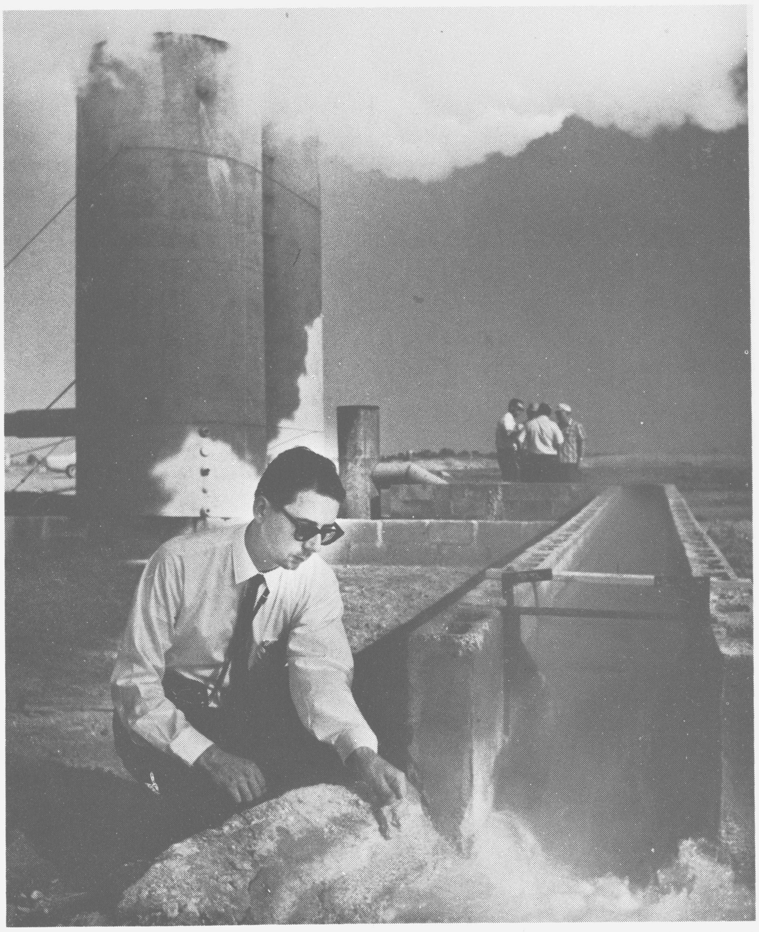
INVESTIGATION OF THE GEOTHERMAL POTENTIAL OF THE LOWER COLORADO RIVER BASIN

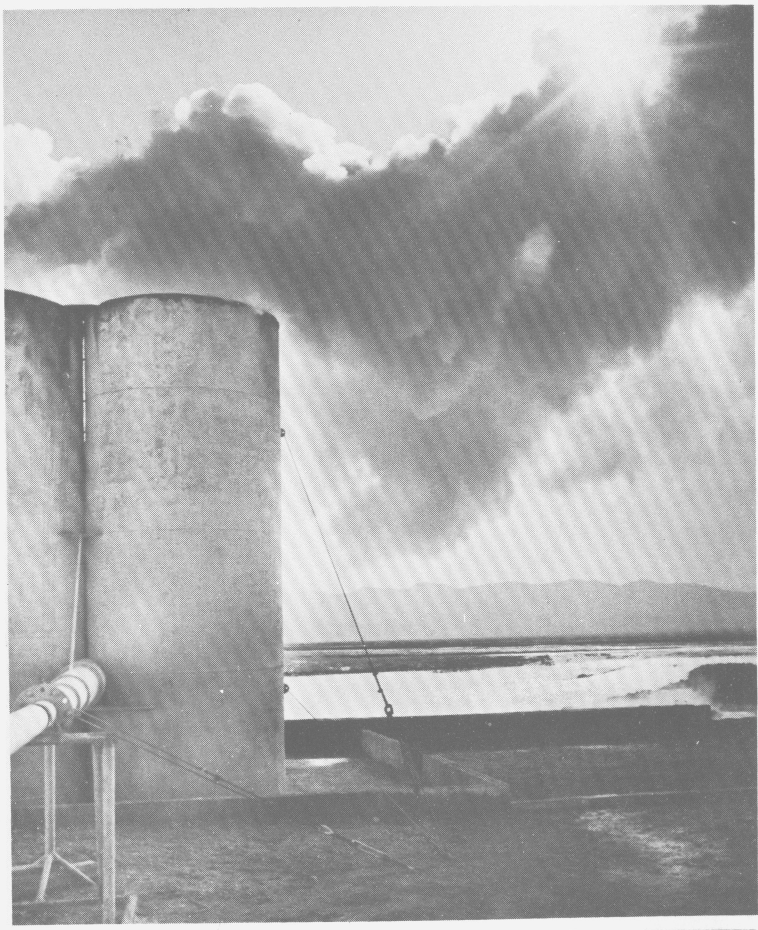
PHASE I - THE IMPERIAL VALLEY PROJECT

Robert W. Rex

UNIVERSITY OF CALIFORNIA
EDUCATION RESEARCH SERVICE
RIVERSIDE

The Institute of Geophysics and Planetary Physics,
University of California,
Riverside, California 92502





Dr. Bob Rex at the Mexican Cerro Prieto geothermal steam field 16 miles south of Mexicali. Well No. M-5 is producing 1,200,000 pounds per hour of steam and brine. This field is being developed by the Federal Commission of Electricity of Mexico for power.

UNIVERSITY OF CALIFORNIA, RIVERSIDE

BERKELEY · DAVIS · IRVINE · LOS ANGELES · RIVERSIDE · SAN DIEGO · SAN FRANCISCO · SANTA BARBARA · SANTA CRUZ

UNIVERSITY OF CALIFORNIA 100 YEARS 1868 1968
A Tribute to the People of California

DEPARTMENT OF GEOLOGICAL SCIENCES

RIVERSIDE, CALIFORNIA 92502

September 4, 1969

Mr. Giancarlo Facca
1023 Timothy Lane
Lafayette, California 94549

Dear Mr. Facca:

This is to acknowledge receipt of your letter of August 14 to Dr. Robert W. Rex and to thank you for the reprints. Dr. Rex is out of town until September 16 so I am enclosing a copy of our Imperial Valley Project, Phase I Report. We will place you on our distribution list and mail you copies of our reports as they are issued.

