GEOHERMAL RESOURCE INVESTIGATIONS

IMPERIAL VALLEY, CALIFORNIA

JANUARY 1972

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Herbert Rogers Jr.
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DEVELOPMENTAL CONCEPTS

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Bureau of Reclamation
Ellis L. Armstrong, Commissioner**

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GEOTHERMAL RESOURCE INVESTIGATIONS

Imperial Valley, California

January 1972

DEVELOPMENTAL CONCEPTS

Bureau of Reclamation

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EXPLANATION

■ Areas of Bureau of Reclamation Geothermal Investigations

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

GEOTHERMAL RESOURCE INVESTIGATIONS
IMPERIAL VALLEY, CALIFORNIA
GENERAL MAP
MAP NO. 1241-300-24

GEOHERMAL RESOURCE INVESTIGATIONS
Imperial Valley, California
January 1972

Foreword

The objectives of this report are to present concepts for geothermal development in Imperial Valley for augmentation of the Colorado River and to outline the need for a research and investigation program. In the course of reaching these objectives, it is necessary to define the resource potential and to select conceptual plans that would meet water needs with the least disturbance to the natural environment.

The Bureau of Reclamation is continuing a cooperative geothermal investigation program with the Office of Saline Water, Geological Survey, State of California, and the University of California at Riverside to ensure a complete evaluation of the potential for developing the resource. Imperial Irrigation District is participating in the program by the contribution of funds.

The Bureau of Reclamation has a statutory responsibility to investigate alternate water supplies to supplement the Colorado River under the Colorado River Basin Project Act (P.L. 90-537, 82 Stat. 885, September 30, 1968). Development of a water supply from geothermal resources in the Imperial Valley of California appears to have a high potential for augmentation of the river from sources within the basin.

This report was prepared under the authority of the Federal Reclamation laws (Act of June 17, 1902, 32 Stat. 388, and Acts amendatory thereof or supplementary thereto) and Public Law 90-537.

GEOTHERMAL RESOURCE INVESTIGATIONS
Imperial Valley, California
Developmental Concepts
Synopsis

This report describes the need for augmenting the Colorado River with high quality water, and shows how the hot geothermal brines of the Imperial Valley could be used to supply this need through multipurpose development of the resource.

The Imperial Valley geothermal resource consists of vast quantities of hot brine. This hot brine will flash into a mixture of steam and brine when pressures are relieved by a well. This mixture will flow to the surface and can be used to produce not only electric power, but also desalted water and possibly mineral by-products. A multipurpose development will not only produce lower cost products than single-purpose development, but will produce essentially the same quantity of electric energy. A further advantage of multipurpose development would be to lower the unit cost of replacement fluids by the economies of scale inherent in large-scale transport. Replacement fluids are considered necessary to prevent land subsidence due to fluid withdrawal from the underground reservoir. Five sources of replacement fluids are considered in the report: Pacific Ocean, Gulf of California, Salton Sea, Wellton-Mohawk Drain, and ground water.

On the basis of preliminary studies, developmental concepts for water and energy production have been prepared and presented in this report with a discussion of the many factors that must be considered for optimum utilization of the resource. The geothermal program outlined herein would be developed in three stages: the Research and Development Stage, the Demonstration Stage, and the Large-Scale Development Stage.

Stage 1: Research and Development Stage

This stage would, through extensive geological, geophysical, and water chemistry investigations, determine the potential and extent of the geothermal resource. Test and disposal wells would be drilled to obtain fluids for testing and determining feasibility of injecting residual and replacement fluids into the periphery of producing zones. Pilot and prototype desalting plants would be constructed and operated to develop data for subsequent stages. Alternative concepts would be investigated to determine the most feasible plan of developing the total resource. This joint program of the Bureau of Reclamation and the Office of Saline Water would require expenditures of about \$16 million over a 7-year period.

Stage 2: Demonstration Stage

This stage would demonstrate the feasibility of large-scale development. The concept presented would use a local salt or brackish water supply for replacement fluids such as Salton Sea, Wellton-Mohawk Drain, or ground water. The magnitude of the development would be about 100,000 acre-feet of fresh water per year and about 400-500 megawatts of electric power. Cost of desalted water produced and delivered would range from \$85 to \$130 per acre-foot and electric energy would be produced at 3 to 5 mills per kilowatt-hour. This analysis does not reflect the large benefits that would accrue by saving the Salton Sea from further destructive salinity buildup if Salton Sea water were used for replacement.

Stage 3: Large-Scale Development Stage

This stage would augment the Colorado River by delivering as much as 2.5 million acre-feet of desalted water annually with electric power production of about 10,000 mw. This volume of output would require importation of Pacific Ocean or Gulf of California water for replacement fluids. Cost of desalted water produced and delivered would range from \$100 to \$150 per acre-foot and electric energy would be produced at 3 to 5 mills per kwh.

The analysis of this stage does not reflect the large water quality improvements that will accrue or major technological breakthroughs that could occur in preceding stages. Even comparatively minor technical advances could reduce costs considerably. For example, if the 10-year estimated life of wells can be improved to 20 years or 30 years, large cost reductions can be effected.

GEOTHERMAL RESOURCE INVESTIGATIONS Imperial Valley, California

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Chapter I
GEOTHERMAL RESOURCE INVESTIGATIONS
Imperial Valley, California

A. Introduction

Serious attention is being focused upon the geothermal resources underlying the Imperial Valley of California. This interest is shared by many groups, Federal and non-Federal, public and private, because of the potential of this resource to resolve pressing problems of meeting water and power demands of the future.

Geothermal deposits have long been known as a source of energy for the production of electricity. Additional opportunities for development exist when geothermal heat is stored in the form of a hot brine, as is the case in the Imperial Valley and in the vast majority of geothermal deposits. In this situation, the resource also has the potential to yield economical new supplies of fresh water by desalting as well as mineral by-products, both concurrent with the production of electricity. With proper planning, this resource may be economically developed for all of these purposes while still protecting environmental quality.

This report recognizes the need for augmenting the Colorado River with high-quality water, and presents the potential of utilizing the hot geothermal brines of the Imperial Valley to meet this need. Preliminary investigations have indicated the presence of substantial quantities of hot brines in this area, and the probability that they could be successfully desalted. On the basis of these preliminary studies, developmental concepts for water and energy production have been prepared. The concepts are presented in this report with a discussion of the many factors that must be considered for optimum utilization of the resources. Many aspects of these concepts have to be investigated, further developed, and then proven. To arrive at the knowledge and the technology that would permit full development of the geothermal resource, the continuation and completion of a research and development program are proposed. The program would be conducted mainly by the Bureau of Reclamation and the Office of Saline Water with assistance from other interested entities over a 7-year period at a cost of about 16 million dollars. The greater part of the technology resulting from this program would be applicable to other water-dominated geothermal resources located throughout the world.

In the developmental concepts presented here, a particular objective has been to determine the compatibility of concurrent production of electricity and water from the geothermal resource. While it would be premature at this time to outline a firm approach to the production and marketing of any commercial power that may be involved, it is anticipated that some form of joint endeavor with non-Federal power suppliers will be formulated.

It is shown in this report that there are, indeed, savings in the joint production of water and power and that the quantity of electrical energy from joint development need not be diminished from the single-purpose production of power. Both products are produced at a lesser cost since drilling, site development, brine disposal, and subsidence control can be shared, and because the water plant may permit a cleaner steam to be sent to the powerplant. Power only development could encounter two costly factors affecting feasibility: the need to dispose of residual brines without environmental degradation; and the need to import other water into the valley to replace steam and brine removed from underground, thereby preventing the large-scale subsidence that might otherwise occur.

