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GEOTHERMAL HEATING FOR THE ARIZONA ENVIRONMENTAL RESEARCH LABORATORY GREENHOUSES

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ABSTRACT

A preliminary study of the technical and economic feasibility of installing a retrofit geothermal heating system is analyzed for the Environmental Research Laboratory Farms greenhouse facility located in Tucson, Arizona. The facility consists of 10.6 acres of greenhouse area, of which 7.4 acres are currently operational. Natural gas or diesel fuel are presently used for heating. The maximum heating load is estimated to be 28,620,000 Btu/hr. Average annual heating energy consumption between 1974 and 1979 was 35,684 million Btu/year for 7.4 acres of greenhouse, costing an estimated $96,703 at 1981 natural gas prices.

Two 2,500 foot geothermal production wells are required, each capable of producing 1,500 gpm of 130°F water. The geothermal water is expected to contain 500 ppm total dissolved solids. Total estimated capital cost for installing the system is $902,946. The expected first year geothermal energy cost savings are estimated to be $58,920. A simple payback of 9.1 years is calculated and the project has a net present value of $961,751. Geothermal heat could be supplied at a cost of $5.39 per million Btu in the first year of operation.

The project as herein present is marginally economic. However, it became clear after the study that an attractive economic case could be made for providing about 50-60 percent of the required heating load as a base load using geothermal energy. The remaining peak load would then be provided by the existing natural gas fired boilers. This option should be studied in greater detail.

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INTRODUCTION

Generally, the sources of energy for greenhouse heating are fossil fuel and electricity. However, with the ever-escalating price of these energy sources, geothermal greenhouse heating systems might become more attractive. An impressive expansion in the development of these systems has taken place in countries such as Japan, Iceland, Hungary, New Zealand and the U.S.S.R. Low-to-moderate temperature geothermal energy has been successfully utilized to provide the heat that is needed to grow vegetables and flowers in greenhouses in these countries.

During 1981, and on the recommendation of the Arizona Solar Energy Commission, the following analysis was performed as a first step in the initiation of a state funded geothermal energy project. During the first three years of evaluation of geothermal resources in Arizona, it became evident that most applications would involve the use of direct heat, rather than for the generation of electricity. In 1981, after consultation with the Arizona Solar Energy Commission, a greenhouse heating project for the Environmental Research Laboratory, University of Arizona, utilizing low temperature geothermal water was selected for analysis. The following study was intended to provide the basic documentation necessary to secure funding for a more detailed analysis, if it should look attractive.

Several factors led to the selection of a greenhouse heating project. The University of Arizona Foundation recently acquired a large greenhouse complex located in Tucson, Arizona, providing public accessibility. Geological indications suggest that the greenhouses are located over a shallow (<3000 ft) geothermal resource. Utility records showed that the greenhouses required heating eight months out of the year and that low temperature heat could be utilized for those needs. Therefore, it was suggested that a greenhouse heating project might have potential as a profitable investment in addition to demonstrating the utilization of geothermal energy.

Other peripheral issues also enhanced the attractiveness of a greenhouse heating project. Greenhouses require a significant amount of water (though considerably less than open field agriculture) for irrigation and for evaporative cooling during the summer months. Presently, water requirements are fulfilled by drawing ground water from shallow aquifers and from the purchase of city water. Geothermal water, previously encountered in the Tucson basin, is of useable quality for non-drinking purposes. The drilling for the utilization of geothermal water for irrigation and evaporative cooling would provide an alternate source of water and partially replace the use of potable water supplies.

The potential benefits resulting from the project deserve consideration. Drilling a geothermal well in the Tucson basin could confirm the existance of a geothermal resource and provide data on its quality, quantity, recharge and longevity. The utilization of geothermal water would demonstrate the technical feasiblity of geothermal heating. In addition, the development of the project would provide long run energy cost savings, conserve fossil fuel and potentially prove to be a profitable investment for the University of Arizona and the State of Arizona. Further, the use of non-potable water for agricultural and research purposes would conserve high quality water resources. Greenhousing, because of its water conservation and controlled environment advantages, could be a future agricultural opportunity for Arizona. The addition of a long-term supply of stable priced heat would allow year round production of agricultural products. This would help preserve, agricultural productivity and income in Arizona despite the depletion of a dependable water supply.

The following analysis represents a preliminary retrofit design for converting the natural gas heating system of the University of Arizona's Environmental Research Laboratory Farms greenhouse facility to a geothermal energy heating system. As the analysis progressed, a number of assumptions were necessary when specific information was lacking. It should therefore be noted that this analysis is a preliminary one, and therefore does not evaluate all of the energy conservation options available nor does it contain precise knowledge of resource characteristics or heating loads. Rather, the analysis provides an estimate of equipment and capital costs necessary for installing a geothermal heating system. It further provides an indication of the energy and dollar savings such a system might provide and serves as an overview of the issues, risks and problems associated with the development of geothermal resources for greenhouse agriculture. In essence, this paper represents a starting point for considering the utilization of local geothermal energy resources and attempts to highlight the costs and benefits which a geothermal heating system offers.

