INFORMATION SERIES 9

Geothermal Energy Development in Colorado:

Processes Promises & Problems

by
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Colorado Geological Survey
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INFORMATION SERIES NO. 9

GEOTHERMAL RESOURCE DEVELOPMENT IN COLORADO

PROCESSES, PROMISES AND PROBLEMS

SUMMARY REPORT
of the
COLORADO TEAM
FOR THE SOUTHWEST REGIONAL GEOTHERMAL
DEVELOPMENT OPERATIONS RESEARCH PROJECT
FOR THE PERIOD
JUNE 1, 1977 - June 12, 1978

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COLORADO GEOLOGICAL SURVEY

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1978

This is a summary report of the Colorado Team for the Southwest Regional Geothermal Development Operations Research Project for the period June 1, 1977 - June 12, 1978. The project was funded by the U.S. Department of Energy, the Four Corners Regional Commission and the New Mexico Energy Resources Board. The Colorado Geological Survey is a subcontractor to the contractor, the New Mexico Energy Institute. Mr. Richard Pearl, Chief, Groundwater Investigations Section, was the Team Leader for the project.

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ABSTRACT

The term "geothermal energy" is a term that means different things to different people. To an increasing number, it means a practical, environmentally compatible energy resource that can, right now, help to relieve an overdependency upon fossil fuels.

The potential for use of geothermal energy in Colorado seems to be substantial. As described by Barrett and Pearl (1978), at least 56 separate areas have surface manifestations of hydrothermal (hot water) resources. These areas are estimated to contain 5.914 quads (5.914×10^{15} Btu) of energy, with extractable energy of 1.48 quads.

Geothermal resources already contribute to Colorado's energy supply. In fact, since the early 1900's, practical uses of geothermal resources have been common in Pagosa Springs, in Southwest Colorado. Residents there have used hot-water wells to heat numerous buildings, including the County Court House, schools, churches, the newspaper office, a liquor store, 2 hotels, 2 service stations, a drugstore, and a bank, as well as for the swimming pool and spa. Where resources are in use in other parts of the State, most are used for swimming pools or baths. A few wells or springs serve other purposes, however, among them space heating and agriculture, including greenhouses, a fish farm and algae-growing.

At least 30 communities seem to be candidates for obtaining all or part of their space- and water-heating needs from geothermal energy. Twenty-three of these are within 10 miles of the resource area. Sixteen are virtually on-site. Based on the analysis, more than 16,000 homes, plus commercial, industrial, and public buildings could be supplied with heat and hot water. Along with this, heat could be supplied for such process uses as dehydrating vegetables and fruits, malting barley, warming hog pens and drying timber. Furthermore, 5 electrical generating units of 50 MWe each could be operating. The technology is readily available for all of these uses.

Seemingly, interest in and awareness of the resources is growing. If leases and permits are made available, along with some economic incentives, some or all of the three potential power-generation sites may be developed by private industry. Perhaps with the assistance of federal programs, initially, lower temperature resources, too, will be developed by private industry. While government can provide opportunities, the outcome depends upon the decisions of numerous individuals throughout the system. Colorado does have geothermal resources that can contribute to the energy supply. It remains to be seen whether these resources will fulfill their promise.

INTRODUCTION

The potential for use of geothermal energy in Colorado seems to be substantial. As described by Barrett and Pearl (1978), at least 56 separate areas have surface manifestations of hydrothermal (hot water) resources. In all, some 120 thermal springs and wells with temperatures over 20°C have been located. These have surface temperatures ranging from 20°C in several areas to a high of 83°C at Hortense Hot Spring southwest of Buena Vista. Using the technique of geochemical modeling, subsurface temperatures estimated for all the 56 areas are between 20°C and slightly over 200°C. The discharge rate is from 1 gallon per minute (gpm) at a number of springs to 2,263 gpm at Glenwood Springs. Contrary to popular opinion, some waters are quite pure, with the total dissolved solids ranging from 84 mg/l at Eldorado Springs southwest of Boulder to a high of 21,500 mg/l at Glenwood Springs (Barrett and Pearl, 1976). Figure 1 shows the resource areas.

The term "geothermal energy" is a term that means different things to different people. To some, it means an exotic resource that might at some point in the distant future, after an enormous technological breakthrough, contribute to the energy supply. To others it is a fluid in which to swim or bathe, either simply for pleasure or for improvement of one's health and well-being. To an increasing number it means a practical, environmentally compatible energy resource that can, right now, help to relieve an overdependency upon fossil fuels.

Expressed most concisely, geothermal energy is "the natural heat, steam, and hot waters of the earth's interior." (Pearl, 1972). It is, in fact, a practical energy resource which is readily usable with existing technology. Although techniques for using heat that is not contained in fluid, known as hot dry rock, are in the developmental stage, geothermal steam and hot water have been used for many years. Lardarello, Italy, has generated electricity with geothermal resources since 1904. Wairakei, New Zealand, and the Geysers in California have more recently begun generating electricity. In 1975 worldwide geothermal generating capacity was estimated to be 1100 MWe (The Futures Group, 1975). Reykjavik, in southern Iceland, uses natural hot water to heat 11,000 houses, plus some greenhouses and swim pools (Zoega, 1974). In Hungary geothermal energy is used to heat homes, greenhouses, cattle stalls, pigsties, chicken houses, hospitals, garages, machine shops, municipal buildings, factories, as well as for hot water supplies and for cooling and drying of agricultural products (Boldizsar, 1974). Other areas using geothermal energy are Japan and Russia, and, in the United States, Boise, Idaho, Klamath Falls, Oregon, and Pagosa Springs, Colorado. Facilities in these areas demonstrate that the technology and know-how are readily available for using geothermal resources.

In the United States, geothermal energy is considered to have significant potential, both for the generation of electricity and for use as direct heat, although estimates of the specific amounts vary widely. As a result, recent Federal policies have been initiated to encourage geothermal development. In 1970 the U.S. Congress passed the Geothermal Leasing Act to allow for issuance of geothermal leases on Federal lands (PL 91-581). In 1974 the Federal Energy Research Development and Demonstration Act was adopted, providing the mandate for geothermal programs that include resource assessment, planning and system development (PL 93-410). Among the planning programs is the Southwest Regional Geothermal Development Operations Research Project, of which this study is a part.

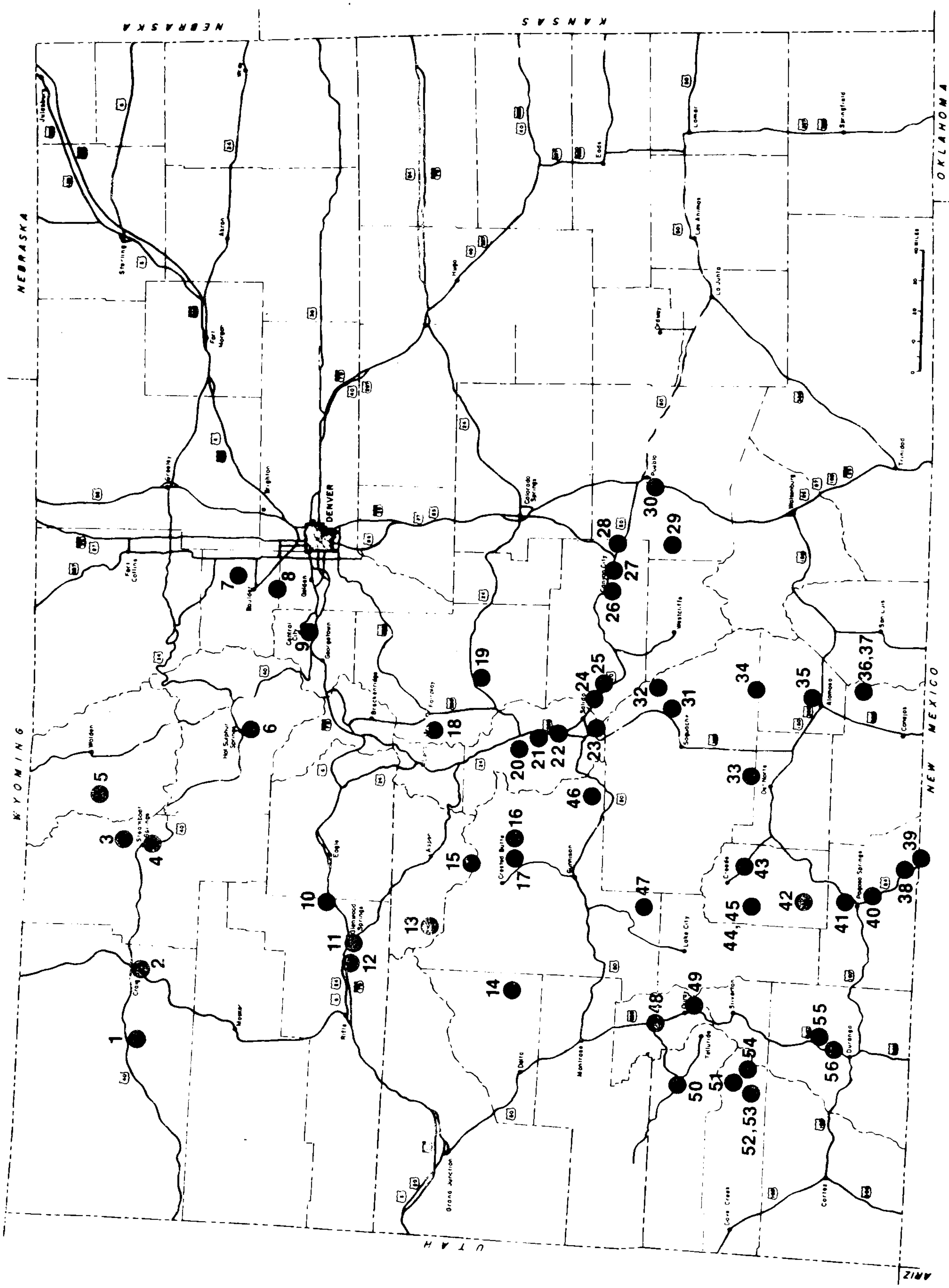

FIGURE 1. GEOTHERMAL RESOURCE LOCATIONS (THERMAL SPRINGS AND WELLS) IN COLORADO.

This project was initiated by the U.S. Department of Energy, Division of Geothermal Energy (DOE/DGE), to identify the potential for development of geothermal energy in the five-state region of Arizona, Colorado, New Mexico, Nevada and Utah. Once that potential was identified, a second objective was the identification of those actions that will be required in order to accomplish that development. Funding was provided to the prime contractor, the New Mexico Energy Institute, by the DOE/DGE, assisted by the Four Corners Regional Commission and the New Mexico Energy Resources Board. Each state arranged for a subcontractor. In Colorado the subcontractor is the Colorado Geological Survey, with staff members Richard H. Pearl, Chief, Groundwater Investigations Section, and Barbara A. Coe, Researcher, comprising the State Team.

This report summarizes the findings of the Colorado Team during the first project year. It is organized into seven sections--the Introduction, Methodology, Status of Geothermal Development, Obtaining Leases and Permits, Development Potential, Constraints to Development, and the Summary and Recommendations. The Methodology section describes the assumptions and the kinds of data used, as well as the methodology for scenario preparation. The next two sections summarize the information that was obtained about geothermal resources in Colorado, including existing uses, leasing, exploration and technical studies, and the leasing and permit requirements. Section V, Development Potential, discusses the estimated potential for the identified hydrothermal (hot water) resources in Colorado. Section VI describes some of the constraints to geothermal development in Colorado. The last section, Section VII, consists of the conclusions and the actions believed to be required in order to accelerate, or even initiate, geothermal development in Colorado.

Numerous individuals provided information and assistance for this study. Their help is greatly appreciated. Among them were the Colorado Team Leader, Mr. Richard H. Pearl, who provided not only direction but also a wealth of information about geothermal resource characteristics. Two of his staff members, Michael Galloway and Jay Dick, also were most helpful in providing valuable and necessary information.

Special mention should be made of the Members of the Colorado Geothermal Resources Development Advisory Committee, who assisted in numerous ways. They are:

Kenneth C. Bull, United States Geological Survey

Senator Martin E. Hatcher, Colorado State Senator

Dr. T. L. Grose, Colorado School of Mines

Jerry Kiel and Dr. Jerry Morse, Colorado Energy Research Institute

Dr. William B. Lord, Institute of Behavorial Sciences, University of Colorado

Frank Piro, Colorado Oil and Gas Conservation Commission

David Robbins, Attorney General's office

Ivo Russpold, Four Corners Regional Commission

Dr. Sadeh, Engineering Research Center, Colorado State University

Thomas E. Schessler and Craig Losche, U.S. Forest Service

Larry Sparks, Colorado Water Conservation Board

Paul L. Summers, U.S. Bureau of Land Management

Peggy Wrenn, Colorado Energy Conservation Office

John Rold, Colorado Geological Survey

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Dr. Charles W. Berge, Gary Crosby and William Nowell, Phillips Petroleum Company

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Dr. Glenn E. Coury, Coury and Associates

William M. Dolan and Harry J. Olson, Amax Exploration, Inc.

John West, City Manager, Glenwood Springs, and other members of the Glenwood Springs Geothermal Resources Development Committee

Dr. Richard Meyer, Western Energy Planners, Consultant to the Southwest Regional Geothermal Resources Development Project

Malcolm Mossman, Occidental Geothermal, Inc.