Little is said in this report of the possibility of producing mineral by-products. Such an effort was previously made in the Imperial Valley, but failed economically, largely because minerals were the only products and had to bear the full cost of the development. However, with the concurrent production of power, water, and minerals, joint costs could be shared and the hot concentrated residual brines and concentrated gas streams from the desalting plants may prove to be ideal feed streams to mineral recovery plants.

Several other possible sources of augmentation measures are currently being investigated under the Western United States Water Plan Study as directed by the Colorado River Basin Project Act of 1968, such as weather modification, desalting of sea and brackish waters, water salvage, reuse of waste water, watershed management, and irrigation management. The results of these studies and of the geothermal investigations would provide information for optimization of augmentation measures.

While this report discusses the potential of developing as much as 2.5 million acre-feet of desalted water per year from the geothermal resource, the actual quantity would be dependent upon the results of the research and development program.

Conceptual plans of the facilities required for the production of such quantities are developed in this report to identify the relative magnitude of costs of large-scale production.

B. Summary

The Colorado River is a river heading for trouble. The Colorado River Compact allocates more water per year for consumptive use by the seven basin states than the runoff records of recent decades indicate are available. There is also an international obligation to deliver 1.5 million acre-feet of water annually to satisfy the requirements of the Mexican Water Treaty. Investigations conducted for the comprehensive framework studies now being completed indicate that unless the riverflow is augmented, the water supply cannot meet future requirements.

Compounding the quantity problem are water quality problems. The Colorado River Basin is characterized by highly saline soils and many saline springs which add significant quantities of salt to the river. The salinity of the river is increasing and, without a major water quality improvement program, projections indicate that the Colorado River at Imperial Dam will increase from about 750 parts per million at present to more than 1,150 parts per million by the turn of the century. The Colorado River water would then become unsuitable for many of its present uses.

One of the prime objectives of the Colorado River Basin Project Act of 1968 is "for the provision of additional and adequate water supplies for use in the upper as well as in the lower Colorado River Basin." A promising source of augmentation is the production of desalted water from the geothermal resources in Imperial Valley, California. This water can be developed on the East Mesa and West Mesa areas, and other federally owned lands in the valley.

Several potential delivery points of desalted water are discussed in this report which would provide varying degrees of improvement in quality. Delivery as far upstream on the Colorado River as possible, such as Lake Havasu or Lake Mead, would provide the greatest benefits that would apply to the entire basin and would include improvement of the Colorado River quality as a major function. The concepts presented represent tentative selections chosen from several alternatives and are based on a preliminary evaluation of the geothermal resources in Imperial Valley.

In order to conduct an orderly geothermal resource development program, it is suggested that the resource be developed in three stages: the Research and Development Stage, the Demonstration Stage, and the Large-Scale Development Stage.

1. Research and Development Stage. The first stage, the Research and Development stage, would, through extensive geological, geophysical, geohydrological, and water chemistry investigations, determine the potential and the extent of the geothermal resource. In addition to well drilling initiated this fiscal year, a number of pilot geothermal test wells and injection wells would be drilled to obtain geothermal fluids for testing and to determine the feasibility of injecting residual and other brines into the periphery of producing zones. Pilot and prototype desalting plants would be constructed and operated to develop data for subsequent stages. To adequately investigate the resource, perform the research, and develop the necessary technology would require Bureau of Reclamation and Office of Saline Water funding of about \$16 million over a 7-year period. The funding schedule is shown as follows, including funds appropriated for Fiscal Year 1972 (investigation year 1):

<u>Investigation Year</u>	<u>Funds Required Millions of Dollars</u>
1	1.1
2	3.0
3	2.7
4	2.4
5	3.6
6	2.0
<u>7</u>	<u>1.2</u>
Total	16.0

Prime questions in this, as well as any other geothermal development are the quantity, quality, and thermal properties of the geothermal fluid. A thorough geothermal investigation program is planned to adequately define the origin of the fluids, recharge to the basin, fluid temperatures and pressures, reservoir porosities and permeabilities, recoverable quantities of hot brine, and the vertical and horizontal extent of hot brine producing zones.

Deep test wells would be required to determine the extent and the quality of the geothermal resource at each thermal anomaly. Test injection wells must be drilled and operated to investigate the technical factors related to acceptance of brine in the deep subsurface reservoirs. As data are collected and interpreted from each test well, further drilling and testing would be programed based on results of previous work. Checkpoints would be established as the investigations proceed to allow for study and decisions to be made as to the next steps to follow.

Little is known at present concerning the desalting of geothermal brines, and various desalting techniques must be researched to determine the most feasible desalting process. An important concept presented in this report serves to point out areas of critical uncertainty. It is expected that these technical problems would be resolved during the Research and Development Stage program, and that many improvements and refinements would be made to the basic development concept. The proposed research would culminate in the design and construction of a prototype plant. The Office of Saline Water has outlined a progressive program to investigate the desalting of geothermal brines.

Environmental aspects would continue to be analyzed. The emission of deleterious gases would be controlled, and the environmentally acceptable means for disposal of waste products such as silica and calcium sulfate would be studied. The location and arrangement of plant facilities would be analyzed to determine the type of installation that would be most suitable to the environment.

Alternative plans for the location of conveyance features would be investigated to determine the best plans. Various points for delivery of desalted water to the Colorado River would be studied and alternative sources of water for injection and cooling purposes would be investigated to determine optimum locations.

It should be emphasized that refinements in the various concepts may lead to lower costs, higher reliability, and technological improvements in processes. The unknowns that now exist should be largely resolved by the proposed research and development program, but some of the unknowns would remain unresolved until undertaking the Demonstration Stage. Plans for large-scale geothermal development, derived after these studies are completed, would be primarily dictated by economic and environmental considerations.

2. Demonstration Stage. The second stage, the Demonstration Stage, would determine the feasibility of developing a significantly large quantity of water. It would be the first phase of actual geothermal development for the purpose of producing a supply of high quality water, and would lead to a large-scale development. Development under this stage is predicated on using local sources of water for cooling and injection purposes. Such local sources might be the Salton Sea, ground water, or the Wellton-Mohawk Drain. Indications are that about 125,000 acre-feet of water could be pumped annually from the Salton Sea. This quantity would support the development of about 100,000 acre-feet of desalted water per year and 420 megawatts of electric generation with a vaporization loss of 25,000 acre-feet for cooling requirements.

Pumping Salton Sea water would have the additional benefit of controlling the salinity of the Sea which, if unchecked, will destroy the fish and wildlife, and drastically reduce the recreational value of the area. Pumping would primarily provide salt removal from the Salton Sea. Further studies would be required to determine secondary measures which would optimize benefits associated with salt removal. These and other factors will be considered in a separate study of the Salton Sea being conducted under the leadership of the Bureau of Sport Fisheries and Wildlife of the Department of the Interior.

Comparable amounts of cooling and injection water could possibly be obtained from the Wellton-Mohawk Drain located near Yuma, Arizona. Local ground water may serve as a short-term or interim supply involving relatively small quantities.

It is estimated that this stage of the geothermal program would include 72 production wells, 100 injection wells, 6 desalting plants, and 6 powerplants. Desalted water would be delivered to existing canals near the geothermal well field or possibly to the Colorado River near Imperial Dam.

Cost analyses suggest that there are significant savings in the joint development and production of geothermal resources in the Demonstration Stage to simultaneously produce distilled water and electric power. Based on tentative allocations of major joint works, such as production wells, injection systems, and water requirements for cooling and injection, a range of water costs of from \$85 to \$130 (26¢ to 40¢ per 1,000 gallons) is indicated using Federal financing at 6 percent interest. The range primarily reflects the sensitivity of the costs to the alternative sources of cooling and injection

water and various options on points of delivery. At similar financing, power costs for internal water processing and conveyance pumping would be about 3 mills per kilowatt-hour. In consideration of the savings resulting from joint production, and based upon a non-Federal fixed charge rate of 14 percent, commercial power costs would approximate 5 mills per kwh. The plant factor of the geothermal complex was assumed to be 90 percent.

