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IRRIGATION PUMPING USING
GEOTHERMAL ENERGY

DOE/RA/50076--10

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ABSTRACT

The potential of using geothermal energy in an isobutane binary system to drive directly a cluster of irrigation pumps was evaluated. This three well geothermal system, based at 150°C (302°F) resource at 2,000 m (6,560 ft), would cost an estimated \$7,800,000 in capital investment to provide 6,000 gpm of irrigation water from 12 water wells. It would serve approximately 4.5 square miles of irrigated agricultural land, with the delivered water costing \$106.76 per acre-foot. This compares with an estimated cost of \$60.78 per acre-foot for a conventional irrigation system driven by natural gas at the current price (1980 dollars) of \$2.72/mm Btu. It is obvious that if natural gas prices continue to rise, or if geothermal resources can be found at depths less than 2,000 meters, then the geothermal irrigation pumping system would be attractive economically.

The results of the geothermal irrigation pumping system points out the importance of designing geothermal energy systems in a cascade mode. The system herein evaluated used only 10-12 percent of the energy in the 150°C (302°F) geothermal resource. The economics would be improved considerably by using the effluent geothermal brine and the turbine condenser waters in a cascade system of first supplying heat to greenhouses or fish farming and secondly blending directly with irrigation waters.

The importance of water to the economy and growth of Arizona was summarized. Total water consumption in Arizona is about 7,600,000 acre-feet annually of which about 87 percent is used for agriculture. Total supply from the Colorado River and water runoff is only 2,600,000 acre-feet per year, resulting in a net potable groundwater depletion of about 4,000,000 acre-feet per year assuming a recharge rate of about 1,000,000 acre-feet per year.

As detailed in several other studies sponsored by the DOE under this project, it is believed that geothermal energy can be utilized not only for its energy resource but also help alleviate Arizona's depletion of potable groundwater. Many geothermal brines in Arizona are sufficiently low in dissolved solids so that they could be blended directly with irrigation waters, thus replacing potable groundwater.

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INTRODUCTION

Irrigation pumping is the key factor in the field of agriculture in Arizona. Approximately 1,250,000 acres are irrigated per year for agriculture. Furthermore, additional irrigated agriculture is being brought into production. The expansion of citrus groves in the Hyder Valley is one example. The energy costs associated with pumping are a major production expense for growers. This report investigates the possibility of using geothermal energy to supply the energy necessary for this irrigation pumping.

Use of geothermal waters for irrigation and reduction in conventional fuel consumption would result in overall water conservation and a healthy economy for several areas of agricultural use. A considerable amount of irrigation water is groundwater, which has to be pumped to the surface before being used. This pumping requires even more energy than surface pumping and is obviously a function of the depth of the water. Wherever hot geothermal water is available in agricultural regions, geothermal energy could be used to produce the power needed for pumping groundwater used in irrigation.

In Arizona there are many places where the combination of deep geothermal water and shallow groundwater exist in the same location. Three possible methods of utilizing these potential geothermal energy resources are considered in this study, as follows:

1. A binary system for turbine power for direct pumping of irrigation water.
2. A binary system for turbine power to drive an electrical generator for remote irrigation areas.
3. An integrated geothermal pumping and irrigation pumping system, still in the development stage by the Sperry Corporation.

IMPORTANCE OF IRRIGATION AND WATER TO ARIZONA

Arizona is a hot, arid region with about 12 inches of precipitation annually. It is the sixth largest state geographically, as shown in Figure 1. It has about three million people, concentrated in the Phoenix and Tucson areas, shown in Figure 2. Yet, agriculture by use of irrigation is a billion dollar industry, being a major economic factor in the State, along with the large copper industry, electronics industry and tourism.

Arizona is largely a state of public lands, illustrated by Figures 3 and 4. Geologically, its lowlands are in the southern half of the State and in the western areas along the Colorado River (Figure 5). These regions contain river valleys that constitute the irrigated areas of the State. The Mogollon Rim separates the Colorado Plateau of the north from the high pine tree country, which in turn separates the Plateau from the lowlands (Figure 6). Major dams are on the Colorado River, the rivers in the mountains to the northwest of Phoenix, and in a few other regions, as shown in Figure 7. The flow of water to these dams are shown in Figure 8. The lowlands contain basins filled with groundwater (Figure 9). These basins were filled to a depth of about 9,000 feet (before reaching volcanic rock) over the past two billion years (Figure 10). Thus, the current status of irrigated lands in Arizona is shown schematically in Figure 11.

