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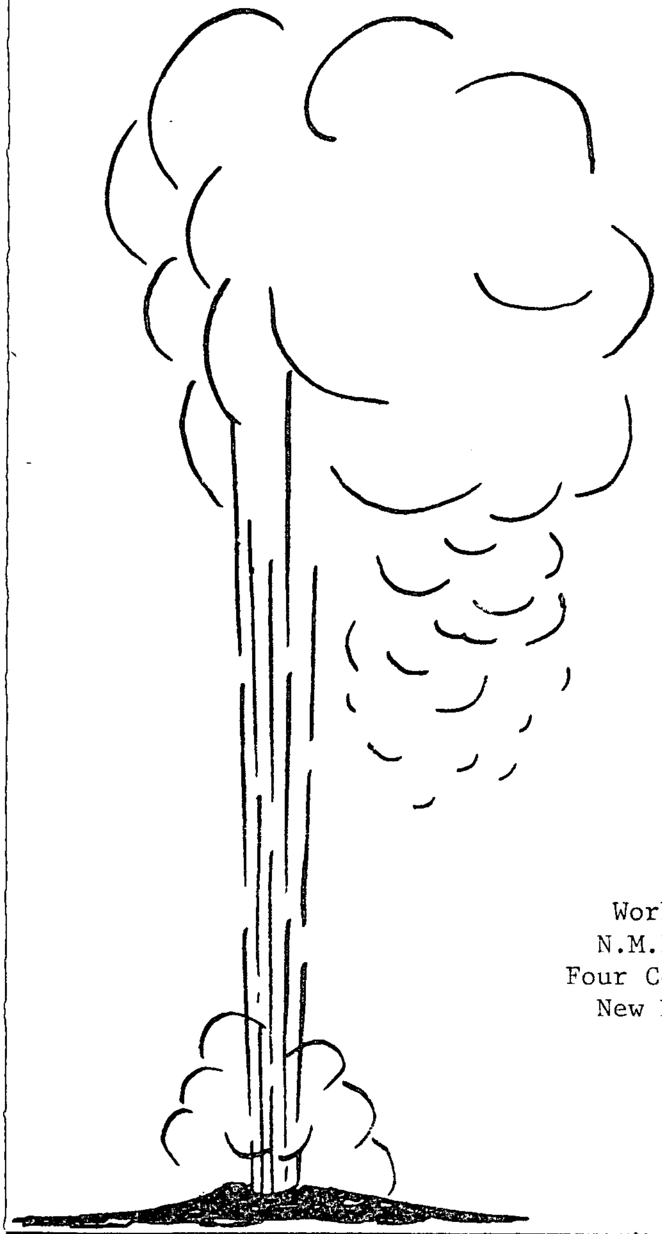

POTENTIAL OF GEOTHERMAL ENERGY IN ARIZONA

Appendix 6 of

REGIONAL OPERATIONS RESEARCH PROGRAM
FOR DEVELOPMENT OF GEOTHERMAL ENERGY
IN THE SOUTHWEST UNITED STATES

Final Technical Report
June 1977 to August 1978

Arizona Solar Energy
Research Commission
Frank Mancini
W. R. Hahman, Sr.
Don H. White
David Wolfe

January 1979

Work Performed under DOE Contract No. EG-77-S043992
N.M.Energy and Minerals Department Project No. 76-262
Four Corners Regional Commission Contract No. 672-066-075
New Mexico State University Sub-Contract No. 3104-X4

New Mexico Energy Institute at
New Mexico State University
Las Cruces, New Mexico 88003

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POTENTIAL OF GEOTHERMAL ENERGY IN ARIZONA

a part of

Arizona Participation in Regional Operations Research for the Development of Geothermal Energy, Southwest United States

Final Report for the period June 12, 1977 - June 11, 1978

I. INTRODUCTION

A. PROJECT ORGANIZATION

The State of Arizona is participating in a geothermal energy development and planning project for the Southwestern U.S.A., sponsored by the Department of Energy and the Four Corners Regional Development Commission. Some of the costs have been shared by the State of New Mexico and the New Mexico Energy Institute, but also others (e.g., the University of Arizona for the participation by the State of Arizona). The study is being directed and coordinated by the New Mexico Energy Institute at New Mexico State University, with participation by the States of Arizona, Colorado, Nevada, New Mexico and Utah.

1. Coordination and Monitoring of Arizona Team Efforts

The Arizona Solar Energy Research Commission in the State of Arizona is the state coordinator and serves as coordinator on policies and as monitor of the Arizona State Team efforts. It has subcontracted most of the work to the Bureau of Geology and Mineral Technology, University of Arizona as outlined below. It also has provided input of institutional and other State of Arizona data as time permitted.

2. Collection of Arizona Geological and Geothermal Data

The Bureau of Geology and Mineral Technology, Geological Survey Branch, University of Arizona, had the responsibility of supplying the scientific and technical information to the project. In particular this includes the compilation of regional geological data, district or area geological data and site geological data concerning geothermal energy potential in the State of Arizona. The data generated was to be used to compile the data for the New Mexico Energy Institute's scenario program for geothermal energy evaluation in the State of Arizona.

3. Preparation of Arizona's Geothermal Utilization Scenarios

The Department of Chemical Engineering, University of Arizona was to make a series of process evaluations and was to prepare preliminary block process diagrams, depicting scenarios for the utilization of geothermal energy in the State of Arizona. A list of all suggested uses would be compiled and maintained, but the major effort would concentrate upon industries in the agricultural, industrial and municipal sectors of the State.

B. OBJECTIVES OF THE PROJECT

The detailed objective and research plan was outlined in the original two-volume proposal submitted to DOE and the Four Corners Regional Development Commission, coordinated by the New Mexico Energy Institute. The following is a summary of those objectives:

1. To Provide the State of Arizona with a viable option which, if exercised, should lead to an environmentally acceptable time-phased commercial development of geothermal energy.

2. To be effective, the program must address local and regional problems.

3. Adopt a mission-oriented approach, having as its goal the acceleration of geothermal energy in commercial applications.

4. Solicit and include local input from interested parties in the state.

5. Develop use scenarios for the time-phased application of geothermal resources, based on the previous objectives.

6. Perform an economic analysis with energy alternatives to ascertain whether a distinct economic advantage exists for geothermal development.

7. Project estimates of electric power costs for geothermal applications and alternatives or conventional sources and these projections should consider alternative actions (i.e. technological improvement, tax incentives or loan guarantees) and their impact.

8. Identify potential regional contributions to the national energy goal.

9. Identify the type, magnitude and scheduling of public action.

Meeting these objectives was to involve conducting an operations research and systems analysis in sufficient breadth and depth to support the formulation of realistic detailed scenarios for the development and commerical utilization of the several geothermal energy resources in the region, considering both electric and non-electric applications of geothermal energy and identifying potential uses and users of the resources, prospective utilization cycles and required development time scales. In developing the scenarios it was considered to have the active participation of industry, state and local governments and the local communities. This study was to include a preliminary analysis of the scenarios to identify impediments to their realization and recommendations for public actions.

In carrying out this project, the following were to be included:

1. Data Pertaining to the Geothermal Energy Resource Base

   a. Location, properties and expected magnitude of all known geothermal resource areas (KGRA's) in the region.

   b. Location, properties and expected magnitude of all potential geothermal resource areas (PGRA's) in the region.

   c. Assessment of the state of knowledge concerning the amount and locations of geothermal energy resources in the region.

   d. Land ownership of all KGRA's and PGRA's (Federal, State, County, Private, Other).

   e. Leases presently applied for.

   f. Exploration and assessment activities completed and in progress.

   g. Information available or inferrable concerning industry plans for exploration, assessment, development, or production.

2. Data Pertaining to Utilization of the Resource

   a. Present usage and users, and their distribution geographically and with respect to transportation, raw materials, labor markets, and other infrastructural elements necessary for successful industrial, agricultural or commercial activities.

   b. Present plans or ongoing projects for new or expanded usage such as new housing developments, industrial expansion or translocated industries.

   c. Present projections for growth in energy consumption in the region through the year 2020, broken down by state, location and type of consumption.

   d. Projections of the availability and cost of alternate energy sources.

   e. Growth plans for prospective energy users (electric and nonelectric).

   f. Prospective users (electric and nonelectric). Their present energy sources and projected availability of those sources through 2020.

3. Data Pertaining to Legal and Institutional Factors

   a. Existing laws which affect the development process (Federal, State, Local).

   b. Regulatory bodies which impact on geothermal enterprises and their specific charters.

   c. Present policies of these bodies.

   d. Business practices, policies and relationships of industrial entities which may significantly affect the potential for utilization of geothermal energy resources.

e. Applicable environmental standards (Federal, State, local).

f. Existing community attitudes and attitudes of those who purport to represent the community (e.g. action groups).

g. Existing land-use plans.

h. Existing water-use plans and water availability.

i. Socio-economic conditions at each prospective site.

4. Data Pertaining to the Economics of Resource Exploitation

a. Major cost factors in exploration and assessment.

b. Major cost factors in field development.

c. Major cost factors in utilization.

d. Tax policies (Federal, State, Local).

e. Capital costs - by industry.

f. Capital amortization policies.

5. Data Pertaining to Technology Development

a. Ongoing federal and non-federal programs and target dates for technology readiness.

6. Data Pertaining to Regional Industry Status

a. Capital position - by industry.

b. Manpower availability.

c. Equipment availability.

As used here the term <u>scenario</u> refers to a reasonable statement of what could be achieved in bringing geothermal power, both electric and non-electric, "on-line". By this definition the scenario is not a projection or prediction of what is likely to happen based on past and present conditions and present programs for geothermal development but it involves positive actions which must be taken by the private and public sectors in order for the scenario to materialize.

For each scenario the following things were to be prepared.

1. A tentative development schedule for each site.
2. A schedule of required decisions by each participant in the development, including approval decisions by regulatory bodies.
3. Delineation of specific existing impediments to each required favorable decision.
4. Analyses of the possible federal or state programs which could enhance the probability of achieving timely development.

The regional program progress will be based on a recognition of the fact that a series of activities must be carried out in order for a geothermal energy resource to progress from an undiscovered resource status to a productive energy utilization status. Included in these activities are geological and geophysical exploration, reservoir assessment and evaluation, reservoir development, plant design and plant construction. Quantitative measures of the resources involved in each of these activities or phases of development can be useful gross indicators of progress in regional geothermal energy resource development.

Several comments regarding these objectives were also made at the start of the project with respect to the State of Arizona as follows:

1. Due to a lack of geological field data on a state-wide basis for geothermal energy, there must be much speculative data provided for the operations research scenarios.

2. Since many persons within the State, as well as many in the other participating states believe that much of the operations research program is getting the "cart before the horse", i.e. "hard data" are needed before some of the scenarios can have real meaning, it was anticipated that (a) educated guesses could be made to supply the data requests and at the same time, (b) major effort would be devoted to collecting the Arizona geological geothermal data and preparing the Arizona utilization scenarios, so that such know-how could be established for the potentialities of geothermal energy in Arizona.

3. Since in the regional scenario preparation, the interpretation of highly specialized geological data must by necessity at times be interpreted by non-geological groups, it was anticipated and desired that members of the Arizona team must interact and review certain aspects of the resulting scenarios. Moreover one should interest as many people and institutions as possible in order to ensure the feasibility and success of geothermal energy when and if developed.

C. RELATED ORIENTATION INFORMATION

In order to have the appropriate background on geothermal energy and also to understand better the potential uses of geothermal energy in Arizona we conducted a literature survey on the present uses of geothermal energy in other places in the U.S.A. and throughout the world. Geothermal energy has already been successfully utilized in many places such as Italy, New Zealand, Iceland, Japan, Soviet Union and the United States, especially in the Geyser region of California. If not for the cheap oil and gas, geothermal energy would have been much more advanced.

So far the main emphasis on use of geothermal energy was on electrical power production where steam was available with secondary consideration to district space heating. Some 1360 MW of power plants are already available in the world and additional power plants of some 600 MW total are in construction. The geothermal power in the U.S.A. is presently around 600 MW and it will be doubled in the next few years. Table 1 shows the electricity generating capacity in the world and the projections for this century. Relatively few other uses of geothermal energy can be found in the literature. A brief summary of the 78 relevant references found in the literature as well as the list of these references are given in Appendix 1 of this report.

It is also interesting to note that geothermal energy is being used and promoted in developed countries and it has great advantages for the non-developed countries. First, it reduces the need for expensive oil and second, smaller power units can be constructed in the range of 15-50 MW, which are average loads for small and medium size communities. For the above reasons geothermal energy if available, might be the preferred energy resource in remote areas of well developed countries. In the past, geothermal water has been used for health purposes spas and for the recovery of chemicals from the brines. These along with other domestic and industrial uses are being considered for wider application.

Geothermal energy is commonly compared with solar energy especially with regard to the low grade heat and low heat density. However, geothermal energy currently has more potential since it is a constant heat supply and needs no heat storage as in the case of solar energy source.

Finally, geothermal energy at temperature levels of up to 250°C is quite feasible to obtain and is available in large quantities and therefore the use of this low grade temperature in the form of heat is a major consideration in this study. Since most of the industrial energy use is indeed in this range of temperature and in fact most of the heat used is at even lower temperatures than 200°C, the geothermal energy is applicable in a wide variety of areas. The list of industries for which low grade heat is required could be very long. The range of temperature needed by the various users is given in Figure 1.

TABLE 1 (*)

ELECTRICITY GENERATING CAPACITY
FROM GEOTHERMAL RESOURCES

	1976 Installed Capacity (MW)	1985 Estimated Capacity (MW)	2000 Estimated Capacity (MW)
United States	522	6,000	20,000
Italy	421	800	-
New Zealand	202	400	1,400
Japan	70	2,000	50,000
Mexico	78.5	400-1,400	1,500-20,000
Soviet Union	5.7	-	-
Iceland	2.5	150	500
Turkey	0.5	400	1,000
Canada	-	10	-
Costa Rica	-	100	-
El Salvador	60	180	-
Guatemala	-	100	-
Honduras	-	100	-
Nicaragua	-	150-200	300-400
Panama	-	60	-
Argentina	-	20	-
Portugal	-	30	100
Spain	-	25	200
Kenya	-	30	60-90
Indonesia	-	30-100	500-6,000
Philippines	-	300	-
Taiwan	-	50	200
Totals	1,362.2	11,335-12,475	14,775-100,000

(*) Meidav, T. et al, 1977, An update of World Geothermal Energy Development, J. Geothermal Energy, Vol. 5, No. 5, p. 34.

saturated steam (110–200 °C); water (20–120 °C); Conventional power production (170 °C and above)

°C	
200	
190	
180	Evaporation of highly concentrated solutions
170	Heavy water via hydrogen sulfide process
160	Drying timber
150	Alumina via Bayer's Process
140	Drying farm products at high rates Food canning
130	Evaporation in sugar refining Extraction of salts by evaporation and crystallization
120	Fresh water by distillation Most multiple-effect evaporations, concentration of saline solution
110	Drying and curing light aggregate cement slabs.
100	Drying organic materials, seaweeds, grass, vegetables, etc Washing and drying wool
90	Drying stock fish Intense de-icing operations
80	Space heating Greenhouses by space heating
70	Refrigeration (lower temperature limit)
60	Animal husbandry Greenhouses by combined space and hotbed heating
50	Mushroom growing Balneological baths
40	Soil warming
30	Swimming pools, biodegradation, fermentations Warm water for year-round raining. In cold climates de-icing
20	Fish hatching and farming

FIGURE 1: TEMPERATURE RANGES FOR DIFFERENT GEOTHERMAL USES (*)

(*) Reistad, G.M., 1975, a. Analysis of potential non-electric applications of geothermal energy and their place in the national economy; Livermore, California, Lawrence Livermore Lab., UCRL51747.

II. GEOTHERMAL RESOURCES IN ARIZONA

A. RULES, REGULATIONS AND INSTITUTIONAL ASPECTS

One of the major problems involved in geothermal energy exploration and use is the compliance with many rules and regulations, both state and federal. What follows is our attempt to outline the various State of Arizona governmental agencies which are involved in the development and use of geothermal energy. Recent legislations in the State affecting geothermal use development are also summarized. Also provided are the various State and federal leasing practices and requirements. It is hoped that this summary will help a potential developer in meeting the various state and federal requirements in an efficient and timely manner.

1. Established Executive Offices

Arizona lacks an executive office which deals exclusively with geothermal development. However, the State Land Department has exclusive lease rights to State trust lands and the Oil and Gas Conservation Commission has exclusive statewide regulatory authority. By virtue of Senate Bill 1018 in 1975, and a subsequent amendment in 1977, House Bill 2062, the Arizona Solar Energy Research Commission was created and empowered to coordinate and encourage the support of all solar and advanced alternate (including geothermal) energy systems research. As provided by law, ASERC shall:

"Encourage efforts by research institutions, local government institutions and home builders in obtaining technical and financial support from the federal government for their activities in solar and advanced alternate energy systems". (Senate Bill 1018 - A.R.S. s 41-574 #3).

ASERC plans to assume a lead role in providing information and research leading to increased geothermal production that is harmonious to the environment.

2. Agencies Related to Geothermal Development

In Arizona state government there are three agencies which include geothermal development as a part of their responsibility: i) Oil & Gas Conservation Commission, ii) Arizona Solar Energy Research Commission, iii) The Arizona State Land Department.

i) The Oil and Gas Conservation Commission regulates the development of oil, natural gas, and geothermal resources within the state and serves as technical consultant to resource developers throughout the state. As provided by law, "the Commission shall so supervise the drilling, operation, maintenance and abandonment of geothermal resource wells as to encourage the greatest ultimate economic recovery of geothermal resources, to prevent damage to and waste from underground geothermal reservoirs, to prevent damage to or contamination of any waters of the state or any formation productive or potentially productive of fossil fuels or helium gas, and to prevent the discharge of any fluids or gases or disposition of substances harmful to the environment by reasons of drilling, operation, maintenance, or abandonment of geothermal resource wells." (A.R.S. § 27-652).

The Oil and Gas Conservation Commission consists of six members of which five are appointed by the Governor with Senate consent. The State Land Commission serves as an ex-officio member. The terms for appointed members are five years.

ii) The Arizona Solar Energy Research Commission (ASERC) collects, analyzes, and provides information and data relating to solar energy technology and other non-polluting renewable energy sources. ASERC cooperates with all federal agencies involved in solar and advanced energy (including geothermal) technology development. The Arizona Solar Energy Research Commission has seventeen members. At the present time the Commission is comprised of the Chairman of the Arizona Power Authority, six representatives from Arizona's three state universities, eight representatives of the business and industrial sectors, and as ex-officio members, the President of the Arizona Senate and the Speaker of the House of Representatives. New legislation provides three year terms.

iii) The Arizona State Land Department is responsible for the planning, development and protection of all forests and natural resources located on state lands. In its administration of the 9.6 million acres of state trust lands (13% of land in Arizona), the Department among other duties, is authorized to:

i. Create long range plans for the exchange, lease, or the sale of state lands (A.R.S. 37-102);

ii. Exercise the power of eminent domain (A.R.S. 37-461);

iii. Officially represent the state in any matter between state and federal government concerning public lands (A.R.S. 37-102);

iv. Engage in many activities administratively relating to the control and supervision of the lands and waters of the state (A.R.S. 37-102, 37-132).

In addition, new legislation (Chapter 87, House Bill 2257, 33rd Legislature) provides that the State Land Department may lease state lands for geothermal development. Regulations pursuant to this law are in the process of being developed by the Department.

3. Organization of the State Legislature

i) Legislature Committees having Prime Responsibility for Geothermal Development and Regulation: A general organization chart of the Arizona State Legislature is shown in Figure 2. The 14 standing committees in the House and the 10 committees in the Senate serve as major forums for the deliberations on the bills. The key committee for geothermal matters in the House is the 15-member Natural Resources Committee, while the Senate has a 9-member committee on Natural Resources and Environment.

ii) Legislative Committees having Oversight Responsibility for Geothermal Development and Regulation: No legislative committee in Arizona is specifically charged with responsibility for oversight of geothermal development and regulation. However, some oversight is carried out as part of the annual appropriations process of the appropriations committees of both houses, and by the Joint Legislative Budget Committee.

4. Legislation Which May be Considered by Future Sessions

i) Dates of the next Legislative session: The Arizona State Legislature convenes on the second Monday in January each year. For this session, the starting date is January 9, 1978. The last day for submission of bills is 36 days after the start of the first session, and 29 days after the start of the second session. As 1978 marks the meeting of the second session of the Thirty-third Legislature, the last day for submission of bills is February 7, 1978.

ii) Anticipated topics/needed Legislation: It appears unlikely that legislation relating to geothermal development will be introduced in Arizona in 1978. Considerable effort went into the preparation of House Bill 2257, passed in 1977, and detailed regulations to implement the leasing provisions are presently being drafted by the State Land Department. It is likely that most interested groups will wait to see how the new laws and regulations will work before mounting a campaign for changes.

There are at least four provisions which may be examined when the time for changes arrives. One concerns the constitutional provision for competitive bids when the Arizona State Land Department sells "products of the land". A 1950 constitutional amendment exempted oil and gas exploration leases from this provision, in order to stimulate exploration and discovery. Some think a similar amendment would be appropriate for geothermal development, especially since many of the provisions of the law are parallel for geothermal and oil/gas resources.

Another need may be further clarification to distinguish geothermal water resources from other water. A criterion of 80°C was part of the original House Bill 2257 last year, but the provision was struck.

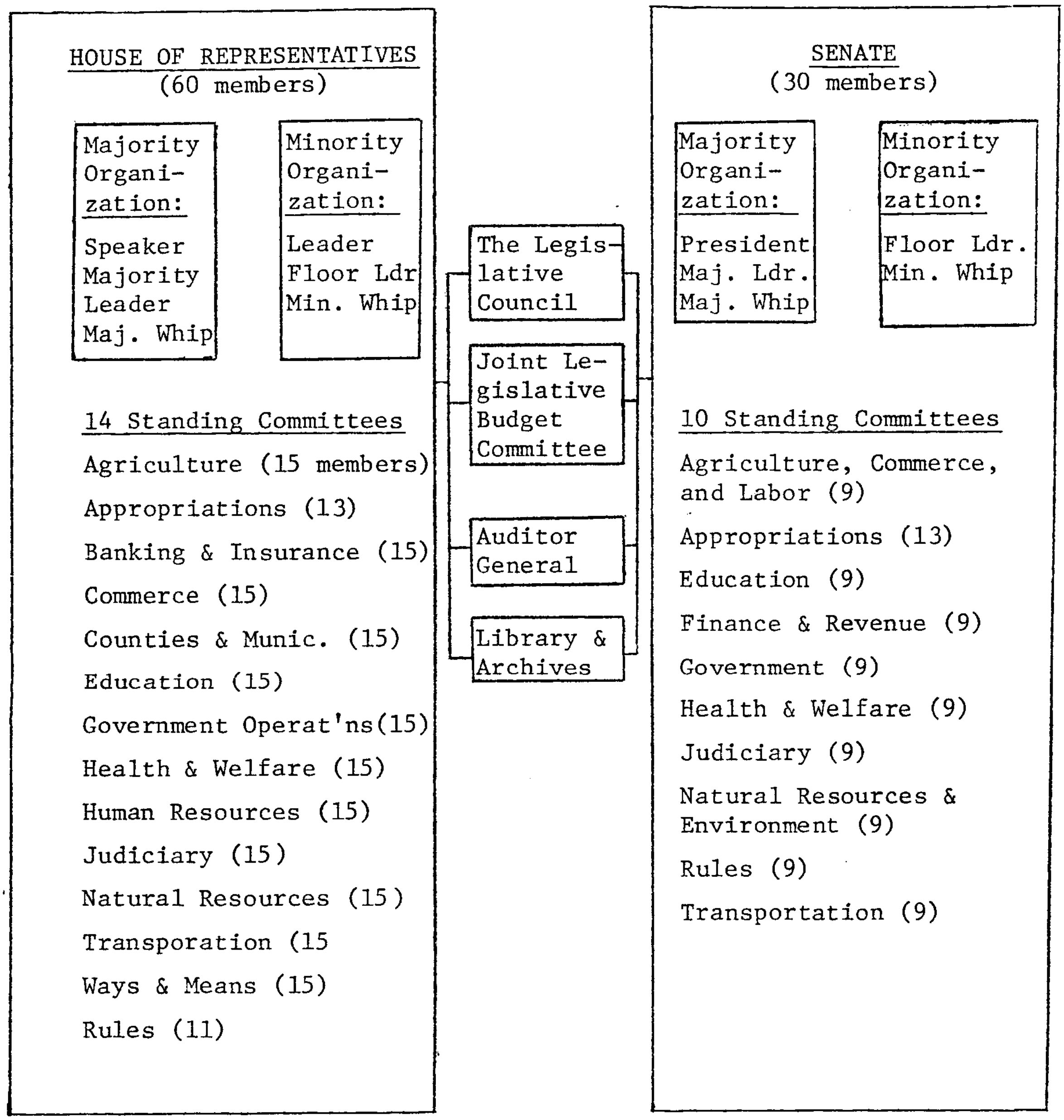

FIGURE 2 : GENERAL ORGANIZATION CHART OF THE ARIZONA STATE LEGISLATURE (*)

(*)Staff members are attached to most of the subdivisions of the Legislature, but are not shown here for the sake of simplicity.

Opponents of this measure pointed out the limitations which would be placed on low temperature resource development by the temperature restriction. Additional criterian needs to be incorporated to make regulation and administration more predictable.

A third item of consideration may be the granting of tax breaks to those industries or residences who either develop or use geothermal energy to alleviate their dependency on oil and natural gas. Legislation granting tax credits and exemptions to those users of solar energy has been enacted this year by the First Regular Session of the Thirty-third Arizona Legislature. *

Finally, a provision to retain State ownership of geothermal rights on State/private land trades could be added.

B. LEASING PROCEDURES

1. Leasing of State Lands

i) Geothermal leases may be initiated by either of two methods, each of which require a competitive bid sale process:

- a. The Land Department may designate likely resource areas which they wish to lease.
- b. An individual or company may apply for a lease on a given tract of state land.

ii) State Land Department reviews proposals, and if they are satisfactory, a notice of availability for lease is published for 10 weeks.

iii) The lease is awarded to the highest qualified bidder with payment of the first year's rental.

Arizona has recently enacted legislation that provides and sets procedures for the leasing of state lands for geothermal resources development. The major provisions of this stature, Chapter 87, House Bill 2257, * are as follows:

i) The State Land Department shall determine and designate known geothermal resource areas (KGRA) into which the lands shall be divided in "reasonably compact" tracts for leasing purposes.

ii) A notice of availability for lease is then published for 10 weeks in Statewide newspapers and publications.

* (H.B. 2068 - Solar Energy tax credit: H.B. 2063 - Solar Energy devices tax exemption)

iii) Upon receipt of an application to lease any state lands (which shall include a description of the land, name and address of applicant, and a $25 filing fee), the Land Department shall offer the tract(s) for lease to the highest and best bidder. The Department shall publish a call for bids. (The State Land Commissioner reserves the right to reject any or all bids).

iv) Bidding shall be on a basis of highest first year's bonus to be paid to the State Land Department at the time of declaration of the highest and best bidder.

v) The State Land Department shall determine the royalty which shall not be less than 12½% of the gross value of the resource at the well head.

vi) The State Land Department shall determine annual rental which shall be not less than $1 per acre for each year the lease is in effect.

vii) The lease shall be for a primary term of 10 years with 2 year extensions on active drilling sites.

viii) There may not be more than 2,560 acres included in any one lease.

ix) Requests to enter into unit operations or pools so as to expedite geothermal resource development must have the approval of the State Land Department.

x) Practices that delay the discovery or development of geothermal resources are illegal.

The State Land Department is given the power to enact regulations that are not explicitly written in this legislation. As mentioned before under "Organization of State Government", regulations pursuant to this law are in the process of being developed by the Department.

The primary unanswered questions in terms of legal procedures which must be initiated are at the state level. After completion of the leasing agreements, two general areas within the State of Arizona's legal requirements must be clarified:

a. Determine legal requirements for exploratory drilling with respect to:

   1. County permits, studies, hearings, and/or certifications.
   2. State permits, studies, hearings, and/or certifications.

b. Determine legal requirements for development of geothermal sources with respect to:

   1. County permits, studies, hearings, and/or certifications.
   2. State permits, studies, hearings, and/or certifications.

New rules and regulations were recently published for the Oil and Gas Conservation Commission and the State Land Department (Articles 2 and 22 - Geothermal Resources).

2. Leasing of Federal Lands

i) U.S. Department of Interior serves as the lead agency. This department's Bureau of Land Management (BLM) controls all federal land-geothermal leasing.

ii) The USDA Forest Services, the Fish and Wildlife Service, and the U.S. Geological Survey join in the preparation of environmental assessments.

iii) There are two basic leasing processes on Federal lands. The choice of which is used depends on whether the land in question is in a "Known Geothermal Resource Area" (KGRA). A KGRA is defined as "an area in which the geology, nearby discoveries, competitive interest, 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 steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose."*

In other words, KGRAs would be delineated by geological information available to USGS, <u>or</u> by the overlap of several lease applications.

a. If an area up for lease is part of a KGRA, it is subject to competitive bidding as shown in Figure 3. This process consists of:

1. Applicant initiates lease request.
2. BLM forwards this to USGS.
3. USGS analyzes request to determine that it qualifies as a KGRA.
4. Surface management agencies assess the environment impact.
5. If acceptable, BLM publishes a request for competitive bidding.
6. Either no bid or best bid is awarded the lease.

b. If an area up for lease is not part of a KGRA, it is subject to the non-competitive leasing process as shown in Figure 4:

1. Applicant initiates request.
2. BLM forwards this to USGS
3. USGS analyzes requests to determine that the area is not a KGRA.
4. BLM reviews and forwards to appropriate land management agencies.
5. Surface management agencies assess the environmental impact.

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* Title 43 CFR Part 3000 section 3200.0-5(k)

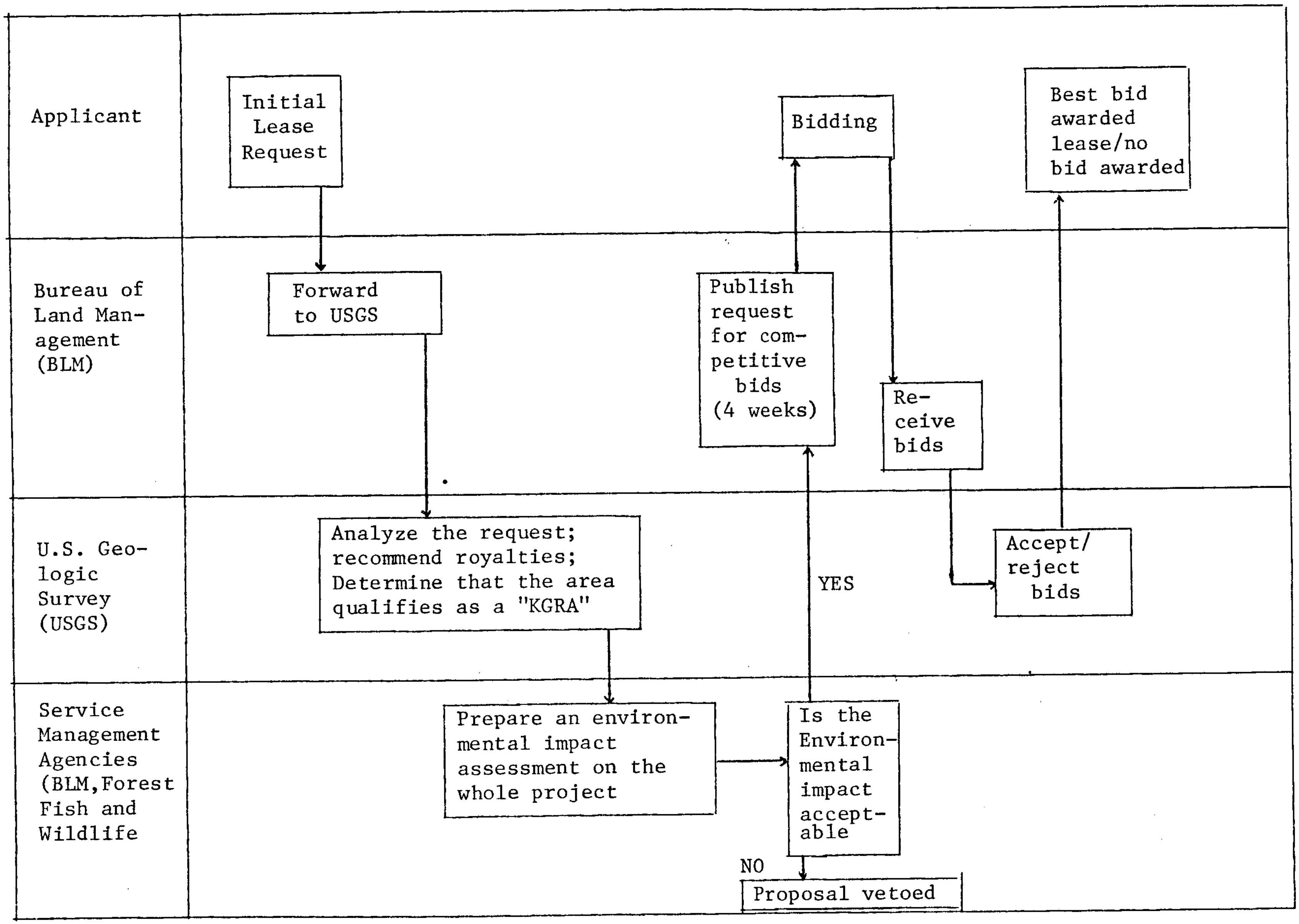


FIGURE 3: COMPETITIVE BIDDING PROCESS FOR THE LEASING OF FEDERAL (NON-INDIAN) LANDS FOR GEOTHERMAL DEVELOPMENT

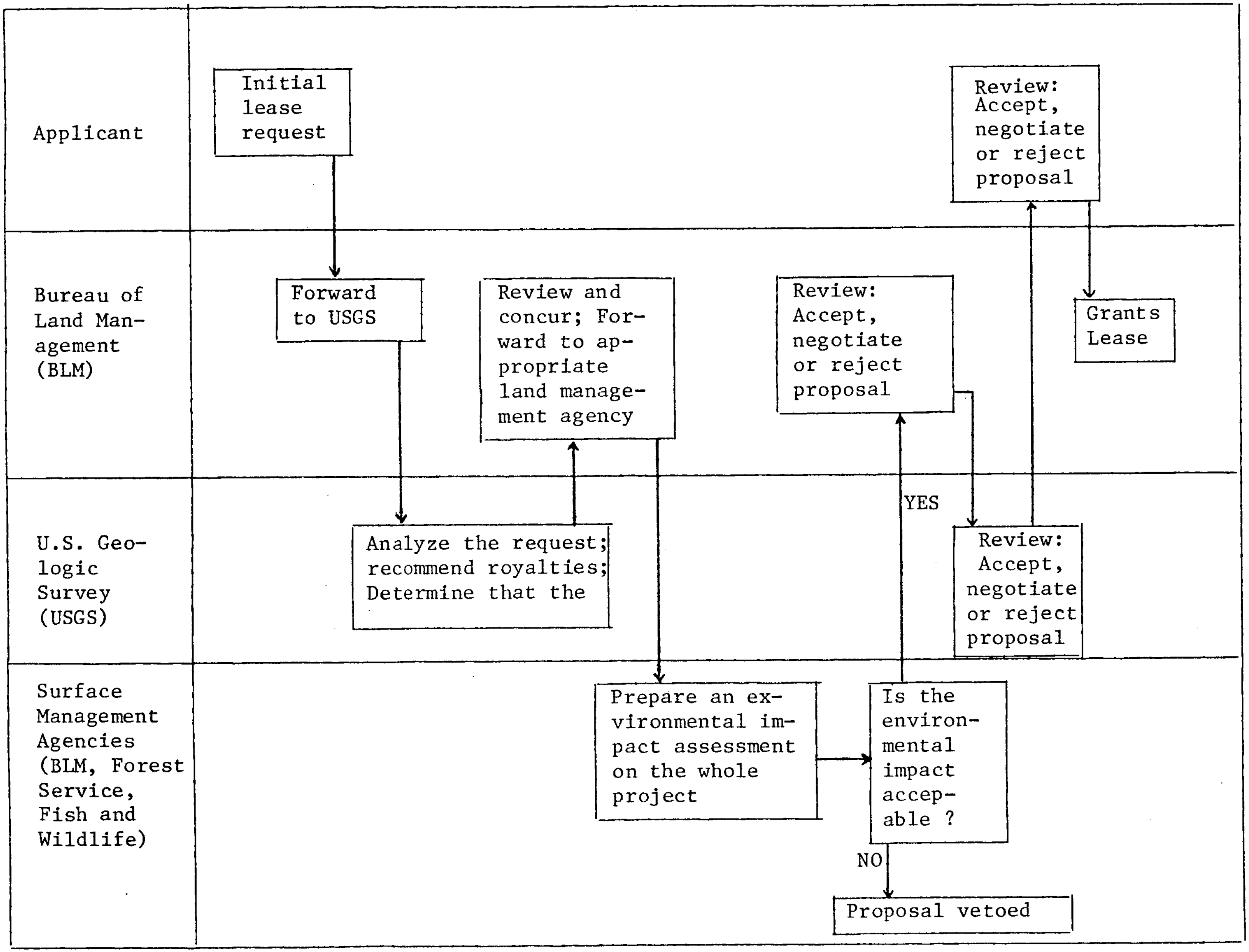


FIGURE 4: NON-COMPETITIVE LEASING PROCESS FOR FEDERAL (NON-INDIAN) LANDS FOR GEOTHERMAL DEVELOPMENT

6. BLM reviews and accepts, negotiates, or rejects proposals.
7. USGS reviews and accepts, negotiates, or rejects proposals.
8. Applicant reviews and accepts, negotiates, or rejects proposals.
9. Lease is granted or not granted.

3. Leasing of Private Lands

There are no state regulations pertaining to the leasing of private lands for geothermal development. However, the Oil and Gas Conservation Commission supervises all "drilling, operation, maintenance and abandonment of geothermal resource wells". A proposed geothermal drilling operation must apply to the Oil and Gas Conservation Commission for a drilling permit. This requirement applies to State, Federal, Indian or private land. It is possible that both the Oil and Gas Commission and the State Land Department could be involved in the cooperative development of a geothermal resource pool.

4. Leasing of Indian Land

Actions that relate to trust resources on federal lands ultimately rest with the Secretary of the Department of the Interior. Accordingly, the leasing of Indian lands for geothermal development has been assigned to the Bureau of Indian Affairs (BIA), and U.S. Geological Survey (USGS). The BIA provides technical and administrative assistance to the Indian Tribe in bid publication, lease contract review, and operations monitoring. USGS evaluates any environmental assessment or impact statement and also provides similar technical assistance. In addition, the USGS has enforcement authority in operation compliance of resource development. Various guidelines for development, however, such as royalties and leasing terms, are left to the Tribe to initiate, giving them a fair degree of flexibility.

5. Creating Incentives

Presently, there are no explicit state enacted incentives for geothermal development. However, the several state agencies which provide technical and administrative assistance, see their actions as indirect inducement techniques. Such mechanisms include the simplification of drilling regulations, inter-agency cooperation with respect to unitization and pooling of resources, and cooperation in monitoring, reporting, and evaluating geothermal resource potential.

6. Pertinent Recent Court Cases and Impacts

There have been no recent court cases in Arizona which relate to geothermal resources. However, sources at the Arizona Oil and Gas Commission cite the case of U.S. v. Union Oil, opinion number 74--1574 of the Ninth Circuit Court of Appeals, as significant. The case is presently before the U.S. Supreme Court.

C. GEOTHERMAL RESOURCE DATA

1. Practical Experience with Geothermal Exploration in Arizona

There has been a limited amount of exploration for geothermal energy in Arizona. In order to learn from that experience, we approached a few companies which were involved in this exploration and asked them for their remarks regarding the problems encountered. Very few replied to our letters of inquiry; therefore we cannot present a full picture of that experience. However, we shall present at least some of the remarks received due to their immediate relevance to our work.

One company which deals with the drilling process suggested that a single department should deal with the issuing of permits even if many agencies have to give their approval. Another company stated it is virtually impossible to document the various problems and experiences they have encountered in geothermal exploration and development, and offered to discuss this with us at a later stage. However, a third company did give us some interesting replies to our questions as follows:

> As far as geothermal exploration in Arizona is concerned, like geological, hydrological, geochemical and geophysical aspects, there were no significant institutional problems and most of those involved were actually very cooperative.

However, as far as the site-specific phase is concerned, companies basically concentrated on private land because the delay encountered in filing for prospective geothermal leases on BLM administered land is outrageous. The most interesting reply, however, was that they deliberately stay away from any known geothermal resource area (KGRA) because of time delays and the usually unworkable lease arrangements required for these areas. We believe presenting even these few remarks to be worthwhile.

From past experience with mineral leasing and development the situation that developers fear most is dealing with the regulations and bureaucracy, not the law. That is why the law should be completely clear and simple if we want a fast development of geothermal energy.

2. Introduction to the Arizona Geology

The paucity of activity in the area of geothermal energy in the State of Arizona quite probably has been caused by institutional impediments and the desert environment.

With the passage of Arizona House Bill 2257, providing for the leasing of state lands for geothermal resources, by both the Arizona House and Senate and approval by the Governor on May 23, 1977, the Arizona State Land Department is now able to accept geothermal lease requests for state lands. The rules and regulations for these leases and other geothermal activities have already been discussed.

The desert environment and receding water tables in Arizona have tended to mask potential geothermal sites. However, there are over 40 hot or warm springs currently mapped in the state. The majority of these known thermal springs are situated in the desert environment of the Arizona Basin and Range physiographic province. A detailed list of these hot springs is given in Table 2.

With the advent of agriculture, numerous irrigation wells drilled in the Phoenix, Casa Grande, Tucson, Florence, Safford and Yuma areas were/are thermal wells. These wells indicate considerable potential for geothermal energy resources. The outcrops of Tertiary and Quaternary igneous rocks shown on the geologic map of Arizona (Fig. 5) further indicate considerable potential target areas in the state. In southern Apache County, south of St. Johns, is a large Tertiary-Quaternary quiet volcanic field (lavender colored on map). This field has potential for both low and high temperature (+200°C) hydrothermal resources as well as potential for hot dry rock.

The San Bernardino volcanic field lies in the southeast corner of Cochise County. This volcanic field, Quaternary in age, has considerable potential for low and high temperature hydrothermal resources as well as for hot dry rock. The igneous extrusive and intrusive rocks fringing Yavapai County and in the Flagstaff area, Coconino County, also present excellent areas for exploration for low to high temperature hydrothermal resources and hot dry rock.

The Quaternary and Quaternary-Tertiary volcanic (igneous extrusive) rocks of Yuma, Maricopa and Western Pima counties again present excellent areas in which to seek geothermal resources. In fact, currently, progressing thermal gradient studies in the areas cited above further indicate the potential that these extrusive and intrusive igneous rocks have to be associated with geothermal resources.

The geologic map and cross-sections of Arizona (Fig. 5) have large areas in the southwest half of the state colored pale yellow and designated QTs in the explanation. This color and designation indicate areas of very young sediments and valley fill. In fact, some of these deep valleys in time past have been enclosed evaporite basins and now contain large quantities of buried salt and anhydrite (1,2). When the mineral anhydrite alters to the mineral gypsum the chemical reaction is exothermic (evolves heat). Possibly some of the warm waters in these deep sediment filled valleys may be attributed to this heat source (3). However, it is more probable that most warm waters in these intermountain valleys result from the deep percolation of water along faults, the warm water then rising and mixing with subsurface or possibly surface waters. Also the possible existence of unexposed, intrusive igneous rocks in these sedimentary basins must not be overlooked. There are young igneous intrusive and extrusive rocks exposed in the mountains bounding these deep sediment filled valleys.