This analysis does not recognize the important fish and wildlife and outdoor recreation benefits that would accrue if conceptually tied to the import of Salton Sea water.

3. Large-Scale Development Stage. The third stage, the Large-Scale Development Stage, would augment the Colorado River by delivering as much as 2.5 million acre-feet of desalted water annually. Large quantities of cooling and injection water would be required for geothermal ground-water maintenance and surface stabilization and would most likely be obtained from the ocean. The ocean water would be used for plant cooling purposes before injection. The power potential associated with the production of 2.5 million acre-feet of desalted water is 10,500 mw and, when produced concurrently with the distillation process of desalting water, could be essentially a pollution-free operation. Up to one-fourth of the power produced would be needed for internal process purposes and pumping for the conveyance of import and product water.

Disposal of residual brines is an important aspect of geothermal development. Residual brine disposal could present a major problem to inland geothermal development, but it is anticipated that the proposed reinjection would be a workable solution.

Water quality improvement would be an important function of augmentation from geothermal reserves. It is estimated that the addition of 2.5 million acre-feet of desalted water containing only 20 ppm of salts to the Colorado River at Parker Dam would lower the average annual salt concentration significantly. If the salinity of the river reaches the projected value of about 1,150 ppm at Imperial Dam, a reduction to approximately 850 ppm could be obtained. The actual reduction would depend upon the salinity of the river at the time of augmentation. To avoid an adverse environmental impact to Lake Havasu, if necessary, the desalted water would be cooled and delivered at 75°F., a temperature approximately the same as the lake water temperature.

In addition to the cost of wells and plant facilities, several major factors affect the cost of producing large quantities of desalted water from geothermal brines in Imperial Valley. Transportation of ocean water for plant cooling purposes and injection, treatment of this water, and the delivery destination of desalted water are the most significant.

As in the Demonstration Stage, the cost of water is very sensitive to the need and source of import water for cooling and injection, and to the points of delivery for product water. Since longer distances would be involved on both scores, the indicated range of costs without recognition of major technological breakthroughs would be from \$100 to \$150 per acre-foot. Because of the long time frame involved, such estimates are conjectural and also must be tempered by the fact that important water quality benefits have not been accounted for. In addition to potential technological breakthroughs, comparatively minor technical advances can importantly reduce costs. For example, if the 10-year estimated life of wells can be improved to 20 or 30 years, cost reductions can be effected.

Chapter II GENERAL BACKGROUND AND POTENTIALS

A. Description of the Resource Area

The resource area extends from the southern California coastline east to the Colorado River. It includes a complex of mountains, plateaus, deserts, and plains, with elevations ranging from 234 feet below sea level at the Salton Sea to the 10,000-foot, and higher, mountain peaks.

The climate of the area varies widely. Maximum temperatures range from well over 100°F. in the desert to about 70°F. in the mountains. Minimum temperatures range from freezing to below 0°F. Average annual precipitation varies from less than 3 inches in some desert areas to more than 40 inches in the mountains.

The principal construction impact areas would be the geothermal and desalting complex in Imperial Valley, California, and the routes of water conveyance facilities. Plate No. 1 shows the general area where potential geothermal facilities would be located.

B. Problems and Needs in the Resource Area

The available surface-water supplies in the Upper and Lower Colorado River Basins have been taxed by expanding agricultural demands and by a generally expanding population which is using water at an increasing per capita rate. To add to the problems of the area, ground water, an important source of water supply in the area, is being depleted at a rapid rate in some locations. The decline resulting from the depletion of the ground-water resource has caused some lands to go out of production, significant increases in pumping costs, and a decline in water quality.

Additional water supplies must be developed to keep pace with the increasing demand and the decreasing ground-water storage. Major water development projects such as Hoover Dam, the Colorado River Aqueduct, the All-American Canal System, the Salt River Project, and large ground-water developments have satisfied essentially all of the necessary water requirements in the Pacific Southwest. However, with construction of the Central Arizona Project and with continued expansion of Upper Basin uses, the day is not far distant when essentially the entire runoff of the Colorado River will be completely utilized. It is anticipated that when the Central Arizona Project starts diverting from the Colorado River, the existing level of diversions by California will have to be reduced.

Compounding the deficient water supply problem is the fact that Colorado River water is increasing in salinity. If allowed to continue, either the Colorado River could become unsuitable for many of the present uses, or it will be necessary to apply increasing quantities of irrigation water for leaching requirements. The increasing salinity also has international implications, being of concern to the country of Mexico.

To help satisfy these needs, the Colorado River Basin Project Act (P.L. 90-537, 82 Stat. 885, September 30, 1968) was passed, and provides for a study of water resources in the Colorado River Basin to find methods of augmenting the natural flows of the river. The Act also states that satisfaction of the requirements of the Mexican Water Treaty constitutes a national obligation and shall be the first obligation of any water augmentation project.

An expanding economy and population also have an increased need for additional electric power. Power is needed to accommodate not only the increase in growth, but also the general increase in per capita power use. Historically, power requirements for the area have doubled every 10 years.

C. Effects of Augmentation

Development of geothermal resources offers a potential for production of desalted water to augment the flows of the Colorado River. This would result in two principal benefits: (1) it would increase the total flow of the river by as much as 2.5 million acre-feet per year which would not only relieve the basin states of the obligation for delivering water to satisfy the requirements of the Mexican Treaty, but would help relieve the anticipated water shortage of all the basin states as well; and (2) the introduction of desalted water with a total dissolved solids content in the order of 20 parts per million would have a marked effect in reducing the salinity of the river. The actual reduction would depend upon the salinity of the river at the time augmentation is made. If the salinity at Imperial Dam reaches the projected future average salinity of 1,150 ppm, augmentation with 2.5 million acre-feet per year above Parker Dam would reduce the average salinity at Imperial to 850 ppm.

Detailed studies would be required to determine the point of delivery of augmentation water that would be acceptable from a water quality standpoint and would provide the greatest advantage in relation to the cost of delivering the water. Also, they would evaluate methods and criteria for the most efficient management of the augmented waters of the Colorado River. These studies would determine:

(1) The effect of delivering geothermal water at various points on the river so that the increased supply can be controlled without waste of Colorado River water in critical low flow or flood periods. Alternatives would need to consider offstream regulation for the geothermal water at points in the lower reaches of the river.

(2) The potential effect of augmentation upon the Colorado River reservoir operation criteria.

(3) The point of delivery that would provide the greatest benefit of water quality control.

(4) How delivery of geothermal water at various temperatures would affect the ecology of the river and what delivery temperatures would be best.

(5) The need and cost for providing mixing facilities at the various potential delivery points.

(6) The advantages and disadvantages of staging various increments of development.

The effects of the above factors would change as the amounts of augmentation water change. For instance, it may not be necessary or practical to deliver relatively small quantities of desalted water to the Colorado River, and it is recognized that large amounts could not now be introduced to the river below Parker Dam without waste. Evaluation of the large-scale concept was made with the assumption that product water would not be delivered to the river before about 1990. It was also assumed that the Upper Basin would develop uses for all of its allotment of Colorado River water.