There are about 3,000 thermal wells and springs in Arizona, with some of the more important thermal wells shown in Figure 12. Some 30,000 wells have now been drilled in the irrigated areas. Total water consumption in Arizona is about 7,600,000 acre-feet annually of which nearly 87 percent is used for agriculture. Total supply from the Colorado River and water runoff is only approximately 2,600,000 acre-feet per year, resulting in a net groundwater depletion of about 4,000,000 acre-feet per year assuming a recharge rate of

Rank	State	Area In Square Miles	Population/Square Mile
1.	Alaska	586,112	0.7
2.	Texas	267,338	46.7
3.	California	158,693	135.6
4.	Montana	147,138	5.1
5.	New Mexico	121,666	9.6
6.	ARIZONA	113,909	19.9
7.	Nevada	110,540	5.5
8.	Colorado	104,247	24.8
9.	Wyoming	97,914	4.0
10.	Oregon	96,981	24.0

Note: The above states comprise 50% of the total land area of the U.S. and its possessions.
Density calculated using 1976 Bureau of Census population estimates.

Figure 1. Arizona Ranks Sixth Largest in Size in United States

Figure 2. Population Distribution in Arizona

Figure 3. Location of Public Lands in Arizona

Figure 4. Location of Military Areas, National Forests, Wilderness Areas and Indian Reservations in Arizona

Figure 5. Generalized Elevations in Arizona

Figure 6. Mogollon Rim of Arizona

Figure 7. Location of Dams in Arizona

Figure 8. Mean Flow Rates of Rivers for 1951-1960 in Arizona

Figure 10. Typical Basins of Lower Plains of Arizona

Figure 11. Schematic of Major Irrigation Areas of Arizona

Figure 12. Major Thermal Wells in Arizona

about 1,000,000 acre-feet annually. The Central Arizona Project will bring Arizona's share of Colorado River water to the Phoenix and Tucson areas by 1985 - 1990, as shown in Figure 13. Arizona is now taking about 1,600,000 acre-feet of water per year from the river, and when the canal is completed, this will be increased to a total of 2,800,000 acre-feet annually. Despite this additional supply of water, a severe depletion of groundwater will occur through the years of the foreseeable future (to years 2000 - 2020).

The estimated annual groundwater pumpage in Arizona for the period 1966-73 is shown below. Today its pumping is roughly the same, probably somewhat larger due to increased population and industry, and this depletion will not be replenished in the foreseeable future:

<u>Irrigated Area</u>	<u>Pumpage, Acre-Feet</u>
Duncan basin	25,000
Safford basin	140,000
San Simon basin	100,000
Willcox basin	300,000
Douglas basin	100,000
Upper & Lower San Pedro basins	92,000
Upper Santa Cruz basin	250,000
Avra Valley	150,000
Lower Santa Cruz	950,000
Salt River Valley	1,700,000
Waterman Wash	55,000
Gila Bend area	180,000
Harquahala Plains area	110,000
McMullen Valley	100,000
Gila River drainage	120,000
Ranegras Plain area	16,000
Gila River - Texas Hill/Dome	220,000
Yuma area	260,000
Sacramento Valley	5,000
Hualapai Valley	4,000
Big Chino Valley	8,000
Little Chino Valley	12,000
Williamson Valley	2,000
Colorado River Flood Plain	17,000
Other areas	100,000
TOTAL	5,016,000

Figure 13. Canal Route of Central Arizona Project for Colorado River Water

Thus, agricultural, industrial, municipal and Indian nation groups are competing for these waters. Several Indian nations have brought suit, claiming prior rights and demanding their fair share of the water. Other suits are in the courts.