Irvin Nielson, Marine Minerals

Abner Hahn, Superintendent of Schools, Pagosa Springs, and other members of the Pagosa Springs Geothermal Resources Development Committee

George Parkins, Colorado Public Utilities Commission

Charles Underwood, General Geothermal

David Ford, Colorado Energy Conservation Office

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METHODOLOGY

To assess the potential for geothermal development in Colorado, several kinds of data were first obtained. These included information regarding procedures for geothermal development, estimates of the amount of geothermal energy available, the market areas, energy demand, and uses for the energy. Scenarios were then prepared that described possible geothermal energy development. In preparing them, the objective was to base them, to the extent possible, upon actual conditions while postulating that an aggressive development program was in place. To make the best use of available time, existing data were obtained whenever possible, from other agencies and officials, as well as from representatives of private industry. Furthermore, a strong effort was made to assure that the data collection was limited to only that information necessary for preparation of reasonably realistic scenarios.

Resource Assessment

To provide the starting point for the geothermal resource data base, the Colorado Team had available an inventory of hot springs and wells that included a brief description of each resource area, surface temperatures and estimated subsurface temperatures (Barrett and Pearl, in press). To aid in the evaluation of the energy content of these resource areas, an estimate was made of the areal extent and thickness of each. Using these estimates, the energy content of each reservoir was estimated, using the method employed in U.S.G.S. Circular 726 (Renner, White, and Williams, 1975), with two minor changes. One change was the assumption of an ambient air temperature of 20°C, rather than 15°C. The other was to use the midpoint of the range of subsurface temperatures estimated by Barrett and Pearl (in press). Table 1 lists the thermal areas, their areal extent and the amount of energy estimated to be contained in each system. The map, Figure 1, shows the location of the areas, and the resource identification numbers. As shown, the amount of geothermal energy contained in all these systems was estimated to total 5,914 quads (1 quad = 10^{15} Btu).

Estimates were then made of the usable energy contained in each thermal system. As indicated in Circular 726 (Renner, White, and Williams, 1975), 25 percent of the stored energy was assumed to be recoverable at the surface, and the efficiency of utilization was assumed to be 24 percent. From these calculations, the total usable energy in the 56 systems was estimated to be 0.35 quads (Table 1). To determine how much of the energy would be available annually, the total usable energy was then divided by 30 years, a commonly-used gauge of economic life for utility facilities. The total energy usable per year from all these areas was estimated to be 0.01 quads.

The reader is cautioned that this is, at best, a rough gauge of the usable energy available. Because of the lack of data, it was not possible to consider variations in permeability, flow rates, or efficiency of specific uses. This estimate is, however, considered to be extremely conservative. Because some systems will be renewable, the actual energy obtained will probably be much greater.

TABLE 1

Resource Assessment

of

Hydrothermal Resources in Colorado

by Jay D. Dick and Richard H. Pearl

February, 1978 (unpublished)

Thermal Spring Areas	Areal Extent (mi^2)	Thickness (ft.) of	Temp. (°C) (midpoint estimate)	Estimated Total Btu (10^{15})	Estimated Useable Btu (10^{15})
Juniper 1	1.01	200(S)	63	.0163	.0009
Craig 2	1.3	500(N)	55	.0428	.0026
Routt 3	0.5	1000(F)	138	.1110	.0067
Steamboat 4	.52	250(S)	70	.0122	.0007
Brand's Ranch 5	0.36	200(S)	49	.0039	.0002
Hot Sulphur 6	1.35	599(N)	75	.0698	.0042
Haystack Butte 7	1.54	300(S)	40	.0174	.0010
Eldorado 8	0.35	1000(S)	35	.0099	.0006
Idaho 9	1.12	1000(F)	80	.1260	.0076
Dotsero 10	0.84	250(S)	39	.0075	.0005
Glenwood 11	1.32	250(S)	65	.0279	.0017
South Canyon 12	0.1	1000(S)	75	.0103	.0006
Penny (Avalanche) 13	1.61	1000(F)	75	.1670	.0100
Colonel Chinn 14	1.55	200(S)	51	.0181	.0011
Conundrum 15	0.45	500(N)	45	.0106	.0006
Cement Creek 16	1.1	150(S)	45	.0078	.0005
Ranger 17	1.11	150(S)	45	.0078	.0005
Rhodes 18	1.53	1000(F)	35	.0432	.0026
Hartsel 19	0.87	500(N)	70	.0409	.0025
Cottonwood Creek 20	1.38	1000(F)	170	.3894	.0234
Mt. Princeton 21	3.14	1000(F)	200	1.0632	.0638
Browns Canyon 22	3.23	1500(S&F)	100	.7291	.0438
Poncha 23	2.19	1000(F)	145	.5150	.0309
Wellsville/Swissvale 24/25	0.94	240(S)	40	.0085	.0005
Canon City 26	0.52	100(S)	50	.0029	.0002
Freemont Natatorium 27	1.0	220(S)	43	.0095	.0006

TABLE 1 (Cont.)

Thermal Areas	Areal Extent (mi^2)	Thickness (st.)	Temp. (°C) (midpoint)	Total Btu (10^{15})	Useable Btu (10^{15})
Florence 28	1.0	200(S)	42	.0083	.0005
Don K. Ranch 29	1.5	500(N)	45	.0353	.0021
Clark Well 30	1.1	200(S)	40	.0083	.0005
Mineral 31	10.1	1000(S)	70	.9406	.0564
Valley View 32	1.05	1000(F)	50	.0593	.0036
Shaw's 33	0.63	500(N)	45	.0148	.0009
Sand Dunes 34	1.5	500(N)	75	.0776	.0047
Splashland 35	1.5	500(N)	75	.0776	.0047
Dexter/McIntyre 36/37	1.2	1000(F)	35	.0339	.0020
Dutch Crowley/Stinking 38/39	1.52	200(S)	65	.0257	.0015
Eoff Well 40	1.5	200(S)	50	.0169	.0010
Pagosa 41	2.15	200(S)	80	.0485	.0029
Rainbow 42	0.99	1000(F)	45	.0466	.0028
Wagonwheel Gap 43	4.24	500(N)	115	.3789	.0227
Antelope/Birdsie 44/45	2.38	500(N)	44	.0537	.0032
Waunita 46	1.4	200(S)	135	.0606	.0036
Cebolla 47	1.86	500(N)	60	.0700	.0040
Orvis 48	0.55	500(S)	75	.0285	.0017
Ouray 49	2.07	1000(F)	80	.2336	.0140
Lemon 50	0.81	425(S&F)	43	.0149	.0009
Dunton/Geyser/Paradise 51/52/53	1.16	400(S)	50	.0262	.0016
Rico 54	1.74	1000(F)	63	.1407	.0084
Pinkerton/Mound 55	0.98	180(S)	50	.0100	.0006
Tripp/Trimble 56	1.0	500(N)	58	.0357	.0021
				5.9142	.3549

(S) Stratigraphic reservoir
(F) Fracture reservoir
(N) unknown

Development Status and Procedures

Another task of the study was to explore the current status of geothermal development activity in Colorado. To obtain this information, records of geothermal leases on public lands were obtained from state and federal agencies. Subsequently, discussions were held with lease holders to learn about the current status and future plans. Additional information and ideas for future development plans were gleaned through various publications and conversations with community groups and potential users.

The investigation of procedures for development, both technical and institutional, was another important aspect of the study. Published documents were reviewed and copies of laws and regulations were obtained from state, federal, and local agencies. From discussions held with numerous officials in both the public and private sector, information was obtained about the actual practices and procedures of geothermal development and regulation, including the length of time generally required for various activities.

To judge what types of leases would be necessary to develop a given site, land ownership was also investigated. The Bureau of Land Management map series provided this information. The probable need for federal leases was based on the assumption that for direct use, they would be necessary only after commercial geothermal development was well established. Therefore, federal leases are assumed to be unnecessary in the early stages of development where private ownership seems adequate to accommodate the development.

Using this information, the resource areas were then organized into categories in order to simplify the scenario preparation. The categories are as follows:

Category I areas with significant commercial activity. No resources areas in Colorado currently seemed precisely to fit Category I.

Category II includes those resource areas where some activity toward exploration or development is known to be occurring. Areas where the activity is directed toward development of power generation are designated IIA. Those areas with activity toward nonelectric uses are shown in Category IIB.

Category III areas where no interest has been shown nor any activity has occurred, is divided into 3 subcategories, based upon: a) lease availability, b) the quality of the resource and the apparent use potential, judging from the proximity of the resource to communities, c) the potential for process use, and d) the competition from other resources. The 3 subcategories are A, High Potential, B, Moderate Potential, and C, Low Potential. Where the resource use area overlaps with another and could be combined into one economic unit, regional use areas are defined. It should be stressed that all these categories and subcategories are somewhat subjectively derived and applicable only to the extent that, and for as long as, the currently available data are accurate. When better information is obtained or if conditions should change, this category placement could be totally inapplicable.

Subcategory A includes areas which are near potential users, have high enough temperatures and have some private land surrounding them. Those areas in IIIB have slightly less ideal conditions.

The resource areas in subcategory IIIC have constraints to their development that seem at this time to virtually preclude their development. In each case, one of the following applies:

1. Leases are not obtainable, because the area is in a designated wilderness area or an area of Federal land that has been withdrawn for wildlife protection.

2. No community is within the range of possible transport of the resource, nor does any process use seem probable within the area.

3. The estimated subsurface temperature of the resource is inadequate for potential uses that seem reasonable for the area.

Complete scenarios were not written for these latter areas. Scenarios in both narrative and chart form were prepared for all the other areas listed. The amount of detail provided was greatest for the highest category, decreasing with the lower category levels.

Table 2 shows the categories to which each of the resource areas was assigned.

Energy Demand Assessment

Several kinds of cultural data were considered to be necessary for devising scenarios that would reasonably reflect characteristics specific to each geothermal resource site. These include population, energy demand, economic conditions, and the potential use areas for the geothermal resources.

Population - Population estimates for 1975 from the report Population Estimates and Projections (U.S. Dept. of Comm., 1976), were used for each of the incorporated municipalities within geothermal resource use areas. Projections for counties in Colorado to the year 2000 were obtained from Colorado Population Trends (State Division of Planning, 1976). Using the "high" projections to allow for some unincorporated places and rural areas, percentages were calculated for each of the communities from the percentage of the total 1975 county population which each represented. Population for the year 2020 was then extrapolated based on the rate of growth between 1975 and the year 2000. A dwelling-unit occupancy rate of 3.0 was assumed in order to determine the probable number of dwelling units.

Energy demand - The energy demand that could be satisfied by direct use of geothermal resources is based upon the current consumption of natural gas in Colorado. According to the Energy Conservation and Policy Office, an average of 151 Mcf of natural gas per year is consumed by residential customers of the Public Service Company of Colorado, who represent 70-percent of statewide natural gas customers. Using a 70 percent efficiency rate to derive beneficial energy and 840 Btu/cu ft results in an average 88,788,000 Btu per dwelling unit per year. Although this somewhat overestimates the need for geothermal resources because it includes a small amount of cooking, this was not considered to be significant. A 50-50 split between residential uses and all others is used in the scenarios to provide a rough estimate of the total energy demand.

Economic Conditions - Some knowledge of the economic conditions around each of the resource areas was necessary in order to determine what energy uses would be most reasonable. This was largely empirical, derived from travel throughout the State, complemented by discussions with staff at the State Division of Commerce and Development (Jack Olson,1978, pers. comm.).

TABLE 2

GEOTHERMAL RESOURCE DEVELOPMENT SCENARIO CATEGORIES
Revised April, 1978

I. SIGNIFICANT COMMERCIAL ACTIVITY - NONE

II. ACTIVITY - LEASES OR DEVELOPMENT EFFORT

A. POWER GENERATION SITES

MT. PRINCETON, COTTONWOOD CREEK, HORTENSE
PONCHA SPRINGS/BROWNS CANYON
CEBOLLA

B. NON-ELECTRIC SITES

GLENWOOD HOT SPRINGS
HARTSEL
PAGOSA SPRINGS
WAUNITA

SAN LUIS VALLEY
- SHAWS
- SAND DUNES
- SPLASHLAND
- MINERAL/VALLEY VIEW

III. NO INTEREST OR ACTIVITY

A. HIGH POTENTIAL

ROUTT/STEAMBOAT SPRINGS
HOT SULPHUR SPRINGS
OURAY
DUNTON/GEYSER/PARADISE
HAYSTACK BUTTE
ELDORADO SPRINGS
IDAHO SPRINGS

B. MODERATE POTENTIAL

JUNIPER/CRAIG
BRAND'S RANCH
SOUTH CANYON
PENNY
CEMENT CREEK/RANGER
WELLSVILLE/SWISSVALE
CANON CITY/FREMONT
DON K RANCH/FLORENCE
CLARK
WAGON WHEEL GAP
ORVIS
RICO
PINKERTON/MOUND
TRIPP/TRIMBLE

C. LOW POTENTIAL

DOTSERO
RHODES
DEXTER/MC INTYRE
STINKING SPRINGS/DUTCH CROWLEY
LEMON
RAINBOW
ANTELOPE/BIRDSIE
CONUNDRUM

Although process uses offer opportunities that may be more financially lucrative, space and water heating were emphasized in the scenarios for several reasons. First, the State is very dependent upon natural gas, which constitutes 41 percent of the total energy consumed. About 30 percent of the supply of natural gas was interruptible in 1974. Seventy-eight percent of the natural gas is used for industrial, commercial, and residential sectors, 71 percent of the residential use being for space heating. Further, the state imports about 60 percent of the natural gas consumed in the State (CERI, 1976). Reducing the demand for natural gas could reduce the dependency upon outside suppliers, as well as conserving the availability of natural gas for areas where alternative supplies are not available.

Furthermore, the encouragement of process uses of energy may be inappropriate in some areas. In most of the geothermal resource locations, existing industry is minimal. An analysis of the probable environmental and socioeconomic impacts is believed to be needed before suggesting the introduction of new industry to specific areas.

In addition, new process uses of energy would increase the net energy consumption. This would not contribute to the goal of energy independence, which is the primary reason for programs to accelerate development of alternative energy resources.

