basins, and on the evaporation losses from the storage basins, phased cooling might be a practical means of reducing water consumption with less expense than would be required for wet/dry or dry cooling towers.

2.6.5 Variable, or floating, power

A power plant is customarily designed for a constant power output that can be assured year-round, as determined by the capacity of the heat rejection system at reasonably worst-case conditions. However, in some special cases it may be more economical to design for a power output that will vary with the capacity of the heat rejection system as it is affected by the ambient conditions. This concept of variable output has been termed "floating power."¹⁹ The penalty in capital cost charges in having equipment installed that is at times partially loaded will tend to be offset by the greater amount of power than can be produced from a given amount of heat dissipation capability. A major disadvantage of the concept is that the system suffers a loss in capacity when it is needed most to meet peak air conditioning loads.

The advantages of the variable output concept are greatest at plant locations where there are wide variations in the available sink temperature as a result of diurnal and seasonal changes. Use of dry cooling enhances

this effect because the sink temperature is then dependent on the ambient dry-bulb rather than the wet-bulb temperature. The advantages are also greater for plants having higher-than-average condensing temperatures, which, again, is characteristic of plants using dry cooling towers. The concept also favors plants with only moderate thermal efficiencies, such as those dependent on relatively low-temperature heat sources. Geothermal power plants qualify in many of these aspects and thus are likely candidates for the variable capacity concept.

REFERENCES FOR SECTION 2

1. Randy D. Horsak, R. W. Beck and Associates, *Heat Rejection from Geothermal Power Plants*, prepared for California Energy Commission and Electric Power Research Institute, Palo Alto, Calif., EPRI ER-1216 (November 1979).
2. Kenneth E. Starling, *Fluid Thermodynamic Properties for Light Petroleum Systems*, Gulf Publishing Co., Houston, Tex., 1973.
3. Joseph H. Keenan et al., *Steam Tables, English Units*, John Wiley & Sons, New York, 1969.
4. American Society of Heating, Refrigerating and Air Conditioning Engineers, *ASHRAE Handbook of Engineering Fundamentals*, Chap. 6, New York, 1978.
5. Max Jakob, *Heat Transfer*, Vol. II, John Wiley & Sons, New York, 1957.
6. L. J. P. Muffler (ed.), *Assessment of Geothermal Resources of the United States - 1978*, Geological Survey Circular 790 (1979).
7. R. T. Alleman et al., "Dry/Wet Cooling Towers with Ammonia as Intermediate Heat Exchange Medium," p. IV-C-163 in *Proceedings of the Conference on Waste Heat Management and Utilization*, University of Miami, Coral Gables, May 1977.
8. R. D. Tokarz et al., *Comparative Cost Study of Four Wet/Dry Cooling Concepts That Use Ammonia as the Intermediate Heat Exchange Fluid*, Pacific Northwest Laboratory, PNL-2661, Sept. 1978.

9. J. P. Rossie et al., *Economics of the Use of Surface Condensers with Dry-Type Cooling Systems for Fossil-Fueled and Nuclear Generating Plants*, R. W. Beck and Associates, ID-26514 (December 1973).
10. F. K. Moore, "Problems of Dry Cooling," p. II-C-109 in *Proceedings of the Conference on Waste Heat Management and Utilization*, University of Miami, Coral Gables, May 1977.
11. B. C. Fryer, *A Review and Assessment of Engineering Economic Studies of Dry-Cooled Electric Generating Plants*, Battelle Pacific Northwest Laboratories, BNWL-1976 (March 1976).
12. P. A. Ard et al., *Costs and Cost Algorithms for Dry Cooling Tower Systems*, Battelle Pacific Northwest Laboratories, BNWL-2123 (September 1976).
13. L. E. Wiles et al., *A Description and Cost Analysis of a Deluge Dry/Wet Cooling System*, Pacific Northwest Laboratory, PNL-2498 (June 1978).
14. A. B. Johnson, Jr., et al., *A Survey of Materials and Corrosion Performance in Dry Cooling Applications*, Battelle Pacific Northwest Laboratories, BNWL-1958 (March 1976).
15. W. V. Loscutoff, *Preliminary Evaluation of Wet/Dry Cooling Concepts for Power Plants*, Battelle Pacific Northwest Laboratories, BNWL-1969 (January 1976).
16. J. W. Currie and T. J. Foley, *Estimation of Benefits from Demonstrating Advanced Wet/Dry Cooling Technology: A Framework and Partial Analysis*, Battelle Pacific Northwest Laboratories, BNWL-2182 (September 1977).
17. F. R. Zaloudek et al., *A Study of the Comparative Costs of Five Wet/Dry Cooling Tower Concepts*, Battelle Pacific Northwest Laboratories, BNWL-2122 (September 1976).
18. J. A. MacFarlane et al., *Combustion* 48(8), 6-12 (February 1975).
19. H. S. Pines et al., *Floating Dry Cooling, A Competitive Alternative to Evaporative Cooling in a Binary Cycle Geothermal Power Plant*, Lawrence Berkeley Laboratory, LBL-7087 (July 1978).

3. RESOURCES PROFILES AND WATER AVAILABILITY SITUATION

Alf D. Shepherd*
Michael W. Mayfield*

3.1 Introduction

This section contains resources profiles of 25 hot-water-dominated geothermal resource areas chosen for study in this report. The geothermal areas included are those having a source temperature greater than 150°C (300°F) and an estimated electric generating potential greater than 100 MW(e) for 30 years.¹ The 25 areas studied are located in California, New Mexico, Oregon, Idaho, Utah, Nevada, Hawaii, and Alaska.[†] Table 3.1 lists these geothermal areas in order of potential generating capacity. The locations of the areas studied and also the locations of the major high-temperature/vapor-dominated systems and other lower-temperature/liquid-dominated resource areas not discussed in this report appear in Fig. 1.1. Figure 3.1 is included here to illustrate the general distribution of potential geothermal resources in the western portion of the United States.

The resources profiles in Sects. 3.3-3.22 briefly discuss the site-specific characteristics that were summarized in Table 1.1 and describe the local availability of a supplementary water source if one is needed for development. The resources characteristics include estimates of the source temperature, chemical properties of the geofluid, and the potential electric generating capacity. Comments are also made regarding ownership of the resource area and any development that has occurred to date or is planned. This type of information can rapidly become out of date, however, and, in some cases, is not readily available.

* Alf D. Shepherd contributed the regional water analysis, and Michael W. Mayfield compiled the geothermal resource profiles.

[†] Despite being bordered on three sides by states having high-temperature resource areas with potentials of greater than 100 MW(e), Geological Survey Circular 790 ascribes no sites of comparable potential to Arizona. A similar comment can be made regarding the state of Washington, which has no significant electric-generating potential listed, yet contains Mount St. Helens and the Cascade Range.

Table 3.1. Ranking of hydrothermal resource areas with source temperatures $>150^{\circ}\text{C}$ and electric generating potential $>100 \text{ MW(e)}$ for 30 years [by MW(e) capacity]

No.	Resource area	State	Mean reservoir temperature ($^{\circ}\text{C}$)	Electric generating potential for 30 years [MW(e)]
1	Salton Sea Area (Imperial Valley)	California	323 ± 8	3400
2	Valley Caldera	New Mexico	273 ± 8	2700
3	Long Valley Caldera	California	227 ± 10	2100
4	Westmorland (Imperial Valley)	California	217 ± 7	1710
5	Surprise Valley	California	152 ± 12	1490
6	Roosevelt Hot Springs	Utah	265 ± 8	970
7	Clear Lake Volcano	California	190 ± 9	900
8	Vale Hot Springs	Oregon	157 ± 2	870
9	Desert Peak Area	Nevada	221 ± 5	750
10	Newberry Caldera	Oregon	230 ± 20	740
11	Coso Area	California	220 ± 11	650
12	Heber (Imperial Valley)	California	175 ± 5	650
13	Brawley (Imperial Valley)	California	253 ± 10	640
14	Stillwater Area	Nevada	159 ± 8	450
15	East Mesa (Imperial Valley)	California	182 ± 7	360
16	Steamboat Springs	Nevada	200 ± 5	350
17	Crane Creek-Cove Creek	Idaho	171 ± 10	340
18	Cove Fort-Sulphurdale	Utah	167 ± 6	330
19	Kamaili Homesteads	Hawaii	273 ± 12	210
20	Mickey Hot Springs	Oregon	205 ± 10	160
21	Brady Hot Springs	Nevada	155 ± 6	157
22	Soda Lake Area	Nevada	157 ± 5	146
23	Geyser Bight	Alaska	208 ± 20	136
24	Beowawe Hot Springs	Nevada	229 ± 8	127
25	Morgan Springs-Growler Springs	California	217 ± 15	116
				20,452

Data Source: L. J. P. Muffler (ed.), *Assessment of Geothermal Resources of the United States - 1978*, Geological Survey Circular 790 (1979).

Fig. 3.1. General distribution of potential geothermal resources in the western portion of the United States.

The estimates of resource temperature and electrical potential were obtained from Geological Survey Circular 790,¹ which contains assessments of the geothermal resources in the United States. The estimates of reservoir temperature are based on chemical evaluation of minerals and elements dissolved in the geothermal fluid. These minerals, known as geothermometers, have temperature-dependent concentration ratios, so it is assumed that the concentration of that substance in a sample of

geothermal fluid is indicative of the temperature of the geothermal fluid at depth. This method assumes that

1. temperature-dependent reactions at depth control the concentration of the constituents used in the geothermometer;
2. the reservoir contains an adequate supply of the reactants;
3. water-rock equilibrium is established in the reservoir;
4. the constituents used in the geothermometer do not reequilibrate with the confining rock as the water flows to the surface; and
5. mixing of thermal and nonthermal groundwater does not occur.

The electrical generating potentials reported in Circular 790 are based upon estimates of subsurface area, ratio of recoverable energy, and the efficiency of conversion for each of the resource areas.¹ There is considerable uncertainty about each of these values. Further, insufficient information is available regarding the degree to which shallow, freshwater aquifers may be affected by removal of geofluids, nor have allowances been made for technical and economic obstacles, such as corrosion, scaling, and hydrogen sulfide control. It must be realized that until extensive drilling and testing of the individual geothermal reservoirs have been completed, the estimated potentials are largely unsubstantiated and serve only as guidelines. As an indication of the uncertainty in the published values, it may be noted that the estimated potential of several of the resource areas changed dramatically (up to an order of magnitude) from the 1975 estimates (ref. 2) to those listed in 1978 (ref. 1).^{*} As more drilling and testing continues, the published estimates will undoubtedly be revised further.

3.2 Water Availability Overview

3.2.1 Uncertainty in water needs for geothermal development

In most cases, it is still premature to judge whether or not an outside source of makeup water will actually be needed for development

^{*} See Sect. 2.5 regarding the methods used to arrive at the estimated potentials listed in Circular 790.

at a particular site. As discussed in Sect. 2, this determination will depend on the temperature of the resource, the type of power cycle employed, the amount of reinjection required, and the local climate.

Reinjection is a major issue because whenever large volumes of groundwater or other fluids are pumped out of the ground, there is the possibility of land subsidence at the surface due to compaction, fracture closing, and thermal contraction. Large-scale subsidence has been caused by oil pumping as well as groundwater pumping in the western United States, and by geothermal fluid removal in New Zealand.^{3,4} For example, geothermal operations at Wairakei, New Zealand, have caused subsidence of up to 4.5 m (15 ft). Concern for subsidence has resulted in Imperial County, California, requiring geothermal operators to reinject a volume of water equal to that removed from the geothermal aquifer.^{5*} Subsidence in the Imperial Valley could cause serious damage to the gravity-controlled irrigation systems of the area. In nonagricultural areas or areas with sprinkle irrigation systems, however, subsidence might not be a problem unless it were severe. In some locations it is possible that withdrawal of geothermal fluids will significantly affect the characteristics and useful life of the geothermal reserve as well as the quantity and quality of groundwater. For this reason it may be necessary not only to require reinjection but to regulate the locations and depth of reinjection wells and the quantities and chemical composition of the reinjected water.

At this time, only Imperial County, California, has a 100% reinjection requirement, and, at this early stage of geothermal development, there is no definite indication that other governmental units will promulgate similar legislation.* If other localities were to require 100% reinjection, water requirements for geothermal development will be great in those areas (see Table 2.1). As indicated in Table 1.1, few of the other geothermal resource areas have a ready supply of unappropriated water available, so water supply could be a limiting factor in such places.

* An exception has been made at Brawley, where 80% reinjection has been allowed (see Sect. 3.3.4).

3.2.2 Difficulties in quantifying water availability

The dependable amount of water available to supply a geothermal electric station in most areas in the western portion of the United States is difficult to determine and may greatly depend on the competing local and regional water demands. If a supplementary water supply for cooling or reinjection will be required for development at a particular site, access to a sufficiently reliable water source will be important to avoid costly shutdowns caused by seasonal water shortages. The suitability of a water source depends upon the quantity of water available, its quality, the variability of the supply over time, the manner in which the water is appropriated, and the environmental, social, and economic implications of its development.⁶ Water availability is, therefore, a locationally specific problem dependent on both its physical characteristics and the competition for its use. Similarly, the magnitude of impact on other users depends upon their ability to compete for water supplies, their ability to conserve water without reducing production, and the ease with which the total water supply can be increased.⁷ Thus, the major water availability issue is the competition for water among users. These conflicts will ultimately be resolved through litigation, economic bidding, or political accommodation, but it is unclear how geothermal energy development, in particular, might fare in different areas, or alternatively what the impacts might be on other water users.

3.2.3 Regional water supply and demand by assessment subareas

This section presents an evaluation of regional water supplies and projected water demands in the nine Water Resources Council's (WRC) Assessment Subareas (ASAs) containing the 25 geothermal resources areas selected for study in this report (Fig. 3.2). As defined by WRC, ASAs are approximations of main-stem segments of major rivers, tributary basins, or combinations of several smaller drainage basins. The 48 contiguous states are divided into 99 ASAs. Projected water use by the major nonenergy water use sectors (e.g., agriculture, manufacturing, domestic, commercial, mining, etc.) were prepared by the Council's member agencies for WRC's Second National Water Assessment.⁸ As illustrated in Fig. 3.2, ASAs are quite large, and ASA-level data do not provide

GEOTHERMAL SITE LOCATIONS WITHIN ASSESSMENT SUBAREAS

Fig. 3.2. U.S. Water Resources Council's Assessment Subareas in the western United States and the locations of the major liquid-dominated geothermal resource areas having the greatest electric generating potential.

sufficient detail for site-specific water analysis. Unfortunately, ASA data are the only projections of water use by all major competing use sectors presently available. Therefore, a comprehensive analysis considering projected water use by all major uses is presently restricted to this rather broad level of spatial resolution. It is still instructive, however, to examine the regional perspective of water supply and demand.

The projected water demands for the energy sector (exclusive of geothermal development) and the critical-month water supply/demand analysis model adapted here were originally prepared for recent DOE-sponsored regional studies of the water quantity impacts of alternative national energy policies by Oak Ridge National Laboratory (ORNL).⁹ The analysis of projected water resources impacts focuses on the seasonal period in each ASA when the total water demand utilizes the greatest proportion of the estimated Critical Surface Supply (CSS). The CSS estimates for each ASA are based upon monthly 95% exceedance stream flows (i.e., a statistic meaning the flow having a 95% chance of being exceeded as a mean for each month), which were then adjusted for the 1975 level of upstream surface-water depletion by all uses.

The amount of existing surface storage capacity and water imports used to support consumptive uses is indirectly represented in the adjusted CSS values. Also, the estimated contribution by groundwater sources to total ASA water supply was examined and a determination made regarding the feasibility of increased groundwater withdrawals. The monthly ASA water supply estimates and projected water consumption were then entered into an automated downstream accounting model to compute the percentage of the CSS consumed in each ASA.¹⁰ The data presented in Table 3.2 for the nine ASAs containing major geothermal areas for electric generation are based on results from a nationwide assessment of the water quantity impacts of the National Energy Plan scenario.⁹ These and other data produced by ORNL were provided to Hanford Engineering Development Laboratory, who utilized them in their *Review of Water Resource Potential for Developing Geothermal Resource Sites in the Western United States*.¹¹ The interested reader is urged to refer to the original ORNL documentation for a more through discussion of methods and limitations.⁶⁻¹⁰

Table 3.2. Regional Water Supply and Demand

Geothermal resource areas			Annual average freshwater consumption by all uses for a normal year ^a in 10 ⁶ m ³ /year (10 ³ acre-ft/year) [10 ⁶ gal/d]			Critical month surface water supply/demand analysis for a dry year ^b									
						Critical water supply month	Critical surface supply in 10 ³ m ³ /d (acre-ft/d) [10 ⁶ gal/d]	Critical month 95% exceedance stream flow in 10 ³ m ³ /d (acre-ft/d) [10 ⁶ gal/d]	Percentage of 1975 freshwater consumption from surface-water sources ^c	Critical month freshwater consumption by all uses in 10 ³ m ³ /d (acre-ft/d) [10 ⁶ gal/d]			Cumulative surface-water consumption by all uses as a percentage of the critical surface supply		
										1975	1985	1990			
Name	State	WRC Assessment Subarea No. (ASA)	1975	1985	2000					1975	1985	1990	1975	1985	1990
Salton Sea	CA	1806	8,133.9	7,333.9	7,302.2	10	11,208	19	75%	14,935	12,720	12,792	100.0%	80.2%	80.9%
Westmorland	CA		(6,594.2)	(5,945.7)	(5,920)		(3,316.5)	(5.6)		(12,112.7)	(10,316.1)	(103,741)			
Heber	CA		[5,887]	[5,308]	[5,285]		[2,960.8]	[5]		[3,945.5]	[3,360.3]	[3,379.2]			
Brawley	CA														
East Mesa	CA														
Long Valley	CA	1807	453.2	443.5	468.4	10	1429	1374	19%	291	307	309	3.9%	4.1%	4.1%
Coso Hot Springs	CA		(367.4)	(359.6)	379.7		(423.0)	(406.6)		(236.40)	(248.7)	(250.8)			
			[328]	[321]	[339]		[377.6]	[363]		[77.0]	[81.0]	[81.7]			
Surprise Valley	CA	1802	7,458.3	8,216.8	8,571.9	9	35,612	15,634	74%	26,953	27,688	28,050	56.0%	58.0%	59.0%
Clear Lake	CA		(6,046.5)	(6,661.5)	(6,949.4)		(10,538.0)	(4,626.2)		(21,859.3)	(22,454.9)	(22,733.0)			
Morgan Springs/Growler	CA		[5,398]	[5,947]	[6,204]		[9,407.7]	[4130]		[7,120.3]	[7,314.3]	[7,404.9]			
Valles Caldera	NM	1302	1,722.9	1,847.3	1,825.2	10	2537	72	75%	3,212	3,028	2,858	96.2%	89.2%	82.5%
			(1,396.8)	(1,497.6)	(1,479.7)		(2,057.8)	(21.3)		(2,604.9)	(2,455.7)	(2,317.9)			
			[1,247]	[1,337]	[1,321]		[670.3]	[19]		[848.5]	[799.9]	[755.0]			
Roosevelt Hot Springs	UT	1602	827.6	748.9	762.7	7	14,616	7230	98%	7,537	6,617	6,741	50.5%	44.4%	45.2%
Cove Ft./Sulphurdale	UT		(671.0)	(607.1)	(618.3)		(4,325.1)	(2,139.5)		(6,112.4)	(5,366.4)	(5,466.7)			
			[599]	[542]	[552]		[3,861.2]	[1,910]		[1,991.0]	[1,748.0]	[1,780.7]			
Newberry Caldera	OR	1702	5558.4	6,648.6	7,049.3	9	301,720	248,323	98%	22,651	28,146	28,104	17.7%	22.1%	22.2%
Mickey Hot Springs	OR		(4,506.3)	(5,390.1)	(5,715.0)		(88,161.9)	(73,481.4)		(6,112.4)	(5,366.4)	(22,792.3)			
			[4,023]	[4,812]	[5,102]		[79,705.9]	[65,600]		[5,938.8]	[7,435.3]	[7,424.2]			
Desert Peak	NV	1604	1,171.7	1,153.7	1,253.2	8	7114	114	99%	7,067	7,084	7,216	98.3%	98.6%	100.4%
Stillwater/Soda Lake	NV		(949.9)	(935.3)	(1,016.0)		(2,105.1)	(33.6)		(5,731.1)	(5,745.5)	(5,852.0)			
Steamboat Springs	NV		[848]	[835]	[907]		[1,879.3]	[30]		[1,866.8]	[1,871.5]	[1,906.2]			
Brady Hot Springs	NV														
Beowawe	NV	1603	1,488.1	1,691.2	1,832.1	7	16,384	2517	98%	14,150	15,921	16,098	84.6%	95.2%	96.3%
			(1,206.4)	(1,371.1)	(1,485.3)		4,848.2	(7,449) ^d		(11,475.7)	(12,912.4)	(13,055.8)			
			[1,077]	[1,224]	[1,326]		[4,328.2]	[665]		[3,738.0]	[4,206.0]	[4,252.7]			
Vale Hot Springs	OR		7,085.2	8,100.8	7,915.6		44,146	19,684		24,961	29,746	29,157			
Crane Creek	ID	1703	(5,744.1)	(6,567.4)	(6,417.3)	9	13,063.2	(5,824.7)	98%	(20,243.6)	(24,124.1)	(23,645.4)	55.4%	66.0%	64.7%
			[5,128]	[5,863]	[5,729]		[11,662.1]	[5,200]		[6,594.0]	[7,858.0]	[7,702.1]			

^aThe Nation's Water Resources 1975-2000, The Second National Water Assessment by the U.S. Water Resources Council, Washington, D.C., December 1978.

^bWater Availability for Energy in 1985 and 1990, J. F. Dobson, and A. D. Shepherd, ORNL/TM-6777, Oak Ridge National Laboratory, October 1979.

^cEstimated percentages by WRC. Groundwater consumption held constant at 1975 level.

^dMonthly 95% exceedance level streamflows sometimes go to zero.

The results of the ASA supply/demand analysis (Table 3.2) indicate that, without geothermal development, potentially severe water shortage problems exist in ASA 1806 (Southern California) containing the Imperial Valley geothermal resources area; ASA 1302 (Middle Rio Grande) containing Valles Caldera; ASA 1604 (Central Lahontan) containing Desert Peak, Stillwater/Soda Lake, Steamboat Springs, and Brady Hot Springs; and ASA 1603 (Humbolt-Tonopah Desert) containing Beowawe. In these areas, the logical, immediate impression is that the percentage of water consumption by all uses (without geothermal development) is so high that it would seem unlikely that any freshwater sources are available without significant transfer from existing users. Further examination, however, adds additional insights regarding the differences among these areas. Table 3.3 presents a comparison of geothermal power station water requirements by ASA, and their effects on regional water supply and demand. A brief discussion of the situation in each ASA follows:

ASA 1806 (Southern California). Development of the total geothermal electric generating potential in Southern California would require a water supply in the range of 908×10^3 to 1816×10^3 m³/d (240 to 480×10^6 gal/d) representing a rather significant 8 to 16% of the area's total CSS. As indicated by the large difference between the CSS and the critical month's 95% exceedance stream flow ($11,208 \times 10^3$ vs 19×10^3 m³/d, or 2961×10^6 gal/d vs 5×10^6 gal/d, respectively), almost all the surface water used during the critical supply month (October) must come from storage or imports, while 25% of the total water use was supplied from groundwater. (Note: the CSS estimate, as used here, assumes water imports remain constant at their 1975 level, so future import reductions, after completion of the Central Arizona project, would worsen the problem.) The water required for geothermal power development would represent 7 to 14% of total projected water consumption for 1990 by all users in the Southern California ASA. This can be interpreted as the percentage of the total use that would need to be retired if all the water were obtained by direct transfer from existing users. If all the water were obtained by direct transfers of appropriations from irrigation, it would require between 12 to 24% of the projected monthly irrigation water consumption.⁶ (Note: some increased irrigation efficiencies are already factored into

Table 3.3. Comparison of geothermal power station water requirements by ASA to critical month water analysis^a

Geothermal resource areas		WRC Assessment Subarea No. (ASA)	Range of annual average water use rates for geothermal power stations totaled by ASA	Percentage of critical surface supply represented by geothermal station water consumption	Percentage of critical month 95% exceedance streamflow represented by geothermal station water consumption	Water use by geothermal stations as a percentage of consumption by all uses (noncumulative) 1990	Additive effect of geothermal water use on the cumulative surface water consumption by all uses as a percentage of the critical surface supply 1990
Name	State		in $10^3 \text{ m}^3/\text{d}$ (acre-ft/d) [10^6 gal/d]				
Salton Sea	CA	1806	908–1,816 (737–1,473) [240–480]	8.1–16.2%	>100%	7.1–14.2%	93.7–101.8%
Westmorland	CA						
Heber	CA						
Brawley	CA						
East Mesa	CA						
Long Valley	CA	1807	371–742 (301–601) [98–196]	26.0–51.9%	27.0–54.0%	120.0–239.9%	47.6–73.5%
Coso Hot Springs	CA						
Surprise Valley	CA	1802	337–674 (273–546) [89–178]	0.9–1.9%	2.2–4.3%	1.2–2.0%	59.2–60.1%
Clear Lake	CA						
Morgan Springs/Growler	CA						
Valles Caldera	NM	1302	367–734 (298–595) [97–194]	14.5–28.9%	>100%	12.8–25.7%	98.9–113.4%
Roosevelt Hot Springs	UT	1602	174–348 (141–282) [46–92]	1.2–2.4%	2.4–4.8%	2.6–5.2%	46.4–47.6%
Cove Ft./Sulphurdale	UT						
Newberry Caldera	OR	1702	117–235 (97–195) [31–62]	<0.1–0.1%	<0.1–0.1%	0.4–0.8%	22.4–22.5% ^b
Mickey Hot Springs	OR						
Desert Peak	NV	1604	227–454 (184–368) [60–120]	3.2–6.4%	>100%	3.1–6.3%	103.6–106.8%
Stillwater/Soda Lake	NV						
Steamboat Springs	NV						
Brady Hot Springs	NV						
Beowawe	NV	1603	16–33 (13–26) [4–9]	0.1–0.2%	0.6–1.4%	0.1–0.2%	96.4–96.5%
Vale Hot Springs	OR	1703	197–394 (157–314) [52–104]	0.4–0.9%	1.0–2.0%	0.7–1.4%	66.5–66.9%
Crane Creek	ID						

^a Calculated by Oak Ridge National Laboratory.^b Includes upstream development.