Sincerely yours,

Carol A. Besack

(Miss) Carol A. Besack
Secretary for Dr. R. W. Rex
Professor of Geological
Sciences

cb

Enc.

INVESTIGATION OF THE GEOTHERMAL POTENTIAL OF THE LOWER COLORADO RIVER BASIN

PHASE I - THE IMPERIAL VALLEY PROJECT

Robert W. Rex

The Institute of Geophysics and Planetary Physics,
University of California, Riverside, California 92502

This page is intentionally blank

Geothermal Summary Information

Geothermal fields suggested in the Imperial Valley: 6-9.

Geothermal brine reserves: 1,000,000,000 acre-ft.

Temperature range of brine in the ground: 500-700°F.

Total number of wells projected: 1000-3000.

Surface pressures of flowing wells: 300-400 psi.

Surface temperatures of flowing wells: 300-400°F.

Flow rates per well (11 3/4" pipe): 1,200,000 pounds per hour (10.6 acre-ft/day).

Depth of typical well: 5,000 feet.

Brine salinity (Mexican type): 2-3 percent dissolved solids.

Brine chemistry: chlorides of sodium, potassium, and calcium.

Cost of typical well: $100,000.

Projected production rate of total Imperial Valley geothermal wells:

3,600,000 acre-ft/year to 10,000,000 acre-ft/year.

Electric power with 1000 wells: 20,000 megawatt.

Steam price per Kw-hr: 0.36 mils.

Heat price: 2 cents per million British Thermal Units.