TABLE 2

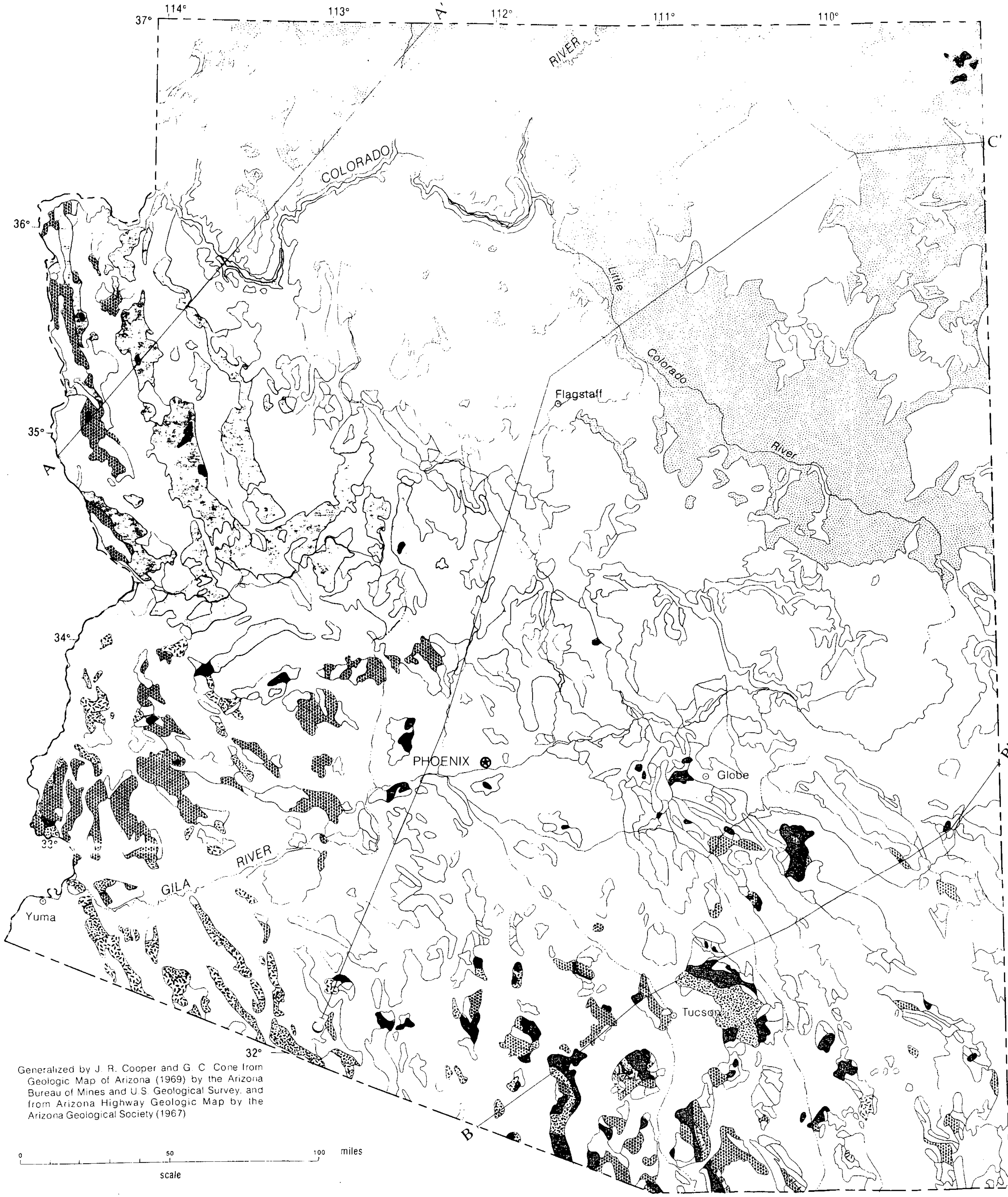
LIST OF HOT SPRINGS IN ARIZONA

Hot Springs	Temp.	Township	Lat.	Long.
*Pioneer Spring	$33^{o}C$	T2S R15E Sec 33	$110^{o}51.6'$	$33^{o}12.6'N$
*Lava Springs	$32^{o}C$	T32N R7W Sec 6	$113^{o}05.4'W$	$36^{o}12.0'N$
Coffers Hot Springs	$36^{o}C$	T16N R13W Sec 36	$113^{o}35.4'$	$34^{o}40.8'N$
Pakon Spring (Reported 38)	$28^{o}C$	T35N R16W Sec 24	$113^{o}57.4'W$	$36^{o}24.9'N$
Quitobaquito (Reported 32)	$26.5^{o}C$	T17S R7W Sec 18 SE 1/4	$113^{o}1.4W$	$31^{o}57.5'N$
Castle Hot Springs	$50^{o}C$	T8N R1W Sec 34 SW 1/4 SW 1/4	$112^{o}21.7'W$	$34^{o}59.0'N$
Radium Hot Spring (Dry)	$60^{o}C$	T8S R18W Sec 12 SW 1/4 SW 1/4	$114^{o}4.2'W$	$32^{o}44.4'N$
Indian Hot Springs	$50^{o}C$	T5S R24E Sec 17 NE 1/4	$109^{o}54.0'W$	$33^{o}0.1'N$
Gillard Hot Springs	$82^{o}C$	T5S R29E Sec 27 NE 1/4 NE 1/4	$109^{o}20.9'W$	$32^{o}58.4'N$
*Grapevine Spring	$33^{o}C$	T5S R25E Sec 9 SE 1/4	$109^{o}51.6'W$	$33^{o}1.2'N$
*Spring	$33^{o}C$	T5S R25E Sec 17	$109^{o}58.8'W$	$32^{o}59.8'N$
*Spring	$34.5^{o}C$	T30N R23W	$114^{o}54'$	$35^{o}42'$
Aqua Caliente Hot Spring	$32^{o}C$	T13S,R16E Sec 20 SW 1/4 SE 1/4	$110^{o}43.8'W$	$32^{o}16.9'N$
Aqua Caliente Hot Spring(Dry)	$32^{o}C$	T20S R13E Sec 13 NE 1/4 NW 1/4	$110^{o}57.8'W$	$31^{o}41.7'N$
Verde Hot Spring	$41^{o}C$	T11N R6E Sec 3 NW 1/4	$111^{o}42.5'W$	$34^{o}21.3'N$
Aqua Caliente Springs (Dry)	$39^{o}C$	T5S R10W Sec 19 NE 1/4 NE 1/4	$113^{o}19.4'W$	$31^{o}59.1'N$
*Spring	$37^{o}C$	T3S R16E Sec 1	$110^{o}42.0'W$	$33^{o}10.2'N$
Hookers Hot Spring	$54.5^{o}C$	T13S R16E Sec 6 NE 1/4 NE 1/4	$110^{o}14.3'W$	$32^{o}20.2'N$
Clifton Hot Springs	$61.0^{o}C$	T4S R30E Sec 18 SW 1/4 SE 1/4	$109^{o}17.8'W$	$33^{o}4.8'N$
Eagle Creek Hot Spring	$42.0^{o}C$	T4S R28E Sec 35 NE 1/4 NW 1/4	$109^{o}26.4'W$	$33^{o}2.9'N$
Little Hanna Creek	$55.5^{o}C$	T1N R31E Sec 29 SE 1/4 NE 1/4	$109^{o}10.8'w$	$33^{o}22.8'N$

TABLE 2 Cont...

Warm Spring	31.5°C	T4S R23E Sec 21 NE 1/4 SE 1/4	109°59.0'	33°4.3'N
Warm Spring Near Indian Hot Springs	33.0°C	T5S R24E Sec 17 NE 1/4 SE 1/4	109°54.0'	33°0.0'N
Very Small Spring or Seep Near Clifton	44.8°C	T4S R30E Sec 19 SW 1/4 NE 1/4	109°17.9'W	33°4.2'N
Warm Spring Near Hooker Hot Springs	32.5°C	T12S R21E Sec 31 NE 1/4 SW 1/4	110°14.4'W	32°20.9'N
Coolidge Dam Hot Springs	36.6°C	T3S R18E Sec. 17 SW 1/4 SE 1/4	110°31.7'W	33°10.3'N
Mescal Warm Springs	29.1°C	T3S R17E Sec 20 SW 1/4 NW 1/4	110°38.2W	33°9.3'N
Hoover Dam Hot Springs	42.2°C	T22S R65E Sec 29 SW 1/4	114°44.7'W	36°0.6'N
Warm Springs Bronco Gulch	30.0°C	T1N R20E Sec 12	110°12.7'N	33°26.4'N
Warm Spring	28.3°C	T18N R13W Sec 25 NW 1/4 SE 1/4	113°36.6'W	34°55.0'N
Honkey Spring	28.3°C	T21S R16E Sec 3 SW 1/4	110°42.2'W	31°38.1'N
Warm Spring	26.0°C	T5S R19E Sec 23 SE 1/4	110°22.5'W	32°59.o'N
*Colorado Pool	Warm	T36N R5E	111°51.6'W	36°31.8'N
*Chalk Mountain	Warm		111°45.0'W	34°5.4'N
*Roosevelt Dam	Warm		111°11.4'W	33°42.0'N
*Little Boiling	Warm		109°34.8'W	33°12.0'N
*Arsenic Cave	Warm		109°49.2'W	33°19.8'N
*Aravaipa	32.2°C	T5S R19E Sec 35	110°22.8'W	32°58.8'N
*Salt Spring	28.3°C		110°40.8'W	33°48.0'N
*Soda	Warm		111°46.8'W	34°38.4'N

* Stands for Rumored Hot Springs - have not been found or have not been field checked.



EXPLANATION

SEDIMENTARY AND VOLCANIC ROCKS

CENOZOIC

QTs — Quaternary and upper Tertiary (Pliocene) sedimentary rocks, mostly unconsolidated; includes scarce lava and silicic tuff

QTv — Quaternary and upper Tertiary volcanic rocks, mostly basaltic in composition

Ts — Middle Tertiary (Miocene and Oligocene) sedimentary rocks; locally include lava and tuff

Tv — Middle Tertiary volcanic rocks of silicic to basaltic composition; includes related intrusive rocks

MESOZOIC

Ks — Cretaceous sedimentary rocks

JȂs — Jurassic and Triassic sedimentary rocks

Mesozoic sedimentary rocks

TȂv — Lower Tertiary to Triassic volcanic rocks; includes some sedimentary rocks

PALEOZOIC

PIPs — Permian and Pennsylvanian sedimentary rocks; shown only on Colorado Plateau

M€ / Pz — Mississippian through Cambrian sedimentary rocks on Colorado Plateau; all Paleozoic sedimentary rocks in Basin and Range province

PRECAMBRIAN

Yp€ — Younger Precambrian sedimentary rocks and intrusive diabase

Op€ — Older Precambrian rocks of all types, including schist, gneiss, and fine- to coarse-grained igneous intrusive rocks

OTHER METAMORPHIC AND INTRUSIVE IGNEOUS ROCKS

TK — Tertiary and Upper Cretaceous intrusive igneous rocks

TM — Post-Paleozoic gneiss and schist

KȂ — Mid-Cretaceous to Triassic intrusive igneous rocks

GEOLOGIC MAP and CROSS-SECTIONS of ARIZONA

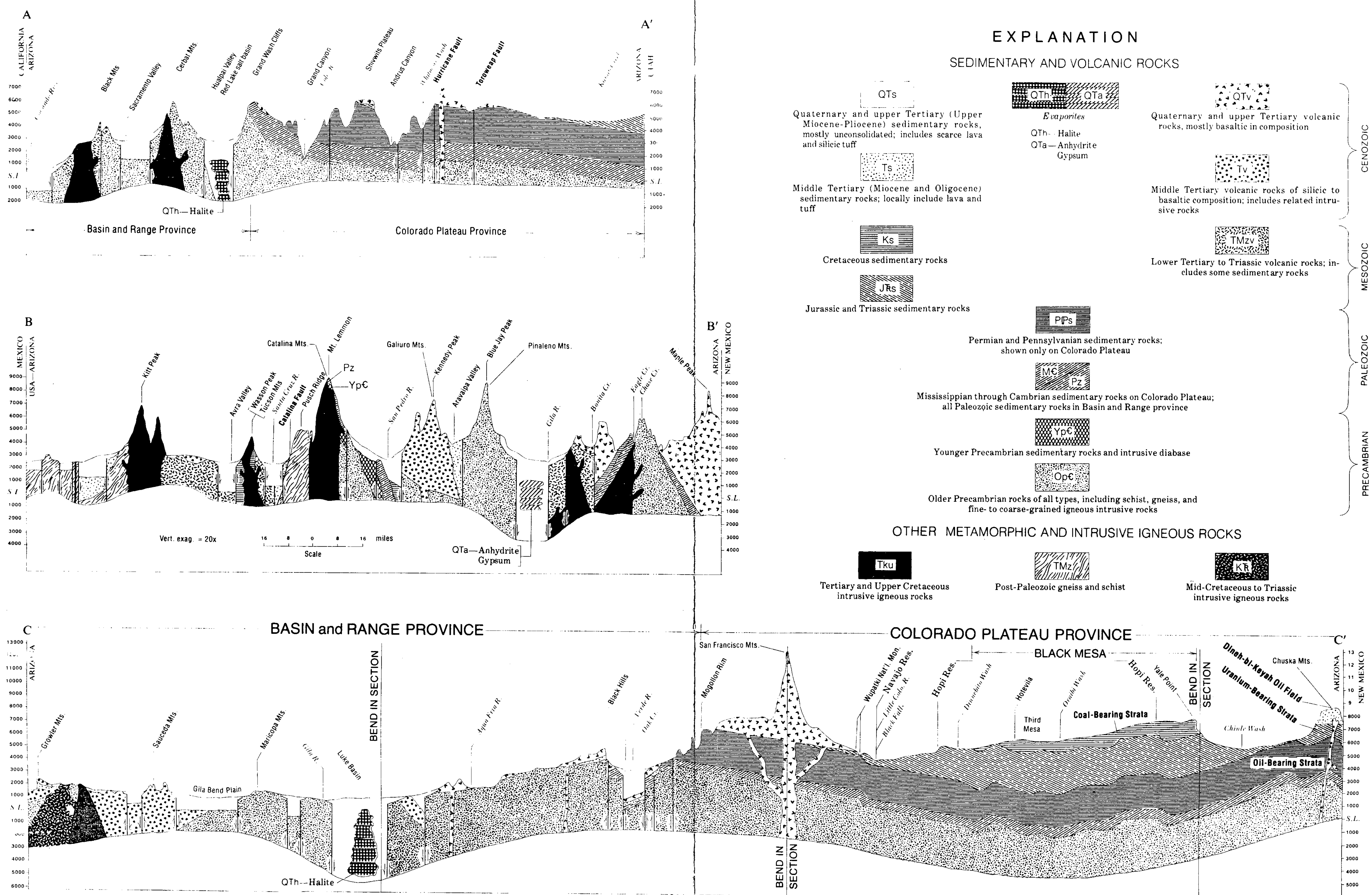


FIGURE 5: GEOLOGIC MAP AND CROSS SECTION OF ARIZONA

Cross-Sections compiled by H. W. Peirce

Therefore as demonstrated above, Arizona has high potential for the existence of geothermal energy resources. However, the potential is not obvious and considerable grass roots exploration work remains to be done.

1. Peirce, H.W., 1974, thick evaporites in the basin and range providence - Arizona: 4th Symposium on salt, Northern Ohio Geol. Society, Cleveland, p. 47-55.

2. Peirce, H.W., 1976, Tectonic significance of basin and range thick evaporite deposits: Arizona Geological Society Digest, Volume X, March; p. 325-339.

3. Gerlach, T., Norton, D., DeCook, K.I., and Sumner, J.S., 1975, Geothermal Water Resources in Arizona: Feasbility Study, University of Arizona U.S. Department of the Interior.

For purposes of categorizing use scenarios for use by the Core Team, site-specific scenarios geothermal resources were to be defined as follows:

Category I: "Sites for which active development work is being pursued by geothermal developers for electric energy or by other parties for non-electric (e.g. space-heating) applications". There is no current activity in this category in Arizona.

Category II: "Sites for which some activity is occurring (e.g. leasing, drilling, temperature gradient holes, etc)., but for which sufficient information is not yet available to construct specific scenarios."

Geothermal leasing activity is discussed below.

Category III: "Sites of minimal activity with essentially no substantive information to base quantity of resource or timetable for development."

Based upon data obtained from regional geologic reconnaissance, thermal springs, wells, and geochemical temperature indicators the following areas have been designated for further work.

a. Springerville - St. Johns area, Apache County, Arizona
b. Clifton - Morenci - Safford area, Greenlee and Graham Counties, Arizona
c. San Bernardino Valley area, Cochise County, Arizona.
d. Castle Hot Springs, Yavapai County, Arizona

The initial programs in these areas consisted of detailed geologic mapping, geophysical evaluations including heat flow measurements, water sampling and analyses and age dating of selected lithologic units.

The geological exploration and evaluation resulted in educated guesses concerning geothermal resources, temperatures, and availability for use in scenarios at various locations.

3. Details on the Geology of Arizona

The State of Arizona may be divided into two physiographic provinces, the Colorado Plateau in the northeast part of the state and the basin and range in the southwest part of the state. There is a transition zone between the two provinces. The complex lithologies and overall structure of the basin and range province are the result of a long history of tectonic activity that commenced during Precambrian times over one billion years ago. The physical features visible today, north and northwest trending mountain ranges and sediment-filled intermontane basins, are the result of complex tectonic activity that commenced approximately 14 million years ago and may have continued to the present in some places.

The Colorado plateau, when compared to the basin and range, is tectonically stable. The land forms that characterize this province are broad plains, plateaus, buttes and mesas. These features have been formed by differential errosion of resistant and nonresistant sedimentary rocks.*

i) Hydrothermal Geothermal Systems

In Arizona, indications of hydrothermal geothermal systems are represented by natural thermal springs and drilled wells. Thermal springs and wells are widely distributed throughout the state but are most abundant in the basin and range transition zone. The possible explanation for this relative concentration of geothermal areas follows: 1. deep circulation of meteoric water through the intense, complex fracture systems of the basin and range and transition zones; 2. igneous rock intrusions, again along fractures or zones of weakness, not exposed at the surface; 3. a combination of the prior two possibilities; 4. heat generated by radiogenic decay of radioactive elements in igneous rocks; 5. Gerlack et al** have suggested the exothermic reaction resulting from the hydration of anhydrite in the evaporation sequences of sediments that occur in some of the intermontane basins.

The paucity of thermal springs and wells, especially wells, in the Arizona section of the Colorado Plateau could be the result of lack of observation. However, the paucity most likely is the result of the plateau's relatively low heat flow.

Hydrothermal resources suitable for electrical generation are expected to be encountered in several areas around the state. These favorable areas have been determined by use of geochemical thermometers indicating projected

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* Arizona Geological Society, 1967, Arizona Highway Geologic Map, M.E. Cooley, compilier.

** Gerlack, T., Norton, D., DeCook, K.J. and Sumner, J.S., 1975, Geothermal Water Resources in Arizona: Feasibility Study, U.S. Dept. of Interior, Office of Water Resources Research.

reservoir temperatures calculated from chemical analyses of water from wells and springs. The favorable areas are the San Bernardino Valley, Clifton-Morenci-Safford, Springerville-St. Johns, Flagstaff, Phoenix, and the Hyder Valley area. Additional exploration is expected to locate other areas favorable for electrical generation from hydrothermal resources.

Hahman, Stone and Witcher*, in their preliminary map compilation of the geothermal energy resources of Arizona, showed both high temperature and low to moderate temperature areas. Most of the favorable areas on this map are situated in the Basin and Range physiographic province. Preliminary investigations seem to indicate that low to moderate temperature geothermal energy will be available for the use of most of the populated areas in the Arizona Basin and range province. The current major uses of low to moderate temperature geothermal resources are in space heating, cooling and agribusiness.

ii) Hot Dry Rock

Arizona has considerable potential for hot dry rock geothermal energy for use in electrical generation, space heating and cooling, agribusiness, etc. Technology's advancement rate will determine the practicality of developing this energy source in Arizona.

Byerly and Stolt**, in their article on the Curie point isotherm in northern and central Arizona, define a rather broad zone through central Arizona where the Curie point is less than 10 km and often less than 5 km below the land surface. The Curie point, that temperature at which magnetic materials lose their magnetic properties, of magnetite is 575°C***. Therefore, if the Curie point is at 5 km one might reasonably expect to have a temperature of approximately 575°C at that depth. The zone where the Curie point is within 5 km of the surface would be a much more favorable zone in which to look for hot dry rock and/or hydrothermal resources associated with young, concealed, silicic, intrusive rocks than a section where the Curie point is at a depth of 20 or 30 km.

In conclusion, Arizona has considerable potential for geothermal energy resources. The geological manifestations of these resources are often very subtle. However, these geothermal resources, for both electric and nonelectric uses, can be located and developed through prudent, integrated programs involving geology, geophysics and geochemistry.

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* Hahman, Sr., W.R., Stone, C. and Witcher, J.C., 1978, Preliminary Map, Geothermal Energy Resources of Arizona, Bureau of Geology and Mineral Technology, Tucson, Arizona.

** Byerly, P.E. and Stolt, R.H., 1977, An Attempt to Define the Curie Point Isotherm in Northern and Central Arizona, Geophysics, Vol 42, No. 7, p. 1394-1400

*** Telford, W.M., Geldart, L.P., Sheriff, R.E. and Keys, D.A., 1976, Applied Geophysics, Cambridge University Press, New York.

4. Preliminary Map of Geothermal Energy Resources of Arizona

During the first year of Arizona DOE/DGE contract, an attempt was made to compile data relevant to geothermal energy in the State of Arizona. As part of this program the Arizona Oil and Gas Conservation Commission was commissioned to prepare a map, scale 1:1,000,000, constructed from their files and published reports on the geothermal energy of Arizona.* Another part of the program was the construction of a lineament map, scale 1:1,000,000 prepared from Landsat imagery by Dr. Larry Lepley**. Dr. Chandler Swanberg furnished the data, contained in New Mexico Energy Institute report number 6, to the Arizona program.*** Therefore, the majority of the information had already been compiled when the U.S. Department of Energy, Division of Geothermal Energy requested the publication of a preliminary map (Fig. 6) on the geothermal energy resources of the state.

The Arizona Bureau of Mines**** ***** had published a map of the outcrops of Quaternary igneous rocks, scale 1:1,000,000 in 1962 and of cinder cones, scale 1:500,000 in 1969. In these two instances all that was necessary was an updating of the material.

Dr. Paul Damon and his associates****** of the Laboratory of Isotope Geochemistry, University of Arizona, Tucson, were kind enough to revise the 1962 map from their extensive age date files. Drafter Dan Dwyer revised the cinder cone map and drafted, registered and stripped the 10 plates for the printing company.

The cooperation of all parties associated with this map is gratefully acknowledged and greatly appreciated. Without the contributors' efforts, the map in its present form would have been impossible to construct.

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* Druitt, C.E. and Conley, J.N., Geothermal Areas, Arizona Oil & Gas Conservation Commission, August 1977.

** Lepley, L.K., Landsat Lineament Map of Arizona, October 1977.

*** Swanberg, C.A., Morgan, Paul, Stoyer, C.H. and Witcher, J.C. Regions of High Geothermal Potential, An Appraisal Study of the Geothermal Resources of Arizona and Adjacent Areas in New Mexico and Utah and Their Value for Desalination and other Uses, July 1977.

**** Arizona Bureau of Mines, Outcrop of Quaternary Igneous rocks, from Map of Outcrops of Tertiary and Quaternary rocks in Arizona, 1962.

***** Arizona Bureau of Mines, Correlation of Cinder Cones, from Geologic Map of Arizona, 1969.

****** Damon, P.E., Shafiqullah, M., and Lynch, D.J., Ages of volcanic fields determined by K-Ar dating at Laboratory of Isotope Geochemistry with support from NSF Grant EAR 76-02590, U.S.G.S. Grant 14-18-0001-G-170 and the State of Arizona, January 1978.

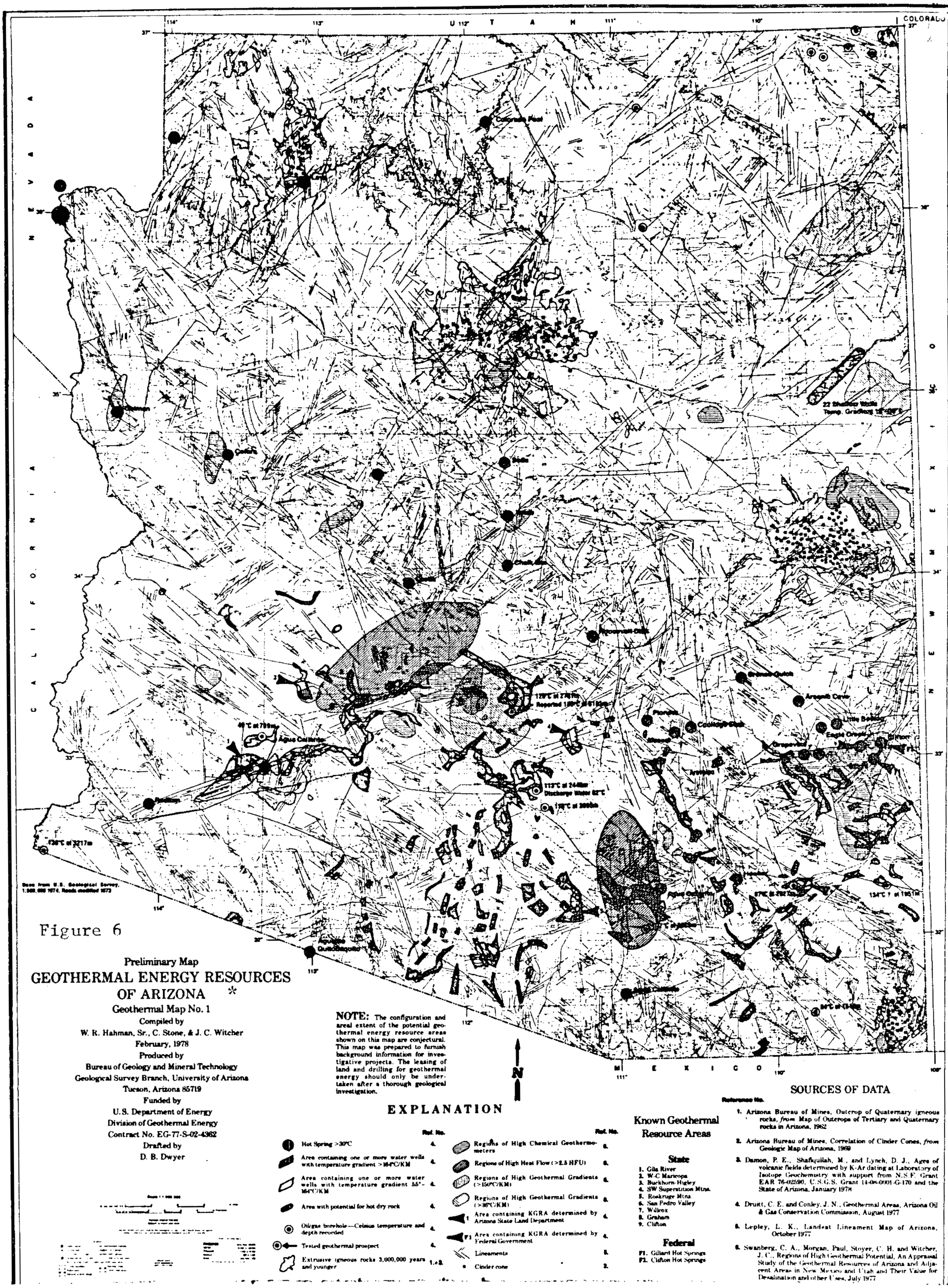

Figure 6

(*) Reduced copy. For large colored map refer to Bureau of Geology and Mineral Technology. Geological Survey Branch, University of Arizona.

i) Discussion

The following interpretative comments are preliminary in nature and should be treated as such.

The areas of favorable geothermal energy potential shown on the map appear concentrated in the southern half of the state. This concentration is apparent because of the greater population density and mineral exploration activity which has generated considerable knowledge of the Basin and Range physiographic province.

Dr. Chandler Swanberg et al., in NMEI number 6, Figure 9, has computed the mean of observed temperatures for wells and springs from both the Colorado Plateau and the Basin and Range physiographic provinces of southwestern United States. The mean temperature for the Colorado Plateau is 16.1°C and for the Basin and Range 26.2°C. Therefore, any well or spring in the Colorado Plateau of Arizona having a temperature in excess of 20°C would be considered anomalous. In the Basin and Range of Arizona any well or spring having a temperature in excess of 30°C would be considered anomalous.

Lepley's lineament study presents some interesting conjectures when analyzed with the other data on the map. It does appear that the northeast (N 40° - 60°C) striking lineaments have a significant relationship with areas of high geothermal energy potential. Field observations in the volcanic field immediately west of Springerville, Arizona tend to support the importance of this northeast direction. Cinder cones appear to be alligned along relict fissure vents striking N 40° - 45° E.

Another apparently important lineament direction is N 40° - 45° W. Favorable geothermal energy areas seem to occur in the vicinity of the intersections of the northeast and northwest lineaments. While this association could well be fortuitous, the geothermal anomalies could well result from more favorable ground preparation of the basement complex. These intersections could have numerous, deeply penetrating fractures extending considerable distances into the earth's crust. The ground water in the intermontane basins could circulate to great depths along these fractures, become heated and rise along these fractures. This action would cause a turnover of the water in the aquifers creating a convection cell or cells similar to the Tucson basin cell.*

ii) Conclusion

This map is the initial attempt to present the knowledge to date on the geothermal energy potential of the State of Arizona.

Thermal gradients calculated from single temperatures in shallow wells have the highest chances for error and may not extend to depth. However, these calculations do point out where the shallow-depth hot water is located.

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* J.C. Witcher, Personal Communication (1978).

Water geochemical geothermometers are reasonably accurate at designating the minimum range of the geothermal reservoir temperatures. The reason it is the minimum temperature is that mixing of non-thermal water with thermal water often occurs prior to the water reaching the sample site.

Measured thermal gradients should be considered the most accurate. Temperature measurements, using a very accurate thermistor probe, are generally taken every five meters from the surface down. Approximately eight readings, over an extended time period, are taken at one downhole station if it is in air. Only one reading is necessary per downhole station if there is fluid in the hole.

It should be noted that the configuration and areal extent of the potential geothermal energy resource areas shown on this map are conjectural. This map was prepared to furnish background information for investigative projects. The leasing of land and drilling for geothermal energy should only be undertaken after a thorough geological investigation.

5. Geothermal Energy Available for Development

For the purpose of this study, Arizona has been divided into 12 geothermally favorable areas. These twelve areas, with rather nebulous boundaries, are as follows: San Bernardino Valley area, Clifton-Morenci-Safford area, Kingman area, Yuma area, Hyder Valley area, Tucson area, Springerville area, Flagstaff area, Willcox area, Palo Verde area, Pinacate volcanic field area and the Phoenix area.

In order to commence this exercise certain assumptions must be made, the major assumptions being that there is geothermal energy available for development and that the conditions for development are favorable. Preliminary investigations indicate favorable geothermal potential in all the above areas; however, there are no proven reservoirs or reserves. Therefore, all energy estimates given in Table 3 are merely best guesses in light of present information and will be subject to change as more data/information becomes available.

The estimated energy in the twelve areas as given in Table 3 has been constructed from a proven, probable and inferred standpoint assuming present technology and with some hot dry rock development. Advancement in exploration, development and generating (energy conversion) technology will of course greatly increase the megawatts of electricity on line.

6. Assessment of Geothermal Resources in Arizona

An assessment of the geothermal resources in Arizona, ranked by temperature (Tables 4,5 and 6) was prepared by Dr. Chandler A. Swanberg of the Department of Earth Sciences, New Mexico State University, Las Cruces. A similar assessment ranked by geographic location (Table 7) was prepared by the Geothermal Group of the Arizona Bureau of Geology and Mineral Technology.

TABLE 3

ESTIMATED GEOTHERMAL ENERGY AT VARIOUS AREAS IN ARIZONA

Electric Power Generation

Area		Proven	Probable	Inferred
1.	San Bernardino Valley	0 MW	50 MW	500 MW
2.	Clifton-Morenci-Safford	0 MW	50 MW	500 MW
3.	Springerville	0 MW	100 MW	500 MW
4.	Flagstaff	0 MW	100 MW	1000 MW
5.	Kingman	0 MW	25 MW	100 MW
6.	Yuma	0 MW	50 MW	50 MW
7.	Hyder Valley	0 MW	50 MW	500 MW
8.	Tucson	0 MW	10 MW	50 MW
9.	Phoenix	0 MW	50 MW	500 MW
10.	Willcox	0 MW	25 MW	100 MW
11.	Palo Verde	0 MW	25 MW	100 MW
12.	Pinacate Volcanic Field	0 MW	100 MW	500 MW
	TOTAL	0 MW	635 MW	4450 MW

Non-electric power-space heating, cooling, agriculture is estimated at 1.5 times total electric power generation for the state.

Non-Electric Power

	Proven	Probable	Inferred
Total electric power x 1.5	0 MW 0 MW	635 MW 952.5 MW	4450 MW 6675 MW
Grand Total	0 MW	1587.5 MW	11,125 MW

TABLE 4

HIGH TEMPERATURE GEOTHERMAL RESOURCES (>150°C)

NAME	LAT.	LONG.	MEASURED SUBSURFACE TEMPERATURE (°C)
Confirmed			
Chandler	33 17.1	111 41.2	184
Prospects			ESTIMATED SUBSURFACE TEMPERATURE (°C)
Clifton H.S.	33 4.2	109 17.9	160
Verde H.S.	34 21.5	111 42.5	150

Potential for Discovery - Areas having groundwaters whose chemical geotemperatures exceed 150°C

San Bernardino Basalt Area	31.4	109.4
Springerville	34.1	109.3
St. Johns	34.4	109.4
Joseph City	34.8	110.4
Flagstaff	35.1	111.9
Oatman	35.0	114.4
Weaver Park	34.4	112.9
Rancoras Plain	33.5	113.7
Rainbow Valley	33.2	112.5
Phoenix	33.4	112.0
San Simon*	32.2	109.3
Yuma*	32.5	114.8

Potential for Discovery - Areas having shallow boreholes whose temperature gradients exceed 150°C/km

Number of Prospects	Aggregate Area
73	2200 km^2

Potential for Discovery - Quaternary Volcanics

Number of Prospects	Aggregate Area
50	11,100 km^2 (C.P. = 9800 km^2, B&R = 1300 km^2)

* Measured temperature 130 - 140°C. See also intermediate temperature geothermal resources confirmed.

TABLE 5

INTERMEDIATE TEMPERATURE GEOTHERMAL RESOURCES (90-150°C)

NAME/AREA	LAT.	LONG	MEASURED* SUBSURFACE TEMPERATURE (°C)
Confirmed			
San Simon	32.2	109.3	134
Yuma	32.5	114.8	138
Prospects			ESTIMATED SUBSURFACE TEMPERATURE (°C)
Gillard H.S.	32 58.4	109 20.9	140
Eagle Creek H.S.	32 2.9	109 26.4	130
Coolidge H.S.	33 10.3	110 31.7	120
Coffers H.S.	34 41.6	113 34.5	120
Cat Tank	32 43.8	109 22.7	115
Javelina Peak	32 31.4	109 25.6	110
Safford Area	32 50.7	109 33.6	110
Indian H.S.	33 0.2	109 54.0	105
Castle H.S.	33 59.0	112 21.7	105

Potential for Discovery - Areas having shallow boreholes whose temperature gradients fall between 36 and 150°C/km

Number of Prospects	Aggregate Area	
-100	36-150°C/km	4900 km^2
	55-150°C/km	6000 km^2

Potential for Discovery - Cenozoic Volcanics

Nearly 20% of the total land surface area of Arizona is covered by Cenozoic volcanic rocks and therefore should be considered as potential areas for geothermal discoveries.

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* Numerous other wells in Arizona have reported gradients in the 90-150°C/km range but have been omitted from this table because the inferred temperature gradient is not sufficiently above normal to constitute a geothermal anomaly. See low temperature resources confirmed.

TABLE 6

LOW TEMPERATURE GEOTHERMAL RESOURCES (20-90°C)

NAME/AREA	LAT.	LONG.	MEASURED TEMPERATURE °C
Confirmed			
Littleton	32.1	110.9	147 * @ 3830m
Casa Grande (North)	32.9	111.5	113 * @ 2440m
Casa Grande (South)	32.8	111.5	110 * @ 3095m
Willcox	32.3	109.9	87 * @ 2027m
Whitewater	31.5	109.8	64 * @ 1510m
Coolidge Area	32 54.2	111 34.0	61
Radium SP.	32 44.4	114 4.2	>50
Hooker's H.S.	32 20.2	110 14.3	53
Buckhorn Area	33 25	111 42.2	49
Hyder Valley	33.1	113.3	49 * @ 789m
Agua Caliente	32 59.6	113 18.3	46
Artesia H.W.	32 43.1	109 42.5	44
Mt. Graham	32 51.8	109 44.9	44
Lucats Spa	32 44.7	109 44.7	42
Palomas Mts.	33 0.0	113 30.5	42
Branon Mtn.	33 6.7	113 24.5	39
Theba	32 55.9	112 45.1	38
Bowie	32 19.1	109 29.0	36
Mobil Area	33 12.2	112 21.9	35
Artesia Area	32 41.0	109 42.3	33
Warm Sp.	33 4.3	109 59.0	42
Hoover Dam Sp.	36.0	114.8	~40
Cottonwood Sp.	36.5	114.0	warm
Lava Sp.	36.2	113.1	warm
Colorado Pool	36.5	111.9	warm
Prescott Sp.	34.6	112.6	warm
Soda Sp.	34.7	111.7	warm
Chalk Mtn. Sp.	34.1	111.7	warm
Roosevelt Dam Sp.	33.6	111.2	warm
Bronco Culch Sp.	33.4	110.2	warm
Mescal Sp.	33.2	110.6	warm
Pioneer Sp.	33.2	110.8	warm
Arsenic Cave Sp.	33.3	109.8	warm
Little Boiling Sp.	33.2	109.6	warm
Graperine Sp.	33.0	109.8	warm
Agua Caliente	32.3	110.7	warm
Agua Caliente	31.8	111.0	warm

Prospects - Water Temperatures in excess of 20°C

In Arizona the entire Basin and Range province which includes roughly ½ the total land surface of the state should be considered to be a low temperature geothermal prospect. The mean water temperature of the Basin and Range is 26°C.

TABLE 6 CONT

Potential for Discovery

The entire Basin and Range province and roughly 1/3 of the Colorado Plateau in Arizona (~60-70% of the entire state) have some type of evidence suggesting the presence of low temperature geothermal resources.

* High temperatures reflect the depth of the well. The inferred temperature gradient is not sufficiently above normal to constitute a geothermal anomaly.

TABLE 7 INFORMATION ON GEOTHERMAL LOCATIONS IN THE STATE OF ARIZONA*

No.	Location	Type of Ownership	Type of Geot. Energy	Depth (km)	Tempt. Range (°C)	Subsidence w/reinjection	Salinity of Source (PPM)	Heat Resv. (Quads)	Envtal Impact	Radius of location (miles)
1	Kingman	Federal & State	HDTF & HDR	2	HDTF: 50° HDR: 200°	Almost	3500	5	Significant	10
2	Flagstaff	Federal State & Indian	HDTF & HDR	1	HDTF: 60° HDR: 210°	Almost none	3000	20	"	20
3	Springer-ville (St Johns)	Federal & State	HDTF & HDR	1	HDTF: 55° HDR: 210°	Almost none	2500	10	Slightly Significant	15
4	Clifton-Morenci-Safford	Federal State & Indian	HDTF & HDR	1	HDTF: 110° HDR: 205°	Possible in Safford	4000	11	Significant	15
5	Willcox	Federal & State	HDTF	0.81	HDTF: 50-80° HDR: 150-200°	Possible	3000	5	"	10
6	Tucson	Federal State & Indian	HDTF	0.5-2	HDTF: 60-90°	Slightly Possible	2000	11	"	15
7	Phoenix	Federal & State	HDTF	0.5-2	HDTF: 80-120°	Slightly Possible	2000	20	"	20
8	Palo Verde	Federal & State	HDTF & HDR	0.5-2	HDTF: 54° HDR: 205°	Almost none	1000	2	"	5
9	Hyder Valley	Federal & State	HDTF & HDR	0.5-2	HDTF: 55° HDR: 209°	Possible	2500	20	"	15
10	Yuma	Federal State & Indian	HDTF	1.2	HDTF: 150-180°	Possible	3500	2	Slightly Significant	5
11	San Bernardino	Federal & State	HDTF & HDR	0.5-1	HDTF: 150-200° HDR: 205°	Possible in some areas	2500	2	"	5
12	Pinacate	Federal & State	HDTF & HDR	0.5-1	HDTF: 150-180° HDR: 200°	Possible in some areas	2500	2	"	5

* Most of the figures given in this table are approximate
HDTF: Hydrothermal fluid, HDR: Hot Dry Rock

For Tables 4-6, Swanberg states that the geothermal resources of Arizona have been "divided into high temperature (>150°C) (Table 4), intermediate temperature (90 - 150°C) (Table 5), and low temperature (20 - 90°C) (Table 6), with further modifications to determine the reliability of the assessment. The "confirmed" category includes only those geothermal areas whose subsurface temperatures have been verified by drilling. The "prospect" category includes those areas which have thermal waters (hot springs and wells) whose chemical constituents suggest a much higher subsurface temperature than can be measured at the surface. The "potential for discovery" category includes those areas which appear promising on the basis of various geological, geophysical, geochemical criteria but for which little or no detailed information is currently available. In preparing the following tables, we have utilized all geothermal data currently available although we have relied heavily upon the geothermal compilation works of Swanberg at al. * and Hahman et al. **.