WRC's irrigation water use projections.⁸⁾ As will be discussed later (Sect. 3.3), such a massive transfer is not feasible in the nation's most productive agricultural area. The additive effect of geothermal water use, if it were simply added to present projections of cumulative surface-water consumption by all users as a percentage of the CSS (Table 3.3), would in this case clearly exacerbate already critical conditions.

ASA 1807 (Lahontan-South). At the ASA level, no apparent surface-water consumption problems are indicated by the very low percentage of cumulative surface-water consumption (about 4% on Table 3.2). This is an area of extreme environments, however, stretching from the Sierra Nevada Mountains across Death Valley. Most of the small amount of existing consumption is used on public lands or for domestic use,⁶ and over 80% of total water use is supplied from groundwater.

The water requirements for full development of the electric generating potential at the Mono-Long Valley and Coso Hot Springs geothermal areas alone would consume from 26 to 52% of the CSS and would represent well over a 100% increase in total water consumption by all users. The additive effects on total cumulative use would represent between 48 and 74% of the CSS. Hence, from the perspective of the area's physical supply and competing uses, surface-water availability would seem stressed, but sufficient. However, what the data do not show is that in reality most of the water of sufficient quality (e.g., the runoff from the Sierra Nevadas) is already controlled by the city of Los Angeles.

Table 3.2 indicates that only 19% of the water used within ASA 1807 comes from surface-water sources. By implication, then, over 80% of the existing consumption within the area is supplied from groundwater. The present rate of pumping is generally depleting the groundwater faster than natural recharge, and for this reason the amount of groundwater's contribution to total water consumption by all users was held constant at the 1975 level in the water supply/demand analysis. Large amounts of geologic groundwater are estimated to be in storage, however, so the question of groundwater mining is an issue of possible concern, if a supplementary water source is required and if lower quality saline water cannot be used for geothermal power plants.

ASA 1802 (Sacramento-Lahontan). No apparently serious surface-water consumption problems are indicated by the estimated rates of water use required for development of the three geothermal areas in ASA 1802 (Table 3.3), which illustrates one of the limitations of aggregate ASA data. The data implicitly assume equal accessibility throughout the analysis area, ignoring any disparity between water supply and demand within the ASA. The individual water availability situations at each geothermal area located within this ASA vary significantly and are discussed in more detail in the resources profiles following this section (Sects. 3.5, 3.6, and 3.8).

ASA 1302 (Middle Rio Grande). Water supplies in central New Mexico are indeed limited and almost totally utilized. Geothermal power station demands at Valles Caldera would present about 14 to 29% of the CSS, equaling 13 to 30% of consumption by all users, while the additive effects would drive the cumulative consumption over 100% (Table 3.3). It is clear that if a supplementary water source were required, geothermal development would probably be restricted.

ASA 1602 (Sevier Lake). The variability of the water availability situation within the ASA is again illustrated in ASA 1602 by the relatively different situations between Roosevelt Hot Spring and the Cove Fort/Sulphurdale area (Sects. 3.10 and 3.11). From the ASA-level analysis, however, no particular water supply/demand problem is indicated, except that the overall volume of water available is not substantial.

ASA 1702 (Upper/Middle Columbia). No regional water availability problems are apparent at the Oregon geothermal sites.

ASA 1604 (Central Lahontan). The ASA data illustrate the problematic water availability situation at the four Nevada geothermal areas contained in this area. Existing, good-quality water sources are all totally in use. However, the percentage that geothermal stations would require of the total consumption by all uses (3.1 to 6.3% on Table 3.3) is within what might be considered a negotiable margin. That is to say, if an outside water source is required for development at any of these geothermal sites, the fate of that development will probably depend greatly on obtaining water rights.

ASA 1603 (Humboldt-Tonopah Desert). Although this area is apparently very similar in its data characteristics to the other Nevada sites in ASA 1604, obtaining supplementary water at Beowawe may be considerably more difficult. This is because the critical month analysis does not indicate the fact that monthly streamflow discharges often go to zero for the entire ASA, leaving mainly storage capacity to support ongoing consumption for these months.^{6,8} These zero-flow months were not identified as the critical months, because the proportional consumption of the CSS is actually lower.

ASA 1703 (Upper/Central Snake). Regional water supplies are so great, and geothermal requirements so comparatively small, that no regional water availability problems are apparent at the ASA-level. ASA 1703 combines the upper and central Snake River drainage and contains both the Vale Hot Springs and the Crane Creek-Cove Creek geothermal resource areas. This ASA as a whole has an extensive amount of irrigation,⁶ which is exemplified at Vale Hot Springs, Oregon, in the Malheur River basin (tributary to the Snake River). Obtaining agricultural water rights and/or maintaining water supply quality (because of irrigation return flows) are typical problems which might be anticipated in this area. Again demonstrating the variability in circumstances within an ASA, the situation in the Crane Creek-Cove Creek geothermal area, just across the Idaho state border, does not present these same typical problems because of the smaller degree of upstream diversions for irrigation on the Weiser River (also a tributary of the Snake River).

3.3 Imperial Valley of Southern California

The Salton Sea, Westmorland, Heber, Brawley, and East Mesa geothermal resource areas in the Imperial Valley (Fig. 3.3) are introduced here as one group because the water resources available and the legal and institutional barriers to use of the resources are much the same throughout the valley. Special problems or considerations unique to a single resource area are covered separately following the general discussion (Sects. 3.3.1-3.3.5).

Fig. 3.3. Geothermal resource areas in the Imperial Valley of California. (Note: to convert acres to hectares, multiply by 0.405.)

The Imperial Valley of California contains about 182,100 ha (450,000 acres) of irrigated farmland, making it the largest block of contiguous irrigated land in the United States.¹² Agriculture dominates the land use and economy of the Imperial Valley, and the protection and preservation of the agricultural lands of the county are of primary concern to the local government. The Geothermal Element of the Imperial County General Plan has stated that "any energy development must be consistent with agriculture" and that "geothermal resources, while potentially of considerable importance, will not be permitted to degrade the environment or threaten the continued viability of irrigated agriculture."⁵ Large-scale removal of geothermal fluids in the Imperial Valley could cause subsidence of the land surface, which could severely disrupt irrigation canals and field delivery systems. To reduce the likelihood of such subsidence, Imperial County requires that an amount of water equivalent to that removed be reinjected into the reservoir.* In this case, the entire amount of cooling tower evaporative and blow-down losses must be supplied by outside sources. The development of 4000 MW(e) of geothermally derived electrical power could require up to approximately $370 \times 10^6 \text{ m}^3/\text{year}$ (300,000 acre-ft/year).

About $3947 \times 10^6 \text{ m}^3/\text{year}$ (3.2×10^6 acre-ft/year) of water is delivered to the Imperial Valley from the Colorado River via the All-American Canal and is controlled by the Imperial Irrigation District (IID). The IID and Imperial County will "authorize the use of fresh water (from the canal system) for demonstration or experimental power plants to a maximum of 75 megawatts net electric in each economic anomaly for the initial five years of operation."⁵ Although it has been stated that continued use of canal water could be permitted at those 75-MW(e) demonstration plants beyond the initial five years of operation "if it is demonstrated by the operator(s) that it is not economically and environmentally feasible to use alternate sources of water," it is clear that Colorado River water is not a viable source of water for full-scale or long-term development of the geothermal resources in the Valley.⁵

* An exception was granted for the 10-MW(e) geothermal power plant at Brawley (see Sect. 3.3.4).

When the Central Arizona Project is completed, the IID's allocation of Colorado River water will be reduced by approximately $450 \times 10^6 \text{ m}^3$ (3.5×10^5 acre-ft). It is planned that this loss of imported water volume will be offset somewhat by increasing efficiencies of application in crop irrigation and by reducing seepage and evaporative losses from the canal delivery network. The net result of the decreased allotment will, however, result in increased competition for water in the Imperial Valley.¹³ Increased efficiencies of delivery and application of canal water also will reduce agricultural return flows in the New and Alamo rivers.¹⁴

The saline waters of the Salton Sea could easily provide all of the water needed for cooling tower makeup or reinjection for full-scale development of the entire Imperial Valley resource. However, the cost of a pipeline to deliver the water to Heber, Westmorland, or East Mesa would probably be prohibitive.¹⁵ The Salton Sea and Brawley KGRAs are located close enough to make use of this water although its low quality could add significantly to the cost. A further consideration is that if the cooling water at a geothermal station has a high total dissolved solids (TDS) concentration, salt drift from the cooling towers could damage nearby crops. It is possible that Salton Sea water could be used for reinjection, although the compatibility of the water with the geothermal reserves in an area is site-specific and needs additional study.

Groundwater is generally not available at the geothermal resource areas in the Imperial Valley, with the possible exception of East Mesa. The groundwater beneath East Mesa is primarily water that has seeped out of the unlined Coachella, All-American, and East Highline canals.¹⁶ If the canals are lined, this recharge to the aquifer will be eliminated. It is also not certain whether pumping of groundwater would cause a significant increase in the leakage rate from the canals.

Agricultural return flows are a possible source of water in the Imperial Valley. Wastewater flowing to the Salton Sea from the New and Alamo rivers totals approximately $1233 \times 10^6 \text{ m}^3/\text{year}$ (1×10^6 acre-ft/year), which is more than enough to supply the water needed for full development of the geothermal resources. Several problems exist with using this water, however. The agricultural runoff contains chemicals, bacteria, and algae that would require construction of a treatment plant. It is

possible that the water could be used for reinjection, although problems regarding the compatibility with the geothermal reserves and/or the effect on groundwater supplies need to be determined. Consumption of agricultural return flows would probably stabilize the presently increasing water level of the Salton Sea, which would tend to increase the salinity of the sea, and may not be environmentally acceptable. Constraints may be placed on diversions from the New and Alamo rivers to protect in-stream uses. Also, flows are unevenly distributed in space and time and may not be sufficient on an annual basis unless storage facilities are provided to meet peak load demands. Also, return flows are likely to be reduced in the future because of improvements of irrigation efficiency. Despite these potential problems, however, agricultural return flows are probably the most promising source of water for geothermal development in the valley.

These aspects of water availability for geothermal development in the Imperial Valley have been more thoroughly discussed by Layton, who understandably concludes that "the extent to which geothermal resources of the Imperial Valley are developed . . . will depend a great deal on the availability of cooling water for power plants."^{14,16,17}

3.3.1 Salton Sea

The Salton Sea geothermal fluids have a median temperature of 323°C (613°F) and are estimated to have the potential to support 3400 MW(e) for 30 years.¹ However, the field has a concentration of dissolved solids of about 250,000 ppm,¹⁸ and development will depend a great deal on the success with which problems of scaling and corrosion of pipes and equipment can be met. An ongoing joint project by San Diego Gas and Electric Company and DOE is investigating these problems.¹⁹

The Salton Sea KGRA contains 38,779 ha (95,824 acres), of which 30,906 ha (76,370 acres) are owned by the State of California or by private owners. Southern California Edison plans to develop 650 MW(e) by 1995, if the problems of scaling and corrosion can be overcome.¹⁸ The DOE development scenario projects 50 MW(e) in 1983, 150 MW(e) by 1985, and 500 MW(e) by 1989.¹⁸

Water supply problems should be less severe in the Salton Sea KGRA than in other parts of the valley because (1) the high temperature of the geothermal fluid will provide higher efficiency and thus less cooling water demand per MW(e) of generation, (2) water from the adjacent Salton Sea could possibly be used either for reinjection, or in the cooling towers after suitable treatment, and (3) the Salton Sea KGRA is near the mouths of the New and Alamo rivers, where flows are greatest.

3.3.2 Westmorland

The Westmorland geothermal anomaly has the potential to produce an estimated 1710 MW(e) for 30 years and has a mean resource temperature of 217°C (423°F).¹ Dissolved solids content of the geothermal fluid is estimated to be 37,000 mg/L.¹⁷ The Westmorland anomaly has not been officially designated as a separate KGRA. Westmorland Geothermal Associates has acquired a DOE-guaranteed loan for the drilling of 19 geothermal wells, which are expected to supply the fluid for a 55-MW(e) double-flash system.^{13,19}

Water supply options for development at Westmorland include agricultural return flows from the New River, Salton Sea water, canal water [for the first 75 MW(e)], and treated wastewater from local facilities.¹³ The Westmorland anomaly is approximately 5 km (3.1 miles) from the New River. By the time that it has reached this location, the New River has acquired most of the agricultural return flows, so flows are well-sustained and the wastewater pollution that is a problem farther south (e.g., at Heber) has been substantially diluted. Water from the New River is, therefore, a possible source of water for development at Westmorland provided that the necessary permits can be obtained (Sect. 3.3.3).

Salton Sea water is a less-desirable option because the greater distance that it would have to be pumped would greatly increase costs, and the higher salinity would increase the expense of any required purification.¹⁵

3.3.3 Heber

The U.S. Geological Survey has reported a median temperature of 175°C (347°F) for the Heber geothermal fluids and estimated the potential

of the field to be 650 MW(e) for 30 years.¹ Salinity of the field is moderately low for this area, at 14,000 ppm.²⁰

The Heber KGRA consists of 23,677 ha (58,508 acres) of land, all of which are state and privately owned.¹⁸ Currently, the San Diego Gas and Electric Company, and Chevron Oil have facilities in this KGRA. Both plan to withdraw water from the New River to supply the heat dissipation systems.⁹ The California Department of Fish and Game (DFG) issued a protest to the granting of this permit because the environmental impact statement for the project predicted that this withdrawal would cause salinity in the Salton Sea to reach toxic levels for game fish two years earlier than would otherwise occur. The DFG has since withdrawn its protest and the use of the water has been approved, but DFG may choose to protest future applications for withdrawal of water from the New and Alamo rivers for similar reasons.²¹

Other problems could also impede use of water from the New River. Its water quality is relatively poor because of the large concentration of sewage and other urban effluents from Mexicali, Mexico. Therefore, extensive treatment of the water will be required. Additionally, because only a small amount of irrigated land is drained by this upper stretch of the New River, flows may not be sufficient to supply cooling needs during periods of low flow. Water storage facilities could thus be required. The use of Salton Sea water for reinjection at Heber has been considered but was rejected because of excessive construction and operating costs for a pipeline.¹⁵

3.3.4 Brawley

The estimated mean resource temperature of the Brawley geothermal reservoir is 253°C (487°F), and the estimated electrical potential is 640 MW(e) for 30 years.¹ The dissolved solids content is not nearly as great as that of the Salton Sea KGRA, but at approximately 100,000 ppm is still high in comparison to most developed geothermal areas.¹⁸ The Brawley KGRA consists of 11,690 ha (28,885 acres) of land, none of which is federally owned.¹⁸

Southern California Edison has built a 10-MW(e) flash-steam plant at Brawley, with steam supplied by Union Oil Company. Southern California

Edison and Union plan to install up to 460 MW(e) of capacity at the site eventually.¹⁹ The DOE geothermal development scenario envisions 500 MWe capacity by 1990.¹⁸

Water availability at the Brawley field is generally good. Both the New and Alamo rivers pass through the KGRA and have accumulated enough agricultural return flows to provide significant year-round supply, unlike the upstream stretches near the Mexican border. Water quality is also better than that which is available at the Heber site, due to dilution of the sewage-contaminated water that enters at the international border by irrigation return flows.²² Water from the New and Alamo rivers is the most likely source of reinjection water in the case of flashed-steam plants and for makeup water for any binary plants built at Brawley. The Salton Sea is approximately 16 km (10 miles) from the Brawley KGRA. It would be possible, although expensive, to pipe saline water from the Salton Sea to Brawley for reinjection, or possibly for cooling tower makeup after treatment.¹⁵

The 10-MW(e) Southern California Edison plant was granted permission to reinject only 80% of the produced geothermal fluid by the California Division of Oil and Gas, the Imperial County Planning Commission, and the Imperial County Board of Supervisors, "based on an analysis that only minor amounts of subsidence would take place."²³ Additional water supplies will not be needed for the Southern California Edison plant due to this allowance. Future additional power plants at Brawley are likely to attempt to get similar allowances. If 80% reinjection is sufficient to prevent subsidence at Brawley, it is possible that the County and the California Division of Oil and Gas will allow 80% reinjection at other Imperial Valley sites. This would greatly reduce the problems of water supply for development of flashed-steam geothermal plants in the Imperial Valley, because less than 20% of the produced fluid may be required for cooling tower makeup. Closed-cycle binary plants would not benefit from such an allowance.

3.3.5 East Mesa

The reported median temperature of the geothermal reservoir at East Mesa is 182°C (360°F). The estimated field capacity is 360 MW(e) for

30 years.¹ The salinity level of the East Mesa fluids is about 8000 ppm, which is the lowest value found in the major Imperial Valley fields.

The East Mesa KGRA consists of 15,526 ha (38,365 acres), of which about 87% is federally owned. Federal development of geothermal resources at East Mesa commenced in 1974 when the U.S. Bureau of Reclamation (now the Water and Power Resources Service) initiated the operation of a geothermal desalination plant. Currently, a project known as the Geothermal Test Facility for testing geothermal resources and components is operated by WESTEC Services, Inc., for DOE.

More than 4452 ha (11,000 acres) of federal land have been leased.¹⁸ Magma Power Company has installed an 11.2-MW(e) power plant that is expected to become operable in 1981. Republic Geothermal, Inc., also has a facility in East Mesa.²⁴ A 48-MW(e) flashed-steam facility, to be constructed by Republic, is among several commercial-scale projects that have been proposed for East Mesa.²⁵

The water resources available at East Mesa are essentially the same as for the rest of the Imperial Valley, with two exceptions: (1) There is a large amount of fresh water in storage beneath parts of East Mesa due to seepage from the Coachella, All-American, and East Highline canals, and (2) the East Mesa area is not as intensely irrigated for agriculture, and restrictions against ground-level subsidence may not be as severe.

It has been estimated that losses from the Coachella Canal alone are approximately $1.2 \times 10^8 \text{ m}^3$ (100,000 acre-ft) per year.¹⁶ Lining of the Coachella Canal is planned, which will eventually eliminate this source of groundwater recharge water. It is possible that pumping of this groundwater would increase the rate of canal leakage, which would constitute removal of previously appropriated water. It may be acceptable to Imperial County and the California Division of Oil and Gas to allow reinjection of only 80% of the removed fluids, so that steam condensate could be used for cooling tower makeup. This would help solve the water supply problems for development at East Mesa and would provide valuable information on the amount of induced subsidence that 80% reinjection would cause in this area.

3.4 Long Valley, California

The median temperature of the geothermal reservoir at the Long Valley Caldera is 230°C (446°F) and the resource is estimated to be capable of producing 2100 MW(e) of geothermal power for 30 years. The salinity level of the resource is from 1000 to 2000 ppm.²⁶ Thus the Long Valley geothermal resource is one of relatively high source temperature and good water quality.

Of the total of 184,236 ha (455,256 acres) in the KGRA, 158,676 ha (392,096 acres) are federally owned, and 25,560 ha (63,160 acres) are state and privately owned.¹⁸ Union Oil Company has drilled two deep wells on private land. The only current development planned in the Long Valley KGRA is a 32-MW(e) cogeneration facility proposed by California Edison for 1985.²² Development at Mono-Long Valley will probably be opposed by the California Fish and Game Department, Indian tribes, and environmental groups. Also, this area is a prime weekend tourism attraction for residents of Los Angeles.

The surface-water supply in the area, including the Owens River, Crawley Lake, and Mono Lake, would probably be sufficient for development of the geothermal resources but much of the surface water is under the control of the Los Angeles Department of Water and Power and is thus unavailable for use.²² The alluvial fills of the Mono-Long Valley region store great amounts of groundwater, but pumping is depleting the groundwater faster than it is being recharged. Future development of the groundwater resources will undoubtedly be limited.¹¹ The highly saline (60,000 ppm) Mono Lake is a potential source of water but the technology of using such highly saline waters is yet to be fully demonstrated and would result in further lowering of water levels, which could severely impact this unique ecological system.

Unless reinjection is required, flash-cycle geothermal plants in Mono-Long Valley should be able to supply their own makeup water with steam condensate. It would be very difficult to obtain sufficient water from other sources.

3.5 Surprise Valley, California

The Surprise Valley geothermal reservoir has a mean temperature of 152°C (306°F) and the capacity to produce approximately 1490 MW(e) of geothermal power for 30 years.¹ This KGRA contains 29,318 ha (72,446 acres), of which 13,699 ha (33,852 acres) are federally owned and 13,111 ha (32,399 acres) are state and privately owned. Of the federal land, 12,939 ha (31,972 acres) belong to the Bureau of Land Management and 761 ha (1880 acres) belong to the U.S. Forest Service.¹⁸ There are at present no known commitments for development of geothermal energy at Surprise Valley, although the DOE development scenario calls for 300 MW(e) by 1990.

The only surface water within or adjacent to the KGRA is found in three small, intermittently dry lakes. The quality of the water in the lakes is very poor, and the volume of water stored in the lakes would probably not be sufficient for cooling of a geothermal power plant. There are a number of small streams and a large freshwater lake (Goose Lake) within 32 km (20 miles) of the KGRA, but a high mountain range (Warner Mountain) separates them from the resource area. The cost of pumping water to the geothermal sites from these sources would probably be prohibitive.

It has been estimated that about $4.9 \times 10^9 \text{ m}^3$ (4×10^6 acre-ft) of groundwater exist in Surprise Valley, but it is not known how much of this is physically usable or legally appropriable.¹¹ The quality of the water is generally good but variable, with TDS values ranging from 166 to 200 ppm.¹¹

It is possible that 100% reinjection will be required in Surprise Valley because of its susceptibility to subsidence.¹¹ If so, the availability of cooling tower makeup water could be a limiting factor in developing the geothermal potential of Surprise Valley.

3.6 Clear Lake Volcano, California

The median temperature of the geothermal reservoir at Clear Lake Volcano is reported to be 190°C (374°F). The Geological Survey has estimated the potential of the field to be 900 MW(e) for 30 years, but

there are no known plans for commercial development at the Clear Lake Volcano area. All current development in the area is at the Geysers vapor-dominated field.

Although Clear Lake is adjacent to the geothermal field, withdrawal of water may not be allowed because of the lake's recreational and aesthetic values. The Clear Lake region has been reported to have the potential for limited additional groundwater development.²⁷ It is not likely that the amount of remaining developable groundwater would be sufficient for the cooling tower makeup needs of a geothermal power facility, however. If an outside source of water were needed because binary systems were used or because of reinjection requirements, the availability of water could constrain geothermal development at Clear Lake Volcano. The effects of the release of hydrogen sulfide and boron gases on the tourist and retirement home industry and on the vineyards in the area may be a concern also.

3.7 Coso Hot Springs, California

The Coso Hot Springs geothermal reservoir has a median temperature of 230°C (446°F) and the potential to produce 650 MW(e) of electrical power for 30 years.¹ The Coso Hot Springs KGRA contains 20,947 ha (51,760 acres), of which 17,535 ha (43,330 acres) are federal and 3411 hectares (8430 acres) belong to the state. Of the federal land, 6754 ha (16,690 acres) are owned by the Bureau of Land Management, while 10,781 ha (26,640 acres) belong to the U.S. Navy.¹⁸ The Navy has signed a contract with California Energy Company, Inc., to develop the Coso field. The electricity produced will be used by the Navy for operations at China Lake Naval Center and other naval bases in Southern California.²⁸

There are only intermittent streams in the Coso area. Haiwee Reservoir is accessible, but it is controlled by the Los Angeles Department of Water and Power, and water from it is not available.²² Data for groundwater are limited for this KGRA. The nearby Indian Wells Valley does have groundwater sufficient for cooling of geothermal power plants at the Coso area, although much of it is of somewhat poor quality (1000-4000 ppm TDS). It is not yet clear if the groundwater in the

Indian Wells Valley will be legally available. This groundwater is the only potential source of water in the Coso Hot Springs area.

3.8 Morgan Springs-Growler Springs, California

The median temperature of the geothermal reservoir at Morgan Springs is reported to be 230°C (446°F). The potential of the field is estimated to be 116 MW(e) for 30 years.¹ Morgan-Growler Springs is not designated as a KGRA.

There are many small streams in the vicinity of the geothermal area such as the North Fork of the Feather River, Mill Creek, and the South Fork of Battle Creek. Nearby lakes and reservoirs include Lake Almanor and Butt Valley Reservoir.

3.9 Valles Caldera, New Mexico

The hydrothermal convection system at Valles Caldera is estimated to have the potential to produce 2700 MW(e) for 30 years. In addition to this, the hot dry rock associated with the hydrothermal system has perhaps 100 times as much thermal energy as does the hot water reservoir. The water in the geothermal resource is reported to be high in chloride content, with a TDS value of 6000 ppm.¹

The Valles Caldera KGRA contains 68,295 ha (168,761 acres), of which approximately 12,140 ha (30,000 acres) are federally owned. About 36,420 ha (90,000 acres) of the KGRA are a part of the Baca Ranch, which is privately owned.²⁶

Union Oil Company has drilled a group of wells and conducted flow tests at Redondo Peak. A 50-MW(e) single-flash plant is planned (with joint funding by DOE and Union) but is being protested by Pueblo Indians, who hold the land in this area to be sacred. An environmental impact statement on the proposed plant has been released.²⁹

Los Alamos Scientific Laboratory is experimenting with hot dry rock heat extraction technologies at Fenton Hill, located on the western boundary of the Caldera. Current flow testing and thermal loop experiments may lead to commercial development.