D. Potential for Electric Power Development

In addition to production of desalted water, comprehensive development of geothermal resources should include the production of electric energy. The joint development of water and power from geothermal hot brine and steam would result in important cost savings in the production of both products. Preliminary studies indicate that up to 10,500 mw of electric power could be jointly developed with 2.5 million acre-feet per year of desalted water. About 2,000 mw would be required for water production and conveyance pumping, and the balance of 8,500 mw could be available to meet the increasing requirements of the Pacific Southwest for commercial power.

E. Other Potential Functions

Utilization of Salton Sea water in conjunction with a water-power geothermal complex could resolve a pressing degradation problem. Although the majority of the

water required for cooling and injection would probably be brought in from the Pacific Ocean or the Gulf of California, preliminary studies indicate that approximately 125,000 acre-feet of water per year could be taken from the Salton Sea for these purposes. The net effect of using Salton Sea water would be a stabilization of the salinity of the Sea, with a slight lowering of the water surface elevation. As discussed subsequently under the Demonstration Stage, additional studies would be needed to evaluate the potential need of physical controls such as diking to aid in maintaining the water surface level of the Salton Sea.

Geothermal brines generally contain a variety of salts which could be developed commercially by private concerns. Previous attempts to recover minerals from geothermal brines in the Salton Sea area have not been economically successful, one of the reasons being that mineral recovery was the only function and had to bear the entire cost of the wells and associated works. In a total geothermal development concept, mineral extraction would be only one segment of the total output and its recovery could become more economical.

Other possible functions of the geothermal development concepts which will not be considered in depth in this report are centralized heating, hot-house agriculture, hot water irrigation, or the possible use of residual brines in mineral spas or health resorts. The extent to which these possibilities can be developed can only be determined after more is known about the geothermal resource.

F. Legal and Institutional Considerations

The two Federal laws which will have the greatest impact on development of geothermal resources in Imperial Valley, California, are the Colorado River Basin Project Act, Public Law 90-537, and the Geothermal Steam Act of 1970, Public Law 91-581. Public Law 90-537 was discussed previously.

The Geothermal Steam Act of 1970, dated December 24, 1970, provides for leasing of geothermal resources on Federal lands to interested private developers. Given the finite extent of the Nation's resources, it is important that the geothermal resources be developed comprehensively, providing for the concurrent production of power, water, and minerals, and any other beneficial uses. Therefore, it is vital that leasing regulations promote the comprehensive development of this important resource.

All work accomplished by the Bureau to date has been on lands owned by the United States. The major portion of the investigations has taken place in an area of Imperial Valley known as East Mesa. These lands are administered by the Bureau of Reclamation. The Bureau has no plans to perform exploration work on any private land. The Demonstration Stage or Large-Scale Development Stage would require a certain amount of rights-of-way for pipelines and related structures which would traverse non-Federal lands.

Legal considerations as to the withdrawal of geothermal brine are still uncertain as to water rights. Compounding the issue is the lack of a definite precedent for such a situation. Large-scale development would require withdrawing up to 3 to 4 million acre-feet of geothermal brine from deep within the earth in order to gain as much as 2.5 million acre-feet per year of desalted water. However, as this brine is withdrawn, it would be replaced with a like amount of water consisting of residual brine from the desalting process and makeup water from the Salton Sea, the Pacific Ocean, or other sources. In effect, the geothermal development would mine only heat from the interior of the earth. This heat would be used to produce desalted water and electric power.

This report will not attempt to offer a legal opinion as to ownership rights for geothermal resources but, instead, will only be used as a starting point for meaningful discussions.

There should be no effect on shallower ground-water aquifers due to the withdrawal of geothermal brine. Continual injection of residual brines and makeup water, as well as the presence of impervious strata, should preclude any lowering of the ground-water table or ground subsidence due to development operations. Injections will be at depths where the salinity of the injected water will not adversely affect the existing quality of the ground water.

Chapter III RESEARCH AND DEVELOPMENT PROGRAM

A. Introduction

The proposed research and development program would include an extensive geological, geophysical, hydrological, geochemical, and process investigation program to adequately evaluate the extent of the resource and determine optimum development. The successful pursuance of this research and development program is of prime importance to the total geothermal program. Many unknowns must be investigated and resolved to adequately plan for a large-scale utilization of geothermal brines. The investigations must proceed on a flexible path to allow for changing conditions and revised processes as new data are developed. A predetermined sequence of operations would be difficult to follow, and changes to facilitate design and process procedures must be made as the investigations proceed. Checkpoints will be incorporated in the program to allow for changing direction as required for optimum development of the entire resource.

The objectives of this geothermal investigation program are to determine the extent of the geothermal resource on Federal land within Imperial Valley, to develop the technology for total development of this geothermal resource, to demonstrate the feasibility of developing large quantities of desalted water, to determine an optimum plan for the delivery of desalted water to the Colorado River and to determine the magnitude and character of related power generation and other associated activities necessary to optimize use of the resource. Plate No. 2 shows potential areas for geothermal development and the present land status. Some of the potential areas extend partially on patented lands; however, Bureau investigations will be confined to Federal lands.

This chapter discusses past geothermal investigations in Imperial Valley and the proposed research and development program.

B. Investigations to Date

Geothermal investigations by the Bureau of Reclamation to date have included geophysical investigations and thermal test drilling in the East Mesa area of Imperial Valley. This work was accomplished in cooperation with the University of California at Riverside (UCR) through a joint investigation program. Research contracts with the

EXPLANATION

- RECLAMATION WITHDRAWAL
- PUBLIC DOMAIN
- MILITARY WITHDRAWAL
- INDIAN RESERVATION
- PATENTED LANDS
- LOCATIONS OF POTENTIAL GEOTHERMAL WELL FIELDS

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

GEOHERMAL RESOURCE INVESTIGATIONS
IMPERIAL VALLEY, CALIFORNIA
LAND STATUS MAP AND LOCATIONS OF
POTENTIAL GEOTHERMAL WELL FIELDS
MAP NO. 1241-300-23

SEPTEMBER 1971

PLATE NO. 2

University have totaled \$450,000 from 1968 to date. In January 1971, the Bureau became actively involved in the program by drilling and logging the geothermal anomalies identified by UCR. An extensive gravity, resistivity, magnetic, heat flow, and geological investigation program by UCR provided the data required to locate the most promising anomalies.

The Geological Survey is assisting the Bureau of Reclamation in determining the quantity and quality of water in storage and the quantity of recoverable hot water. A level network for a subsidence monitoring program is presently being established in Imperial Valley in cooperation with the State of California, Imperial County, Imperial Irrigation District, Geological Survey, National Oceanographic and Atmospheric Administration, Bureau of Land Management, and the Bureau of Reclamation.

The Imperial Irrigation District has shown an intensive interest in geothermal development and has contributed \$15,000 in funds to the Bureau of Reclamation for research and investigations of geothermal resources in Imperial Valley.

The exploratory drilling program has defined three thermal anomalies in the East Mesa area that apparently have the potential to produce geothermal steam and brine. The anomalies, Mesa, Dunes, and Border, are shown on Photograph No. 1. As indicated by geophysical and geological work accomplished to date, the most promising is the Mesa anomaly.

Since January 1971, 18 temperature holes have been drilled (Nos. 114 through 131) in the East Mesa and Glamis-Ogilby areas as shown on Plate No. 3. The holes range in depth from 375 feet to 1,468 feet. Table 1 lists pertinent data for each drill hole. Photograph No. 1 shows the drill hole locations and the site of the Cerro Prieto well field in Mexico. Photograph No. 2 shows a typical well drilling operation in the East Mesa area.