As detailed in other studies under this project sponsored by the DOE (see Additional Related Reports), it is believed that geothermal energy can be utilized not only for its energy resource but also to help alleviate Arizona depletion of potable groundwater. Geothermal brines can be used for power plant needs, copper flotation and leaching, certain irrigation waters and possibly in other heating and cooling applications.

OVERLAPPING IRRIGATION AREAS AND GEOTHERMAL ENERGY IN ARIZONA

Irrigated agriculture is an important segment of the economy of Arizona. Fortunately, it is located mainly in Southern Arizona, where also is believed to be most of Arizona's geothermal energy resources. The major irrigation areas and crop distribution are shown in Figure 14. More specifically, five irrigation areas are discussed below, where there may be overlapping geothermal energy resources.

1. Irrigation in Maricopa County

Irrigation in Maricopa County basically surrounds Phoenix, and extends east of Phoenix beyond Mesa, extends northwest of Phoenix beyond Peoria, west of Phoenix beyond Litchfield Park, (Goodyear, Arizona), and southwest of Phoenix beyond Buckeye, as shown in Figures 15 and 16. The potential geothermal resources, as shown in Figure 17, overlap irrigation areas both west and east of Phoenix. Further details in these geothermal resources are given in the Geothermal Development Plan for Maricopa County (1).

2. Irrigation in Pinal County

Irrigation in Pinal County surrounds Casa Grande and extends northwest to Coolidge and Florence and south to Eloy and Red Rock (see Figures 18 and 19). A second irrigated area is shown in the western part of the county, extending from Maricopa in the north to Stanfield in the south. Two potential geothermal resources overlap these irrigated areas, namely, surrounding Casa Grande, Coolidge, Eloy and Maricopa, as shown in Figure 20. Further details on these geothermal resources are given in the Geothermal Development Plan for Pinal County (2).

Figure 14. Irrigation Areas with Crop Distribution in Arizona

Figure 15. Irrigation in Phoenix Area of Maricopa County in Arizona

Figure 16. Geothermal Resources Overlapping Irrigation in Phoenix Area of Maricopa County in Arizona

Figure 17. Locations of Potential Geothermal Resource Areas in Maricopa County

Figure 18. Irrigation Areas of Pinal County in Arizona

■ AREAS FAVORABLE FOR DISCOVERY OF GEOTHERMAL RESOURCES

✱ AMAX GEOTHERMAL TEST WELL

0 16
miles

Figure 20. Locations of Potential Geothermal Resource Areas in Pinal County

3. Irrigation in Pima County

Irrigation in Pima County is mainly northwest of Tucson as shown in Figures 21 and 22. However, it also exists south of Tucson and could be expanded in that area by the Papago Indians. Potential geothermal areas, as shown in Figure 23. Further details on these geothermal resources are given in the Geothermal Development Plan for Pima County (3).

4. Irrigation in the Safford Area

The fertile valley of the Gila River, running through Safford, is an irrigated area, as shown in Figures 24 and 25. A large geothermal resource is believed to overlap this area, as shown in Figure 26. Further details on these geothermal resources are given in the Geothermal Development Plan for Graham/Greenlee counties(4).

5. Irrigation in the Hyder Area

The area surrounding Hyder (and Hyder Hot Springs) is irrigated, including an extensive area to the southwest, as shown in Figures 27 and 28. The location of geothermal resources in the area are in the extreme western edge of Maricopa County (see Figure 17) and the extreme eastern edge of Yuma County (see Figure 29). Further details on these geothermal resources are given in the Geothermal Development Plan for Yuma County (5).

Figure 21. Irrigation Areas of Pima County in Arizona

Figure 23: Locations of Potential Geothermal Resources in Pima County

Figure 24. Irrigation in Safford Area of Graham County in Arizona

Figure 25. Geothermal Resources Overlapping Irrigation in Safford Area of Graham County in Arizona

■ AREAS FAVORABLE FOR DISCOVERY OF GEOTHERMAL RESOURCES

✱ HOT SPRINGS

① MARY MACK WELL

② MOUNT GRAHAM MINERAL BATH WELL

Figure 26. Locations of Potential Geothermal Resource Areas in Graham and Greenlee Counties