This page is intentionally blank

0.0 ABSTRACT

The Imperial Valley Project (IVP) is a program initiated by a team of staff members of the Institute of Geophysics, University of California at Riverside to develop the geothermal resources of the Lower Colorado River delta which includes the Imperial Valley of Southern California and adjoining areas. Initial efforts are concentrated on the Imperial Valley but later field studies will include work in Arizona, Mexico, and possibly Nevada to define the extent and quality of geothermal resources.

In the first phase of the study, already in progress, a combination of geological and geophysical methods is being employed to map out promising potential sources of geothermal energy.

Following a critical evaluation of the preliminary exploration phase, we propose to conduct extensive field tests to provide the essential data necessary to determine the economics of exploitation of geothermal energy for power generation, water desalination, and possibly mineral extraction.

If the preliminary economic evaluation is favorable we intend to pursue a full scale investigation involving a detailed scientific evaluation of the geothermal energy reserve of the entire geothermal area. This study is to be accompanied by engineering and economic evaluation of the potentialities for development of geothermal energy in the Lower Colorado Basin for water desalination and power generation.

The current phase of operation, costing some $40,000, is supported by federal, state, and industry contributions. This level of funding is permitting a minimum program of geophysical exploration and geothermal investigation over a small portion of the promising areas. If the preliminary results are favorable, additional support will be sought in order to complete the first phase of the project.

1.0 INTRODUCTION

The Imperial Valley Project (IVP) is an applied research program intended to provide geologic, hydrologic, engineering, and economic information necessary for development of the geothermal resources of the delta of the lower Colorado River.

The project is being directed in its initial phase by Dr. R. W. Rex, as the Principal Investigator, and Dr. T. Meidav, as the Geophysical Project Director. Both are members of the Department of Geological Sciences and the Institute of Geophysics of the University of California at Riverside. The two named investigators have the support of several other faculty members who are expected to join the study in its later phases when more support becomes available. The project is being administered within the Institute of Geophysics and Planetary Physics at Riverside.

The proposed study consists of a number of phases. The initial phase, already underway, is concerned with collection of basic geochemical and geophysical data to demonstrate the most useful and reliable techniques that might be employed to survey the geothermal energy resources of the Imperial Valley quickly and economically.

This initial effort is being supported by the U.S. Bureau of Reclamation, the National Science Foundation, and the Standard Oil Co. of California. Other industrial support has been solicited but at present is not available.

2.0 THE OBJECTIVES OF THE IVP

(1) Reduce the risk for exploitation of geothermal energy to the point where industry and government can cooperate to develop the large untapped geothermal resources in the Imperial Valley by locating the principal potential steam fields, determine their chemistry, size of reserves, and productive potential including direct testing of wells.

(2) Provide impartial scientific information to governmental and public agencies to assist in regional planning for optional energy and water resource development.

(3) Bring together potentially interested parties who might cooperate in forming an operating system to develop and control the presently underdeveloped water resources of the lower Colorado delta area, including groundwater, drainage water, Salton Sea water, and ocean water.

(4) Perform field and laboratory research needed to support planning, economic evaluation, and engineering feasibility studies.

(5) Train scientists and engineers in geothermal energy-related technology to provide personnel needed by industry and government to support development of this resource.

(6) Test and develop advanced scientific techniques for geothermal exploration in general which may be used in other areas as well, after having been tested and proven in the Imperial Valley.

3.0 HISTORY OF GEOTHERMAL DEVELOPMENT IN THE IMPERIAL VALLEY

Geothermal energy is being developed commercially in the Imperial Valley in the Cerro Prieto area south of Mexicali where at least 17 wells have been completed. A contract has been signed for a Japanese steam power plant with 75,000 Kw capacity to be completed in 1970 (Fig. 1).

U. S. developments have been largely restricted to the Buttes area at the south end of the Salton Sea (Fig. 1) where several test wells have shown the presence of a hypersaline hot brine that is of uncertain commercial value because of the excessive proportion of hypersaline brine to steam. Unlike the Mexican brine, the Buttes brine is highly corrosive on the slightest exposure to air, and toxic metals make potash recovery presently non-competitive with Canadian potash. Recovery of other metals including silver may be possible in the future but does not appear to be commercial at present.