The Rio Grande River is the principal source of surface water in the vicinity of the Valles Caldera KGRA. The river has an average

annual flow of approximately $863 \times 10^6 \text{ m}^3/\text{year}$ (700,000 acre-ft/year). The water has been appropriated for irrigation since the 1890s,¹⁹ but it may be possible to purchase water rights from individual appropriators.

The high-quality groundwater of this area has been highly developed, and it is unlikely that appropriations of large amounts for cooling tower makeup will be allowed. There are large quantities of brackish groundwater in the general vicinity of the Valles Caldera that are apparently available for appropriation, however.¹¹ To develop 2500 MW(e) at Valles Caldera would require from 125×10^6 to $250 \times 10^6 \text{ m}^3/\text{year}$ (100,000 to 200,000 acre-ft/year), based on a water requirement of 50 to 100 $\text{m}^3/\text{year} \cdot \text{kW(e)}$ [40 to 80 acre-ft/year·MW(e)]. The actual requirement may be closer to the lower value because of the relative high temperature of the geothermal fluids. To acquire water from the agricultural sector would require the retirement of 405 to 607 ha (1000 to 1500 acres) of irrigated land for each 100 MW of generating capacity, or a total of 10,000 to 15,000 ha (34,000 to 68,000 acres) of land with 2500 MW(e) of generating capacity, based on a crop requirement of $1.0 \text{ m}^3/\text{m}^2$ per year.

The high temperature and high quality of the geothermal fluid in the hydrothermal system at Valles Caldera indicate the potential for flashed-steam power cycles that would require no outside source of cooling tower makeup water unless reinjection is required. The bedrock of the Caldera is volcanic and not likely to be susceptible to subsidence caused by fluid removal unless tuffaceous sediments are present. The Caldera is believed to be in the final stages of collapse, so some sinking may occur which will not necessarily be caused by geothermal fluid withdrawal. The Environmental Impact Statement for the 50-MW(e) plant states that "induced subsidence of the land surface resulting from geothermal fluid production is not expected to be likely or measurable at the surface and may even be less significant than occurring naturally."²⁹ Thus, it will probably not be necessary to have 100% reinjection to control subsidence.

If the hot dry rock resource is developed, very large quantities of water will be required; water equal to the cooling tower makeup requirements and any loss to the bedrock through nonproductive fractures in the bedrock will be needed. This will probably amount to 125 to

190 m³/year·kW(e) [100 to 150 acre-ft/year·MW(e)] of generating capacity. This water will have to be obtained from the purchase of existing water rights or from undeveloped brackish groundwater supplies.

3.10 Roosevelt Hot Springs, Utah

The U.S. Geological Survey reports that the mean reservoir temperature of the Roosevelt field is 265°C (509°F) and that the reservoir is sufficiently large to produce 970 MW(e) for 30 years.¹ The salinity of the geothermal fluid averages about 7000 ppm.²⁶

The Roosevelt Hot Springs KGRA consists of 12,056 ha (29,791 acres), of which 9952 ha (24,592 acres) are federally owned and controlled by the Bureau of Land Management. The remainder is either state-owned or private. A number of wells have been completed and tested. Development of the resource has been retarded by the lack of a buyer for the power produced. Phillips Petroleum, the major developer in the area, has now negotiated a contract with Utah Power and Light Company for the construction of a 50-MW(e) flashed-steam plant. Electricity produced from the Roosevelt geothermal field has also been proposed as a potential source of power for the MX missile system.

Approximately 5.67×10^7 m³/year (46,000 acre-ft/year) of water are currently consumed by all sectors of use in Beaver County, Utah. Irrigation accounts for approximately 96% of the water use in the county. If the entire cooling needs for 900 MW(e) of generation potential at Roosevelt Hot Springs had to come from an outside source, between 44×10^6 and 8.8×10^6 m³/year (36,000 to 72,000 acre-ft/year) of water would be required. The lower figure represents over three-fourths of the water use of the entire county at the present time, and the higher figure is much higher than the present rate of consumption in the county.

There are only ephemeral streams in the vicinity of the Roosevelt KGRA. The Beaver River is not far from the field, but it is almost always dry because of upstream withdrawals for irrigation. Although there is a large aquifer in the unconsolidated materials of the valley fill in the Milford area, withdrawals of groundwater for irrigation and watering of livestock have exceeded the rate of recharge in recent

years. The level of water in wells in the area of Roosevelt Hot Springs dropped as much as 9 m (30 ft) from 1959 until 1972. The entire natural groundwater recharge of the 3004 km² (1160 sq miles) in the Milford area is estimated to be only about 33×10^6 m³/year (27,000 acre-ft/year).³⁰ It is to be noted that this is not likely to be sufficient to supply the makeup water needs of a 300-MW(e) geothermal power plant. It is thus unlikely that geothermal plants will be able to obtain their cooling water from groundwater supplies.

There is not a sufficient supply of surface- and/or groundwater in the area for large additional uses. Subsidence has already occurred in the Milford area because of mining of the shallow groundwater. Although this is not considered to be of great consequence, further subsidence could be caused by removing the geothermal fluids without reinjection.³⁰ The high temperature and relatively low salinity of the resource favor flashed-steam generating systems, which would use steam condensate for cooling.

3.11 Cove Fort-Sulphurdale, Utah

The mean reservoir temperature at the Cove Fort-Sulphurdale KGRA is 170°C (338°F). The geothermal reservoir is estimated to have the potential to produce 330 MW(e) for 30 years.¹ The KGRA consists of 9742 ha (24,074 acres) of land, 8522 ha (21,059 acres) of which are federally owned. Approximately 7690 ha (19,000 acres) have been leased for geothermal exploration and development.¹⁸

Cove Creek, a tributary to the Sevier River, is the only surface-water resource in the vicinity of the Cove Fort-Sulphurdale KGRA. Cove Creek drains an area of 425 km² (164 sq miles) and has an annual average discharge of 0.68 m³/s (24 cfs, or 17,375 acre-ft/year).¹¹ This quantity might be sufficient to supply the makeup needs of a geothermal power plant of 250-MW(e) capacity, but most of the water has already been appropriated. The Sevier River basin is the source of water for the Intermountain Power Project (see Sect. 1.3), which has contracted to purchase water rights at a cost of \$1.42/m³ (\$1750 per acre-ft).

The Cove Fort-Sulphurdale KGRA is in an area that has a large amount of groundwater in storage, but the water is being depleted at a

rapid rate by pumping, and no new permits are being granted for ground-water withdrawal.³¹ Water is thus not available in large quantities in the Cove Fort-Sulphurdale area, and geothermal development could be severely limited for this reason. The most likely source of water would be from the transfer of existing water rights.

Current water consumption by all sectors in Millard County, in which the Cove Fort-Sulphurdale KGRA is located, is approximately $194.9 \times 10^6 \text{ m}^3/\text{year}$ (158,000 acre-ft/year). Irrigation accounts for over 97% of the water consumed in the county. Therefore, a 100-MW(e) geothermal power station would require only 2 to 5% of the water currently used by all sectors in the county. Even if water had to be purchased and transferred from the agricultural sector, the impact on that sector would not be excessively large. However, this does not include the impact of other energy or ancillary development, nor does it consider the effect of agricultural retirements on the local or regional agribusiness infrastructure.

3.12 Vale Hot Springs, Oregon

The U.S. Geological Survey has reported that the average temperature of the geothermal resource at Vale Hot Springs KGRA is 160°C (320°F) and that the field has the potential to produce 870 MW(e) for 30 years.¹ The KGRA contains 9303 ha (22,988 acres) of land, of which at least 5666 ha (14,000 acres) have been leased for geothermal exploration and development. Union Oil Company, Republic Geothermal, Inc., and Geothermal Resources, International, all have leases in the area, but to date, development has been limited.¹⁸

The Malheur River, together with its several reservoirs, is the principal source of surface water in the vicinity of the Vale Hot Springs KGRA. The water in the river is already appropriated for agricultural uses but may be obtained through purchase or trade-offs with the users. Groundwater is abundant in the alluvial sand and gravel deposits of the Malheur Valley, and wells commonly yield 0.03 to 0.16 m^3/s (500 to 2500 gpm).¹¹

The relatively low temperature of the geothermal fluid may be one reason for lack of development of the Vale Hot Springs KGRA. Nonelectric

uses of the geothermal heat are being considered, such as residential heating and processing of sugar beets.¹⁸ The high-yield aquifers of the Malheur Valley show promise for supplying cooling tower makeup water for geothermal power plants, as does the Malheur River itself, but use of these water resources may require the purchase of water rights presently used in irrigation.

3.13 Newberry Caldera, Oregon

The median temperature of the geothermal reservoir at Newberry Caldera is 230°C (446°F). The heat in storage is believed to be sufficient to produce 740 MW(e) for 30 years.¹

The Newberry Caldera KGRA contains 12,660 ha (31,284 acres), most of which is presently owned by the U.S. Forest Service. The Forest Service has not allowed commercial exploration of this KGRA to date, but the U.S. Geological Survey plans to drill an exploratory well to a depth of 91 m (300 ft).³² If this project is successful, the Forest Service may allow commercial exploration in the area.

Paulina Lake, drained by Paulina Creek, and East Lake are in the center of the volcanic crater left by the collapse of Newberry Caldera. Newberry Caldera is in the area of the High Desert Groundwater Reservoir as defined in Geological Survey Professional Paper 813-S.³³ This area contains large amounts of groundwater in storage and is capable of producing moderate to very large yields.³³

3.14 Mickey Hot Springs, Oregon

The U.S. Geological Survey has reported the median temperature of Mickey Hot Springs to be 205°C (401°F) and has predicted that the resource is sufficient to produce 160 MW(e) for 30 years.¹ The Springs are located in the Alvord Desert, and surface water is not generally available. There are no perennial streams in the area, and the small lakes in the vicinity are only seasonally filled. The High Desert groundwater region has a large amount of groundwater in storage and produces moderate to very large well yields. The quality of the water, however, is generally low and may require pretreatment.³³

3.15 Desert Peak, Nevada

The potential geothermal power generation in the Desert Peak area is estimated to be 750 MW(e) for 30 years. The average temperature of the resource is 221°C (430°F).¹ Dissolved solids in the fluid average about 7500 ppm, including a high concentration of silica.³⁴

Phillips Petroleum Company has drilled approximately 50 temperature-gradient holes up to 152 m (500 ft) deep and at least three deep geothermal wells. Desert Peak is one of three sites being considered by a consortium of power companies for a 10-MW(e) demonstration plant, to be followed by a 50-MW(e) commercial plant.

The Humboldt River flows into Humboldt Lake and Toulon Lake in the vicinity of the geothermal field. The Truckee River and irrigation canal system are 16 to 24 km (10 to 15 miles) to the southwest. However, the water from these sources is totally appropriated for irrigation. The State of Nevada permits exchange of water rights, so it may be possible to buy water from the current appropriators.

Groundwater in the vicinity of Carson Sink is abundant and unappropriated but is of relatively poor quality, and TDS concentrations range up to 3000 ppm.³¹ Thus, regulations under the Safe Drinking Water Act may limit options for reinjection.

Because the demand for surface water in the region already exceeds the supply, it is unlikely that additional water for a geothermal power station could be obtained from current surface supplies.⁶ Current water consumption by all sectors in Churchill County, Nevada, is approximately 247×10^6 m³/year (200,000 acre-ft/year). The Desert Peak and Brady Hot Springs geothermal areas are both in this county. If an outside source of makeup water were needed, full development of both of these geothermal fields could require 44×10^6 to 88×10^6 m³/year (36,000 to 72,000 acre-ft/year) of water, representing 18 to 36% of the current water use in the county. In addition, the Stillwater and Soda Lake KGRAs are also in Churchill County, and development of their electrical potential could require another 30×10^6 to 60×10^6 m³/year (24,000 to 48,000 acre-ft/year) if reinjection or binary systems were required.

3.16 Stillwater Area and Soda Lake, Nevada

The most recent estimate of the U.S. Geological Survey shows an average temperature of 159°C (318°F) and a potential for 450 MW(e) of geothermal power generation for 30 years in the Stillwater Area.¹ The average concentration of dissolved solids in the geothermal fluid is 7000 ppm.³⁴ The Soda Lake area, which is part of the same KGRA, has a mean temperature of 157°C (315°F) and the potential for 146 MW(e) for 30 years.¹

The Stillwater-Soda Lake KGRA consists of 91,159 ha (225,260 acres) of land in Churchill County, Nevada. A number of geothermal wells have been drilled in the Stillwater area. Union Oil Company is currently active and has drilled three deep wells on private land. There are currently no known plans for construction of electrical generating plants in the Stillwater area. Some of the shallow wells there have been used in the past for space heating and bath houses. The Soda Lake field has been explored by both industry and government. The Geological Survey has drilled a series of temperature-gradient holes in the area and has produced a groundwater isotherm map of the area. A geothermal well has been drilled to a depth of about 1311 m (4300 ft) by Chevron and Phillips.³⁴

There are numerous small lakes and reservoirs in the area, many of which are a part of the Stillwater National Wildlife Refuge. Such water would presumably not be available for diversion and use. There are also a large number of irrigation canals diverting water from the Carson River. Whether this water could be obtained for use by a geothermal power plant by arrangements with the individual appropriators is conjectural. Groundwater in the area is abundant, due to the natural inflow to Carson Sink plus the accumulated agricultural effluents from irrigation. The salinity of the groundwater is relatively high, with TDS concentrations commonly greater than 3000 ppm.³¹ Nevertheless, this brackish groundwater may be the most available source of water for a geothermal power station.

3.17 Steamboat Springs, Nevada

The median temperature of the geothermal reservoir is reported to be 200°C (392°F), and the reservoir has an estimated potential of 350 MW(e) for 30 years.¹ The TDS concentrations of the geothermal fluids range from less than 1000 ppm to over 4000 ppm, with significant amounts of sodium, chlorine, and silica. Anomalous concentrations of arsenic, antimony, mercury, cesium, and boron are also found in the geothermal fluids at Steamboat Springs.³⁴

The Steamboat Springs KGRA consists of 3606 ha (8911 acres), of which approximately one-half is federally owned and the other half is owned by the state or by private interests.¹⁸ Over 100 shallow geothermal wells have been drilled in the Steamboat Springs area. Some of these have been drilled to produce hot water for domestic heating and commercial uses (such as greenhouse heating and the manufacture of plastic explosives). The hydrothermally deposited and altered rock has been mined in the past for cinnabar and sulfur.³⁴ In 1980 Phillips Petroleum attempted to drill a geothermal well to a depth of several thousand meters, but problems with drill bit drift were encountered in the hard volcanic bedrock.³⁵ Southern Union Production and Magma Power Company have also been involved in development of geothermal energy at Steamboat Springs.¹⁸

DOE's scenario for geothermal development calls for 50 MW(e) on-line in 1985, another 50 MW(e) in 1988, and an additional 100 MW(e) in 1990. The area has good potential for district heating, as it lies at the edge of suburban Reno, which has a population of 120,000 in the metropolitan area.¹⁸

Steamboat Creek flows on the east side of the KGRA and Steamboat Ditch on the west side. The average flow of Steamboat Creek is approximately 12.3×10^6 m³/year (10,000 acre-ft/year), but all of this water, as well as the water in Steamboat Ditch, has been appropriated and is not available. Washoe Lake is approximately 8 km (5 miles) to the south.

The groundwater of the area is being pumped at a rate exceeding recharge by irrigators and domestic users. The State of Nevada Department of Water Resources is granting no new appropriations for groundwater

wells in the area.³⁶ Because the State Engineer has designated geothermal development as a preferential use under Sect. 534.120 of the Nevada Code, it is likely that enough water could be appropriated for drilling and construction of test or prototype facilities.³⁷ Whether enough water is available for cooling of full-scale geothermal electrical generating plants is conjectural, however.

Water supplies in the vicinity of Steamboat Springs are extremely limited, and demand already exceeds supply in the region.⁶ It is possible that air emissions standards could force the use of closed-loop binary systems at Steamboat Springs because the topographic basins in which Reno-Sparks and Carson City are located already have severe air pollution problems, especially during thermal inversions. The high concentrations of mercury, boron, and arsenic in the geothermal fluid could contribute to this pollution. If a flashed-steam system is not feasible at Steamboat Springs, geothermal power plant development would need supplementary water. In this event, development could be constrained by inadequate water supplies. Purchase of water rights from irrigators in the area is a possible water source, but the cost of water obtained in this manner is likely to be high.³⁶ Thus, the amount of development possible would depend primarily upon the socioeconomic trade-off involved.

Approximately 101×10^6 m³/year (82,000 acre-ft/year) of water are consumed by all sectors in Washoe County where Steamboat Springs is located. Agriculture accounts for 85% of this figure with most of the remainder going to public supply.³⁷ A 100-MW geothermal plant would require 4.9×10^6 m³/year to 9.9×10^6 m³/year (4000 to 8000 acre-ft/year), so full development of the geothermal resources at Steamboat Springs could require up to 35×10^6 m³/year (28,000 acre-ft/year), based on the U.S. Geological Survey estimate of the electrical generation potential of this field. This quantity would represent a significant proportion of current water use in the county.

3.18 Brady Hot Springs, Nevada

The median temperature of the geothermal resource at Brady Hot Springs KGRA is 155°C (311°F), although hotter water may be present at

greater depth.¹ The dissolved solids content of the fluid ranges from 1000 to 2600 ppm, with high concentrations of chlorine and silica.³⁴ The electrical energy potential has been estimated at 157 MW(e) for 30 years.¹

The Brady Hot Springs KGRA consists of 3848 ha (98,508 acres), of which 24,021 ha (59,358 acres) are federally owned. The remaining 15,843 ha (39,150 acres) are either privately owned or are owned by the state of Nevada.¹⁸

There has been a great deal of interest and exploratory activity in the Brady Hot Springs KGRA, and at least six companies have drilled in the area. Geothermal Food Processors has been operating a food products dehydrating plant using the geothermal heat in a closed-loop system, backed by federally guaranteed geothermal development loan. The same company has plans to build a plant that will produce 10×10^6 gal of alcohol per year, using geothermal process heat.²⁹ A 1978 ERDA development scenario projected that 50 MW(e) would be installed by 1983, 100 MW(e) by 1986, and 200 MW(e) by 1988.¹⁸

The comments regarding water resources for Desert Peak also apply to Brady Hot Springs, because the two sites are only about 6.5 km (4 miles) apart. As with Desert Peak, surface water is totally appropriated and groundwater is of a poor quality, so sources of supply for geothermal power plant makeup water are very limited.

3.19 Beowawe Hot Springs, Nevada

The best estimate of the temperature of the geothermal fluid at Beowawe Hot Springs is 229°C (444°F), and the estimated volume and temperature of the resource are sufficient to support 127 MW(e) of electrical generation for 30 years.¹ Dissolved solids average about 1000 ppm in reported samples.³⁴

The Beowawe Hot Springs KGRA consists of 13,446 ha (33,225 acres), of which one-half is federal land and one-half is state and privately owned.¹⁸ Phillips Petroleum, Magma Power Company, Southern Union Products Company, Chevron, and Getty Oil Company have all leased land in the area, and a number of exploratory wells have been drilled. There are apparently no definite plans for developing electric generating facilities

in the near future, although the Beowawe site is one of three sites being considered by a consortium of power companies for a 10-MW(e) commercial plant. Chevron has completed three deep wells in the last two years and is in the process of drilling another. The Half Circle Ranch Development Corporation has proposed to build a geothermal alcohol plant at Beowawe and has applied for a DOE loan guarantee.³⁸ DOE's Division of Geothermal Energy scenario for development of geothermal energy calls for 50 MW(e) of capacity in 1983 and for additional 50-MW(e) units to be installed in 1986 and 1988.¹⁸

The Humboldt River is the primary source of surface water in the vicinity of the Beowawe Hot Springs KGRA, but this water is already appropriated for irrigation purposes. The Whirlwind Valley, in which Beowawe Hot Springs is located, has poor groundwater potential. The yield is estimated to be less than 6.17×10^6 m³/year (5000 acre-ft/year), and there are legal constraints to additional development of groundwater.³⁷ Great difficulty would be incurred in locating a sufficient supply of cooling tower makeup water for a geothermal power station located in this KGRA unless a flashed-steam system were used and little or no reinjection was required.

3.20 Crane Creek and Cove Creek, Idaho

The median temperature of the Crane Creek-Cove Creek geothermal reservoir is reported to be 171°C (340°F). It has been estimated that this geothermal area could generate 340 MW(e) of electricity for 30 years.¹ The relatively low temperature of this resource makes it less attractive from the standpoint of cycle thermal efficiency.

The Crane Creek KGRA contains 1757 ha (4342 acres) of land, of which 1312 ha (3240 acres) are federal and 446 ha (1102 acres) either state or privately owned. Over 405 ha (1000 acres) of the federal land have been leased for geothermal exploration and development.¹⁸ Some exploratory drilling has occurred, but no firm plans for development have been announced. Phillips Petroleum Company has recently drilled several temperature-gradient holes, plus one deep well to 2438 m (8000 ft), but no data have been made available. The DOE geothermal development scenario calls for 50 MW(e) to be installed by 1988, followed by another 100 MW(e) in 1990.¹⁸

The Weiser River, which has an average annual flow rate of $33.3 \text{ m}^3/\text{s}$ (1176 cfs or 851,388 acre-ft), flows through the KGRA.¹⁸ Crane Creek Reservoir is nearby, and the Snake River is approximately 24 km (15 miles) from the Crane Creek KGRA. The Crane Creek area is underlain by one of the most productive aquifers in the region and much of it is still available for appropriation.³³ It appears that water supplies in the area may be sufficient for full geothermal development.

3.21 Kamailei Homesteads (Puna District), Hawaii

The Kamailei Homesteads area has a median temperature of 273°C (523°F) and the potential to produce 210 MW(e) for 30 years.¹ Exploration is at an early stage, so these estimates may change significantly. The dissolved solids concentration of the geothermal fluid is about 2000 ppm.¹⁸ Drilling and exploration in the Puna area are taking place mostly on private and state lands, so little information is currently available concerning the success of these operations. A 3-MW(e) flashed-steam power plant is being built by the HGP-A Development Group, with funding from the University of Hawaii, DOE, the State of Hawaii, the County of Hawaii, and the Hawaii Electric Light Company.³⁹

There is no surface water in the vicinity of the Puna well site because of the high porosity and permeability of the soil and bedrock. The Puna area is underlain by bedrock that holds large volumes of groundwater in three zones. The top layer is a perched water table, which is thin and discontinuous. The quantity of water in this layer is not sufficient for power plant cooling tower makeup. Much larger volumes of water are impounded in the substrate by impermeable dikes along rift structures. The lowest lying, and the largest, of the three groundwater reservoirs occurs as a basal unit floating on the underlying seawater. Some of this water is brackish due to mixing with the seawater, but the degree of salinity varies greatly from place to place. Large-scale pumping of water from the basal lens would probably promote further encroachment of seawater.²²

The use of ocean water for cooling of geothermal plants, either in a once-through cooling system, or in evaporative towers, could be considered for the Puna field. The presently drilled geothermal well is located about 4.8 km (3 miles) from the sea and at an elevation of 183 m (600 ft) above sea level, however, and piping and pumping cost could be prohibitive.²²

The extremely high rainfall rates in the vicinity of the Puna site (3560 mm/year, or 140 in./year) could provide a substantial amount of water, but, to meet the makeup needs of a 100-MW(e) plant, it would be necessary to provide a lined collection basin with an area of at least 200 to 250 ha (500 to 600 acres). Both the environmental impacts and the costs of this arrangement appear to be marginal.

The relatively high temperature of the geothermal fluids at Puna would probably permit the use of flashed-steam systems that can use condensate as a source of cooling tower makeup water. Subsidence is not expected to be a serious problem in the Puna District. Groundwater supplies are also ample, providing that saltwater encroachment does not create a problem. It is not likely that water supply will constrain development in the Puna District.

3.22 Geyser Bight, Alaska

The median temperature of the geothermal reservoir is reported to be 208°C (406°F), and the area is projected to have the potential to produce 136 MW(e) for 30 years.¹ The Geyser Spring Basin KGRA contains 8482 ha (20,960 acres). There are no known development plans for the Geyser Spring Basin at this time.

The most abundant source of cooling water at the Geyser Spring Basin is ocean water. Streams and lakes in the area are frozen for long periods during the year, and therefore are probably not a practical source of water. It is not likely that water availability will retard development of the geothermal energy at Geyser Spring Basin.