Enormous benefits can be derived, on the other hand, from promotion of new process uses where the adopted policy is to encourage economic growth. Because energy availability is an increasingly important facet of industrial location decisions, economically depressed areas can benefit if their geothermal resources are made available for industrial use.

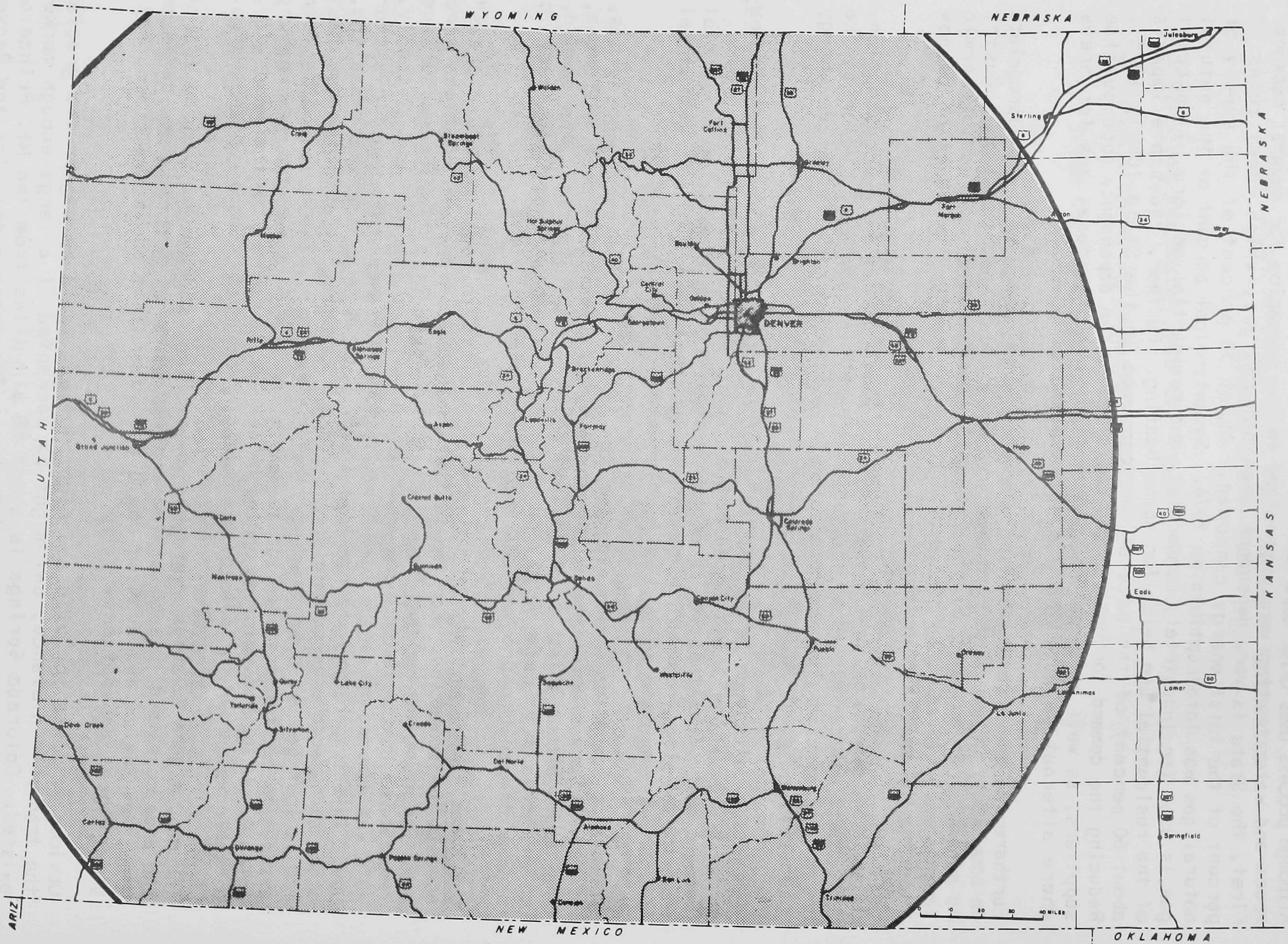
To develop scenarios envisioning any sort of use for geothermal resources, it was necessary to assume the existence of a market demand. In most instances, that means either a lack of sufficient natural gas to satisfy the demand, or an increase in natural gas prices. In addition, it was necessary to assume comparable project costs at the different sites.

Use Areas - Several analyses ultimately resulted in the final "use areas" used in the scenarios. For the initial analyses, several assumptions were made. One assumption was that the highest of the range of estimated subsurface temperatures in each resource area would be available at the surface. Secondly, 40°C was assumed to be the lowest temperature that would be beneficial for use. This temperature was considered sufficiently high for space heating, since such temperatures are currently used. A further assumption was that 1°C is lost per mile in transporting the resource. The resource is then assumed to be transportable for as many miles as will lower the temperature to 40°C. Using the existing spring or well as the center of the reservoir, a circle was drawn to indicate the potential use area of each resource area.

The map, Figure 2, shows that when an outline is drawn to include all of the area contained in each of the circles, most of Colorado and parts of Utah, New Mexico and Wyoming could use Colorado's geothermal resources, given these assumptions.

Obviously, costs for pipe and rights-of-way would be higher the greater the transport distance, but might be warranted if a large enough market existed. Colorado Springs is about 68 air miles from the Mt. Princeton resource area; Denver is about 100 miles. The water supply for the Denver suburb of Aurora is currently piped from the same valley that contains the

FIGURE 2



POTENTIAL GEOTHERMAL RESOURCE USE AREA IN COLORADO BASED ON 1^{O}C TEMPERATURE LOSS PER 1 MILE.

Mt. Princeton resource area. A geothermal resource use area that would include the cities of Denver and Colorado Springs might also be feasible, depending upon the future value and supply of the various energy resources.

For a second analysis, circles were drawn around the hot springs locations on a map of the state. The equivalent of 30 miles was used to indicate the maximum distance that geothermal fluid may be transported. Again the hot spring or well is used as a center. As Figure 3 shows, approximately half the state theoretically could use geothermal resources.

To be more commensurate with current economic assumptions, more conservative use areas were assumed. If the initial analysis of the potential use area showed it to be less than 30 miles in radius, the smaller radius was used. Where analysis showed the use area to be 30 miles or more, a 30-mile radius was used. The municipalities within that radius were then identified. When communities fell within more than one resource area, they were assigned to the nearest area. This analysis resulted in much smaller use areas, as shown on Figure 4. Then, the use areas were altered so that the estimated geothermal energy supply in each compared with the estimated natural gas demand. The resulting use areas were smaller still than previously in some cases. Since estimates of the resource potential were very conservative, often one small community was estimated to consume all of the energy estimated to be available. To further refine the use areas, topography was cursorily examined, resulting in elimination from the scenarios of long-distance pipelines over extremely rugged terrain. These use areas are shown in the section entitled Resource Potential.

Scenario Preparation

Scenarios were then prepared for both power generation and low-temperature sites. For power generation, only geothermal resources that are considered to have subsurface temperatures of at least 200°C are considered feasible.

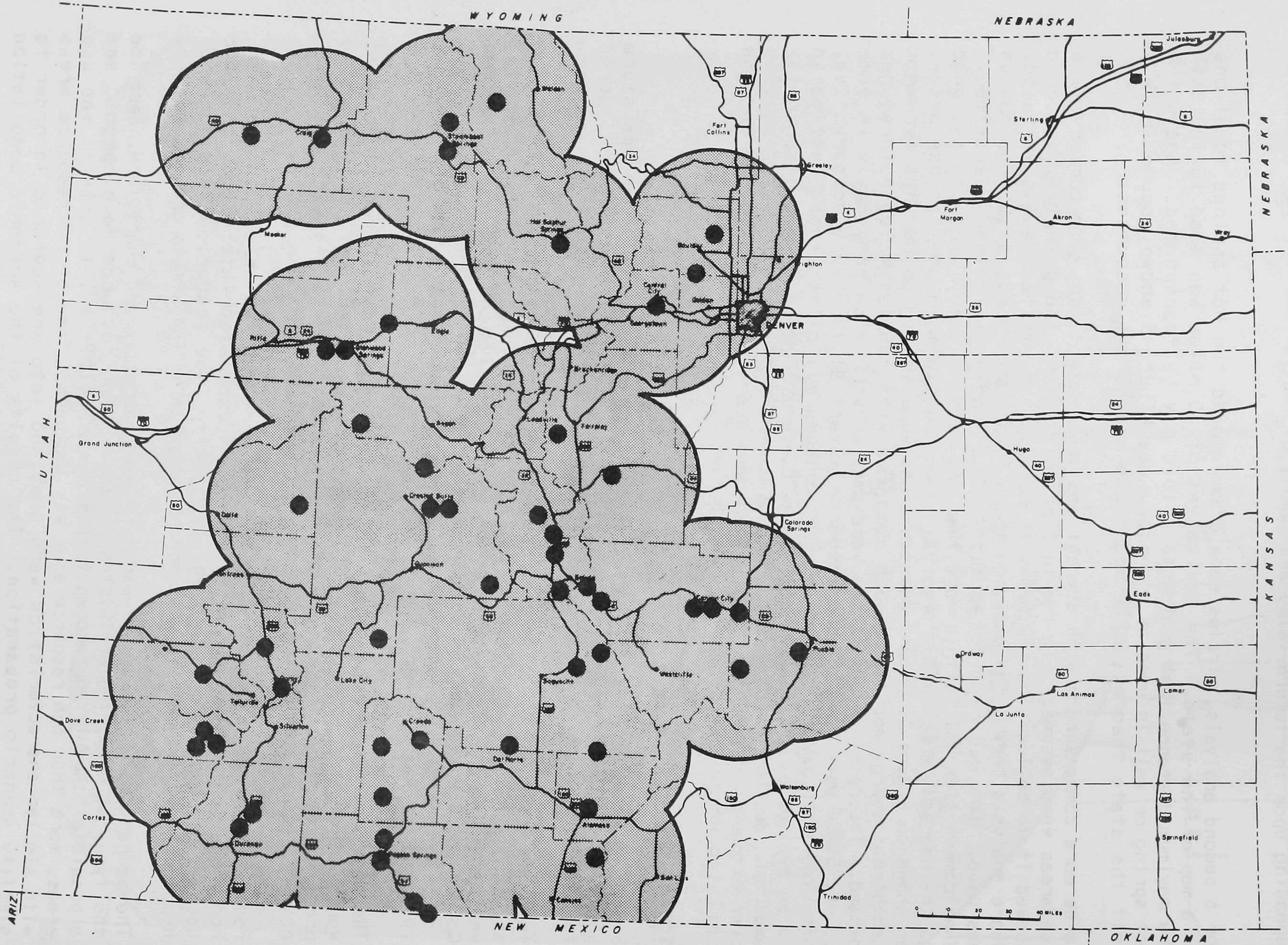
In those areas where the lessees considered the temperatures to be suitable, as well as indicating that some work was planned, power generation potential was assumed. The areas are: Mt. Princeton and Poncha Springs in Chaffee County and Cebolla in Gunnison County (Amax Exploration, Chevron Resources, Inc., Occidental Geothermal and Phillips Petroleum Company representatives, 1977, 1978, pers. comm.).

The plans for these areas as well as the problems constraining development were discussed at some length with the lessees. Then, following scenario preparation, the draft scenarios were submitted to the lessees for their review and refinement.

For the low-temperature sites, scenarios were derived in one of two ways. For those sites where potential developers expressed interest in specific uses, those uses were indicated. Otherwise, the scenarios were somewhat hypothetical, although they incorporated existing industries and population.