Table 7 presents the resource assessment on the basis of the 12 most favorable locations in Arizona. The table includes land ownership, type of resource, environmental considerations, estimated heat reserve and other pertinent data. Fig. 7 is a map of Arizona showing counties and the locations of each of the 12 areas. The heat reserves in Table 7 were calculated as follows:

In order to estimate the heat energy in a geothermal reservoir in Quads; we will use the following equation,

$$H = \frac{\pi \cdot D^2 \cdot d \cdot Cp \cdot \Delta T \cdot \rho}{4} \times \frac{(5280)^3}{10^{15}} \qquad \text{(i)}$$

where:

π = 3.1416
H = potential amount of heat energy in reservoir (in Quads)
D = diameter of geothermal resource area (in miles)
d = depth (in miles)
Cp = specific heat of rock
ΔT = temperature drop by source
ρ = density of rock (in lb/ft^3)

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* Swanberg, C.A., Morgan, Paul, Stoyer, C.H., and Witcher, J.C., Regions of High Geothermal Potential, An Appraisal Study of the Geothermal Resources of Arizona and Adjacent Areas in New Mexico and Utah and their value for Desalination and other Uses, NMEI Report No. 6, July, 1977

** Hahman, Sr., W.R., Stone, C. and Witcher, J.C. 1978, Preliminary Map - Geothermal Energy Resources of Arizona, Bureau of Geology and Mineral Technology, Tucson, Arizona

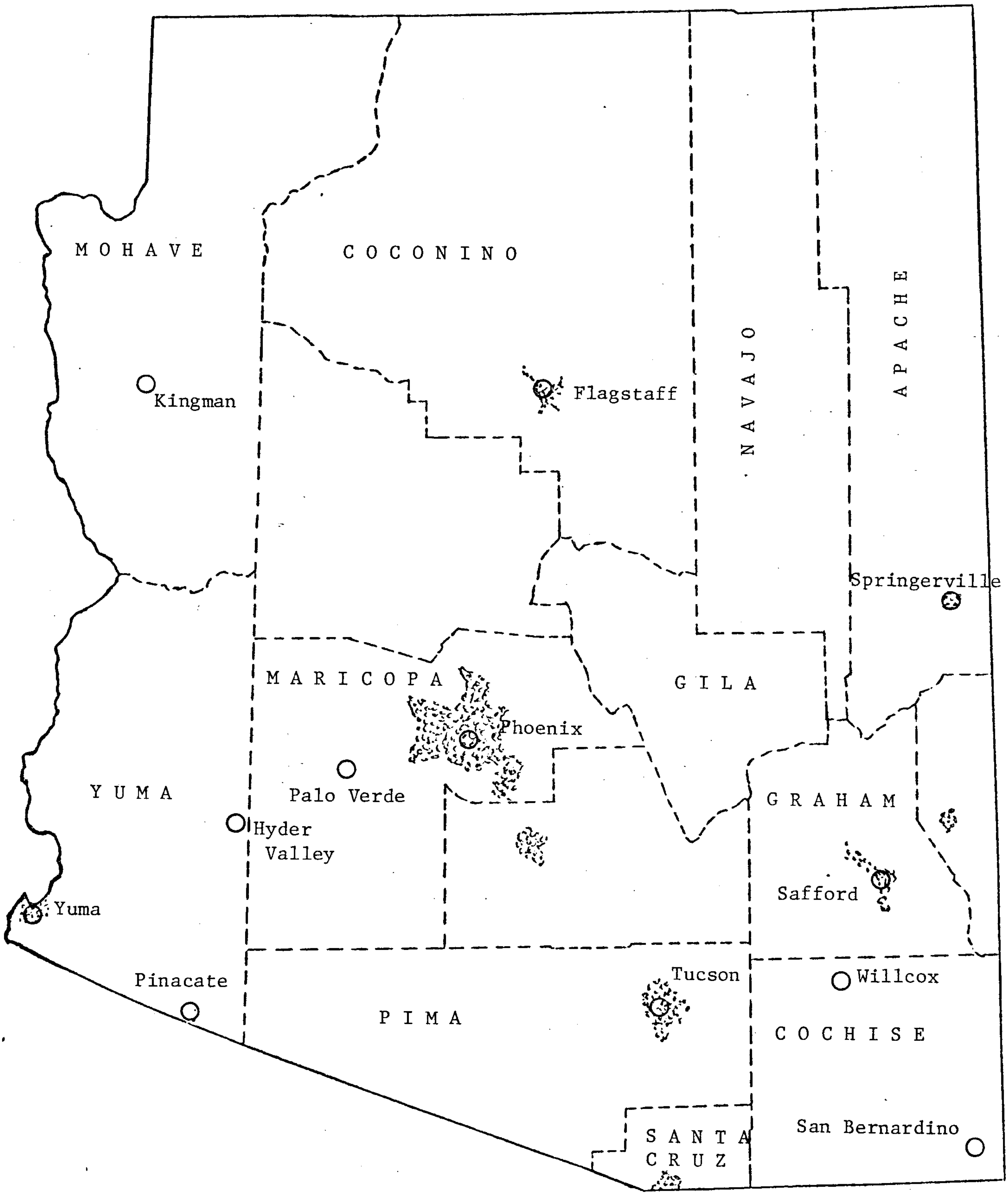


FIGURE 7: LOCATION MAP FOR AREAS OF ARIZONA REFERRED TO IN THIS REPORT

Conversion factors,
5280 = conversion factor from miles to feet
10^{15} = conversion factors from BTU to Quads

To illustrate how this equation is used; let us calculate an estimate for the heat energy in the Kingman area.

Assume that:

D = 20 miles
d = 0.25 miles
Cp= 0.2 BTU/lb ^{o}F
$\Delta T = 10^{o}F$
$\rho = 200\ lb/ft^3$

$$H \text{ (in Quads)} = \frac{\pi(20)^2\ (0.25)\ (0.2)\ (10)\ (200)\ (5280)^3}{(4)\ (10^{15})}$$

$$H = 4.62 \text{ Quads} \simeq 5 \text{ Quads}$$

Thus the heat energy in the geothermal resource reservoir was estimated using equation (i). All the amounts of heat energy for the twelve areas in Table 10 were estimated in the same way.

7. Geothermal Leasing and Drilling Activity in Arizona

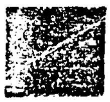
i. Leasing

Leasing activity has increased significantly on both state and federal lands in Arizona during the past year (see Figures 8-14). Several lease applications and two Notices of Intent to Conduct Geothermal Resource Exploration Operations have been filed at various Bureau of Land Management (BLM) Arizona district offices. On the state level one lease renewal and one new lease application were filed with the State Land Department.

Reed Nix of Nix Drilling Company, Globe, Arizona, obtained a lease on state land T5S R24E S16 in November, 1972, to drill a geothermal test hole. Drilling commenced April 23, 1974, and continues to the present. In November, 1977, Nix applied for a two year lease extension, but the extension was not granted by the State Land Department. Four individuals jointly applied for a geothermal lease on state land on the Hassayampa Plain, T5N R6W S36 and T4N R6W S2, in March, 1978. Upon receipt of such applications the State Land Department must advertise for competitive bidding for ten weeks. Lease issuance is currently pending action by the BLM, which is conducting an environmental study of surrounding federal land.

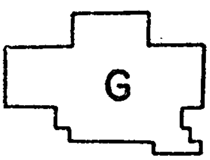
The BLM Safford District Office reported on seven older noncompetitive geothermal lease applications on federal lands in the Clifton area, within townships T4-6S R28-30E. Dates and applicants are unknown; however, four of the leases were granted to Phillips Petroleum Company, Del Mar, California,

LEGEND FOR THE FOLLOWING FIGURES (8 - 14)



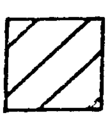
Federal Geothermal Resources Lease Application

Federal Notice of Intent to Conduct Geothermal Rescurces Exploration Operations



Gillard Hot Springs; Federal Known Geothermal Resource Area (K G R A)

Clifton Hot Springs; Federal Known Geothermal Resource Area (K G R A)



State of Arizona Designated Known Geothermal Resource Area (K G R A)

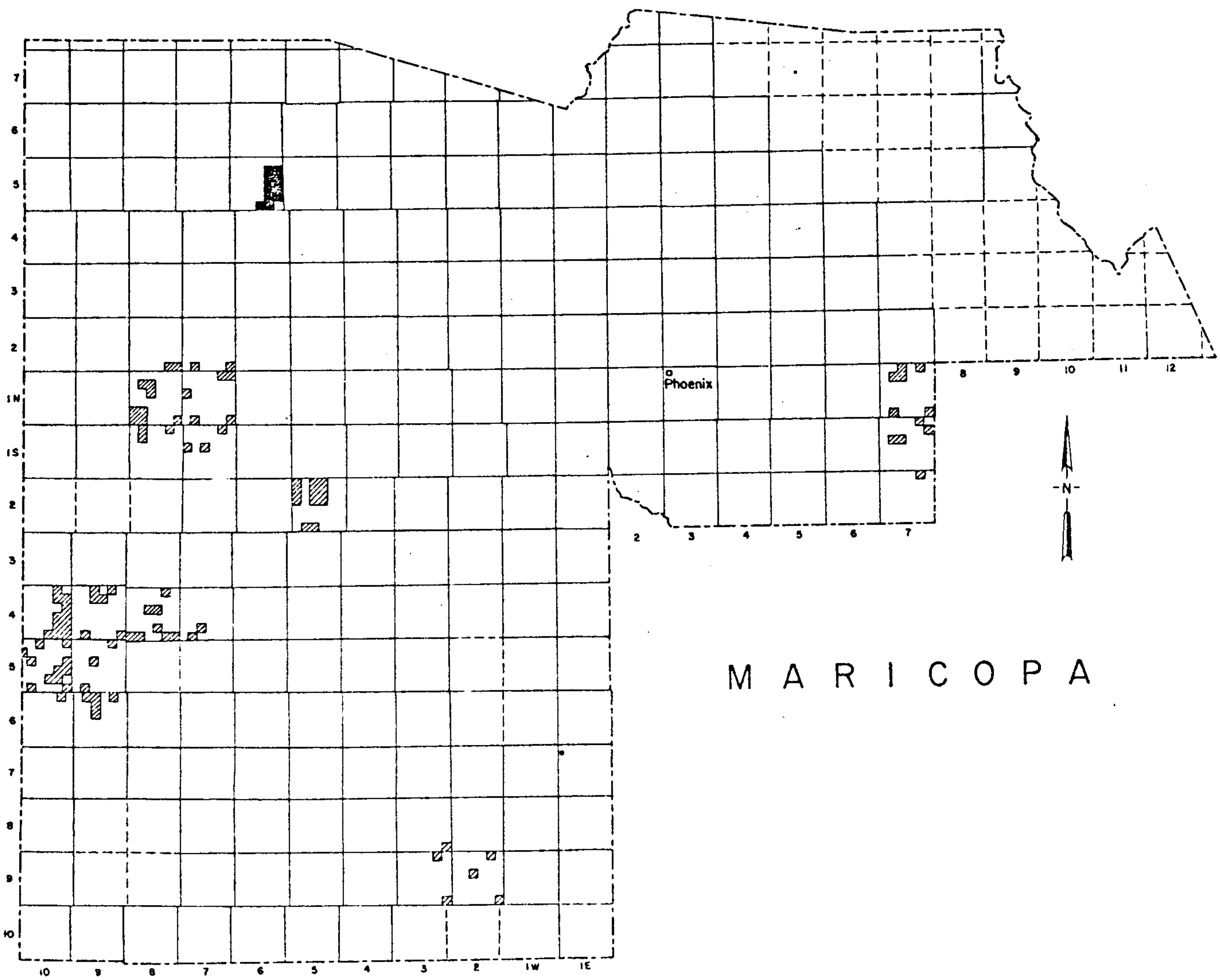


FIGURE 8: GEOTHERMAL LAND STATUS OF MARICOPA COUNTY, ARIZONA, AS OF APRIL 1978. SEE LEGEND.

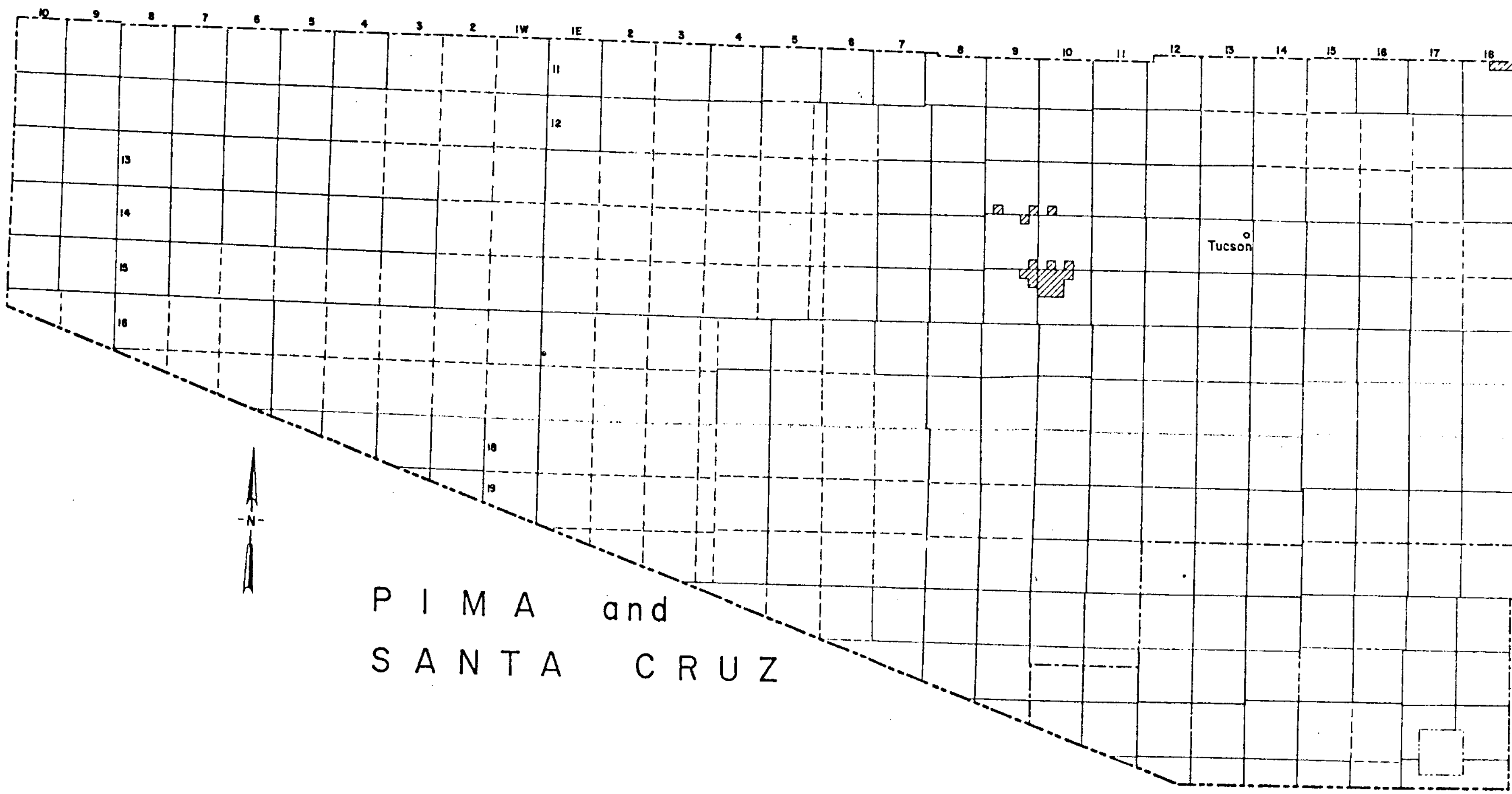


FIGURE 9: GEOTHERMAL LAND STATUS OF PIMA AND SANTA CRUZ COUNTIES, ARIZONA, AS OF APRIL, 1978. SEE LEGEND.

GRAHAM and GREENLEE

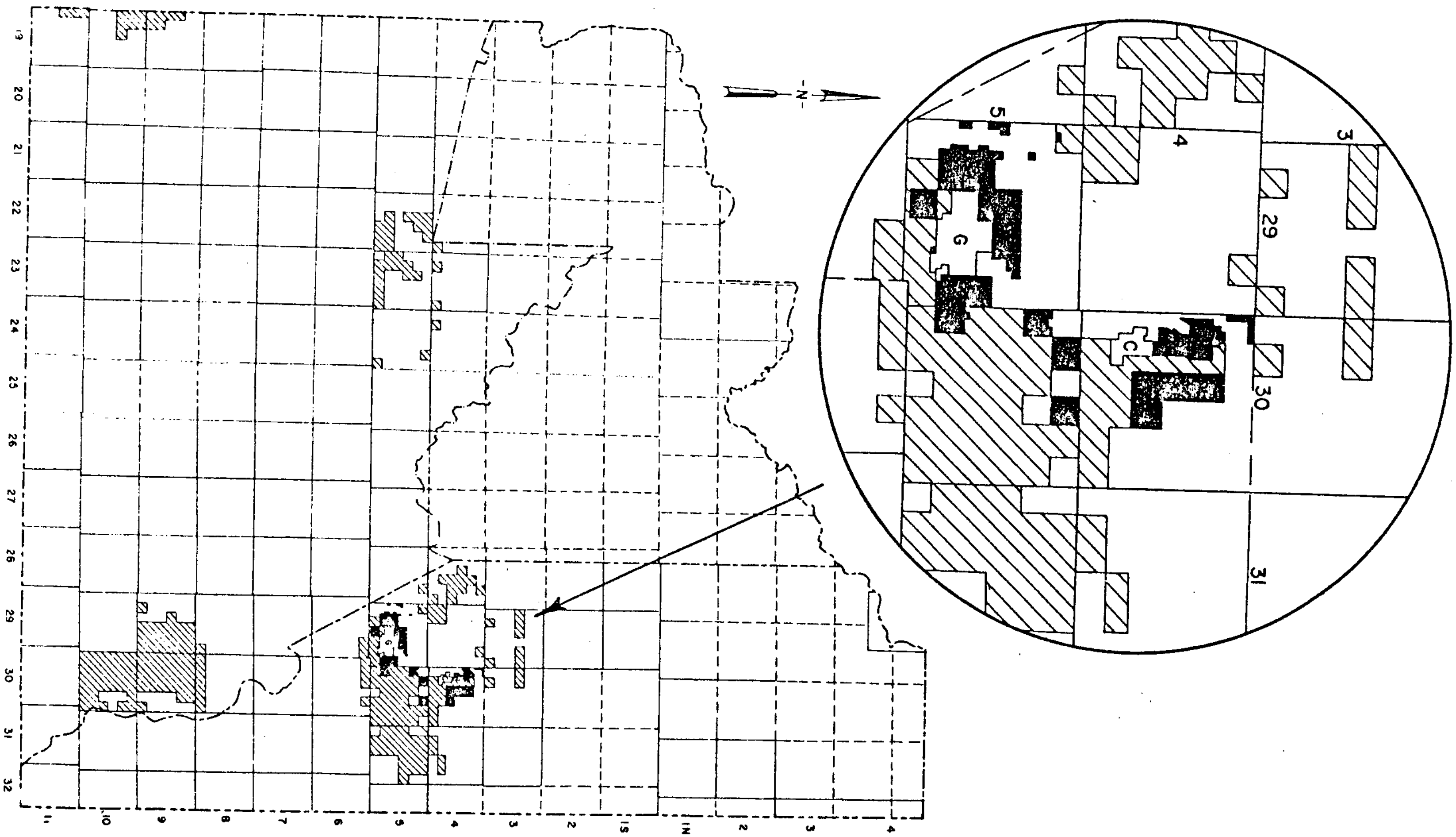


FIGURE 10: GEOTHERMAL LAND STATUS OF GRAHAM AND GREENLEE COUNTIES, ARIZONA, AS OF APRIL, 1978. SEE LEGEND

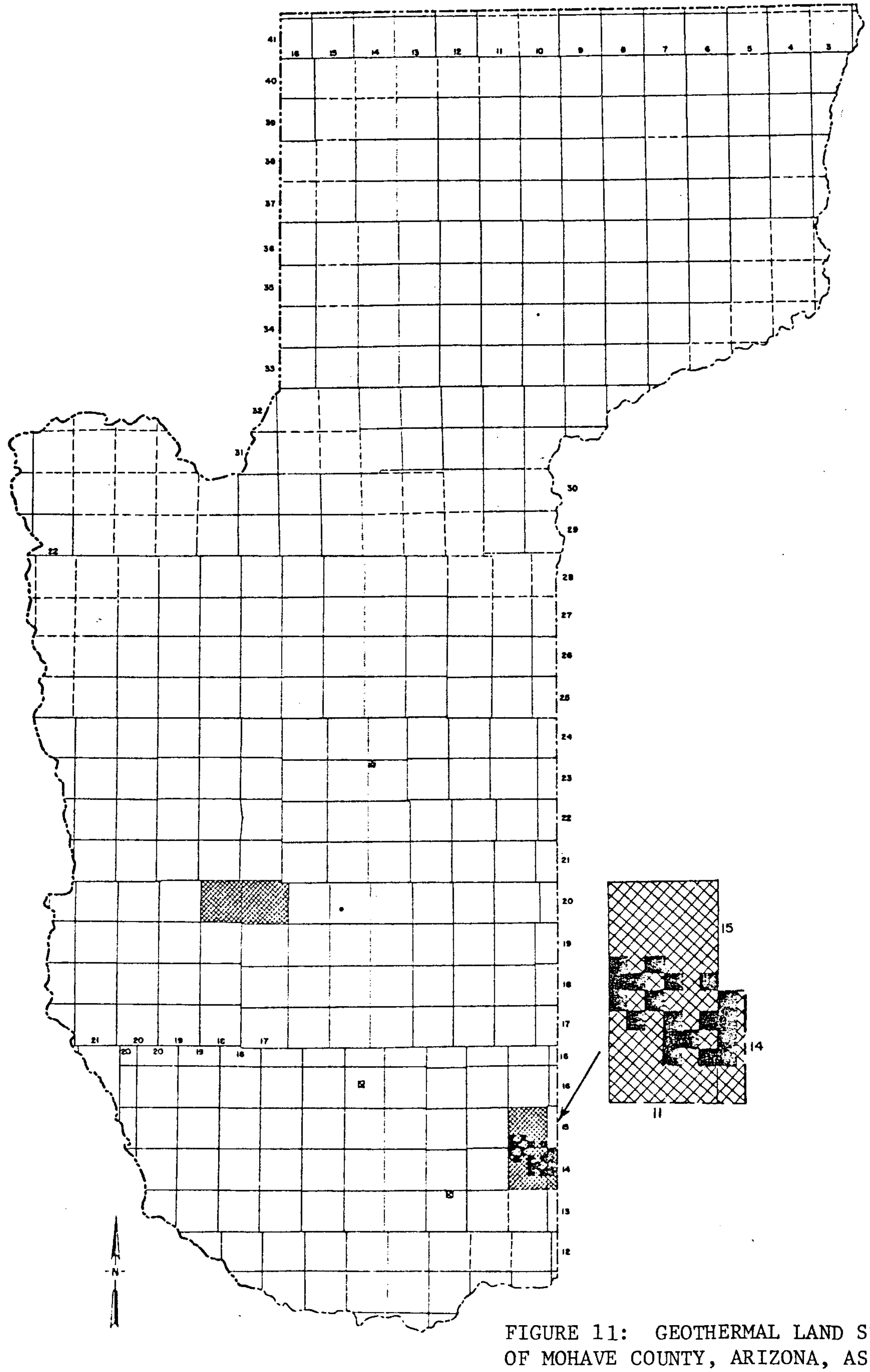


FIGURE 11: GEOTHERMAL LAND STATUS OF MOHAVE COUNTY, ARIZONA, AS OF APRIL, 1978. SEE LEGEND.

M O H A V E

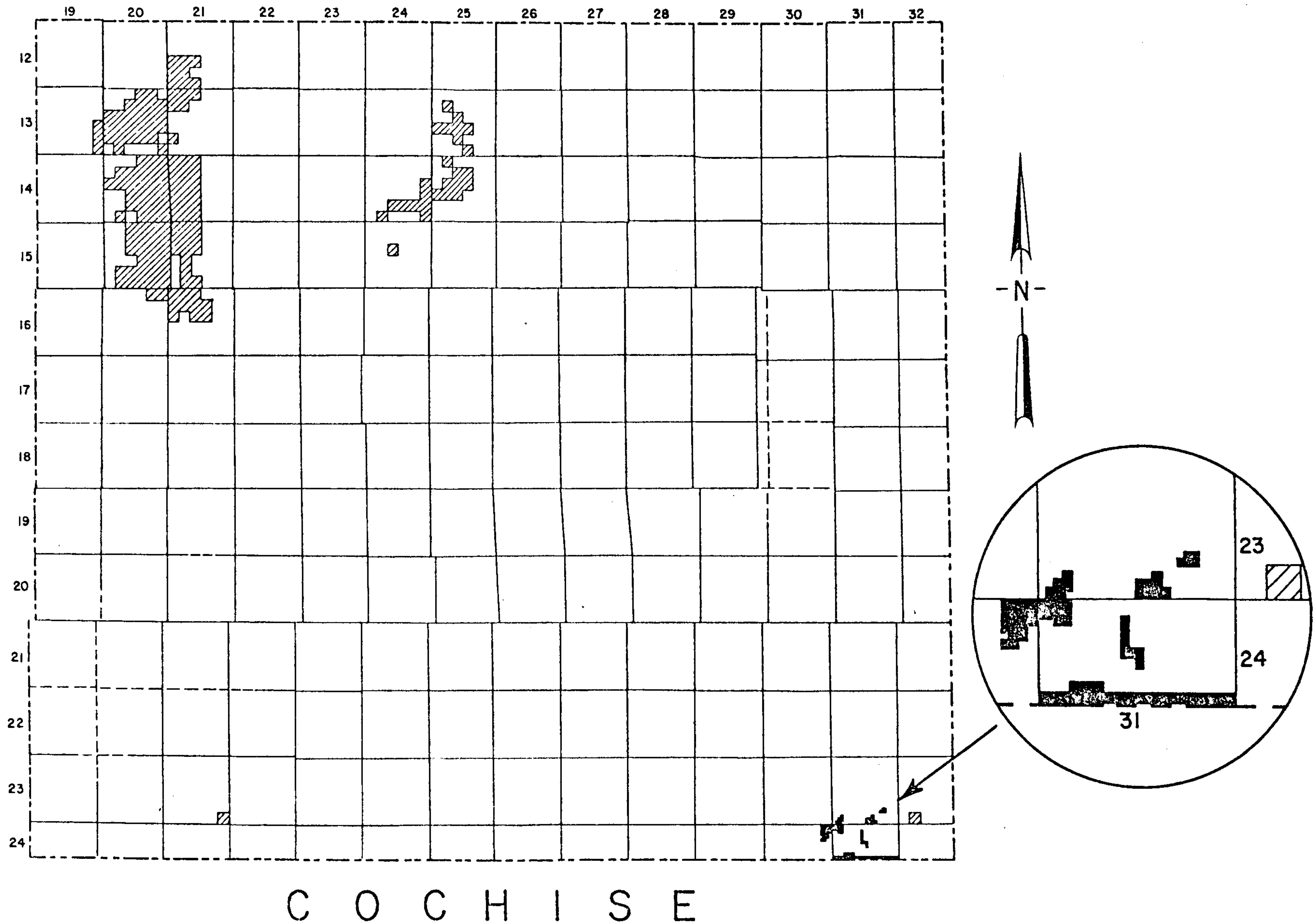
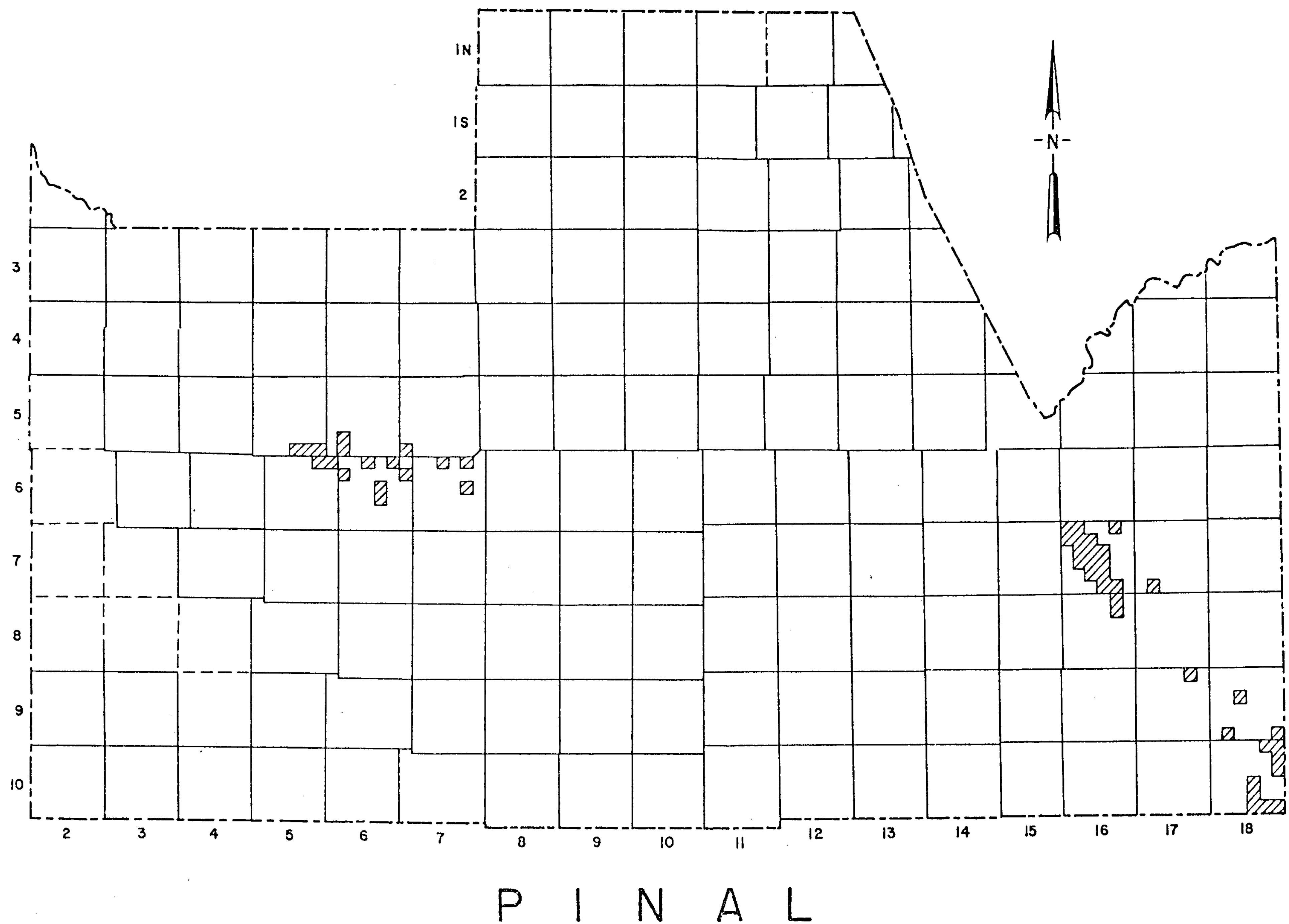


FIGURE 12: GEOTHERMAL LAND STATUS OF COCHISE COUNTY, ARIZONA AS OF APRIL 1978. SEE LEGEND.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P I N A L

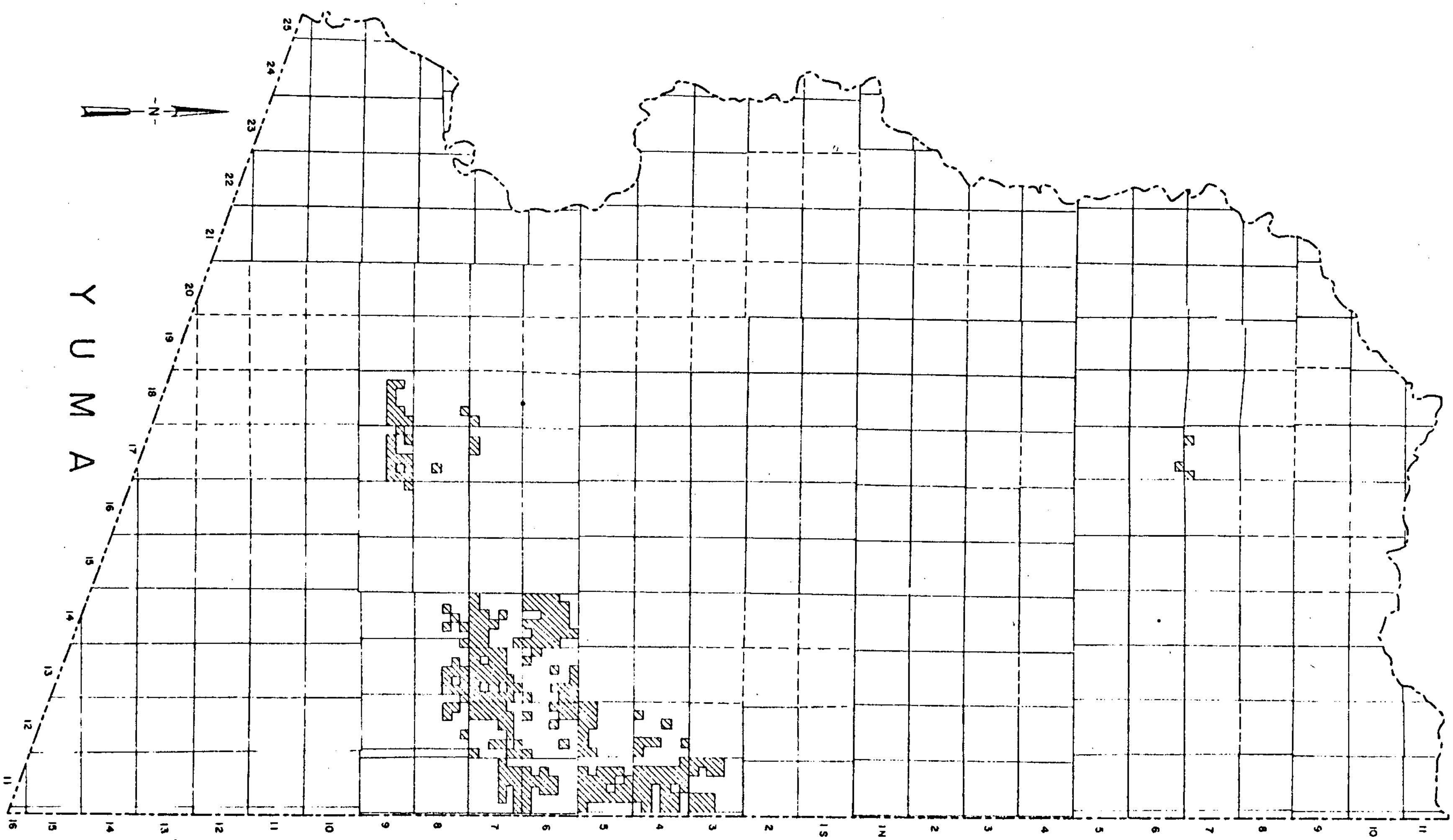


FIGURE 14: GEOTHERMAL STATUS OF YUMA COUNTY, ARIZONA AS OF APRIL, 1978. SEE LEGEND

on July 1, 1975. All of the applications may have been filed by Phillips as all sections are in proximity.

Geothermal leasing of federal land during the past year has been even more active than in former years. The BLM Kingman Resource Area Office reported receiving two Notices of Intent, one from the U.S. Geological Survey, Menlo Park, California, to drill five shallow (400 ft) heat flow holes in the Kingman district (see drilling section, below) and a second from Cyprus Georesearch of Los Angeles, California, to conduct three geophysical surveys in each of two areas: T20N R17-18W near Kingman and T15N R11W and T14N R10-11W south of Wickieup. The Kingman BLM office also received a geothermal lease application from a Utah lease broker for 20 sections south of Wickieup in townships T14-15N R10-11W. The lease applications are pending completion of an environmental assessment of the area.

On other federal lands, geothermal lease applications were filed in September and October, 1977 by Chevron U.S.A. Inc., Denver, Colorado for land near the San Francisco Peaks. Chevron applied for 56,091.6 acres within the township T21-25N R7-9E, but in December 1977, they withdrew applications on 8,558.77 of those acres. The status of these applications is currently unknown but probably is pending an environmental assessment.

Southland Royalty Company, Fort Worth, Texas applied for geothermal leases on 2,899.23 acres of federal land in San Bernardino Valley within the townships T23S R31E and T24S R30-31E. The applications were filed in December, 1977 and action is pending an environmental assessment of the area by the BLM Safford District Office.

On January 1, 1977 the BLM Phoenix District Office granted a geothermal lease to Gary and Frances Smith for federal land on the Hassayampa Plain, specifically T5N R6W S25. This section is continguous to land under application from the State Land Department by four individuals mentioned above, two of whom are also Gary and Frances Smith.

ii. Drilling Activity

Three deep geothermal test wells have been drilled in the state to date, with limited success. Two of these wells were drilled in 1973 by Geothermal Kinetics Systems, Phoenix, Arizona near Chandler. The well locations are T2S R6E S1 NE SE and T2S R6E S1 SE NE. Amax Exploration, Inc., Denver, Colorado, drilled the third well near Eloy, T7S R8E S8 SE SW, in 1974. The fourth geothermal test well is that mentioned above, being drilled by the Nix Drilling Company.

In March, 1978, the U.S. Geological Survey, as mentioned above, began drilling five shallow (400 ft) heat flow holes in the Kingman area. It is the intention of the U.S.G.S. to drill a total of 50 shallow heat flow holes throughout southern Arizona during 1978, for geothermal exploration. It is also anticipated that the Bureau of Reclamation will fund a drilling program in the Springerville area for shallow (500 ft) heat flow holes during 1979 with additional and possibly deeper holes in the Clifton area.

8. Known Geothermal Resource Areas (KGRA's)

Figures 8-14 also illustrate areas of state and federal land classified as Known Geothermal Resource Areas (KGRA's) by either a state or federal agency. Both of the federal KGRA's, Clifton and Gillard, were automatically designated by federal regulation, on the basis of overlapping geothermal lease applications. All state KGRA's, on the other hand, were so classified at the discretion of the State Land Department.

Both the federal government and the State Land Department have the authority to classify land under their jurisdiction as a KGRA solely on the basis of its being "an area in which the geology, nearby discoveries, competitive interests, and other indicators would, in the opinion of the Department (or Secretary, DOI for federal land), engender a belief in the men who are experienced in the subject matter that the prospects for the extraction of geothermal resources are good enough to warrant expenditures of money for that purpose." This rather arbitrary discretion is seen as a potential problem by many working in the field of exploration and development of low- to moderate-temperature, direct utilization geothermal energy.

The problem of low-temperature geothermal energy and the KGRA process was addressed recently in a report to Dr. Donald Elmer, DOE/DGE, by Kaufman and Laughlin*. This report, along with the way the Department of the Interior is claiming public lands valuable for geothermal steam and amounted geothermal resources, is given in Appendix III. In brief, the report points out the problem of subjecting development of low-temperature, direct utilization geothermal energy resources to the same restrictive regulations governing the development of high temperature resources. The extended time frame and the excessive costs involved in bringing low-temperature geothermal on line create impediments to its development which can seldom be surmounted by the small communities and businesses most likely to use and to benefit from such alternate energy sources.

* Kaufman, E.L. and Laughlin, A.W., Report by Geological Research group G-6 Los Alamos Scientific Laboratory, Los Alamos, New Mexico

III. ARIZONA DATA BASE

A. DATA BASE AND PHYSICAL RESOURCES

Arizona is the sixth largest state in the nation, yet its population is only 2.35 million. Moreover, Phoenix and Tucson comprise 70% of the populace (Figure 15). Elevation ranges from about sea level (at Yuma) to over 12,000 feet near Flagstaff. Consequently, large areas of low population density are exploited by the agricultural and lumber industries, (Figs 16,19). Geothermal resources may be developed to augment existing power sources for these and other industries statewide. Water is necessary to support most of these industries; here Arizona's aridity poses serious problems. Fig 18 shows the depth to ground water in wells for various sedimentary basins statewide. While there is a water shortage, a project to augment existing supplies has begun. The Central Arizona Project will import Colorado River water to Phoenix via aqueducts (Fig.20) and even as far south as Tucson.

Land ownership is divided between Forest Service. BLM, private, public, Federal, State, Indian and military reservations (Fig. 21). Ownership is a paramount importance in the initial evaluation of a geothermal resource, in that some parties are dealt with more cooperatively than others, with respect to both time and investment capital. Private land is generally the most advisable land type on which to develop a geothermal resource. Percent ownership by type is given in Table 8.

Arizona is heavy in cattle feed lots and agriculture, importing cattle from Texas, Mexico, and Colorado and exporting the meat to California. That is a big business, being the 7th largest State in such activities.

Lastly, Arizona is blessed with many mineral deposits and large quantities of by-product sulfuric acid (Figs. 22, 23). Several geothermal use scenarios involving solution mining are being developed. It is too soon to say much about their potential until more technical facts are assembled and evaluated. However, it could turn out to be the most important non-electrical application of geothermal energy in Arizona.