Figure 27. Irrigation in Hyder Area of Yuma County in Arizona

Figure 28. Geothermal Resources Overlapping Irrigation in Hyder Area of Yuma County in Arizona

Figure 29. Locations of Potential Geothermal Resource Areas in Yuma County

PUMPING COSTS FOR VARIOUS IRRIGATION LIFTS IN ARIZONA

Extensive cost data on irrigation wells and pumping costs are available for all of the counties in Arizona prepared by the Cooperative Extension Service, College of Agriculture, University of Arizona (6). Irrigation pumps in Arizona are powered by natural gas internal-combustion engines and electric motors, divided almost equally between these two energy sources. However, the rising energy costs of the 1970's has caused the industry to examine diesel engines, LP gas engines and solar energy.

For shallower wells, such as the Gila Bend area, the total cost of pumping one acre-foot of water is about \$22 for a 210 foot lift and about \$32 for a 400 foot lift, as shown in Figure 30. For deeper wells, such as in the Queen Creek area, the total cost is about \$54/acre-foot for 500 foot lift and about \$70/acre-foot for a 750 foot lift. These costs are based on the following:

Type Fuel	Overall Pumping Efficiency, %	Fuel Price	Pump Efficiency, %
Natural Gas	15.4	\$2.72/mm/Btu	60
Electricity	54.0	\$0.0314/KWH	60
Diesel	16.0	\$0.75/gal	60
LP Gas	15.4	\$0.57/gal	60

*The efficiency of the new pump is about 80% but drops during operation due to wear on the bowls by abrasive sand and corrosive action of minerals in the water.

Other assumptions include fixed capital costs based on pumping 4,320 hours (180 days) at a given specified rate of discharge, and depreciation rates as practiced currently in Arizona. A typical total cost is shown below in Table 1 for a natural gas-powered engine for a 16-inch well, 1200 feet

Figure 30. Typical Irrigation Pumping Costs by Conventional Systems in Arizona

Table 1. Cost of Pumping Irrigation Water in 1980, 600 Foot Lift.
Well No. 5 - Natural Gas Power
Maricopa County -- Queen Creek Area

Specifications and Assumptions

1. Well is drilled and cased with 16 inch casing to 1200 feet.
2. Well pumps 1000 GPM and 796 acre-feet annually.
3. Depreciate well 25 years with 0 percent salvage
4. Depreciate pump assembly..... 15 years with 3 percent salvage
5. Depreciate power unit..... 15 years with 3 percent salvage
6. Depreciate bowls..... 03 years with 0 percent salvage
7. Compute interest on average investment at 10.00 percent.
8. Compute taxes on 18.00 percent of average investment using a tax rate of \$11.15 per \$100 assessed valuation.
9. Compute insurance on average investment in power assembly (items 5-7 below) at \$1.02 per \$100 value.

Price quotations (including 5.0 percent sales tax) --- 12/20/79

1.	Drilling cost and casing installation	\$ 26,400
2.	Casing, foundation and test pumping	25,055
3.	Pump assembly (8 inch column)	19,991
4.	14 inch bowls (7 stages)	4,512
5.	Power unit --- 295 HP motor and cooler	36,451
6.	Drive line and right angle gear drive	8,405
7.	Installation labor and site costs	4,356

TOTAL Cost of Well \$125,170

Annual Fixed Costs

Depreciation	\$ 8,037
Interest	6,362
Taxes	1,277
Fire and lightning insurance	259

TOTAL \$ 15,935

Water Cost Per Acre-Foot

1. Fixed Cost	=	15935./796. AF	=	\$ 20.02
2. Energy Costs	=	(0.00318 * 10.68 * 600)/.154 * .25546	=	33.80
3. Repairs	=	.010441 * 600	=	\$ 6.26
4. TOTAL Cost				\$ 60.08

Where 0.00318	=	MCF of gas to lift 1 AF of water 1 foot at 100 percent overall efficiency
10.68	=	number of therms per 1000 cubic foot of gas
600	=	feet of lift
.154	=	overall efficiency stated as a decimal
.25546	=	cost of natural gas per therm incl sales tax
.010441	=	cost of plant repairs, maintenance, lubrication attendance per foot of lift

Therms of natural gas used to pump 1 AF = 132.32 796 AF = 105,327 Therms

deep, with a pump operating at 1,000 gpm.