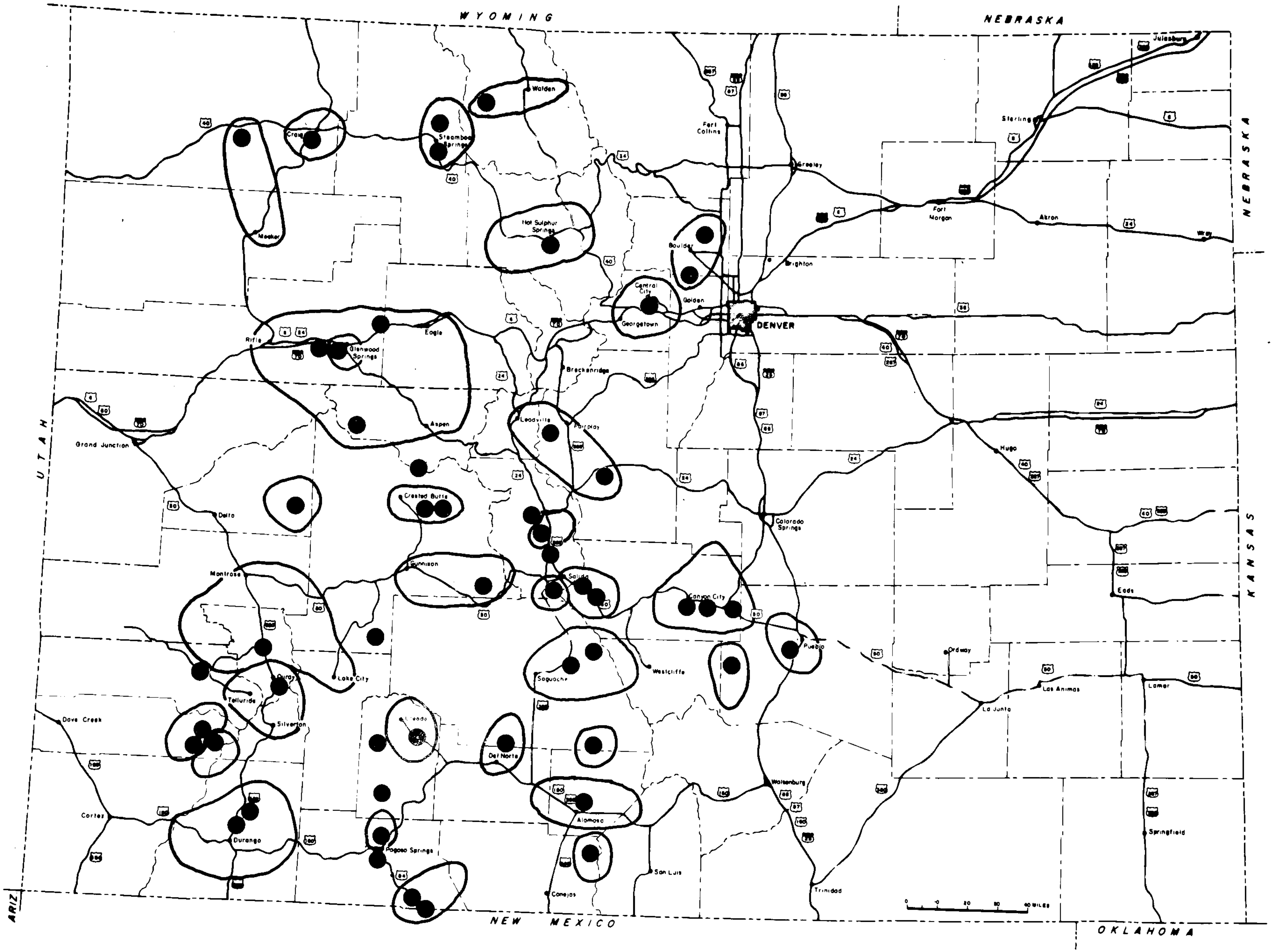
The scenarios, which were prepared in both narrative and chart form, describe the types of uses, the activities necessary for resource development, and a possible schedule for accomplishing those activities. In some of the use areas, more than one resource area was included. Some of the resource areas with similar characteristics were combined into one scenario in order to simplify scenario preparation. The results of the scenario compilation are described in the Resource Potential section.

FIGURE 3



POTENTIAL GEOTHERMAL RESOURCE USE AREAS IN COLORADO BASED ON 30 MILE RADIUS FROM SURFACE EXPRESSIONS.

FIGURE 4



POTENTIAL GEOTHERMAL RESOURCE USE AREAS IN COLORADO BASED ON NEAREST COMMUNITIES.

STATUS OF GEOTHERMAL DEVELOPMENT IN COLORADO

Geothermal resources already contribute to Colorado's energy supply. In fact, since the early 1900's, practical uses of geothermal resources have been common in Pagosa Springs, in Southwest Colorado. Residents there have used hot-water wells to heat numerous buildings, including the County Court House, schools, churches, the newspaper office, a liquor store, 2 hotels, 2 service stations, a drugstore, and a bank, as well as for the swimming pool and spa. Although the corrosion of heating system equipment, along with the low price and availability of natural gas induced the conversion of some geothermal systems to natural gas, 12 wells are still in use. (Dick and Galloway, unpublished report, 1978). A list of the known wells is found in the Appendix.

Where resources are in use in other parts of the State, most are used for swimming pools or baths. A few wells or springs serve other purposes, however, among them space heating and agriculture, including greenhouses, a fish farm and algae-growing. Table 3 shows the known users and uses in geothermal resource areas throughout the state.

Interest in developing the geothermal resources in Colorado has grown since the beginning of the 1970's. Because of the problem of transporting the energy to the user, most of the recent interest has been in geothermal power generation. Toward this end, some leasing and exploration activity have occurred. It is commonly believed, however, that Colorado's resources offer high enough temperatures for power generation in only a few areas, given today's economic criteria. Efforts toward the development of low-temperature uses such as space or water heating of industrial or agricultural process use so far seem minimal. However, several planning and preliminary engineering studies emphasizing these uses are either completed or underway. Judging from conversations with potential developers throughout the state, interest is growing. If a planned development of a district heating system in the town of Pagosa Springs is funded by the Department of Energy, this may well be the first step toward significant development of the low-temperature geothermal resources throughout Colorado.

TABLE 3

CURRENT USES OF GEOTHERMAL RESOURCES IN COLORADO 1978

Type of Use	Name of Area
Swimming Pools	Juniper Hot Springs
	Steamboat Hot Springs
	Hot Sulphur Springs
	Eldorado Warm Springs
	Idaho Hot Springs
	Glenwood Hot Springs
	Cement Creek Hot Springs
	Cottonwood Creek Hot Springs
	Mt. Princeton Hot Springs
	Hortense Hot Springs
	Poncha Hot Springs
	Shaws Warm Spring
	Splashland Hot Water Well
	Pagosa Hot Springs
	Wagon Wheel Gap Hot Springs
	Upper Waunita Hot Springs
	Ouray Hot Springs
	Pinkerton Hot Springs
	Valley View Hot Springs
Baths	Juniper Hot Springs
	Hot Sulphur Springs
	Idaho Hot Springs
	Glenwood Hot Springs
	South Canyon Hot Springs
	Mineral Hot Springs
	Valley View Hot Springs
	Cebolla Hot Springs
	Orvis Hot Springs
	Ouray Hot Springs
	Dunton Hot Springs
	Paradise Hot Springs

TABLE 3 (Cont.)

Space Heating	Cottonwood Creek/Jump Steady Hot Springs - Mt. Princeton - cabins/House, resort
	Wright Hot Water Wells - 2 houses
	Poncha Hot Springs - 1 house
	Sand Dunes Swimming Pool Well - 1 house
	Ouray - 2 motels
	Pagosa Springs - approx. 10 buildings
	Upper Waunita Hot Springs - headquarters building
Other	
Laundry	Hot Sulphur Springs
Greenhouses	Penny Hot Springs
	Wright Hot Water Wells
	Tripp Hot Springs
Algae Growing	Wellsville
Irrigation	Dutch Crowley
Bottled Water	Clark Artesian Well
	El Dorado Warm Spring
Fish Farming	Sand Dunes Hot Water Well

SOURCES: Barrett and Pearl, 1978 and unpublished data from Dick and Galloway, 1978.

The development of a geothermal resource for either power generation or direct uses, such as space heating, involves several steps, namely leasing, exploration and development. A program may begin with preliminary exploration followed by acquisition of leases in areas that seem to offer potential. Or it may begin with identification of desired uses, followed by feasibility studies and finally location of a suitable resource.

Table 4 shows the tasks that are usually required for development of a geothermal resource system and the minimum amount of time that will probably be required for each. Some of the tasks may, of course, be accomplished simultaneously. The following sections describe the status of the various activities.

Leasing

Although records of the geothermal leases with private parties in Colorado are not readily available, listings of leases on public lands were obtained from the State and Federal agencies. As Table 5 shows, federal geothermal leases are active in Known Geothermal Resource Areas (KGRA) on a total of 5,035 acres.

Noncompetitive geothermal leases on federal lands were issued on 28,487.5 acres as shown on Table 6. On state lands, geothermal leases are in effect on a total of 83,192 acres, as shown on Table 7. Applications for other leases, which were submitted as early as 1974, are still pending. These applications are primarily for leases on national forest lands.

No new leases on public lands have been issued since August, 1977. In fact, in late 1977, federal leases on about 8,021 acres and state leases on about 31,487 acres were dropped by the lessees. Since most of the lessees are interested primarily in resources suitable for power generation, while most of Colorado's resources are considered to be lower temperature, the lack of vigorous leasing is not surprising.

The areas in which leasing of federal and state acreage has occurred are:

Mt. Princeton Hot Springs No. 21A
Poncha Springs No. 23
Mineral Hot Springs/Valley View No.31/32
Sand Dunes Swimming Pool Hot Water Well No. 34
Splashland Hot Water Well No. 35
Waunita Hot Springs No. 46
Cebolla Hot Springs No. 47

Exploration

Exploratory work in the geothermal areas may be grouped into three categories: 1) preliminary exploration, especially geophysics and geochemistry; 2) thermal gradient holes; 3) test wells. The main activities in each category are described below.

1) Preliminary Exploration - Although the information concerning geophysics and geochemical analyses performed by private companies is scant, undoubtedly both types of exploration have been done in a number of areas. And in one area, Pagosa Springs, the Colorado Geological Survey (CGS) had geophysical work performed in the fall of 1978. CGS also performed geochemical tests for the 56 identified thermal areas (Barrett and Pearl, 1978).

TABLE 4

STEPS FOR GEOTHERMAL RESOURCE DEVELOPMENT

APPROXIMATE MINIMUM TIME	ACTIVITY
2 mo.	PRELIMINARY EVALUATION OF AREAS
	OBTAIN LEASES
2 mo.	BLM
3 mo.	USFS
7-8 mo.	State
?	Fee
	PERMITS FOR GRADIENT HOLES
2 mo.	State
3 mo.	USGS
1 mo.	USFS
2 mo.	CONTRACT FOR DRILLING
1/2	DRILL GRADIENT HOLES & EVALUATE
3 mo.	FEASIBILITY AND ENGINEERING STUDIES
	OBTAIN FINANCING FOR EXPLORATORY WELLS
1 mo.	Loan
6 mo.	Bond Issue
6 mo.	Government
	PERMITS FOR EXPLORATORY WELLS
2 mo.	State - O&GCC, Engineer, WQCC, APCC
3 mo.	USGS
1 mo.	USFS
2 mo.	City or County
2 mo.	HIRE DRILLING CONTRACTOR
1 mo.	DRILL EXPLORATORY WELL
1 mo.	EVALUATE POTENTIAL OF RESOURCE
1 mo.	OBTAIN WATER RIGHTS IF NECESSARY
1 mo.	SECURE MARKET OR ESTABLISH HEATING/COOLING DISTRICT
	OBTAIN FINANCING FOR DEVELOPMENT
1 mo.	Loan
6 mo.	Bond Issue
6 mo.	Government
2 mo.	PERMITS FOR DEVELOPMENT
3 mo.	R.O.W. FOR PIPELINES
2 mo.	CONTRACT FOR CONSTRUCTION OF FACILITIES
6 mo.	INSTALL SYSTEM
1 mo.	OBTAIN FINANCING FOR PRODUCTION WELLS
1 mo.	Loan
6 mo.	Bond Issue
6 mo.	Government
	PERMITS FOR PRODUCTION, DISPOSAL, ETC.
2 mo.	State
15 mo.	USGS
1 - 18 mo.	USFS
6 mo.	County or City
2 mo.	HIRE DRILLING CONTRACTOR
1 mo.	DRILL ONE WELL

TABLE 5

FEDERAL ACTIVE COMPETITIVE GEOTHERMAL LEASES

(KGRA'S)*
IN COLORADO
December, 1977

LESSEE	ACRES	TOWNSHIP & RANGE	DATE ISSUED
The Anschutz Corporation	915	49 N, 8 E	1975
Phillips Petroleum Company	2484	45 N, 8 E	1975
Phillips Petroleum Company	1636	45 N, 9 E	1975
	5035		

*Designated Known Geothermal Resources Areas by Federal Government

SOURCE: Bureau of Land Management, Denver, Colorado

TABLE 6

FEDERAL ACTIVE NON-COMPETITIVE GEOTHERMAL LEASES
IN COLORADO
December, 1977

LESSEE	ACRES	TOWNSHIP & RANGE	DATE ISSUED
Buttes Resources Company	781.32	46 N, 2 W	1977
	2,226.88	46 N, 1 & 2 W	1977
	1,804.57	46 N, 1 ! W	1977
	1,040.04	46 & 47 N, 2 W	1977
	1,970.30	46 & 47 N, 2 W	1977
Chevron Oil Company	1,867.94	46 & 47 N, 2 & 3 W	1977
	2,127.56	46 & 47 N, 3 W	1977
	645.74	47 N, 3 W	1977
	160.00	45 N, 9 & 10 E	1975
Earth Power Corporation	1,000.00	46 N, 10 E	1976
Geothermal Kinetics, Inc.	1,000.00	37 N, 12 E & 38 N, 13 E	1975
	1,106.00	29 W, 73 W	1975
	827.31	38 N, 13 E & 29 S, 73 W	1975
	1,042.47	29 S, 73 W	1975
Ladd Petroleum Corp.	883.65	45 N, 11 E	1975
	280.00	46 N, 10 E	1975
Occidental Petroleum	80.00	49 N, 8 E	1975
	1,280.00	49 N, 3 E	1975
	2,113.30	49 N, 7 & 8 E	1975
	1,549.66	49 N, 9 E	1975
	1,286.17	51 N, 8 E	1975
Phillips Petroleum Co.	320.00	46 N, 10 E	1975
	1,120.00	45 N, 10 E	1975
	1,644.50	46 N, 10 E	1975
	329.50	46 N, 11 E	1975
	28,487.51		

SOURCE: Bureau of Land Management, Denver, Colorado

TABLE 7

COLORADO STATE ACTIVE GEOTHERMAL LEASES

December, 1977

LESSEE	ACRES	TOWNSHIP & RANGE	COUNTY
General Geothermal, Inc.	9,639.90	41 N, 6 E	Saguache
		45 N, 9 E	
		46 N, 10 E	
	8,183.33	39 N, 11 E	Alamosa
		40 N, 12 E	
	360.00	49 N, 8 E	Chaffee
	640.00	35 N, 2 W	Archuleta
	640.00	12 S, 75 W	Park
	480.00	11, 12 S, 75, 76 W	
	560.00	35 N, 1 W	Archuleta
Geothermal Products, Inc.	2,004.85	14 S, 78 W	Chaffee
	3,692.00	15 S, 78 W	
	1,280.00	15 S, 78 W	
		14 S, 78 W	
Mapco, Inc.	640.00	40 N, 11 E	Alamosa
	1,625.00	41 N, 11, 12 E	Saguache
	17,895.00	41 N, 10, 11, 12 E	
	9,611.88	39, 40 N, 11, 12 E	
	3,920.00	37, 38 N, 11, 12 E	Alamosa
	2,532.24	42, 43, 44, 45 N, 10 E	Saguache
Marine Minerals	640.00	40 N, 12 E	Alamosa
Occidental Oil Co.	640.00	49 N, 4 E	Gunnison
Petro-Lewis	2,004.85	14 S, 78 W	Chaffee
	3,692.31	15 S, 78 W	
	1,280.00	15 S, 78 W	
		14 S, 79 W	
	3,226.61	50 N, 8 E	
	1,560.00	49 N, 7 E, 9 E	
		50 N, 8 E	
	40.00	14 S, 78 W	
Phillips Petroleum	1,764.40	48, 49 N, 4, 5 E	Gunnison & Saguache
Underwood, C. A.	3,520.00	14 S, 78 W	Chaffee
		45, 46 N, 8, 9, 10 E	Conejos, & Saguache
	1,120.00	33 N, 8 E	Conejos
TOTAL	83,192.37		

2) Gradient Holes - Gradient holes are known to have been drilled in only two thermal areas in Colorado. At the first, Mt. Princeton Hot Springs, one 2,000-ft hole was drilled in the fall of 1978 by Amax Exploration, Inc. At Pagosa Springs, the second site, the Colorado Geological Survey drilled 5 holes in the fall of 1977. Chevron has a permit from U.S.G.S. to drill five shallow thermal gradient holes in the Cebolla area. Presumably, that drilling will be done in the summer of 1978.