ENVIRONMENTAL RESEARCH LABORATORY GREENHOUSE COMPLEX

The Environmental Research Laboratory (ERL) Farms are located at 6818 South Country Club Road in Tucson, Arizona. The facility was constructed in the late 1960's and has been owned by several private agricultural firms over the years. The greenhouses were most recently used to grow commercial vegetables in a controlled environment. The most recent owner was Superior Farms Company, who grew tomatoes and cucumbers before going out of business in 1980. At that time, the greenhouse facility was donated to the University of Arizona Foundation, which established the greenhouses as a research facility for the Environmental Research Laboratory.

The Environmental Research Laboratory was founded in 1967 at the

University of Arizona and is currently a self-supporting research branch. The Lab conducts research in the development of controlled-environment systems for the integrated production of water/food/power. Systems developed by this laboratory permit the growing of agricultural crops within air inflated greenhouses. Research is also conducted in the use of solar energy as an integral part of controlled-environment systems. Current research at the farms include projects for Disneyland, Kraft Foods, an agriculture research project and a halophyte research project.

The greenhouse complex of the ERL Farms is composed of six greenhouse structures. The greenhouses are constructed of fiberglass sidewall with air-inflated polyethylene roofs. The total area of the complex is 10.6 acres. However, greenhouse #4 will not be operational in the immediate future. The actual greenhouse area to be heated for purposes of this report is 7.4 acres.

The ERL greenhouses are presently heated by a hot water distribution system. Boilers fired by natural gas or diesel fuel heat water which is then circulated to unit heaters (radiator and fan units) through an underground network of supply and return pipes. The unit heaters in each greenhouse are suspended overhead and provide both the heating and air circulation needs of the greenhouses. A diagram of the greenhouse complex and its heating system is shown in Figure 1.

The essential elements of a unit heater are a fan and motor, a radiator and an enclosure. Filters, dampers and directional outlets are also included. Unit heaters have three principal characteristics: 1) relatively large heating capacities in compact casings, 2) the ability to project heated air in a controlled manner over a considerable distance, and 3) a relatively