B. ENERGY USE IN ARIZONA

Because of the low population of the state, Arizona's energy distribution is dissimilar to that of most other states. Natural gas lines cross the state and gasoline is pipelined from Los Angeles and El Paso (Fig. 24). Power production is scattered and many rural areas do not have power. The dependence upon remote markets for fossil fuels for transportation further emphasizes the lack of local sources of crude oil (Fig. 24). Arizona does have coal reserves and there are several large coal power plants including one served by coal slurry pipeline as shown in Fig. 24. Transportation as well as commerical and residential heating and cooling comprise the bulk of energy used in Arizona. As shown in Table 10, 37.2%

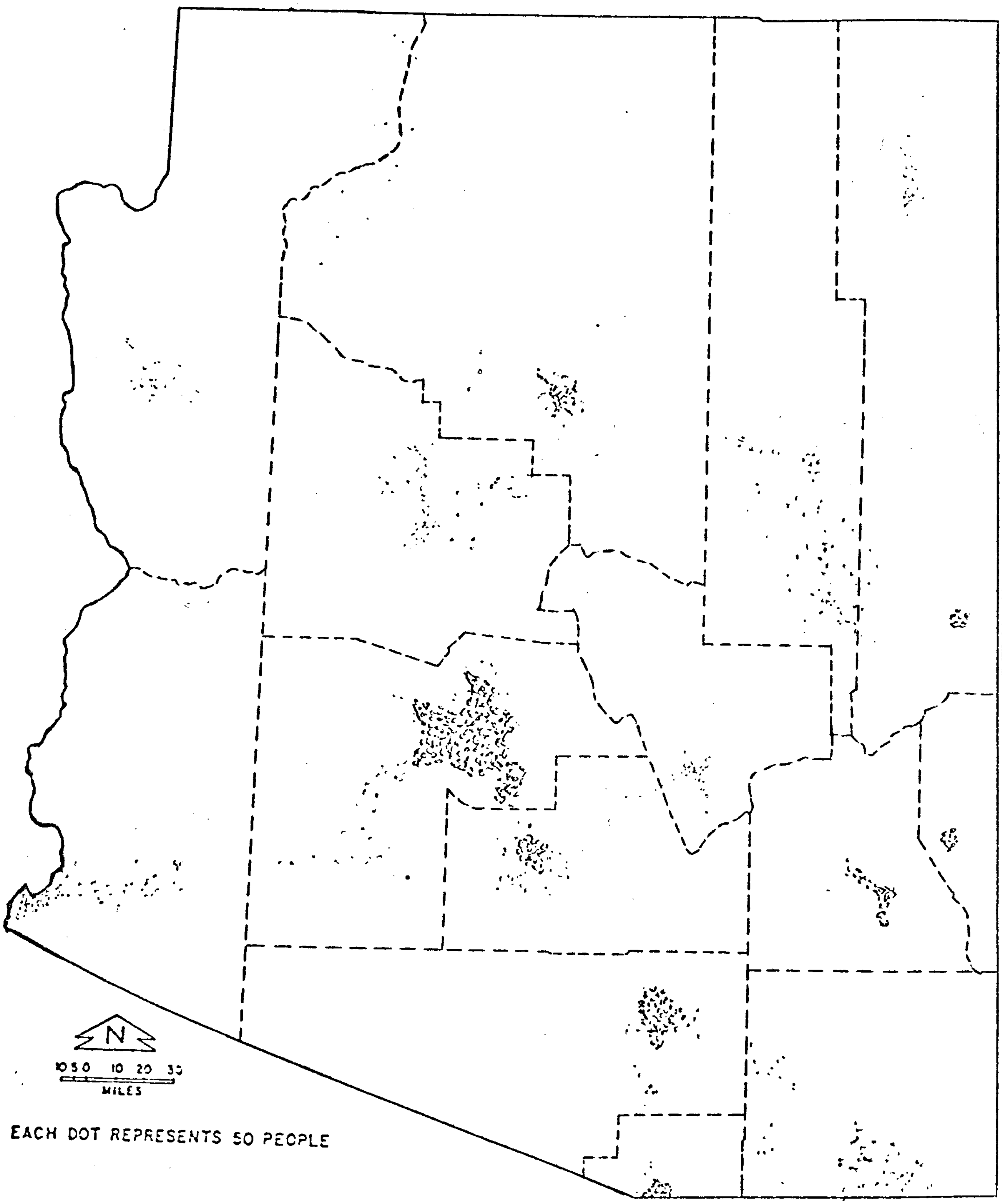
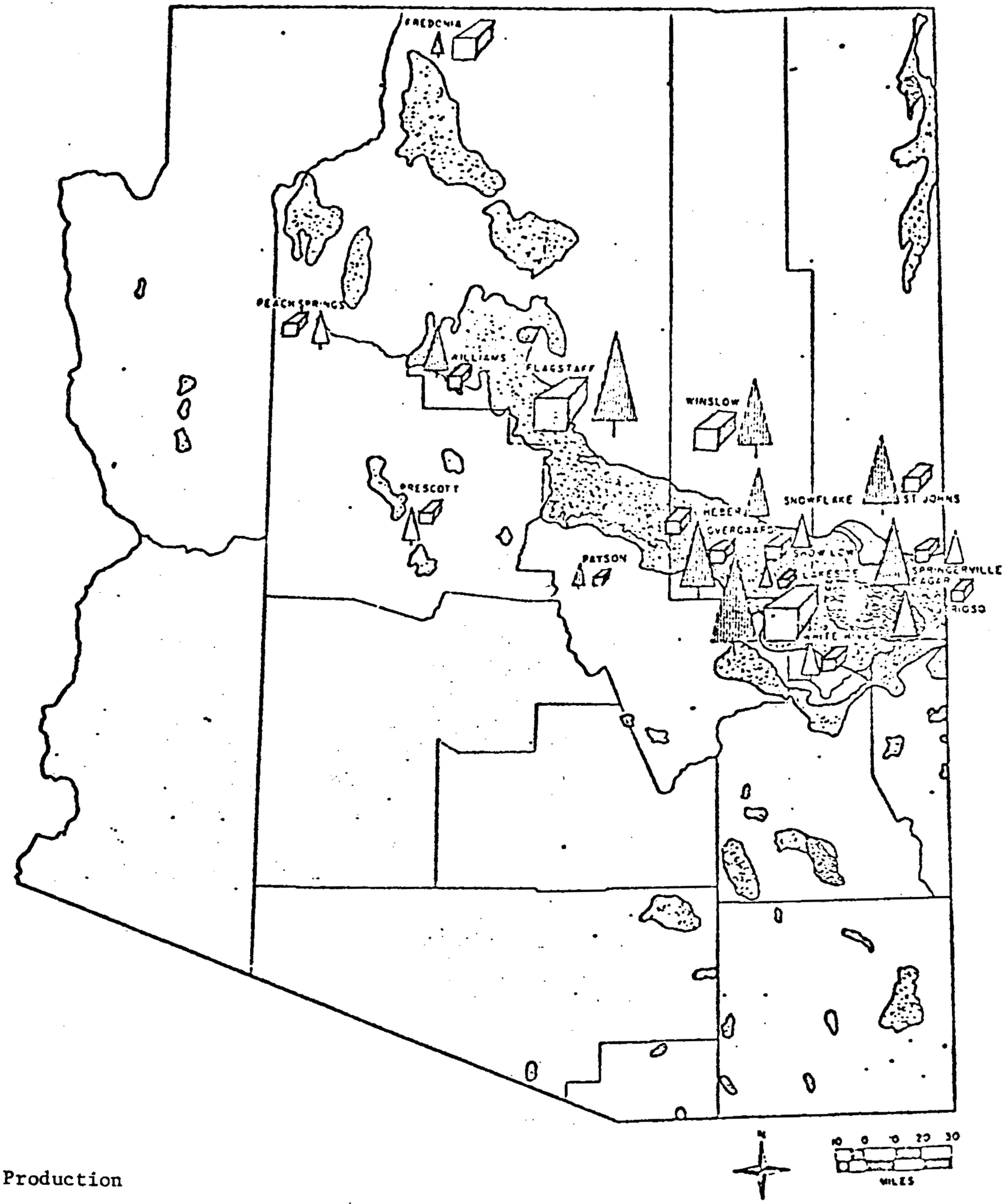


FIGURE 15: POPULATION DISTRIBUTION IN ARIZONA (*)
(*) 1970 Census



Logging Production

Over 420 M/Day

150-200 M/Day

50-80 M/Day

25-40 M/Day

Quantity unknown

Sawmill Production

Over 375 M/Day

200-210 M/Day

50-85 M/Day

30-40 M/Day

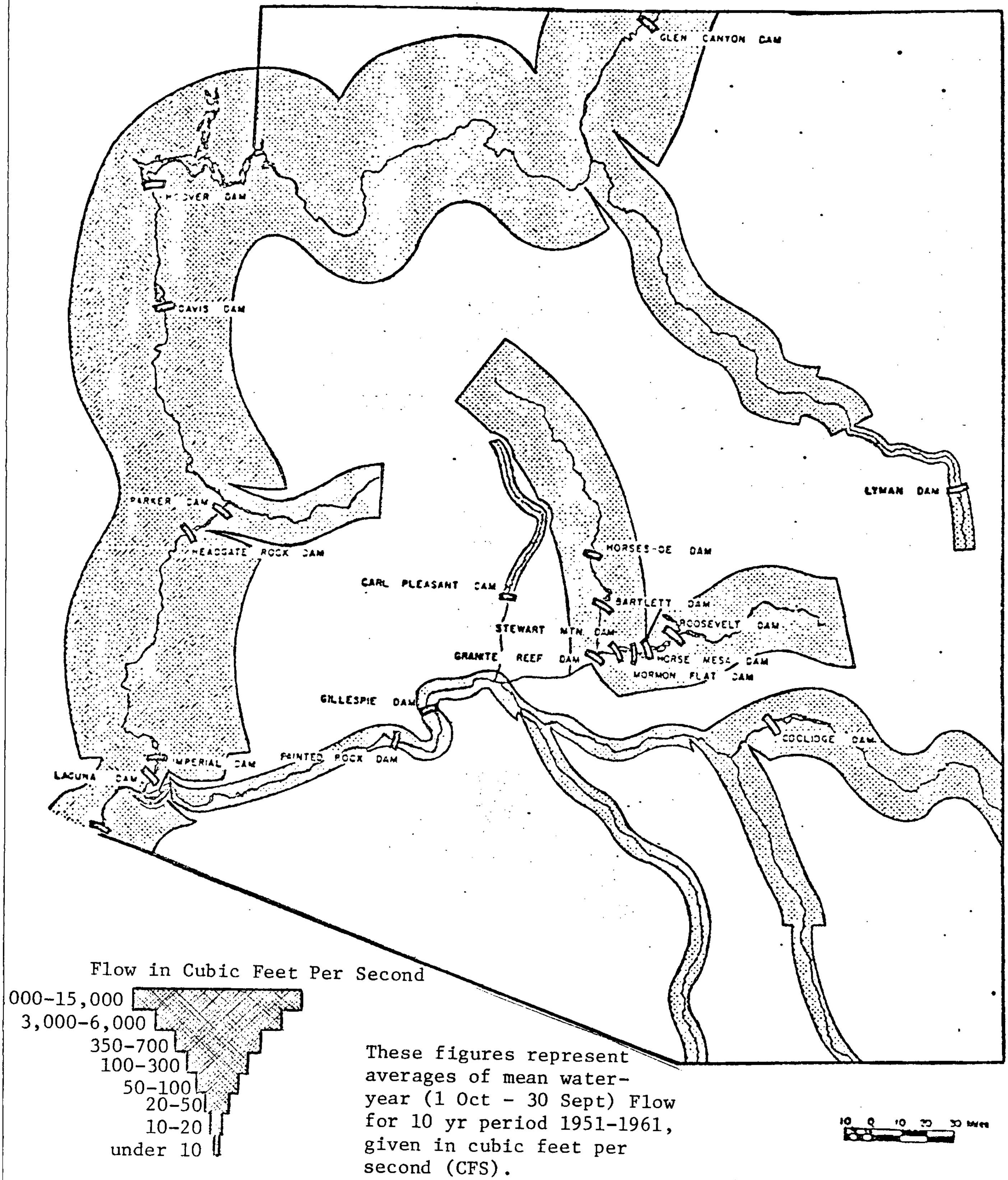
Quantity unknown

Ponderosa Pine

Spruce B Fir

Production Figures in Thousands of Board Feet Per Day

FIGURE 16: LOGGING AND SAWMILL OPERATIONS IN ARIZONA (*)
(*) Directory of Forest Products Industry, 1964



These figures represent averages of mean water-year (1 Oct - 30 Sept) Flow for 10 yr period 1951-1961, given in cubic feet per second (CFS).

FIGURE 17: COLORADO RIVER DISCHARGE MEAN FLOW 1951-1960 (*)
(*) Geological Survey, Water Supply Paper 1733

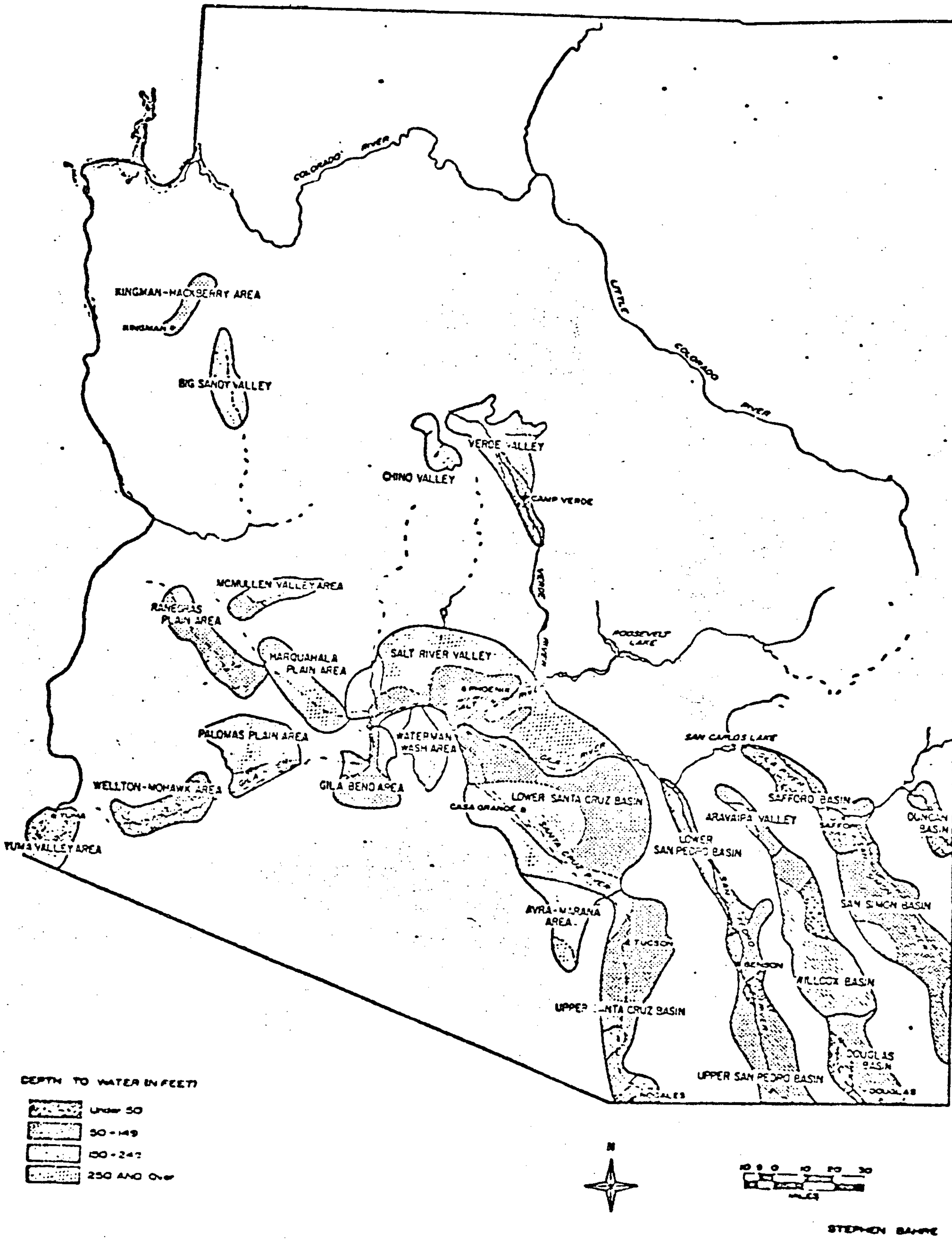


FIGURE 18: AVERAGE GROUND WATER LEVEL IN SELECTED BASINS AND AREAS(*)
(*) USGS Ground Water Report on Arizona

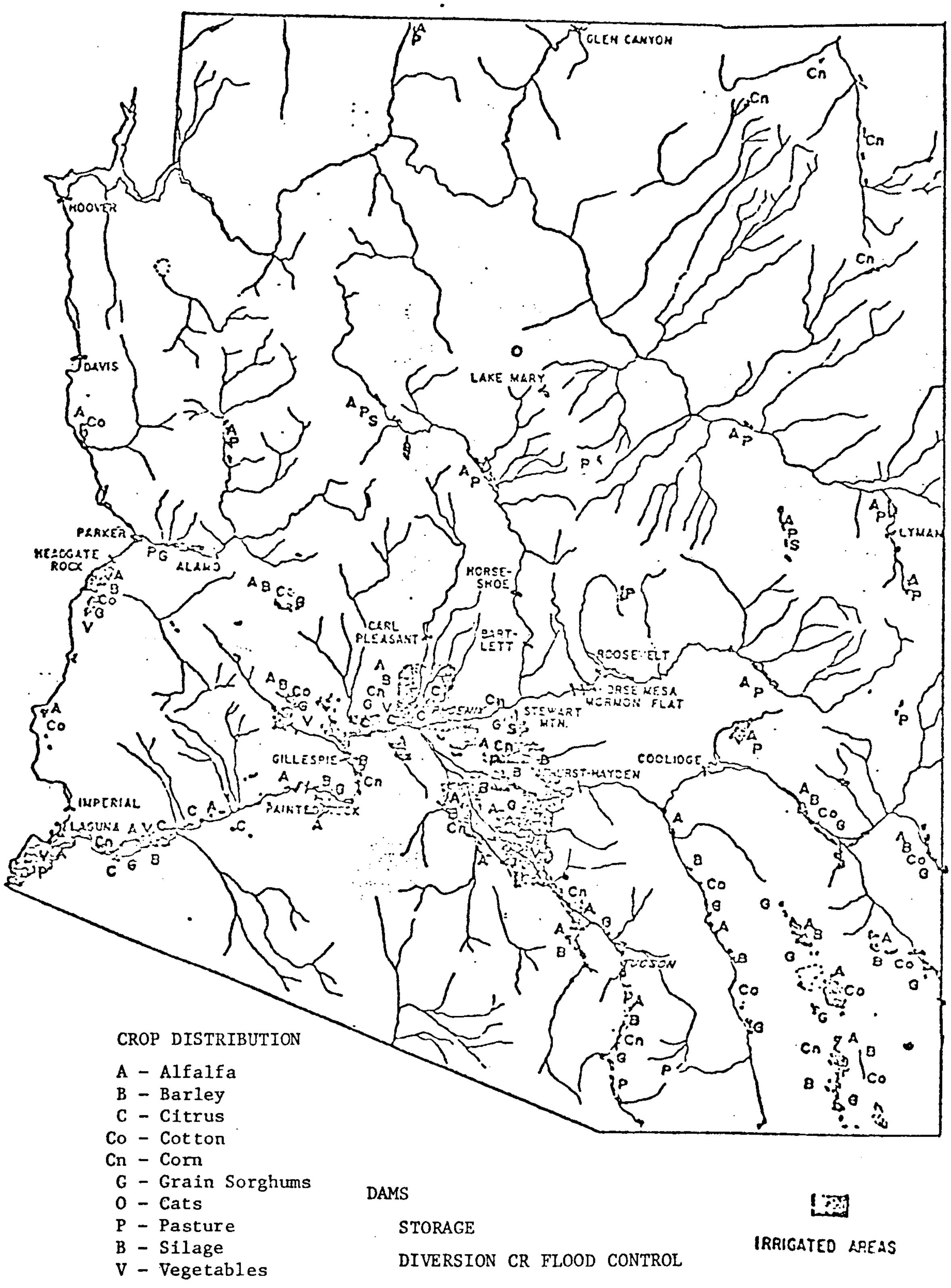


FIGURE 19: CROP DISTRIBUTION AND IRRGATED AREAS

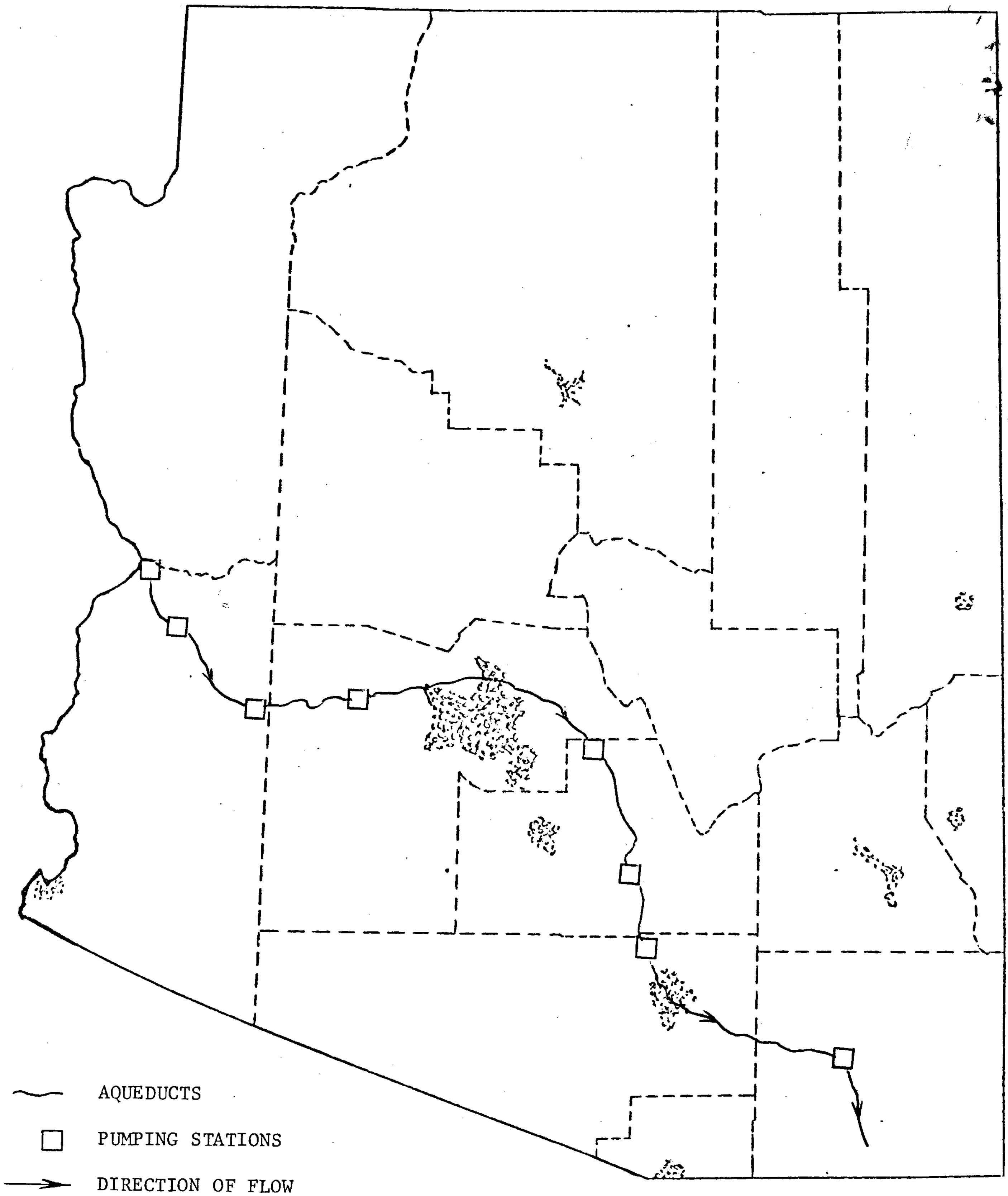


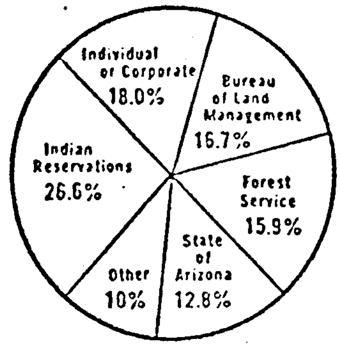
FIGURE 20: CENTRAL ARIZONA PROJECT

TABLE 8

ARIZONA

LAND

OWNERSHIP



ARIZONA LAND OWNERSHIP AND ADMINISTRATION BY COUNTY

(in Thousand Acres)

County	Forest Service	Bureau of Land Management	Indian Reservation	State of Arizona
Apache	480	130	4,447	705
Cochise	517	290	—	1,446
Coconino	3,319	646	4,401	1,042
Gila	1,717	59	1,143	28
Graham	395	779	1,000	494
Greenlee	780	172	—	145
Maricopa	730	1,848	268	583
Mohave	33	4,362	596	505
Navajo	488	97	4,214	327
Pima	385	373	2,488	957
Pinal	223	560	558	1,237
Santa Cruz	450	—	—	51
Yavapai	2,013	571	4	1,387
Yuma	—	2,255	230	427
TOTAL	11,531	12,142	19,349	9,334

County	Individual or Corporate	Other*	Total	% of Total
Apache	1,235	154	7,151	9.8%
Cochise	1,639	112	4,004	5.5
Coconino	1,617	862	11,887	16.4
Gila	92	1	3,040	4.2
Graham	282	—	2,950	4.1
Greenlee	102	—	1,199	1.7
Maricopa	1,585	891	5,905	8.1
Mohave	1,573	1,417	8,486	11.7
Navajo	1,194	23	6,343	8.7
Pima	813	897	5,914	8.1
Pinal	864	—	3,442	4.7
Santa Cruz	296	—	797	1.1
Yavapai	1,203	1	5,179	7.1
Yuma	543	2,936	6,391	8.8
TOTAL	13,038	7,294	72,688	100.0%

*Includes land administered by National Park Service, Department of Defense, Bureau of Sport Fisheries and Wildlife, Bureau of Reclamation and other miscellaneous public land (County, State and Federal).

Source: Arizona Crop & Livestock Reporting Service, "Arizona Agricultural Statistics, 1976."

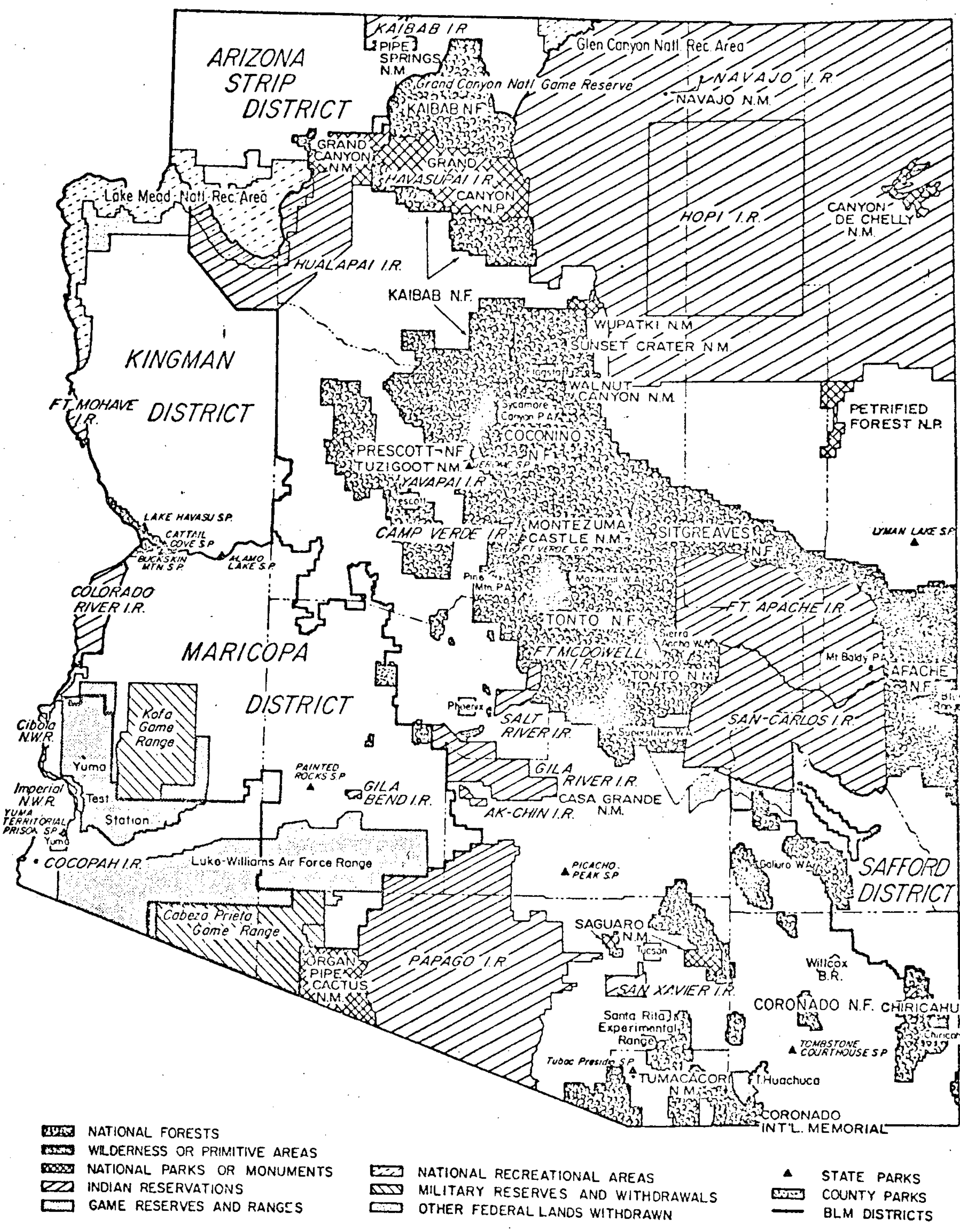
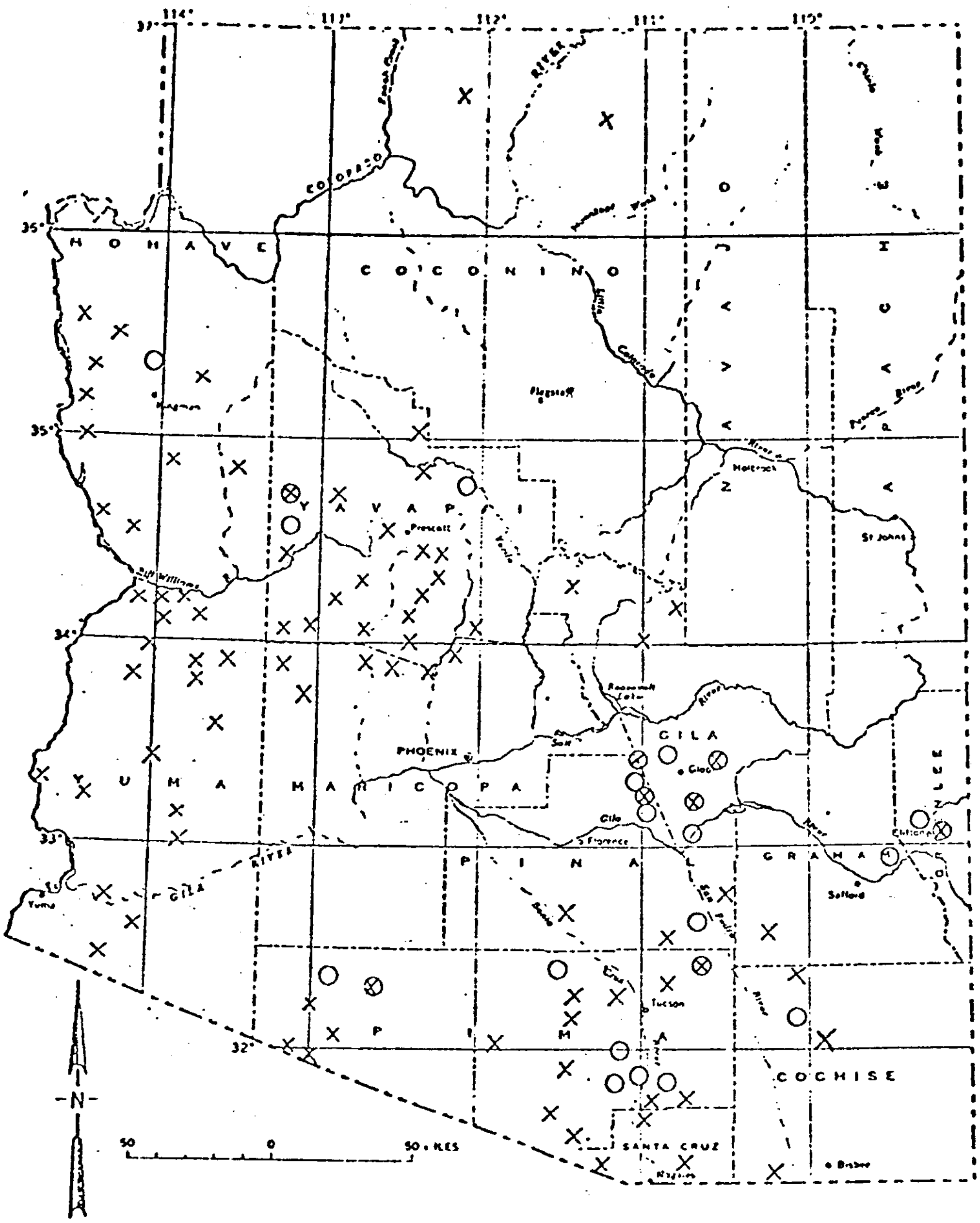


FIGURE 21: LAND OWNERSHIP BY LOCATION



⊗ Large Sulfuric Acid Plants, recovering SO_2 from copper smelter stack gases

TOTAL CAPACITY: 12,500 Tons per day

COPPER PRODUCTION

X 10 – 50,000 TONS

O MORE THAN 50,000 TONS

FIGURE 22: COPPER MINES AND SULFURIC ACID PLANTS IN ARIZONA

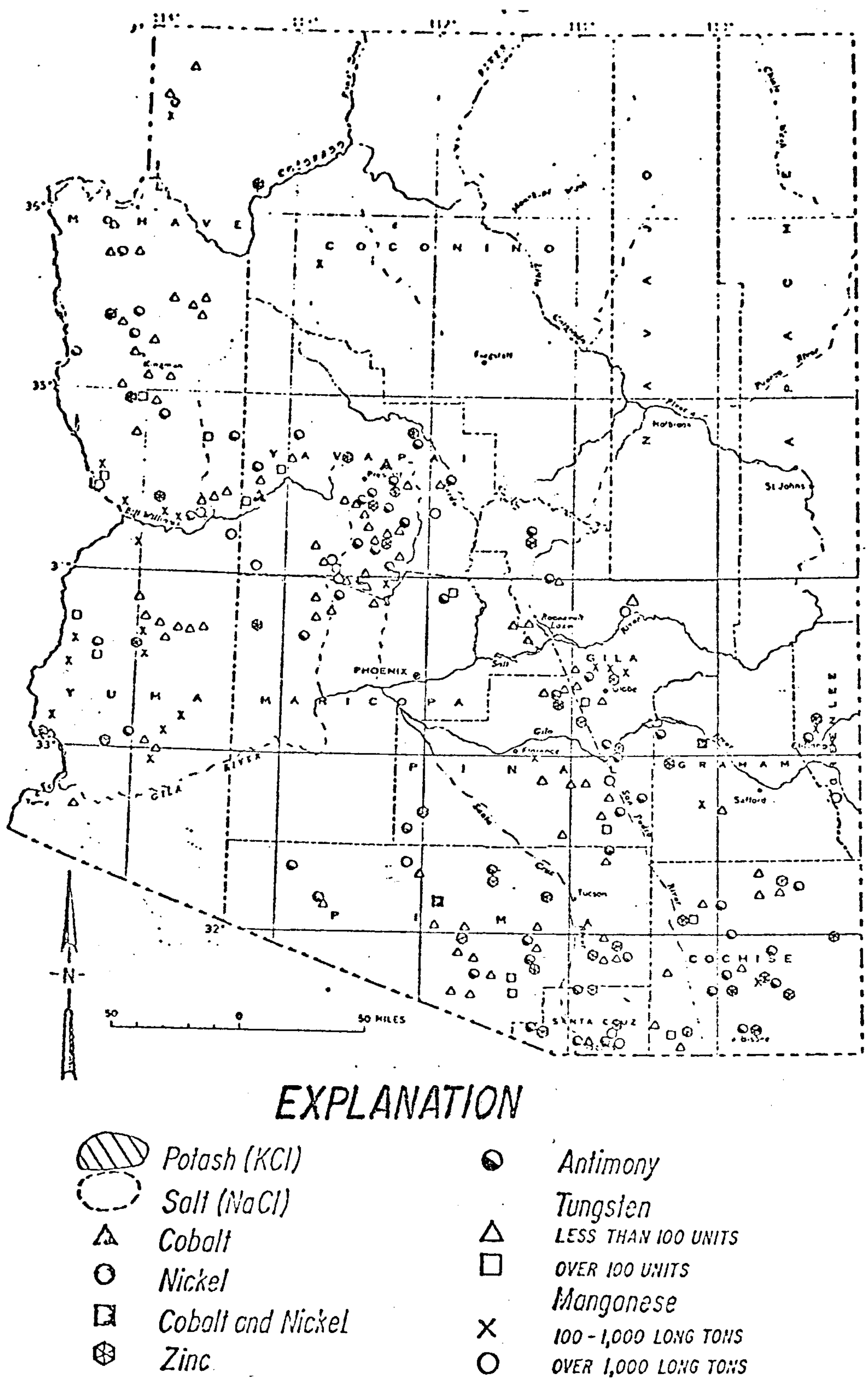
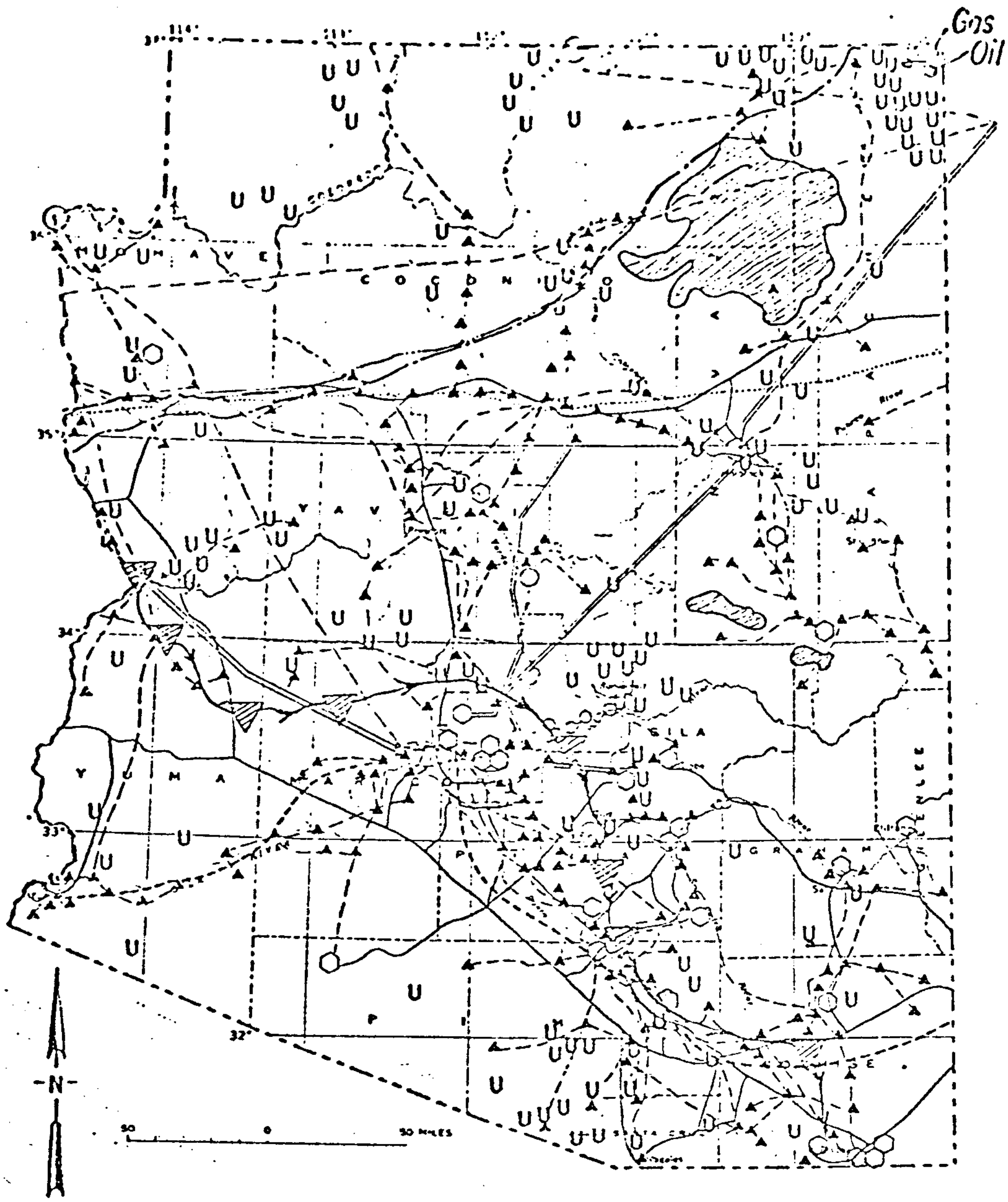


FIGURE 23: VARIOUS MINERAL DEPOSITS IN ARIZONA



PIPELINES

- El Paso Natural Gas
- Transwestern Natural Gas
- Southern Pacific Petroleum
- Coal Slurry
- Crude Oil

GENERATION PLANTS

Steam

Hydro

- Natural Gas
- Crude Oil

TRANSMISSION LINES

- Over 80,000 volts
- Under 80,000 volts
- △ Substation
- Pumping Station

Aqueducts

Direction of flow

Bituminous Coal

U Uranium

FIGURE 24: POWER SOURCES IN ARIZONA

of Arizona's energy consumed is in the form of electricity, 34.1% for transportation and only 12.1% for industrial and 16.2% for residential uses. Arizona is growing very fast so energy consumption doubles every ten years.

Electrical use is characterized by unusual daily and seasonal peak loads. The high cooling demand in the summer afternoons causes daily peak loadsto be different than in the winter (Fig 25) and also results in a seasonal peak during the hottest months, June - September (Fig 26). Also affecting this peak is the shutdown of a few industries (Motorola, Honeywell, etc), during weekends. Utilization of geothermal space-heating or cooling must be performed carefully, for the price of electricity may rise if the base power loads are removed from the present suppliers.

The total consumption of energy in Arizona increased from 250 trillion BTU in 1960 to 450 trillion BTU in 1970. Present consumption is near 700 trillion BTU per year. Tables 9-12 offer different perspectives of energy use by consumption type, energy source, and a chronological break-down from 1960-1975. This data led to the prediction that consumption would double each decade.

C. ARIZONA'S WATER SITUATION

Most of Arizona has an arid to semiarid climate. The main surficial water discharge in Arizona is the Colorado River drainage system. Arizona has smaller ephemeral streams (i.e., that flow part of the year) resulting from the summer monsoon season of July and August. Tucson and Phoenix each receive an average annual precipitation of 12-15 inches. This meager recharge is but a small fraction of the water used each year. This recharge is less meaningful each year as water is used in ever increasing quantities for irrigation agriculture, the copper industry and the expanding population. The source of most water is pumped groundwater; consequently the water table is dropping at a significant rate in areas of heavy pumping. The volume of water that is extracted from the ground every year is 2,000,000 acre-feet. Hydrologists estimate problems recovering water in the future due to the higher energy required to pump deep ground water to the surface, as well as the possibility that one day some places will just dry up.

Salinity of groundwater like that in the Buckeye, Arizona area is in the brackish range. To obtain potable water they must desalinate the water using an electrodialysis method. Yuma has a reverse asmosis plant to upgrade the water that the United States must supply Mexico via the Colorado River under treaty agreement. So the water problem is realized in its lack of both availability and cleanliness. Development of a geo-thermal resource could help tackle both problems, depending upon the temp-erature of the reservoir, its size, depth and porosity. Under favorable conditions with respect to these parameters, geothermal energy would be highly beneficial to Arizona by reducing the cost of energy consumption.