REFERENCES FOR SECTION 3

1. L. J. P. Muffler (ed.), *Assessment of Geothermal Resources of the United States*, Geological Survey Circular 790 (1978).
2. U.S. Geological Survey, *Assessment of Geothermal Resources of the United States*, Geological Survey Circular 726, (1975).
3. Joseph F. Poland, "Land Subsidence in Western United States," in *Focus on Environmental Geology*, ed. by R. W. Tank, Oxford University Press, New York, 1973.
4. E. John Finnemore, "Potential Land Subsidence at Geothermal Development Sites," *Geotherm. Energy* 5(5) (1977).
5. Imperial County, California, *Geothermal Element to the Imperial County General Plan*, El Centro, Calif., 1977.
6. A. D. Shepherd et al., *Energy Competition-for-Water in Potential Water Availability Problem Basins*, A Progress Report to the Applied Analysis Branch, Environmental Impacts Division, Oak Ridge National Laboratory (Draft Final Report, November 1979).
7. James M. Greenwood et al., *Water: Conservation and Efficient Resource Management*, Oak Ridge National Laboratory (Draft Final Report, June 1980).
8. *The Nation's Water Resources 1975-2000*, The Second National Assessment by the U.S. Water Resources Council, Washington, D.C., December 1978.
9. Jerome E. Dobson and Alf D. Shepherd, *Water Availability for Energy in 1985 and 1990*, ORNL/TM 6777 (October 1979).
10. James H. Tulley, Jr., and Alf D. Shepherd, *A Status Report on the Oak Ridge Automated Downstream Accounting Model Program System Structure*, ORNL/SUB/13848 (April 1980).
11. J. C. Sonnichsen, Jr., *A Review of Water Resource Potential for Developing Geothermal Resource Sites in the Western United States*, Hanford Engineering Development Laboratory, HEDL-TME-79-74 (July 1980).

12. Imperial Irrigation District, *From Desert Wasteland to Agricultural Wonderland: The Story of Water and Power*, IID, El Centro, Calif. (1977).
13. *Environmental Assessment, Geothermal Loan Guarantee Program, Westmorland Development Project*, U.S. Department of Energy, DOE/EA-0058 (1979).
14. D. W. Layton, *Water for Long-Term Geothermal Energy Production in the Imperial Valley*, Lawrence Livermore Laboratory, UCRL-52576 (September 1978).
15. Salton Sea Study Group, *What are Current Costs and Feasibility of Using Salton Sea Water for ReInjection into Geothermal Reservoirs?* unpublished document, Sacramento, Calif. (1980).
16. David Layton (ed.), *An Assessment of Geothermal Development in the Imperial Valley of California*, DOE/EV-0092 UC-66e (July 1980).
17. D. Layton, "Water-Related Impacts," *An Assessment of Geothermal Development in the Imperial Valley of California*, ed. by D. Layton, DOE/EV-0092 (July 1980).
18. Mitre Corp., *Site-Specific Analysis of Geothermal Development - Data Files of Prospective Sites*, Vol. III, 1978.
19. B. Rintoul, "Geothermal Review," *Geotherm. Energy* 8(4) (1980).
20. Electric Power Research Institute, *A Comparison of Hydrothermal Reservoirs of the Western United States*, EPRI ER-346 (1976).
21. "Staff Report for Hearing Applications 25794 and 25818," State of California Water Resources Control Board, Division of Water Rights (January 1980).
22. System Development Corporation, *Regional Systems Development for Geothermal Energy Resources*, Vols. II and III, 1979.
23. Imperial County Planning Department, *Imperial Valley Action Plan, Development Schedule Subtask B, Final Report, August 20, 1979*, Imperial County Contract No. 500-142 (7/8).

24. D. F. Snoeberger and J. H. Hill, *Identification of Technologies for Geothermal Development in the Imperial Valley of California*, LLL UCRE-52548 (1978).
25. Republic Geothermal, Inc., *East Mesa Geothermal Project Plans of Operation 48-MW (net) Power Plant*, 1978.
26. Wapora, Inc., *Geothermal Fact Book*, Industrial Environmental Research Laboratory, Office of Research and Development, Cincinnati, Ohio, September 1978.
27. *California's Ground Water*, State of California, Department of Water Resources Bulletin No. 118, September 1975.
28. California Division of Oil and Gas, *Geotherm. Hotline* 10(1) (1980).
29. U.S. Department of Energy, *Final Environmental Impact Statement -- Geothermal Demonstration Program 50-MW Power Plant, Baca Ranch, Sandoval and Rio Arriba Counties, New Mexico*, DOE/EIS-0049 (1980).
30. *Water Resources of the Milford Area, Utah, with Emphasis on Ground Water*, State of Utah Department of Natural Resources Technical Publication No. #43, 1974.
31. Geological Survey *Summary Appraisals of the Nation's Ground-Water Resources -- Great Basin Region*, Professional Paper 813-G (1974).
32. Telephone conversation with Charles Wassinger, District Geothermal Supervisor, U.S. Geological Survey, Santa Rosa, Calif., May 1980.
33. Geological Survey, *Summary Appraisals of the Nation's Ground-Water Resources -- Pacific Northwest Region*, Professional Paper 813-S (1979).
34. Larry J. Garside and John H. Schilling, *Thermal Water of Nevada*, University of Nevada-Reno, Mackay School of Mines Bulletin #91 (1979).
35. Personal interview with Bernard Moroz, District Geothermal Supervisor, U.S. Geological Survey, Reno, Nevada.
36. Personal interview with Jack Cardinali, Nevada Department of Water Resources, Carson City, Nevada.

37. State of Nevada Water Planning Report No. 2, *Estimated Water Use in Nevada*, State Engineer's Office, Carson City (1974).
38. Susan Voyles, "Firms Spend Millions to Learn Nevada's Potential," *Reno Gazette/Journal*, Nov. 9, 1980.
39. "HGP — A Wellhead Generator Feasibility Project," *Geotherm. Energy* 8(3), (March 1980).

4. LEGAL STRUCTURES GOVERNING THE DEVELOPMENT OF GEOTHERMAL RESOURCES

Carey S. Rosemarin

4.1 Introduction

This section, which primarily addresses the legal acquisition of cooling tower makeup water and geothermal fluid, has two purposes: (1) to provide the proper context in which to examine the respective legal systems described in the series of fundamental outlines of state water laws and (2) to identify potential constraints to geothermal development. The outlines of state water laws pertinent to geothermal development provide a basic idea of the regulatory environment with which a geothermal developer will have to deal to acquire cooling water. The outlines also indicate the extent to which the states subject geothermal resources to regulation in the same manner as they do conventional water. Whether state water law should be applied to geothermal resources is a point of controversy. Uncertainties surrounding this issue could retard geothermal power plant development.

The water laws for the states of California, New Mexico, Oregon, Idaho, Utah, and Nevada are outlined in Sects. 4.3 through 4.8. Each is written in a standard format that reviews the mechanics of the water law of each state, including that pertaining to groundwater. An outline of the laws governing geothermal resources is also included, but the emphasis in this case is the relationship that such laws have with the water laws of the respective state. The outlines are intended to convey basic information about the regulatory environment of each state but are not purported to be a complete analysis. The scope of this study did not permit detailed examination of the administrative regulations of each state; therefore, additional constraints may exist, or some of those listed possibly could be dealt with informally or eliminated. The sections of the outlines discussing issues and potential constraints to development of geothermal energy are derived largely from a comparison of the state water and geothermal laws and are somewhat hypothetical in nature.

It is necessary to keep in mind that this report is concerned with two separate state-regulated resources — "conventional" water and geothermal fluid. The legal situation is even more complicated in that both state and federal regulations are involved, and it is not always clear which regulations apply to which site. This uncertainty is the major legal problem in geothermal resource development.

4.2 Legal Definition of Geothermal Resources

It must first be determined whether a particular state currently treats geothermal resources as it does water, or as some other resource, such as oil or gas. If no federal ownership is involved, the inquiry need not proceed because state law will apply. If, however, the federal government owns the resource, the analysis must proceed to a second stage. The Geothermal Steam Act of 1970¹ gives the government clear power to lease geothermal resources on federally owned land. In Known Geothermal Resource Areas (KGRAs),* leases are acquired according to a competitive bidding system. The key issue is whether federal law applies to the exclusion of state law when conflicts occur between federal lessees and state water or geothermal users.

Water allocation is, for the most part, a matter of state law. All western states employ some variation of the doctrine of prior appropriation. A basic tenet of this system is that those who divert water to a beneficial use first have a superior right to those who do so later. Beneficial uses are essentially those which are not wasteful and are considered to be socially beneficial. Power production has so qualified, but, as has been noted,² beneficial use is a changing concept, and it is conceivable that energy production technologies which consume large amounts of water could be judged nonbeneficial. It is also possible that the cost-benefit of water consumption for power production could be considered greater than that for agricultural uses in one state, but less beneficial in another.

* KGRAs are defined as federal holdings likely to yield developable quantities of geothermal energy.

In most western states, one who wishes to use water applies to the office of the state engineer or similar body for a permit. The permit may be granted, based on the availability of unappropriated water, considerations of the rights of existing appropriators, and the public interest. The applicant then has a specified time within which to complete construction and apply the water to beneficial use. Under this system, water can be used on land which is not adjacent to the water source, and water rights can be transferred. In the event of a dispute, all appropriators of a particular stream or part thereof can have their rights determined by a court in an "adjudication."

At the present time, a state may impose the prior appropriation doctrine on conventional water alone, in which case the geothermal developer would comply with established appropriation procedures for acquiring makeup water only. However, some states extend their water law to cover geothermal fluid as well. Those that do not may select oil and gas law as the appropriate regulatory regime. It has been noted³ that state legislatures, in recognizing a "new" resource, have acted to identify it with one that is more familiar in order to facilitate exploitation. The problem is that the more traditional bodies of law to which geothermal resources may be assigned have developed over time in response to particular needs. Since not all of these legal accommodations meet the needs of geothermal resources, there is a type of "forced fit" in some states which could produce impediments to maximum economic utilization. For example, it has been suggested that the possibility of drilling dry holes in geothermal explorations could cause a violation of the time period allowed for applying water to a beneficial use, resulting in the loss of priority.

Presently, there appears to be relatively little agreement on which legal approaches and sets of laws will yield the greatest benefits in terms of economic return, conservation, and minimum negative environmental impact. As with any new subject that the law must address, the best scheme will probably be one that borrows components from familiar areas but is flexible enough to accept innovative responses to matters peculiar to geothermal resources. In the ensuing paragraphs, arguments favoring and opposing the extension of the prior appropriation doctrine to geothermal resources will be discussed briefly.

4.2.1 Extending the prior appropriation doctrine to geothermal resources

Disadvantages to geothermal development

Olpin and Tarlock have considered at length the relationship between water law and geothermal development in the western states.^{3,4} Specifically, they have focused on the potential constraints that conventional water users can place on geothermal developers because of various definitions of geothermal resources in terms of property rights and ownership. As noted earlier, states have defined geothermal resources as they would a mineral for purposes of regulation of drilling. A central problem is that these definitions are used for a different purpose, the definition of property rights. Because of this, geothermal resources are usually forced into the realm of prior appropriation, thereby granting "ownership" of the resource to the state. However, Olpin and Tarlock note that "the heat transfer medium links geothermal resources to water, but the use to which they are put does not."⁵ Because of this functional difference Olpin and Tarlock oppose prior appropriation as an allocation mechanism for geothermal resources. They argue that exploitation of a resource requires efficient allocation.⁶ Efficient allocation, in turn, is dependent upon property rights that are exclusive. Prior appropriation is not exclusive because it allows interference by conventional water users. Interference can arise in the initial application for a permit, when an existing water user can protest permit issuance on the basis of possible injury to his rights. The applicant must then disprove any hindrance. This issue may also arise after a permit has been granted, and the geothermal developer may have to restrict pumping to ensure protection of senior rights. Olpin and Tarlock advance several other arguments that support the contention that policies which favor the application of the prior appropriation system are ill-suited to the needs of the thermal resource developers.

As an alternative, the authors suggest ownership of the resource in the overlying landowner, with regulation by the state.⁷ After proper investigation, the developer would be allowed to operate with the presumption that geothermal resources are physically separate from conventional water sources. Prior permit holders would have the opportunity to rebut the presumption on presentation of convincing evidence.

The concerns voiced by Olpin and Tarlock have merit, and their proposed system appears to be reasonable. On the other hand, they have supplied no evidence that supposed interference with conventional water has in fact seriously impacted geothermal drilling. Additionally, individual water users may have more difficulty in rebutting the developers' presumption of noninterference than developers would have in establishing the separation of resources without the proposed system. Therefore, it is worthwhile to examine the views of the proponents of the use of prior appropriation.

Advantages to geothermal development

Essentially, there are two variations on the theme of prior appropriation. Vranesh and Musick⁸ support a regulatory scheme which integrates geothermal resources into the state's water law. Alternatively, Sato and Crocker⁹ support the application of the prior appropriation doctrine to geothermal resources, but in a structure which is separate from the water rights administration. Both schools of thought view the problem of interconnection between geothermal resources and conventional water differently than do Olpin and Tarlock.

Vranesh and Musick do not believe that the functional differences between conventional and geothermal water warrant different treatment for the latter. Instead, they see a need to legally integrate the two resources because they are physically related (i.e., withdrawal of one may affect use of the other). They also advanced several other arguments for adopting prior appropriation. For example, they note that the system serves to allocate a scarce resource among new users but protects existing rights. Ultimately, the argument continues, geothermal resources are water and it is thus anomalous to assign one property regime to geothermal fluid (i.e., correlative rights, which allows each developer "an equal opportunity to obtain and produce his just and equitable share of the geothermal resources") and another (prior appropriation) to water which results from cooled geothermal fluid. Similarly, they point out that subjecting the geothermal driller to oil and gas

regulation is an unnecessary burden that can constrain development. The authors state in conclusion:

If we will acknowledge that geothermal resources are to be treated like water, the remaining key question concerns only how to go about obtaining it. Most of the western states recognize the appropriation doctrine, in some form or another in regard to the administration of water, and they have understood and used this doctrine for the past century. The doctrine has, since its inception, stood for the protection of other rights, both junior and senior. Combined with modern technology and skilled supervision, be it in the form of an oil and gas commission or a state engineer, there need be no fear of waste.¹⁰

Sato and Crocker suggest another form of prior appropriation. Following a very detailed analysis, they conclude that prior appropriation and state "ownership"¹¹ provide the best of several methods of resource allocation. Recognizing the same shortcoming as Olpin and Tarlock, they find existing water laws inadequate to serve the purposes of geothermal resource development. They write:

One of the anomalies in groundwater allocation in some states is the failure to integrate the groundwater allocation with surface supply allocation even when the supplies are physically interconnected. If one of the requisites for efficient resource allocation is a definition of a property right that grants security to a supply, the lack of integration is a serious flaw.¹²

Because prior appropriation can integrate new with existing rights and yields some security, Sato and Crocker feel it provides the most advantageous method of resource allocation.

Sato and Crocker propose a system administered by a state agency which would acquire considerable knowledge about the resource and thus provide responsible management. For example, in reviewing the permit applications of prospective developers, the authors recommend the issuance of a conditional permit in situations in which it cannot immediately be determined whether existing rights will be injured. The agency's role would continue in limiting the right granted in terms of the resource use. Thus, the proposed agency would take a more active role than the traditional state engineer's office. Moreover, unlike the water appropriation license which is granted in perpetuity, the geothermal license would have a limited tenure, with the possibility of renewal according

to seniority. This device permits flexible management of the resource in response to its particular behavior. Furthermore, resolution of conflicts with conventional water users would theoretically be relatively easier because of the common form of regulation.

Regardless of the particular system that is implemented, it appears that there must be some mechanism to distinguish geothermal resources from other, similar resources.¹³ Otherwise, protective devices geared to other resources could impede geothermal development.

It appears that the states whose laws have been examined in this segment have not entirely succeeded in this task. As noted in the discussion of Olpin and Tarlock's conclusions, a state's definition of geothermal resources has important implications but must be viewed as part of a regulatory network, not in isolation. Table B.1 in Appendix B outlines the geothermal permit process for New Mexico and clearly shows that water and water rights are but one concern of the geothermal developer. The systems in other states are similarly complex. The legislatures of two states, California and New Mexico, defined geothermal resources broadly enough to include water, yet granted regulatory authority to their respective oil and gas agencies. Oregon and Idaho similarly do not define the resource as water per se but recognize its close relation to water. For example, Oregon treats those geothermal resources under 121°C (250°F) and less than 61 m (200 ft) deep as water, and Idaho requires an appropriation of water if construction of a geothermal well "will involve the use of water."¹⁴ Finally, Utah and Nevada have given jurisdiction of geothermal resources to their respective state water allocation agencies, though Nevada allows a separate regulatory scheme for geothermal resources.

4.2.2 Conflicts between state and federal law

The lack of distinction between geothermal resources and water has produced issues that may have to be resolved in litigation, and the uncertainties which presently exist in state law could constrain geothermal development. Some of these issues are identified in the state outlines (Sects. 4.3 through 4.8). As stated earlier, however,

if federal ownership is involved, the analysis cannot cease even if uncertainties are removed from state law. Constraints may surface in situations where lessees of federal resources conflict with the use of conventional water or geothermal fluid under state law.

In the first instance, the distinction between ownership and regulation must be made clear. That one must own a resource before leasing it is basic, but it is not always a simple matter to determine who does own particular property. The case of *United States v. Union Oil Company*¹⁵ illustrates the point. In that litigation it was held that when the federal government passed the tract of land in question to the original private owner, a homesteader, it did not include geothermal resources in the grant. Thus, the federal government, and not the surface owner, was the proper lessor. However, the state does not lose its regulatory powers merely because of federal ownership, as federal ownership combined with state regulation is not an infeasible arrangement. The problem is to determine the extent of regulation by each jurisdiction. Congress, in the Geothermal Steam Act of 1970, states only that

Nothing in this chapter shall constitute an express claim or denial on the part of the Federal Government as to its exemption from State water laws.¹⁶

Olpin and Tarlock are probably correct in their assertion that Congress's nonanswer to the issue is a signal that jurisdictional boundaries are to be established by existing doctrines, which seem to grant considerable regulatory authority to the states.¹⁷

The delineation between state and federal water rights is largely governed by the federal reserved-water-rights doctrine. The United States Supreme Court has explained this body of law in the following manner:

[W]hen the Federal Government withdraws its land from the public domain and reserves it for a federal purpose, the Government, by implication, reserves appurtenant water then unappropriated to the extent needed to accomplish the purpose of the reservation. In doing so the United States acquires a reserved water right in unappropriated water which vests on the date of the reservation and is superior to the rights of future appropriators. Reservation of water is empowered by the Commerce Clause, Art. I, §8, which permits regulation of navigable streams, and the Property Clause, Art. IV, §3, which permits federal regulation of federal lands.

The doctrine applies to Indian reservations and other federal enclaves, encompassing water rights in navigable and nonnavigable streams.¹⁸

The doctrine was first recognized in 1908¹⁹ in a case dealing with non-navigable waters on Indian reservations and was most recently applied to groundwaters.²⁰

The issue of federal reserved rights itself presents considerable controversy. Its opponents cite the impediment to state water planning imposed by the existence of unquantified federal reserved rights.²¹ In response to President Carter's Water Policy Message to Congress of June 6, 1978,²² progress has been made toward quantification of federal water rights,²³ but problems are not likely to be eliminated in the near future (i.e., during the initial stages of development of geothermal energy production). Therefore, it is possible that uncertainty about federal reserved rights could impede commercial utilization of this resource.

Before the doctrine can be applied to geothermal resources, there must be a "reservation" of the resources by the federal government.²⁴ It can be argued that there has been such a reservation,²⁵ although there has been no official ruling on this point. If geothermal resources are the subject of a reservation, then they would hold a priority date as of the date of that reservation for purposes of coordination with a state prior appropriation scheme. If not (and an analysis by Olpin and Tarlock suggests that this is the case²⁶), then the priority of the federal applicant is lower than existing permit holders.

Two qualifiers must be added at this point. First, where there has been no reservation but the federal government has authority to "manage" federal lands, as it apparently does under the Geothermal Steam Act, federal rights with respect to water are not as plenary as if they were reserved, but rather exist under a different set of rules.²⁷ As stated, federal applicants would be subject to state regulation by having to acquire a state permit and a low priority. However, if state regulation becomes too onerous and conflicts with federal policy, the supremacy clause of the Constitution²⁸ dictates that state law must yield.

Second, even if geothermal resources are reserved, important questions remain. For example, it is not likely that federal lessees, as opposed to the federal government itself, can take advantage of reserved rights. In any event, all federal lessees have chosen to comply with state law with respect to geothermal fluid, and none has asserted federal reserved rights with respect to cooling tower makeup water. As the previous discussion shows, however, this is no guarantee of freedom from conflict.

Illustrations of those conflicts which may occur appear in the following outlines. Each is written in a standard legal format that reviews the mechanics of the water law of each state, including that pertaining to groundwater. For each state an outline of the laws governing geothermal resources is also included, but the emphasis of this part is the relationship that such laws have to the respective state's water laws. In the outlines, frequent reference is made to the account of the water laws of western states prepared for the Los Alamos Scientific Laboratory by Gould.²⁹ Table 4.1 explains the abbreviations used in the outlines.

Table 4.1. Abbreviations used in Sects. 4.3-4.8

CPR	California Public Resources Code Section
CWC	California Water Code Section
ICA	Idaho Code Annotated Section
NMSA	New Mexico Statutes Annotated Section
NRS	Nevada Revised Statutes Section
ORS	Oregon Revised Statutes Section
UVA	Utah Code Annotated Section

4.3 California

A. Type of System

1. Prior appropriation
2. Authority
 - a. California Constitution, Art. 10, Sect. 2
 - b. *Lux v. Haggin*, 10 P. 674 (Cal. 1886)
3. Location of potential major sites (Fig. 4.1)

Fig. 4.1. Location of potential geothermal resource areas in California.

B. Permit System and Riparian Rights

1. Permitting Authority – Water Resources Control Board (CWC 1250)
2. Procedure and Requirements
 - a. Any person (CWC 1252) may apply for a permit to appropriate surface water or water in "subterranean streams flowing through known and definite channels" (CWC 1200) setting forth pertinent data, including the amount and source of water requested (CWC 1260).
 - b. Notice of receipt of application is given, first to government entities and then to the general public and each is given an opportunity to protest the approval of the application (CWC 1300 to 1331).

- c. After a hearing on protested applications (CWC 1340, 1351), a permit may be granted (CWC 1350) if unappropriated water is available and the application is for a beneficial use (CWC 1375) and if it is not thought that "the proposed appropriation would not best conserve the public interest" (CWC 1255).
 - d. Gould (ref. 2, pp. 85-91) has alluded to five statutory provisions which lend some meaning to "public interest."
 - i. In acting on permit applications, the Board is to be guided by the State's policy of according the "highest use" to domestic and irrigation purposes respectively (CWC 1254).
 - ii. In acting on permit applications, the Board is to "consider the relative benefit to be derived" from all beneficial uses and from reuse of the water sought to be appropriated (CWC 1257).
 - iii. The Department of Fish and Game is to be notified of all permit applications, and the Board is to consider water required for recreational and ecological in-stream uses in determining the amount of water available when doing so is "in the public interest" (CWC 1256).
 - iv. The Board is to consider uses "specified to be protected in any relevant water quality control plant" (CWC 1257).
 - e. The Board can grant permits subject to conditions (CWC 1391, 1253) and can reserve jurisdiction to change the permit (CWC 1394) if:
 - i. A period of actual operation is necessary to determine the conditions necessary to protect vested rights and to assure utilization of the water in the public interest.
 - ii. The application is for a part of a larger project and conditions cannot be determined until other applications are acted upon.
 - f. On the application of water to beneficial use, the permit holder reports to the Board (CWC 1600), which makes an inspection (CWC 1605) and determines whether to issue a license (CWC 1610) and whether to issue it for the amount of water specified in the permit (CWC 1610.5).
 - g. California has also enacted provisions for "urgent but only temporary" diversions of water not to exceed six months (CWC 1425 to 1431).
3. Riparian Rights (Unlike most other western states, riparian rights still play an important role in California.)
- a. As against water rights by prior appropriation, the priority of riparian rights is from the date that the riparian land (land adjacent to a water body) passed into private ownership. (But see C.2.c below.)

- b. Unlike water rights based on prior appropriation, riparian rights are not lost by nonuse. (But see C.2.c below.)
- c. In response to a California Supreme Court decision, California adopted a state constitutional amendment in 1928 which required that water rights be "limited to that amount of water required for a reasonable beneficial use" (Gould, ref. 2, p. 77).
- d. Gould (p. 92) notes that water subject to riparian rights can be used
 - i. On land abutting a body of water.
 - ii. On lands which formerly were riparian and to which riparian rights were reserved.
 - iii. Only on lands within the watershed.
 - iv. Only on lands which were originally riparian and never lost that status through conveyance.

4. Preferences

- a. Although not likely to have a great impact on geothermal development, Gould (p. 92) notes that California does allow the acquisition of water by prescription (use for specified period of time without complying with statutory procedures for acquiring water).
- b. CWC 106 states, "It is hereby declared to be the established policy of this State that the use of water for domestic purposes is the highest use of water and that the next highest use is for irrigation."
- c. Gould (p. 82) has noted that the section quoted in B.4.6 (above) has been used as a basis for a condition in the permit of a generating plant that its use was not to interfere with future agricultural or municipal appropriations.
- d. As has been explained in the outline for Oregon (Sect. 4.6, Part B.3.e), the Klamath River Basin Compact (CWC 5901) enumerates specific use preferences, which can be superior to prior rights in the Klamath River Basin.
- e. California follows the traditional riparian preference for domestic uses (*Prather v. Hoberg* 150 P. 2d 405, 412).
- f. A user may temporarily appropriate a surplus of water held by a municipality but must yield when the municipality needs that quantity of water (CWC 1462).

C. Administrative Structure

- 1. At the state level, two agencies can exert considerable influence over the use of water in California.
 - a. The Water Resources Control Board is primarily responsible for the allocation of water.
 - b. The Department of Water Resources is responsible for planning and development.