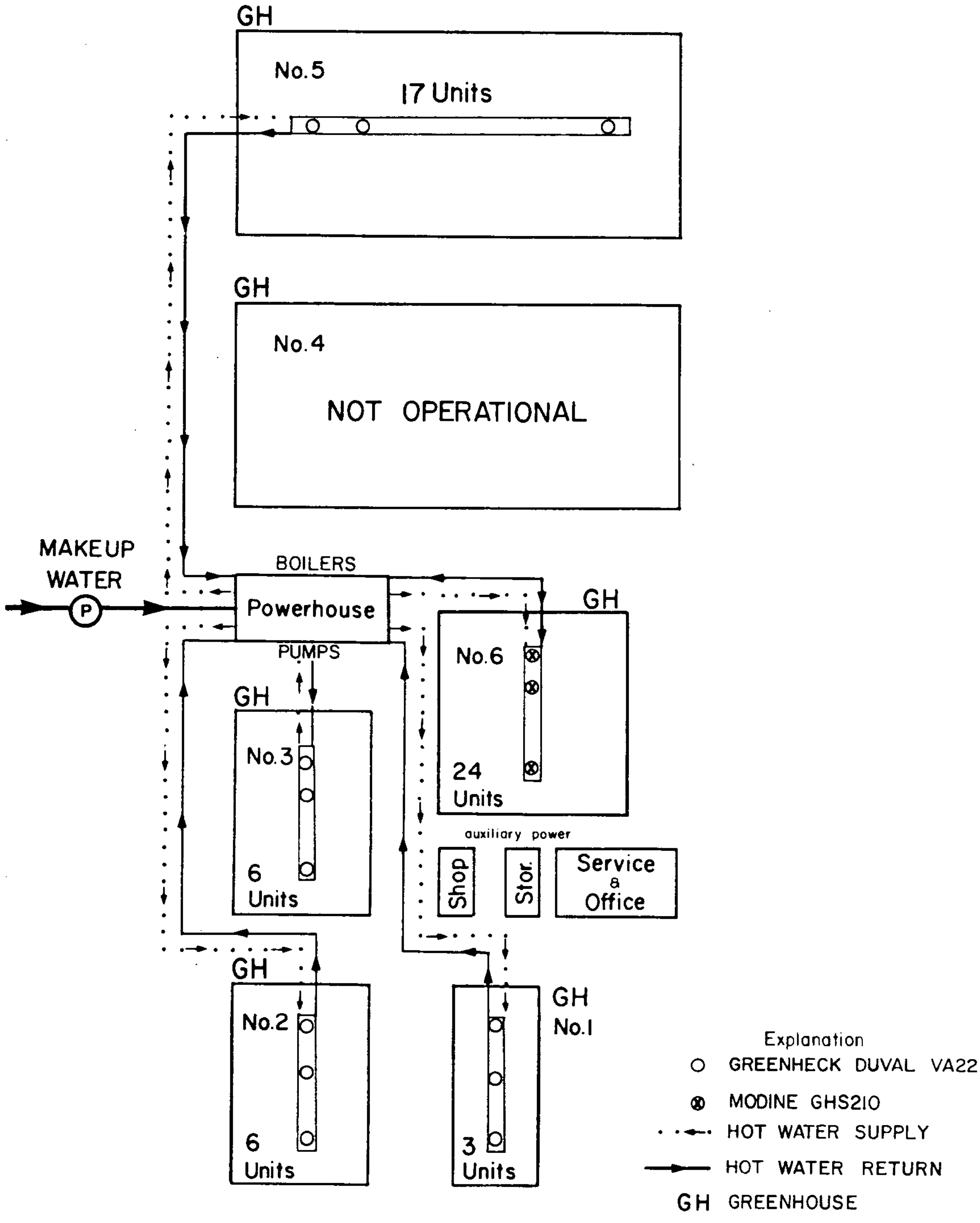

Figure 1: Greenhouse complex layout and current heating system

low installed cost per Btu of output.

The first step in the analysis is to estimate the design heating load for the greenhouses. An estimate is necessary because over the years the actual engineered heat load calculations of the facility were lost. However, it is known that hot water enters each unit heater at 160^{o}F and exits at 130^{o}F. Also, the total water flow for the entire heating system is 1,908 gpm. Given these conditions, the current ERL heating system, when operating at full capacity, can deliver an estimated 28,620,000 Btu/hr.

The heated air is currently distributed with two types of specially designed unit heaters. Thirty-two of the models are Greenheck Dual VA22 unit heaters and 24 of the models are Modine GHS 210 unit heaters. Figure 1 presents the distribution of these unit heaters within the five operating greenhouses. The water flow to each Greenheck unit heater is 47.7 gpm, and the water flow to each Modine unit heater is 15.9 gpm. Given the above inlet and outlet water temperature, Table 1 presents estimated heating loads and calculated Btu/hr ratings for each of the five operational greenhouses.

Greenhouse energy consumption is directly related to weather conditions and temperature to be maintained in the greenhouse. Table 2 presents average monthly natural gas consumption for the period 1974-1979 based on Superior Farm Company records. During this period, the greenhouses were kept at 60^{o}-65^{o}F during the night and 65^{o}-75^{o}F during the day. Table 2 also presents the monthly and annual cost of the natural gas based on actual natural gas rates in effect on January 1, 1981.

From the information contained in Table 2, it is concluded that for the 10.6 acre greenhouse complex the expected natural gas cost for 1981 would be \$138,521. However, greenhouse #4 will not be operational in the immediate future. Therefore, the estimated natural gas cost for 7.4 acres is \$96,703

TABLE 1: CALCULATED HEATING LOADS AND UNIT HEATER CAPACITIES*

Greenhouse #	Model #	Number of Heaters	Total Flow Rate (gpm)	Heat Delivered (Btu/hr)	Calculated Output per Unit Heater (Btu/hr)
1	VA22	3	143.1	2,146,500	715,500
2	VA22	6	286.2	4,293,000	715,500
3	VA22	6	286.2	4,293,000	715,500
5	VA22	17	810.9	12,163,500	715,500
6	GHS 210	24	381.6	5,724,000	238,500
TOTAL			1,908	28,620,000	

*Efficiency losses are not included in these calculations.

TABLE 2: NATURAL GAS CONSUMPTION

Month	Average Monthly Consumption, 1974-79 (MCF)	Cost at 1/1/81 natural gas rate ($2.71/MCF includes fuel adjustment and applicable taxes)
January	8,964	$24,292
February	8,642	23,420
March	7,082	19,192
April	5,580	15,122
May	2,240	6,070
June	--	--
July	--	--
August	--	--
September	--	--
October	1,623	4,398
November	7,646	20,721
December	9,338	25,306
TOTAL (10.6 acres)	51,115 MCF	$138,521
(7.4 acres)		$ 96,703

for the year 1981.

THE PROPOSED GEOTHERMAL GREENHOUSE HEATING SYSTEM

The following analysis provides a preliminary design for a retrofit geothermal heating system for the ERL greenhouse complex using the existing unit heaters, pumps and piping system wherever possible. The analysis also includes additional unit heaters, pumps and pipes as needed. Lastly, an economic analysis is performed in order to judge the profitability or benefit from the use of geothermal energy in place of natural gas as a heat source.

For purposes of this analysis, it is assumed that a significant geothermal resource capable of producing 130°F water exists beneath the greenhouse site. The assumption is based in part on preliminary exploration of the geothermal resource potential of the Tucson Basin, undertaken in 1979 by J.C. Witcher of the Arizona Bureau of Geology and Mineral Technology - Geothermal Group. In addition, a well owned by Tucson Electric Power Company located one mile east of Irvington Road and Palo Verde Road, approximately three miles from the greenhouse site, produces 57°C (135°F) water from aquifers between 410 meters (1,350 ft) and 640 meters (2,100 ft). The wells greatest water production is obtained at 564 meters (1,850 ft). The average temperature gradient is 60°C/km (4.3°F/100 ft) while the normal gradient in the Tucson Basin is 35° to 45°C/km (2.9 to 3.4°F/100 ft). The anomalous 60°C/km (4.3°F/100 ft) temperature gradient indicates upward migration of thermal water from depth (see Glossary of Geological Terms).