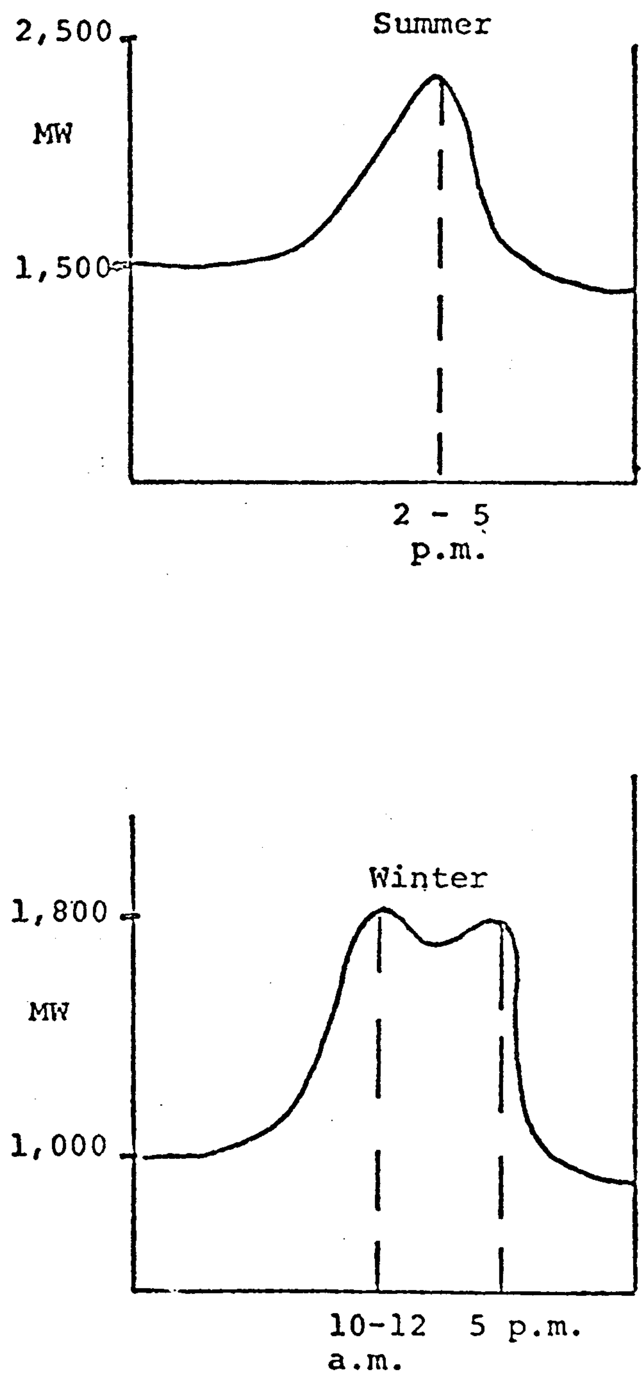


FIGURE 25: DAILY ELECTRIC PEAKS IN ARIZONA

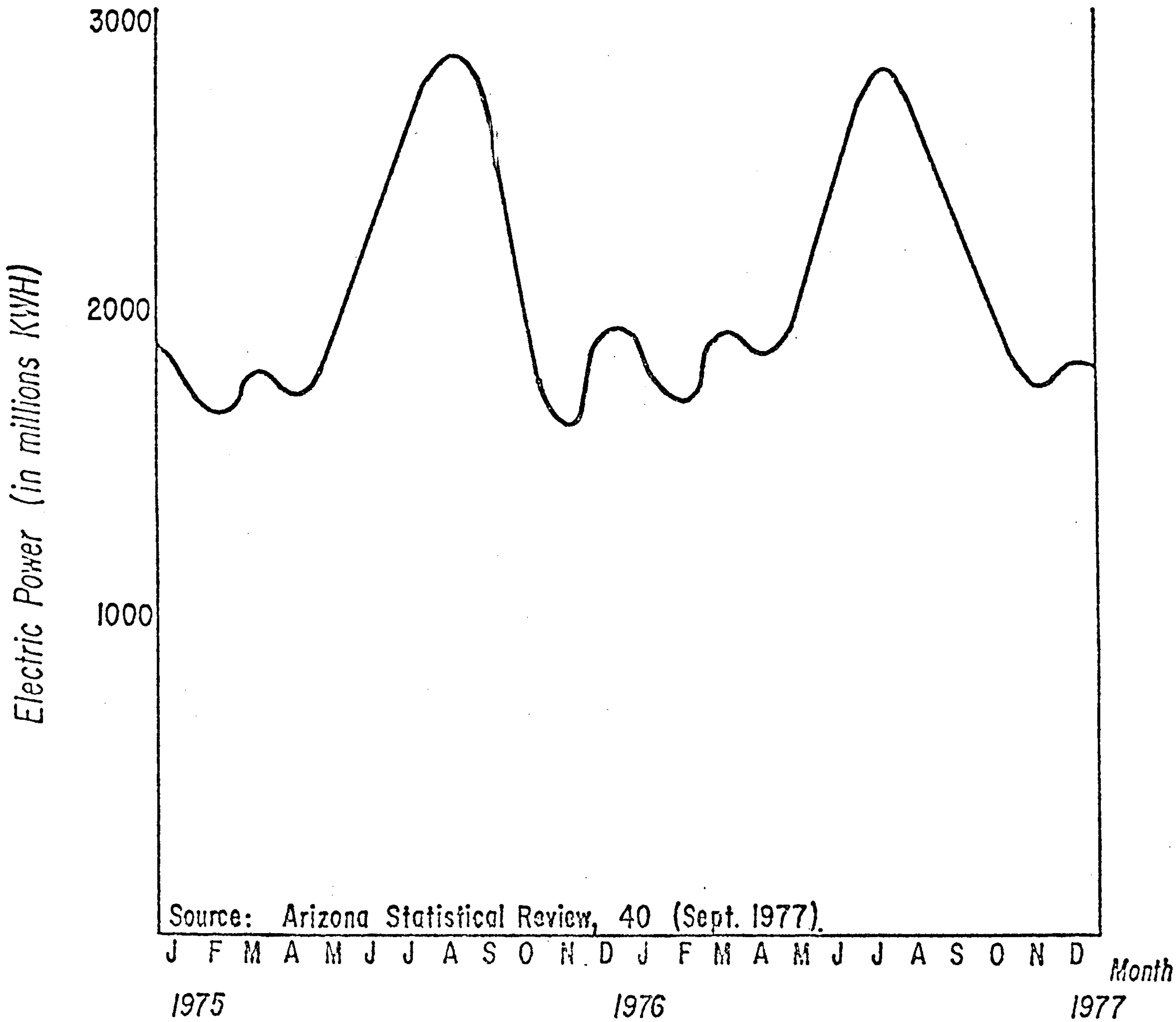


FIGURE 26: SEASONAL PEAK ELECTRIC LOADS IN ARIZONA

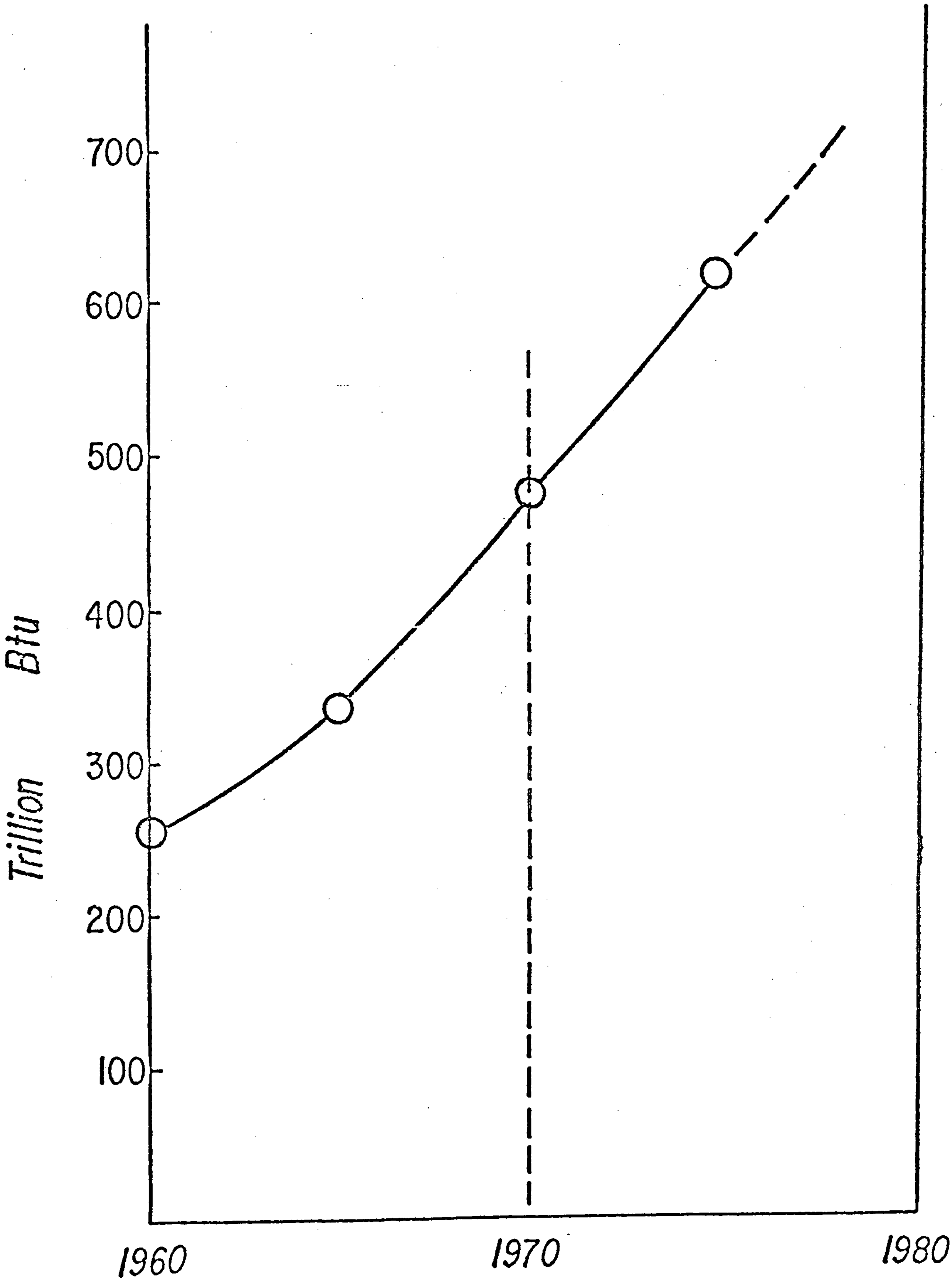


FIGURE 27: ARIZONA TOTAL ENERGY CONSUMPTION

TABLE 9

ARIZONA GROSS ENERGY INPUTS[a]
SUPPLY SOURCES BY USER CLASS, 1975*
ENERGY USED (IN TRILLION BTU'S)

	Coal	Natural Gas	Petroleum	Hydro-power	Total
Household/ Commerical	--	72.3	27.1	--	99.3
Industrial	2.4	52.5	19.5	--	74.4
Transportation	--	17.7	191.9	--	209.6
Electric	83.1[b]	18.3	49.6	77.8	228.8
Miscellaneous	--	--	2.3	--	2.3
Total	85.5	160.8	290.3	77.8	614.4

Percent of Energy Used

	Coal	Natural Gas	Petroleum	Hydro-power	Total
Household/ Commercial	--	45.0	9.4	--	16.2
Industrial	2.8	32.6	6.7	--	12.1
Transportation	--	11.0	66.1	--	34.1
Electric	97.2[b]	11.4	17.1	100.0	37.2
Miscellaneous	--	--	0.7	--	0.4
Total	100.0	100.0	100.0	100.0	100.0
Percent of Sources	13.9	26.2	47.2	12.7	100.0

[a]Includes BTU equivalent of total electricity sold from instate plants and net imports.

[b]Net imports attributed to coal.

*Preliminary

Source: Compiled by University of Arizona from official and private sources.

TABLE 10

SUMMARY

ARIZONA GROSS ENERGY CONSUMPTION

IN 1975

Energy Source	Percent	
Oil	47.2	Much transportation
Natural Gas	26.2	Much commercial/residential
Hydroelectric	12.7	— Electricity
Coal	13.9	

Consumption (Market)	Percent
Electricity	37.20
Transportation	34.10
Industrial	12.10
Residential/Commercial	16.20
Miscellaneous	0.40

TABLE 11

ARIZONA TOTAL ENERGY CONSUMPTION

1960-1975

Trillion BTU

Year	Resi-dential	Com-mercial[a]	Indus-trial	Trans-portation	Total[b]
1960	46.7	31.8	78.7	104.2	261.5
1961	41.8	40.6	87.5	100.9	271.2
1962	40.7	43.9	86.2	104.4	275.6
1963	43.6	47.0	88.5	112.1	291.4
1964	50.8	53.2	94.5	119.3	317.9
1965	53.3	61.2	101.1	124.0	339.7
1966	55.6	68.7	105.2	134.4	364.1
1967	58.6	70.1	102.5	142.4	373.8
1968	62.1	73.5	113.6	158.2	407.5
1969	70.7	82.1	124.9	172.8	450.8
1970	77.8	93.0	131.9	182.7	486.0
1971	90.0	101.2	143.9	190.8	526.6
1972	101.2	117.3	154.9	212.0	587.2
1973	112.1	140.5	155.7	225.5	635.9
1974	111.2	143.2	156.7	212.3	626.3
1975	119.2	140.3	142.9	209.6	614.4

a) Includes government sector and nonprofit organizations.

b) Includes miscellaneous uses.

TABLE 12

ARIZONA ENERGY CONSUMPTION BY FUEL SOURCE

1960-1975

Trillion BTU

	Natural Gas		Petroleum Liquids			Electric Sales		
	R_a	C^{**}_a	R_a	C^{**}_a	I^*_a	R_b	C^{**}_b	I_b
1960	28.1	8.2	1.3	7.9	48.6	17.3	15.7	30.1
1961	25.9	10.9	1.8	8.7	54.2	14.1	21.0	33.3
1962	22.9	12.9	2.4	8.4	57.3	15.4	22.6	28.9
1963	24.2	13.7	2.4	10.1	61.0	17.0	23.2	27.5
1964	29.3	17.3	2.5	10.6	65.6	19.0	25.3	28.9
1965	26.0	19.8	2.4	10.1	65.8	24.9	31.3	35.3
1966	25.8	18.5	1.6	14.8	69.2	28.2	35.4	36.0
1967	26.2	15.6	2.5	15.0	64.6	29.9	39.5	37.9
1968	27.5	16.2	2.3	18.0	73.6	32.3	39.3	40.0
1969	29.3	17.2	2.6	21.3	78.4	38.8	43.6	46.5
1970	30.6	17.8	3.2	27.6	77.3	44.0	47.6	54.6
1971	33.6	22.1	3.1	23.4	82.5	53.3	55.7	61.4
1972	35.2	23.5	3.2	28.3	90.2	62.8	65.5	64.7
1973	37.5	32.9	3.0	33.4	90.2	71.6	74.2	65.5
1974	33.0	33.4	3.3	31.7	87.3	74.9	78.1	69.4
1975	38.8	33.4	2.3	24.8	74.4	78.1	82.1	68.5

*Industrial data is combination of Natural Gas & Petroleum Liquids i.e. nonelectric energy

**Includes government sector & nonprofit organizations

a) U.S. Bureau of Mines, IC8705, Historical Fuels and Energy Consumption Data, 1960-1972; IC8722 for 1973; 1974-75 compiled by University of Arizona

b) Edison Electric Institute, Statistical History 1961-70; Yearbooks 1960, 1971-75.

R = Residential

C = Commerical

I = Industrial

IV. GEOTHERMAL USE SCENARIOS

A. INTRODUCTION

The geothermal energy potential in Arizona appears large but is presently unproven. Geological studies indicate that geothermal sources exist in arizona of both the hot rock and hydration-field type. Temperatures in the range of 30-300°C can be expected. Due to the lack of significant geothermal well drilling most of the predictions are based on the knowledge of the geological conditions and water well temperature data. Minimum 500 ft depth of well is required to get reliable data on temperature gradients. Evidence of thermal activity is also available from oil and geothermal drillings. A map showing areas of geothermal potential is shown in Figure 7. Heat flow measurements in the basin range region where half of Arizona lies, average about 2.2 HFU, significantly higher than the crystal heat flow of 1.2 - 1.5 HFU*. Harnessing terrestrial heat flow depends on the existence of reservoirs of hot water in Arizona valleys and the economics of exploiting the resource as planned.

1. Preliminary Evaluation

Preliminary evaluation of some of these data has shown that many potential geothermal areas do exist in the State of Arizona. Should they be found, geothermal reservoirs may be suitable for various use applications and that many may be potential multi-use resources. In addition, evaluation has facilitated preliminary selection of several potentially favorable sites for the immediate development of practical planning diagrams, or site-specific scenarios.

Arizona has the fastest population growth of all states in the U.S.A. The growth of Arizona (as well as Florida and Nevada) during 1977 to 1985 is projected as 25% in population and 56% in earnings, compared with 7% and 35% for the U.S.A. Due to the heavy use of conventional mechanical refrigeration for air conditioning Arizona also has an excessive electrical load in the summer. These two factors cause many problems in planning for power expansions, but at the same time present an opportunity to plan a shift to alternative energy sources, such as geothermal energy. Many non-electrical uses have been identified to date, based in part on Arizona's industrial base in mining and electronics, its irrigated agriculture and the need for hot water for food processing, new industry and communities in the many desert regions of sparse population.

During the first year of participation in this Southwest Geothermal Project, the majority of funding and research was directed toward the identification of (a) potential geothermal resource areas in the State and

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* Norton, D. Gerlach, T., Decook, K.J. and Summer, J.S., "Geothermal water resources in Arizona - Feasibility Study", Technical report, Office of Water Research and Technology Project A-054 - Arizona, The University of Arizona, Aug. 1975

(b) typical cross-section of potential geothermal use scenarios. The responsibility of investigating these two main activities was given to the Arizona Bureau of Geology and Mineral Technology and the Department of Chemical Engineering respectively, both of the University of Arizona; the Arizona Solar Energy Commission accepted the responsibility of obtaining data on leasing activity and State-level institutional constraints, with the hope that most of these data can be obtained from on-going groups in the government and industry of the State.

Scenarios for the use of geothermal energy have been approached first (a) by examining the current and future needs for energy in Arizona, and from what possible sources the energy must come and (b) by reviewing the basic resources of the State, including people, water, industry, mining fossil fuels, agriculture, and current technological situations. Some 70 letters were sent to selected corporations of the State, attempting to reach a cross-section of energy consumers, state geological and water well data were reviewed, as well as international geothermal literature. Both daily and seasonal peak energy loads were identified, together with the type of energy needed. With these data in hand, a cross-section of potential geothermal use scenarios began to evolve, always keeping in mind the competitive picture of alternative sources of energy. Table 13 gives the geothermal energy potential uses in Arizona in summary form. While Table 14 presents the list of twenty-two scenarios discussed in this report.

2. Potential Constraints and Advantages

Economic feasibility of geothermal energy depends on the influence of many potential factors and advantages. Table 15 comprises a list of these parameters. This qualitative list will be continuously expanded, revised and refined throughout the remainder of the project.

a: Potential impediments

i. General Potential Impediments

Utilization of geothermal resources, in general, faces several impediments. Geothermal energy is considered a low-value energy due to the fact that it provides heat energy only, a fraction of which can be used efficiently. The extraction of this energy often involves many costly operations (e.g., drilling and pumping) which may not be offset by the value of the extracted energy (as occurs in petroleum exploration and production). Problems may be encountered such as the hot brine scaling equipment with silica, finding an appropriate means of brine disposal, and extensive lengthy governmental requirements for procedure. These inhibit production of geothermal energy and increase costs. However the use of geothermal energy by the private sector may lower the demand for electricity from utilities, causing an increase in the prices of electricity. This increased revenue may offset the costs associated with the impediments.

TABLE 13

GEOTHERMAL ENERGY POTENTIAL USES IN ARIZONA

I. POTENTIAL GEOTHERMAL ENERGY UTILIZATION IN ARIZONA

A. Agriculture

1. Irrigation Pumping
2. Brackish Water Utilization
3. Grain Drying
4. Hot Water for Dairies
5. Refrigeration for Lettuce Processing
6. Cotton Milling and Cottonseed Oil Extraction
7. Citrus Processing
8. Pecan Processing
9. Integrated Alfalfa Dehydration/Cattle Feedlots

B. Industrial

1. Mining
2. Copper Processing
3. Lumber Kiln Drying
4. Wood Pulp Processing
5. Other Industry that can use low temperatures in their processing (existing and potential)

C. Municipal

1. Conventional Electricity
2. Peak Electricity
3. Commercial Building Heating
4. Commercial Building Cooling

II. GEOTHERMAL ENERGY IN PERSPECTIVE WITH OTHER ENERGY SOURCES IN ARIZONA

A. Coal
B. Gas
C. Oil
D. Nuclear
E. Solar

TABLE 14

LIST OF SCENARIOS DISCUSSED IN THIS REPORT

SCENARIO #	TITLE
1	Space cooling for an industrial complex (Case Study: Electronics firm in Phoenix)
2	District heating and cooling (Case study: Retirement community outside Phoenix)
3	New communities
4	New industries
5	Energy storage for heat pump systems
6	Central Arizona Project/Peak Power
7	Wind energy/geothermal/energy storage
8	Hot igneous rock and power plant
9	Coal mining operations
10	Preheating/sulfur removal in coal field power plants
11	Solution mining
12	Hot Water for conventional mining
13	Hot mines
14	Salt production
15	Desalination
16	Biosalinity agriculture
17	Greenhouse/hydroponics
18	Irrigation pumping (Case Study: Hyder Valley area)
19	Crop drying
20	Kiln drying of lumber
21	Lettuce chilling
22	Sugar beet plant

TABLE 15

GENERALIZED IMPEDIMENTS AND ADVANTAGES TO USE OF GEOTHERMAL ENERGY

I. POTENTIAL IMPEDIMENTS

A. General

1. High cost for low-value energy
2. Excessive governmental regulations
3. Generally causes an increase in cost of electric power
4. Corrosiveness and scaling
5. Disposal of brines
6. Distance from ocean (for disposal)
7. Competition from local fossil fuels

B. Specific for Arizona

1. Sparse geothermal data
2. Heterogenous land ownership
3. Must pump geothermal well water
4. Overall scarcity of potable water
5. Must compete with solar energy
6. Must compete with coal
7. Must compete with Alaskan oil

II. POTENTIAL ADVANTAGES

A. General

1. Hot water near surface economical
2. Dry steam and 50-year well economical
3. Dry hot rock/water injection attractive
4. Remoteness of Southwest from oil & gas production
5. Sheer size of Southwest states (among the largest)

B. Specific for Arizona

1. Good geothermal prospects based on geology
2. Steep temperature gradients based on water wells
3. Existence of hot springs
4. Rapid growth of State of Arizona
   a. Can we cope with changes in power demand
   b. Can we cope with general changes in energy
5. State of Arizona is still developing
   a. New communities can be planned
   b. New industries can be planned
6. State of Arizona rich in low-concentration minerals
7. State of Arizona has surplus sulfuric acid
8. Solar energy available for pond evaporation

ii. Potential Impediments in Arizona

Of the obstacles presently hindering the development of geothermal energy in Arizona, the most important is the need to discover a shallow geothermal reservoir near a population center. The conditions involving use of the resource are 1) legal consent to drill, 2) public approval of the chosen method of brine disposal, 3) type of land ownership overlying the geothermal resource and 4) overall economic projections of geothermal use as compared to projection of other energy sources, such as energy from Alaskan oil, coal and our sun.

The location of geothermal reservoirs in Arizona is being sought by various agencies, including the Geothermal Group of the Arizona Bureau of Geology. Once a reservoir is found, the effect of the aforementioned impediments on the intricate economics of competing energy sources must be evaluated.

b. Potential Advantages

i. General Potential Advantages

Production of geothermal energy may be profitable under conditions where high temperature water and proximity to the surface result in low cost to the entrepenuer, who may be forced into extra expenditures due to the potential impediments. The advantages of having a shallow hot water reservoir that lasts 50 years or more may outweigh the costly impediments. Technological advancements may render some of the impediments less significant.

Geological understanding will continue to improve in Arizona, where data on heat flow has been sparse. High geothermal gradients have been measured. Water flows hot from some springs. Consequently, most predictions depend on the geologist's educated guess. The rate of geological data input will increase sharply in the coming years, aiding exploration geologists in their quest for a hydrothermal reservoir. Should they be able to define a resource, geothermal energy development could proceed following the first successful drilling test. Geoscientists at the Geothermal Group of the Arizona Bureau of Geology have indicated that there is a good potential in Arizona for geothermal energy. Users of the resource would have to understand the scenarios and all steps involved. Potential users are listed in Table 16.

B. DETAILS ON THE SCENARIOS

For the more detailed study of the scenarios an extensive amount of data was needed; consequently the Arizona background was considered and relevant data was collected. A list is shown in Table 17. The key point in our thinking in the second iteration stage was to look for

TABLE 16

CATEGORIES OF POTENTIAL GEOTHERMAL USERS IN ARIZONA

UTILITY COMPANIES

MINING INDUSTRIES

SOLID STATE AND COMPUTER INDUSTRIES

OTHER MANUFACTURING INDUSTRIES

AGRICULTURAL INDUSTRIES

FOOD INDUSTRIES

INDIAN INDUSTRIES

INSTITUTIONAL FACILITIES

EXISTING COMMUNITIES

NEW INDUSTRIAL COMMUNITIES

NEW RETIREMENT COMMUNITIES

STATE WATER SUPPLY SYSTEMS

TABLE 17

COLLECTION OF ARIZONA BACKGROUND DATA

ANALYSIS OF EXISTING ENERGY SOURCES

ANALYSIS OF CURRENT ENERGY UTILIZATION

PROJECTION OF ENERGY SOURCES TO 2020

PROJECTION OF ENERGY UTILIZATION TO 2020

ARIZONA WATER SITUATION

POPULATION GROWTH CRISIS

TRENDS IN IRRIGATION AGRICULTURE

SOLUTION MINING POTENTIALS

BIO-SALINITY AGRICULTURE POTENTIALS

BIO-SALINITY FOOD POTENTIALS

NEW COMMUNITY PLANNING

integrated systems. Improved economics and reuse of water wherever possible are two important driving forces. For example, take the geothermal water, heat could be extracted and the waste water used for agriculture if possible.

A full detailed analysis of the scenarios was not possible this year and was proposed for next year's study. All of these scenarios are only theoretical and preliminary in nature with many simplifying assumptions; they should be treated as such. This is due to the lack of abundant geothermal field data in Arizona. A literature survey on the use of geothermal energy has been conducted and these scenarios were based on information accumulated from the literature survey. These are plans presented to illustrate how geothermal energy can be used in Arizona.

1. Geothermal Use Scenarios for Arizona

A number of the following scenarios tend to overlap in one form or another; but they are presented to show specifically the various uses of geothermal energy in Arizona.

Scenario #1: Space cooling for an industrial complex (Case Study: Electronics firm in Phoenix)

Location: Phoenix
Temp : 250°F
Depth : 1200 ft
Salinity: 2000 ppm
Land : Federal
Development: 1990

i. Introduction

The first scenario comprises a design for comfort cooling with a geothermal power source. An absorption cooling system would convert geothermal steam to refrigerated air, relieving the large summer electric load. Fig. 28 presents the steps of the site-specific scenario developments in flowchart form.

The hot summers of Phoenix normally have temperature ranges between 80°F and 115°F in each twenty-four hour period. The industrial plant in this case study has two large buildings with a combined total area of 170,000 square feet. The combined cooling load of the buildings is 3,230,000 KWH; the peak load is 1450 kilowatts.

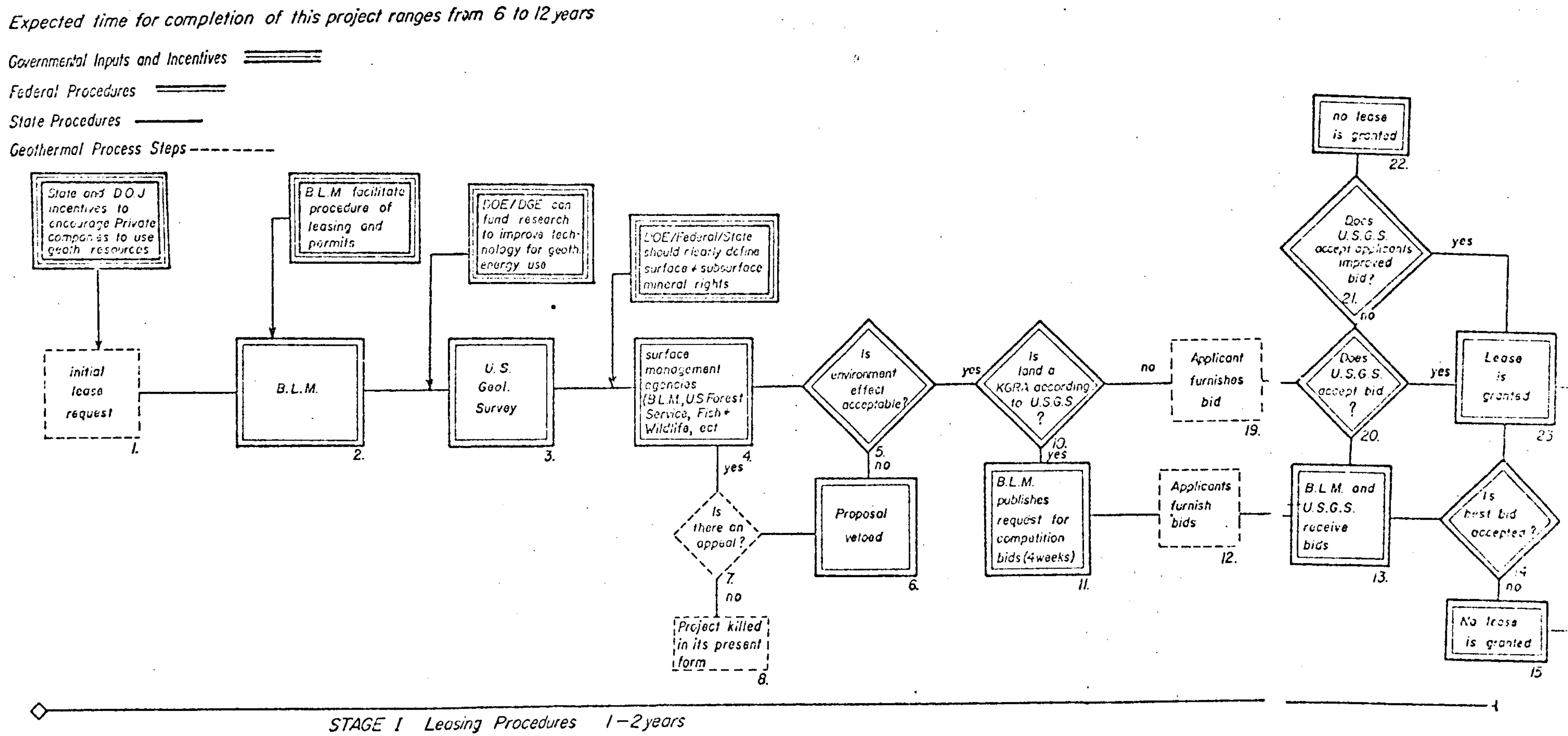


FIGURE 28: SPACE COOLING PROJECT - FEDERAL LANDS

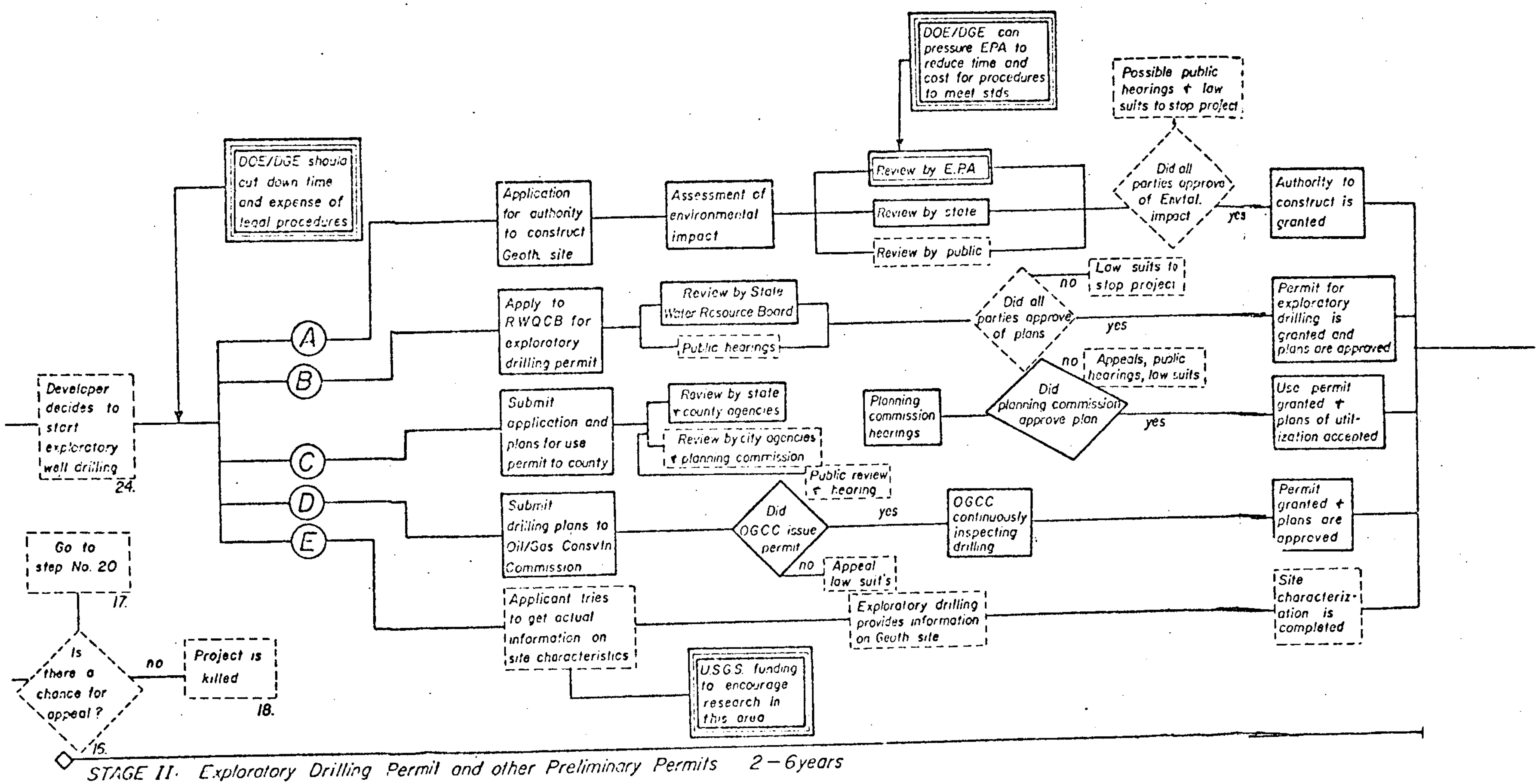


FIGURE 28 CONTINUED

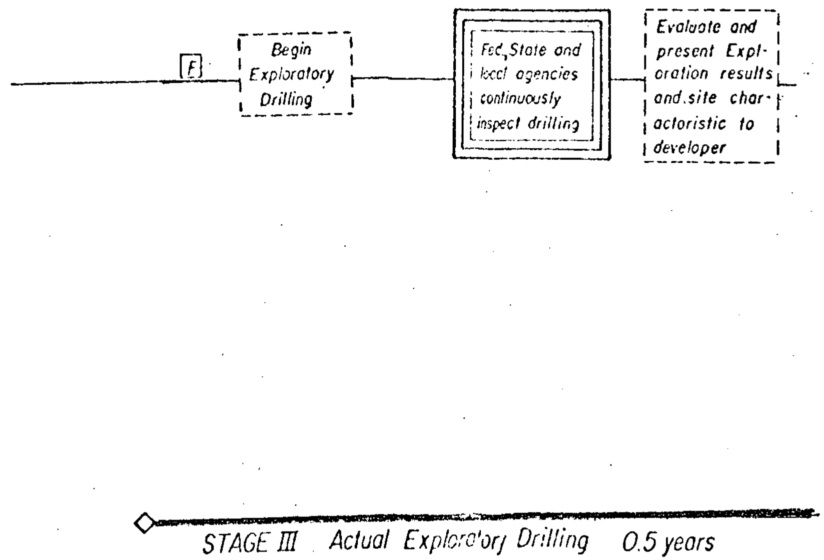


FIGURE 28: CONTINUED

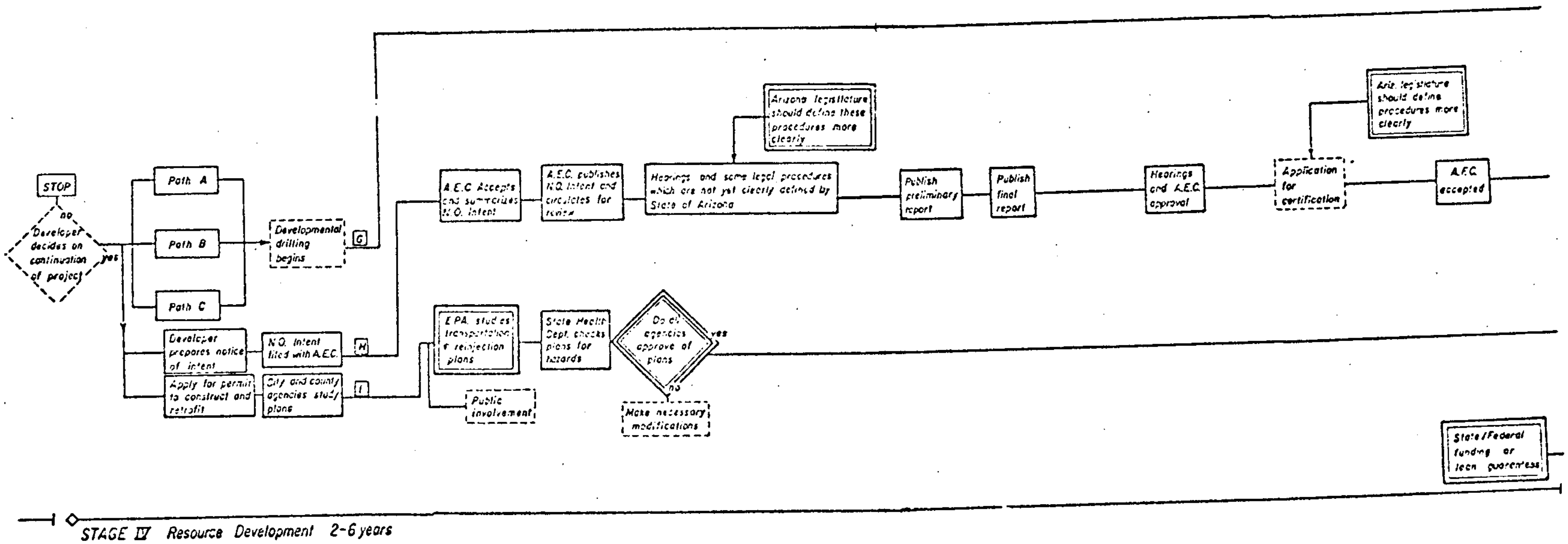


FIGURE 28 CONTINUED

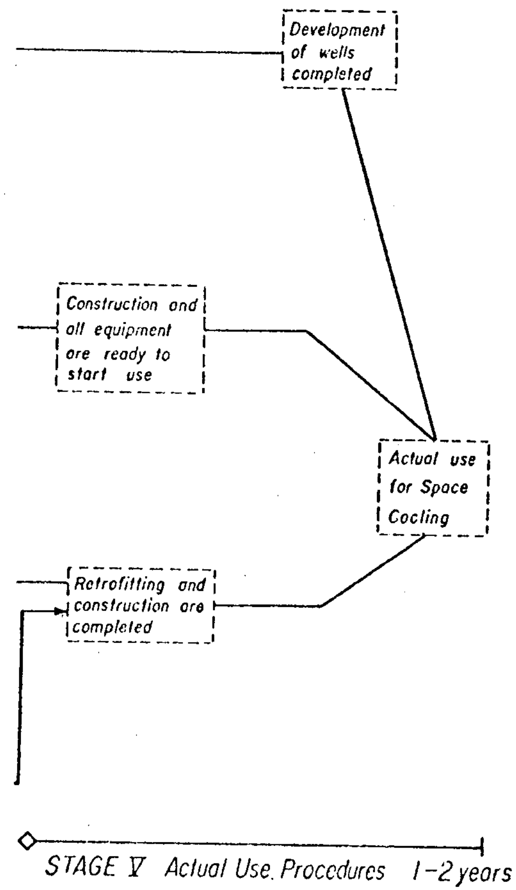


FIGURE 28 CONTINUED

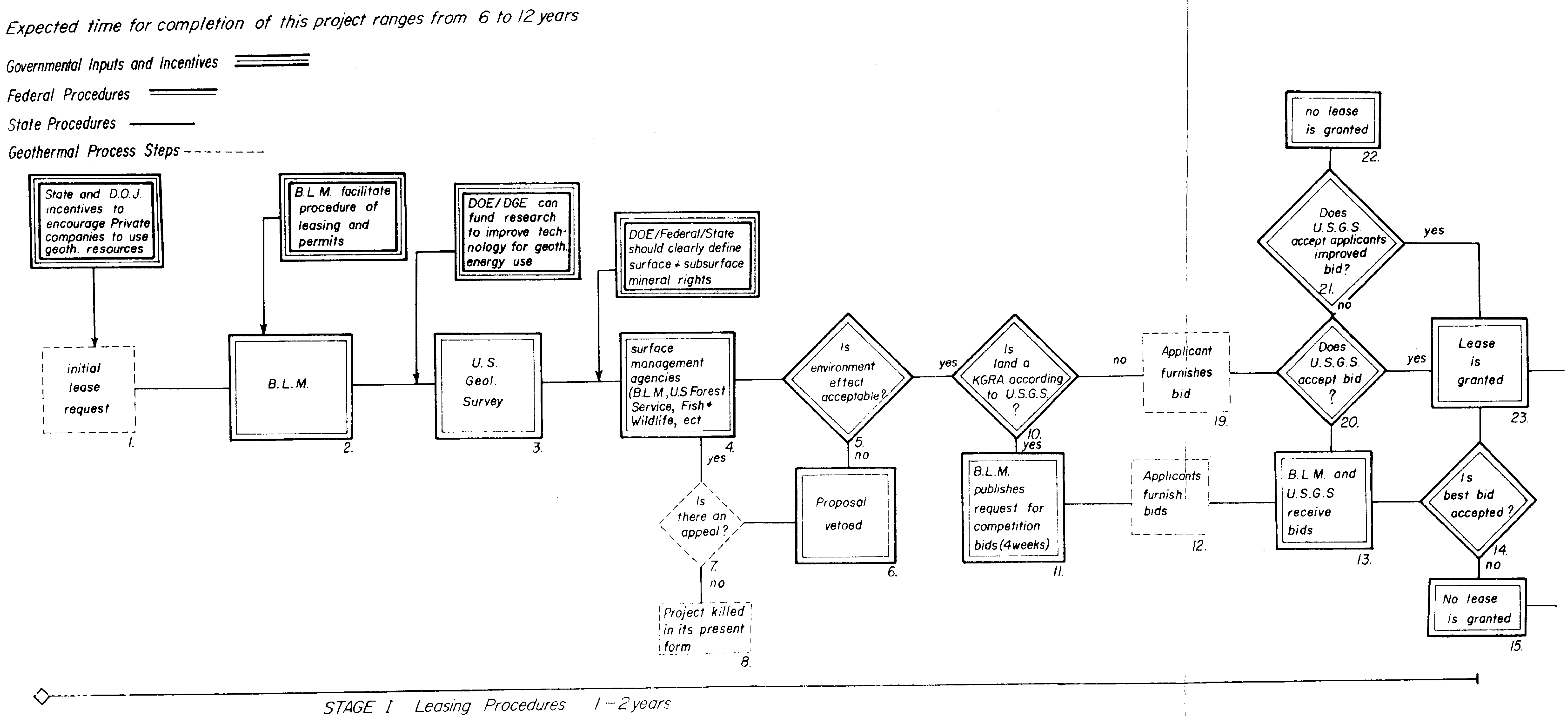
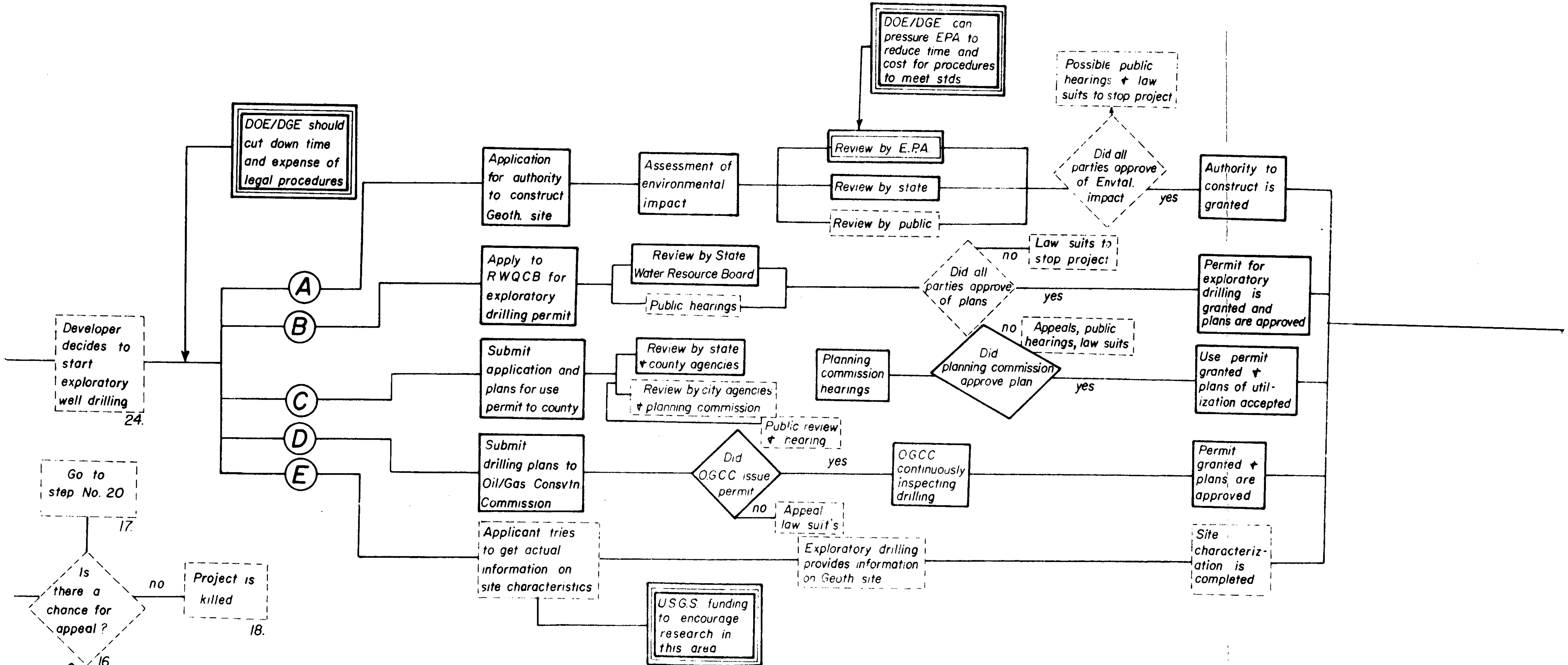
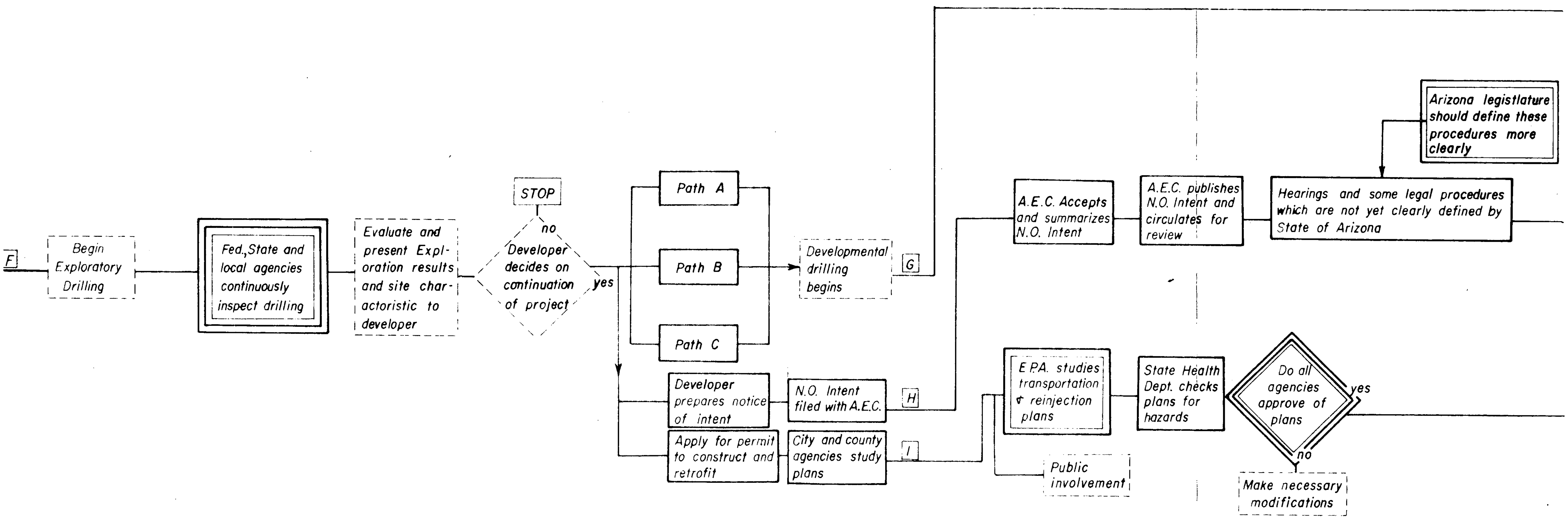