2. Duties of Water Resources Control Board

- a. Approve applications to appropriate water (CWC 1250, 1350).
- b. Approve applications to change the point of diversion, or place or purpose of use (CWC 1701).
 - i. The Board may hold a hearing on the application (CWC 1703) and must do so if a protest is filed.
 - ii. In order to grant the application, the Board must find that existing rights will not be injured (CWC 1702).
 - iii. Gould (p. 79) points out that CWC 1706 states that persons holding appropriations which date prior to 1913 need not seek approval by the Board to make such a change, and as to them, the only restriction is the prevention of injury to the rights of other users.
 - iv. The Board's approval is not needed for a change of use on riparian lands, but the new use must still be reasonable and beneficial.
- c. Determine water rights in adjudication proceedings (CWC 2500 to 2900).
 - i. The California Supreme Court, in *In Re Waters of Long Valley Creek Stream System*, 599 P. 2d 656 (Cal. 1979) clarified the Board's adjudication powers, the exercise of which could have serious implications for future users of a given "stream system" (surface waters and subterranean streams, CWC 2500).
 - ii. The case decided that at least in situations where the Board is to determine rights in the entire stream system, it may, in the interests of certainty:
 - "Decide that an unexercised riparian claim loses its priority with respect to all rights currently being exercised" (at 668).
 - In some cases, "determine that the future riparian right shall have a lower priority than any uses of water it authorizes before the riparian in fact attempts to exercise his right" (at 668-669).
 - "Make determinations as to the scope, nature, and priority of the right that it deems reasonably necessary to the promotion of the state's interest in fostering the most reasonable and beneficial use of its scarce water resources" without extinguishing future riparian rights (at 669).
 - Determine, even after an adjudication is final, whether a proposed riparian use should be permitted, in light of other uses on the stream (at 669, n. 15).

- d. Act as a referee in cases for the determination of water rights referred to the Board by the courts (CWC 2000).
- e. Supervise trial distribution of water pursuant to agreements and court orders (CWC 1051.5).
- f. Investigate all bodies of water (CWC 1051).
- g. Receive statements of water diversions and use, primarily by non-permit holders (CWC 5100-5108, Supp. 1980).

3. Duties of the Department of Water Resources

- a. Adopt and report to the legislature amendments to the State Water Plant (CWC 1004).
- b. Administer and supervise water development projects (CWC 12601).
- c. Create Watermaster Service Areas in certain parts of the state, as needed (CWC 4025, 4026, 4027) to ensure proper distribution of water (CWC 4151).

D. Regulation of Groundwater

1. Gould (p. 70) states that California has adopted no statutory scheme governing water rights, but rather has for the most part let rules be determined by judicial decision.
2. Thus, neither the Water Resources Control Board nor the Department of Water Resources is charged with general supervisory powers over the administration of groundwater rights (p. 74).
3. Basic rules governing the use of groundwater are as follow:
 - i. *Katz v. Walkinshaw*, 70 P. 663, 74 P. 766 (affirmed on rehearing) indicated that:
 - One who uses groundwater on overlying land has priority over a later user of that water on a nonoverlying tract, but only as to the amount necessary for use on the overlying land, with the surplus going to the later user (74 P. 772).
 - In a dispute between two overlying users, correlative rights apply, and each is entitled to "a fair and just proportion" (74 P. 772).
 - One who makes no use of groundwater is not entitled to enjoin its use by another but may be able to do so at the time of use (74 P. 772).
 - As between users of groundwater for use on nonoverlying lands, the doctrine of prior appropriation applies.
 - ii. As between one who uses groundwater on nonoverlying land, and one who later reasonably uses the same source of water on overlying land, the right of the latter is superior *Burr v. MacLay Rancho Water Company*, 98 P. 260 (Cal. 1908).
 - iii. *Pasadena v. Alhambra*, 207 P. 2d 17,29 (Cal. 1949) points out, however, that use on nonoverlying land which is

not surplus is wrongful and may ripen into a prescriptive right under certain conditions. Therefore, during a shortage, nonoverlying users and overlying users may have to decrease their uses proportionately.

4. Persons who divert groundwater or surface water in certain counties must notify the Water Resource Control Board (CWC 4999 to 5008).
5. The Water Resources Control Board may sue to impose restrictions to groundwater pumping "to prevent destruction of or irreparable injury to the quality of such water" (CWC 2100). Gould (p. 24) notes that this provision allows a groundwater adjudication, which has not yet been utilized.
6. A notice of intent to construct a well must be filed with the Department of Water Resources (CWC 13750) and the Department or respective Water Quality Control Board may require an affected city or county to adopt well construction standards to protect water quality (CWC 13800 to 13806).
7. Gould (pp. 74-75) notes that inadequate state control over groundwater has been one reason for the organization of local water management bodies which may govern the use of groundwater in certain areas and that some counties require a permit to divert water beyond basin boundaries (pp. 92-93).
8. Gould (pp. 95-96) has also concluded the following on the basis of *Pasadena v. Alhambra*, 207 P. 2d 17 (Cal. 1949), and *Los Angeles v. San Fernando*, 537 P. 2d 1250 (Cal. 1975):
 - a. At least in rechargeable aquifers, groundwater mining is prohibited.
 - b. Historic pumping levels are not protected.

E. Regulation of Geothermal Resources

1. Geothermal Resources Act of 1967 — primarily governs leasing (CPR 6902 to 6925.2).
2. CPR 3700 to 3776 — primarily governs actual drilling.
3. Definition (CPR 6903): "Geothermal Resources" shall mean the natural heat of the earth, the energy, in whatever form, below the surface of the earth present in, resulting from, or created by, or which may be extracted from, such natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases, and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas, or other hydrocarbon substances.
4. Exploration and development permits are issued by the State Lands Commission (CPR 6904).
5. Reinjection of geothermal resources "or the residue thereof" is expressly authorized (CPR 6921, Supp. 1980).
6. Voluntary unitization of the resource is expressly authorized (CPR 6923, 3756).
7. The State Lands Commission may restrict any drilling operation under a lease of state resources on a finding of unreasonable risk of pollution or contamination (CPR 6925.1, Supp. 1980).

8. The State Oil and Gas Supervisor is to require that wells be operated to prevent damage to surface and groundwater (CPR 3714, 3741) and that they be operated to maintain the public welfare and to encourage maximum economic recovery (CPR 3700), and counties and cities may additionally so regulate if not in conflict with state regulation (59 Ops. Atty. Gen. 461, 8-24-76).
9. Low-temperature geothermal wells are those drilled to recover resources not hotter than the boiling point of water (CPR 3703, Supp. 1980).
10. The Division of Oil and Gas in the Department of Conservation is to be the lead agency under the California Environmental Quality Act for all geothermal exploratory projects but can delegate this responsibility to a county that has adopted a geothermal element as part of its general plan (CPR 3715.5, Supp. 1980).
11. Maps of nongeothermal groundwater shall be prepared by the Supervisor to protect such resources (CPR 3716).
12. Approval by the Supervisor must be obtained prior to drilling (CPR 3724, Supp. 1980).
13. The Geothermal Resources Board (GRB) is comprised of the Director of Conservation, the State Geologist, the Oil and Gas Supervisor, the Executive Officer of the State Lands Commission, the Chairman of the Water Resources Control Board, Director of Water Resources, President of the Public Utilities Commission, and the Director of Fish and Game (CPR 3742, Supp. 1980).
 - a. The GRB is to collect data "to allow for the most orderly development of geothermal resources" (CPR 3742.1).
 - b. The GRB issues a "certificate of primary purpose" on finding that an applicant's well is "primarily for the purpose of producing geothermal resources and not for the purpose of producing water usable for domestic and irrigation purposes" (CPR 3742.2).
 - c. The certificate serves as evidence of title to the geothermal resources produced, unless it is shown that such resource is useful for domestic or irrigation purposes without further treatment and not "as a byproduct incident to the production of geothermal resources" (CPR 3742.2).
14. On request, well records that are required to be filed with the Division of Oil and Gas may be kept confidential for five years (CPR 3752).

F. Issues/Potential Constraints to the Development of Geothermal Energy

1. Gould has pointed out several areas relating to the discretion of the Water Resources Control Board which could introduce considerable uncertainty into the assessment of geothermal development potential.

- a. The Board must consider the "public interest" in the approval of a new appropriation (B.2.c), but such a review is absent from the initiation of groundwater and riparian rights, except to the extent that the requirement that water uses be reasonable and beneficial includes the public interest (Gould, p. 86).
 - b. Similarly, there appears to be no statute providing for consideration by the Board of the public interest in the transfer (as opposed to initiation) of water rights, but the Board has indicated that it nonetheless has this power (Gould, pp. 97-98). The exercise of such authority could restrict the transferability of water rights and thus limit a source of water for geothermal developers.
 - c. It has also been noted (Gould, p. 87) that, based on the Board's authority to issue permits with conditions (B.2.c), a lower court has held that a permit must be issued if unappropriated water is available and if conditions imposed on the permit can remedy adverse effects.
 - d. Furthermore, the extent of the Board's authority to reject applications in anticipation of receiving applications for uses favored by the legislature (B.2.d.ii, B.4.b, B.4.c) is not known.
2. Considerable uncertainty exists in California water law because of (1) the lack of a mechanism for coordinated groundwater management and (2) the recognition of riparian rights.
 3. Two developments may eliminate some of this uncertainty.
 - a. Concern over the types of problems discussed in F.2 (above) led to the creation of the Governor's Commission to review California Water Rights Law, which recommended legislative changes in a December 1978 report. Some recommendations are expected to be accepted by the legislature and thus could affect the validity of statements made in this outline.
 - b. Gould (p. 100) noted that it was unclear whether future riparian uses could be quantified in an adjudication. That issue was decided by the California Supreme Court (C.2.c) in late 1979, in favor of quantification. Although the decision apparently does not affect riparian rights on streams that have not yet been adjudicated, it provides considerable certainty on streams that have been.
 4. Gould (pp. 102-4) has noted that the question of whether water saved through more efficient use can be used by the innovator has not been addressed recently but that cases from the turn of the century may provide some precedent for such control.
 5. Conceivably, the definition of geothermal resources (E.3) could include water.
 - a. It is possible, however, that the provisions for acquisition of a certificate of primary purpose (E.13.b) bar assertion of jurisdiction by the Water Resources

Control Board once the certificate is acquire and, thus, bar applications of provisions of the state water law.

- b. If geothermal resources were considered water, then they would be subject to groundwater law, which, as has been shown (D.1, D.2), is not a highly developed system. This hypothetical situation could become a problem in the future because apparently no person has ever applied for a certificate of primary purpose.
 - c. If a certificate of primary purpose is issued, thus indicating title to the fluid produced, and complete reinjection is not required, it would then appear that the developer could dispose of the condensate, subject to federal and state pollution laws, in any manner.
6. Both Sato and Crocker (ref. 9, at 481, 486-489) and Olpin, Tarlock, and Austin (ref. 4, at 831-834) criticize the certificate of primary purpose device for its failure to address ownership of resources in place, as opposed to rights to the resource after it is withdrawn. Therefore, it is not known whether a geothermal developer whose pumping interferes with conventional water rights is subject to an injunction (prohibition of continued pumping) on a suit by the conventional water user.

4.4 New Mexico

A. Type of System

- 1. Prior appropriation
- 2. New Mexico Constitution, Art. 16, Sect. 1-3

B. Permit System

- 1. Permitting authority — State Engineer (NMSA 72-5-1)
- 2. Procedure and Requirements
 - a. Apply to the State Engineer, including the amount of water needed and other information required by regulation (NMSA 72-5-1).
 - b. The State Engineer instructs the applicant to publish a notice, including places, amount, and purpose of the appropriation (NMSA 72-5-4).
 - c. The State Engineer holds a hearing if objections are filed (NMSA 72-5-5).
 - d. The State Engineer approves the permit if water is available (NMSA 72-5-6) and if approval is not contrary to the public interest (NMSA 72-5-7).
 - i. A lesser amount of water than that requested may be granted (NMSA 72-5-6).
 - ii. The State Engineer may vary the periods of annual use (NMSA 72-5-6).
 - iii. The legislature gave no indication of matters which are included within the "public interest," but the

New Mexico Supreme Court has interpreted the term broadly in *Young & Norton v. Hinderlider*, 15 N.M. 666, 110 P. 1045 (1910).

- e. The State Engineer issues a license on proof of application of the water to a beneficial use (NMSA 72-5-13).
- f. Changes in purpose, diversion, storage, or use, are authorized (NMSA 72-5-24).
 - i. The change cannot be allowed to the detriment of existing rights on the stream (NMSA 72-5-24).
 - ii. The same is true for a change of well location or water use (NMSA 72-12-7).
 - iii. Water can be diverted from one "stream or drainage" into another (NMSA 72-5-26).
- g. Transfer of water rights
 - i. Water rights may be transferred outright (NMSA 75-5-22).
 - ii. Water rights may be transferred subject to a lease, as provided by the Water Use Leasing Act (NMSA 72-6-1 to 72-6-7).
 - The lease may provide for immediate or future use (NMSA 72-6-3).
 - The lease may not exceed a term of ten years but may be renewable (NMSA 72-6-3).
- h. *State v. Crider*, 78 N.M. 312, 431 P. 2d 45 (1967) permits cities to appropriate water for future use, subject to application of the water to beneficial use within a reasonable time.
- 3. Preferences — There appear to be no preferences to the use of water by other sectors of the economy which could interfere with the priority of use by a geothermal developer, other than in emergency situations (NMSA 72-5-25).

C. Administrative Structure

- 1. The State Engineer is the Director of the Water Resources Division of the Natural Resources Department, and has "general supervision of waters of the state and of the measurement, appropriation, distribution thereof, and such other duties as required" (NMSA 72-2-1).
- 2. Duties of the State Engineer:
 - a. Approve permits for the appropriation of water (NMSA 72-5-6, 72-5-7).
 - b. Establish boundaries of any "underground stream, channel, artesian basin, reservoir or lake" (NMSA 72-12-12) and grant licenses to qualified drillers in such areas (NMSA 72-12-13).
 - c. As necessary for the "economical and satisfactory apportionment of water," divide the state into water districts and subdistricts, according to drainage areas

(NMSA 72-3-1) and appoint a watermaster for such districts (NMSA 72-3-2).

- d. Obtain injunctions against persons who divert water unlawfully (NMSA 72-5-39).
- e. Initiate procedures for an adjudication of any stream system to determine rights to the use of such waters, or alert the State Attorney General to intervene in an adjudication initiated by private parties, where required to protect the public interest (NMSA 72-4-15).

D. Regulation of Groundwater

1. "The water of underground streams, channels, artesian basins, reservoirs, or lakes, having reasonably ascertainable boundaries" are subject to appropriation (NMSA 72-12-1).
2. Procedure and Requirements
 - a. Apply to the State Engineer for a permit, including source and amount of water to be appropriated (NMSA 72-12-3).
 - b. The State Engineer publishes notices (NMSA 72-12-3).
 - c. If protests are filed or "if the State Engineer is of the opinion that the permit should not be issued," then the permit may be denied with or without a hearing (NMSA 72-12-13).
3. Permits to appropriate are only required in basins declared to have reasonably ascertainable boundaries (NMSA 72-12-20), and one must acquire a license from the State Engineer to drill in such areas (NMSA 72-12-12). Basins declared to date are shown in Fig. 4.2.
4. A change of location of use of a well is authorized in the manner used for a new appropriation (NMSA 72-12-7).
5. *City of Albuquerque v. Reynolds*, 71 N.M. 428, 379 P. 2d 73 (1962), held that the State Engineer was authorized to require the retirement of surface rights as a condition to the use of groundwater where groundwater and surface waters were inter-related.
6. With limited exception, transport of groundwater out of New Mexico is prohibited, as is pumping New Mexico groundwater from outside the state boundaries (NMSA 72-12-19).
7. Gould (p. 275) notes that *Mathers v. Texaco*, 77 N.M. 230, 421 P. 2d 771, N.M. (1966), held that the State Engineer is authorized to allow mining of nonrecharging aquifers and states that the case "suggests the State Engineer can and should apply a flexible rule, adjusting withdrawal rates and pumping levels to fit the particular situation at hand."
8. The point of diversion of a surface appropriator can apparently be changed to a groundwater source when, as Gould points out (pp. 286, 128), the groundwater is a source of water to the original appropriation and there will not be injury to existing rights.
9. Artesian wells are under the jurisdiction of the State Engineer and artesian conservancy districts (NMSA 72-13-2), and storage of waters from such wells is restricted to irrigation uses and in quantity (NMSA 72-13-10).

Fig. 4.2. Underground water basins in New Mexico declared as restricted for further appropriation of water rights.

E. Regulation of Geothermal Resources

1. Geothermal Resources Conservation Act (NMSA 71-5-1 to 71-5-24)
2. Definition (NMSA 71-5-3)
 - a. "Geothermal resources" means the natural heat of the earth, or the energy, in whatever form, below the surface of the earth present in, resulting from, created by, or which may be extracted from this natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas, and other hydrocarbon substances.
 - b. "Low-temperature thermal reservoir" means a geothermal reservoir containing low-temperature thermal water, which is defined as naturally heated water, the temperature of which is less than boiling at the altitude of occurrence, which has additional value by virtue of the heat contained therein, and if found below the surface of the earth, or in warm springs at the surface" (NMSA 71-5-3).
3. The Oil Conservation Commission and the Oil Conservation Division of the Energy and Minerals Department may have concurrent powers under the act (NMSA 71-5-6).
4. Purpose of Act
 - a. To protect the public welfare and natural resources of the state and to "encourage maximum economic recovery" (NMSA 71-5-2).
 - b. The statute contains numerous sections on the prevention of waste and on resource allocation.
5. The Division has the power to require "certificates of clearance for the production or transportation of geothermal resources" (NMSA 71-5-8).
6. The Division also has authority to (NMSA 71-5-8):
 - a. Prevent geothermal resources and other fluids from moving to other strata.
 - b. Prevent premature cooling of the geothermal resource by "water encroachment" or other means.
 - c. "Permit and regulate the injection of fluids into geothermal reservoirs and low-temperature reservoirs."
 - d. Regulate disposition of geothermal resources to prevent contamination of fresh water.
7. On lands under lease by the state, wells may be used for reinjection on approval of the Commissioner of Public Lands (NMSA 19-13-13 — Note that this section is not part of the Geothermal Resources Conservation Act).

F. Issues/Potential Constraints to the Development of Geothermal Energy

1. Though regulated by state agencies concerned with oil (E.3), the definition of geothermal resources is broad enough to include water (E.2).

- a. Appropriation is required in "declared basins" (D.3) prior to use. "Declared basins" are shown in Fig. 4.3.
- b. The restrictions on artesian well reservoirs (D.9) may also apply.
- c. Olpin, Tarlock, and Austin (ref. 4, at 854-97) suggest that overlapping jurisdiction by state oil agencies and water agencies can cause conflicts. For example, geothermal development may be stymied in basins closed to further appropriation. It is also not clear whether a geothermal developer who interferes with the rights of a water user can be prohibited from further withdrawal.

ORNL - DWG 80 - 17765R

Fig. 4.3. Policies on the appropriation of groundwater in Utah.

2. As Gould (p. 286, n. 127) notes, several cases, in other contexts, have already been faced with the issue of hydrological communication between groundwater and surface water (D.8). A bill proposed in 1978 that would have allowed geothermal developers to supersede water rights on provision of "offset water" or the payments of compensation, was defeated by the state legislature. However, the State Engineer, according to discussions with that office, currently plans a scheme that includes a permit for geothermal development based on a "water replacement plan."
3. The authority of the State Engineer over groundwater not in a declared groundwater basin (D.1, D.3) is not entirely clear. It appears that the State Engineer may intervene in suits by or against conservancy districts irrespective of whether a declared groundwater basin is in issue.
4. The restriction on storage of artesian waters (D.9) may affect cooling of geothermal plants and may eliminate the use of nongeothermal artesian waters as sources of cooling tower makeup water.
 - a. This increases the potential usefulness of the leasing procedure (B.2.g).
 - b. It also emphasizes the concept of a "future appropriation" (B.2.h) which, as Gould notes (p. 266), is not likely to be extended to energy facilities.
5. New Mexico has no statute or court decision which directly addresses the disposition of water saved through more efficient use, but Gould (pp. 282-85) is of the opinion that current state law could allow ownership and subsequently, transfer by the more efficient user.
6. Transfer of water
 - a. Gould (p. 277) notes that at least one conservancy district prohibits the transfer (B.2.f) outside the district without its consent, but this position has not yet been judicially tested.
 - b. Gould (p. 274) also alludes to the issue of whether New Mexico's restrictions on the transport of groundwater (D.6) are constitutional.
 - c. It may be that acquiring a water right from an existing permit holder (B.2.g) may be easier than making a new appropriation because there appears to be no provision for a public interest determination (B.2.d) by the State Engineer in such a transfer. On the other hand, this method of acquiring water rights would be subject to the change-of-use provisions (B.2.f) in many cases.

4.5 Utah

A. Type of System

1. Prior appropriation
2. Authority

- a. *Stowell v. Johnson*, Utah 215, 26 P. 290 (Utah 1891)
- b. UCA 73-1-3

B. Permit System

- 1. Permitting authority — State Engineer (UCA 73-3-2, Supp. 1979)
- 2. Procedure and Requirements
 - a. Apply to State Engineer, setting forth required data, including amount and source of desired appropriation.
 - b. The State Engineer publishes a notice of the application (UCA 73-3-6).
 - c. After allowing time for receipt of protests (UCA 73-3-7), the State Engineer must approve the application if:
 - i. Unappropriated water is available.
 - ii. Existing rights will not be impaired.
 - iii. The proposal is physically and economically feasible.
 - iv. The applicant is financially able to complete the project.
 - v. The appropriation will not "interfere with [the water's] more beneficial use for irrigation, domestic or culinary, stock watering, power or mining development or manufacturing [and will not] unreasonably affect public recreation or the natural stream environment, or ... prove detrimental to the public welfare."
 - vi. The applicant supplies proof of application of the water to a beneficial use (UCA 73-3-16, Supp. 1979) and the State Engineer issues a certificate (UCA 73-3-17).
- 3. The State Engineer may issue temporary permits not exceeding one year (UCA 73-3-5.5, Suppl. 1979).
- 4. The State Engineer may also limit the tenure of permits for power and other purposes but not to a period "less than that ordinarily needed to satisfy the essential and primary purpose of the application" (UCA 73-3-8, Supp. 1979).
- 5. Preferences
 - a. The Utah Supreme Court, in *Tanner v. Bacon*, 136 P. 2d 957 (Utah 1943), interpreted the statute quoted in B.2.c.v, (above) to mean that the State Engineer is authorized to limit a prior application in favor of subsequent applications. In this case, water rights for a power project were held to be subordinate to a subsequent application which proposed the use of water for domestic, irrigation, and power purposes and which was found to be "more beneficial."
 - b. UCA 73-3-21, which states that in times of scarcity preference is to be given to domestic and then agricultural uses, was alluded to in *Tanner v. Bacon* as giving guidance to the State Engineer.
 - c. The Governor is authorized to withdraw waters from further appropriation for any use, when dictated by the welfare of the state (UCA 73-6-1).

C. Administrative Structure

1. Department of Natural Resources, Division of Water Resources

- a. The Board of Water Resources is the policy-making body of the Division of Water Resources (UCA 73-10-1.5).
- b. The Division of Water Rights is the water rights authority of the state (UCA 73-2-1.1, Supp. 1979).
- c. The State Engineer is the Director of the Division of Water Rights (UCA 73-2-1.2).

2. Duties of the State Engineer:

- a. "To secure the equitable and fair apportionment and distribution of the water according to the respective rights of appropriators" (UCA 73-2-1).
- b. Sue to enjoin unlawful diversion (UCA 73-2-1).
- c. Establish water districts (UCA 73-2-1).
- d. Grant applications to appropriate water from Utah for use in other states only after evaluating and making public the advantages of such appropriation (UCA 73-2-8, Supp. 1979). [The Bear River Compact provides a different procedure (Gould, p. 398).]
- e. Deliver biennial reports to the Governor (UCA 73-2-10, Supp. 1979).
- f. Cooperate with other federal and state agencies in the investigation of underground and surface water generally, and with approval of the Governor and the Executive Director of Natural Resources, cooperate with other agencies in investigations for the purpose of adjudication of water rights (UCA 73-2-1, 73-2-15, Supp. 1979).
- g. Conduct informal proceedings for the settlement of disputes over water or its distribution (UCA 73-2-16).
- h. "To plug, repair, or to otherwise control artesian wells which are wasting public water" (UCA 73-2-21, Supp. 1979).
- i. Grant applications to appropriate water (UCA 73-3-1).
- j. Grant approvals for a change in the point of diversion or place or purpose of use or for temporary changes but only on payment of compensation if vested rights are impaired (UCA 73-3-3).
 - i. The statute states that applications for changes should not be rejected because they may impair existing rights.
 - ii. Such changes may be approved as to "part of the water" on payment of compensation.
- k. Conduct procedures for the determination of water rights (UCA 73-4-1, UCA 73-4-3, Supp. 1979).
- l. Appoint water commissioners, under certain circumstances, for the distribution of water (UCA 73-5-1).
- m. "To prevent waste, loss, pollution or contamination of any waters whether above or below the ground" (UCA 73-5-9).
- n. Approve transbasin diversions of water (UCA 73-3-20).

3. Board of Water Resources

- a. As the policy-making body of the Division of Water Resources, the Board's functions are largely oriented toward development projects (UCA 73-10-1 to 73-10-30, Supp. 1979).
- b. While the board is to prepare a state water plan (UCA 73-10-15), there is no provision that forces action in accordance with it.