It is assumed that a geothermal well could be drilled at the greenhouse site and exhibit characteristics similar to the Tucson Electric Power Company well. Production wells would be drilled to a depth of 762 meters (2,500 ft), though actual production may occur at a shallower depth. It is further assumed that the geothermal water, under artesian pressure, would rise to within 400 feet of the surface, where pumping rates of up to 2,000 gpm would be possible. In addition, the geothermal fluid would contain an estimated 500 ppm of total dissolved solids. Geothermal water of this quality would be suitable for direct use in the heating system (i.e. a heat exchanger would not be required).

As a word of caution, it has not been proven that the ERL Farms greenhouse site sits atop a geothermal resource of the character and quality described above. Geological exploration is recommended in order to properly site a production well which would minimize the risk of failure. It is beyond the scope of this analysis to prescribe a detailed exploration and drilling program. It is believed that based on the resource evidence already available, the assumptions outlined above are reasonable and accurate.

The geothermal heating system would replace the boilers with geothermal energy production wells. A diagram of the proposed geothermal system is shown in Figure 2. The geothermal fluid would be pumped through main supply lines and into the unit heaters by turbine pumps. Motorized valves, controlled by thermostats, would regulate the rate of flow required to maintain greenhouse temperatures. Upon exit from the unit heaters, the cooled geothermal water would be collected through a network of return lines for disposal or reuse.

As a result of the geothermal fluid temperature (130^{o}F) being lower than the boiler-supplied water temperature (160^{o}F), additional unit heaters, pumps and piping would be needed in order to meet the heating demand. To assess the performance of the existing unit heaters when 130^{o}F inlet water is provided, it is necessary to derate the heating capacity of each unit heater. Based upon specifications of unit heater manufacturers, it is assumed that each 10^{o}F drop in inlet temperature results in a 7.2 percent loss of heating capability. Therefore, with a 130^{o}F inlet temperature, 21.6 percent of the