FIGURE 28: SPACE COOLING PROJECT - FEDERAL LANDS

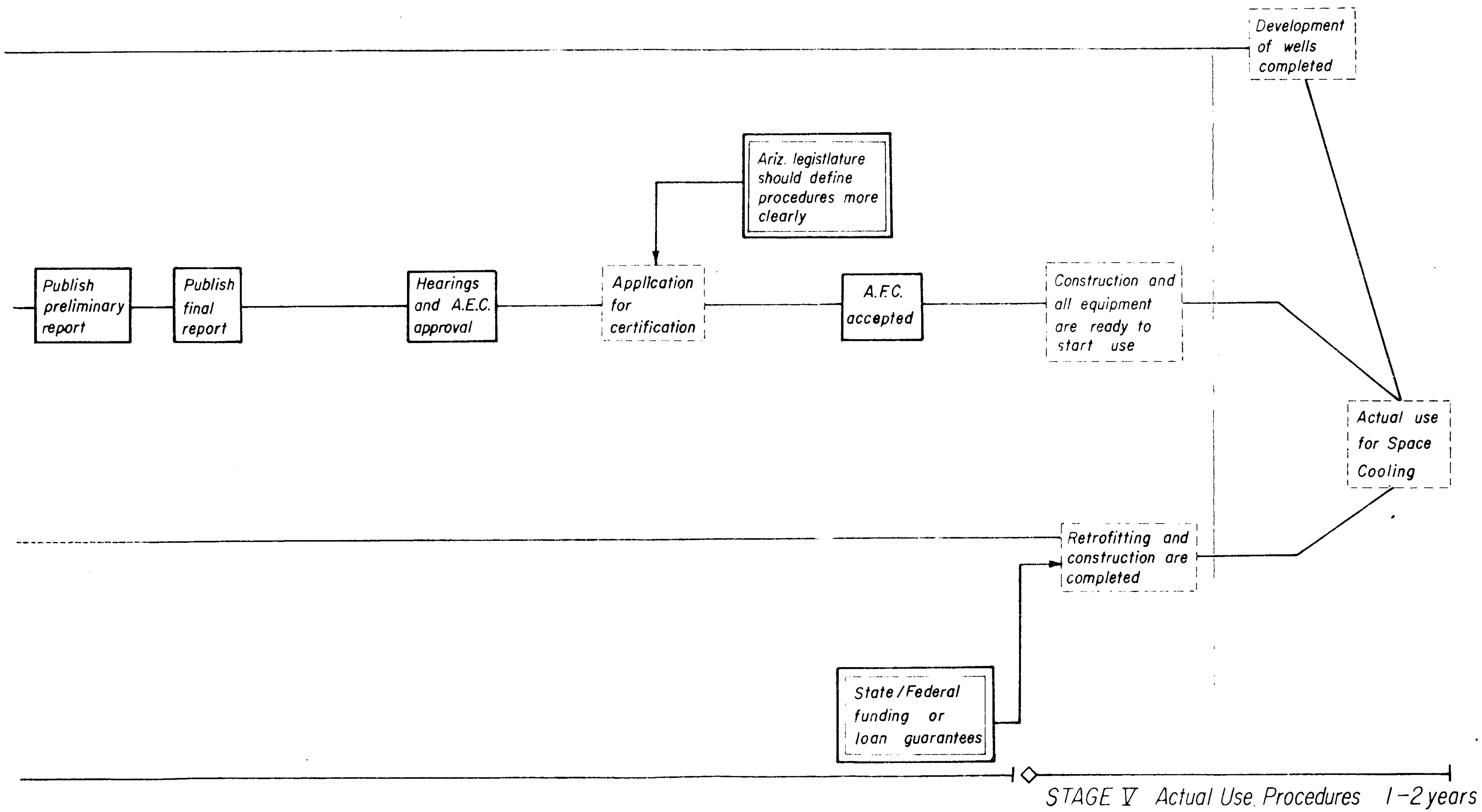


STAGE II Exploratory Drilling Permit and other Preliminary Permits 2 – 6 years



STAGE III Actual Exploratory Drilling 0.5 years

STAGE IV Resource Development 2-6 years


Publish preliminary report
Publish final report
Hearings and A.E.C. approval
Ariz. legistlature should define procedures more clearly
Application for certification
A.E.C. accepted
Construction and all equipment are ready to start use
Development of wells completed
Actual use for Space Cooling
Retrofitting and construction are completed
State/Federal funding or loan guarantees
STAGE V Actual Use Procedures 1-2 years

ii. Design Calculations for the Proposed System

To convert kilowatts to BTUs per hour, we multiply by 3413 BTU per hour/kilowatt. Thus, Q = peak load = 5.0 MM BTU/hr. Q is the amount of cooling required per hour. The design will be based on this value of Q. If Arkla absorption chillers with a capacity of 250 tons of refrigeration (1 ton refrigeration = 12000 BTU/hr) are used,

$$\begin{aligned} N &= \text{no. of chillers required} \\ &= 5.0 \text{ MM BTU/hr} \div (250 \text{ tons/chiller})(12000 \text{ BTU/hr-ton}) \\ &= 1.7 \end{aligned}$$

Thus we need two 250 ton Arkla absorption chillers. The operating temperatures of the Arkla Chiller is 200°F for inlet temperature and 184°F for outlet temperature.

Using a closed cycle to prevent corrosion problems due to salinity of geothermal brine and using regular water at 75°F, the heat exchanger must heat this water to 200°F so it will meet the inlet temperature of the Arkla Chillers. The assumed geothermal resource has a well-head temperature of 250°F with a depth of 1200 ft and total dissolved solids of 2000 ppm. Thus, the inlet and outlet conditions for the heat exchanger are as in Fig. 29. Assuming 10°F temperature approach, the required flowrate from the well is

$$\begin{aligned} m &= \frac{\text{required energy}}{(\text{heat capacity})(\text{temp change})} \\ &= 5.0 \text{ mm BTU/hr} \div (1 \text{ BTU/lb.-}^\circ\text{F})(250^\circ - 210^\circ\text{F}) \\ &= 125{,}000 \text{ lbs/hr.} \end{aligned}$$

Assuming an overall heat transfer coefficient, u, with allowance for scaling factor,

$$u = 100 \text{ BTU/hr.-ft}^2\text{-}^\circ\text{F}$$

and using a 316 stainless steel tubing heat exchanger, we can compute the area required for the heat exchanger, A.

$$\begin{aligned} \Delta\overline{T}_L &= \text{log mean temperature} \\ &= [(250^\circ - 200^\circ - (210^\circ - 75^\circ)] \div \ln[(250^\circ - 200^\circ)/(210^\circ - 75^\circ)] \\ &= 85.6^\circ\text{F} \end{aligned}$$

$$\begin{aligned} T_m &= \text{corrected temperature} \\ &= \Delta\overline{T}_L \times 0.9 \\ &= 77^\circ\text{F} \end{aligned}$$

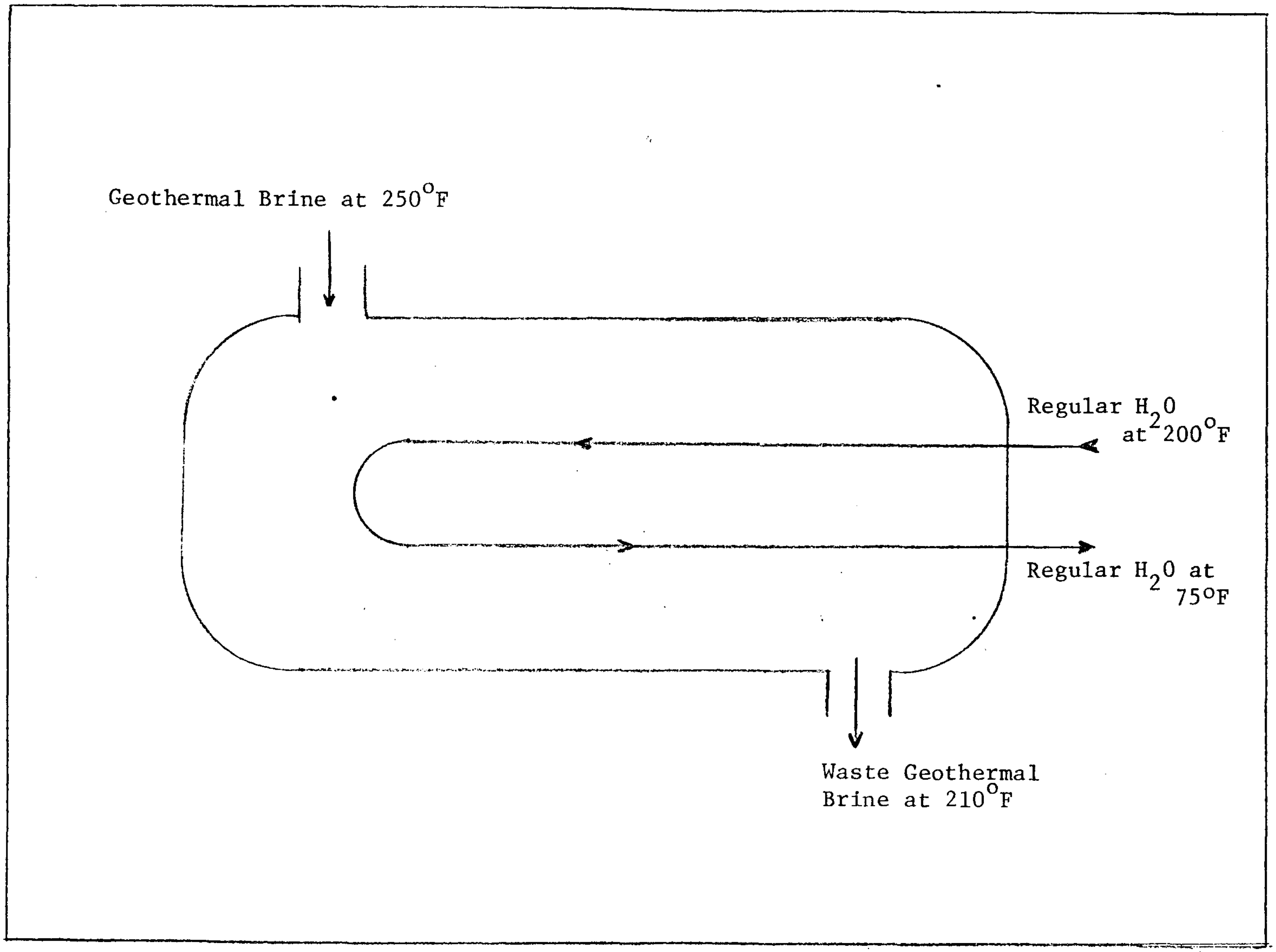


FIGURE 29: INLET AND OUTLET CONDITIONS FOR THE HEAT EXCHANGER

Since $A = Q \div [u \times T_m]$,

$A = 5.0 \text{ MM BTU/hr} \div (100 \text{ BTU/hr.ft}^2.^\circ F)(77^\circ F)$
$\quad = 650 \text{ ft}^2$

Thus the area to be used in the heat exchanger is 650 square feet.

iii. Cost Estimates

a. Cost of Well

One production well and one reinjection well are needed. The depth of the production well is assumed to be 1200 ft, at a cost of $50 per foot. The depth of the reinjection well is assumed to be 1000 ft, at a cost of $40 per foot. Total cost of well drilling
= (1200 ft)(50 dollars/ft) + (1000 ft)(40 dollars/ft)
= $100,000

b. Cost of Absorption Chillers

Each Arkla Absorption Chiller costs $120,000. Two units are required, totaling $240,000. This cost does not include installation.

c. Cost of Heat Exchanger

The cost of a 316 stainless steel tubing heat exchanger with an area of 650 ft is $15,000.

d. Estimated Capital Investment

Cost of items in parts a, b and c is:
$100,000 + $240,000 + $15,000 = $355,000.
This cost, other equipment, and installation costs are shown in Table 18.

e. Estimates of Simple Payout Period

Four cases have been studied. Each assumes a $732,000 capital investment, which is taken from Table 18 with $32,000 added to cover any miscellaneous well costs. Both 20-year and 5-year depreciation times are viewed as well as the same cases with tax incentives added. Calculations leading to the payout period length are tabulated below for each of the four cases.

TABLE 18

ESTIMATED COST OF PROJECT - SCENARIO #1

No.	Description	Cost
1	Items a, b and c	$355,000
2	Cost of pumps (for well, and 2 pumps for transmission of geothermal brine to building and from building to reinjection well)	$ 20,000
3	Cost of 4 in blacksteel insulated transmission pipe 1000 ft long buried in the ground	$ 15,000
4	Cost of 4 in blacksteel un-insulated reinjection pipe 1000 ft long buried	$ 10,000
5	Cost of installation of above equipment	$110,000
6	Cost of retrofitting the cooling system in the building	$ 90,000
7	Cost of Design	$ 40,000
8	Cost of permits and procedures for development of geothermal resource	$ 60,000
	ESTIMATED CAPITAL INVESTMENT	$700,000

Case 1: $732,000 Capital Investment
20 Year Depreciation

Gross Income*	[(Load x KWH/yr) x cost/KWH] [(3.23 x 1,000,000) x .036]		$116,280
*(Gross Income = Annual Utility Cooling Bill)			
Gross Expense			
Operating:		50,000	
Depreciation:		36,600	
		86,600	$86,600
Gross Profit			$29,680
Income Tax (50%)			$14,840
Net Profit			$14,840
Credit Depreciation			$36,600
Total Applicable to Simple Payout			$51,440

$$\text{Payout} = \frac{\$732,000}{\$\ 51,440} = \underline{\underline{14.2\ \text{years}}}$$

Case 2: $732,000 Capital Investment
5 year Depreciation (Tax Incentive of Fast Amortization)

Gross Income*(same as Case 1)		$116,280
Gross Expense		
Operating:	50,000	
Depreciation:	146,400	
	196,400	$196,400
Gross Profit		-$80,120
Income tax credit (50%)		$40,060
Net Profit (Income Tax Credit)		$40,060
Credit Depreciation		$146,400
Total Applicable to Simple Payout		$186,340

$$\text{Payout} = \frac{\$732,000}{\$186,340} = \underline{\underline{3.9\ \text{years}}}$$

Case 3: $732,000 Capital Investment
20 year Depreciation
DOE Pays 50% as part of PON System (DOE Incentive)

Gross Income*		$116,280/yr
Gross Expense		
Operating:	50,000	
Depreciation:	36,600	
	86,600	$ 86,600
Gross Profit		$ 29,680
Income Tax (50%)		$ 14,840
Net Profit		$ 14,840
Credit Depreciation		$ 36,600
Total Applicable to Simple Payout		$ 51,440

$$\text{Payout} = \frac{\$366,000}{\$\ 51,440} = \underline{\underline{7.1 \text{ years}}}$$

Case 4: $732,000 Investment
5 year Depreciation (DOE Incentive & Tax Incentive)
DOE pays 50% as part of PON System

Gross Income*		$116,280
Gross Expense		
Operating:	50,000	
Depreciation:	146,400	
	196,400	$196,400
Gross Profit		-$80,120
Income tax credit (50%)		$ 40,060
Net Profit (Income tax credit)		$ 40,060
Credit Depreciation		$146,400
Total Applicable to Simple Payout		$186,340

$$\text{Payout} = \frac{\$366,000}{\$186,340} = \underline{\underline{2.0 \text{ years}}}$$

Scenario # 2: District heating and cooling (Case study: Retirement community outside Phoenix)

Location: near Phoenix
Temp : 280°F
Depth : 3000 ft
Salinity: 2000 ppm
Land : Private
Development: 1990

i. Introduction

District heating and cooling draw heavily from energy resources, particularly the cooling load. This use design has two basic cases (scenario #2 and #3), one of which retrofits an existing community and the other designed for heating and cooling a new community. We begin by assuming that an existing community outside Phoenix can use geothermal well to provide the means of district heating and cooling. The case that develops geothermal usage in a new community will be discussed in scenario no. 3 which is similar to this scenario. A diagramatic representation of this scenario is given in Fig. 30.

ii. Description of Community

Let us choose a community of 10,000 houses near Phoenix. This area has a variable temperature range. Between the months of May and September the temperature is 65°F - 80°F at night; and 85 - 115°F during the day. Thus almost no heating is needed during this period, while a tremendous amount of cooling is required. However, during the months of November to April the temperature ranges from 30°F to 55°F at night; so a good amount of heating is needed. During the day the temperature is 50 - 85°F and either cooling or heating may be required.

iii. Wells' Characteristics

Flowrate of Brine: 2.5×10^5 lb/hr per well
Distance of wells from plant: 2 miles
Depth of injection well(s): 2000 ft

iv. System's Description and Energy Requirements

Assuming the area of each house is 2000 ft^2 and the energy required for heating and cooling (assuming that all houses have a forced air cycle for both heating and cooling) is 36,000 KWH/yr. Therefore total energy needed for all houses is 3.6×10^8 KWH/hr.

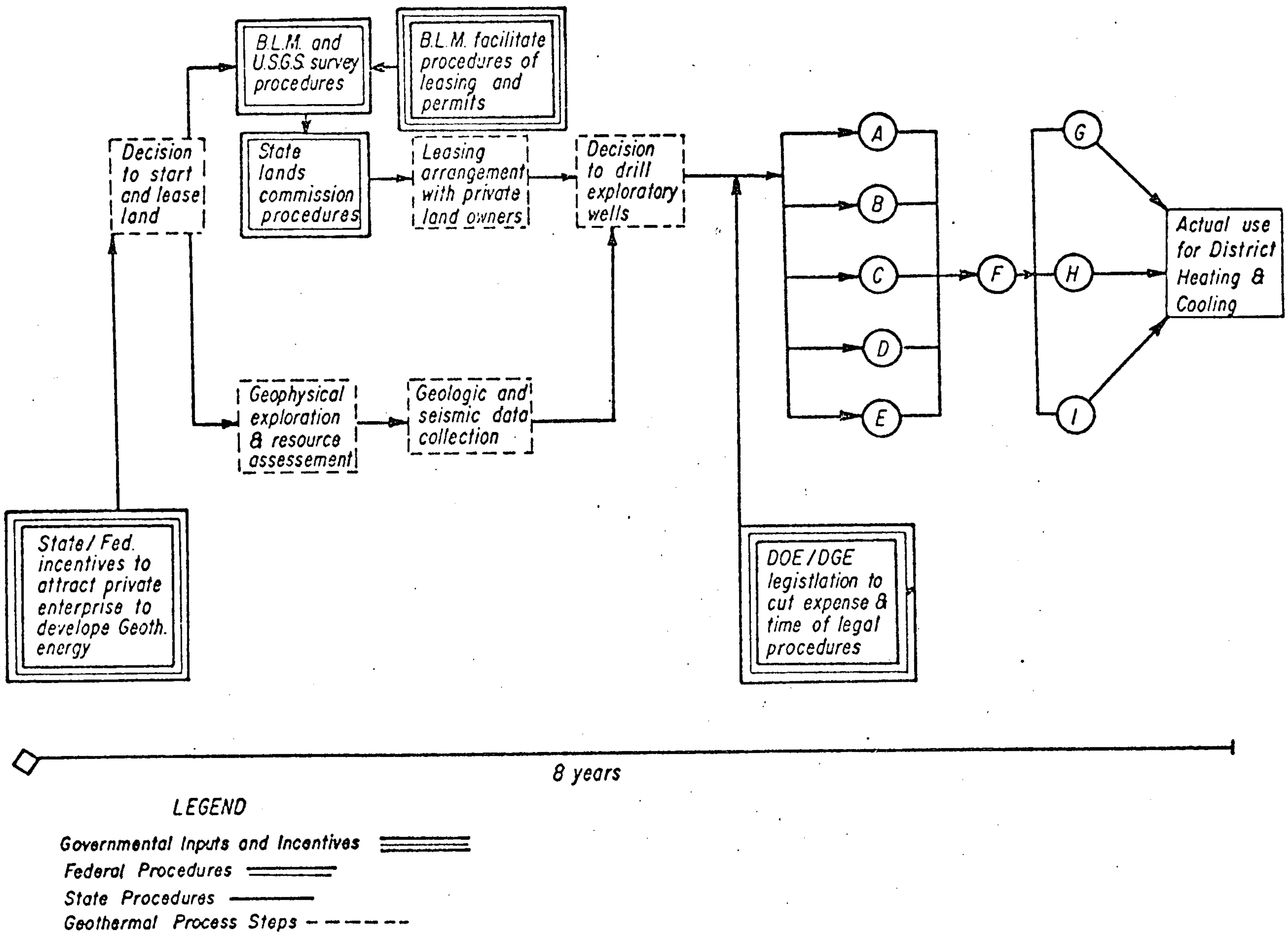


FIGURE 30: DISTRICT HEATING AND COOLING - PRIVATE LAND

The system that will be used is described as follows: a centralized plant with heat exchangers and absorption cooling system will be used. This system is depicted in Figure 31. The geothermal well provides brine at 280°F, which is used to heat regular water passed through a heat exchanger. Assume temperature of water is 70°F, assume that flowrate of brine in heat exchanger is equal to flowrate of regular water. Assume the fresh water in the heat exchanger is heated to 205°F, and is sent through insulated distribution pipelines to the houses, where they act as a source of heat for the fat in the force air cycle unit in the house. The thermostat of each unit in the house will be used to regulate the temperature in the rooms. The temperature of the hot water reaching the house is about 200°F. This fresh hot water could be used for household washing, etc. Assuming a 10°F approach let us calculate required flowrate for heating in the winter season.

Q = energy required = (flowrate)(heat capacity)(temp. change)
$= mC_p\Delta T$
m = flowrate = $(3.6\times10^8$ KWH)(3413 BTU/KWH)$\div$(280°-215°F)(3600 hr)
$= 5.2 \times 10^6$ lbs/hr

For cooling, m = 1.3×10^6 lbs/hr
Assuming the flowrate for each well is 250,000 lbs/hr.
No. of wells = 5×10^6 lbs/hr $\div$ 2.5×10^5 lbs/well-hr
= 20 wells

Using heat exchangers with 316 stainless steel tubings, each has an area of 15,000 ft^2. Four heat exchangers are needed. Each costs $120,000. If we use Arkla Solaire absorption units, each with 2500 tons of refrigeration, we need about 5 Arkla units at $600,000 for each unit.

Let us now try to estimate the total cost of this project. (Most of the above calculations are approximations, based upon fallable assumptions)

v. Cost Estimates

Cost of production wells = no. of wells x depth x cost/ft
So cost of prod. wells = 20 x 3000 x 50 = $3,000,000
Assuming only 10 injection wells, 2000 ft. as depth of well and at a total cost of $40/ft, the cost of injection wells = 10 x 2000 x 40 = $800,000. Cost of heat exchangers without installation = 4 x 120,000 = $480,000. Cost of Absorption Chillers = 5 x 600,000 = $3,000,000 without installation.

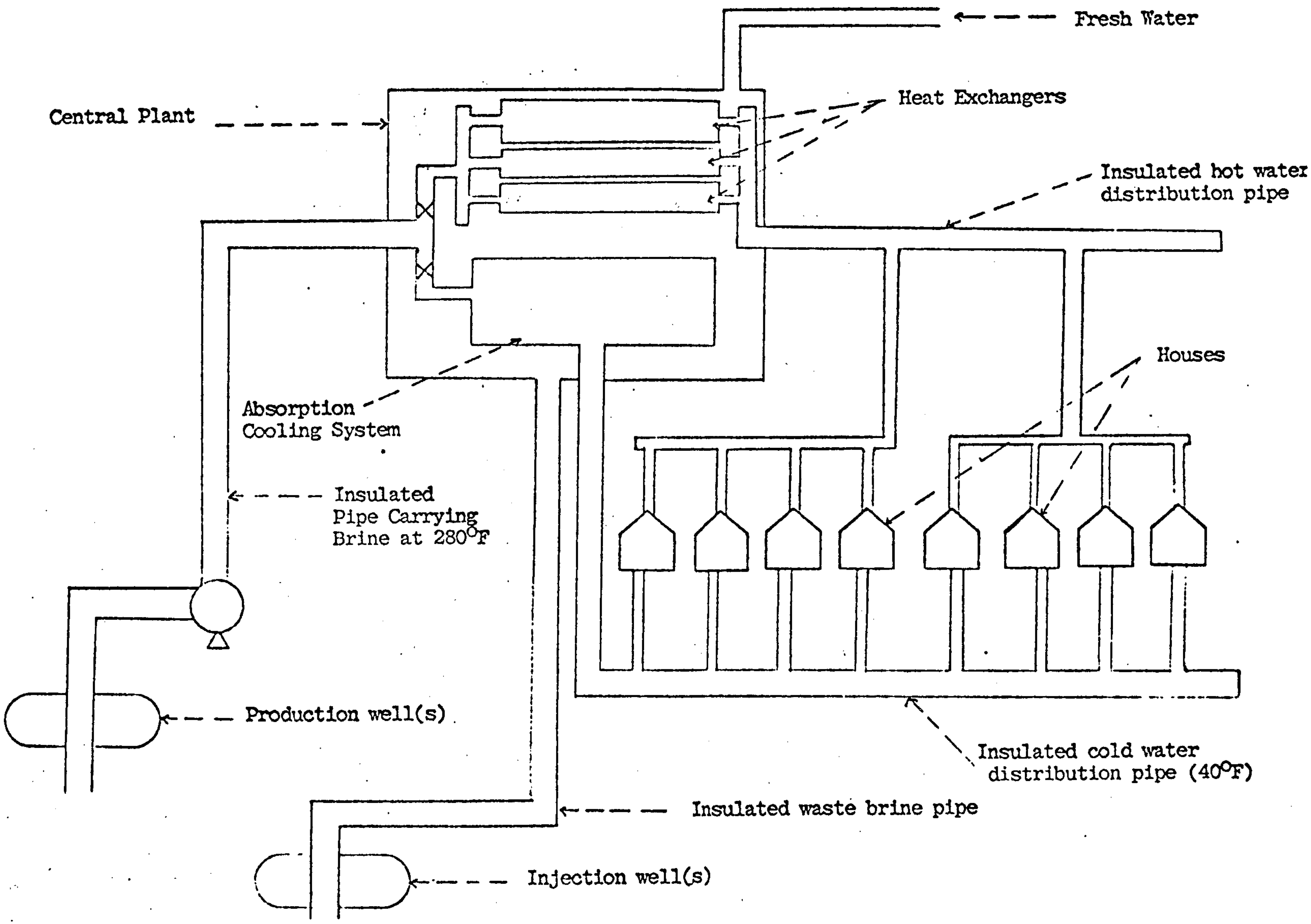


FIGURE 31: SCHEMATIC REPRESENTATION OF DISTRICT HEATING AND COOLING SYSTEM

A preliminary estimate of the total capital investment for this project is \$25,000,000. The rate of return based on a simple payout with ten years amortization is calculated as follows:

G = Gross income - Annual utility bill for houses
= Load (KWH/yr) x cost (\$/KWH)
= $3.6 \times 10^8 \times 0.036 = 13{,}000{,}000$ \$/yr

Op = operating cost
= \$200,000 per year (approximately)

$$Dp = \text{Depreciation} = \frac{\text{Total capital investment}}{\text{Years project is expected to last}}$$

= \$25,000,000/10 years = 2,500,000 \$/yr

Pg = gross profit = G -(Dp + Op)

= 13,000,000 -(2,500,000 + 200,000)

= \$10,300,000 per year

Pn = net profit after 50% tax = 5,150,000 \$/yr

$$\text{Simple payout} = \frac{25{,}000{,}000}{5{,}150{,}000 + 2{,}500{,}000} = 3.3 \text{ years}$$

Scenario #3: New Communities
Case Study: Pinacate area

Location :	Unpopulated geothermal areas
Temperature:	260°F
Depth :	1 km
Salinity :	2500 ppm
Land :	private
Development:	1995

i. Introduction

This scenario takes the area of Pinacate as a case study for using geothermal resources for space heating and cooling of residential homes. The geothermal heating and cooling system will be incorporated into the houses as they are constructed. As this new community expands the geothermal resources could be used along with conventional fuels in various areas of industry. At the present time we will consider the use of geothermal energy for comfort heating and cooling.

ii. Description of Community

Pinacate is a relatively remote area which as a good geothermal potential that could be used as a source of energy for a new residential community. Pinacate's hot dry climate points immediately to relative amounts of the energy required for cooling as compared with heating. This is because Arizona has a wide temperature range. The temperature range at Pinacate from May till August is 60 - 85°F at night and 85 - 115°F during the day. As predicted, a large amount of energy is needed for cooling, while from September till April the temperature ranges from 30 - 55°F at night; and 60 - 85°F during the day. Consequently, a moderate amount of energy is also required for heating.

Let us assume that a construction company is planning to build 200 housing units in Pinacate, and that the Department of Energy proposed to give this construction company a grant to encourage this company to build houses with individual geothermally based heating and cooling units.

iii. Well Characteristics

Flow rate of brine: 160,000 lb/hr
Distance of production and injection wells from houses: 1 mile

iv. System's Description and Energy Requirements

The system used in this scenario is described as follows; the geothermal well provides the hot brine that is transported to the houses by a 10 in. insulated pipe one mile long. This main pipe branches into smaller insulated pipes; (200 smaller pipes, 2" in diameter) one pipe for each house. We assume that the area of each house is 2000 ft^2; and all the houses have air conditioning units that use a forced air cycle. These air conditioning units can be used as coolers or heaters and the temperature inside the house is regulated by a thermostat. Each house has a heat exchanger unit and an absorption cooling unit. The hot brine will be sent into the heat exchanger to heat regular water at 70°F. This water comes out at a temperature of 200°F and is used in the air conditioning unit to produce hot air. On the other hand, the brine will be used in the absorption cooling unit to cool regular water from 70°F to 40°F. This cold water is used in the air conditioning unit to give cold air. For both cases of cooling and heating the brine does not circulate in the houses' plumbing pipes; it only circulates in the heat exchanger and absorption cooler, limiting problems of pipe corrosion and scaling. The waste water brine is sent through a small pipe which is connected to a main uninsulated pipe that flows into the injection well.

Let us calculate the required flowrate for all the houses; by calculating the flowrate required for each house. Assuming that each house requires 40,000 KWH/yr for heating and cooling and assuming that all this energy goes to heating,

m = required flowrate = $Q/C_p\Delta T$

$= (40{,}000\ \text{KWH})(3413\ \text{BTU/KWH}) \div (260^\circ - 210^\circ\text{F})(3600\ \text{hrs})$

$= 760$ lbs/hr

Total flowrate for all houses = $760 \times 200 = 1.52 \times 10^5$ lb/hr and

$$\text{no. of wells} = \frac{\text{total flowrate}}{\text{flowrate/well}} = \frac{1.52 \times 10^5}{1.6 \times 10^5} = 1 \text{ well}$$

Thus one production well with a flowrate about 160,000 lb/hr and one injection well are needed.

Each house will have its own heat exchanger which will cost about \$2500, and an absorption cooling unit which will cost \$2600 with a capacity of four tons of refrigeration. Assume cost of installation to be \$2000 for both the heat exchanger and absorption cooler, including pipes and labor.

v. Cost Estimates

Assuming the total cost of drilling to be \$60/ft, the production well will cost \$120,000 and injection well \$90,000. Assume cost of equipment for well to be \$50,000 (including pump and other miscellaneous items). Assume cost of 10" main pipe and 2" diameter branching pipes all insulated and installed to be \$100,000. Total cost of equipment in 200 houses including installation is \$920,000; but this cost would have been encountered anyway without using geothermal. If the houses had gas-fired heaters and air conditioning units the total cost of these units for all houses would be close to \$920,000, so this cost will not be included in the total cost of the project.

Thus total cost of project using geothermal energy is \$400,000. If we estimate the average cost of heating and cooling per month in one house to be \$30, then cost of heating and cooling per year for 200 houses is \$72,000.

Based on a simple payout and five years amortization, with 50% tax credit to compensate for net loss due to fast amortization, the payout will be in five years.

Scenario #4: New industries

Location	:	To be determined
Temperature	:	variable; 80°C if possible
Depth	:	1-2 km
Salinity	:	2000 ppm
Land	:	private if possible
Development	:	1990

This scenario considers possible industries that could use low temperature energy sources. It may be possible to attract new industries to Arizona by demonstration of a low temperature resource. Some of the industries that are being considered are: the dairy industry, baking industry, poultry raising, orange juice concentrate plant, tomato puree, and heavy water production. The dairy industry is considered in this scenario. A dairy has already been successfully retrofitted to geothermal sources in Klamath Falls, Oregon. The idea is therefore well worth perusing for Arizona's dairies.

The dairy company under consideration now uses a 170°F heat source for approximately 21 seconds, in the pasturization process. The heating requirements need a temperature source of 80° - 340°F and uses 6 x 10^9 BTU/year of natural gas energy. The cooling process is presently done electrically and requires 2.5 x 10^6 KWH/year. After the products are cooled, they are kept in storage facilities @ 35°F. Geothermal energy could be used for this industry if a resource is near the dairy. The system in Oregon could be used as a model for plans in Arizona.

Scenario #5: Energy storage for heat pump systems

Location	:	Phoenix, Tucson
Temperature	:	60 - 120°C
Depth	:	0.5 - 2 km
Salinity	:	2000 ppm
Land	:	Federal, state
Development	:	1990

This scenario involves using a heat pump system for heating purposes, or possibly heating and cooling process combined. The success of this geo-utilization is dependent on the finding of a high porosity aquifer near the surface containing low-temperature water; the colder the better. If such an aquifer were found, it would be considered as a cooling source for large schools, hospitals, and other large units. If this operation was deemed successful individual home units could then be considered.

The heat pump with cold storage should be compared with an absorption cooling unit operated on hot geothermal waters. For places with heating loads in winter time, the same heat pump can be used.

Technically, we should compare the central cooling and distribution of chilled fluid through houses with individual heat pump use, in which the cool water is circulated from a central source. The same question applies for absorption cooling units, where either the chilled fluid is transferred through the houses or the hot geothermal waters are pumped. In any case, best efficiency can be expected if the flow to each individual unit is in parallel rather than in series thus preventing reduction of temperature from one unit to another.

Scenario #6: Central Arizona Project/Peak Power

Location :	Tucson, Phoenix
Temperature:	60-120°C
Depth :	0.5-2 km
Salinity :	2000 ppm
Land :	Federal, state, Indian
Development:	1990

This scenario is designed to use either geothermal sources or a binary cycle to run turbines for the direct pumping of steam. The turbines would be used to power the pumps at the pumping station. This scenario would also evaluate whether or not it would be cheaper to use the geo-source or to use coal from the Four Corners Area to generate the electricity and have the investment of the transmission lines to the stations. 1.2×10^6 acre feet of water will be pumped 900 ft high and then distributed to Tucson and Phoenix. For this scenario to work, the economics for electric pumping should be analyzed in comparison with steam turbine pumping, both with regard to investment cost and operational cost.

Scenario #7: Wind energy/geothermal energy/energy storage

Location :	White Mtns, Flagstaff
Temperature:	60°C, 210°C (HDR)
Depth :	1 km
Salinity :	2500-3000 ppm
Land :	Indian, State, Federal
Development:	1990

This scenario is designed for the northern mountainous areas of the state. If it designed to use wind energy as a supplement to geothermal or solar energy. This energy would be used in the paper and lumber industries, as well as for recreational and other related uses. For example, lakes that tend to freeze over could have a small area that would be kept ice-free in winter. This would deter fish deaths due to lack of oxygen and freezing.

Scenario #8: Hot igneous rock and power plant

Location : Springerville/St. Johns, Safford Chandler
Temperature: 210°C
Depth : 1 km
Salinity : 2500 ppm
Land : Federal, State, Indian
Development: 1990

This scenario studies the injection of water into hot igneous rock strata to obtain steam for power production and industrial uses. Geologic information indicates that hot dry rock resources may exist near Springerville. If the temperature of the rock is very high the system could be quite economical. However, the technology to develop hot dry rock is still in the early stages.

Scenario #9: Coal mining operations

Location : Four-Corners area
Temperature: 60-200°C
Depth : 1-2 km
Salinity : 3500 ppm
Land : Indian
Development: 1990

This scenario is designed for the coal-fired power plants that service Arizona and Southern California. The geothermal waters would be used for coal washing, dust control, slurry transporation, and local vegetation replanting. The potential energy of the geo-water would also be integrated into the systems.

Scenario #10: Preheating/sulfur removal in coal field power plants

Location : Willcox
Temperature: 110°, 205° C HDR
Depth : 1 km
Salinity : 4000 ppm

Land	:	Federal, State, Indian
Development:		1990

Since warm water will dissolve sulfides in coal (primarily FeS_2) more quickly than cooler water, geothermal waters could be used for the planned coal-fired power plants scheduled in the Springerville and the Willcox areas of Arizona. EPA air quality standards often require the removal of some sulfur prior to the release of coal smoke into the air. An adaption comprising the fundamental technical ideas involved in Burbank, California's plans for geothermal energy use will be made. This scenario will also examine the use of Four Corners coal and will critically examine how much sulfur is removed and how much coal can be saved in a large plant, if geothermal energy were used.

Scenario #11: <u>Solution mining</u>

Location	:	Statewide (Kingman)
Temperature:		50-200°C
Depth	:	1 - 2 km
Salinity	:	2000-4000 ppm
Land	:	State, Federal, Public
Development:		Completed by 1990

Solution mining is an important scenario for Arizona. It is designed for the use of geothermal waters for the leaching processes in solution mining. The major advantages of using geothermal water is that since the water is already hot, dissolution occurs more rapidly. Solution mining via geothermal waters seems to be technically feasible but there are several pitfalls. To be successful an expertize in solution mining is needed, especially on the geological engineering aspects. This expertize is needed to direct the study to ore bodies of an economically feasible size, but have the correct geological structure to make the solution mining applicable. The proper chelating agents must be used for the recovery of the metals also. The most promising metals for this type of system are copper, cobalt, nickel and uranium, but other metals should also be considered (e.g. chronium, tin, antimomy, and the other so-called "strategic" metals). This technique has already been successfully tested and is in use in several places. Solution mining can reach deeper ore reserves, making the mining less expensive.

In some instances the solution mining may leave caverns which could be used as huge storage facilities (e.g. petroleum supplies). These caverns are also being considered for storing chemicals to be used later for energy production. These chemicals are produced and stored, for example in the summer time when using solar energy, and are used in the winter time to supplement the low grade solar energy.

At this initial stage of the project a literature search has been conducted on the methods and different techniques used in solution mining. It has been found that solution mining has been practiced for several years. It has been applied to extract various ore deposits such as uranium and copper (in Arizona), and to disintegrate coal with a basic aqueous solution in order to form a slurry which can be extracted. Solution mining techiques have been combined by C.H. Jacoby with geothermal fluid techniques to extract NaCl deposits.

Our impression now is that solution mining is a technically feasible operation which in some instances is much more advantageous than conventional mining techniques. Solution mining provides an opportunity for 1) cost reduction, 2) extracting deposits which cannot be mined by conventional methods, 3) meeting environmental standards by careful control of solution mining techniques.

The major advances in the understanding of the chemistry and mineralogy of the process, along with new developments in the technologies of explosive, nuclear, petroleum, salt and geothermal fluid industries, will enable research workers in this area to develop a commercially workable method of solution mining that employs geothermal waters for highest efficiency. Improvement of solution mining techniques is being studied.

Scenario #12: Hot water for conventional mining

Location :	Tucson
Temperature:	60 - 90°C
Depth :	1-2 km
Salinity :	2000 ppm
Land :	State, Federal, Private
Development:	Completed 1990

This is somewhat different than the solution mining scenario in that it deals with the process currently used in the copper industry. The present rate of copper leaching could be increased at least three-fold if the operating fluid is at 35°C, instead of the normal ambient temperature of 21°C. This demonstrates that the hotter the leaching fluid, the better the production results, so the use of geothermal water would be extremely desirable. This would conserve energy used to heat the storage pond water and create a better production rate, as well as preventing the storage ponds from cooling down to 10°C in the winter months.