The Buttes area is actually underlain by two separate types of geothermal brine. The deeper brine is the very hot hypersaline brine, while above it occurs a cooler less saline brine of approximately 1-3 percent dissolved solids that is noncorrosive. The contact between these two brines dips to the south. It is at approximately 2,000-2,500 feet at the I.I.D. well No. 1 near Red Hill; at about 5,000-6,000 feet at the Sinclair No. 1 about four miles south; and none found at all to a depth 13,000 feet at the Wilson No. 1 just east of Imperial. This same less saline non-metalliferous brine is also produced in the Mexicali steam field. Its widespread occurrence over most of the valley makes it attractive to try to locate areas where high temperature brines greater than $550^{\circ}F$ come within 5,000 feet of the surface. Preliminary exploration over the past decade suggests that there are a number of possible geothermal locations in the Imperial Valley, some on federal, some on state, and some on private land.

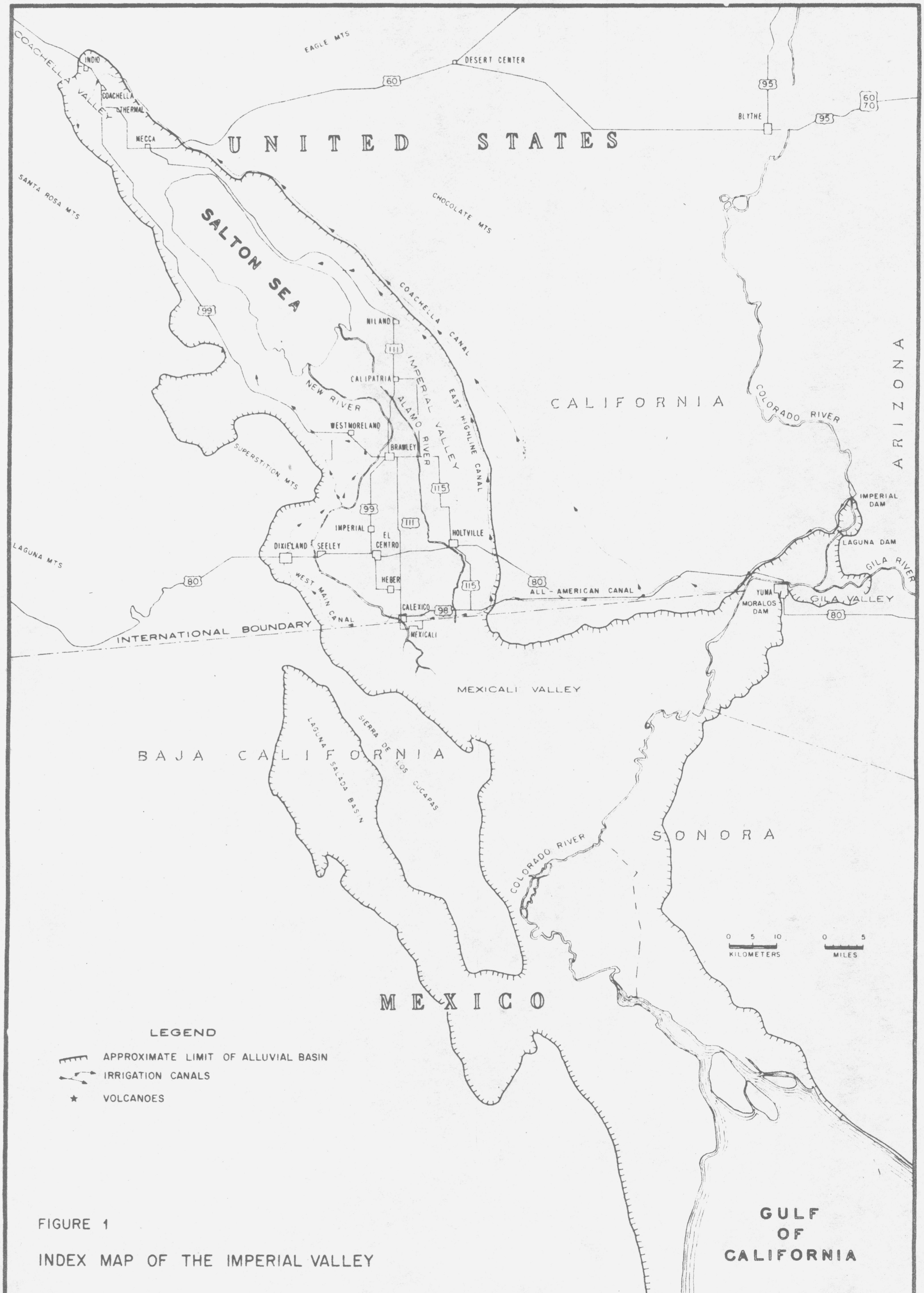


FIGURE 1

INDEX MAP OF THE IMPERIAL VALLEY

LC46-685

This page is intentionally blank

No significant commercial development of the steam potential of the Imperial Valley fields has occurred because of the problem of brine disposal. Approximately two pounds of brine are produced for every pound of steam and the brine disposal costs currently inhibit commercial development of steam. Consequently, development of a large market for geothermal brine is essential for development of the lower Colorado basin geothermal potential.

The only market evident for very large quantities of geothermal brine is for saline water conversion. Traditionally, water distribution falls into the public section of the economy. On the other hand, geothermal steam wells themselves involve application of sophisticated scientific technology developed by the petroleum industry in the course of steam-assisted oil recovery research. In addition, the individual steam wells will probably have a limited lifetime of five to ten years; will require careful specialized maintenance; and will need to be supported by a technology research program typical of oilfield technical service support. The logical division, therefore, is for private industry to drill and operate the wells and to sell steam and brine to public or semi-public agencies or utilities to produce potable water and power.