D. Regulation of Groundwater

1. Groundwater is the property of the public (UCA 73-1-1) and is therefore subject to appropriation (UCA 73-3-1).
2. Groundwater is appropriated by means of the same procedure as surface waters (UCA 73-3-2, Supp. 1979).
3. In *Wayman v. Murray City* (23 Utah 2d 97, 458, P. 2d 861, 1969) the Utah Supreme Court reasoned that the general policy of Utah's water law, to put water to beneficial use, required the application of a "rule of reasonableness" to the use of groundwater.
 - a. Thus, the rule of "first in time, first in right" is not applied rigidly to the use of groundwater.
 - b. "This involves an analysis of the total situation: the quantity of water available, the average annual recharge in the basin, the existing rights and their priorities. All users are required where necessary to employ reasonable and efficient means in taking their own waters in relation to others to the end that wastage of water is avoided and that the greatest amount of available water is put to beneficial use" (458 P. 2d 861, 865).
 - c. Historic pumping levels are probably not protected, thus allowing new users to come in.
 - d. Gould (pp. 399-400) notes that although *Wayman* could be read as favoring groundwater mining under some circumstances, the case did not decide that point and thus it is not clear whether groundwater mining is permissible.
4. The State Engineer has general administrative supervision of groundwater (UCA 73-2-1). The map in Fig. 4.3 shows how this authority has been implemented.
5. "The State Engineer is authorized to plug, repair, or to otherwise control artesian wells which are wasting public water" (UCA 73-3-21).
6. On approval by the State Engineer, junior groundwater appropriators who injure the rights of senior groundwater appropriators may continue such use on replacement of the injured party's water (UCA 73-3-23).
7. The State Engineer is authorized to hold a hearing to determine "whether the underground water supply within [a given] area is adequate for the existing claims," and to divide the water among the claimants if it is not (UCA 73-5-1).

E. Regulation of Geothermal Resources

1. The Utah Legislature did not define "geothermal energy," but mentioned the "production of water to be used for geothermal energy production," and granted jurisdiction over such resources to the Division of Water Rights (UCA 73-1-20).
2. Geothermal wells are to be operated in accordance with the public welfare and maximum economic recovery (UCA 73-1-20).
3. The Division of Water Rights has adopted regulations (Rules and Regulations of the Division of Water Rights for Wells Used for the Discovery and Production of Geothermal Energy in the State of Utah, March 1, 1978) under its legislative mandate.
 - a. "Geothermal Resources" means the natural heat energy of the earth, the energy in whatever form which may be found in any position and at any depth below the surface of the earth, present in, resulting from, or created by, or which may be extracted from such natural heat and all minerals in solution or other products obtained from the material medium of any geothermal resource [Rule 1-2(k)].
 - b. Geothermal developers must appropriate geothermal fluid in the same manner as conventional water (Rule 2-1-1).
 - c. "Appropriation of water for geothermal purposes shall not be considered mutually interchangeable with water for any purpose" (Rule 2-1-1).
 - d. "Water, brine, steam, or condensate produced during a geothermal operation may be subject to further appropriation if physical conditions permit" (Rule 2-1-1).
 - e. Distribution of the geothermal resource is apparently to be based on correlative rights (Rule 2-4-3) which is defined as the operator's "just and equitable share in the geothermal resource" (Rule 1-2).
4. A more complete bill, the Geothermal Resource Conservation Act, has been introduced as of June 1980 but not been passed by the State Legislature.

F. Issues/Potential Constraints to the Development of Geothermal Energy

1. Taken in isolation, the current geothermal statute:
 - a. Does not classify geothermal resources as mineral or water, thereby leaving the question of ownership of the resource unsettled [as in *United States v. Union Oil* 549 F. 2d 1271 (9th Cir. 1977)].
 - b. Does not differentiate between conventional and geothermal water, thus possibly subjecting geothermal fluid and conventional water to all aspects of the state's water law.
 - c. Does not give the Division of Water Rights authority to unitize, although this might be inferred from legislative encouragement to maximize economic recovery (E.2).

2. Gould (p. 391) has noted that it is uncertain whether compensation must be paid if preferences are invoked during periods of water scarcity (B.5.b).
 - a. If not, then operation of geothermal facilities may be subject to interruption (see Fig. 4.3).
 - b. In any event, geothermal facilities must compete with these preferred uses for the initial appropriation, as the section can be considered as a preference at the application stage (Gould, p. 391).
 - c. Whether or not compensation must be paid, it is not clear whether geothermal water could be used for agricultural and domestic uses (B.5.b) despite the regulation by the Division of Water Rights against interchangeability (E.3.b).
3. Note that while agricultural and domestic users may not be able to afford to interfere with geothermal uses during times of shortage (assuming compensation is required per F.2 above) geothermal operations will be able to compensate injured parties (C.2.j) when acquiring existing water rights.
4. As has been suggested by Gould (pp. 395-96), it is not known how the discretionary use of authority will affect energy-producing facilities but two areas are of particular concern:
 - a. The broad discretion of the State Engineer in determining the public welfare (B.2.c.v), especially as interpreted by the Utah Supreme Court (B.5.a).
 - b. The Governor's authority to withdraw water from further appropriation (B.5.c).
5. Olpin, Tarlock, and Austin (ref. 4, p. 865) indicate that as to state lands, a lease must be acquired in addition to an appropriation. This, in conjunction with the mention of correlative rights (which appear to be inconsistent with prior appropriation) (E.3.e), shows that Utah treats geothermal resources as both water and minerals. This dichotomy could produce serious conflicts between geothermal developers and (a) conventional water users and (b) overlying landowners who may own the resource. Olpin, Tarlock, and Austin also noted the problem presented by Utah Power and Light, which has attempted to acquire geothermal rights by application to the State Engineer only, without first acquiring a lease. The issue is unsettled.
6. Gould (pp. 403-4) notes that a proposal to transfer to a new use water which has been saved through increased efficiency is treated like other applications for a change in use based on *East Bench Irrigation Co. v. Deseret Irrigation Co.* 271 P. 2d 449 (Utah 1954) and *Piute Reservoir and Irrigation Co. v. West Panguitch Irrigation and Reservoir Co.*, 364 P. 2d 113 (Utah 1961).
 - a. The key determination in these cases was whether downstream appropriators would be worse off with the transfer than without it. This question must be answered in the negative before any such transfer can be considered.

- b. It is questionable whether such transfers are in all respects treated as other proposals for a change in use, since in the latter (C.2.j), the legislature allows existing rights to be affected on payment of compensation.

4.6 Oregon

A. Type of System

- 1. Prior appropriation
- 2. Authority — *Hough v. Porter*, 95 P. 732 (Ore. 1908); 98 P. 1083 (Ore. 1909); 102 P. 728 (Ore. 1909)

B. Permit System

- 1. Permitting authority — Water Resources Director (Director), with approval by Water Policy Review Board (Board) in some cases (ORS 537.160, 537.170)
- 2. Procedure and Requirements
 - a. File application with the Water Resources Director, enclosing required data, including the source and amount of water to be used (ORS 537.140).
 - b. The Director must grant an opportunity for a public hearing if the proposed use could conflict with public rights (ORS 537.170).
 - c. The Director approves the application if water is to be applied to a beneficial use and if withdrawal will not conflict with existing rights (ORS 537.160).
 - d. If the Director believes that the proposed use may adversely affect the public interest, he refers the application to the Board, which holds a public hearing, (ORS 537.170).
 - e. The Board considers the following factors to determine whether the proposed use is in the public interest (ORS 537.170):
 - i. Is the water being conserved for its highest possible use, including power development?
 - ii. Does the proposed use provide for maximum economic development?
 - iii. Is the required amount of water available for appropriation?
 - iv. Is the proposed use wasteful or unreasonable?
 - v. Are water rights being protected?
 - vi. Does the proposed use conform with the state water resources policy?
 - f. If the Board determines that the proposed use would prejudice the public interest, it must reject the application or require its modification. Otherwise, it must approve the application (ORS 537.170).

- g. The Director issues a water rights certificate upon his satisfaction that diversion of the water to a beneficial purpose has been completed (ORS 537.250).

3. Preferences

- a. The Board may classify virtually all water sources as to their highest and best use and thus restrict uses to those specified in the classification (ORS 536.340).
- b. The Board may prescribe preferences to the use of water resources by means of a "water resources statement" (ORS 536.340).
- c. In formulating a program for the use of water resources (ORS 536.300) the Board is to consider the legislative declaration of policy that human consumption shall be given preference in deciding on competing applications, or in times of shortage [ORS 536.310 (12)].
- d. Another provision evinces a preference for domestic and agricultural uses, but as Gould (p. 330) notes, *Phillips v. Gardiner* (469 P. 2d 42, Ore. App. 1970) held that such preferences do not supersede chronological priority, and therefore, "it seems that once a non preferred use matures into a vested water right the preference statutes generally have no effect." However, see B.3.e and B.3.f (below).
- e. The Klamath River Basin Compact establishes an order or preference superior to all water rights acquired after the effective date of the Compact (ORS 542.610, Art. III).
- f. In "critical" groundwater areas, the Director is to accord preference to domestic and agricultural uses and then other uses, in his discretion, irrespective of priority.
- g. To protect environmental values, the legislature has withdrawn numerous water bodies or parts thereof, from appropriation (ORS 538.110 to 538.300).

C. Administrative Structure

- 1. The Water Resources Department consists of the Water Policy Review Board, the Water Resources Director, and their respective staffs. The Water Resources Director is the chief executive of the Water Policy Review Board (ORS 536.008).
- 2. Duties of the Director
 - a. Oversee water distribution (ORS 540.030), including that of groundwater (ORS 537.777).
 - b. Perform duties delegated to him by the Board, to whom he is responsible (ORS 536.032).
 - c. Divide the state into water districts (ORS 540.030).
 - d. Approve proposals for appropriation of water (ORS 537.160).
 - e. Approve proposed changes in the point of diversion, or place or purpose of use (ORS 540.520, ORS 540.530).
 - f. Designate critical groundwater areas and impose conditions in accordance therewith (ORS 537.730, ORS 537.735).

- g. Withhold from appropriation water which may or will be used for certain projects (ORS 542.040).
 - h. Investigate groundwater resources and determine rights to appropriate the particular reservoir in accordance with the state law of groundwater appropriation (ORS 537.665).
 - i. Make an initial determination of rights to water in streams (ORS 539.020) and groundwater (ORS 537.670).
3. Duties of the Water Policy Review Board
- a. The Board shall establish policy statements.
 - i. Based on water resources investigations, the Board is to formulate a program for water use and issue statements of policy (ORS 536.300).
 - ii. Some matters to be considered in the formulation of policy include (ORS 536.310):
 - Existing rights and future beneficial uses.
 - Economic development.
 - Multiple uses of water.
 - Protection of groundwater supplies.
 - Minimum stream flows.
 - iii. Projects not in compliance with the state policy can proceed only after compliance with an established procedure (ORS 536.360, ORS 536.370).
 - b. By means of a water resource policy statement, the Board may classify waters (and thus restrict the uses to which they are put) and prescribe preferences (ORS 536.340).
 - c. The Board may withdraw waters from further appropriation (ORS 536.410).
 - d. The Board is to review applications referred to it by the Director and determine whether they contravene the public interest (ORS 537.170).

D. Regulation of Groundwater

1. The legislature enacted the Ground Water Act of 1955 (ORS 537.505 to 537.795).
2. Geothermal prospecting wells and production wells of more than 610 m (2000 ft) in depth are excluded from the definition of "well" in the Ground Water Act (ORS 537.515) and the Director is charged with adopting rules governing reinjection of fluids from wells of less than 610 m (2000 ft) in depth, and whose fluids are less than 121°C (250°F) or have been appropriated under the Ground Water Act (ORS 537.783).
3. A procedure for appropriation of groundwater, largely similar to that of surface water, is established by ORS 537.615 to 537.630. However, as Gould (pp. 339-40) notes, there is no provision for reference to the Board to determine public interest issues.

4. Uses of groundwater prior to the date of the act are protected (ORS 537.585, 537.595).
5. The Director is authorized to hold a hearing when he believes proposed appropriation will conflict with existing surface- or groundwater rights (ORS 537.622).
6. The director may investigate groundwater reservoirs and make a final determination of rights thereto (ORS 537.665 to 537.695), and his findings of fact must include "the lowest permissible water level in each groundwater reservoir" (ORS 537.685).
7. Critical Groundwater Areas (see Fig. 4.4)
 - a. The Director may declare and define a critical groundwater area (ORS 537.730 to 537.735) if:
 - i. Groundwater levels are declining excessively.
 - ii. Groundwater appropriations conflict with one another.
 - iii. Groundwater has been or will be polluted.
 - b. The declaration of a critical groundwater area may include provisions for (ORS 537.735):
 - i. Prohibiting future appropriations.
 - ii. Apportioning water according to priority.
 - iii. According preference first to domestic and livestock uses and then other uses irrespective of priority (B.3.f above).

Fig. 4.4. Groundwater basins in Oregon restricted for further appropriations.

- iv. Other measures necessary to protect the public welfare, health, and safety.

E. Regulation of Geothermal Resources

1. Oregon Geothermal Resources Act (ORS 522.055 to 522.990)
2. Definition [ORS 522.055 (7)]

- a. Geothermal resources means the natural heat of the earth, the energy, in whatever form, below the surface of the earth present in, resulting from, or created by, or which may be extracted from the natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases, and steam, in whatever form, found below the surface of the earth, exclusive of helium or of oil, hydrocarbon gas, or other hydrocarbon substances, but including, specifically:
 - i. All products of geothermal processes, embracing indigenous steam, hot water, and hot brines;
 - ii. Steam and other gases, hot water, and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations;
 - iii. Heat or other associated energy found in geothermal formations; and
 - iv. Any by-product derived from them.
 - b. The statute does not apply to all geothermal fluid (ORS 522.025).
 - i. Provisions relating to the "location and drilling" of production wells do not apply to wells producing as of July 1, 1975.
 - ii. Provisions relating to the "location and drilling" of wells do not apply to production wells 610 m (2000 ft) or less in depth and under 121°C (250°F).
 - iii. Provisions relating to the "location and drilling" of wells do not apply to production wells 610 m (2000 ft) or less in depth in cases where the fluid has been appropriated under Oregon groundwater law.
- #### 3. Permits
- a. Prospect wells (ORS 522.055)
 - i. A permit must be obtained from the State Geologist prior to drilling test wells less than 610 m (2000 ft) in depth.
 - ii. On receipt of the application, the State Geologist circulates it to the Water Resources Director, among others.
 - b. Geothermal wells for production and reinjection
 - i. A permit must be obtained from the State Geologist prior to drilling any production or reinjection well (ORS 522.115).

- ii. On receipt of the application, the State Geologist circulates it to the Water Resources Director and the Water Policy Review Board (ORS 522.125).
 - iii. In addition to conditions imposed by the State Geologist, conditions of the Water Resources Director, in accordance with the legislative policy on groundwater appropriation (ORS 537.525) must be incorporated into the permit [ORS 525.135 (4)].
- c. With some exceptions, prior to reinjection, a water pollution control facilities permit must be obtained from the Department of Environmental Quality [ORS 522.019 (3)].
- 4. Interference with conventional water
 - a. The policy of the legislature is to prevent interference by geothermal operations with water already in, or to be put to beneficial use, and to develop geothermal resources consistently with protection of water resources (ORS 522.015).
 - b. "In addition to any other liability" the operator is liable for violation of permit conditions relating to the protection of groundwater (ORS 522.155).
 - c. The Board of the State Department of Geology and Mineral Industries must adopt standards for geothermal operations for the protection against contamination of groundwater and surface waters (ORS 522.155).
 - d. The Board of the State Department of Geology and Mineral Industries is authorized to issue orders for "the protection of existing and future beneficial uses of water" and "maintaining the renewability of geothermal resources and any other natural resources" (ORS 522.815).
- 5. Reinjection (ORS 522.019)
 - a. Reinjection or disposal other than into the same reservoir from which the fluid was withdrawn, requires a determination by the State Department of Geology and Mineral Industries that such is required by the legislative policy on geothermal resources (ORS 522.015) and the public interest.
 - b. "Disposal by other means may include any secondary use of geothermal fluid after the primary use ... for electrical power generation Secondary uses may include, but shall not be limited to, use of condensate resulting from electrical power plant operations for plant cooling purposes or use of such geothermal fluid for agricultural, commercial, or industrial purposes."
 - c. The State Department of Geology and Mineral Industries must adopt rules governing reinjection of fluid derived from wells 610 m (2000 ft) or more in depth, and at least 121°C (250°F).

F. Issues/Potential Constraints to the Development of Geothermal Energy

- 1. As Gould (p. 336) points out, powers over water given the Water Policy Review Board are broad, but in some respects, uncertain.

For example, extending the reasoning of a 1962 attorney general's opinion which indicated that power over groundwater resources resides in the Director (p. 342), it may be that no agency has authority to classify and withdraw groundwaters, notwithstanding C.3.b and C.3.c (above).

2. Gould (p. 344-45) also notes that Oregon's power plant siting legislation grants authority to a Siting Council to designate areas unsuitable for energy facilities; it could also conflict with Oregon's water law because while the certificate issued by the Siting Council is binding on state agencies, the legislature has given similar authority to the board regarding compliance with the state water policy. A constraint could arise where the Council grants a certificate, but the Board disapproves of the water use.
3. With respect to groundwater mining, Gould (pp. 347-48) notes that although there are no direct legislative or judicial statements, some statutes (see, e.g., D.5, D.6, and D.7 above) appear to prohibit mining but allow some drop in pumping levels, at least in relation to rechargeable aquifers.
4. Gould (p. 349) suggests that it may be easier to acquire existing water rights (C.2.e, above) rather than initiate new ones because the latter requires a public interest consideration whereas a transfer apparently does not.
5. Although Oregon appears to exclude hotter geothermal resources from the operation of its water law, the Director and/or Board may be able to exert considerable influence.
 - a. The Geothermal Resources Act has not yet been subjected to judicial review, and the extent of "location and drilling" (C.2.b) may not be clear.
 - b. If it is determined that the geothermal statute does not apply, the question may be asked to what extent does the water law apply.
 - c. In reviewing an application for a geothermal permit [forwarded from the State Geologist (see C.2.b)], the Water Resources Director can, in effect, impose conditions to protect water resources.
 - d. It would appear that no appropriation is needed to divert geothermal fluid to a "secondary use" (C.5.b) although this matter has not been tested judicially and conditions as to secondary uses are stated on water use permits.
 - e. It is not clear which sections of the statutes would govern geothermal resources which are located both above and below 610 m (2000 ft) under the surface, and having temperatures both hotter and cooler than 121°C (250°F).
6. The State Department of Geology and Mineral Industries would appear to have authority to require 100% reinjection on a case-by-case basis (E.5.a).
7. It would appear that geothermal resources that meet the 610 m/121°C (2000 ft/250°C) criteria are to be treated as minerals (with ownership in the overlying landowner). Those that do not are subject to the state's water law. In any event, the ownership section of the statute (ORS 522.035) is of little help because it says that ownership of

geothermal resources is in the surface owner but qualifies the statement by indicating that it is not to deprive the state of rights it might have if the resource was water.

4.7 Nevada

A. Type of System

1. Prior appropriation
2. *Reno Smelting Works v. Stevenson*, 21 P. 317 (Nev. 1889)

B. Permit System

1. Permitting Authority — State Engineer (NRS 533.325)
2. Procedure and Requirements
 - a. Apply to State Engineer, setting forth amount of water desired, source, and other pertinent data (NRS 533.330, 533.335).
 - b. The State Engineer publishes notice of the application at the expense of the applicant (NRS 533.360).
 - c. On the filing of a protest, a hearing may be held at the discretion of the State Engineer (NRS 533.365).
 - d. Applications are to be approved (NRS 533.370) if the proposed use will do neither of the following:
 - i. Impair the value of existing rights.
 - ii. Be "deterimental to the public welfare."
 - e. Applicant submits proof to the State Engineer of the application of water to a beneficial use (NRS 533.410) and the State Engineer issues a certificate (NRS 533.425).
3. Preferences
 - a. Other than that for groundwater (D.7, below) there appear to be no statutory preferences to the use of water (Gould, p. 242).
 - b. Gould (p. 242) noted that the State Engineer's Office was engaged in water planning which would influence allocation decisions under the State Engineer's "public welfare" authority (B.2.d).
 - c. The State Engineer is also to review government proposals for water development projects to ensure their compatibility with the State Water Resource Plan (NRS 532.165).

C. Administrative Structure

1. The Department of Conservation and Natural Resources consists of the State Engineer and the Division of Water Planning.
2. Duties of the State Engineer
 - a. Approve the application for the appropriation of surface water (NRS 533.325) and groundwater (NRS 534.050).
 - b. Approve applications for a change in place of diversion or manner or place of use (NRS 533.325).

- i. Applications to change a use to one "involving the industrial purpose of generating energy to be exported out of Nevada may be denied based upon the public interest and the economic welfare" (NRS 533.520).
 - ii. With limited exceptions, water currently applied to beneficial use in Nevada may not be transferred to uses outside the state (NRS 533.520).
 - iii. NRS 533.040 states that water rights are to remain with their place of use but can be transferred if it becomes "impracticable to use water beneficially or economically" at that place.
 - iv. In another section, NRS 533.370, the legislature directs the State Engineer to approve applications for change unless it will conflict with existing rights or will be detrimental to the public interest.
 - c. Supervise the distribution of water (NRS 533.305) and appoint officials to assist in that duty (NRS 533.270, 533.275).
 - d. Divide the state into water districts to ensure the proper utilization and conservation of water resources (NRS 533.300).
 - e. Conduct studies and inventories for flood control water development projects (NRS 532.165).
 - f. Designate groundwater basins (NRS 534.030) and determine whether to establish groundwater boards therein (NRS 534.035).
 - g. Initiate procedures for the adjudication of water rights (NRS 533.090 to 533.265).
 - h. Permits for the initial appropriation of water can be granted for use outside Nevada if the state in which the water is to be used allows its water to be used in Nevada (NRS 533.5.5).
 - i. Gould (p. 247) notes that Nevada has no statutes prohibiting transbasin diversion, and that water can be diverted for use anywhere within Nevada, with the exception of waters covered by the California-Nevada Interstate Compact.
3. The Division of Water Planning is primarily an advisory and data analysis organization (NRS 540.031, 540.051).

D. Regulation of Groundwater

- 1. Rights to the use of groundwater can only be acquired by the same appropriation procedures used for surface waters (NRS 534.020, 534.080).
- 2. In "designated basins," a permit to appropriate must be acquired prior to sinking a well, whereas in non designated basins a well can be drilled without a permit, but a permit must be acquired prior to any diversion of the water (NRS 534.050).

3. In designated basins there may be groundwater boards (NRS 534.035) to which the State Engineer must submit all applications for appropriation of groundwater and changes in groundwater rights.
 - a. The board renders advice on the proposal.
 - b. In case of disagreement, the State Engineer prevails.
4. The legislature has expressly stated that an appropriation of groundwater "must allow for a reasonable lowering of the static water level" to be determined by the State Engineer, and new appropriations can be granted even though they may cause a lowering of the water level (NRS 534.110).
5. The State Engineer may restrict withdrawals according to priority "where it appears that the average annual replenishment to the groundwater supply may not be adequate for the needs of all permittees and all vested-right claimants," and may restrict the drilling of new wells where they "would cause an undue interference with existing wells" (NRS 534.110).
6. In designated basins which are being depleted, the State Engineer may make such rules "as are deemed essential for the welfare of the area involved" (NRS 534.120).
7. In designated basins which are being depleted, preferences may be utilized in granting applications to appropriate groundwater among the following uses (NRS 534.120):
 - a. Domestic
 - b. Municipal
 - c. Quasi-Municipal
 - d. Industrial
 - e. Irrigation
 - f. Mining
 - g. Stock-watering
8. It appears that groundwater mining is prohibited (D.5), although this issue has not clearly been settled.

E. Regulation of Geothermal Resources

1. Definition: "... unless the context otherwise requires, geothermal resource means heat or other associated geothermal energy found beneath the surface of the earth" (NRS 534A.010).
2. "Any water and steam encountered during geothermal exploration is subject to the appropriation procedures" for surface water and groundwater (NRS 534A.040).
3. The State Engineer is authorized to adopt regulations for the development of geothermal resources, including those for the prevention of pollution and waste, and defining geothermal areas (NRS 534A.020).

F. Issues/Potential Constraints to the Development of Geothermal Energy

1. Gould (pp. 244-245) notes that the scope of the State Engineer's "public welfare" discretion (B.2.d) is unknown since the phrase has not been judicially interpreted, and the legislature indicated no criteria.

2. Transfer of water rights to new uses.

- a. The constitutional validity of two Nevada provisions is open to question (Gould, pp. 250-51).
 - i. The section allowing denial of a proposed change of water use for generation of electricity for export out of Nevada (C.2.b.i) may violate the commerce clause of the Constitution since it promotes economic protectionism.
 - ii. For the same reason, the section prohibiting transfer of existing rights to uses outside the state (C.2.b.ii) may also be unconstitutional.
- b. Gould (p. 250) points out that unlike other states, Nevada extends consideration of the public interest beyond the initial application process to the transfer process (C.2.b.vi) and that although this has not been an impediment to date, it could be in the future.
- c. Similarly, the section allowing a transfer if it becomes "impracticable" to use a water right on the land to which it is attached (C.2.b.v) has remained dormant (Gould, p. 249).
 - i. Depending on the definition of "impracticable," this section could constrain development if it is "revived."
 - ii. The exact effect of the statute cannot be determined because it is unknown whether impracticability was meant to be the exclusive basis for a transfer.

3. Gould (pp. 245-46) has suggested that the Nevada Utility Environmental Protection Act (NRS 704.820 to 704.900), which covers geothermal energy, could be a constraint to development because:

- a. The State Environmental Commission (of which the State Engineer is a member) could prevent construction because of an adverse public interest determination, and
- b. The Commission may deny the use of Nevada's natural resources to be used for generating electricity which is to be exported from Nevada.

4. Gould (p. 251) has stated that transfer of water saved through more efficient uses is an area not yet addressed in Nevada, but it should be noted that, as in other states, the rights of junior appropriators to return flows have been protected in Nevada.