Scenario #13: Hot mines

Location :	Underground Mining Areas (Clifton)
Temperature:	50-90°C
Depth :	1-2 km
Salinity :	2000 ppm
Land :	State, Federal, Private
Development:	1990

This scenario is concerned with the correction of an existing problem. Some underground mines have hot waters in them, causing severe ventilation and temperature control problems. This scenario's purpose is to see if these hot geothermal waters can be used for an advantageous purpose, instead of the problems they now cause.

Scenario #14: Salt production

Location :	Yuma, Hyder Valley
Temperature:	60-180°C
Depth :	0.5 - 2 km
Salinity :	2500 - 3500 ppm
Land :	Federal, state, Indian
Development:	1990

Extensive beds of salt exist in Southern Arizona. This scenario considers the use of geothermal water to recover the salt from these beds. The effluent waters would be used to dissolve the concentrated salts for the production of the raw material; then the waste geo-water would be reinjected in the salt storage caverns thus created. Alternatively, the waste water could be left with the salt brines to be purified by solar pond evaporation with the caverns used to store petroleum products under the USA policy of having on hand a reserve supply of crude oil and/or other selected products.

Scenario #15: Desalination

Location :	Yuma, Phoenix
Temperature:	150-180°C
Depth :	1.0 - 2.0 km

Salinity	:	3500 ppm
Land	:	Federal, State and Indian
Development:		1990

This scenario as shown in Figure 32 considers the utilization of hot steam or hot waters to convert brackish waters, including the geothermal waters, to potable water. A good example of this type of operation is the Geysers project and that of the East Mesa test site. An example of a calculating process is given in this scenario. This scenario is important because water is scarce in Arizona, e.g., in the Northern part of the state, or are brackish, e.g. in the Safford area. Geothermal water could be helpful in solving the water problem in several ways:

1. Desalinate brackish or sea water using geothermal heat.
2. Use the condensed steam obtained after condensation of flashed geothermal water.
3. Use geothermal water as is wherever it happens to be of potable quality.

Two desalination plants are now in operation in Arizona.

1. At Buckeye using the electrodialysis method.
2. At Yuma using the reverse osmosis method.

At Buckeye potable water for 3000 people is produced while in Yuma they desalinate 600 acre feet/day (approx. 800,000 m^3/day).

In Arizona the amount of water consumed exceeds the amount being replenished by 2,200,000 acre feet/year. So the water problem becomes progressively more acute. This water can be considered as a nonrenewable resource, some people saying that it is "being mined"*. 89% of the water in Arizona is used for agriculture 16% for industrial and municipal use and 1% for fish and wildlife.

The import of water through the Central Arizona project will be only 1,200,000 acre feet/year, barely half the above mentioned overdraft. Therefore it is of great importance to make plans for the desalination of sea or brackish water. Since the cost of energy is a very significant factor in the desalination process, geothermal production at reasonable cost could be a very important asset for the desalination process; it is a source of both the water and the energy. About 7,000,000 acre feet/year is used in

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* H.W. Peirce, Field Notes, 6 No. 2, June 1976

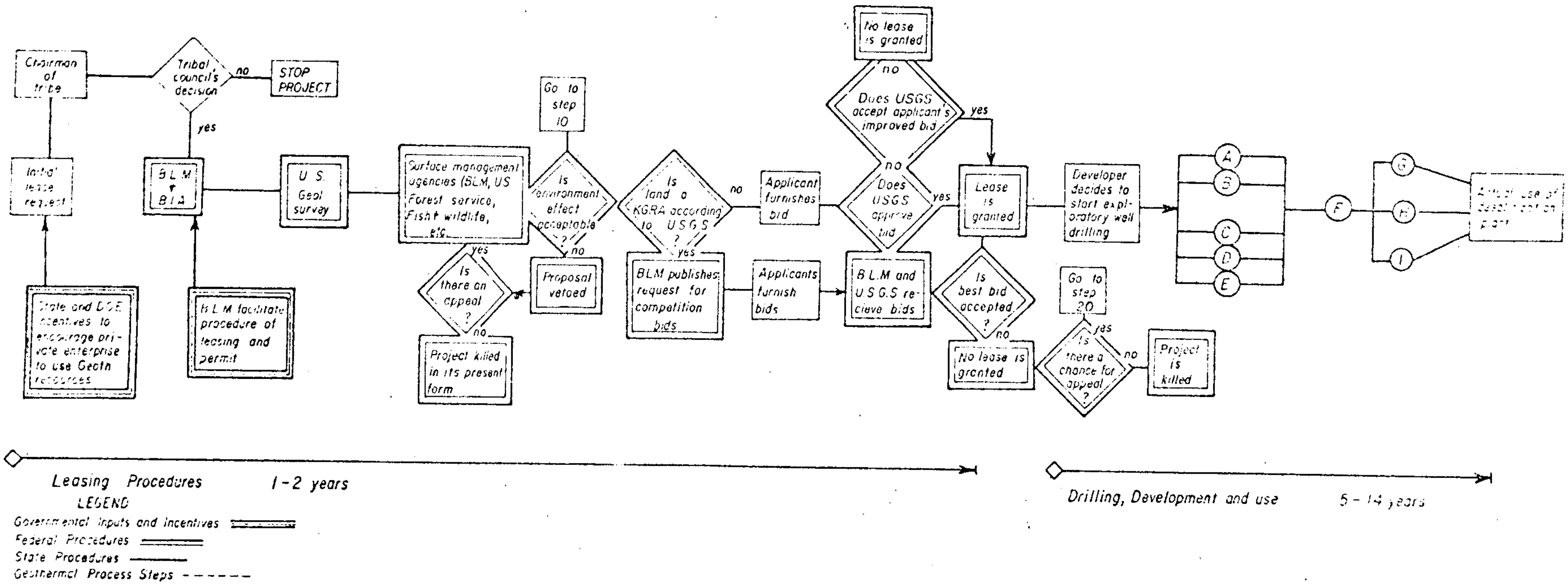


FIGURE 32: DESALINIZATION PROJECT - INDIAN LANDS

Arizona of which 5,000,000 is pumped from the ground (50% of it not being replenished) and 2,000,000 acre feet/year which comes from the Colorado river.

A Preliminary Calculation for Desalination

Objective: To calculate the amount of geothermal energy needed to produce 100 m^3/day of potable water from sea water. The temperature of the steam (geothermal) is 150, 200, 250°C.

The following calculations and assumptions will be based on the report:

Description of the equipment used - the solar collectors being replaced by a source of geothermal energy, other equipment the same. The actual operation given in the report by Hodges et al. is as follows:

a. Assume that the geothermal energy can be converted 100% into actual usable energy in the heating process.

b. Air water contact Equipment
Plane surface evaporators are used, which provides one enthalpy transfer unit operating at 1000 cfm air flow and 25 gpm water flow. A packed tower is used. The packing material is Dow's Maspac Fm-90, plastic tower packing.

c. Heat exchangers - conventional design consists of 6 shell and tube units. Area was over 1000 ft^2. Wire mesh was used to support film and promote turbulence.

Assuming steady-state conditions:
The total area of solar collectors -
#1: (150;)(9'8") = 1450 ft^2
#2: (98')(14') = 1372 ft^2
#3: (50')(3') = 150 ft^2
total area = 2972 ft^2

Taking the data at N_T = 5 (number of transfer units per component)

q_s = 2000 BTU/sq ft. day
γ = 5 lb/sq ft. hr (import of brine)
outside temp. = 70°F.

* Hodges, C.N. et al. Separate Component Multiple-effect Solar Distillation

The solar collectors have a glazing specific productivity:
0.10 gal/sq. ft-day
Brine input:

$$\frac{(5\ \text{lb})}{(\text{sq.ft hr})}(2972\ \text{ft}^2) = (14860\ \frac{\text{lb}}{\text{hr}})(\frac{24\ \text{hr}}{\text{day}}) = 356640\ \frac{\text{lb}}{\text{day}}$$

total energy/day:

$$\frac{(2000\ \text{BTU})}{\text{sq.ft day}}(2972\ \text{ft}^2) = 5.944 \times 10^6\ \frac{\text{BTU}}{\text{day}}$$

total output:

$$\frac{(0.10\ \text{gal})}{\text{sq.ft day}}(2972\ \text{ft}^2)\ \frac{(8.3121\ \text{lb})}{\text{gal}} = 2470.35\ \frac{\text{lb}}{\text{day}}\ \text{of fresh water}$$

Substituting geothermal energy for the solar energy input - calculate amount of steam at 150°F, 200°F, 250°F needed:

$$Q = 5.944 \times 10^6\ \text{BTU/day}$$

At $T_s = 150^\circ F$, steam-sat'd vapor

$V_g = 97.20\ \text{ft}^3/\text{lb}$

$h_g = 1125.7\ \text{BTU/lb}$

$Q = h_g$ (amount of steam needed)

$$5.944 \times 10^6\ \frac{\text{BTU}}{\text{day}} = 1125.7\ \frac{\text{BTU}}{\text{lb}}\ (\frac{X\ \text{lb}}{\text{day}})$$

$$X = 5280.3\ \text{lb}\ \frac{\text{steam}}{\text{day}}\ \text{at } 150^\circ F$$

which is

$$(5280.3\ \frac{\text{lb}}{\text{day}})(\frac{97.20\ \text{ft}^3}{\text{lb}}) = 5.1324 \times 10^5\ \frac{\text{ft}^3}{\text{day}}\ \text{of steam } (150^\circ F)$$

produces $2470.35\ \frac{\text{lb}}{\text{day}}$ fresh water

+ the amount of water in steam

These calculations are based entirely on the process of solar distillation. Calculations differing from the solar distillation data can not be made since the data apply only to these processes.

If geothermal energy in form of 150°F water:

$Q = \dot{m}\, C_p \Delta T \qquad C_p = 1.0\ \frac{BTU}{lb^\circ F}$

$\dot{m} = \frac{5.944 \times 10^6\ BTU/day}{\left(\frac{1\ BTU}{lb^\circ F}\right)(150^\circ - 70^\circ)} = 7.43 \times 10^4\ \frac{lb}{day}$ producing 2470.35 lb H_2O

Steam at 200°F:

$h_g = 1145.8\ \frac{BTU}{lb} \qquad V_g = 33.67\ ft^3/lb$

$(5.944 \times 10^6\ \frac{BTU}{day}) / 1145.8\ \frac{BTU}{lb} = 5187.6\ \frac{lb}{day}$ steam at 200°F

$(5187.6\ \frac{lb}{day})(33.67\ \frac{ft^3}{lb}) = 1.7466 \times 10^5\ \frac{ft^3}{day}$ steam at 200°F

producing 2470 lb/day H_2O

Water at 200°F

$\frac{5.944 \times 10^6\ BTU/day}{\left(1\ \frac{BTU}{lb^\circ F}\right)(200-70)} = 4.5723 \times 10^4\ \frac{lb}{day}$ H_2O (l) at 200°F

Steam at 250°F:

$h_g = 1163.8\ \frac{BTU}{lb} \qquad V_g = 12.84\ ft^3/lb$

$(5.944 \times 10^6)/1163.8) = 5107.4\ \frac{lb\ steam}{day}$ at 250°F

$(5107.4\ \frac{lb\ steam}{day})(13.84\ \frac{ft^3}{day}) = 7.069 \times 10^4\ \frac{ft^3}{day}$ steam

Water at 250°F

$\frac{5.944 \times 10^6\ BTU/lb}{\left(\frac{1\ BTU}{lb^\circ F}\right)(250-70^\circ F)} = 3.302 \times 10^4\ \frac{lb}{day}$ water at 250°F

Similar calculations can be made using different number of transfer units per component.

Scenario #16: <u>Biosalinity agriculture</u>

Location :	Yuma area, Arizona
Temperature:	150 - 180°C
Salinity :	3500 ppm
Depth :	1-2 km
Land :	State, Federal, or Indian
Development:	ready by 1990

This scenario uses the basic concepts of biochemical and related technologies for the growing of plants, micro-organisms, and the more primitive forms of plants and animals of the sea, so that these plants and animals can be integrated into a food chain system. This is especially promising for use in cattle and poultry feed supplements. The waste irrigation waters of the Yuma area could be combined with geothermal waste waters to consolidate potential irrigation resources. Yuma's proximity to the Pacific Ocean may also prove an influential factor. Other probable locations would be the Tucson and Phoenix areas.

Scenario #17: <u>Greenhouse/hydroponics</u>

Location :	Tucson, statewide
Temperature:	70 - 80°C
Depth :	1 km
Salinity :	2000 ppm
Land :	State
Development:	2000

Greenhouse production of winter vegetables could be aided via the use of geothermal H_2O. The University of Arizona has developed controlled-environment vegetable agriculture, and is recognized as the leader in the field, exemplified by the commercial operations now in existence in Abu Dhabi, Iran, Mexico and Arizona. The geothermal water would be used to heat the greenhouse, the waste water, then treated with nutrients and used for irrigation of the crop. The major problem is the salt content of the water; it causes the plants to wither faster. This can be easily overcome by rinsing the soil with PH balanced H_2O. This scenario appears unattractive for many parts of Arizona, but it still is worth consideration for the future.

Scenario #18: Irrigation pumping (Case Study: Hyder Valley area)

Estimates of Resource Characteristics

Subsurface Fluid Temp (^oC)	:	Range 55-210^oC Best Estimate - 200^oC
Total Dissolved Solids	:	2500 - 4000 ppm
Overlying Rock		
Depth	:	0.5-2 km
Land Status		
BLM Administered	:	22.55 x 10^5 acres
State land	:	4.27 x 10^5 acres
Indian Res.	:	2.3 x 10^5 acres
Individual & Corp.	:	5.43 x 10^5 acres
Misc. Public Land	:	29.36 x 10^5 acres
Development Status	:	Working Approx in 1990

The purpose of this study is to find an alternate fluid other than steam to produce peak power for a plant. The power could be used for irrigation pumping when the peak power is not demanded. This scenario was located in an irrigation area, with an orange juice concentrate plant in the vicinity. The irrigation pumping would be used to expand the citrus groves in Hyder Valley. (Yuma County's harvested crops total 322,360 acres, oranges 13,460 acres). Details on Institutional procedures for this scenario are given in Figure 33.

The major problem of using a geothermal fluid for the pumping as well as irrigation, is the total dissolved solid content (i.e. salinity). The water must have a low salinity 0-500 ppm in order for the fluid to be feasible. If the salinity is above this range a desalination process must be included in the scenario set-up. This is an added cost that must be considered in the economic evaluation.

The irrigation pumping in Arizona is about 1,250,000 acre feet of water but much more pumping of water is going on in Arizona and will extend even more with the Central Arizona project which will pump some 1,200,000 acre feet/year to an elevation of 900 ft. and afterward distribute it in the state mainly to Tucson and Phoenix. Therefore the great amount of pumping needed could be made at times when there is no peak demand of electricity and thus make the consumption of electricity more even during the day or season of the year. To be successful, it will be necessary to line up the loads for this particular scenario system so that it is also operating at nearly 100% of capacity. Since Arizona uses of electricl energy are much larger in the summer, as well as more irrigation pumping in the summer, it will be necessary to find a base load for non-peak uses for the geothermal system

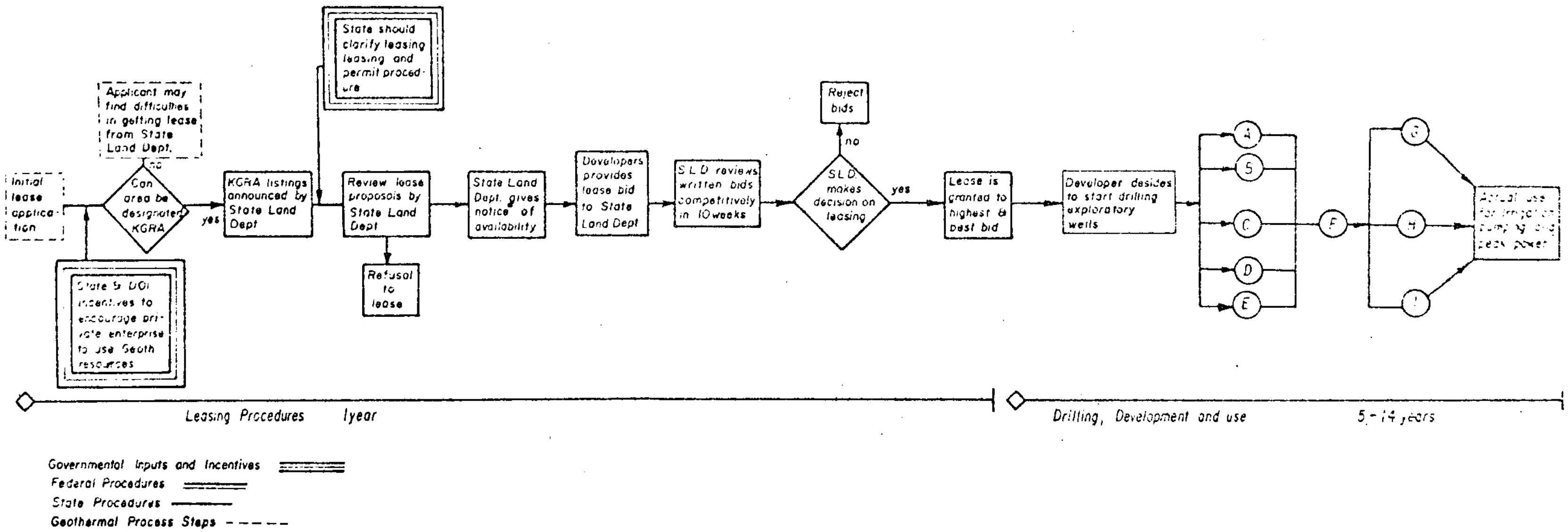


FIGURE 33: IRRIGATION PUMPING/PEAK POWER - STATE LAND

such that it can run at a higher capacity in the winter than in the summer. Also, it will be necessary for this off-peak use to be interruptable so that the irrigation pumping and the peak power generation can be accommodated. There is no obvious first choice for the off-peak use of such power or direct steam or direct hot water, but one agricultural candidate for such interruptable processing operation is the manufacturing of frozen orange juice in the Yuma area. Possibly some other interruptable agricultural or food processing operation not now in existance, but which could be moved from California to Arizona, could use geothermal power. The combination of an industrial plant with the irrigation pumping would also make the use of power more uniform thus using the industrial plant only in the off peak power period.

The use of solar energy for irrigation pumping in Arizona has been considered many times and therefore geothermal energy would be even more appropriate having more advantages than the solar energy system because geothermal water is at a constant temperature all the time (day and night) and in some cases by adding water to the area, if the water is suitable for use.

Binary system or steam turbines could be used. In the G.E. Report by J.H. Eskesen a total of ten compounds were selected as possible working fluids for the geothermal binary cycle:

> Propane, Propylene, Isobutane, N-Butane, Isopentane, N-Pentane, $CHClF_2$, CH_2F_2, Ca Cl F_5 and Ammonia.

Comparison of steam turbine and binary cycles:

> "If the noncondensible gas content in the brine is low, a dual flash steam turbine cycle will produce more power per unit or brine flow than a dual flash/binary cycle, but less power than the Brine/Binary Cycle" *

The best candidate for the Binary Cycle at the specific resource in question is N-Butane. The N-Butane cycle operating on the 500^{o}F resource is investigated in detail.

Scenario #19: <u>Crop drying</u>

Location :	Yuma, Casa Grande, Tucson
Temperature:	60 - 120^{o}C
Depth :	1-2 km
Salinity :	2000-3500 ppm
Land :	State, Private, Federal, Indian
Development:	Completed 1990

*JH Eskesen, Geothermal Energy report.

This scenario is designed to replace the steam used in the drying and pelleting of grain processes with a geothermal source. The steam used is in the 80 - 100°C range and it must be wet steam for the grain drying. For the pelleting process it must be dry steam. The products obtained are used primarily in cattle feed lots. The major set back to using geo-energy for this type of process is the high salinity content. The geo-water would have to be partially desalinable to use in the dehydration process.

Scenario #20: Kiln drying of lumber

Location	:	Springerville/St Johns
Temperature	:	55°C, HDR 210°C
Depth	:	1 km
Salinity	:	250 ppm
Land	:	Federal and State
Development	:	1990

This scenario would involve the use of geothermal energy for the conventional approach of kiln drying. It would also consider new approaches to drying systems that would take advantage of the low humidity in Arizona. The geothermal energy could also supply some off-peak power to the lumber mills, as well as be used for heating the buildings in the winter. Other probable locations would be Fredona and White Mountains areas.

Scenario #21: Lettuce chilling

Location	:	Willcox
Temperature	:	HDTF 50-80°C
		HDR 150-200°C
Depth	:	0.8 km
Salinity	:	3000 ppm
Land	:	Federal, State
Development	:	Completed 1990

The lettuce grown in the Willcox area during the winter months is shipped throughout the U.S.A. after it is harvested, it must be rapidly chilled to 4.4°C for storage. This is presently done by use of mechanical refrigeration systems. This scenario is an appraisal of the integration of this energy load into a larger geothermal absorption cooling system. It should be determined if the load could then use "off-peak" energy, so that the peak electrical energy use could be backed out.

Scenario #22: Sugar beet plant

Location :	Chandler
Temperature:	HDTF 50 - 80°C
	HDR 150-200°C
Depth :	1.4 km
Salinity :	3000 ppm
Land :	Federal, State
Development:	1990

This scenario as shown in Figure 34 is designed to retrofit part of the sugar production process to use geothermal brine integrated with conventional fuels to help alleviate Arizona's peak load. The present sugar refining process requires relatively large quantities of low pressure steam. Thus, it provides a good potential for geothermal use.

i. General Description of the Sugar-beet refining process

This process can be presented in a simplified form as follows: Sugar beets are washed, then sliced into cossettes; the cossettes are put into hot water where the sugar is leached out by diffusion. This makes a raw juice which is heated further and purified. The purified juice is filtered then the water content is reduced by evaporation to give a thick juice, this juice is now filtered and crystals are allowed to form. The crystals and juice are then certrifuged, after which the sugar crystals are dried and packaged. At the same time we have a by-product, the pulp of the beets, after the sugar is leached from beets by diffusion. The pulp is dried and sold as a by-product.

Geothermally generated steam at 25 - 28 psig and 270°F can be used in the evaporation stage and thus geothermal brine can provide approximately 25% of steam used in the process.

ii. Description of the Stages where Geothermal Brine Could be used

a. Evaporation stage - The geothermal brine at 300°F will pass through a heat exchanger to produce steam at 270°F from potable water. This design is chosen to avoid corrosion problems in the machinery and installations of the process. The exhaust brine is injected in an injection well. Using the Holly Sugar Plant in Brawey, California as an example for energy calculations, we can say that the total process steam requirement, for a sugar-beet plant that processes 270 tons of beats per hour, is 460,000 lbs of steam per hour. Geothermal wells can provide 25% of that steam requirement, i.e. 115,000 lbs/hr of steam at 270°F and

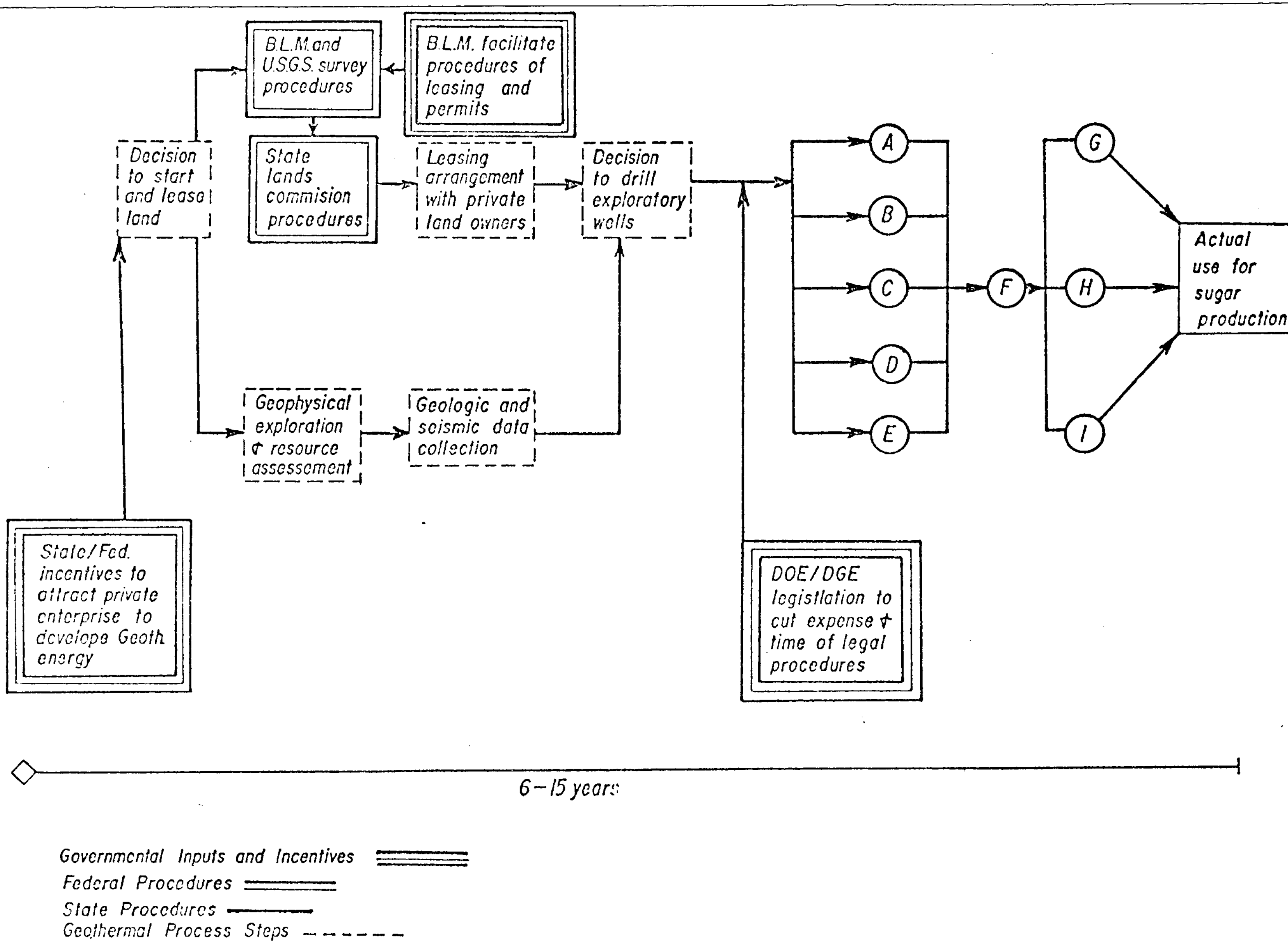


FIGURE 34: SUGAR PLANT OUTSIDE PHOENIX -PRIVATE LAND

26 psig in energy units we get, ($115{,}000 \frac{lbs}{hr} \times 1180 \frac{BTU}{lb} = 1.36 \times 10^8$ BTU/hr), $1.36 \times 10^8 \frac{BTU}{hr}$. Assuming that 1 $\frac{ft^3}{hr}$ of natural gas gives 10^3 BTU/hr, we can calculate the amount of gas savings by using geothermal energy; natural gas savings/hr = $\frac{1.36 \times 10^8 \text{ BTU}}{1000 \text{ BTU}} = 1.36 \times 10^5$ ft^3/hr. Thus using geothermal resource provides a savings in natural gas use of 136,000 ft^3 per hour.

b. Pulp Drying stage - Pulp drying uses about 40% of the energy required for the overall process. This stage is separated from the other operations of sugar refining and can be retrofitted very easily to use geothermally heated dryers. Again using the Brawley sugar plant example, the energy required for pulp dryers is approximately 270 MM BTU/hr. So the savings in natural gas per hour by using geothermally heated dryers is a significant 0.27 MCF/hr.

c. Refrigeration demand - A sugar-beet plant with the same capacity as the Brawley Sugar Plant requires 100 tons of refrigeration for the processes of crystallization and bulk sugar cooling. Geothermal brine at about 240°F could be used in an absorption cooling unit to provide 100 tons of refrigeration.

iii. Geothermal Wells' Characteristics

Temperature of hydrothermal fluid	:	300°F
Depth of Well(s)	:	3000 ft
Salinity of Brine	:	2000 ppm
Land status of site	:	Federal land
Assumed flowrate from each production well	:	500,000 lb/hr
No. of production wells	:	5
Total Flowrate from all wells	:	2.5×10^6 lb/hr
Depth of each injection well	:	3000 ft

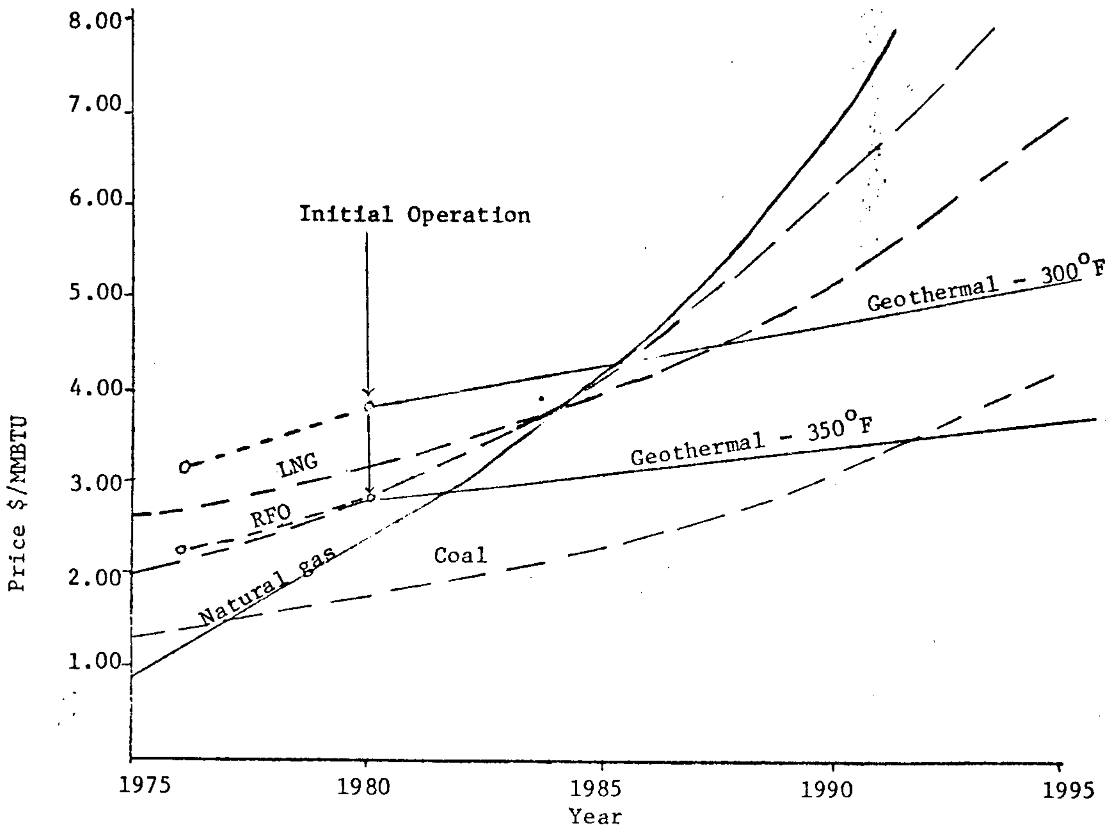
iv. Economic Comparison

This cost comparison will not consider actual cost of equipment needed for retrofitting; we will calculate an estimate of the cost of production and injection pipes. Then we will consider the savings in conventional fuels which will be encountered if geothermal energy is used in the above mentioned stages of the process.

Total cost of well = depth x cost/ft = 3000 x 50
total cost of well = \$150,000/well
total cost for 5 production wells and 5 injection wells including pumps and other equipment is \$1,500,000.

If geothermal site is 2000 ft away from sugar plant, the cost of insulated pipes is \$100,000. While cost of reinjection pipes (uninsulated) is \$80,000. Therefore; total cost of wells and pipes is \$1,680,000.

Assuming that the campaign period is 174 days, savings in energy (if we retrofit parts of evaporation stage to use geothermal energy) are 1.36×10^4 ft^3 x 24 x 174 = 56.7 MCF/campaign. Savings during pulp drying is 1127.52 MCF/campaign. Savings in fuel for refrigeration is 2840 BBLOIL/campaign. Therefore, total savings per campaign are 1184 MCF of natural gas and 2840 BBLOIL. Thus, we can see the savings in energy and cost of operation if we consider the possibility of the increase in the prices of conventional fuel. Figure 35 shows fuel price comparisons given for sugar-plant in Brawley.



Fuel Price Projections

Legend

Natural Gas - Consumer (industrial) prices for gas in Calif - Economics of Oil and Gas for Use in Calif., S.H. Clark

LNG - Synthetic fuels commercialization Program, Vol. III. and S.H. Clark

Residual Fuel Oil (RFO) - Low Sulfur fuel oil Electric Utilities Study TRW Systems and Energy

Coal - 1976 U&1 Costs escalated @ 6%/year

Geothermal - Cascaded from Boiler to Dryer geothermal Sugar Refining only (5½ mos.)

FIGURE 35: FUEL PRICE PROJECTION COMPARISONS OF CASCADED 300°F AND 350°F GEOTHERMAL SYSTEMS TO FOSSIL FUELS

V. ANALYSIS OF GEOTHERMAL POTENTIAL

A. SURVEY OF CURRENT NON-ELECTRIC APPLICATIONS OF GEOTHERMAL ENERGY

Non-electric applications of geothermal energy are of great importance in the development of our geothermal resources. Most of these applications are at a temperature below 250°C; and the fact that geothermal wells with a brine temperature below 250°C are abundant around the world and occur at moderate depths makes us realize the importance of using these geothermal resources as an alternate source of energy for non-electrical usage. *,**

Many different industries use temperatures of 250°C or below in certain stages of their industrial processes. Table 19 gives a list of such industries and the temperature range in some stages of the process and the amount of energy used in that temperature range.*** As shown in Table 19 a total of 5.823 Quads of energy are used in industry at below 250°C. However, non-industrial and commercial uses of energy require a temperature much lower than 250°C. For example, residential heating uses a temperature range of 50-74°C in most cases. So to show the potential for non-electric geothermal applications, Fig. 36 gives the temperature range and the amount of energy used in that range for all non-electric applications. From Fig. 36 we see that space heating in the United States requires 12.080 x 10^{12} BTU. Moreover, the bulk of the energy used is at temperatures up to 200°C. In addition, if we extend the above applications to approximate the realizable potential for non-electrical geothermal applications in the U.S., it is estimated that geothermal energy could provide 20 to 40% of the total potential indicated in Figure 36 or 10 to 20% of U.S. energy consumption.

It is a well known technical fact that the recovery of geothermal energy in non-electrical applications has a greater efficiency than the recovery for electrical applications. This, together with the realization that temperatures used in non-electrical applications are low to moderate, have made the use of geothermal resources economically competitive with conventional fuels used in non-electric applications. Geothermal resources are extensively used in several locations around the world like in Reykjavik and Lake Myvatin in Iceland, and Kaveran in New Zealand. The use of geothermal resources world wide encompasses a great variety of non-electrical applications such as space heating, agricultural uses and in industry.

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* Stanford Research Institute, 1972, Patterns of energy consumption in the United States; Stanford, California

** Lindal, B., 1973, Industrial and other applications of geothermal energy, in geothermal energy; Review of research and development: Paris, UNESCO (L (No. 72-97138, p. 135 - 148).

*** Reistad, G.M., 197, Analysis of potential non-electrical applications of geothermal energy and their place in the national economy: Livermore, California, Lawrence Livermore Lab., UCRL 51747.

TABLE 19

ESTIMATED USES OF PROCESS STEAM AT VARIOUS TEMPERATURES IN INDUSTRIAL SECTORS

Industry	Temperature Range (°C)		Total Steam use (% of sector)	Energy use 10^{12} BTU)
Primary Metals	≥250		~100	350.0
Chemical and Allied	≥250		5.0	54.7
Products	225-249	15%	7.5	82.0
	200-224		7.5	82.0
	175-199		25	273.5
	150-174		25	273.5
	125-149		30	328.2
Total			100	1093.9
Petroleum	225-249	20%	7	67.2
	200-224		7	67.2
	175-199		6	57.6
	150-174		40	384.0
	125-149		40	384.0
Total			100	960.0
Food and Kindred	150-174		10	90.0
Products	125-149		45	405.0
	100-124		45	405.0
			100	900.0
Total			100	900.0
Paper and Allied	175-199		70	703.5
Products	150-174		30	301.5
			100	1005.0
Other Industries*	≥250		7	407.6
	225-249		2	116.5
	200-224		2	116.5
	175-199		19	1106.4
	150-174		19	1106.4
	125-149		21	1222.8
	100-124		7	407.6
	75-99		2	116.5
	50-74		21	1222.8
Total			100	5823.1

* Divided according to steam use in other categories, except for space heating component since all space heating appears in this category. Space heating is classified as heating in the 50 to 74°C temperature range.

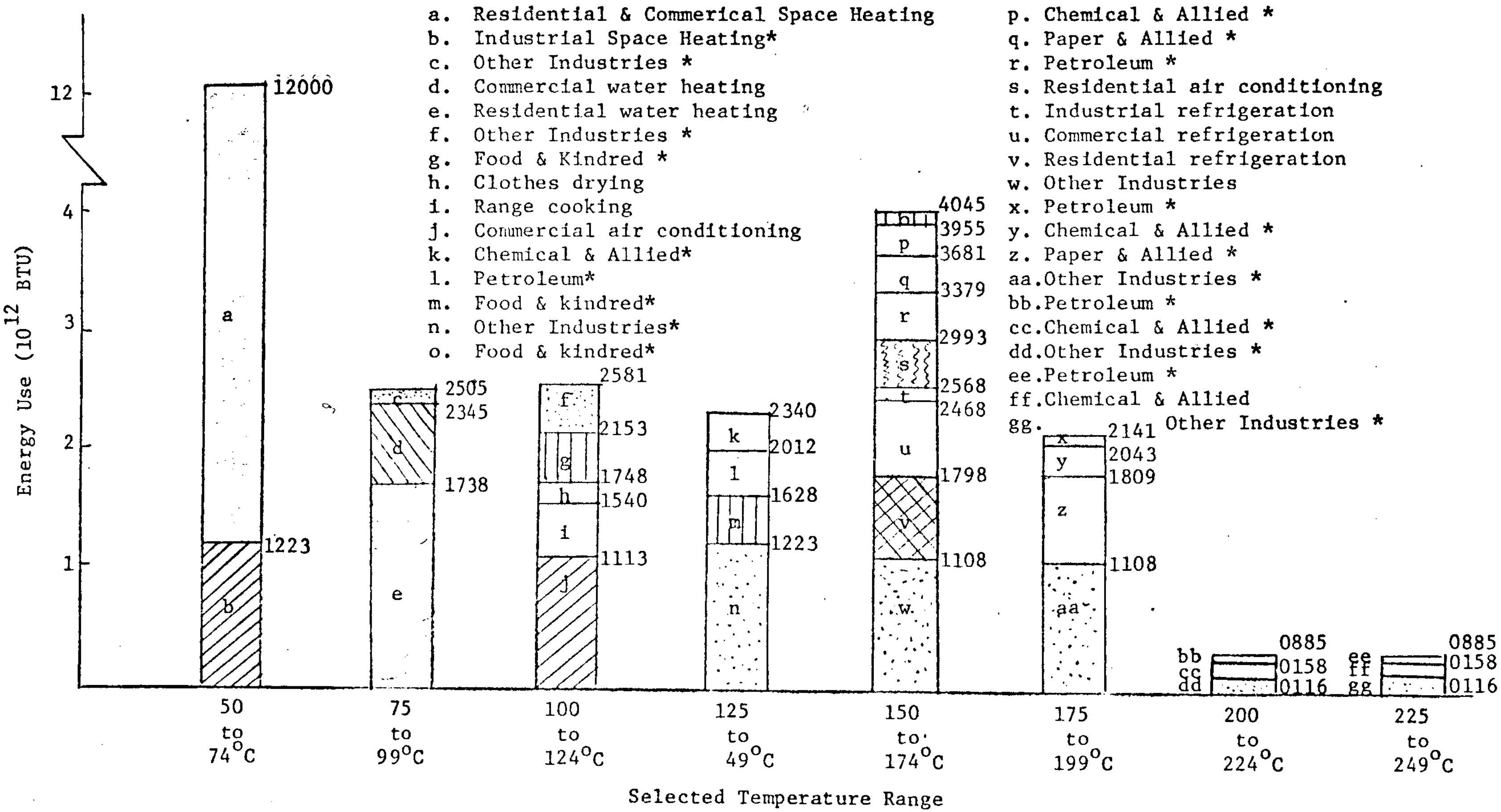


FIGURE 36: ESTIMATED HEATING ENERGY USE IN SELECTED 25°C TEMPERATURE RANGES
(*) INDICATES PROCESS STEAM USE IN SECTOR

B. ECONOMIC ASPECTS

1. Pricing of Geothermal Energy in Arizona

Pricing the energy obtained from a geothermal reservoir is an important yet complex problem. Predicting the price of an energy unit prior to geothermal development requires an insight into the future of the energy market. Various approaches to the problem have been studied and are outlined below.

i) Geothermal Steam Value for Electricity at a Given Location

Steam for the production of electricity is priced according to the value of the kilowatt-hour. The amount of steam from geothermal sources needed to supply one kilowatt hour is worth the going price of that unit of energy. Appraisal of geothermal energy's value is therefore based on the output of electricity it can produce per unit of steam.

ii) Delivered Alternative Fuel Value for Thermal Energy at Given Location

Consider the alternative fuel values compared to geothermal energy values at different locations. We want to know the value of fuel being replaced at a particular place. This value equals the value of geothermal energy which replaces it. The number of BTUs supplied is very important this causes a problem when low-grade heat is considered since BTUs at low-level temperatures are less valuable than at high-level temperatures.

iii) Capital Investment to Recover Low-Temperature Geothermal Energy

Problems with salt content of brine and other pollutants often occur. Knowing temperature and depth of the resource prior to making the capital investment allows a better estimate of necessary capital expenditures early in the project. The time to recover a capital investment is therefore an important assessment to make. Costs for using heat exchangers and pumping also hinge on the depth, salinity, and temperature of the thermal water in the reservoir. For example, the geothermal gradient influences the optimum surface area to be used on heat exchangers.

iv) Quality of Geothermal Energy based on Carnot Efficiency

Where geothermal steam is suitable for power production, the Carnot cycle could be seen as giving one good appraisement of the "quality of energy." Carnot efficiency depends on the temperature difference between the geothermal brine and the wastewater.

v) The cost of Geothermal Energy

The cost of geothermal energy must be commensurated with alternative energy systems, be they solar energy or any other type of energy used in Arizona. Geothermal energy must compete with all alternative sources of energy. Table 20 outlines an approach to analyzing Arizona's energy alternatives. Arizona has neither oil nor natural gas, but Alaskan oil may be transported across Arizona in existing pipelines in the near future. Coal is abundant in Arizona and electrical power generation from coal at several power plants helps meet the State's power requirement as well as portion of Southern California's demand. The first nuclear power plant is currently under construction and its expansion is already being planned. Future use of coal gasification and/or liquefaction depends upon current DOE, R & D results. New absorption refrigeration technology, if developed, would be good for the geothermal as well as for solar energy. If developed, heat pump technology could also lower geothermal energy costs. Each storage technology is also important especially for solar energy. It is also important for helping on daily peak power loads. For example, if all homes in Arizona were to install a rock bed energy storage system, then two-stage evaporative cooling systems could be used during all peak power periods during the summer, instead of electricity.