The problems of partial private and partial public sector contribution to geothermal development has led to an impasse in Imperial Valley geothermal developments where everyone seems to be waiting for someone else to make the first move. The Imperial Valley Project is intended to be a first move by the University of California to bring together both the public and private sectors of our economy in this area for the public welfare.

4.0 PROBLEMS EFFECTING FURTHER DEVELOPMENT OF GEOTHERMAL ENERGY IN THE VALLEY

We presently lack sufficient detailed scientific information to evaluate the economics of the geothermal potential of the lower Colorado basin. We need to know in considerable detail the location of potential steam fields, the amount of hot brine reserves; the chemical character and possible corrosiveness of the brines; the depth and shape of potential steam reservoirs to assist in well planning; and the origin and possible recharge mechanisms of groundwater in order to determine the life of the steam fields. We also need to determine the feasibility of pressure maintenance by ocean water or Salton Sea water injection; the maximum productivity of different reservoir sands; and possible sand formations that could be used for brine disposal.

If all the porosity of the sediments of the Imperial Valley were collapsed and the water squeezed out to the surface, the valley would be covered with a sea about 3000 feet deep. This is almost a thousand times the volume of the Salton Sea today. Consequently, the large groundwater reservoir in the valley could easily serve as a sink for the excess salts of the Salton Sea or of sea water charged to the groundwater reservoir for a period of 10-20 years at minimum.

Mexican-type brines contain 1.5 to 2.5 percent dissolved solids and can yield about 90-95 percent of their water without becoming saturated with salt. The Mexican-type brines contain no sulfate and the first phase to reach saturation is sodium chloride. Consequently, a desalination plant fed by geothermal brine might yield approximately 90 percent distilled water and about 10 percent concentrated brine which could be reinjected underground in cool areas. This would leave approximately 25 percent of the geothermal steam for industrial uses or power generation.