3) Test Wells - One exploratory geothermal well has been drilled in Colorado. Mapco in 1974 drilled a 9,480-ft well on the eastern side of the San Luis Valley near the Great Sand Dunes area to determine temperature gradient and hydrologic properties of the aquifer, as well as oil and gas potential. The test was inconclusive, although high bottom hole temperatures were encountered, and water flowed to the surface in 21 minutes from depths of 5,304 to 5,491 ft. (Completion Report, Colorado Oil and Gas Conservation Commission).

One exploratory well is now being drilled by the Colorado Geological Survey at Pagosa Springs. This 2,000 ft deep well is funded by the U.S. Department of Energy (DOE). If a usable resource is found, the town of Pagosa Springs will assume ownership of the well and put the resource to beneficial use. A similar exploration program will be conducted in the Glenwood Springs area sometime in 1979.

In the Mt. Princeton, Cebolla, and Poncha Springs areas, the companies who hold leases in those areas plan to drill test wells if and when the additional leases they have requested are obtained and if preliminary exploration findings are satisfactory.

Technical Studies

Other efforts directed toward geothermal development include planning, engineering and feasibility studies, as well as preliminary investigations. Among these planning studies is one being conducted by the National Council of State Legislatures to define state legislation needed to encourage geothermal development and this operations research project.

Engineering and feasibility studies that have been conducted include the evaluation of reconversion to geothermal heat of the heating systems in the Pagosa Springs schools (I.A. Engen, 1977), residential space heating in Glenwood Springs (Nannen, Kreith, and West, 1975), and barley malting and sugar-beet processing in the San Luis Valley (Coury and Associates, in preparation). A current study is investigating the use of geothermal resources for residential space heating and other uses in the San Luis Valley (Coury and Associates, in preparation).

Preliminary investigations for other geothermal development have been indicated, some through requests for information from the CGS. Among these are heating for hogpens, greenhouses, homes and resorts in various areas. These may represent only a small percentage of the preliminary investigations actually underway. Since any new project must begin with some sort of preliminary investigation, this may mean the start of numerous future geothermal resource development projects.

OBTAINING LEASES AND PERMITS

Before any new geothermal development can occur in Colorado, certain legal requirements must be met. In this section, the two primary requirements, obtaining leases and permits, are discussed. As indicated, the requirements vary depending upon whether the ownership of the land and/or mineral rights is federal, state or private.

Leasing

Developers generally have obtained geothermal leases on wide areas, usually several thousand acres, in an area in which they are interested. This assures that they will have adequate control of any discovery that might be made. In the case of federal land, control in advance of a discovery is especially vital. If a discovery is made, the area may be designated a Known Geothermal Resource Area (KGRA). In KGRA's, leasing is competitive, with no allowance for preferential leasing rights to the company making the discovery. For this reason, a company must have control of the area before they can justify spending large sums of money on exploration. In Colorado, the KGRA provision usually makes the acquisition of a combination of federal, state and private leases necessary. Especially where much of the land ownership is "checkerboarded" or split among various types of jurisdictions, obtaining several types of leases may be the only way to control sufficient amounts of acreage. The steps necessary for obtaining leases vary depending upon what entity owns the land and the minerals.

Private Lands and Minerals

Where ownership is private, leases are obtained simply through negotiation and contractual agreement with the owner. The transaction is then usually reported by the lessee to the county clerk of the county or counties in which leases are located.

State-Owned Lands or Minerals

Leasing of state-owned land and minerals is under the jurisdiction of the Board of Land Commissioners, whose mandated objective is to maximize the income from state lands. Under the Board are four sections, Minerals, Rights-of-Way, Surface and Accounting. The Minerals Director is responsible for administration of geothermal leases, and the accounting department is responsible for collection of the rental and royalty payments for these leases (T. E. Bretz, 1978, pers. comm.).

To obtain a state geothermal lease, an application is filed with the Minerals Section. The request is then posted on the bulletin board, and a questionnaire is circulated for comment among state, local and federal agencies, as well as county commissioners' and county planners' offices in the respective county or counties. The feasibility and impacts of the proposal are evaluated, taking into consideration the comments returned from other agencies and individuals. After reviewing all the information, the Board decides whether or not to issue the lease. The entire process usually requires about six months. Leases may also be auctioned, but have been noncompetitive thus far because of limited interest in geothermal leasing.

Prior to any exploration or development, the Board must be notified. The applicant must also post bond to guarantee compliance with the Board's requirements for restoration of the surface and settlement of damages to the surface property. The lessees must agree to conduct his operations in a manner satisfactory to federal and state agencies concerned with air and water pollution. Further, he is required to submit reports following drilling, and to pay an annual rental, a minimum royalty and, where there is production, a production royalty. The amounts are established by the Board.

Although various types of leases have been issued by the Land Board since adoption of the Colorado Constitution, geothermal leases have been issued only since 1973, when the Geothermal Resources Act was adopted (CRS 36, Art. 1, Sec. 113).

Federal Lands or Minerals

Geothermal leases on federal land or mineral ownership are issued by the Bureau of Land Management (BLM) of the U.S. Department of the Interior (USDI), as mandated by the Regulations on the Leasing of Geothermal Resources (43 CFR 3210.2). The procedures for leasing vary depending upon whether or not the area has been designated a Known Geothermal Resources Area (KGRA).

If the area is not a KGRA, an application for leases is filed with the BLM. The surface management agency, which may be the BLM, the U.S. Forest Service (USFS) or the Bureau of Indian Affairs (BIA), in consultation with the United States Geological Survey (USGS), assesses the probable environmental impacts and determines the necessary mitigation procedures, which are added to the lease application. The Menlo Park, California, USGS office reviews the lease stipulations for adequacy and for compatibility with development of the lease. The USGS investigates to ensure that the area has not been classified as a KGRA following submittal of the application. The lease is then sent to the applicant who may accept or refuse the lease with its stipulations.

Lease applications may also be rejected by the BLM in the event the environmental analysis indicates that critical environmental considerations and mitigation measures cannot be implemented (43 CRF 3210.4).

The Geothermal Steam Act defines "Known Geothermal Resources Area" as "an area in which the geology, nearby discoveries, competitive interests, or other indicia would, in the opinion of the Secretary, engender a belief in men who are experienced in the subject matter that the prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose" (P.L. 91-581).

Based upon this definition, all wells within a five mile area of a discovery well are classified as part of the KGRA if the extent of the geologic structure is unknown, unless the USGS determines that the geothermal resource is in a different geologic structure. If the geologic structure is known, all land in the structural area is considered to be part of the KGRA. In addition, if during the same filing period, two or more applications have an overlap of 50 percent or more, the entire area is classified as an administrative KGRA (Kenneth Bull, 1978, pers. comm).

In a KGRA, lands are leased competitively to the bidder offering the highest bonus bid, if it is above the minimum acceptable bid. Before offering such lands for lease, the impacts on the environment must be assessed, the comments of appropriate federal agencies, business and industry and private organizations must be solicited, and public hearings may be held. If issuance of leases may significantly affect the environment, an environmental impact statement may be required (Kenneth Bull, 1978 pers. comm).

The first term of any lease is for 10 years. The law requires diligent exploration, determined by a review of the USGS Area Geothermal Supervisor. After the fifth year, annual exploration expenditures must be at least twice the year's rental payment. However, expenditures during the first five years as well as excess expenditures during subsequent years may be credited to help fill the expenditure requirements. The lease may continue for up to 40 years as long as geothermal steam is produced or utilized in commercial quantities, with preferential right to renewal for a second 40-year term (43 CFR 3203.1).

In some cases the land is privately owned, while the mineral rights are owned by the federal government. After a long appraisal, the courts in 1978 determined that the geothermal resources belong with the mineral rights. This means that both mineral and surface rights must be obtained from their respective owners in order to conduct any geothermal operations on such properties.

Permits

The permit requirements for geothermal operations also vary depending upon the ownership, except that prior to drilling any geothermal well in Colorado, a permit must be obtained from the Colorado Oil and Gas Conservation Commission. Other state permits may be required, depending upon the particular activities. In some cases, the county or municipality in which the well will be drilled may also require a permit. If the well will be drilled on federal or state land, the approval of the respective government agency is required.

State Permits

To obtain a permit to drill (or deepen) a geothermal well, an application must be filed with the Director of the Oil and Gas Conservation Commission, along with a filing and service fee of $75.00. If the permit is requested for an exploratory well, the application must include a "written statement based on competent geological opinion or data derived from similarly situated geothermal resource areas containing whatever information the Commission requires to carry out the purposes as described in Section 34-70-102 of the Act." (State of Colorado, Oil and Gas Conservation Commission, 1975). If the permit requested is for a development well, information is required from the drilling of the discovery well, competent geological opinion or data from a "similarly situated geothermal resource area" as follows:

1) Names and addresses of the owner, operator and their designated agents
2) Location of the wells and their proposed depth
3) Description of the base
4) Amount and extent of anticipated surface development
5) Mitigation measures for land subsidence, water and air pollution and noise pollution
6) Proposed methods of by-product disposal and recovery
7) Mineral and chemical composition of brine and gases of the geothermal resource
8) Proposed casing program
9) Other information required by the Commission

Permission must also be obtained to recomplete or abandon a well or to change the specific manner in which any of the operations is carried out. Drilling and completion rules limit or specify ways some of the operations are to be conducted. Following any operation, a report must be filed with the Commission describing in detail the work done and the manner in which it was done, the daily production and other pertinent information. A monthly production report is required, as well. Confidentiality is protected by the provision that logs so marked shall be kept confidential for six months following their filing.

The applicant for a drilling permit must also submit evidence of public liability insurance. Except where a bond has been required for federal or Indian leases, a bond of at least $10,000 is required to assure that when the well is abandoned, it will be plugged in the manner in which the rules require.

The staff of the Oil and Gas Conservation Commission is authorized to issue the permits and to maintain the records of activity. The 5-member commission conducts hearings to resolve questions relating to the administration of the Geothermal Act, such as spacing of wells, correlative rights, unitization, pollution, and any other problems or conflicts that may arise.

An application for a geothermal well must also be referred by the Commission to the State Engineer for his determination whether the well will have any adverse effect upon existing water rights. Either he must, within 60 days, find no adverse effect, or he must recommend denial of the permit (Frank Piro, 1977, 1978, pers. comm).

Permit for Fluid Discharge - In the case of geothermal exploration, field development or power plant operation, a developer may wish to discharge geothermal fluid into a stream or injection well. If so, he must obtain a permit from the Colo. Dept. of Health, Water Quality Control Division, since a 1973 amendment to the Colorado Water Quality Control Act gave the Division control of the issuance of permits for the discharge of pollutants into surface and subsurface waters in the state. Either heat or dissolved solids could pollute the water in excess of the water quality standards.

The Water Quality Control Division regulations state that a developer must submit an application at least 180 days prior to the date upon which he wants to begin discharging material into the stream. Prior to issuance of a permit, a public hearing and a 30-day public review period may be required.

The U.S. Environmental Protection Agency, the federal agency that provides a large part of the operating funds for the Division, may prevent issuance of permits not considered to be in conformance with the federal regulations (Water Quality Control Commission, 1977, and Bud Flynn, 1978, pers. comm.).

Air Pollution Permit - The Colorado Department of Health Air Pollution Control Commission and its staff are responsible for controlling point-source emissions and ambient air quality as established by the Federal Clean Air Act and the Colorado Air Pollution Control Act of 1970 (Air Pollution Control Commission, 1977). A potential developer is advised to contact the agency even when not anticipating the release of any material into the air. If the Commission officially exempts a project, the developer will be protected in case of any unexpected release of pollutants. Furthermore, the developer will wish to be informed about all the regulations that are applicable.

Geothermal System Development Permits - Permits are required in order to construct a power plant or utility system except where a municipally-owned public utility will provide service within its boundaries.

The Colorado Public Utilities Commission (PUC) issues permits and regulates activities of common carriers, pipelines, electrical facilities, telephone systems, telegraph systems, or water systems for public use. The staff, which is divided into the Transportation and the Fixed Utilities Sections, provides technical and administrative assistance to the Commission as well as testifying at hearings when necessary.