The Office of Saline Water has begun construction of an experimental desalting test unit at Wrightsville Beach, North Carolina, to determine viable desalting processes that can be applied to geothermal brines. The test unit will be operated initially by using synthesized fluids resembling those expected in Imperial Valley. After operations on synthesized fluids are completed early in 1972, and a producing well is drilled, the test unit will be moved to Imperial Valley. In addition, the Office of Saline Water has initiated process studies designed to fit the desalting unit into an optimized

Photo No. 1. High altitude view looking south from East Mesa area into Mexico.

Table 1
DRILL HOLE DATA
Geothermal Resource Investigations
Imperial Valley, California

Drill Hole Number	Anomaly Location	Total Depth Feet	Maximum Temperature Recorded °F.	Computed Temperature Gradient °F. Per 100 Feet
114	Border	1,468	135.4	-- 1/
115	Dunes	375	231	-- 1/
116	Mesa	1,420	221	11.4
117	Dunes	562	153	-- 1/
118	Dunes	562	117	-- 1/
119	Dunes	562	106	-- 1/
120	Dunes	562	192	-- 1/
121	Dunes	562	169	-- 1/
122	Mesa	562	142	9.7
123	Mesa	562	145	10.8
124	Mesa	562	125	8.4
125	Mesa	520	116	5.9
126	Mesa	562	125	6.2
127	Mesa	1,406	176	7.2
128	Mesa	562	130	8.2
129	Mesa	1,000	160	7.7
130	Glamis-Ogilby	715	106	2±
131	Glamis-Ogilby	581	132	10±

1/ Temperature data indicated erratic temperatures at various depths and representative thermal gradients could not be computed.

Test holes penetrated deltaic deposits of sand and clay, primarily in the areas of the Dunes, Border, and Mesa anomalies. Sand and gravel fan deposits were penetrated in the Glamis-Ogilby areas. Hole No. 115 penetrated silica cemented sandstone, and hole No. 131 penetrated volcanics at 472 feet and intrusive dike rock (probable bedrock) at 565 feet.

Photo No. 2. Typical drill site on the sandy surface at the East Mesa area.

Bureau of Reclamation Photograph

P-1215-300-11149

comprehensive system. In such a system, the geothermal resource would be developed to produce any combination of water, power, and mineral by-products. These process studies will identify at an early stage those critical areas of comprehensive resource research that need further study. Indeed, many of these critical areas have already been identified, as is reflected by the proposed research and development program.

C. Proposed Future Work

Future investigations and development work would be a joint Federal program with the Bureau of Reclamation and the Office of Saline Water as the principal participants. Other Federal agencies, State and local governmental entities, universities, and expertise from the private sector will be called upon as their services are needed and for informational exchanges.

The underground portion of the R&D program would consist of exploratory well drilling to define the full range of geological and hydrological parameters, production well drilling and operation, and injection well drilling and operation as required. Also included would be the investigation and delineation of other geothermal anomalies. The aboveground portion of the program will consist progressively of the construction of a 50,000 gallon-per-day test unit, a 200,000 to 500,000 gpd pilot desalting plant, and the development of technology necessary to support a large geothermal desalting plant. This technology would include process studies and economic evaluation, evaluation of corrosion and scaling tendencies of the brine and vapor, feed pretreatment studies, materials and equipment evaluation, heat-transfer studies, by-product recovery studies, and effluent disposal studies. This work would be accomplished, in part, by cooperating agencies and institutions.

More detailed data are needed at the most promising Mesa anomaly. This can be accomplished by drilling a deep hole to the steam-producing zones. The Bureau's Fiscal Year 1972 geothermal program includes the drilling of a deep test well to some 6,000 feet. It is proposed to drill this hole on the Mesa anomaly, which is shown on Plate No. 3. Information developed from proposed heat measurements, core samples, logs, and flow tests would substantially improve the definition of the Mesa anomaly and provide the necessary data for preliminary design of the desalting plant. Preliminary information for powerplant design would also result from this test.

Geological exploration by test wells and geophysical surveys are required in other areas of Imperial Valley, such as the West Mesa area and the Glamis-Ogilby area, as well as further work of the same kind in the East Mesa area. Important investigations to be accomplished in new areas are gravity work and resistivity surveys. These surveys appear to be the most economical methods for locating thermal anomalies in the geological environment of Imperial Valley.

Plate No. 2 shows potential areas for locating geothermal well fields. Areas on the West Mesa and new areas on the East Mesa have not been identified as geothermal areas by geophysical investigations, but have been identified as potential areas because of their proximity to the San Andreas, San Jacinto, or other known or inferred faults.

Future investigations would be extended to other promising areas such as the Gila River drainage in Arizona, south and east of Yuma. Relatively inexpensive gravity surveys, aeromagnetism, and, possibly, infrared scanning processes could readily define promising geothermal areas.

Ground subsidence monitoring systems would be established for early detection of the need for increased pressure maintenance by water injection. Also, seismic monitoring stations would be placed at strategic locations before geothermal fields are developed.

While some desalted water from the geothermal resource can be obtained from the steam that is used for energy production and then condensed to water, the primary source would be from desalting of the geothermal brine itself. Because of the composition and temperature of this brine, it is anticipated that either a multistage flash or multieffect distillation process would be used. Although much of the technology developed by OSW for the distillation of sea water would be applicable to geothermal brines, the differences in the two feed sources are significant enough to require developmental studies directed specifically toward the geothermal feed stock.

Among the first studies required are the determination of processes that would allow the low-cost energy of this high-temperature feed source to be used to advantage, while coping with the particular problems that would arise due to the expected corrosion and scaling tendencies of the geothermal brine. Silica within the geothermal brine will tend to scale equipment as the brine cools. Furthermore, particles entrained by the high velocity liquid may have strong eroding characteristics. This latter effect plus the

corrosiveness of dissolved H_2S require that special emphasis be placed on resistant but economical construction materials. Chemical treatment of the geothermal brine, upstream of the distillation plant, might prove to be the most effective means of avoiding some of these problems.

Early developmental efforts would be directed toward the recovery of by-products from the residual brine and the disposal of wastes from the distillation plant. Since different brine compositions are expected from different geothermal fields, the techniques for both by-product recovery and waste disposal would be difficult to identify in advance of actual tests of specific well outputs. Data must be developed in all areas to permit the handling of those feed stocks.

These preliminary studies would culminate in the construction of a prototype desalting plant in investigation years 5 and 6. This plant would be fully integrated to take geothermal brines from wells in the Imperial Valley, and would operate in conjunction with the appropriate feed pretreatment, by-product recovery, and waste disposal systems. Power from geothermal steam would be utilized to service the distillation plant.

The Office of Saline water experience with sea water indicates that the appropriate size for a prototype plant of this type is 2 to 3 million gallons per day of product water for an annual production of about 2,000 to 3,000 acre-feet. This size plant would amply highlight both the construction and operation problems likely to be encountered in large geothermal desalting plants. Data obtained from the prototype plant would permit the extrapolation of design parameters to the large plants. Desalted water would be delivered to local canal systems during test operations.

The results of the above investigations would culminate in the completion of a final report by investigation year 7. Table 2 shows a breakdown of the stage one investigation costs of the Bureau of Reclamation and Office of Saline Water program. Table 3 gives a funding summary, by investigation year, of the proposed program.