Cost figures at this stage are at best tenuous because all past desalination plant designs have been optimized for fossil or nuclear steam costs of 22-35 cents per million B.T.U.'s. We have set geothermal brine costs at about 1 cent per million B.T.U.'s with a reasonable premium for steam in order to pay the wells out in four years or less. At this price heat for desalination is almost free coming to about 12-15 dollars per acre-ft. Plant amortization and operating costs will probably come to 40 to 70 dollars per acre-ft.

The cost of geothermally desalinated water is obviously much greater than present Colorado River water and, therefore, it would have to be considered as incremental water in competition with Eel River water or Columbia River water. It appears most reasonable that development of a lower Colorado water grid could include this new distilled water and that withdrawals of Colorado River water could be made by exchange of Imperial Irrigation District Colorado River water allocations outside of the I.I.D. at desalinated prices and use of desalinated water locally in the Imperial Valley at Colorado River prices. Additional exchanges of Owens River water might be made for Colorado River water delivered to the Metropolitan Water District. This in effect would introduce a two level price structure for southwest U. S. water. Riparian rights holders would get their historical prices while newer buyers would have to pay incremental water prices. This effectively restricts new users to municipal and industrial users. For the purpose of regional development and growth consideration should be given to protecting agricultural access to riparian rights from municipal and industrial users who could afford to pay incremental prices.

Addition of salt-free distilled water to the I.I.D.'s water allotment would permit salinity reduction and reduce the amount of leach water needed for salinity control of irrigated areas. Consequently, desalinated water would help cushion the effect of the reduced Colorado River allocation to the I.I.D. as a consequence of recent court decisions. In addition, steam separated from geothermal brines at the well head would be available for power generation at very low cost. This steam is usually superheated a few degrees; has a pressure of 300-400 psi; and a temperature of 300-450°F. Mexican experience in the next three years should demonstrate feasibility of geothermal power production in the Imperial Valley. The cost of geothermal steam is approximately 0.36 mils per Kilowatt-hour of electricity produced.

The steam fields will produce, at least for a number of years, from single phase brine reservoirs. It appears that produced steam could be sold at about 1-2 cents per million B.T.U. and pay out well and surface production equipment in about 24-48 months. The Mexicans have shown 1,000,000 to 1,200,000 pound per hour flowing wells to be reasonable and a large number of wells flow at friction-limited rates. Consequently, even larger wells should be tested in the future.

5.0 ULTIMATE POTENTIAL DEVELOPMENT IN THE IMPERIAL VALLEY

5.1 Reserves

An approximate estimate can be made of the regional geothermal potential of the Imperial Valley of California and Mexico based on the work of Rex (1965) and the Mexican studies. The values given are only approximate but serve to indicate the large size of the geothermal reserves. The key information known at this time is that the entire valley is a geothermal province with an average heat flow of two to three times the continental average. The key difference between the cool and the hot areas is that convective cells of hot waters rise along some of the faults and fault complexes in the valley and give rise to very steep temperature gradients in some local areas. In other areas low salinity cold waters move across the valley in shallow aquifers and local near surface heat flow is less strongly influenced by upward moving deep waters. Consequently, economic development of geothermal waters will occur in the areas of highest heat flow. However, geothermal wells in these shallow hot areas should drain geothermal fluids from the entire surrounding areas and the entire deep portion of the basin can be considered to be filled with geothermal brine.

The geothermal area is estimated to cover at least two million acres. There appears to be about 20,000 feet of sediment in the basin and if the lower 15,000 feet are filled with hot brine and we assume an effective average porosity of 10 percent, we would have three billion acre-feet of geothermal reserves or more than two hundred times the annual flow of the Colorado River. The heat content of the minerals which make up the nonaqueous 90 percent of the rock is slightly greater than that of the hot brine assuming 10 percent porosity and, consequently, injection of cold sea water as part of pressure maintenance program could extract additional heat and potentially nearly double the previous ultimate reserve estimate.

Production of ten million acre-feet per year of geothermal brine would, therefore, utilize approximately less than one hundredth of the total reserves in the valley.