5. Gould (p. 242) has also alluded to the lack of clarity in the section which provides for assigning preference to uses of groundwater (D.7).

- a. Other than the consideration of public welfare, there are no criteria for assigning preferences.
- b. It is not clear whether the statute affects applicants for permits or existing appropriators as well.

6. Although groundwater mining may be prohibited (D.8), talks with a representative of the Division of Water Resources (12/13/79) indicate that a distinction could be made for geothermal fluid.
7. It appears that geothermal resources are governed by the same law as that governing the use of groundwater. Unless a distinction between conventional groundwater and geothermal fluid is made, the mandatory allowance for seasonable lowering of static water levels (D.4) could interfere with maximum economic production of geothermal energy. Also, geothermal resources could become subject to the same vagaries as groundwater.
8. On the other hand, when applying the groundwater law to geothermal resources, action taken by the State Engineer (D.5, D.6) could serve to assure maximum economic recovery. In fact, the State Engineer has granted permits for geothermal development in the same area in which he has denied groundwater permits.
9. Although geothermal resources are clearly subject to regulation by the State Engineer, the definition of geothermal resources neither expressly includes nor excludes water. Thus, it is conceivable that a question of ownership of the resource could arise.

4.8 Idaho

A. Type of System

1. Prior appropriation
2. Idaho Constitution, Art. 15, Sect. 3

B. Permit System

1. Permitting Authority — Idaho Department of Water Resources (DWR) (ICA 42-204, ICA 42-219, Supp. 1980)
2. Procedure and Requirements
 - a. Apply to DWR, setting forth pertinent data, including the water source and amount of water (ICA 42-202).
 - b. Notice (ICA 42-203, Supp. 1980).
 - i. DWR gives notice of the application to appropriate water, with source and quantity.
 - ii. DWR holds a public hearing on project by any interested party.
 - c. DWR may reject the permit or grant it with conditions on finding that (ICA 42-203, Supp. 1980):
 - i. Quantities under existing rights will be reduced.
 - ii. Water supply is insufficient for the proposed use.
 - iii. The application was not made in good faith or was made for delay or speculation.
 - iv. The applicant does not have sufficient financial resources to complete the work.

- v. The proposal conflicts with local public interest "where local public interest is defined as the affairs of the people in the area directly affected by the proposed use."
- d. Within a specified time, the applicant submits to DWR proof that it has diverted the water in question to beneficial use (ICA 42-217, Supp. 1980).
- 3. Preferences — Art. 15, Sect. 3 of the Idaho Constitution gives preference to domestic and agricultural use and, in some circumstances, mining uses, but only on payment of fair compensation.

C. Administrative Structure

- 1. Duties of DWR
 - a. Issue permits (ICA 42-204, Supp. 1980).
 - b. Approve changes in the point of diversion or place of use (ICA 42-222, Supp. 1980).
 - c. Divide the state into water districts (ICA 42-604) for the purpose of aiding in the distribution of water (ICA 42-607).
 - d. Take action to protect groundwater resources (ICA 42-233a, Supp. 1980, ICA 42-237a, Supp. 1980, ICA 42-231) (see Fig. 4.5).
 - e. Supervise water distribution (ICA 42-602).
 - f. Commence actions for the adjudication of water rights (ICA 42-1406).
- 2. Duties of the Idaho Water Resource Board (ICA 42-1734 Supp. 1980).
 - a. Formulate a policy and program for the conservation, development, and use of all unappropriated water resources of the state and adopt a state water plan.
 - b. Foster and encourage minimum stream flow for aquatic life and the minimization of pollution.
 - c. Institute judicial proceedings to have water rights established by court decree on any stream, lake, or underground water basin.
 - d. In some cases, generate and wholesale hydroelectric power.
 - e. Finance and acquire water rights for specific water projects.
 - f. Conduct and cooperate in water studies.
 - g. Inventory unappropriated water in the state and make recommendations for its use (ICA 42-1736B Supp. 1980).
 - h. Approve or disapprove all project proposals involving a reservoir of greater than $1.23 \times 10^7 \text{ m}^3$ (1.0×10^4 acre-ft) (ICA 42-1737, Supp. 1980).

D. Regulation of Groundwater

- 1. All groundwater is subject to appropriation, but not in the same sense as surface waters.

Source: Idaho Department of Water Resources,
"Water User's Handbook 6 (1977)."

Fig. 4.5. Critical groundwater areas in Idaho.

- a. Prior appropriators of groundwater are protected in "the maintenance of reasonable groundwater pumping levels" as established by DWR (ICA 42-226, Supp. 1980).
- b. ICA 42-237a(g) Supp. 1980 allows DWR to:
 - i. Prohibit groundwater withdrawal during periods of shortage.
 - ii. Establish pumping levels in areas of common groundwater supply.

- c. Water shall not be deemed available for a water rights if withdrawal from the groundwater source would affect "the present or future use of any prior surface-or groundwater right or result in the withdrawing of the groundwater supply at a rate beyond the reasonably anticipated average rate of future natural recharge" [ICA 42237a(g), Supp. 1980].
- d. Gould has noted that the Idaho Supreme Court, in *Baker v. Ore-Ida Foods, Inc.*, 513 P. 2d 627 (Idaho 1973), has interpreted these statutes to mean that:
 - i. Senior appropriators are not protected in historic pumping levels but may have to reduce to reasonable pumping levels.
 - ii. The value of a "reasonable pumping level" may change.
 - iii. DWR's determination of reasonable pumping levels is presumed to be correct.
 - iv. Mining of rechargeable aquifers is prohibited.
 - v. Senior appropriators may enjoin pumping by junior appropriators that will cause mining or will lower pumping depths below reasonable levels.
- 2. Except for domestic purposes (ICA 42-227, Supp. 1980), appropriation of groundwater is by permit (ICA 42-229).
- 3. DWR has "general" power to protect groundwater resources (ICA 42-231, 42-237a, Supp. 1980).
- 4. DWR has authority to designate "critical groundwater areas," (see Fig. 4.4) which are those that cannot support existing and proposed demands (ICA 42-233a, Supp. 1980), but such designation does not imply denial of all future permit applications per se.
- 5. In "noncritical" areas DWR can require recharge for proposed withdrawals of 1.23×10^7 m³/year (1.0×10^4 acre-ft/year) which will adversely affect existing water rights (ICA 42-233a, Supp. 1980).

E. Regulation of Geothermal Resources

- 1. Idaho Geothermal Resources Act (ICA 42-4001 to 42-4015)
- 2. Definition — Geothermal resource means the natural heat energy of the earth, the energy, in whatever form, which may be found in any position and at any depth below the surface of the earth present in, resulting from, or created by, or which may be extracted from such natural heat, and all minerals in solution or other products obtained from the material medium of any geothermal resource. Geothermal resources are found and hereby declared to be sui generis, being neither a mineral resource nor a water resource, but they are also found and hereby declared to be closely related to and possibly affecting and affected by water and mineral resources in many instances [ICA 42-4002(c)].

3. Prior to well construction, developers must acquire a geothermal resource well permit from the Idaho Department of Water Resources (ICA 42-4003).
4. The application for a permit to construct a well must be accompanied by an application for appropriation "if the construction or operation of such well will involve the use of water, or if such well may be expected to yield water to be used, for any beneficial purpose, other than as a mineral source, an energy source, or otherwise as a material medium..." [ICA 42-4003(b)].
5. Any person constructing any well of 910 m (3000 ft) or more in depth in a designated geothermal area must first obtain a geothermal resource well permit [ICA 42-4003(g)].
6. Applications must comply with regulations of the Water Resource Board [ICA 42-4004(a)].
7. The Director of DWR must determine whether the well is in the public interest, including consideration of:
 - a. Measures to protect ground- and surface-water quality.
 - b. "The probability that such interdependence [between the geothermal resource and water resources] may cause such groundwater sources to be inadequate to meet demands on them under existing water rights" [ICA 42-4044(b)].
8. Permit Issuance (ICA 42-4005, Supp. 1980)
 - a. A proposed well that is not in the public interest may not be issued a permit.
 - b. A permit can be issued with conditions but no permit may be issued if the well "may be expected to unreasonably reduce the quality of any surface or groundwaters below the quality which such waters would have had but for the proposed well."
 - c. If DWR finds that a proposed well will unreasonably affect prior groundwater rights a permit cannot be issued unless groundwaters are appropriated under Idaho water law.
9. The Water Resource Board is empowered to promulgate rules for the administration of the Geothermal Resources Act (ICA 42-4010).

F. Issues/Potential Constraints to the Development of Geothermal Energy

1. Since acquisition of water that is put to beneficial use requires an appropriation (see E.4, above), it would appear that, assuming the appropriation permit is granted, in time of shortage, senior appropriators of groundwater may claim that which is being withdrawn by the geothermal developer after it is used for power production.
2. Idaho is clearly concerned about aquifer communication between geothermal and conventional water resources.

- a. Note that DWR grants permits for both appropriation and geothermal development.
- b. Notwithstanding their classification as sui generis (E.2) (i.e., in a class by itself, rather than being grouped with water or minerals), geothermal resources are shifted to the law of water resources if geothermal drilling will unreasonably affect prior groundwater rights (E.8.c).
 - i. If this occurs, then an appropriation permit must be acquired (E.8.c).
 - ii. However, no appropriation permit can be issued if it will unreasonably affect prior rights (D.1.a, D.1.c).
 - iii. Also, since groundwater mining appears to be prohibited in rechargeable areas (D.1.d), it would appear that a senior groundwater appropriator could prevent further pumping by a junior geothermal developer/appropriator (D.1.d).
 - iv. It is likely that the groundwaters referred to in ICA 42-4005 (E.8.c) are those which the geothermal development is unreasonably affecting.
3. As noted by Gould (p. 189) since appropriation of water commenced before the advent of mandatory permits remains in effect, interference with an unforeseen valid appropriator who does not hold a permit could obstruct a geothermal development.
4. ICA 42-4003(e) provides that uses of geothermal fluid for particular nonelectric production purposes requires only a water appropriation permit and not a geothermal permit. This is apparently true even if the geothermal fluid is of sufficient temperature to produce electricity.
5. Current law does not provide for a transfer of purpose of use (C.1.b, Gould, p. 186) and bills before the legislature could conceivably prohibit a change of water use from agriculture to energy production, if enacted. Also, the Idaho Supreme Court, in *Baker Industries v. Georgetown Irrigation District* (610 P. 2d 546, Idaho 1980) recently confirmed that the Department of Water Resources, at least in some situations, has no power to approve a change in the purpose or use of an existing water right.
6. Olpin, Tarlock, and Austin (ref. 4, pp. 846-47) allude to several points that suggest that among geothermal developers, correlative rights (a proportionate sharing scheme) apply, but prior appropriation applies between geothermal users and water users.

REFERENCES FOR SECTION 4

1. 30 U.S.C., Sects. 1001 to 1025 (1976).
2. G. Gould, *State Water Law in the West: Implications for Energy Development*, LA-7588 (January 1979).
3. Olpin and Tarlock, *Water That Is Not Water*, 13 LAND AND WATER L. REV. 391, 398-99 (1978).
4. Olpin, Tarlock, and Austin, *Geothermal Development and Western Water Law*, 1979 UTAH L. REV. 773 (1979).
5. Olpin and Tarlock, *supra* note 3, at 399.
6. Olpin, Tarlock, and Austin, *supra* note 4, at 792.
7. Olpin, Tarlock, and Austin, *supra* note 4, at 795.
8. Vranesh and Musick, *Geothermal Resources: Water and Other Conflicts Encountered by the Developer*, 13 LAND AND WATER L. REV. 109 (1977).
9. Sato and Crocker, *Property Rights to Geothermal Resources* (pt. 2), 6 ECOLOGY L. Q. 481 (1977).
10. Vranesh and Musick, *supra* note 8, at 148-49.
11. Sato and Crocker, *Property Rights to Geothermal Resources* (pt. 1) 6 ECOLOGY L. Q. 247, 309 (1977).
12. Sato and Crocker, *supra* note 9, at 548-49.
13. See generally: D. Sacarto, *State Policies for Geothermal Development: Uncovering a Major Resource* 46 (1976) (National Conference of State Legislatures, Denver).
14. Idaho Code Annotated, Sect. 42-4003(b).
15. 549 F. 2d 1271 (9th Cir. 1977).
16. 30 U.S.C., Sect. 1021 (1976).
17. Olpin and Tarlock, *supra* note 3, at 408.

18. *Cappaert v. United States*, 426 U.S. 128, 138 (1976).
19. *Winters v. United States*, 207 U.S. 564 (1908).
20. *Cappaert v. United States*, 426 U.S. 128 (1976).
21. See generally: U.S. General Accounting Office, *Reserved Water Rights for Federal and Indian Reservations: A Growing Controversy in Need of Resolution* (Nov. 16, 1978, CED-78-176).
22. *President's Message to Congress Transmitting Federal Water Policy*, 14 WEEKLY COMP. OF PRES. DOC. 1044 (June 12, 1978).
23. Task Force on Federal Non-Indian Reserved Water Rights, Office of the Solicitor of the U.S. Department of the Interior, *Report of Federal Task Force on Non-Indian Reserved Rights; Task Force 5a - President's Water Policy Implementation* (June 1979).
24. *Federal Power Commission v. Oregon*, 349 U.S. 435, 448 (1955).
25. Olpin and Tarlock, *supra* note 3, at 412-19.
26. Olpin, Tarlock, and Austin, *supra* note 4, at 807-10.
27. Office of the Solicitor, U.S. Department of the Interior, *Federal Water Rights of the National Park Service, Fish and Wildlife Service, Bureau of Reclamation, and the Bureau of Land Management: Solicitor's Opinion No. M-36914* at 15-18 (June 25, 1979).
28. U.S. Constitution, Art. 6, Sect. 2.
29. G. Gould, *supra* note 2.

Appendix A

METHOD OF ESTIMATING MAKEUP WATER REQUIREMENTS

Roy C. Robertson

Appendix A

METHOD OF ESTIMATING MAKEUP WATER REQUIREMENTS

A.1 General

In brief, the method of analysis consists of estimating the heat rejected from simplified flashed-steam and binary (isopentane) cycles, and, after assuming a concentration factor, estimating the evaporation and makeup water requirements from an analysis of the tower performance.

The boiler temperature in both cycles was assumed to be a function of the resource temperature, as shown in Fig. 2.3. The turbine exhaust temperature was assumed to be 2.8°C (5°F) above the temperature of the circulating water leaving the flashed-steam condenser and 11°C (20°F) above the water leaving the binary system condenser. The steam will expand into the wet region and the isopentane into the superheated region. A terminal difference of 2.8°C (5°F) was assumed for both the steam and binary system condensers. A turbine efficiency of 70% was assumed for the steam turbine and 83% for the binary turbine. The ratio of the net bus-bar output of the plant to the gross generated output was taken to be 0.90 for the flashed-steam system and 0.80 for the binary system, the latter requiring a boiler feedpump and, because of the lower thermal efficiency, also requiring more power for the cooling tower auxiliaries. A plant factor of 90% was assumed for both cycles, which seems reasonable for a well-established geothermal power industry.

The cooling tower performance was first estimated assuming the effluent air to be saturated. The initially assumed approach temperature was then adjusted if necessary to provide a tower efficiency dry-bulb temperature reasonably below the entering water temperature. This difference was assumed to be 1.7°C (3°F), and the adjustment to the approach temperature was usually reasonable. Using the adjusted approach temperature, the ambient air conditions, and the circulating water temperatures, the enthalpy of the exit air was estimated using the Mickley method, as described below. Once a first estimate of the leaving enthalpy is obtained, the correlations for the psychrometric properties can be more

precisely identified and the calculations repeated. The makeup rates could be estimated for various resource temperatures, ambient wet- and dry-bulb temperatures, and concentration factors.

The average wet- and dry-bulb temperature published by Beck¹ for four typical geothermal reserve areas in the southwest was used to estimate makeup water requirements. These data are shown in Table 2.1. Using these values also allowed comparison of the estimated makeup rates with those published by Beck. The flashed-steam rates were roughly about 10% lower than the Beck values at lower resource temperatures and about the same at higher resource temperatures. The estimated binary cycle makeup requirement at a 182°C (360°F) resource temperature was about the same as the Beck value. This correspondence is considered acceptable, particularly in view of the simplified, nonoptimized systems assumed for this study.

The nomenclature used in the analysis is given in Table A.1. The program is explained in Table A.2, and the program is listed in Table A.3.

Table A.1. Nomenclature

Temperatures, °F

T	Used as operator
T _φ	Wet-bulb
T ₁	Boiler exit
T ₂	Turbine exhaust
T ₃	Intermediate temperature in Mickley method step solution
T ₄	Condenser hot well
T ₅	Circulating water to tower
T ₆	Makeup water
T ₇ or Y ₇	First step in Mickley method
T ₈ or f	Water temperature leaving tower
T ₉	Trial temperature on saturated line in Mickley method
D _φ	Dry-bulb entering tower
D ₁	Terminal difference at steam and binary condensers
D ₂	Difference between condenser exit water temperature and steam turbine exhaust temperature
D ₃	Difference between condenser exit water temperature and binary turbine exhaust temperature

Table A.1 (continued)

A1	Approach
E	Tower exit
R1	Range
Y	Resource temperature
<u>Flow rates, lb/h</u>	
L1	Cooling water circulation
L2	Blowdown
L3	Makeup
L4	Evaporation
$W\phi$	Working fluid rate to turbine
<u>Efficiencies</u>	
N1	Turbine, flashed-steam system
N2	Net/gross load, flashed-steam system
N3	Overall plant thermal efficiency
N4	Turbine, binary system
N5	Net/gross load binary system
<u>Heat loads, Btu/h</u>	
O1	Plant rejected heat
O2	Tower heat load
<u>Pressures, psia</u>	
P1	Partial pressure water at $T\phi$
P2	Partial pressure water at $D\phi$ and $T\phi$
<u>Enthalpies, Btu/lb</u>	
H	Used as operator
$H\phi$	Δh_s in turbine
H1	h_f leaving boiler
H2	h_{fg} leaving boiler
H3	h_f at turbine exhaust
H4	h_{fg} at turbine exhaust
H5	h after isentropic expansion
H7	h_f at condenser hot well
H8	Air entering tower
H9	Air leaving tower
I1 or H8	Step in Mickley method
I3	On saturated line in Mickley method
$I\phi$	Size of h step in Mickley method
<u>Entropies, Btu/lb - °R</u>	
S1	s_g at boiler exit
S2	s_f at turbine exhaust
S3	s_{fg} at turbine exhaust
S5	Isopentane at 100°F
S6	Isopentane at 140°F

Table A.1 (continued)

<u>Humidity ratios, lb/lb</u>	
W1	Air entering tower
W2	Air leaving tower
<u>Miscellaneous</u>	
A	α in Mickley method
B	Barometer, psia
C	Specific heat water
F1	Concentration factor in tower
J3	Used in solution of quadratic equation
J4	Used in solution of quadratic equation
J5	Used in solution of quadratic equation
J6	Used in solution of quadratic equation
J7	Used in solution of quadratic equation
R2	L/G ratio in tower
R3	LHL/THL in tower
F5	Constants in correlations properties air-water-vapor mixture
F6	Constants in correlations properties air-water-vapor mixture
F7	Constants in correlations properties air-water-vapor mixture
X1	Steam turbine exhaust quality after $ds = 0$
J	Operator
K	Operator
M	Operator for significant figures
Z	Constants in correlations for air-water-vapor mixtures
L/G	Ratio of mass flow rates of circulating water to air in cooling tower

Table A.2. Program summary

<u>Line No.</u>	
100	Read data: resource temperature, dry-bulb temperature, wet-bulb temperature
110-140	Operators
150-330	Input data and parameters
340	Boiler temperature based on resource temperature (T1)
<u>Flashed-steam system</u>	
350-360	h_f and h_{fg} of steam leaving boiler (H1, H2)
380-400	s of steam leaving boiler (S1)
410	Turbine exhaust temperature (T2)
470-430	h_{fg} and h_f of steam at turbine exhaust temperature (H3, H4)
440-450	sf and s_{fg} of steam at turbine exhaust temperature (S2, S3)

Table A.2 (continued)

Line No.	
460	Quality of steam in turbine exhaust (X1)
470-480	Δh for isentropic expansion ($H\phi$)
490	Steam rate for 1 kWe ($W\phi$)
500-520	Heat rejected from power cycle ($Q1$)
530	Thermal efficiency of flashed-steam cycle (N3)
<u>Approximate cooling tower performance</u>	
560-630	Print statements
640-670	Ambient air W and h ($W1$, $H8$)
680	Assumed makeup water temperature ($T6$)
690-720	Temperature of water to tower ($T5$) and water leaving tower ($T8$), water circulation rate ($L1$), air mass flow rate (G)
730	Mid-range "Z" constants from subroutine
750-780	"I" terms for solving quadratic equation
800	Calculation of leaving air h, $H9$, assuming saturation
870-880	Repeats calculation for $H9$ based on "Z" constants for range in which initial calculation of $H9$ falls
890	Temperature of exit air, E , based on $H9$ at saturated conditions
920	Checks to see that exit air dry-bulb temperature, E , is at least 3°F below entering water temperature, $T5$. If not, increases approach temperature, $A1$, by 1 and goes to start of calculation, line 420
970-1000	Calculation of $W2$ from $H9$ (assumed saturated) and calculation of approximate values of $L4$, $L2$, $L3$; prints makeup rate based on saturated conditions
<u>Mickley cooling tower analysis</u>	
1060-1300	First step (Note: subroutine 2530 reduces significant figures in printed values)
1320	If next value of $I1$ exceeds $H9$ (based on saturated condition at top of tower), goes to line 1500
1330	If next value of $I1$ equals $I3$ on saturation curve, exit condition is taken to be saturated, with $I3 = H9$, in line 1430
1340-1360	If neither of above, repeats calculation for next value of $I1$
1370-1430	If exit air is saturated fixes values of $H9$ and E
1450	Steps back one step and increases Δh steps by 1/10th of Δh and repeats steps until $I1$ exceeds $H9$
1580	Estimates (not saturated) exit air temperature and enthalpy; recalculates evaporative rate, $L4$, to satisfy mass and energy balance
1590	Recalculates makeup rate ($L3$)

Table A.2 (continued)

Line No.	
	<u>Binary cycle</u>
1690	Boiler temperature based on resource temperature (T1)
1700-2010	Entering isopentane h and s based on saturation at T1 (H1, S1)
2030	Turbine exhaust temperature (T2)
2060	Turbine exhaust pressure (P2)
2070-2200	Δh for isentropic expansion (H)
2240	Plant heat load (Q3)
2250	Thermal efficiency of binary cycle (N3); tower performance is assumed to be the same for flashed-steam and binary cycles; therefore, makeup rate is in proportion to plant heat load
2280-2340	L3 = makeup rate for flashed steam x Q3/Q1
2350-2760	Subroutines

Table A.3. Program

```

LIST
100 READ Y,D0,T0
110 K=0
120 J=0
130 Z4=0
140 Z9=0
150 DATA 360,73,57
160 PRINT "      WATER CONSUMPTION GEO. STATIONS, July 28,1980,T1/F27"
170 PRINT
180 A1=10
190 D1=7
200 D3=20
210 R1=20.6
220 N1=0.7
230 D2=5
240 H2=0.9
250 H4=0.83
260 H5=0.8
270 P=0.9
280 C=1
290 A=6
300 R2=1.4
310 B=14.696
320 F1=5
330 I0=2
340 T1=(230.93-0.253488*Y)/(1-0.001421*Y)
350 H1=(0.87912699*T1-15.439264)/(1-2.6072E-4*T1)
360 H2=(1072.510388-1.359242*T1)/(1-9.0026E-4*T1)
370 IF T1>376 THEN 400
380 S1=3.43675-0.57561*T1+0.2
390 GO TO 410
400 S1=2.04762-0.00563*T1+0.755
410 T2=T0+A1+D1+R1
420 H3=T2-32
430 H4=1089.75139-0.36642*T2+1.079

440 S2=0.00533*T2+0.808-0.09049
450 S3=2.37153-0.01358*T2+0.792
460 X1=(S1-S2)/S3
470 H5=H3+X1*H4
480 H0=H1+H2-H5
490 W0=3412.14*P/(N1*H0*N2)
500 T4=T0+A1+R1+D2
510 H7=T4-32
520 Q1=W0*(H1+H2-H0*N1-H7)
530 N3=341214/(3412.14+Q1)
540 Z9=Z9+1
550 IF Z9=>2 THEN 620
560 PRINT "T1=";T1,"D0=";D0,"T0=";T0,"A1=";A1,"D1=";D1,"R1=";R1,"N1=";N1

```

Table A.3 (continued)

```

570 PRINT "D2=";D2,"N2=";N2,"P=";P,"R2=";R2,"B=";B,"F1=";F1,"C=";C
580 PRINT "Alpha, A =" ;A,"I0=";I0;" Btu/lb","Y=";Y,"T2=";T2
590 PRINT
600 PRINT " ", "Flashed steam cycle"
610 PRINT
620 PRINT "Plant heat load, Q1=";Q1;" Btu/hr-MWe", "A1=";A1
630 PRINT "Efficiency of flashed-steam cycle =" ;N3
640 P1=EXP(52.1828366-12133.62738/(T0+459.69))-4.8289466*LOG(T0+459.69))
650 P2=P1-(B-P1)*(D0-T0)/(2800-1.3*T0)
660 W1=0.6248*P2/(B-P2)
670 H8=0.2403*D0+W1*(1061.65+0.4287*D0)
680 T6=T0+2
690 T5=T0+A1+R1
700 T8=T0+A1
710 L1=Q1/R1
720 G=L1/R2
730 GOSUB 2620
740 J3=(F1*(T0-30)-T0-A1)/(F1-1)
750 J4=Z7/J3
760 J5=Q1/(J3*G)+H8/J3-W1
770 J6=1/J3-J5*Z7-Z6
780 J7=-(J5+Z5)