These funds would provide for the necessary geophysical work, drilling of test wells, and the investigation of viable desalting techniques. Concurrently, other tests would be run on the effects of desalted water flowing into Lake Havasu, possible economical production of mineral by-products, and the full effects of withdrawing water

Table 2
STAGE ONE INVESTIGATION COSTS
Geothermal Resource Investigations
Imperial Valley, California

	Cost \$1,000	Investigation Year
I. RESOURCE INVESTIGATION		
A. Reports	25	1 - 2
B. Exploratory drilling, etc.		
1. Drill and case wells	205	1 - 3
2. Log and test wells	230	1 - 3
3. Geologic, geophysical, and chemical studies	250	1 - 3
4. Continue exploration to select wells (heat flow, resistivity, gravity, magnetic, and ground noise studies)	<u>1,150</u>	1 - 6
Subtotal	1,835	
C. Geothermal wells		
1. Drill and case wells	1,100	1 - 4
2. Test production wells	450	1 - 4
3. Site preparation and injection wells	500	2 - 4
4. Operate production and injection wells	840	2 - 7
5. Geologic, geophysical, and chemical studies	640	2 - 6
6. Drill observation wells	100	3
7. Monitoring--subsidence and seismic	<u>320</u>	2 - 7
Subtotal	3,950	
D. Technical support		
1. Bureau of Reclamation	2,390	1 - 7
2. Other agencies and institutions	<u>1,300</u>	1 - 7
Subtotal	3,690	
E. Appraisal report (including desalting costs and results of desalting studies)	<u>200</u>	5 - 7
Total Resource Investigation	9,700	
II. DESALTING STUDIES		
A. <u>Basic Studies</u>		
1. Determine brine and vapor composition	50	2 - 6
2. Material studies: scaling, corrosion	50	2 - 6
3. Chemistry of geothermal brines	<u>220</u>	1 - 6
Subtotal	320	
B. <u>Process Support Studies</u>		
1. Two-phase flow studies	60	1 - 2
2. Heat transfer tests	250	1 - 4
3. Small desalting test unit	270	1 - 2
4. Feed treatment studies and testing	200	1 - 4
5. Disposal of brines and gases: studies and testing	300	1 - 5
6. Component testing	<u>200</u>	3 - 5
Subtotal	1,280	
C. <u>Process Studies</u>		
1. Flow sheet development and evaluation	80	1 - 3
2. Flow sheet optimization	<u>60</u>	2 - 4
Subtotal	140	
D. <u>Process Testing at Geothermal Site</u>		
1. Pilot plant design and construction	400	2 - 4
2. Pilot plant testing	400	4 - 6
3. Prototype plant design and construction	3,100	5 - 6
4. Prototype plant testing	<u>660</u>	6 - 7
Subtotal	4,560	
Total Desalting Studies	6,300	
Grand Total	16,000	

Table 3
 INVESTIGATION COST SUMMARY
 Geothermal Resource Investigations
 Imperial Valley, California

	Unit: Millions							
	Investigation Year							Total
	1	2	3	4	5	6	7	Cost
Bureau of Reclamation	0.8	2.2	2.0	1.6	1.2	1.2	0.7	9.7
Office of Saline Water	0.3	0.8	0.7	0.8	2.4	0.8	0.5	6.3
Total	1.1	3.0	2.7	2.4	3.6	2.0	1.2	16.0

Fiscal Year 1972 is Investigation Year 1.

from the Salton Sea. Colorado River operations must be fully investigated to determine the effects of delivering desalted water to local canal systems in Imperial Valley. The effects of augmentation on power releases from Hoover, Davis, and Parker powerplants must also be analyzed.

Chapter IV GEOTHERMAL RESERVES

A. Defining Criteria

Three aspects of the geothermal reserves were considered in the evaluation of the resource. They are: (1) the magnitude of the heat supply, (2) the quantity of recoverable water; and (3) the quality of the recoverable water.

The heat flow from the plastic mantle into the crust in the Salton trough is substantially greater than the world average. Our exploration is concerned with local areas of high heat flow in the Imperial Valley that are referred to as anomalies.

The quantity of ground water stored in the Salton trough depends upon the character, extent, and thickness of saturated sediment. The recoverable water depends upon the effective porosity of the sediments and the density of the water. In much of the Imperial Valley area, the sediments are predominantly sandy and extend to depths below 10,000 feet (see Plate No. 4).

The quality of the water in the saturated sediments ranges between wide limits. Mineral concentration has been affected by systems of convecting hot and cold ground water. Water that will be utilized from the convective hydrothermal systems is estimated to range in total dissolved solids from about 3,000 ppm to as much as 30,000 ppm. The principal salt expected to be encountered is sodium chloride.

B. Geologic Dimensions of the Imperial Valley

1. Structure. The Imperial Valley, California, set in the Salton structural trough, is astride a global rift. The rift is identified with an oceanic spreading center known as the East Pacific Rise which, throughout most of its length, traverses the Pacific floor from Australia to the head of the Gulf of California, disappearing there beneath the North American Continent. Crustal distention at that juncture causes an oceanic plate to drift by a continental plate and, at the same time, each plate is drifting away from the other.

The Salton trough is, therefore, a rift zone with many faults. Heat flow occurs along these faults in substantial magnitude by convecting hot water. Some of the faults are mappable on the surface, but many are buried by surficial deposits.

2. Stratigraphy. The stratigraphy of the Imperial Valley in the Salton trough includes the basement rocks and all rocks lying above it. Basement rocks comprise a faulted complex of granite gneiss and schist, and form a graben some 20,000 feet deep.

NOTE

Data Compiled and Interpreted by Walter Randall, University of California, Riverside.
For Location of Cross Section See Geologic Map No. 1241-300-26

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

GEOHERMAL RESOURCE INVESTIGATIONS
IMPERIAL VALLEY, CALIFORNIA

**CROSS SECTION OF AVERAGE PERCENT
VOLUME OF SAND BODIES
IN SEDIMENTARY SECTION**

DWG. NO. 1241-300-35

OCTOBER 1971

PLATE NO. 4

Interior-Reclamation, B.C., Nev. 10-71

The basement complex has been invaded here and there by magma which has solidified in dikes and other irregular bodies. Next in age to the basement rocks are volcanics which have been erupted onto the surface and subsequently have been buried or remain exposed. The volcanic rocks are of acidic, intermediate, and, to a lesser extent, basic mineralogical composition.

The stratigraphic sequence of sediments within the Salton trough is poorly known. The information available from logs of wildcat oil test wells, thermal test holes, and other wells suggest the following: (1) the sediments are predominantly sandy; (2) deltaic sedimentation predominated over the past 4 million years; (3) shallow lakebeds and wind-laid sand accumulated in response to inundation of parts of the delta and the building of extensive desert areas; and (4) present day surficial deposits consist of lakebeds in the center of the Imperial Valley and aeolian and fan deposits on the flanks (see Plate No. 5).

From the standpoint of recovering geothermal fluids, the important sediments are the sandy deltaic deposits. All available electric logs of wells drilled in the Imperial Valley were examined and the thickness of sand units was measured by the University of California at Riverside under contract with the Bureau of Reclamation. The relative thickness of the sand units to other rock types, mainly clay-shale, was calculated in terms of percentage volume per 50-foot and 500-foot intervals. The percent volumes are plotted in log form and the suggested parastratigraphic relationships are shown on Plate No. 4. The high percentage volume of sand in the American Petrofina Well 27-1 suggests a sand wedge that may be due to the intercalation of sand dunes with typical deltaic and lake deposits. The stratigraphy indicates an unusually capacious fluid reservoir down to 5,500 feet and an excellent reservoir down to 10,000 feet.

C. Geophysical Aspects of the Salton Trough

The Salton trough is one of the more active seismic areas in the world, with movement generally taking place horizontally on faults with continuing subsidence. The continuous rifting, and the associated movement on the boundary of the trough and along interior faults, generate earthquakes of two types. It is believed that heat flow along the main faults causes creep movement, as opposed to stick-slip movement, and leads to many earthquakes of the first type. These are generally of magnitude 1 or less on the Richter scale and cannot be detected without instruments. In the cooler

areas of the Salton trough, it is believed that slippage occurs as stick-slip rather than creep and leads to the second type of earthquake. These occur less frequently and are larger, reaching magnitudes of 5 to 7.5 on the Richter scale, so as to be detectable in the vicinity without instruments. The last large earthquake, of magnitude 7.0, occurred in 1940.