Regardless of the nature of moderate errors in the above figures it is evident that the geothermal reserves are sufficiently large so as to open the possibility of making a significant contribution, perhaps by a factor of two, to the water supply of the southwestern United States providing sea water can be brought into the Imperial Valley.

5.2 Pressure maintenance by sea water injection at Yuma Mesa

One possible area for introduction of sea water is in the old Colorado channel at Yuma Mesa. Here dredging of the old channel and construction of a port for Mexico, California, and Arizona would introduce sea water into the upper delta.

Drilling in the Algodones Dunes which reach almost to Yuma Mesa indicates that a major prism of sand penetrates deep into the subsurface below the present dunes. If this subsurface extension is extensive and reaches the port area, it should be relatively easy to inject sea water below the present fresh waters into these deep sands and use them as an aqueduct to distribute cold salt water across the basin. There is as much as two hundred feet of drop from sea level to some of the prospective geothermal areas. The resultant pressure gradient should assist the spreading of sea water through the various aquifers in the valley.

The use of the Yuma port as a source of sea water for pressure maintenance is probably of equal or perhaps greater importance than commercial utilization by Arizona and California as a port.

5.3 Unknowns and further information needed

The validity of these estimates and extrapolations from preliminary data will have to be established. Specifically, we need to know the distribution of various types of waters, both saline and fresh; the nature and transmissability of various aquifers; the relationship of the flow patterns of both hot and cold waters; and the chemistry and quantities of the various geothermal brines. We, also, need to evaluate the costs of various engineering alternatives considering both the entire system and various subsystems.

5.4 Initial stages

Initial pressure maintenance efforts would not necessarily need sea water. Approximately 1,130,000 acre-ft per year of drainage water flow into the Salton Sea from the Imperial Valley. All of this water eventually evaporates leaving the salts behind in the Salton Sea where the salinity has been increasing. Diversion of some Salton Sea water and drainage water into a pressure maintenance operation could provide a means for stabilizing both the level and salinity of the Salton Sea at some preselected level lower than its present one. The residual geothermal brines from the desalination plant could also be reinjected into cool aquifers at intermediate depths as part of this program. Later development of a drainage system running to the sea, possibly along the banks of the ship canal or along the valley of the New River is a long range solution whose use would depend on an economic or technical advantage over subsurface disposal.

5.5 Geothermal wells

Approximately thirty successful geothermal wells have been drilled in the Imperial Valley. The great majority of these have flowed at casing friction-limited rates; consequently, we have little information concerning the ultimate productivity of large diameter bore holes. The most productive well to date has been the Cerro Prieto Field Well No. M-8, which flowed two million pounds of steam and brine per hour during a blowout which was later brought under control. Flow at this rate stressed the sandstone around the bore hole and the well produced excessive amounts of sand. Numerous wells in this field are producing at 1,200,000 pounds per hour. However, 16-20 inch diameter wells might produce between 2-4 million pounds per hour. It is probable, therefore, that average well productivity will be at least in the 1,000,000 to 1,500,000 pounds per hour range. Total life of a well is currently unknown but will probably be at least five to ten years in the Mexican steam field. Silica scale is laid down inside the well bore where some of the brine flashes to steam. Mexican experience shows that this scale can be readily removed by mechanically reaming the well once or twice per year. The silica scale laid down in the Imperial Irrigation District Well No. 1 in the Buttes area is worth about $1000 per ton for its silver content. It is premature at this time to predict any economic mineral recovery from the geothermal brines, but there has been considerable interest at the Buttes field by a number of companies. A small amount of calcium chloride is now produced commercially by the Chloride Products Co. However, to a very large extent the future promise of mineral recovery depends on supporting the cost of the wells from the sale of steam and the heat and water of the brines. Minerals and metals, also, appear to be primarily by-products when one considers the quantities of salts coproduced with a million acre-ft per year of brine. Large scale sulfur recovery may be feasible from a Mexican type of brine which contains about a quarter of a percent of hydrogen sulfide in the carbon dioxide gas that is the main non-condensable gas in the steam.