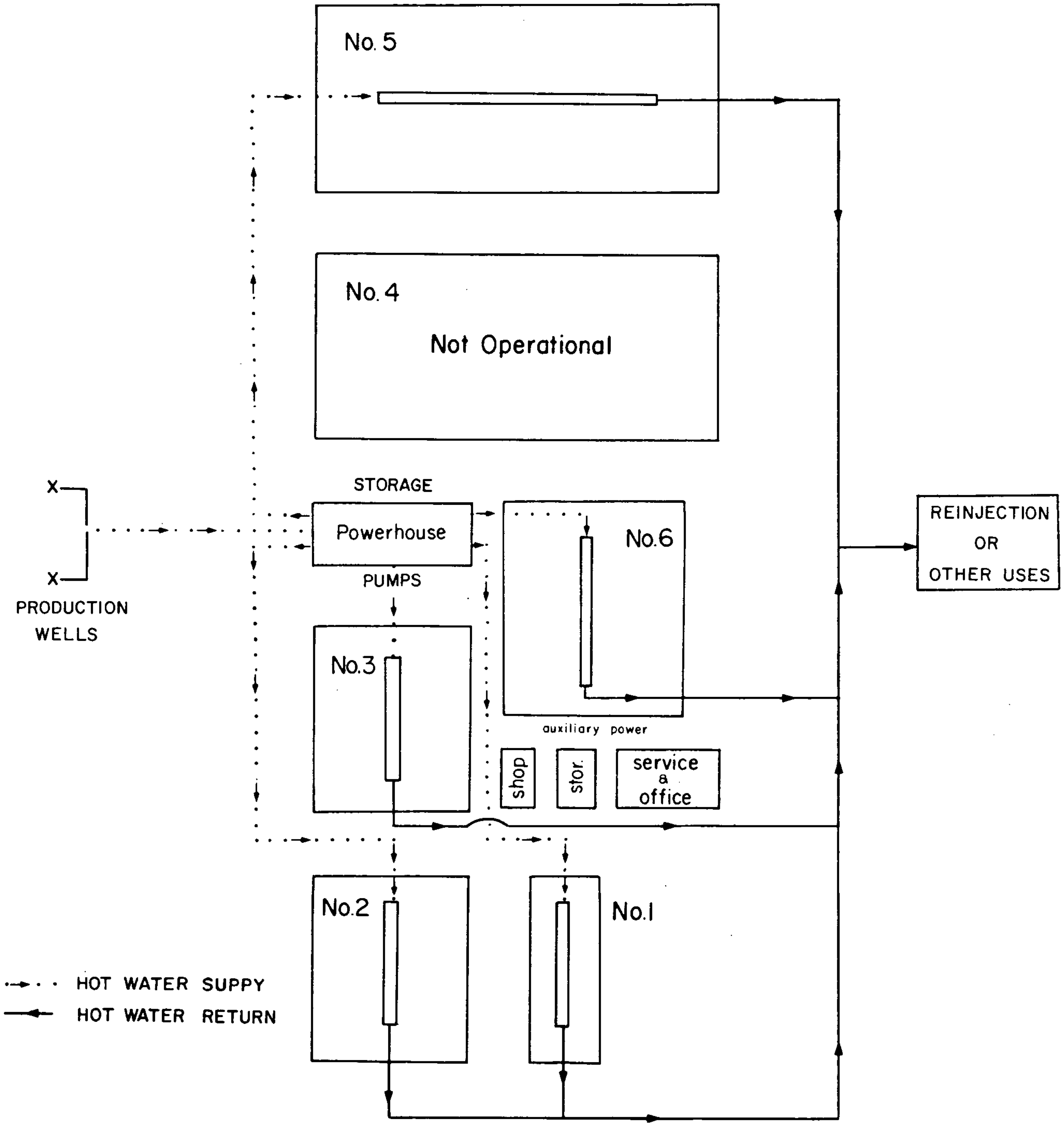

Figure 2: Proposed geothermal heating system

heating capability will be lost. By comparing Table 3 with Table 1, a heating deficiency of 6,181,920 Btu/hr is created because of the reduced inlet temperature.

TABLE 3: CORRECTED HEATING CAPABILITIES FOR EACH GREENHOUSE

Greenhouse #	Unit Heaters	Total Flow (gpm) (130°F Inlet)	Calculated Output per Machine (Btu/Hr)	Calculated Output per Greenhouse (Btu/hr)
1	3	143.1	560,952	1,682,856
2	6	286.2	560,952	3,365,712
3	6	286.2	560,952	3,365,712
5	17	810.9	560,952	9,536,184
6	24	381.6	186,984	4,487,616
		TOTAL		22,438,080

SYSTEM COMPONENTS AND CAPITAL COSTS

Two geothermal production wells, each with a depth of 2,500 feet would be required for the greenhouse heating system. B & G Drilling Company, Mesa, Arizona, recommended drilling two 26-inch diameter wells with 16 inch casing to the bottom of the hole. The estimated cost of completing such a well is $80 per foot. The two wells would be adequate to meet the peak heating load for the greenhouse complex and provide additional capacity should greenhouse #4 be used in the future.

In addition to the production wells, a method of disposing of the geothermal fluid must also be devised. Current Arizona Oil and Gas Conservation Commission regulations recognize two acceptable disposal methods for geothermal fluid, reinjection or disposal by ponding. The ERL Farms facility has an evaporation pond currently used for disposing of pumped high nitrate irrigation water. However, the pond probably could not handle the additional geothermal fluid. Therefore, the cost estimate includes a 12" reinjection well drilled to 1,800 feet. The estimated cost of the reinjection well is $99,000.

A second option for disposal might also be considered. Table 4 presents a chemical analysis of waters obtained from the Tucson Electric Power Company hot well. The dissolved solids content of the geothermal water is favorably low and suitable for irrigation. Should similar water be found beneath the ERL Farms facility, the geothermal water might be productively used for crop irrigation and as makeup water for the evaporative coolers. The result would be the replacement of currently pumped irrigation water with cooled geothermal water obtained from the deeper acquifer. The reduction in irrigation water pumping would reduce electrical costs and reduce shallow ground water withdrawals. However, current ground water regulations in the State of Arizona may prohibit such secondary use of geothermal fluid. The issue has not been adequately resolved but the option appears to offer favorable results.

Each well would require a 300 hp pump capable of supplying 1,500 gpm. The pumps selected for the production wells are two Johnston 7-stage 14 cc pumps and would be set at 600 feet. The price of this pump is estimated at $54,900 each. Maintenance of the Johnston pumps depends greatly upon the type, temperature and abrasiveness of fluid being pumped, the depth of the pump setting and straightness of the well. As a result, the pump life must be estimated.

The production wells are assumed to be located one-half mile from the greenhouse complex. This assumption is made in order to include a cost item

TABLE 4: SAMPLE OF CHEMISTRY FOR 135°F WATER ENCOUNTERED IN THE TUCSON BASIN

Constituent	Concentration
Calcium	3 ppm
Magnesium	.8ppm
Sodium	174 ppm
Bicarbonate	69 ppm
Carbonate	20 ppm
Hydroxide	0 ppm
Sulfate	220 ppm
Chloride	40.5 ppm
Flouride	4.9 ppm
Total Hardness (grains/gallons)	.6
Total Hardness	14 ppm
Phenolpthalein Alkalinity	1 ml
Bromcresol Green-Methyl Red Alka	5.4 ml
pH	9.1-
Silica	39 ppm
Total Conductivity	790 mmhos
Dissolved Solids	514 ppm

Source: Tucson Electric Power Company

for fluid transmission without knowledge of an actual production well site. The calculated pipe diameter of the main supply line is 13 inches. Commercial steel pipe is the preferred pipe material, and would cost $25 per foot. Total cost of the pipe is estimated to be $66,000. Pipe installation at $45 per hour would cost approximately $6,000.