The location and character of active faults in the Imperial Valley are only imperfectly known at this time. It is important that this knowledge be increased, so that logical planning can be undertaken for both large-scale withdrawal of fluids from the reservoir and large-scale injection of the same or other fluids.

The Imperial Valley is geologically constituted so that surface conditions can be evaluated to some degree by geophysical methods. Thermal, gravity, resistivity, ground noise detection, and seismic shooting yield results that can be interpreted in relation to geologic limits. One example is the resistivity map (Plate No. 6) which shows two important aspects of the hydrogeology of the East Mesa: (1) the increase in salinity from southeast to northwest and (2) a 5 ohm-meter closure embracing about 19 square miles in Townships 15 and 16 South and Range 17 East. The dark green shows high resistivity where the total dissolved solids content ranges up to 1,000 ppm, grading through a color scheme to red where the total dissolved solids content ranges up to 300,000 ppm. Within the resistivity closure east of Holtville, the total dissolved solids content is 3,320 ppm at a depth of 1,400 feet.

D. Availability of Geothermal Fluid

Preliminary estimates of the recoverable ground water above a depth of 10,000 feet in the Imperial Valley are in the order of 1.1 billion acre-feet.

It is recognized that the amount of geothermal fluid to be extracted would far exceed natural ground-water recharge. Therefore, the hydraulics of the convective hydrothermal system must be understood in order to utilize the energy and water without subsidence. The quantity of water stored in the convective hydrothermal system is a function of the porosity. Approximate values of the porosity of the sediments penetrated in test holes can be obtained from sonic logs, using a technique that corrects for shale content and compaction. Available sonic logs of deep "wildcat" test holes show that porosities of sediments to a depth of 10,000 feet range from less than 10 to more than 50 percent of voids and average between 20 and 30 percent. Utilizing

the above methods of determining porosity, the amount of water in storage can be quantified as the actual dimensions of the hydrothermal convective system are known.

Information on the recoverable storage must be obtained to predict the yield of the well fields. Effective porosity as related to recoverable storage can be measured with reasonable accuracy by special geophysical logs, including dual induction, compensated density, and sidewall neutron porosity. Values thus obtained are also considered to be closely related to permeability in a thermal environment wherein formation drainage is enhanced by the occurrence of low density water. Permeabilities measured throughout the sand bodies to date, in addition to the low density of the contained hot water, suggest high yields can be obtained from properly designed production wells. It is estimated that yields would be equivalent to about 2.5 cubic feet per second from producing sands 250 to 300 feet thick.

The feasibility of injecting brines is influenced by the physical and chemical makeup of the brines and the hydraulic characteristics of the reservoir. There are numerous potential problems that could require solutions, including mineral precipitation, corrosion of casings and screens, compatibility with reservoir fluids, and optimum well spacing. It is anticipated that injection wells would be designed with significantly more screen than production wells because of the greater density and high mineral content of the water to be injected.

Chapter V DEVELOPMENT OF CONCEPTS

A. Introduction

This chapter discusses various conceptual plans for the comprehensive development of geothermal resources in Imperial Valley for a usable water supply and electric power production. While several alternatives appear viable and deserve additional study, conceptual plans will be defined in some detail for two of the alternatives. One is a concept of the Demonstration Stage utilizing water from the Salton Sea, and the other conceptualizes the Large-Scale Development Stage with the importation of water from the Pacific Ocean and the delivery of product water to Lake Havasu. A cost analysis was prepared for the Salton Sea concept to indicate the general magnitude of costs involved and the relative significance of various cost components.

Staging the development has the advantage of allowing decision points and changes of direction to be incorporated in the development program. This would permit changing plans to improve feasibility as more information is obtained and before large expenditures of funds are committed for wells, plant, and conveyance facilities.

The conceptual plans presented are based on preliminary data obtained from initial geophysical and geohydrological investigations and temperature measurements made in Imperial Valley and from preliminary process investigations. Much of the data used to prepare the designs, estimates, and OM&R costs for production wells and estimates for powerplants was obtained from available data on the existing geothermal well developments at Cerro Prieto, Mexico. It is expected that geothermal fluids obtained in Imperial Valley would be similar to those at Cerro Prieto. Discussions with Mexican engineers provided substantial information on cost data and plant layouts. Available data obtained from The Geysers steam field in northern California were also used in the preparation of this report.

Disposal of residual brines from the desalting plants would be accomplished by reinjection in periphery injection wells around each producing steam field. In addition, import water for injection into the geothermal ground-water aquifers to prevent subsidence would come from local or distant sources. This water would also be used for plant cooling purposes and then mixed with the residual brines from the desalting plants before injection. The danger of subsidence and possible seismic activity from

withdrawing large volumes of geothermal fluids will probably prohibit geothermal development without recharge by injection.

The cost effectiveness analysis for the large-scale importation of recharge fluids will probably confirm the need for multiuse development of the resource for water, power, and possibly mineral extraction in order to achieve a low unit cost. Single-purpose development may not be economical when the need for importation of recharge water is considered. Treatment of the residual brine, ocean water, and the Salton Sea water would be required before injection into the ground to avoid undesirable changes in the ground-water reservoir.

B. Demonstration Stage

1. Physical Features of Conceptual Plans. The Demonstration Stage or second stage would be the initial step in the actual development of the geothermal resource. This stage would include the importation of cooling and injection water from one of several local sources such as the Salton Sea, shallow ground water or from the Wellton-Mohawk Drain. Product water could be delivered to local canal systems or nearby points in the Colorado River. Demonstration of the feasibility of a moderate size geothermal development, without the large investment cost of transporting water from the ocean and delivering desalted water to distant points on the Colorado River, would be the major function of this stage of development. It would provide a system for testing the operation of an entire geothermal well field and associated equipment before funds are committed to a large-scale geothermal development. This stage would provide values independent of a large-scale development by providing an improvement in salinity of water in local areas.

Pumping water from the Salton Sea appears to be a logical concept of importing water since major construction and environmental obstacles are not apparent and, in fact, the environmental aspects of the Salton Sea could be enhanced by controlling its salinity. This would not be, however, the least expensive plan for the demonstration stage import system.

The most attractive import system, from a cost standpoint, would be pumping shallow ground water near the geothermal well field. Several important problems are associated with mining shallow ground water and, consequently, this source does not appear to be practical except as a short term or interim supply involving relatively small quantities. Lowering the local ground-water table may increase the seepage from

the Coachella and All-American Canals; it may increase the pump lift for irrigation wells located across the border in Mexico; and it may reduce inflow to the Salton Sea, thus, affecting the environmental aspects of the Sea. Further studies would be required to determine the full effects of pumping shallow ground water.

Taking water from the Wellton-Mohawk Drain would furnish a possible source of cooling and injection water. Such a plan could have important water quality benefits.

Several alternatives for the delivery of desalted water were also considered. Desalted water could be delivered by gravity to the All-American Canal downstream from drop No. 4; it could be delivered upstream from drop No. 4 by pumping or possibly pumped to the Coachella Canal. Also, it could be pumped to the Colorado River at Imperial Dam. Each alternative has merit and would enhance the quantity and quality of the river and/or canal flows, but the difference in costs would be substantial. The least costly alternative is the gravity canal to the All-American Canal and the most costly is the pump system to the Colorado River.