```

```

790 IF J3<0 THEN 820
800 H9=(-J6+SQR(J6^2-4*J4*J7))/(2*J4)
810 GO TO 830
820 H9=(-J6-SQR(J6^2-4*J4*J7))/(2*J4)
830 Z4=Z4+1
840 IF Z4>2 THEN 870
850 GOSUB 2560
860 GO TO 740
870 H=H9
880 GOSUB 2370
890 E=T
900 PRINT "E=";E,"G=";G,"H8=";H8,"H9=";H9
910 PRINT
920 IF E<=T5-3 THEN 950
930 A1=A1+1
940 GO TO 410
950 H=H9
960 GOSUB 2450
970 W2=W
980 L4=G*(W2-W1)
990 L2=L4/(F1-1)
1000 L3=L2+L4
1010 Q2=Q1-L2*(T8-32)+L3*(T0+2-32)
1020 PRINT "Tower heat load, Q2=";Q2,"T5=";T5
1030 L3=L3*3.2228
1040 PRINT "Evap. rate based on sat. cond.=";L3;" acre-ft/yr"
1050 PRINT
1060 I1=H8
1070 T7=D0
1080 I3=I1*2
1090 T3=T8-(I3-I1)/A
1100 H=I3
1110 GOSUB 2370
1120 T9=T
1130 IF ABS(T9-T3)<0.02 THEN 1100

```

```

1140 T=(T9+T3)/2
1150 GOSUB 2290
1160 I3=H
1170 GO TO 1090
1180 M=I1
1190 GOSUB 2530
1200 I1=M
1210 M=I3
1220 GOSUB 2530
1230 I3=M
1240 M=T7
1250 GOSUB 2530
1260 T7=M
1270 M=T3
1280 GOSUB 2530
1290 T3=M

```

Table A.3 (continued)

```

1300 PRINT "I1=";I1,"T7=";T7,"I3=";I3,"T3=";T3
1310 I1=I1+I0
1320 IF I1>H9 THEN 1450
1330 IF I1>I3 THEN 1370
1340 T7=T7-I0*(T7-T3)/(I3-I1)
1350 T8=I0/R2+T8
1360 GO TO 1080
1370 PRINT "Exit air is saturated"
1380 I3=H9
1390 H=H9
1400 GOSUB 2370
1410 E=T
1420 J=J+1
1430 PRINT "Exit air temp.,E=";E,"Exit air h,H9=";H9
1440 GO TO 1590
1450 I1=I1-I0
1460 I0=I0/10
1470 PRINT
1480 J=J+1

1490 IF J=2 THEN 1520
1500 GO TO 1300
1510 PRINT
1520 PRINT "Entering air W1=";W1,"Entering air h,H8=";H8
1530 PRINT "Exit air temp.,T7=";T7,"Exit air h,I1=";I1
1540 W2=(H9-0.2403*E)/(1861.65+0.4287*E)
1550 L4=Q1/((H9-H8)/(W2-W1)-J3)
1560 L3=(L4+L4/(F1-1))*3.2228
1570 M=L3
1580 GOSUB 2530
1590 L3=M
1600 PRINT "TOWER MAKEUP FOR FLASHED-STEAM SYSTEM=";L3;" acre-ft/yr-MWe"
1610 PRINT
1620 PRINT " ", "Binary cycle"
1630 PRINT
1640 T1=(230.93-0.253488*T1)/(1-0.001421*T1)
1650 IF T1>360 THEN 1810
1660 IF T1>200 AND T1<240 THEN 1700
1670 IF T1>240 AND T1<280 THEN 1750
1680 IF T1>280 AND T1<320 THEN 1720
1690 H1=(-492.6621277+1.62621277*T1)/(1-0.00329787*T1)
1700 S1=(1.199305264-0.003682193*T1)/(1-0.003070175*T1)
1710 GO TO 1800
1720 H1=(-6064.4-82.855*T1)/(1+0.2*T1)
1730 S1=(1.21585688-0.00555005*T1)/(1-0.00458716*T1)
1740 GO TO 1800
1750 H1=(-622.74+0.1930385*T1)/(1+3.8462E-4*T1)
1760 S1=(1.10178571+9.1011E-4*T1)/(1+5.102E-4*T1)
1770 GO TO 1800
1780 H1=-617.7+0.375*T1
1790 S1=(0.9259+0.01577375*T1)/(1+0.0125*T1)
1800 GO TO 1960
1810 IF T1>360 AND T1<400 THEN 1930
1820 IF T1>400 AND T1<440 THEN 1900
1830 IF T1>440 AND T1<480 THEN 1870

1840 H1=(-721.3724324+0.69905856*T1)/(1-6.93E-5*T1)
1850 S1=(0.8885+0.00142871*T1)/(1+4.1667E-4*T1)
1860 GO TO 1960
1870 H1=(-694.1817369+0.72149843*T1)/(1-2.6746E-4*T1)
1880 S1=(0.84574615+0.00181212*T1)/(1+6.4103E-4*T1)
1890 GO TO 1960
1900 H1=(-853.6201342+0.59099473*T1)/(1+0.8686E-4*T1)
1910 S1=(0.55986076+0.00488487*T1)/(1+0.00253165*T1)
1920 GO TO 1960
1930 H1=(-356.113855+1.333026*T1)/(1-0.00347178*T1)
1940 S1=(1.35893916-0.00454899*T1)/(1-0.00342205*T1)
1950 GO TO 1960
1960 T2=T0+A1+R1+D3
1970 PRINT "T1=";T1,"D3=";D3,"T2=";T2
1980 PRINT "N4=";N4,"N5=";N5
1990 P2=EXP(44.66218-8024.91/(T2+459.63))-4.31559*LOG(T2+459.63)
2000 IF T1>360 THEN 2070
2010 S5=(1.20792941+0.0594196*P2)/(1+0.05490196*P2)

```

Table A.3 (continued)

```

2020 S6=(1.2652137+0.06432712*P2)/(1+0.05616438*P2)
2030 T2=80*(S1-S5)/(S6-S5)+180
2040 I5=(-617.106174+0.776958*T2)/(1-6.7716E-4*T2)
2050 I6=(-621.044697+0.718168*T2)/(1-5.4376E-4*T2)
2060 GO TO 2120
2070 S5=(1.2652137+0.06432712*P2)/(1+0.05616438*P2)
2080 S6=(1.40676364+0.00222909*P2)/(1+0.06363636*P2)
2090 T2=200*(S1-S5)/(S6-S5)+180
2100 I5=(-619.5760599+0.68638294*T2)/(1-4.8526E-4*T2)
2110 I6=(-622.7340298+0.68198528*T2)/(1-4.6017E-4*T2)
2120 H2=(P2-10)*(I6-I5)/I5+I5
2130 H0=H1-H2
2140 W0=3412.14*P/(N4*H0*N5)
2150 T4=T0+A1+R1+D1
2160 H7=220.367+0.55*T4-1000
2170 Q3=W0*(H1-H0*N4-H7)
2180 N3=341214/(Q3+3412.14)

2190 PRINT "Plant heat load binary cycle=";Q3
2200 PRINT "Efficiency of binary cycle =" ;N3
2210 L3=Q3/Q1*L3
2220 M=L3
2230 GOSUB 2530
2240 L3=M
2250 J=J+1
2260 IF J=1 THEN 1620
2270 PRINT "MAKEUP RATE FOR BINARY SYSTEM=";L3;" acre-ft/yr-MWe"
2280 END
2290 IF T=>100 THEN 2350
2300 IF T=>70 THEN 2330
2310 H=(1.5711376+0.242078*T)/(1-0.0065262*T)
2320 GO TO 2360
2330 H=(-0.8674745+0.2941802*T)/(1-0.006019*T)
2340 GO TO 2360
2350 H=(-13.2166552+0.4647555*T)/(1-0.0053633*T)
2360 RETURN
2370 IF H=>71.73 THEN 2430
2380 IF H=>34.09 THEN 2410
2390 T=(-6.4902133+4.1309008*H)/(1+0.026959*H)
2400 GO TO 2440
2410 T=(2.9487856+3.3992765*H)/(1+0.0204627*H)
2420 GO TO 2440
2430 T=(28.4378683+2.1516691*H)/(1+0.0115401*H)
2440 RETURN
2450 IF H=>71.73 THEN 2510
2460 IF H=>34.09 THEN 2490
2470 W=(-0.0010255+3.681E-4*H)/(1-0.007969*H)
2480 GO TO 2520
2490 W=(-0.0053983+5.907E-4*H)/(1-0.002008*H)
2500 GO TO 2520
2510 W=(-0.0113544+7.426E-4*H)/(1-4.131E-4*H)
2520 RETURN
2530 M1=10*(4-INT(LGT(M)))

2540 M=INT(N*M1+0.5)/M1
2550 RETURN
2560 IF H9>71.73 THEN 2660
2570 IF H9>34.09 THEN 2620
2580 Z5=-0.0010255
2590 Z6=3.681E-4
2600 Z7=-0.007969
2610 RETURN
2620 Z5=-0.0053983
2630 Z6=5.907E-4
2640 Z7=-0.002008
2650 RETURN
2660 Z5=-0.0113544
2670 Z6=7.426E-4
2680 Z7=-4.131E-4
2690 RETURN

```

Table A.3 (continued)

RUN

WATER CONSUMPTION GEO. STATIONS, July 28, 1980, T1/F27

T1=285.960036033	D0=73	T0=57	A1=10
D1=7	R1=20.6	N1=0.7	
D2=5	N2=0.9	P=0.9	R2=1.4
B=14.696	F1=5	C=1	
Alpha, A =6	I0=2 Btu/lb	Y=360	T2=94.6

Flashed steam cycle

Plant heat load, Q1=17333.9521893 Btu/hr-MWe	A1=10
Efficiency of flashed-steam cycle =16.4471456545	
E=88.2946256279 G=601.030564123 H0=24.3571418682	H9=53.5913524953

Plant heat load, Q1=17429.5429313 Btu/hr-MWe	A1=11
Efficiency of flashed-steam cycle =16.3717105344	
E=88.2901676211 G=604.353083608 H0=24.3571418682	H9=53.5854837033

Plant heat load, Q1=17526.2349886 Btu/hr-MWe	A1=12
Efficiency of flashed-steam cycle =16.2961070372	
E=88.2857107479 G=607.705790175 H0=24.3571418682	H9=53.5796170757

Plant heat load, Q1=17624.0494792 Btu/hr-MWe	A1=13
Efficiency of flashed-steam cycle =16.2203330759	
E=88.281255008 G=611.097416061 H0=24.3571418682	H9=53.5737526114

Plant heat load, Q1=17723.0080202 Btu/hr-MWe	A1=14
Efficiency of flashed-steam cycle =16.144386577	
E=88.2768004007 G=614.520710024 H0=24.3571418682	H9=53.567890309

Tower heat load, Q2=18064.7613622 T5=91.6
 Evap. rate based on sat. cond.=57.3647224302 acre-ft/yr

I1=24.357	T7=73	I3=33.641	T3=69.453
-----------	-------	-----------	-----------

I1=26.357	T7=72.026	I3=34.967	T3=70.993
I1=28.357	T7=71.713	I3=36.341	T3=72.526
I1=30.357	T7=71.985	I3=37.754	T3=74.053
I1=32.357	T7=72.751	I3=39.208	T3=75.573
I1=34.357	T7=73.914	I3=40.703	T3=77.085
I1=36.357	T7=75.373	I3=42.243	T3=78.59
I1=38.357	T7=77.029	I3=43.828	T3=80.088
I1=40.357	T7=78.792	I3=45.461	T3=81.578
I1=42.357	T7=80.587	I3=47.142	T3=83.06
I1=44.357	T7=82.363	I3=48.874	T3=84.533
I1=46.357	T7=84.087	I3=50.659	T3=85.997
I1=48.357	T7=85.746	I3=52.499	T3=87.453
I1=50.357	T7=87.34	I3=54.395	T3=88.898
I1=52.357	T7=88.869	I3=56.371	T3=90.331

I1=52.357	T7=88.869	I3=56.371	T3=90.331
I1=52.557	T7=89.946	I3=56.57	T3=90.474
I1=52.757	T7=89.026	I3=56.769	T3=90.617
I1=52.957	T7=89.109	I3=56.969	T3=90.76
I1=53.157	T7=89.196	I3=57.17	T3=90.903
I1=53.357	T7=89.286	I3=57.371	T3=91.045
I1=53.557	T7=89.378	I3=57.572	T3=91.188

Entering air W1=0.00623566716039 Entering air h, H0=24.3571418682
 Exit air temp., T7=89.378 Exit air h, I1=53.557
 TOWER MAKEUP FOR FLASHED-STEAM SYSTEM=57.414 acre-ft/yr-MWe

Binary cycle

T1=285.960036033	D3=20	T2=111.6
N4=0.83	N5=0.8	
Plant heat load binary cycle=23905.3617038		
Efficiency of binary cycle =12.490673697		
MAKEUP RATE FOR BINARY SYSTEM=77.442 acre-ft/yr-MWe		

A.2 Mickley Method for Cooling Tower Analysis

The Mickley method for estimating cooling tower exit conditions of the air-water-vapor mixture, described by Jakob,² was arranged for graphical solutions but was adapted to computer solution. As shown in Fig. A.1, the condition of the air entering the tower is plotted on an h - t plane (Point 1). On an extension of the enthalpy line through Point 1, the temperature of the water leaving the tower is plotted as Point 2. An "operating line" is drawn from Point 2 upwards at a slope of L/G to the entering water temperature. A line is drawn through Point 2 to the saturation curve (Point 3) at a slope of α , which is assumed. The value of α is generally taken as 4 to 6, but the actual value used has little effect on the calculated results. A small enthalpy step of Δh is assumed. [A value for Δh of 4652 J/kg (2.000 Btu/lb) was used in this study, except at the top of the tower where Δh was made equal to 465.2 J/kg (0.200 Btu/lb).] The point at which a horizontal line drawn through the next enthalpy step crosses a line drawn between Points 1 and 3 is the condition of the air at the beginning of the next step. The process is repeated until

- a. The condition of the air at Point 1 falls on the saturation curve, indicating that the air leaving the tower is saturated.
- b. The enthalpy at Point 1 reaches the enthalpy of the air leaving the tower, as estimated from an energy balance on the tower.
(In this analysis, this condition was approached with smaller steps of Δh than were used lower in the tower.)

Knowing the leaving air temperature as well as enthalpy allows the humidity ratio to be calculated and the evaporation rate to be estimated. This rate will be lower than the rate estimated if the tower effluent is assumed to be saturated, but, since the exit conditions are usually very close to saturation, the difference is not great.

Fig. A.1. Mickley method of approximating wet cooling tower exit air conditions.

REFERENCES

1. Randy D. Horsak, R. W. Beck and Associates, *Heat Rejection from Geothermal Power Plants*, prepared for California Energy Commission and Electric Power Research Institute, Palo Alto, Calif., EPRI ER-1216 (November 1979).
2. Max Jakob, *Heat Transfer*, vol. II, John Wiley & Sons, New York, 1957.

Appendix B

EXAMPLE OF GEOTHERMAL PERMITTING PROCESS FOR NEW MEXICO

Carey S. Rosemarin

Table B.1. Permits by agency^a

State agency	Permit	Required prior to	Estimated time for issuance	Note
State Land Office	Lease for geothermal rights	Any activity on state land	2 months	Sold at public auction to highest bonus offered
Oil Conservation Division	Permit to drill geothermal well including permit for WQCC discharge to groundwater	Drilling of geothermal well	Few days	Bonds must be posted; designated agent licensed SCC
State Engineer	Permit to drill exploratory well	Drilling in designated basin	Automatic	Granted for up to 1 year
State Engineer	Well driller's license	Drilling in designated basin	Few days	
State Engineer	Appropriation of water rights	Use of water	Indefinite	
State Engineer	Permit to drill development well	Drilling development well in designated basin	Few days	Must have water rights and apply water to beneficial use
Public Service Commission	Certificate of necessity and convenience	Commencement of construction of generating plant	2-18 months	Should begin application at conceptualization
Taxation and Revenue	Gross receipts tax number	Conducting business in New Mexico	1 day	
Environmental Improvement Division	1. Permit to discharge water to surface water; OCD approves groundwater discharge plan	Construction	4-6 months +	Should consider requirements at conceptualization
	2. Permit to discharge air contaminant	Construction	4-6 months +	Should consider requirements at conceptualization
	3. Permit to install septic tank	Construction	2 days	Need soil and slope data
	4. Permit to construct public water system	Construction	2-4 months	Definition of "public" system complex
	5. Permit to operate coffee shop, etc.	Operation	2-4 months	Very detailed regulations

Table B.1 (continued)

State agency	Permit	Required prior to	Estimated time for issuance	Note
State Corporation Commission	License to do business in New Mexico	Applying for drilling permit from OCD	2-3 months	
Construction Industries Division	Building permit	Construction	1 week-1 month	
State Archaeologist	Permit to conduct archaeological survey on State lands	Activity on land	1 week	
State Archaeologist	Permit to conduct archaeological survey on private land using mechanical earth moving equipment	Activity on land	1 week	
NM Heritage Program	None			
Energy Resources and Development Division	None			

^aWQCC = Water Quality Control Commission; SCC = State Corporation Commission; OCD = Oil Conservation Division.

Source: Energy and Minerals Department, New Mexico Energy Resources and Development Division, *New Mexico Handbook for Geothermal Resource Development*, state and local regulation concerning environmental water from Planners Ltd., Denver, for the U.S. Department of Energy, 1979.

Appendix C

CONVERSION FACTORS USED IN THIS REPORT

Roy C. Robertson

Table C.1. Conversion factors used in this report

Multiply	By	To obtain
acres	4,046.86	m ²
acres	0.404686	hectares (10 ⁴ m ²)
acre-ft/year	1,233.482	m ³ /year
acre-ft/year per MW(e)	1.233482	m ³ /year per kW(e)
Btu/lb	2.324444	J/g
Btu/lb·°R	4.184000	J/g·°K
cfs	0.02831685	m ³ /s
cfs	448.83117	gpm
cfs	2446.5715	m ³ /d
(°F - 32)	5/9	°C
ft	0.304	m
ft ³	0.02831685	m ³
gal	3.785412 x 10 ⁻³	m ³
gal	3.0688833 x 10 ⁻⁶	acre-ft
gpm	63.09020 x 10 ⁻⁶	m ³ /s
hectares	10 ⁴	m ²
sq. miles	2.589988	km ²
miles	1.609344	km
psi	6.894757	kP

INTERNAL DISTRIBUTION

1. H. G. Arnold	42. R. E. MacPherson
2. S. E. Beall	43. R. E. Males, Consultant
3. C. R. Boston	44. L. B. Maudlin
4. H. M. Braunstein	45. L. N. McCold
5. R. L. Burgess	46. L. J. Mezga
6. N. S. Cardell	47. J. B. Mills
7. R. S. Carlsmith	48. L. I. Moss, Consultant
8. R. H. Chapman	49. J. W. Michel
9. F. C. Chen	50. S. M. Mitchum
10. N. C. Chen	51. W. R. Mixon
11. W. B. Cottrell	52. R. W. Murphy
12. F. A. Creswick	53. D. C. Parzyck
13. G. A. Dailey	54. F. S. Patton, Jr.
14. R. M. Davis	55. C. H. Petrich
15. J. E. Dobson	56. H. Postma
16. N. Domingo	57. A. W. Reed
17. R. C. Durfee	58. C. R. Richmond
18. M. D. Eden	59-73. R. C. Robertson
19. D. M. Eisenberg	74. D. J. Rose, Consultant
20. Emergency Tech. Library	75. M. W. Rosenthal
21. R. J. Friar	76. G. Samuels, Jr.
22. W. Fulkerson	77-91. A. D. Shepherd
23. C. A. Gallagher	92. J. W. Sims
24. C. C. Gilmore	93. V. K. Smith, Consultant
25. R. E. Goodson, Consultant	94. I. Spiewak
26. D. L. Greene	95. W. P. Staub
27. V. O. Haynes	96. H. E. Trammell
28. R. F. Hibbs	97. D. B. Trauger
29. E. L. Hillsman	98. L. F. Truett
30. N. E. Hinkle	99. E. A. Vineyard
31. H. W. Hoffman	100. A. H. Voelker
32. R. B. Honea	101. M. Whiting, Consultant
33. D. B. Hunsaker, Jr.	102. T. J. Wilbanks
34. P. R. Intemann	103. D. J. Wilkes
35. S. V. Kaye	104. B. B. Wood
36. M. J. Kelly	105. H. E. Zittel
37. T. R. LaPorte, Consultant	106. ORNL Patent Office
38. C. G. Lawson	107-108. Central Research Library
39. D. W. Lee	109. Document Reference Section
40. R. Lee	110-113. Laboratory Records
41. R. N. Lyon, Consultant	114. Laboratory Records - RC

EXTERNAL DISTRIBUTION

115. R. L. Aamondt, Los Alamos Scientific Laboratory, P.O. Box 1663, Los Alamos, NM 87544
116. C. H. Bloomster, Battelle-Pacific NW Laboratory, Richland, WA 99352
117. G. E. Brandvold, Sandia Laboratories, P.O. Box 5800, Albuquerque, NM 87115
118. M. F. Conover, Radian Corporation, P.O. Box 9948, Austin, TX 78766
119. R. B. Coryell, Geothermal Program, National Science Foundation, Washington, DC 20550
120. R. H. Dart, Idaho National Engineering Laboratory, EG&G, Inc., 550 2nd Street, Idaho Falls, ID 83401
121. O. Jack Demuth, Idaho National Engineering Laboratory, EG&G, Inc., 550 2nd Street, Idaho Falls, ID 83401
122. Ron DiPippo, Division of Engineering, Brown University, Box D, Providence, RI 02912
123. Robert Fulton, Lawrence Berkeley Laboratory, 1 Cyclotron Road, Bldg. 90, Rm. 1070-J, Berkeley, CA 94720
124. David Goldenberg, TRW - Suite B-202, 800 Oak Ridge Turnpike, Oak Ridge, TN 37830
125. J. F. Hermance, Geological Sciences, Brown University, Providence, RI 02912
126. T. C. Hinrichs, Magma Power Company, 5143 Sunset Blvd., Los Angeles, CA 92112
127. I. J. Ingvarsson, Aerojet Nuclear Company, 550 Second Street, Idaho Falls, ID 83401
128. Ben M. Johnson, Battelle Pacific NW Laboratory, P.O. Box 999, Richland, WA 99352
129. G. Johnson, Bechtel Corporation, P.O. Box 3956, San Francisco, CA 94119
130. Joseph Kestin, Division of Engineering, Brown University, Box D, Providence, RI 02912
131. J. T. Kuwada, Rogers Engineering Company, Inc., Pine Street, Sixth Floor, San Francisco, CA 94111
132. Alan D. K. Laird, Mechanical Engineering Dept., University of California, Lawrence Berkeley Laboratory, Berkeley, CA 94720
133. Ray LaSala, Division of Geothermal Energy, Department of Energy, 12th and Pennsylvania Avenue, Mail Stop 3344, Washington, DC 20461
134. G. W. Leonard, ATDD (P&E) HPDD, Department of Navy, China Lake, CA 93555
135. A. Lundberg, L-505, University of California, Lawrence Livermore Laboratory, P.O. Box 808, Livermore, CA 94550
136. P. Marto, Naval Postgraduate School, Monterey, CA 93940
- 137-146. Clifton B. McFarland, Division of Geothermal Energy, Department of Energy, 12th and Pennsylvania Avenue, Mail Stop 3344, Washington, DC 20461

- 147-150. Michael W. Mayfield, Henningson, Durham, and Richardson,
9047 Executive Park Drive, Knoxville, TN 37919
151. K. Mirk, Lawrence Berkeley Laboratory, University of California,
Berkeley, CA 94720
152. K. P. Murphy, Specialty Chemicals Division, Allied Chemical Corp.,
P.O. Box 1069, Buffalo, NY 14240
153. J. Nugent, Geothermal Energy, San Diego Gas & Electric Co.,
P.O. Box 1831, San Diego, CA 92112
154. J. J. Perona, Chemical and Metallurgical Engineering Dept.,
University of Tennessee, Knoxville, TN 37916
155. W. L. Pope, Lawrence Berkeley Laboratory, Bldg. 90-2082,
Berkeley, CA 94720
156. R. R. Reeber, Division of Geothermal Energy, Department of Energy,
12th and Pennsylvania Avenue, Mail Stop 3344, Washington, DC 20461
- 157-161. Carey S. Rosemarin, U.S. Environmental Protection Agency,
Mail Code 5E WHME, 230 S. Dearborn Street, Chicago, IL 60604
162. J. W. Rushing, Oak Ridge Operations Office, Dept. of Energy,
P.O. Box E, Oak Ridge, TN 37830
163. G. Simay, City of Burbank, 164 W. Magnolia Blvd., Burbank, CA
91503
164. Ken E. Starling, College of Engineering, School of Chemical Engi-
neering, and Materials Science, University of Oklahoma, Norman, OK
73069
165. R. A. Walter, Battelle-Pacific NW Laboratory, P.O. Box 999,
Richland, WA 99352
166. Jud F. Whitbeck, Idaho National Engineering Laboratory, EG&G, Inc.,
550 2nd Street, Idaho Falls, ID 83041
167. Office of Assistant Manager for Energy Research and Development,
DOE-ORO, Oak Ridge, TN 37830
- 168-597. Given distribution as shown in TID-4500 under UC-66d,
Geothermal Energy - Utilization Technology (25 copies - NTIS)
- 598-798. Regional and Urban Studies Section Distribution List