Proposed development of geothermal utility facilities would be reviewed by the Fixed Utilities staff prior to consideration by the Commission. The utility construction permit process usually requires from three to four months (George Parkins, 1978, pers. comm.).

Federal Permits

Geothermal operations on federal lands or minerals are under the jurisdiction of the USGS, subject to the authority of the Secretary of the Interior and the Director of USGS (30 CFR, 270.10.). Some preliminary exploration and "casual" uses that do not disturb the land, improvements or resources may be done without obtaining leases (43 CFR 3209.0).

If leases are held, approval may be obtained from the surface management agency of a "Notice of Intent and Permit to Conduct Exploration Operations," in order to conduct such activities as geochemical and geophysical surveying and drilling of shallow gradient holes (43 CFR 3209.0).

Prior to drilling thermal gradient holes, lessees have been required to obtain approval of a plan of operations, a lengthy process. Recent regulation revision, however, requires submittal by the lessee of a description of development and its approval by the U.S.G.S. With this change, a lessee or non-lessee may now obtain approval in most cases in less than 30 days (Kenneth Bull, 1978, pers. comm.).

Any drilling other than thermal gradient holes may be done only by the lessee or his agent on his own leases. Prior to conducting activities, a plan of operations must be approved by the USGS. Such plans of operations may cover one or a combination of activities, as follows: exploration, collection of baseline data, development, injection, production, and utilization. All require an environmental analysis, which is reviewed by numerous organizations and individuals (60 in Colorado, at this time) (Kenneth Bull, 1978, pers. comm).

The plan of operations must include, in addition to a description of the primary activities, a description of the measures to be taken for protecting the environment, for disposal and reclamation, and for monitoring. If the plan of operations is for production, disposal or utilization plans, baseline data are required, including air and water quality, noise, seismic and land subsidence and ecological systems covering a period of one year. The baseline data may be obtained from other sources if available. After the environmental analysis is conducted by the USGS, it is reviewed by the surface management agency and must be jointly approved by the two agencies. Interested parties, including state and local governments, are invited to comment. The entire process usually requires a minimum of from three to six months (30 CFR 270.35).

Plans of operation are reviewed by a geothermal advisory panel. If the area is a newly identified geologic area or if the operation is unusual, the panel may hold a public hearing, extending the review process to about nine months' time. A full environmental impact statement (E.I.S.) may be required for any plan if considered to be necessary by Washington offices of the responsible agencies. An EIS usually adds about two years to the process (Kenneth Bull, 1978, pers. comm.).

A geothermal operator on federal leases must file reports periodically, including:

1. Report of significant effect on the environment or industrial accident.
2. Log and well history.
3. Monthly report of operations.
4. Monthly report of sales and royalties.
5. Annual report of compliance with environmental protection requirements.
6. Annual report of expenditures for diligent exploration operators.

Production royalties are determined by the area supervisor of the U.S.G.S. (30 CFR 270.02).

Local Permits

Both counties and municipalities are permitted by legislation to regulate numerous activities, including geothermal development, within their boundaries. But such authority must be specifically implemented by adopting regulations. Not all local governments in the state have felt it necessary or wise to expand their regulations to include geothermal resource development. In those instances where regulations for geothermal development have been adopted, they are often made a part of the subdivision regulations.

Following is a description of the procedures required by one county where geothermal resources are regulated. Since the procedures would probably be similar in other areas, this should provide an indication of the kinds of requirements to be expected.

Alamosa County - Alamosa County has included in their subdivision regulations mineral regulations that specifically refer to geothermal resources. To obtain county approval to develop a geothermal resource, the developer first meets with the planning commission or staff informally about the specific requirements. He then prepares and submits a proposal that is circulated to various agencies, including the Colorado Geological Survey, for review and comment. After those comments have been received, the application goes through final review by the planning commission, which recommends denial or approval. Then the proposal is submitted to the Board of County Commissioners, which holds a public hearing to allow interested parties to comment. The Commissioners then decide whether or not to allow the activity.

It is expected that the time required to obtain permission for exploration activity would be at least two months. For development activity six months would probably be required (Alamosa Planning Office, 1977).

DEVELOPMENT POTENTIAL

Geothermal energy undoubtedly can make a significant contribution to the total energy supply in Colorado. Although the geothermal energy in the community of Pagosa Springs has been barely tapped, its importance there may be observed. The other 55 identified resource areas, plus those not yet discovered, are virtually untapped. Although data are lacking for an accurate assessment, the potential of the 56 identified hydrothermal systems has been estimated. As Table 1 showed, those areas are estimated to contain 5.914 quads (5.914 x 10^{15}Btu) of energy, with extractable energy of 1.48 quads. The total usable energy after extraction of 0.35 quads was converted to annual usable energy, resulting in an estimated 0.01 quads. Although this equals only about three percent of the total natural gas consumption for the state in 1972 (CERI, 1976), it is theoretically sufficient to supply more than 112,000 dwelling units.

While this amount of geothermal energy would make a significant contribution to the total energy supply, it is believed to be extremely conservative. The estimates of available energy are necessarily conservative because of the lack of sufficient exploration data to assure that any of the geothermal systems are renewable. Moreover, sequential use of the resources from process use to space heating can increase the efficiency of use of the resources enormously.

At least three areas seem at this point as though they might have high enough subsurface temperatures for economical generation of electricity. These areas are: Mt. Princeton and Poncha Springs in the Upper Arkansas Valley and Cebolla or Powderhorn in southern Gunnison County. Discussions with industry officials resulted in an estimated potential of 100 MWe for Mt. Princeton, 200 MWe for Poncha Springs and 200 MWe for Cebolla (Amax Exploration, Occidental Geothermal, Inc., and Chevron Resources Company, 1978, pers. comm.). Figure 5 shows a composite of the scenarios for the power generation sites. Before development can proceed even to the stage of drilling of test wells, however, additional leases will be required. In the first two areas, Mt. Princeton and Poncha Springs, federal lease applications are pending. In the Cebolla area, leases on private land are needed.

To envision potential low temperature uses, communities were matched with resource areas, based on their proximity and the amount of energy estimated to be available. This allowed the demand/supply congruity to be estimated. It also supplied data that may be used for subsequent feasibility testing of the direct use of the resource for the predominant existing demand sector, space and water heating. Tables 8, 9, and 10 show the estimated energy demand and supply for the developable low temperature geothermal resource areas.

Figure 5.
POSSIBLE GEOTHERMAL ENERGY DEVELOPMENT SCHEDULE
FOR COLORADO

Electrical Power

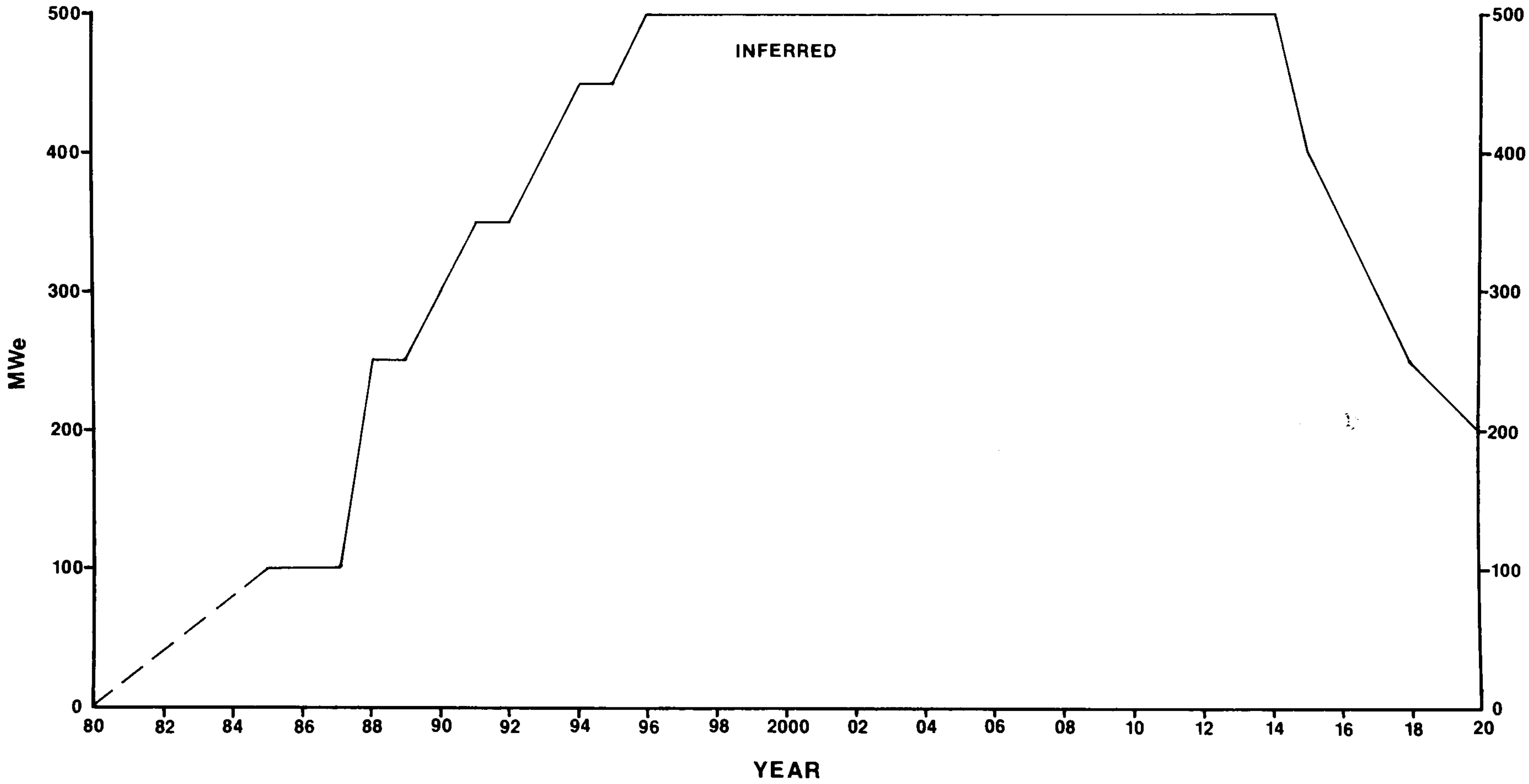


TABLE 8
CATEGORY II B
AREAS OF KNOWN ACTIVITY

Area Name	Number	Use	Distance	1975 Estimated Dwelling Units	1975 Estimated Natural Gas Demand (10^{12} Btu's)	2020 Estimated Dwelling Units	2020 Estimated Natural Gas Demand (10^{12} Btu's)	Estimated Usable Energy Available (10^{12} Btu's)	Estimated Usable Energy Available Per Year for 30 Years (10^{12} Btu's)
Glenwood	11	space heat Glenwood Springs	0	1,784	.32	3,796	.68	1.7	.06
Hartsel	19	space heat Fairplay	16	215	.04	271	.04	2.5	.08
Splashland	35	Alamosa	2	2,807	.50	8,083	1.44	4.7	.16
Sand Dunes	34	Baca Grande	14	225	.02	10,000	1.78	4.7	.16
Shaws	33	greenhouse	0	NA*	.02	NA	NA	.9	.03
Mineral/Valley View	31/32	space heat Saguache timber kiln barley melting potato flakes	12	226	.04 .04 .22 .86	380	.06	60.0	2.00
Pagosa Springs	41	space heat Pagosa Springs	0	524	.09	1,481	.26	2.9	.10
Waunita	46	space heat Gunnison timber drying	22	1,880	.33	4,326	.77	3.6	.12

*Not applicable

TABLE 9
CATEGORY III A
NO KNOWN ACTIVITY BUT HIGH POTENTIAL

Area Name	Number	Use	Distance	1975 Estimated Dwelling Units	1975 Estimated Natural Gas Demand (10^{12} Btu's)	2020 Estimated Dwelling Units	2020 Estimated Natural Gas Demand (10^{12} Btu's)	Estimated Usable Energy Available (10^{12} Btu's)	Estimated Usable Energy Available Per Year For 30 Years (10^{12} Btu's)
Routt/Steamboat	3/4	space heat Steamboat	0	1,004	.18	1,832	.33	7.4	.25
Hot Sulphur Springs	6	space heat		820	.14	NA	NA	4.2	.14
		Granby	14						
		Kremmling	14						
		Hot Sulphur Spgs.	0						
Haystack Butte	7	space heat new subdivision	0	337	.03	NA	NA	1.0	.03
Eldorado Springs	8	space heat resort	0	112	.02	NA	NA	.6	.02
Idaho Springs	9	space heat Idaho Spgs.	0	707	.13	2,985	.53	7.6	.25
Ouray	49	space heat Ouray	0	281	.05	832	.15	14.0	.47
Dunton/Geyser/ Paradise	51,52,53	Dunton	0	10	.002	NA	NA	1.6	.05

TABLE 10
CATEGORY III B
AREAS OF MODERATE POTENTIAL

Area Name	Number	Use	Distance	1975 Estimated Dwelling Units	1975 Estimated Natural Gas Demand (10^{12} Btu's)	2020 Estimated Dwelling Units	2020 Estimated Natural Gas Demand (10^{12} Btu's)	Estimated Usable Energy Available (10^{12} Btu's)	Estimated Usable Energy Available Per Year For 30 Years (10^{12} Btu's)
Juniper/Craig	1/2	space heat Craig	24/.7	1,809	.32	2,241	.40	3.5	.12
Brand's Ranch	5	space heat Walden	16	325	.03	NA	NA	.2	.007
South Canyon	12	space heat New Castle	8	247	.05	NA	NA	.6	.02
Penny	13	space heat Carbondale Basalt	12 13	549	.10	1,050	.19	10.0	.33
Col. Chinn	14	space heat Paonia	3	444	.08	NA	NA	1.1	.04
Cement Creek/ Ranger	16/17	space heat Crested Butte	7	289	.05	NA	NA	1.0	.03
Wellsville/ Swissvale	24/25	space heat Salida	4	1,729	.31	NA	NA	.5	.02
Canon City/ Fremont	26/27	space heat Canon City	0	4,264	.76	NA	NA	.8	.03
Don K Ranch/ Florence	28/29	space heat Florence	18/4	1,051	.19	NA	NA	2.1	.09
Clark	30	space heat new subdivision at Pueblo	0	225	.02	NA	NA	.5	.02