SPERRY GEOTHERMAL IRRIGATION PUMPING SYSTEM

Sperry Research Center has under development a novel binary electrical power system, integrated directly with the geothermal well. The working fluid Freon 114 is heated down-hole and drives a down-hole turbine for geothermal brine pumping, as well as rising to the surface as vapor to drive an electrical turbine. The Sperry down-hole pump obtains its energy to pump the geothermal brine well water directly from the hot brine itself, as shown in Figure 31, as reported by Sperry Research Center (7). The working fluid is sent down to the pumping unit through a down-hole heat exchanger, which consists of two annuli formed by the well casing and two concentric lengths of standard oil field tubing. The working fluid flows down the inner annulus, and the hot brine flows up the outside annulus.

This pumping system has a higher efficiency because it involves only two energy conversions, namely, heat to turbine rotation and impeller rotation to fluid pressure and flow. The pump is placed sufficiently deep in the geothermal well (500 to 1,500 feet) so that the hydrostatic head of the brine will provide an adequate pressure at the brine pump inlet to prevent flashing and solids deposits.

In addition to potentially more efficient brine pumping and eliminating the mechanical feed pump, the gravity-head system eliminates the pinch effect in heat transfer. This is due to heat exchange occurring at constantly increasing pressure and thus at constantly changing specific heat for the working fluid. It has been estimated by Sperry that the gravity-head system should have a 37 percent larger net electrical output than a comparable conventional binary system. In addition, the capital cost of the plant and wells should be less.

Figure 31. Schematic of the Sperry Gravity - Head Downhole Pump for Power Production

Sperry Corporation has been investigating this technology for electrical power at DOE's Geothermal Test Facility at East Mesa, Imperial County, California under a contract with DOE. Prior to this contract, a combination of National Science Foundation, Energy Research and Development Agency (ERDA) and Sperry internal funding sponsored a well test on the 13,000 rpm turbine only, with steam as the fluid. This was operated for 42 days at the Heber KGRA in facilities managed by Chevron Resources Company for Chevron, San Diego Gas and Electric Company and Magma Power Company (8, 9). The more recent contract with DOE was to field test a more realistic electrical power system using dichlorotetrafluorethane (R-114) as the working fluid. There was a delay in the testing when the well liner collapsed at 500 feet before the pump was installed. The project was terminated by the DOE when the well became unusable.

The Sperry technology is designed to boost efficiency for high volume pumping of geothermal fluids. The downhole pump could, with some modification, be used in irrigation pumping and other direct-use applications. The working fluid would probably be R-115 instead of R-144. Instead of using conventional shaft-driven or submersible pumps, Sperry's system would utilize the downhole energy of the geothermal brine. The pump would cut energy costs because, once fired, it can virtually drive itself. The Sperry pump uses a downhole heat exchanger to transfer energy from the geothermal fluid flowing through the well casing to the working fluid of a supercritical Rankine power cycle. The refrigerant operates also the pump to lift the geothermal brine towards the surface. The working fluid is condensed on the surface and then set back down through the heat exchanger to the downhole turbine-pump. Only a small amount of energy is extracted from the geothermal brine by the pumping.

This method of using geothermal energy has several potential advantages over conventional coal-fired or nuclear methods. A feed pump between the condenser and the downhole heat exchanger would not be needed, as the weight of the column of working fluid would act to pressurize the working fluid if the geothermal well were deep enough.

Thus, for irrigation pumping (a variation of the electrical system) the economic benefits would depend upon the physical properties of a cold irrigation aquifer being located over a hot geothermal brine. Ideally, one would like the following:

- a) A geothermal resource of at least 200°F - 250°F (93°C - 121°C) at a depth less than 10,000 feet (3,048 meters);
- b) shallow groundwater aquifers of less than 1,000 feet (305 meters) at the same location as the geothermal resource;
- c) wide temperature extremes between the two waters.

Since the Sperry system is still under development -- in fact, failed mechanically during the 1981 field test then in progress -- the application to irrigation pumping in Arizona has not been carried beyond this stage.