All evidence to date suggests that both the Buttes and Mexican fields have single phase brine reservoirs and that steam forms by flashing in the well bores. The evidence in the Mexican steam field is somewhat ambiguous. The majority of the wells in Mexico clearly tap a hot brine, but recent drilling has yielded a well with 1500 psi shut in pressure suggestive of penetration into a gas reservoir. Normal flowing pressures are 200-400 psi and steam and brine temperatures range from 400-600°F depending on the pressure drop. A detailed review of the thermodynamics of the Buttes field has been published by Helgeson (1968). The majority of the Mexican data are unpublished but considerable information is available on request.

This type of information is needed for each of the potential U.S. fields in the Imperial Valley in order that the economics of their exploitation can be evaluated.

5.6 Economics of wells

Only approximate figures can be presented for well costs but a reasonable estimate is that the average well will be 5000 feet deep. If one uses 13-5/8 inch I.D. casing with 11-3/4 inch liner, which is a minimum figure if the rocks will sustain the resultant flow rate, then the cost per well for well and surface hardware including steam-brine separator and prorated share of gathering line cost is about $100,000. Well spacing will probably be 500-1000 feet if current experience in the Valley is indicative. Production of 1,000,000 to 1,200,000 pounds of steam and brine per hour appears reasonable. This mixture should have an average recoverable enthalpy of 500 B.T.U.'s per pound. The wells would, therefore, be producing about 500,000,000 to 600,000,000 B.T.U.'s per hour. If we set a sale price of one cent per 1,000,000 B.T.U.'s, this means a value of $5-6 per hour or $120-144 per day per well. Assuming production for 350 days per year would yield a gross of $42,000-50,000 per year. Assigning approximately half of the gross to operating costs, including royalties, taxes, etc., the wells should pay out in four years or approximately half of their estimated lives. Obviously, a small increase of efficiency or of energy price of even one cent per million B.T.U.'s will have a major favorable impact on the profitability of the steam wells. Some small increment to the base energy price may be necessary to cover waste brine reinjection costs, but basically the approximate fair cost of geothermal heat in the Imperial Valley is near 1-2 cents per million B.T.U.'s. This compares to 25-35 cents per million B.T.U.'s for fossil fuel heat and 22-25 cents per million B.T.U.'s for the more optimistic nuclear figures. Future nuclear cost projections suggest further declines, but there is no nuclear heat source on the horizon anywhere near the cost of geothermal heat. This does not mean, however, that geothermal steam is clearly competitive with nuclear power for electricity generation. Nuclear steam is dry, high pressure, high temperature steam that can be used very efficiently in large power plants. Imperial Valley geothermal steam is relatively low pressure, low temperature steam, well suited for small power plants but less attractive for large units. Furthermore, it is accompanied by large amounts of hot brine which must be utilized to make the entire venture economic. Consequently, geothermal energy in the Imperial Valley offers its greatest potential for a combined desalination-power program.

Industrial uses for low cost process steam are numerous and it is not feasible to enumerate them here but one possibility might be production of deuterium using preliminary solar concentration followed by the use of the hydrogen sulfide exchange technique used by DuPont at Savannah River. The low cost of heat in the Imperial Valley might sufficiently drop the cost of heavy water to the point where heavy water reactors could compete with light water reactors with a fuel cost savings by using natural instead of enriched uranium.

Industrial process heat uses, however, face the same problem that faces production of electricity, namely disposal of the coproduced brines. Here again water desalination is the key to brine disposal.

Desalination pilot plant studies of various types of Imperial Valley brines are needed to work out the economics of large scale operations. The pilot plants will each need a few test wells to provide the necessary feed brine. One of the major objectives of the U.C.R. Imperial Valley Project is to provide scientific information to assist in locating, drilling, and testing these initial wells. Research in support of this geothermal desalination effort is being carried out by the Sea Water Conversion Research Laboratory of the University of California at Berkeley under the direction of Dr. Alan Laird.