CATEGORY III B
AREAS OF MODERATE POTENTIAL

Area Name	Number	Use	Distance	1975 Estimated Dwelling Units	1975 Estimated Natural Gas Demand (10^{12} Btu's)	2020 Estimated Dwelling Units	2020 Estimated Natural Gas Demand (10^{12} Btu's)	Estimated Usable Energy Available (10^{12} Btu's)	Estimated Usable Energy Available Per Year For 30 Years (10^{12} Btu's)
Wagon Wheel Gap	43	space heat Creede	10	208	.04	422	.07	22.7	.76
Orvis	48	space heat Ridgeway Montrose	4 28	2,665	.47	NA	NA	1.7	.06
Rico	54	space heat Rico Stoner Ski Lodge	0 17	99	.02	119	.02	8.4	.28
Pinkerton/Mound	55	space heat Animas Valley	0-10	NA	.02	NA	NA	2.7	.02
Tripp/Trimble	56	space heat Animas Valley	0-10	NA	.07	NA	NA	2.1	.07

Scenarios were then compiled for the identified use areas. Thirty-nine areas were combined into 27 scenarios for low-temperature applications. The scenarios showed that, at the very least, ample energy seemed to be available to supply a substantial portion of the space and water heating for 27 incorporated municipalities, plus several subdivisions and settlements. Twenty-three of these are within 10 miles of the resource area. Sixteen are virtually on site. In 14 areas, federal leases seemed to be required, if not at the outset, then later in order to expand systems. Ten of those were national forest leases. Thirteen areas seemed to require only fee leases. Figure 6 shows the use areas.

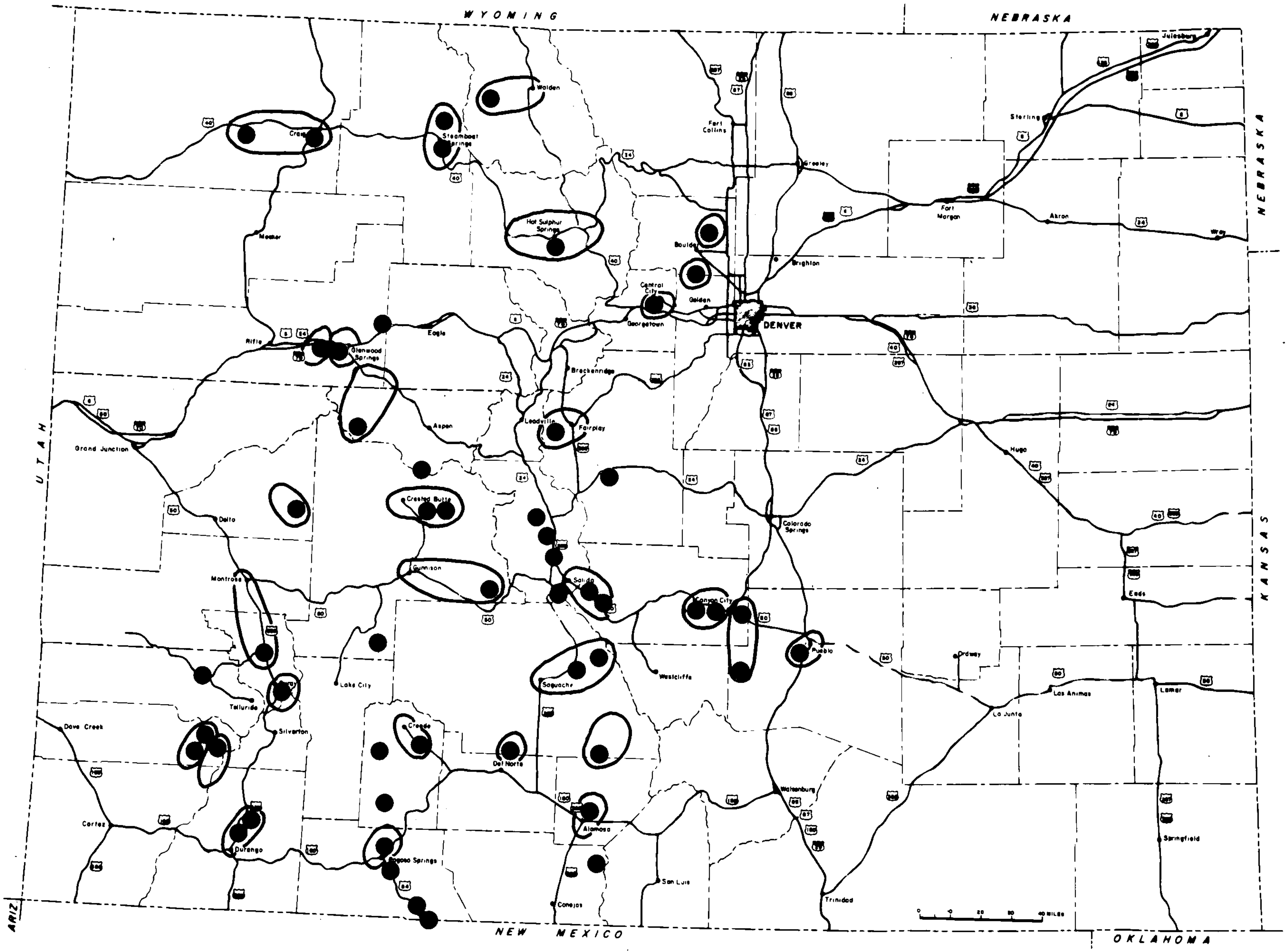
In those 27 areas enough energy for more than 16,000 homes, plus an equivalent amount for existing industrial, commercial, and public buildings seemed to be available. Also indicated in the scenarios were two timber kilns, one feed lot, one hog pen, three greenhouses, one barley malting plant, and one food dehydrating plant. The composite of the low temperature scenarios, Figure 7, shows a total of 0.003 quads on line by 1991.

The opportunity for realizing this magnitude of geothermal development is limited by the economics of converting structures from natural gas to geothermal. Retrofitting to use geothermal heat is generally not competitive with the existing price of natural gas. However, in those areas where new structures of sufficient number and size are being built, and especially where electricity, propane, or solar is the only available heat source other than geothermal, the economies of geothermal use are greatly enhanced. Moreover, it may be the case that retrofitting is economically justified over the long run. If geothermal systems were developed now, the energy would be available for new buildings when they were built. Over a period of time, economies of scale could then be effected.

In these scenarios the emphasis was on space and water heating. For the most part too little information was available to judge specifically where agricultural and industrial process uses should be suggested. Enormous benefits can be derived, however, from promotion of new process uses where economic growth is appropriate. Because energy availability is an increasingly important facet of industrial location decisions, economically depressed areas can benefit if their geothermal resources are made available for industrial use. Especially in those areas where a surplus of geothermal energy is discovered, process uses could be encouraged. The following table lists some of the uses that seem promising for Colorado.

As shown, a wide variety of uses of geothermal resources is possible. As shown previously, the resource estimates indicated a substantial amount of available energy. Yet, little development has occurred. Whether the use of the resources does begin to meet its potential will probably depend largely upon the removal of existing barriers and the provision of new opportunities. Some of these possibilities are described in the next two sections.

FIGURE 6



POTENTIAL GEOTHERMAL RESOURCE USE AREAS IN COLORADO FOR SCENARIOS, JUNE, 1978.

Figure 7.
POSSIBLE GEOTHERMAL ENERGY DEVELOPMENT SCHEDULE
FOR COLORADO

Low Temperature

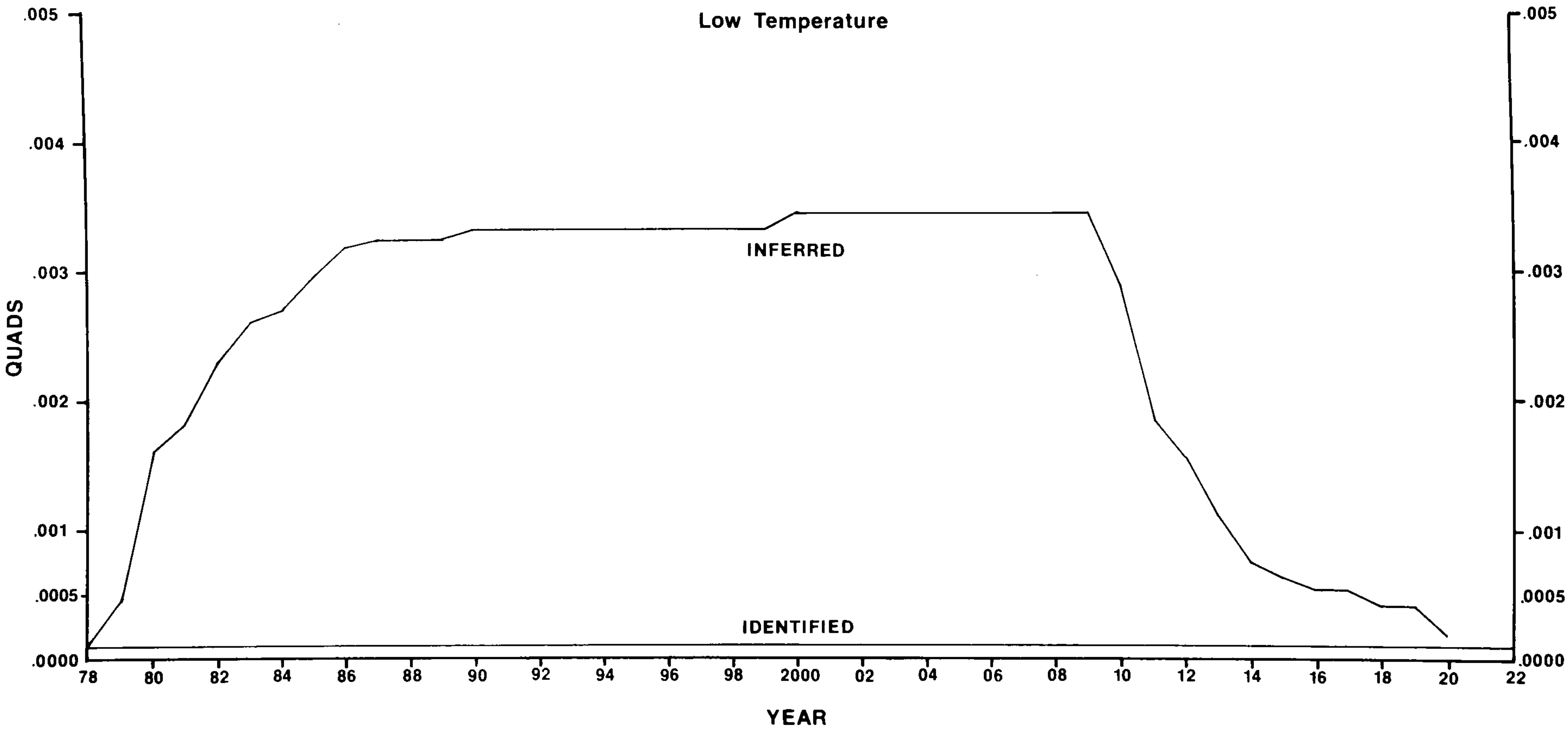


TABLE 11

SOME POTENTIAL USES FOR

GEOTHERMAL RESOURCES

IN COLORADO

POWER GENERATION

SPACE HEATING OF SCHOOLS, OFFICES, STORES, HOMES, WAREHOUSES, ETC.

WATER HEATING

SPACE COOLING

REFRIGERATION OF FOOD PRODUCTS SUCH AS FRUIT, LETTUCE, SPINACH

BIOMASS PROCESSING FOR FUEL, FERTILIZER

FEEDLOT WARMING

LIVESTOCK PEN WARMING FOR POULTRY, HOGS

CROP DRYING SUCH AS ALFALFA

DIATOMACEOUS EARTH DRYING

APPLE, PEACH, PEAR, PRUNE, APRICOT DEHYDRATION AND FREEZE-DRYING

POTATO, ONION, CARROTS, TOMATO, BELL PEPPER, CHILI DEHYDRATION

WOOD CHEMICALS

MANUFACTURE OF PLYWOOD, VENEER, PARTICLE BOARD, LUMBER CURING

PAPER AND PULP

DAIRY FARMING INCLUDING MILK CHILLING AND PASTEURIZATION

MUSHROOM GROWING

FREEZE DRYING

SODIUM CHLORIDE PRODUCTION

SOIL STERILIZATION

SEED DRYING

NAHCOLITE DAWSONITE PROCESSING

ALUNITE PROCESSING

WOOL DRYING

SWIM POOLS, BATHS

TROPICAL GARDENS

CONSTRAINTS TO GEOTHERMAL DEVELOPMENT

Several conditions have constrained geothermal development in Colorado. Among the most prominent are federal regulations and procedures for leasing and permit approval and the lack of financial incentives. Other conditions may limit development in the future. Among these are state water policy and laws. Probably the most restrictive constraint, though, is the lack of a system for delivery of geothermal energy for direct use. The following describes these constraints in some detail.