2. The Economics of Geothermal Energy Compared to that of Fossil Fuels

Currently, geothermal energy use appears to be generally uneconomical compared to the conventional sources of energy like natural gas, fuel oil and coal. Exceptions occur in areas with high pressure steam, like in the Geyser geothermal areas. Nevertheless, any large geothermal reservoir could become an economical alternative source of energy in the future, especially when the conventional energy sources start to run short and as the prices of these conventional fuels constantly continue to increase. Moreover, the cost of using geothermal energy could be reduced as the technology of drilling is improved.

Let us first discuss the cost of geothermal energy versus the cost of the other fuels. Figure 37 shows the price projections for conventional fuels to the year 1995. It is predicted that these prices will increase several fold thus making the cost of geothermal energy quite competitive. Figure 37 shows that the cost of coal will be more than triple while natural gas will increase almost by an order of magnitude before the next century begins.

Figure 38 shows cost projections for conventional fuels versus geothermal where geothermal costs will be competitive with the costs of other fuels in about the year 1990 for the lowest cost alternative and in the year 1982 for the highest cost alternative.

The case study of the Holly Sugar Plant of Brawly, California * provides a good example where geothermal energy used in the sugar processing industry is practically as economical as the other fuels used and will be more economical than all these fuels in the year 1993, according to the price projections in Figure 35. Consequently, the constant decrease in the conventional fuel reserves and the increase in the prices of these

* Russel O.P., Use of Geothermal Heat for Sugar Refining. Final report Oct. 1, 1976 - May 31, 1977. TRW System and Energy, Redonda Beach, Calif.

TABLE 20

ANALYSIS OF ENERGY ALTERNATIVES

OIL IN ARIZONA

NATURAL GAS IN ARIZONA

ALASKAN OIL ACROSS ARIZONA

COAL IN ARIZONA

ELECTRIC POWER GENERATION IN ARIZONA

COAL GASIFICATION IN ARIZONA

COAL LIQUEFACTION IN ARIZONA

NUCLEAR POWER PLANTS IN ARIZONA

NUCLEAR POWER EXPORT

COAL POWER EXPORT

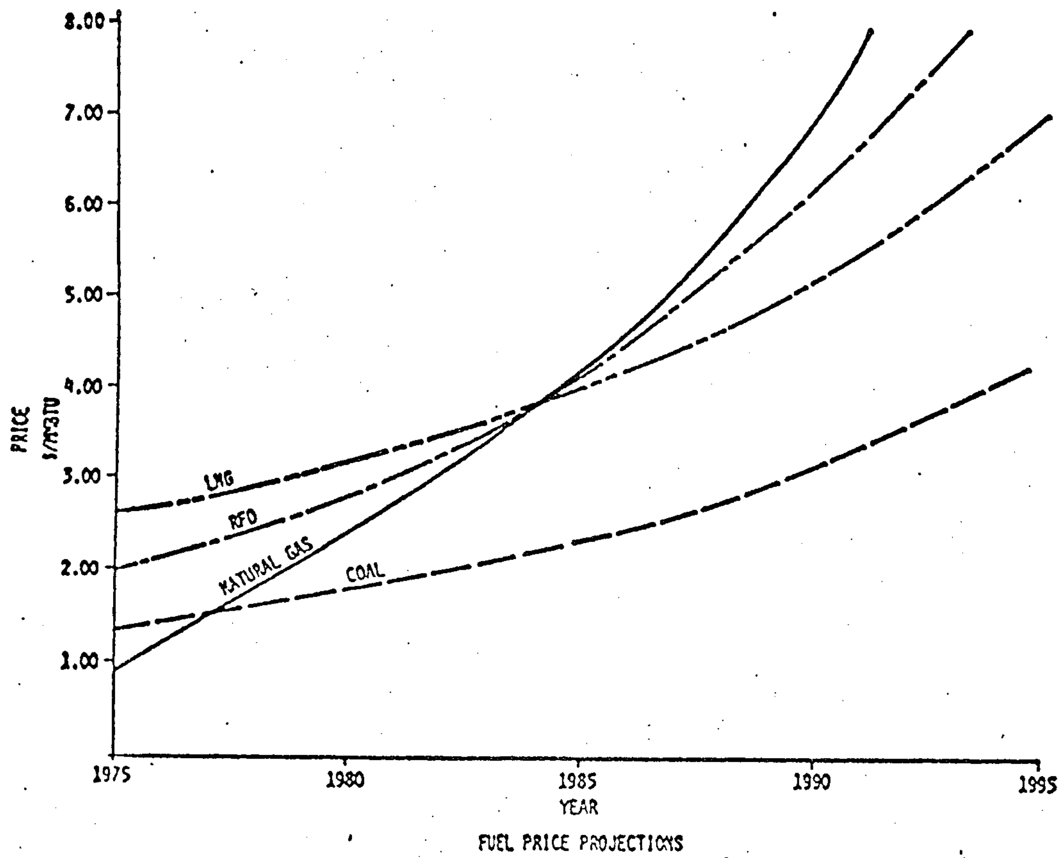
ENERGY CONSERVATION IN ARIZONA

MODIFIED ARCHITECTURE FOR ARIZONA

NEW ABSORPTION REFRIGERATION TECHNOLOGY

HEAT PUMP TECHNOLOGY

ENERGY STORAGE TECHNOLOGY



LEGEND

Natural Gas - Consumer (industrial) prices for gas in California - Economics of Oil and Gas for use in Calif. S.H. Clark

LNG - Synthetic fuels Commercialization Program, VDY III and S.H. Clark

Residual Fuel Oil (RFO) - Low Sulfur Fuel Oil Electric Utilities Study. TRW Systems and Energy

Coal - 1976 U&1 costs escalated @ 6%/year

FIGURE 37: FOSSIL FUEL PRICE PROJECTIONS

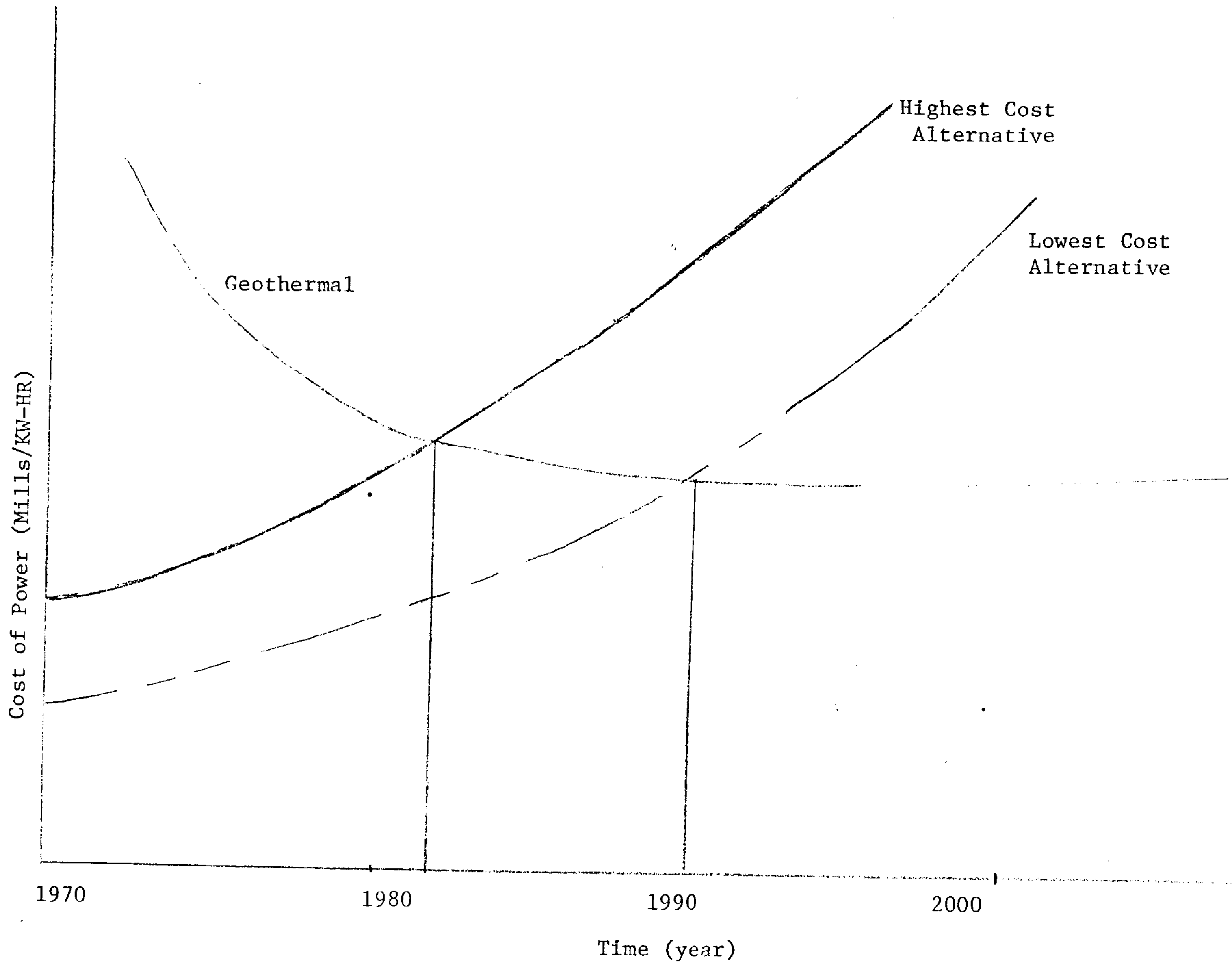


FIGURE 38: PROJECTIONS OF COST OF POWER PRODUCTION

fuels will enhance the attractiveness of geothermal resources. Table 21 gives a comparison of cost \$/MMBTU for fuel versus geothermal water. Table 22 gives the amount of energy recoverable from geothermal resources.

Drilling cost is a major factor in the economics of this energy source. Drilling for geothermal brine costs more than drilling for oil. There are several factors that cause this increase.

i. Geothermal drilling usually takes place in harder rock formations than oil drilling, thus the drilling rate decreases and the bit life is reduced, causing delay in time to replace the bit. In order to illustrate this point, Figure 39 gives the average US Petroleum well costs. An oil well 10,000 ft feep costs \$230,000 for drilling which is \$23/ft. The cost of a geothermal well 10,000 ft deep is \$870,900, i.e. \$87.09/ft according to the report No. Sand 76-0228 published by Sandia Laboratories in June 1976. But if a new type of bit is used such as the Terra-Bit proposed by Sandia Laboratories the cost/ft is reduced by 54%; i.e. new cost/ft is \$40.33.

An equation that computes the cost/ft is

$$F_c = \frac{C\,L + V\,(D + \frac{t}{2}) + B}{RL} \tag{1}$$

where F_c = Cost in \$/ft
- R = Penetration rate (ft/hr)
- D = Depth per bit system (ft)
- L = Bit life (hours)
- C = Rig rate (\$/hr)
- B = Cost per bit (\$)
- t = Interval to be drilled (ft)
- V = Average trip rate hr/1000 ft)

Another report by Mitre published in December 1977 gives more conservative estimates for cost/ft as a function of hardness of rock and depth of well. These estimates are given in Table 23 where we see that cost/ft increases largely if the rock is abnormally hard or if the reservoir occurs at a level below 5000 ft.

ii. Geothermal drilling progresses in rock formations having higher temperatures than are encountered in oil or gas drilling. Higher drilling costs also result because improved high temperature downhole motors must be used to apply enough power to the rock face for both directional and straight hole drilling. High-temperature drilling fluids should be developed which can reduce drilling time and minimize fluid related problems. Finally, better bits with higher preformance in high temperature rock formations should be developed. This improved equipment will cost more than the conventional equipment used for oil drilling, but they may increase the efficiency of geothermal drilling in the future. Factors which determine penetration rates are outlined in Table 24.

TABLE 21 FOSSIL FUEL AND GEOTHERMAL PRICE PROJECTIONS

($/MMBTU)

	FUEL TYPE							
YEAR	NATURAL GAS	RESIDUAL FUEL OIL	COAL	LIQUEFIED NATURAL GAS	GEOTHERMAL CASCADED - 300°F	GEOTHERMAL CASCADED- 350°F	GEOTHERMAL CASCADED/OFF SEASON 300°F	GEOTHERMAL CASCADED/OFF SEASON 350°F
1976	1.42	2.10	1.38	2.70	3.10	2.22	1.73	1.27
1980	2.44	2.89	1.74	3.20	3.91	2.80	2.18	1.60
1985	4.25	4.21	2.33	4.00	4.32	3.09	2.41	1.77
1990	7.05	6.19	3.12	5.25	4.77	3.42	2.66	1.95
1995	11.82	9.09	4.17	7.00	5.26	3.77	2.94	2.16

TABLE 22 (*)

POTENTIAL RECOVERABLE ENERGY FROM GEOTHERMAL RESOURCES IN THE U.S.

	TEMPERATURE	POTENTIAL RECOVERABLE (1)
HYDROTHERMAL:	High $150^{o}C$ +	14 to 154 quads
	Mid 90^{o}-150^{o}	110 quads
	Low 15^{o}-90^{o}	81.8 quads
	TOTAL HYDRO	205.8 to 345.8 quads
GEOPRESSURED:	TEMPERATURE	POTENTIAL RECOVERABLE (2)
	High $150^{o}C$ +	81 to 315 quads
	Mid 90^{o}-150^{o}	270 to 1050 quads
	Low 15^{o}-90^{o}	178 to 693 quads
	TOTAL GEOP.	529 to 2058 quads
TOTAL COMBINED:	TEMPERATURE	POTENTIAL RECOVERABLE
	High $150^{o}C$ +	95 to 469 quads
	Mid 90^{o}-150^{o}	380 to 1160 quads
	Low 15^{o}-90^{o}	260 to 775 quads

This represents, at a minimum, roughly 10 times our present annual consumption or at a maximum, about 35 times our present use levels.

(*) Elmer, D.B., An Open Letter on Geothermal Energy and Energy Consumption, Geothermal Energy Magazine, page 40, Vol. 5 No. 5, 1977.

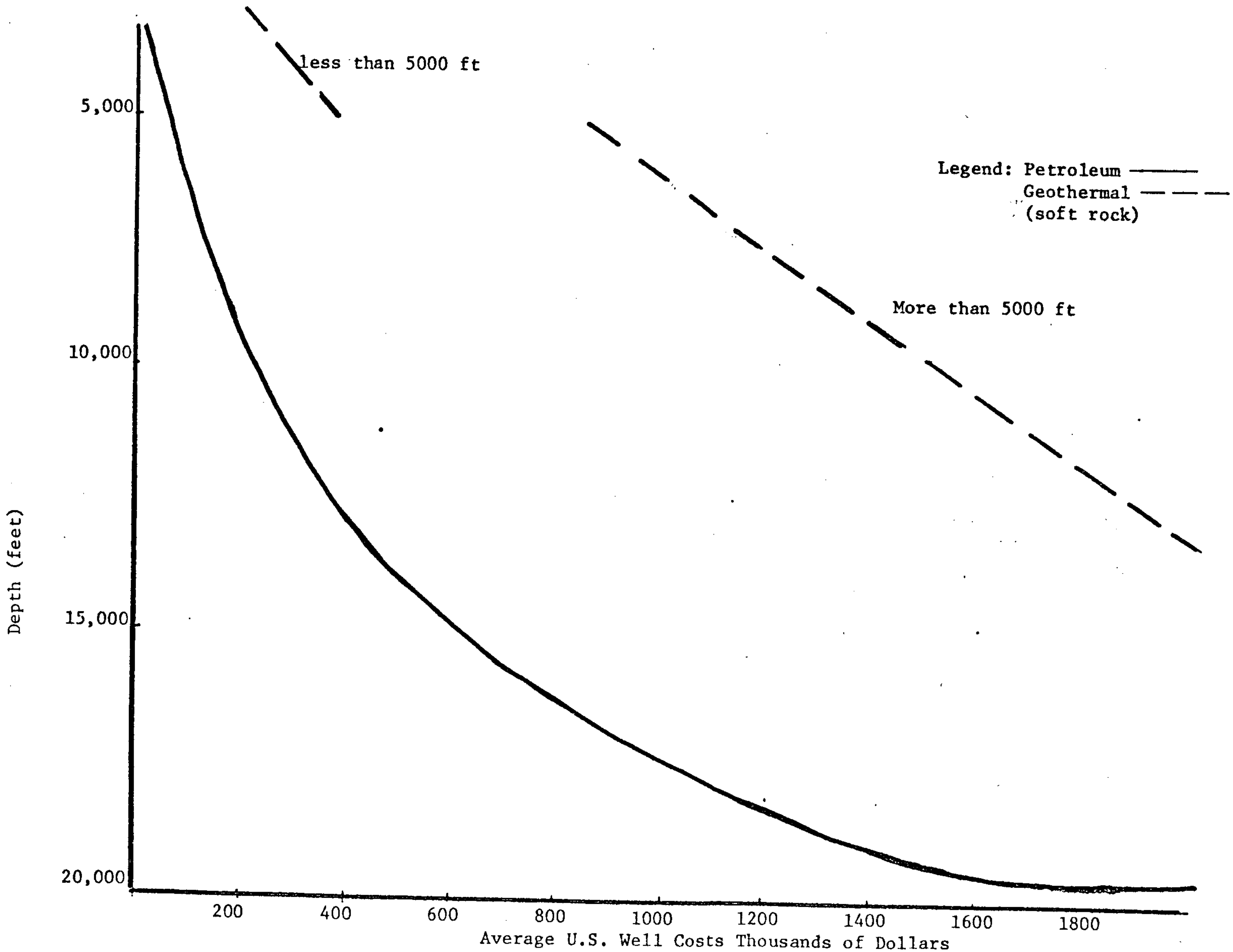


FIGURE 39: AVERAGE U.S. PETROLEUM AND GEOTHERMAL WELL COSTS

TABLE 23 (*)

FOOTAGE COSTS FOR GEOTHERMAL DRILLING
AS A
FUNCTION OF ROCK TYPE AND WELL DEPTH

ROCK HARDNESS	COST/FOOT (1977 DOLLARS)	
	<5000 FEET	>5000 FEET
Soft	80	160
Medium	100	120
Medium-Hard	125	250
Hard	200	400

(*) Friedman, E.J., et al, Prospects

TABLE 24 (*)

FACTORS WHICH DETERMINE PENETRATION RATE

1. Personnel efficiency
   a. Competence
      (1) experience
      (2) special training
   b. Psychological factors
      (1) company-employee relations
      (2) pride in job
      (3) chance for advancement

2. Rig efficiency
   a. State of repair, preventive maintenance
   b. Proper size
   c. Ease of operation, degree of automaticity, and power equipment

3. Formation characteristics
   a. Compressive strength
   b. Hardness and/or abrasiveness
   c. State of underground stress (overburden pressure, etc)
   d. Elasticity - brittle or plastic
   e. Stickiness or balling tendency
   f. Permeability
   g. Fluid content and interstitial pressure
   h. Porosity
   i. Temperature

4. Mechanical factors
   a. Weight on bit
   b. Rotating speed
   c. Bit type

5. Mud properties
   a. Density
   b. Solid content
   c. Flow properties
   d. Fluid loss
   e. Surface tension-wettability

6. Hydraulic factors-essential bottom hole cleaning

(*) Friedman, E.J., et al., Prosp.

iii. Corrosion of pipes also increases the cost of drilling. Considerable attention to metals specification and design techniques is required to keep corrosion at an acceptable level. Research into prevention of geothermal brine corrosion is currently being conducted.

These are some of the factors that cause an increase in the cost of geothermal drilling. To sum up the complete picture of the economics of geothermal energy use, we should emphasize the fact that the initial capital investment required for exploratory drilling, development and completion of geothermal well is large and presently discourages the exploration for geothermal resources. This may continue until the cost of developing this energy becomes competitive with the cost of using energy from conventional fuels. The cost breakdown of a completed steam well is given in Table 25, where a well 7000 ft deep costs $1,000,000 i.e. $143.3/ft. Thus, if we wish to develop and use the reserves of geothermal energy available at the present time, more incentives should be provided such as loans for exploration and development companies, tax credits, cutting the time and expense of "red tape" for leasing and permits procedures, and improving the drilling technology.

TABLE 25(*)

DRILLING AND COMPLETION COSTS AT THE GEYSERS

Cost of Completed Steam Well (7000 ft)

Build road, location and cellar	$ 50,000
Move rig in and out	65,000
Rig operating for 70 days	315,000
Air compressor rental	40,000
Fuel for rig and air compressors	34,000
Excessive drill pipe wear	25,000
Hardbanding drill pipe	3,000
Drill pipe and drill colar inspection	6,000
Water	15,000
Waste Disposal	20,000
20" Conductor pipe	4,500
13-3/8" casing	52,500
9-5/8" casing	67,500
Cement and Services	50,000
Rent 20" Hydril and Rotating Head	10,000
Rent shock sub and stabilizer	10,000
Rent monel drill collar and directional instruments	10,000
Drilling mud	30,000
Well head and muffler and flow line	20,000
Miscellaneous transportation	10,000
Logging	8,000
Mud well logging	25,000
Bits (27)	55,000
Miscellaneous	50,000
Direct supervision and overhead	28,000
	$1,003,500

(*) Friedman, E.J. et al. Prospects for Improvement in Geothermal well Technology and their Expected Benefits, Dec. 1977, MITRE

VI. INTERACTION WITH STATE GROUPS

A. EXPLORATION OF INDUSTRIAL POTENTIAL USERS IN ARIZONA FOR GEOTHERMAL ENERGY

In order to assess the value of the proposed scenarios and appraise potential users of geothermal energy in Arizona, we sent letters to over seventy companies and institutions asking for details concerning their energy usage. We principally wondered how geothermal energy could be useful to them. A list of companies and institutions that were approached is given in Table 26. Many replied by letter or phone, emphasizing their use of very high grade energy for which geothermal is not applicable. Others offered specific answers and suggestions for geothermal use. Some just said they could not participate in the study, supplying data without elaboration on the reasons.

Companies using very high temperature (>2000^{o}C) cannot benefit from geothermal application. However, low grade temperatures are used for heating in a pulp and paper plant. This being a small fraction of their energy consumption, they could not guess how useful geothermal could be in their case, although they are willing to cooperate in later studies. One particular company expressed great interest in solar or geothermal energy and willingness to discuss the matter further. They operate three plants and in 1976/77 for heating purposes they used:

a) 201096 therms. in Plant No. 1 (1 therm = 100,000 BTU)
b) 60000 therms. in Plant No. 2
c) 24000 therms in Plant No. 3

and 10,000 gallons of oil was used at the plant No. 1 when gas was not available. Temperature needs were between 80^{o}F and 338^{o}F. For cooling purposes they used electrical power as follows:

a) 6,000,000 Kwh in plant no. 1
b) 2,500,000 Kwh in plant no. 2
c) 1,335,000 Kwh in plant no. 3

The cooling temperatures are from 170^{o}F to 32^{o}F for milk products and to -20^{o}F for ice-cream storage.

A company which is operating several facilities thinks that a part of their energy use is amenable to alternative energy sources like geothermal and solar. It is worth mentioning that at least in one case they have already included solar energy. They expressed great interest in our project and are willing to work with us. One of their buildings requires 3 MW power which could be one geothermal power unit. They suggested that for economic evaluation the cost of 0.03 $/kwh and $0.17/therm of gas should be used.

A firm that uses hot water responded very favorably to our inquiry, they already have a program underway exploring the possibility of using solar energy and boiler waste heat. They produce their hot water by adding

TABLE 26

LIST OF COMPANIES WHICH WERE ASKED
ABOUT ENERGY USE AND POTENTIAL
GEOTHERMAL ENERGY APPLICATION

Phelps Dodge Corporation
Ajo, Arizona 85321

Phelps Dodge Corporation
Douglas, Arizona 85607

Industrial Asphalt
Phoenix, Arizona 85034

Inspiration Consolidated Copper Company
Inspiration, Arizona 85537

Mallin Brothers Iron and Metal Company
Phoenix, Arizona 85041

Cudahy Food Company
Phoenix, Arizona 85001

Can-Am Corporation
Douglas, Arizona 85607

Armour Food Company
241 West Jackson
Phoenix, Arizona 85030

Honeywell Information Systems
Phoenix, Arizona 85029

Honeywell Process Control Division/Phoenix
Phoenix, Arizona 85029

Phoenix Cement Company
Phoenix, Arizona 85012

Ray Mines Division
Hayden, Arizona 85235

Sahuaro Petroleum and Asphalt Company
Phoenix, Arizona 85005

The Tanner Companies
Parker, Arizona 85344

R.E. Darling Companu, Inc.
Tucson, Arizona 85705

Motorola Government Electronics Division
Scottsdale, Arizona 85252

Motorola Inc. Semiconductor Products Division
Phoenix, Arizona 85008

Hexcel Corporation
Casa Grande, Arizona 85222

Burr-Borwn Research Corporation
Tucson, Arizona 85706

Apache Powder Company
Benson, Arizona 85602

West-Cap Arizona
Tucson, Arizona 85706

Tektron
Goodyear, Arizona 85338

Unidynamics/Phoenix, Inc.
Goodyear, Arizona 85338

Talley Industries of Arizona, Inc.
Mesa, Arizona 85201

Airesearch Manufacturing Company of Arizona
Phoenix, Arizona 85034

Sperry Flight Systems
Douglas, Arizona 85936

Western Electric Company, Inc.
Phoenix, Arizona 85002

Willcox Packing House
Willcox, Arizona 85643

Hamilton Aircraft Company, Inc.
Tucson, Arizona 85706

Goettl Bros. Metal Products, Inc.
Phoenix, Arizona 85016

Hughes Aircraft Company-Tucson Manf. Div.
Tucson, Arizona 85734

Anaheim Citrus Products
Yuma, Arizona 85364

Asarco Hayden Plant
Hayden, Arizona 85235

Arizona Portland Cement Company
Phoenix, Arizona 85013

Arizona Castings, Inc.
Tempe, Arizona 85281

Pioneer Paint and Varnish Company
Tucson, Arizona 85711

Southwest Forest Industries/Snowflake Paper and Pulp Division
Snowflake, AZ 85937

Southwest Forest Inds.
Phoenix, Arizona 85011

Kaibab Industries
Phoenix, AZ 85036

Deer-O Paints & Chem's Ltd.
Phoenix, AZ 85008

Southwest Feed & Seed Company
Phoenix, AZ 85035

Rainbo Baking Company of Phoenix
Phoenix, AZ 85007

Holsum Bakery, Inc.
Phoenix, AZ 85005

Capitol Castings Div.
Tempe, Arizona 85282

Paul Lime Plant Inc.
Douglas, Arizona 85607

Astro-Lite Battery Co.
Tucson, Arizona 85719

Chevron Asphalt Co.
Phoenix, Arizona 85005

Chemical Dist. DBA AZ Agrochemical Co.
Phoenix, AZ 85034

TABLE 26 CONTINUED

Arizona Refining Company
Phoenix, Arizona 85001

Tucson Coca-Cola Bottling
Company
Tucson, Arizona 85705

Seven-Up Bottling of
Phoenix, Inc.
Phoenix, Arizona 85007

Producers Cotton Oil Co.
Phoenix, Arizona 85001

Pepsi Cola Metropolitan
Bottling Company, Inc.
Phoenix, Arizona 85040

Kalil Bottling Company
Tucson, Arizona 85719

Casa Grande Oil Mills
Casa Grande, Arizona 85222

Anderson, Clayton & Company
Phoenix, Arizona 85062

Hayden Flour Mills
Tempe, Arizona 85281

Arizona Feeds
Casa Grande, Arizona 85222

Arnold Pickle and Olive Co.,
Phoenix, Arizona 85006

Spreckels Sugar Division
Chandler, Arizona 85224

Shamrock Foods Company
Phoenix, Arizona 85009

Safeway Stores, Inc.,
Milk Department
Tempe, Arizona 85282

Foremost Foods Company
Phoenix, Arizona 85021

Carnation Company
Phoenix, Arizona 85012

Borden, Inc.
Phoenix, Arizona 85030

Swift Fresh Meats Company
Tolleson, Arizona 85353

Associated Milk Producers,
Inc.
Gilbert, Arizona 85234

steam to cold water, and would definitely consider geothermal or any other alternative energy. They operate several similar plants and they would be willing to use one as a demonstration plant.

Arizona's total energy use is estimated to be 2,280,870 MMBTUs/year or about 34,196 gallons of fuel per year. Potential savings are estimated to be forty times as much for the nation. The range of temperatures used in the estimations are 110°F, 140°F and 180°F. One of the big space users in Tucson uses its energy in the range of 72-78°F all year around. The amount of Natural gas used per year is in the range of 1,500,000 ft^3 of gas totaling some $2500/year. Electrical use amounts to 5,000,000 Kwh totaling some $220,000/year.

Another big company uses energy for heating and cooling as follows:

a) Production and building heating or cooling 29.2 million Kwh/hr.
b) Power heating 700,000 therms annually in terms of natural gas.

The ranges of temperatures are for cooling 40-44°F and for heating 212°F (10%) and 330°F (90%). They congratulated this project and expressed interest in receiving information about new development of other energy sources. A mining company is using some 500,000 ft^3/day of natural gas for drying ore samples at 250°F and some 130 tons of refrigeration by electric power costing 3/Kwh. Most of the smelter operations use natural gas for elevated temperatures (above 400°F). They are also interested in the results of this study and are willing to supply more data if necessary.

An interesting use was suggested for geothermal energy by one of the companies. They maintain 800,000 gallons of water at 120°F where the surface area is 132,000 ft^2 and ambient temperature is 73°F. Humidity and wind conditions were not specified. Geothermal use in this case should be very economical.

One plant used natural gas and has switched now to oil for the furnaces, used to keep tanks of asphalt hot. This operation is continuous: 24 hours a day and 7 days/week. All together, the burners are supplying 4.5 million BTU. This does not include space heating and cooling. They suggest coming to the plant and getting additional information needed for the planning of geothermal energy development and use.

Another company which appreciated very much our study supplied comprehensive data on their energy uses, which we won't reprint in detail for the sake of the confidentiality. Total electric consumption for year 1977 was around 35,000,000 KWh and some 250,000 therm of natural gas. 60% of one company's energy is used in the range of 400-140°F.

The rest is either lower grade heating in the range of 70-140°F or cooling between 0° and 70°F using electricity. Their annual energy cost is around $40,000 including space heating and air conditioning.

Another company which gave very detailed information used in 1976, 1,128,300 MCF of gas, 940,500 gallons of oil and 9,000,000 Kwh of electrical power.

Several companies have found interest in the study but did not have readily available information and promised to send it at a later stage. On the whole the replies were good and cooperative. We hope to extend the communication with these industries in the next year's study by mutual visits and discussions.

Late in the project we found that James V. Davey* has conducted a similar comprehensive study on the geothermal-heat utilization. In this study Davey made 75 contacts with people from industries such as food processing and machinery, chemicals, pulp and paper, horticulature and dairies. These industries are all heat intensive and suitable for using geothermal energy. The replies he received, like ours, ranged from no interest to great enthusiasm.

It is initially obvious that geothermal energy is not yet well recognized and a basic educational and promotional program is needed as well as local and federal encouragement and incentives.

B. PROPOSED ARIZONA WORKSHOP - AUGUST 1978

We have proposed that a geothermal workshop be arranged in Arizona where we will discuss problems with the various agencies and potential users involved. We include people from the State agencies handling State oil and gas conservation, Arizona solar, legal aspects, state, a preliminary outline of the program is given in Table 27. The problems of water, power geology, and related problems will be discussed. Representatives of potential users of geothermal energy should also be invited.

* Davey, J.V. "Survey report - Study of Information/Education, Discussions with remote industries and public institutions on the Direct-heat utilization of geothermal energy", Energy and Environmental Division, Lawrence Berkeley Lab, University of California, Berkeley, CA., March 1977.

TABLE 27

TENTATIVE ARIZONA WORKSHOP PROGRAM - AUGUST 1978

WORKSHOP
GEOTHERMAL ENERGY PLANNING AND EVALUATION
FOR THE STATE OF ARIZONA

Sponsored by: Arizona Solar Energy Research Commission and Bureau of Geology and Mineral Technology

Overview

Geothermal Resources
Leasing and Drilling Activity
Governmental Regulations
Arizona's Energy Pattern
Potential Geothermal Uses

Workshop Topics

1. Summer Peak Power Alleviation
2. Irrigation Pumping
3. Daily Peak Power Assistance
4. The Water Situation
5. General Utilization of 100-400°F Energy
6. Population Growth and Community Planning
7. Recovery of Low-Grade Processing
8. Agricultural and Food Processing
9. State Regulations, Hindrances and Incentives
10. Federal Regulations, Hindrances and Incentives
11. Potential Geothermal Research Advances

VII. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

Geological features of the state of Arizona have shown that there is good potential for geothermal energy; however, few exploratory wells have been drilled. Resource data were compiled on the basis of temperature gradients in water wells (and a few oil wells), hot springs, geochemistry of ground waters and the absolute age of rocks. For example, the San Francisco Mountain area has been identified not only as a source of hot dry rock and/or hot water but also as potential magma tap. The compilation of resource data in this first year of study was only partially completed, due to budget limitations, but there is sufficient data to conduct scenario planning, assuming the resources do exist in the state.

From a geothermal energy use standpoint, the energy needs for Arizona have been reviewed. The major potential moderate temperature uses (up to 250°C) in the U.S.A. and worldwide were collected for possible application to Arizona. Two iterations of the twenty-two "use scenarios" (given in Table 14) were made. There is a major need for electrical power systems and/or cooling absorption systems to help alleviate the larger air conditioning peak loads of hot summers of Arizona. Also, many interesting non-electrical potential uses were identified, based on the unique desert features, mining, irrigated agriculture, potential food processing, and planning for both industrial and personal needs, of the fastest growing state in the U.S.A.

The information currently available is too limited to enable presentation of exact and detailed scenarios for Arizona geothermal use. Therefore, the scenarios suggested at this stage were based mainly on local energy and economic conditions in Arizona with the application of current energy technology. As more data becomes available we shall be able to evaluate more exact uses of geothermal energy. However, from the work so far it is clear that additional research as well as economic studies are needed before geothermal energy gains widespread use.

We propose to continue the assembly and evaluation of all basic resource data. We need to generate definite use scenarios for geothermal energy utilization in the State of Arizona. Where gaps exist in the data base, information should be gathered to fill these voids. In general, the work should continue to expand the broad-spectrum, statewide data base necessary to identify and evaluate geothermal resources planning use scenarios and starting in-depth evaluation of site specific scenarios will be necessary to demonstrate geothermal potential. Increased emphasis should be placed upon planning, scenario flow charts, and identification of the actions necessary to realize geothermal energy use economically.

B. CONCLUSIONS

1. There has been very little drilling and exploration for geothermal energy in Arizona, yet we have evidence that resources may be there.

Geothermal energy will eventually be a factor in Arizona, but it will require industry awareness and additional funding for exploration work before this occurs.

2. At an early stage it was determined that Arizona has a heavy electrical peak load in the summer, due to air conditioning. It would be beneficial if integrated systems involving geothermal energy could be used to reduce this load.

3. There is a shortage of water in most of Arizona. It appears that the potential uses of biosalinity agriculture, integrated with geothermal energy resources might help alleviate this situation.

4. The possibility of integrating geothermal energy with certain specific solution mining projects is interesting in Arizona.

5. The population growth rate of Arizona is the highest in the nation, and therefore should allow reasonable lead time for the proper planning of geothermal exploration and development.

6. The cooperation of many groups may make it possible to establish new communities in Arizona that could be environmentally attractive through the use of geothermal energy.

C. RECOMMENDATIONS

1. Second Year on Current Project

For future work on this project we propose the specific tasks as outlined below. It proposes to reduce effort upon data collection, and increase effort upon planning and scenario development, assisted where necessary by a reasonable amount of effort upon special planning and scenario identification studies.

a. Data and Information Collection

Since certain data were collected during the first year, the main emphasis should be to obtain only that data and information necessary to develop scenarios. Resource assessment data are necessary to prescribe the energy/power base of the scenarios. Fewer institutional impediments and action recommendations should be emphasized, to assist planning the acceleration of much needed exploration drilling in Arizona. Also, any significant geothermal technology developments, additional potential geothermal resource areas, leasing and drilling activity and regulatory actions should be reported.

b. Scenario Development

Another iteration of the 22 site-specific scenarios should be conducted, especially those which show promise. These should then be aggregated on a state level into (a) three broad belts of the state and (b) into some 10 to 12 specific geothermal resource areas. The development of these scenarios should be coordinated with state institutional groups and the key state groups dealing with power, mining, industry and agriculture, for example via an in-state workshop. Such a workshop, its structure and the agencies involved were proposed earlier in this report.

c. Planning Activities

The main planning activity should involve defining the events required to achieve the site-specific and state-aggregated scenarios reported during the first year of study. For this to be comprehensive and realistic, it is proposed to call upon the combined expertise within the Arizona Oil and Gas Conservation Commission, the Arizona Solar Energy Research Commission and the Division of Economic and Business Research, University of Arizona. This effort should be assisted by (a) more frequent and extensive interactions with those interested in geothermal energy, utilities, State government groups and potential users, (b) the identification of problems associated with geothermal implementation, (c) an assessment of the fast development of the area, and (d) understanding which groups could be helpful in the development of geothermal energy. Finally, a reconsideration may point out other ways to accelerate the rate of geothermal development in Arizona by say, 50 percent.

d. Special Studies to Achieve State Goals

Some of the scenarios proposed during the first year of study are only partially identified. These include several areas of great importance to Arizona involving water problems, mining and the excessive summer cooling load. A special effort should be made in the future to more clearly identify the plans related to these important problems. This should involve certain technology evaluations and preliminary feasibility studies. A more detailed and defined pattern of pursuit is warranted at this stage and is proposed below.

2. Exploratory Drilling in Arizona

As indicated in many sections of this report there is a high potential for geothermal resources in the State of Arizona. Many water wells have been drilled but only four geothermal exploratory wells have been drilled. Therefore, it is imperative that more geothermal exploratory wells be drilled in the state as soon as possible. This may transpire through industry awareness and/or certain incentives being extended by the Department of Energy. The Arizona Bureau of Geology is also continuing its research into geothermal energy potential in Arizona and may drill some heat flow holes next year.

3. Interactions with Local Groups

The first year's work showed many possibilities for geothermal energy use in Arizona. Increased interactions with local groups in the state, consisting of potential suppliers of geothermal energy, potential users and the various agencies that must be involved would be beneficial. It should augment the objectives of the Department of Energy in the current project. The project progressed this past year in this respect by contacting some 70 companies in Arizona, visiting a number of places, and making preliminary plans for geothermal workshop for August 1978.

4. Department of Energy Assistance

The Department of Energy, with its base of research in energy, should make it convenient for teams researching aspects of geothermal energy to gain access to the energy data currently being generated. This should include, but not be limited to the following:

a. Status of advanced cooling systems.
b. Status of advanced power turbines.
c. Status of binary power units.
d. Status of drilling techniques and costs.
e. List of location and addresses of expertise in all areas of energy utilization.
f. List of pilot and demonstration plants.
g. Detailed report of low temperature energy application uses in industry.
h. Incentives for profit, for the few places where practical.
i. Predict future costs and prices of energy.
j. Publicize the potential of geothermal energy.
k. Organize workshops.
l. Compilation of the laws and regulations for geothermal energy exploration and application.

VIII. APPENDIX 1 - PARTIAL LITERATURE SURVEY

This partial literature review is based on 78 articles on geothermal energy. It places all geothermal literature into nine general categories. Each is composed of a brief description and a list of articles which constitute that category. The articles are referenced by number to the bibliography.

GENERAL

This category is for articles that give general overviews of geothermal usage, (20,27,28,45,46). One article contains approximate values of energy consumption and temperatures needed for certain applications (24). Some of the articles are concerned mainly with regional developments; Alaska (14), Japan (43(2)), Idaho (26), New Zealand (44(4)). Another article: Geothermal Wastes (60).

AGRICULTURE

In agriculture, geothermal resources are mainly used for greenhouse heating, hydroponics, and irrigation. Hydroponics is the practice of growing plants without soil. An excellent example of this is the Hobo Wells Project in Wendel, Calif., (where 99^{o}C geothermal water is used at a flowrate of 12001 unit (gallons)/min). (1) A general view of the heat required, the equipment needed and other basic requirements is presented (7). In greenhouses, geothermal energy is mainly used for heating the building (2,47(1),64). Another facet of geothermal energy in agriculture is in the field of animal husbandry (8,45(2)). Other pertinent articles: 21,25.

INDUSTRIAL (FOOD PROCESSING)

Geothermal energy is now being used in industrial processes, some of which include the lumber industry (44(2)), dairy processing (e.g. milk pasturization) (3,44(3)), dehydration and sugar beet processing (5). A more detailed analysis of some of these processes is given by B. Lindal (2). Geothermal energy is also used in the process of making filters from diatomaceous earth (65).

HEATING AND COOLING

The major use of geothermal energy today is in the process of space heating and cooling. Cooling research has not progressed as far as the research for space heating, but some research has been done (18,19). Space heating, the process of using the natural heat of the geothermal fluids to heat buildings, has been widely researched. There have been several different schemes developed for space heating (32,38). A study of existing installations is given by S. Einarsson (33). There have been many other articles written dealing with space heating and its future worldwide (3,13,29,34,35,36,37,40,42(1,2),43(1),34(1),47(2)).

DESALINATION

Most geothermal fluids contain a considerable salt quantity. If the salt is not removed from these geo-brines, undesirable scale will build up in the equipment used in most any process (16). Two ways to prevent this are: use of a multi-flash unit or a vertical tube exchanger (12). Geothermal steam is also used in the desalination of sea water (22,56); some of these salts can be saved after extraction (63). Other articles: 57.

MISCELLANEOUS

This category describes some limited uses of geothermal resources. One such usage is for health treatments (9). The production of heavy water may also use geothermal water (61). Some processes have even been described as linear programs (23). A specific example of geothermal usage is that of the East Mesa Test Site in Imperial Valley, Calif., (59).

TECHNICAL CONSIDERATIONS (PROCESSES AND EQUIPMENT)

This category deals with techniques of construction, functions of wells, etc., and the processes and equipment needed for the process (4). Information obtained from drilling must be considered an important factor (11,42(4)), because well data determines the temperature, size and capacity of the reservoir to be suitable for the proposed use (for heat systems, 30, 48). Another process considered is the use of a gravimetric loop (where circulation is based on the density difference of the fluids in a closed column (62)). The equipment used in the processes must also be considered. One of the best apparatuses for heat transfer with geothermal fluids is the heat pump (6,77). A heat exchanger is often needed in the process, too (72,73,74), down hole exchangers: (43(3),44(1)). Some general data and calculation methods of heat measurements have also been developed (2,17,25,39). Other articles: (13,15,39,42(3),78).

ENVIRONMENTAL AND WASTE DISPOSAL

The major environmental concern with respect to geothermal energy is the composition of the wastewater (49,51). The major component in the discharge that environmentalists are concerned with is hydrogen sulfide (H_2S). In an attempt to stop H_2S emissions, there have been H_2S abatement schemes developed (50,55). The high mineral content of geo-fluids also commonly results in deposits of scale (41,43(4)). This pertains especially to fluids containing silica and arsenic (52,53). Some geo-fluids contain rare elements that can be extracted and used (54).

ECONOMICS AND EVALUATIONS

One of the fundamentals of geothermal energy usage is its relationship with other energy sources (i.e. fossil fuels, solar energy, and nuclear power) (66,68). To compare the various sources the economic feasibility of using geothermal energy must be understood (71,75). R.A. Walter describes a computer program that simulates all major facets of a geothermal system and calculates the cost of energy production with respect to certain cost conditions (i.e. sunk costs, life of the plant, revenues, etc)(76). Other articles (67,69,70, economics of space heating 31).

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