However, it is believed that its development should be followed. There are areas in Arizona where irrigation pumping is from such depths that it is becoming both uneconomic and impractical from an operations standpoint. The Sperry Pumping system fits such situations technically. There is insufficient data at this time to make an economic evaluation under such conditions.

EVALUATION OF GEOTHERMAL IRRIGATION PUMPING IN HYDER AREA

A more detailed evaluation of utilizing geothermal energy for use in irrigation pumping in Arizona is made in this section. There are three approaches that might be considered as follows:

1. Direct turbine drive of large irrigation pumps by a binary fluid, heated by geothermal energy.
2. Generation of electricity by a geothermal binary fluid system, and then using that electricity locally for electric-driven irrigation pumps.
3. Application of the Sperry down-hole turbine to specific irrigation locations in Arizona, to take advantage of the potentially more efficient system being developed by Sperry Corporation.

Preliminary calculations showed that System No. 1 would be more economic than System No. 2 in Arizona. Also, System No. 3 is still under development. Therefore, System No. 1 was selected for more detailed study. The Hyder area, which has geothermal resources, was chosen to illustrate the use of a geothermal resource in irrigation pumping. More detailed information on the geothermal resource than given in the earlier general section on overlapping geothermal/irrigation areas is also included.

Geothermal Resource in the Hyder Area

Certain details can be outlined on the geothermal resources of the Hyder area. A review of existing geological, hydrological and temperature data from the Dateland-Hyder area was carried out by the Arizona Bureau of Geology and Mineral Technology - Geothermal Group (11).

Temperature measurements and chemical geothermometry suggest three areas where 40° to 100° C (104°F to 212°F) waters may be found at depths of 500 to 1,000 meters (1640 feet to 3280 feet). Projection of thermal gradients indicate 200°C (392°F) temperatures may be encountered at depths as shallow as 2,000 meters (6560 feet). Such a projection assumes continuation of the most favorable thermal gradients.

The basin-fill sediments in the Hyder area are similar to those in other basins in southern Arizona. There are mixtures of fine to medium-grained clastics, coarser sands and conglomerates. All sediments are believed to have been deposited since late Cretaceous-early Tertiary time.

Most wells in the Hyder area contain more than 2 mg/l fluoride and about one-third of those sampled contain more than 5 mg/l. No well is currently known to contain more than 10 mg/l fluoride. Recommended limits on fluoride in drinking water for this area is 1 mg/l or less. The higher concentrations of fluoride generally occur east of the line between Baragan Mountain and the Agua Caliente Mountains. No obvious variance in concentration can be seen along the axis of the Gila River. Most wells within the area contain between 500 and 5,000 mg/l dissolved solids. The few wells which exceed 5,000 mg/l are located near the Gila River. Less than 10 percent of dissolved solids is in the groundwater moving away from the Gila River.

Most of the wells completed in the Hyder area are used for irrigation of cotton, grapes, wheat and citrus crops. Approximately 250 wells were reviewed, in the field or through a literature search. The majority of these wells were completed to a depth of less than 100 meters.

There are 73 wells within the Hyder area with recorded temperatures and whose depths exceed 100 meters. An additional 28 wells have been completed to depths less than 100 meters. The weighted mean temperature gradients as well as the ranges for each of the depth intervals are as follows:

<u>Interval (Meters)</u>	<u>Number of Wells</u>	<u>Average Depth (Meters)</u>	<u>Arithmetic Mean Gradient ($^{\circ}$C/km)</u>	<u>Weighted Mean Gradient ($^{\circ}$C/km)</u>
0-100	28	57.9	149.7	119.6
100-200	37	150.6	69.7	68.8
200-400	26	293.0	37.4	36.1
>400	10	482.2	27.9	27.1

In summary, the status of geothermal resources in the Hyder area appears to be as follows:

1. Eighty-eight wells and springs within the Hyder areas have reported temperatures in excess of 30°C (86°F). A complete inventory of the more than 250 wells will no doubt reveal additional warm or hot water occurrences.
2. Assuming normal temperature gradients, the deeper portions of the basin should contain waters within the 50 to 150°C (122°F to 302°F) range.
3. Abnormal temperature gradients occur along the margins of gravity lows or on the basin-side of inferred deep structures. The deep structures may provide communication between the heat source or sources and the aquifers which display the higher temperature gradients.
4. Areas of geothermal interest are: 1) the inferred deep portion of the basin north of Baragan Mountain, 2) the area just south of Horn, 3) and the area south of Turtleback Mountain and Agua Caliente Mountain

Geothermal Turbine-Drive Irrigation Pumping

From the information in the previous section, an area in the Palomas Plain of the Hyder area should have a geothermal resource of 150°C (302°F) at a depth of 2,000 m (6562 ft). This is based on a proven geothermal resource of 66°C (150.8°F) at 500 m (1640 ft) and a temperature gradient in that area of $60^{\circ}\text{C}/\text{km}$. This temperature is sufficient to drive a turbine for direct use of irrigation pumping. In the binary system, the geothermal brine is passed through a heat exchanger where its thermal energy is transferred to a clean, low-boiling secondary fluid, isobutane. The secondary fluid drives the turbine which, in turn, drives the irrigation pump as shown in Figure 32.

Economic Evalution of Geothermal Irrigation Pumping in the Hyder Area

The following assumptions were made for this economic evaluation (10):

Assumptions

. Temperature of geothermal fluid	150°C
. Ambient temperature	35°C
. Exhaust temperature	55°C
. Temperature difference between working fluid & brine	30°C
. Downhole pump efficiency	90%
. Turbine efficiency	78%
. Irrigation pump efficiency	85%

The Hyder Valley has approximately 30 square miles that is irrigated. It is believed that the three geothermal wells outlined above could serve about 4.5 square miles as follows:

. Approximate area	4.5 x 640 = 2,880 acres
. Irrigation requirement	3.5 acre-feet/acre/year
. Total irrigation requirement	10,080 acre feet/year
	6,000 gallons/min
. A 200 H.P. pump can pump to a height of 400 feet	535 gpm
. No. of pumps	12
. Total H.P.	2,400

A summary of the estimated capital investment is as follows:

	<u>Dollars</u>
. 3 - Geothermal Production Wells	\$4,000,000
. 1 - Geothermal Reinjection well	1,200,000
. 3 - Geothermal Heat Exchange Systems	800,000
. Geothermal Distribution Piping	600,000
. 12 - Geothermal Turbine/Pump Systems	<u>1,200,000</u>
ESTIMATED TOTAL CAPITAL INVESTMENT	\$7,800,000

For direct comparison purposes, the estimated cost of pumping irrigation water is calculated on the same basis as that used for conventional irrigation systems (see Table 1).

Annual Fixed Costs of Geothermal Pumping System:

Depreciation, 15 yrs.	\$ 520,000
Interest	397,000
Taxes	80,000
Insurance	<u>16,000</u>
TOTAL	\$1,013,000

Water Cost per Acre-Foot

Fixed Cost = \$1,013,000/10,080 Acre-Feet	\$100.50
Energy Costs	-0-
Repairs	<u>6.26</u>
TOTAL WATER COST	\$106.76

This estimated cost for geothermal pumping of \$106.76 per acre-foot can be compared with the conventional cost \$60.78/AF shown in Table 1. Obviously,

if natural gas costs continue to rise in Arizona or if geothermal resources of 150°C (302°F) can be found at depths less than the 2,000 m (6560 ft) herein assume, then the proposed geothermal irrigation pumping system can be very attractive economically.

IMPROVEMENT OF ECONOMICS BY CASCADE SYSTEMS

One of the main disadvantages of the geothermal irrigation pumping system evaluated above is its low thermal efficiency. The pumping system could utilize only 10-12 percent of the geothermal energy in the 150°C (302°F) resource. Obviously, the effluent geothermal brine and the turbine condenser waters should be used for a secondary use in a cascade system. Many agricultural uses are available for such cascade systems, including greenhouses, fish farming and shrimp farming. Such cascade systems were not evaluated in this study.