Leases and permits - One severe constraint is the inability of developers to obtain the necessary leases. Even if all other conditions are favorable, without leases to protect the company's investment, no development can proceed. In Colorado, leases on national forest lands are needed in the Mt. Princeton and Poncha Springs areas, and fee leases are needed in the Cebolla area. Applications for leases on national forest lands have been pending since 1974. In light of the failure of the Forest Service to aid in the issuance of leases, it seems probable that their goals conflict with the goal of acceleration of geothermal development. The problem may well be one of conflicting legislative mandates, which can only be resolved legislatively.

Obtaining permits for geothermal operations on federal lands is sometimes a long and tedious process. Such delays can cause investment funds to be diverted to other investments. Only when investors can expect a return on their investment in a reasonable or at least predictable time are they willing to commit to that investment. Furthermore, such delays can simply frustrate potential developers such that they abandon the effort.

Economics - Natural gas prices are not yet high enough to generate widespread conversion of direct use systems such as space heating from natural gas to geothermal resources. Even though many types of projects are economically feasible, drilling test wells to locate the resources is costly and risky. The current tax structure provides no incentives for the encouragement of geothermal exploration.

Financing of geothermal projects can be a serious problem, even though numerous uses are economically feasible, barring retrofitting. Small communities or small businesses often lack funds to cover substantial front-end expenditures. Lenders may be reluctant to risk funds on innovative or untested projects. Bond issues are frequently defeated because of the reluctance or inability of taxpayers to become more heavily obligated. Indeed, many communities in Colorado with limited paid staffs may be severely limited in their ability even to prepare applications for federal grants.

System Development - Although industry is undertaking high-temperature geothermal development, currently no formalized system for low-temperature geothermal development exists in Colorado. Technicians in numerous fields are evaluating resources, potential uses and constraints, and potential users are exploring geothermal applications in various industrial and agricultural processes. Communities are planning establishment of district heating systems. But for a commercial geothermal energy industry to develop, in this as in any other commercial venture, able and determined enterpreneurs must see and then seize the opportunity to make a profit. Few people are aware of the potential of the resource, know how to use it, and have the necessary funds to develop it.

Technology - There are no apparent major constraints to geothermal development arising from technology deficiencies. What could be a problem, however, is that sufficient amounts of the necessary equipment and services might not be available. This includes drill rigs, pipe and other hardware, plus the skilled workers to build and operate the equipment. Furthermore, an increased demand could in the future increase geothermal development costs such that geothermal energy is still not competitive.

Environment Reports - Environmental assessments will be necessary prior to many new geothermal developments. The manpower requirements for assessments, and when necessary, for environmental impact statements, could be enormous were an accelerated development program to be initiated.

Water - The availability of water will be a major consideration in Colorado as in other western states in geothermal development plans. Most projects will need to avoid excessive consumptive use of water. Heat exchangers can be of help where practicable, as can reinjection of the fluid.

The limitation of water rights may also indirectly affect the development. For example, new water rights may be unavailable in the San Luis Valley, one of the prime areas for low-temperature geothermal development. Since Colorado must meet its treaty obligations to provide water from the Rio Grande River, concern has been expressed that existing water rights might be endangered in the future. If so, the lack of water could limit future agricultural production in the Valley and thereby curtail operation of processing plants for agricultural products.

Some of these conditions are now limiting geothermal development. Others are possibilities that may or may not come to pass in the future. There will undoubtedly be others that are as yet unidentified. These conditions are controlled by various sectors, some are by the federal government, some by the energy industry, by potential users and potential enterpreneurs, others by the physical attributes of the sites. The U.S. Department of Energy, Geothermal Resources Division, is making a concentrated effort to find ways to relieve constraints to geothermal development. If the State of Colorado should also choose to encourage the use of geothermal resources, undoubtedly appropriate legislation and policy could be enacted that would aid that goal.

SUMMARY AND CONCLUSIONS

This 10-month study has attempted to estimate the potential for geothermal resource development in Colorado. It has also attempted to identify those conditions that seem to impede that development. As a third objective, it has attempted to identify at least preliminarily those actions that seem necessary to advance the development of geothermal resources.

The results show that geothermal resources in Colorado do have significant potential. Geothermal energy in the amount of 5.914 quads was estimated to be in the 56 hydrothermal (hot water) systems identified in Colorado. This is theoretically sufficient for heating more than 112,000 homes for a 30-year period.

However, geothermal energy use is limited by the distance it can be transported. For that reason, industry has been interested primarily in high-temperature resources for power generation. Since most of Colorado's resources seem more suitable for such near-site uses as space heating, a site-specific assessment was necessary for these. That analysis illustrated that most resource areas are close enough to population concentrations to be useful. There is, however, a lack of congruency between the magnitudes of the energy demand and supply in many areas. Even so, at least 30 communities seem to be candidates for obtaining all or part of their space- and water-heating needs from geothermal energy.

Based on the analysis, more than 16,000 homes, plus commercial, industrial, and public buildings could be supplied with heat and hot water. Along with this, heat could be supplied for such process uses as dehydrating vegetables and fruits, malting barley, warming hog pens and drying timber. Furthermore, 5 electrical generating units of 50 MWe each could be operating. The technology is readily available for all of these uses.

The system for developing geothermal resources in Colorado seems, so far, to be reasonably straightforward. Geothermal leasing on public land is permitted by law and regulation. Experts are available to provide the necessary services. The state regulatory system seems reasonable. In light of this, the question then is, "why are the geothermal resources not being developed?"

Several impediments seem to be conspicuous. The most important one seems to be a lack of market demand for geothermal resources. Until recently natural gas was plentiful and cheap in most areas in Colorado. Even now, natural gas costs may not be sufficiently high to stimulate competition from geothermal where the expense of conversion of heating systems must be borne. If natural gas prices increase substantially, through deregulation or additional taxes, all alternatives will become more attractive. Federal incentives, such as depletion allowances and tax credits, would probably stimulate geothermal development even more. Other forms, such as a direct subsidy of part of the cost of drilling test wells, may be appropriate.

Secondly, policies and actions of public agencies and other institutions profoundly influence development of energy resources. The existing leasing laws and procedures make obtaining federal leases in advance of major exploration necessary. Those same laws and procedures make it virtually impossible to obtain geothermal leases, at least on national forest lands. Leasing problems must be reconciled in some manner if significant development of geothermal resources is to to occur. Although these problems might be resolved through the development of more efficient procedures, they may require action as strong as new legislation. To make investing in geothermal resource development a sound venture, criteria for designation of a known geothermal resource area might need to be revised and leasing might need to include provisions to protect and motivate the developer.

A third constraint is that geothermal development is expensive, initially, and includes a certain amount of risk. Few communities or interested entrepreneurs at this stage have the financial means to support the front-end costs of an entire geothermal development process. For low-temperature development, federal loan and grant programs will be of the utmost benefit for initiating geothermal resource uses that can then serve to stimulate ideas and action in other areas. At this stage, too, technical assistance for planning and feasibility studies will probably be a key ingredient in accelerating or even initiating geothermal development in Colorado.

A fourth hindrance may be illustrated by the following excerpt from the report Future Energy Alternatives for Colorado: "Geothermal energy is estimated to be minimal" [because of the] "lack of knowledge about Colorado's geothermal resources and the economics of geothermal development" (CERI, 1976, p. 51). Enlightenment of both lay persons and professionals in the energy field is essential if geothermal development is to be realized. Demonstration programs and information dissemination programs can be of enormous benefit in making known the opportunities geothermal resources offer.

The accomplishment of geothermal development, at least the low-temperature resources, appears at this time to be largely dependent upon federal government assistance. An attempt was made, therefore, to list and quantify the actions by the various federal agencies that seem necessary in order to realize the development envisioned in the scenarios. Although this is only one of many possible views, it may at least provide a starting place for further discussion of ways to stimulate development of this idle resource.

As shown in Table 12, federally guaranteed loans or grants will probably be needed for up to 13 geothermal utility systems. Federal funding for as many as 11 test wells may be needed. Another small sum is indicated for an Outreach Program to disseminate information and provide technical assistance. About 13 federal leases, most on national forest land, might need to be issued by the BLM in order to accomplish the geothermal development. To develop these leases, at least 10 environmental reports would have to be prepared by the U.S. Forest Service and about 30 permits would have to be issued by the U.S. Geological Survey. After this investment of federal funds, it is conjectured that private industry will be firmly established and will continue the development using private monies.

These are substantial commitments of monetary resources and staff time, for which economic analyses have not yet been done. Such analyses will indicate what monetary value may result from what level of investment. Undoubtedly, the direct costs and the direct benefits of both programs and individual projects will be calculated. Individual projects will probably be weighed in two different ways, both as government investments and as potential business investments. But such commitments must also be weighed in the context of the long-range potential and the long-range opportunity.

TABLE 12

REQUIRED FEDERAL AGENCY ACTIVITIES

FOR LOW TEMPERATURE GEOTHERMAL RESOURCE DEVELOPMENT IN COLORADO

INDICATED BY SECOND ITERATION SCENARIOS

NUMBER OF ACTIVITIES AND DOLLARS

Agency and Activity	YEAR 1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
DOE - GUARANTEED LOAN OR GRANT -														
SYSTEM DEV.*	3 $2,000,000	5 $2,000,000	5 $4,500,000											
TEST WELL *	4 $ 600,000	7 $1,000,000												
OUTREACH PROGRAM*	Consultant, part-time $ 10,000	$ 20,000												
BLM - ISSUE LEASES-														
BLM LAND	2													
FS LAND		1	6	3								1		
R.O.W.-BLM LAND		1				1								
USFS - EAR'S/EIS'S	1	6	3								1			
R.O.W.			1			4								
USGS - PERMITS -														
TEST WELLS - BLM LAND		1				3								
USFS LAND			1	2	3									
FIELD DEV - BLM LAND		2		4		4								
USFS LAND		2		3	1	1		2						1
SYSTEM DEV. -														

As an example, retrofitting of structures now might effect economies of scale in the long run, although conversion from natural gas to geothermal heating is generally not considered to be economically feasible currently.

A community may have insufficient new construction to support a geothermal well, yet new structures that are being built may be forced to use electric heat. Developing geothermal resources now could assure that the energy would be available as needed and effect economies of scale over a longer period.

Also, because of moratoriums on gas taps in many parts of the State, electricity is becoming more and more popular for space heating. Not only is such use thermodynamically inefficient, but increased electricity demand must ultimately require more power-plant capacity. Use of thermodynamically efficient geothermal resources for space heating can keep the demand for electricity from increasing unnecessarily (Elmer, 1977).

Also, development of geothermal resources may spur the development of new industry. New jobs could be created in the geothermal industry itself if private business takes up the task of geothermal development for both high- and low-temperature resources. Secondary employment would then be generated by the need for supplies and services. Further, the availability of geothermal energy can attract new energy-using industries. This could significantly improve the economy of many areas of the state.

Other considerations are nonquantifiable. The resource temperatures are appropriate to the direct uses, enhancing energy efficiency. Many of the geothermal systems will probably be renewable. One use for which the resources are ideally suited, namely space heating, is an essential energy need, not a frivolous one. These attributes may outweigh other more concrete ones in decisions by individuals, industry, and government to invest both money and time in geothermal development.

None of Colorado's resource areas are currently in the development phase. Some leases have been issued, and some preliminary exploration has occurred. Planning and preliminary studies that are both completed and underway may lead to development in the near future. Seemingly, interest in and awareness of the resources is growing. If leases and permits are made available, along with some economic incentives, some or all of the three potential power-generation sites may be developed by private industry. Perhaps with the assistance of Federal programs initially, lower temperature resources, too, will be developed by private industry. While government can provide opportunities, the outcome depends upon the decisions of numerous individuals throughout the system. Colorado does have geothermal resources that can contribute to the energy supply. It remains to be seen whether these resources will fulfill their promise.

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APPENDIX A

STATUS OF

GEOTHERMAL WELLS IN PAGOSA SPRINGS

AS OF OCTOBER, 1977

WELL DESCRIPTION AND NUMBER		TEMPERATURE	DEPTH	DATES	STATUS	WELL NAME
1.	Spa Motel, by Pool	46°C	400'(+)		in use	Giordano #1
2.	(Spring Inn) by Spa Motel		385'(+)		not used	Spring Inn
3.	N. parking lot by river				abandoned	
4.	Courthouse well		85'(±)	~1930 (d)	in use	Courthouse
5.	Plugged courthouse well	56°C	85'(±)	~1920 (d)	abandoned	Abandoned courthouse
6.	Courthouse- SW	~44°C (?)	85'	~1935 (d)	not used	Martinez
7.	Texaco Well- E	57°C	85'		in use	Texaco #1
8.	Texaco Well- W					Texaco #2
9.	County garage					County garage
10.	New Football Field				abandoned	Football field
11.	Harvey Catchpoles Well					Catchpole
12.	Perkins' Well					Perkins
13.	Standard Station	59°C	~300-400'		in use	Amoco
14.	Brown Well (Wilsey)				in use	Brown-Wilsey
15.	Montroy Well				to be used	Montroy
16.	Rexall Drugstore			1964 (a)	abandoned	Drugstore
17.						
18.						
19.						
20.	Rumbaugh Well	~58°C (?)		late 1920's (d)	in use	Rumbaugh
21.	Well behind Adobe Inn				not used	Bank
22.	W.of Adobe Inn by Lewis St.	67°C (?)		early 1900's(d)	in use	Adobe Inn
23.	Methodist Church	56°C	400'	1969 (d)	in use	Methodist Church
24.	O.B.Sanders	34°C	468'	1960 (d)	in use	Sanders
25.	Spa Motel well near Spring Inn Well	52°C	400'(+)		in use	Giordano #2
26.	Spa Motel N of bathouse	43°C		1954 (d)	in use	Giordano #3
27.	Sinter Cone well N.of river	54°C				Sinter Cone
28.						

(d) drilled
(a) abandoned