Table 5 summarizes the heating deficiency created by the lower inlet temperature for each greenhouse and provides an estimate of the cost of purchasing additional unit heater capacity. It should be noted that unit heaters are common, off-the-shelf items available from local wholesale outfits. However, the cost of the additional heaters will vary with their rated capacities. The estimated costs provided here are based on unit heater sizes greater than 200,000 Btu/hr.

TABLE 5. COST ESTIMATE FOR ADDITIONAL UNIT HEATERS BY GREENHOUSE

Greenhouse #	Current Heating Capability (Btu/hr)	Corrected Heating Capability	Heating Deficiency	Additional Water Flow Required (gpm)	Estimated Unit Heater Cost*
1	2,146,500	1,682,856	463,644	39.4	$1,391
2	4,293,000	3,365,712	927,288	79	2,782
3	4,293,000	3,365,712	927,288	79	2,782
5	12,163,500	9,536,184	2,627,316	224	7,882
6	5,724,000	4,487,616	1,236,384	105	3,709
TOTAL	28,620,000	22,438,080	6,181,920	526.4	$18,546

*Cost estimates are based on a unit heater price of $3.00 per 1000 Btu of peak output.

Also clear from Table 5, additional water flow is required for the operation of the geothermal system. The calculated increase in flow is 526.4 gpm, implying that the geothermal production wells must produce at least 2,435 gpm to meet the maximum heating load for the five greenhouse buildings. To provide hot water to the added unit heaters, additional supply and return pipe are also required. Currently, supply and return pipes are two inch diameter steel pipe. Although the exact length of pipe required was not calculated, that depends on the placement of the additional unit heaters within each greenhouse, it is estimated that 6,500 feet of two-inch diameter steel pipe would be required. The estimated cost of two-inch diameter steel pipe is $1.80 per foot. The total estimated distribution piping cost is $11,700 and pipe installation is estimated to cost $4,000.

In addition to piping and trenching costs for the production and transmission system, at least one 50 horse-power circulation pump is needed to handle the additional water flow rate to the unit heaters. The estimated cost of a general purpose single stage 50 horse-power pump is $7,500.

Additional cost would also be incurred in insulating the pipelines extending from the production well to the greenhouse site. Although these costs were not directly estimated, a contingency figure of $30,000 is included in the analysis to include polyurethane foam insulation, pump and wellhead valves and other miscellaneous fittings and valves.

Table 6 presents a summary of costs necessary for the construction of a geothermal heating system for the Environmental Research Laboratory. Although

TABLE 6. COST SUMMARY - GEOTHERMAL GREENHOUSE HEATING SYSTEM

Item	Cost
Production Well (2) (2500 ft @ $80 per ft)	$400,000
Reinjection Well (1) (1800 ft @ $55 per ft)	99,000
Production Well Pump (2) @ $54,900 ea	109,800
Transmission Pipe	66,000
Transmission Pipe Installation	6,000
Distribution Pipe Cost	11,700
Distribution Pipe Installation	4,000
Circulation Pumps	7,500
Additional Unit Heaters	18,546
Insulation, valves, fittings, misc.	30,000
SUBTOTAL	$752,456
Engineering (10%)	75,200
Contingency (10%)	75,200
TOTAL INVESTMENT COST	$902,946

these reported costs are estimates, it is believed that they conservatively approximate an actual installed system cost. However, cost savings should be considered and appear possible. For example, avoidance of reinjection well costs would provide a significant savings. It might also be possible to deepen existing wells rather than drilling two new production wells, providing a substantial cost savings. Existing water well pumps might also be useful, rather than purchasing new pumps. Similar options might be available for other needed equipment. In summary, the cost estimate presented here is conservative by design and significant capital costs savings are possible.

As a result of the replacement of the current ERL Farms heating system with a geothermal heating system, the boilers currently in use would no longer provide the primary heating water. The ERL has seven boilers, all commmercial water tube boilers manufactured by Cleaver-Brooks. The total purchase price of the seven boilers was $119,000. Since the boilers will no longer be needed, it may be possible to resell some or all of them to help offset the geothermal system cost. For the following analysis, it is assumed that the boilers are retained for backup in the event of a failure in the geothermal system.

ECONOMIC ANALYSIS

From the preceding analysis, the technical feasibility of installing a geothermal heating system at ERL is relatively straightforward. Uncertainties exist regarding the exact characteristics of the resource but further exploration could eliminate those uncertainties. The remaining questions is whether the geothermal system makes economic sense. Two analyses are performed to answer this question. First, the project will be analysed as an investment opportunity for the University of Arizona. Second, it is compared to a conventional natural gas heating system in terms of dollars per unit of energy delivered. Favorable answers to both of these questions are necessary before the project should be considered.

As was previously shown, the total investment cost for the geothermal system is conservatively estimated at $902,946. Once the system is installed, it will also experience operating costs in the form of electrical energy to run pumps and additional fan units plus normal maintenance costs. Table 7 presents an estimate of normal operating and maintenance costs. Electrical costs are estimated based upon a current electrical cost of $.05 per kilowatt-hour and 1,790 hours of equivalent full load operation. Annual maintenance costs are conservatively estimated at two percent of the total investment cost or $62,406 per year.