BLENDING GEOTHERMAL BRINES WITH IRRIGATION WATERS

Many low-temperature and medium-temperature geothermal brines in Arizona have sufficiently low dissolved solids that a considerable percentage can be blended directly with the irrigation water being pumped from the ground. This results in two distinct benefits, namely, (a) alleviation of the depletion of Arizona's potable groundwater, by its replacement with geothermal brines and (b) reduction of the quantity of geothermal brines that require reinjection into the ground. For example, many of the thermal wells in the Hyder area, detailed earlier in this report, contain between 500 and 5,000 mg/l dissolved solids. Thus, a considerable percentage of these waters (obtained at greater depths) could be blended with the conventional irrigation waters for use in agricultural irrigation. Such blended water systems were not evaluated in this study.

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ADDITIONAL RELATED REPORTS

The following fifteen reports were prepared by the Evaluation of geothermal Utilization group:

1. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Maricopa County, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 79-8.
2. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Pima County, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 79-9.
3. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Graham/Greenlee Counties, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 79-10.
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11. White, D.H. and Goldstone, L.A., 1982, Geothermal Energy for Copper Dump Leaching, prepared for the U.S. Department of Energy, Contract No. DE-FC03-80RA50076, and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-15.
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Other related reports include the following:

1. Acorn Engineering Associates, 1982, Geothermal Feasibility Study for Decker Land Development, Tucson, Arizona: Unpub. Report for Oregon Institute of Technology, Contract No. TA 1-82: State of Arizona Bureau of Geology and Mineral Technology Open-File Report.
2. Frank, Helmut J., ed., 1982, Arizona's Energy Future: Making the Transition to a New Mix, Tucson: University of Arizona Press.
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4. Pasqualetti, M.J., Goldstone, L.A. and Stone, Claudia, 1981, Land Use Planning for Geothermal Development-Scottsdale, Arizona, partially funded by the U.S. Department of Energy, Contract No. DE-FC03-80RA50076 and the City of Scottsdale Planning Department: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-8.

Open-File reports can be obtained by writing to:

State of Arizona Bureau of Geology
845 N. Park Avenue
Tucson, Arizona 85719

or to

Arizona Solar Energy Commission
1700 W. Washington, Room 502
Phoenix, AZ 85007

In addition, reports prepared for the U.S. Department of Energy can be obtained by contract number from

U.S. Department of Energy
Technical Information Center
P.O. Box 62
Oak Ridge, TN 37830

GLOSSARY OF GEOLOGICAL TERMS

Anomalously shallow depth - unusually or unexpectedly shallow depth.

Basin-range graben bound by deep faults - an area usually ten to hundreds of km² in area that has been down dropped along deep faults relative to the surrounding mountains; the grabens become filled with sediments to become valleys.

Curie-depth - the depth at which rocks become hot enough to lose their magnetic properties, ~ 525°C. Curie temperature within 5-10 km of the surface are an indicator of geothermal resource potential.

Deep circulation - the natural movement or flow of ground water, as a result of convection, whereby it descends and becomes heated at depth and then rises toward the surface.

Deep sediment-filled, faulted basin - see basin - range graben.

Depth of Curie-isotherm analysis - technique used to estimate depth to the Curie temperature.

Hot dry rock production - a method for extracting useful heat in a deep dry hole; accomplished by fracturing the hot rock between two deep holes, and pumping cold fluid into one and bringing hot fluid out of the other.

Geothermometer - an empirical formula, based on the temperature-dependent solubility of certain minerals, used for estimating deep fluid temperatures in a geothermal reservoir.

Magnetotelluric survey - an electromagnetic method in which natural electric and magnetic fields are measured. Models of the crust can then be constructed and resistivities at great depth can be predicted.

Major range bounding faults - fractures or fracture zones along which mountains have risen relative to down dropped grabens.

Shallow magmatic intrusion - a body of magma that has intruded its way upward into shallower crust.

Na-K-Ca geothermometer -- (also, quartz geothermometer, chalcedony geothermometer) - see geothermometer.

Tectonic history - the cycle that relates the larger structural features of the Earth's crust to gross crustal movements and to the kinds of rocks that form in the various stages of developments of these features.