TABLE 7: ESTIMATED OPERATING AND MAINTENANCE COSTS

Annual Maintenance Cost		$ 18,060
Electrical Costs:		
Production Well Pumps (2 at 300 hp each)	40,051	
Circulation Pump (50 hp)	3,311	
Additional Unit Heaters (15 hp)	984	
Total Electrical Cost		$ 44,346
TOTAL OPERATING AND MAINTENANCE COSTS		$ 62,406

In addition to the annual operating and maintenance expenses, the capital investment cost must be depreciated. It is assumed that the University of Arizona could issue A-rated tax exempt 15 year bonds at 12 percent interest. If $902,946 were borrowed for 15 years, an annual payment of $130,042 is required. Therefore, the total annual cost (operation, maintenance and debt service) of the geothermal heating system is $192,448. The actual savings of the geothermal system is the (1981) fuel cost avoided (see Table 2) minus the operating cost incurred, or $34,297.

Although savings are available in the first year, changing energy and maintenance costs will create different savings in each future year. Table 8 presents a 20-year projection of natural gas costs, geothermal system operating and maintenance costs, annual savings and present value of savings. Data Resources, Incorporated (DRI) long-range price forecasts are used as the basis for projecting future natural gas costs. DRI forecasts nominal natural gas price increases to average 19 percent per year between 1982 and 1991, and 10 percent per year between 1992 and 2001. Underlying inflation rates during these time frames are projected to be 10.3 percent and 6.7 percent, respectively. To simplify the following analysis and remain conservative, a 20 year annual inflation rate of 7 percent is assumed and natural gas price increase assumptions are reduced to 13 percent between 1982 and 1991 and 10 percent between 1992 and 2001. Use of the higher cost escalation rates would result in substantially higher cost savings and improve the economic feasibility analysis.

Electricity prices and maintenance costs are assumed to increase at eight percent per year over the life of the project. Electricity price increases are expected to result principally from increases in fuel, labor and tax over the next 20 years rather than from the construction of new generating capacity. A discount rate of 10 percent is used to calcuate the present value of savings.

From the results of Table 8, it is clear that the geothermal system provides significant savings in energy costs. The present value of the savings discounted at 10 percent is $1,864,697. However, two further considerations are necessary. First, the cost of geothermal heat compared with the 1982 cost of natural gas. It is estimated that the 1982 cost of natural gas is $3.40 per million Btu delivered to the greenhouse site. Assuming 80 percent boiler efficiency in the current system, the actual cost of hot water is $4.25 per million Btu.

TABLE 8: 20 YEAR PROJECTION OF GEOTHERMAL SYSTEM SAVINGS

Year	Annual Natural Gas Cost	Electricity & Main. Costs	Geothermal Savings	Present Worth of Savings (10% Discount)
1982	$121,326	$ 62,406	$ 58,920	$ 58,920
1983	137,098	67,398	67,700	63,364
1984	154,921	72,790	82,131	67,877
1985	175,060	78,614	96,446	72,461
1986	197,818	84,903	112,915	77,122
1987	223,534	91,695	131,839	81,862
1988	252,594	99,030	153,564	86,683
1989	285,431	106,953	178,478	91,587
1990	322,537	115,509	207,028	96,580
1991	364,467	124,750	239,717	101,663
1992	400,914	134,730	266,184	102,625
1993	441,005	145,508	295,497	103,570
1994	485,106	157,149	327,957	104,497
1995	533,616	169,721	363,895	105,407
1996	586,978	183,298	403,680	106,302
1997	645,675	197,962	447,713	107,179
1998	710,243	213,799	496,444	108,041
1999	781,267	230,903	550,364	108,887
2000	859,394	249,376	610,018	109,717
2001	945,333	269,326	676,007	110,533
		TOTAL	$5,768,497	$1,864,697

To estimate the cost of the geothermal energy per million Btu, the annual cost is divided by annual heat used. The annual geothermal cost is a combination of operating costs plus debt service necessary to amortize the original capital investment. Based on a five year average, 35,684 Mcf of natural gas is consumed each year for 7.4 acres of greenhouse, which is equivalent to 35,684 million Btu per year assuming 1,000 Btu per standard cubic foot. The annual geothermal cost is $192,448 resulting in a geothermal unit energy cost of $5.39 per million Btu. Additional system utilization during any year would reduce the geothermal cost because additional units of energy would offset the fixed debt payment. Further, if Greenhouse #4 were brought into use in the future, the geothermal energy cost would fall to $3.76 per million Btu. However, for the 7.4 acres considered, geothermal energy is currently more expensive than natural gas.

From the above analysis we can conclude that a geothermal system attempting to provide the peak heating load is only marginally economical. However, more than the average heating load could be met by a single geothermal well, requiring a capital cost investment of only approximately $600,000, about 66% of the initial proposed system. In addition, the maintenance and operating cost would be reduced by approximately $25,000 per year. The geothermal system could be backed up by the existing natural gas boilers to meet the peak heat demand. Such a system designed to provide the average heating load is more economical and can compete successfully with the present price of natural gas.

SUMMARY AND REMARKS

The geothermal greenhouse heating system as proposed for the Environmental Research Laboratory Farms is technically feasible but only marginally attractive under current natural gas prices. From a technical standpoint, hardware necessary to construct such a system is readily available and has proven reliable. However, the economic analysis suggests that the geothermal system have a nine year payout, and would not provide an adequate return on investment from energy savings. In addition, despite recent natural gas price increases, natural gas can be purchased at lower unit cost than the geothermal heat. Natural gas prices have not yet reached a level necessary to justify a project of this magnitude. The geothermal system currently offers less reliance on fossil fuel energy sources and reduces the risk of interruptible natural gas service.

Several other comments are appropriate. The analysis relies heavily on the level of future energy prices, a topic of much speculation. Although a sensitivity analysis is not included, changes in energy price assumptions would affect the final results. Energy price increases over twenty years were chosen conservatively so as not to bias the results in a more favorable manner. Further, capital cost estimates do not reflect efforts to avoid certain costs or to optimize the system. A future, more detailed analysis should consider less expensive disposal methods, the use of hot water storage facilities to meet peak heating demand and avoid well costs, or the use of currently available equipment. Further, the use of geothermal energy to provide a base load of, say, 60 percent, and the use of the boilers for peak load should be investigated.

REFERENCES

1. Anderson, David N. and Lund, John W., Direct Utilization of Geothermal Energy - A Technical Handbook, Geothermal Resources Council Special Report No. 7, 1979.

2. Armstead, H., Christopher H., "'Other' Uses for Geothermal Heat", Geothermal Energy, London: E. and F.N. Spon Ltd., 1978.

3. ASHRAE Handbook, Fundamentals, 1977.

4. ASHRAE Handbook, Equipment, 1978.

5. Bates, Robert, "Geothermal Greenhouse Operations in Susanville, California, in Major Expansion", Geothermal World Directory, 1977-78.

6. Boren, Kenneth L., "The Use of Geothermal Fluids to Heat a Large Greenhouse Complex". A Symposium on Geothermal Energy and Its Direct Uses in the Eastern United States, Special Report No. 5, Geothermal Resources Council, April 1979.

7. Data Resources, Inc., U.S. Long-Term Review, DRI, Lexington, Massachusetts, Spring 1981.

8. Eastlake, William B., "Economics for Geothermal Direct - Use", Geothermal Energy Magazine, April, 1980.

9. Kreith, Frank and Black, William Z., "Heat Exchangers", Basic Heat Transfer, New York: Harper & Row, 1980.

10. Modine Application Data 10-204:1, 1980.

11. Wehlage, Edward F., The Basics of Applied Geothermal Engineering, West Covina, California, Geothermal Information Service, 1976.

12. Witcher, J.C., A Preliminary Study of the Geothermal Potential of the Tucson Metroplitan Area: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 79-2d, 1979.

13. Witcher, J.C., Geothermal Resource Potential of the Tucson Basin, Arizona: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-27, 1981.

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.

4. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Pinal 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 79-11.

5. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Yuma 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 81-18.

6. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Cochise - Santa Cruz 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 80-9.

7. Goldstone, L.A. and White, D.H., 1982, Geothermal Development Plan: Northern Arizona 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 80-10.

8. Goldstone, L.A. and White, D.H., 1982, Maryvale Terrace: Geothermal Residential District Space Heating and Cooling, 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 81-11.

9. White, D.H. and Goldstone, L.A., 1982, Evaluation of Geothermal Cooling Systems in Arizona, 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 81-13.

10. White, D.H. and Goldstone, L.A., 1982, Irrigation Pumping Using Geothermal Energy, 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.

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.

12. White, D.H. and Goldstone, L.A., 1982, Geothermal Energy for Copper Flotation Enhancement and Leaching of Tailings, 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 81-10.

13. White, D.H. and Goldstone, L.A., 1982, The Potential of Hybrid Geothermal/Coal Fired Power Plants in Arizona, 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 81-8.

14. Malysa, L.M. and White, D.H., Hahman, W.R., Mancini, F., and Goldstone, L.A., 1980, Arizona Geothermal Institutional Handbook, prepared for the U.S. Department of Energy, Contract No. DE-FC07-79ID12015, and the Arizona Solar Energy Commission: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 80-7.

15. White, D.H. and L.A. Goldstone, 1982, Executive Summary: The Potential of Utilization of Geothermal Energy in Arizona, 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 82-1.

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.

3. Johannessen and Girand Consulting Engineers, Inc., 1981, Feasibility Study for Geothermal Water Space Heating for the Safford Federal Prison Camp, Safford, Arizona: Unpub. Report for the Oregon Institute of Technology, Contract No. TA 18-80: State of Arizona Bureau of Geology and Mineral Technology Open-File Report 81-30.

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 Cneter
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 km^2 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.