For the purpose of determining prospective costs as an indication of the relative merit of geothermal development for water production, the Salton Sea concept was selected for a subreconnaissance study. The size of the plan was based upon the development that can be accomplished by importing about 125,000 acre-feet of water from the Salton Sea. Removal of this quantity of water from the Salton Sea would halt its increasing salinity and prevent the vast recreational and fish and wildlife values of the Sea from being destroyed. Thus, additional benefits beyond the production of water and power would be provided by this concept. It is estimated that about 100,000 acre-feet of desalted geothermal water could be produced under the second stage, based on the amount of recharge water that can be obtained from the Salton Sea. Under this concept, the desalted water was assumed to be pumped to the All-American Canal above drop No. 4.

Electric power generating plants which could be integrated into stage two could develop approximately 420 megawatts of electric power from the steam. Internal power requirements, including pumping for import and delivery of water supplies, would be about 30 mw.

The major features of the Demonstration Stage would include production wells, desalting plants, powerplants, injection wells, the import water aqueduct from the Salton Sea, and the desalted water delivery system. All features, except the import aqueduct and the delivery system, would be included in the geothermal module arrangement.

a. Geothermal Module. The geothermal module would consist of 12 geothermal wells, one desalting plant, and a powerplant. The geothermal module would be formed as an octagon of eight wells, with four additional wells in the center of the octagon. Spacing of the wells would be about 800 feet on a grid pattern. The desalting plant and powerplant would be located inside the octagon providing the shortest pipe lengths possible from the wells. Average production per module would be 16,700 acre-feet of desalted water and 550,000 megawatt-hours of electric energy annually. The various features combined within the module are discussed in the following sections:

(1) Geothermal Wells. It is estimated that 72 production wells would produce about 100,000 acre-feet of desalted water per year. This estimate is based on a shutdown period for well maintenance of about 36 days per year. Each well would develop approximately 480,000 pounds of brine and 120,000 pounds of steam per hour.

Production wells would be drilled to the steam-producing zone at estimated depths ranging from 4,500 to 6,000 feet. The well design would include three strings of casing as follows: a 20-inch conductor string to about 300 feet; a 13-3/8-inch intermediate string to about middepth; and a 9-5/8-inch production string to the top of the production zone. All strings would be cemented to the ground surface. A mill slotted 9-5/8-inch screen would be run with the production string, equipped with a formation collar packer, and landed opposite the producing zones. To obtain an equivalent flow of about 2.5 cfs per well, it is anticipated that 200 to 300 feet of the producing sands would have to be screened.

When the geothermal fluid surfaces through the production wells, it would remain under pressure but the pressure will be lower than in the producing formation. As the fluid rises in the well casing, about 20 percent would flash into steam to produce a steam and brine outflow from the well. A separator located on the surface would separate the steam from the brine and both fluids would be delivered to the desalting plant. The flow of the fluids would be controlled to maintain the desired pressures.

There would be a certain amount of noncondensable gases which would have to be removed from the steam before it is passed to the generating stations. These gases include carbon dioxide, hydrogen sulfide, ammonia, and trace amounts of carbon monoxide and other hydrocarbons. One concept of removal and disposal would be to remove the gases from the first stage of the desalting process, compress them, and reinject

them into the ground in injection wells. Various chemical treatment processes could also be used to dispose of noxious gases.

(2) Desalting Plant. The desalting plant, along with its associated equipment for treating geothermal brine and desalted water, constitutes the highest cost portion of the water production system. Consequently, it is particularly important that the process design be optimized. Moreover, this optimization must be accomplished in full consideration of the relationship between the desalting plant and the powerplant, and of the interface between the desalting plant and any possible mineral by-product recovery plants. The design philosophy has been to achieve a desalting plant that is simple in concept, reliable, and easy to maintain and operate. The concept presented here takes advantage of the special characteristics of the geothermal resource, and leads to the best design of the entire system. In particular, because the geothermal brine feed is hot as compared to seawater feed to normal desalting plants, the process will differ somewhat in appearance from seawater desalting units. However, many of the components of the geothermal desalting unit itself will be similar to seawater systems and current technology will be used in these components. Problems relating to unusual brine chemistry and higher than normal temperatures and pressures will require further investigation.

It is recognized that all developmental problems have not been solved. In fact, the concept presented here points up areas of critical uncertainty. It is expected that these technological problems would be resolved during the Research and Development Stage, and that many improvements and refinements would be made to the basic developmental concept. Some of the more probable and more significant changes to the basic concept that might be anticipated are discussed in Chapter VI.

The desalting process discussed below can be more easily followed by referring to Figures 1 and 2. The desalting process used is a high-yield multieffect system with vertical tube evaporators (VTE). The plant is designed to produce high purity desalted water in an amount up to 75 percent of the geothermal brine fed to it, or 60 percent of the fluid produced at the wells. Additional desalted water would be recovered from the steam condensate at the powerplant to give a total product yield of 80 percent of the fluid produced at the wells.

The process design is based upon an overall systems analysis to result in an optimum utilization of geothermal energy with respect to the desalting and

NOTE

This Diagram Shows One Unit of
a Two Unit Desalting Plant
associated with a 12 Well
Module.

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GEOHERMAL RESOURCE INVESTIGATIONS

IMPERIAL VALLEY, CALIFORNIA

TYPICAL GEOHERMAL MODULE SCHEMATIC DIAGRAM DESALTING CYCLE

DWG. NO. 1241-300-30

OCTOBER 1971

FIGURE 1

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GEOTHERMAL RESOURCE INVESTIGATIONS IMPERIAL VALLEY, CALIFORNIA TYPICAL GEOTHERMAL MODULE SCHEMATIC DIAGRAM POWER CYCLE

DWG. NO. 1241-300-31
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FIGURE 2

powerplants and possible by-product recovery plants. Steam and hot brine produced at the well, in the expected weight ratio of about 1 to 4, would be processed at the central desalting unit. The desalting plant consists of three VTE effects with brine flowing upward within the tubes. The last effect is sent to the powerplant for production of electric energy. As discussed later in Chapter VI, a small net gain in total energy production is expected from this arrangement, as compared to the direct processing at the powerplant with the higher energy but lower purity wellhead steam.

Silica in the geothermal brine would come out of solution in the desalting plant and would be carried in the residual brine as very small particles. Efforts must be taken to prevent scaling of the heat transfer tubes in the VTE unit by the particles. Also, the particles must be removed from the residual brine before it is reinjected into the reservoir. Disposal of silica solids which results from the removal process will be required.

Because of the high temperature of operation of the evaporating units, it is expected that boric acid in the geothermal brine would also evaporate to a small extent. This would result in the presence of about 1 ppm of undesired boron in the product water. To prevent crop damage due to the boron, a boron removal unit would be required as part of the product water treatment process.

Salton Sea import water would be used to condense the steam at the powerplant and to cool the hot desalted water from the desalting plant. The heated Salton Sea water would then be injected into the geothermal reservoir, along with the hot residual brine, to replace the fluids removed from the reservoir. To avoid damaging effects upon the underground reservoir, the injection water would be chemically treated as necessary. This would require, primarily, the neutralization of alkaline materials and the removal of calcium sulfate.

(3) Powerplants. Powerplants would be included as part of the comprehensive development to generate power from the steam portion of the geothermal well output. Condensed steam from the powerplants would be cooled and added to the desalted water delivery system from the desalting plant. Cooling water would be Salton Sea water.

It is premature at this time to outline a firm approach to the production and marketing of any commercial power that may be involved; however, it is anticipated that some form of joint endeavor with non-Federal power suppliers will be formulated.

Preliminary investigations indicate each powerplant would produce about 70 mw based on 12 wells per module. The maximum power development from the second stage would be about 420 mw and would have a 90 percent plant factor. Photograph No. 3 shows the 75 mw powerplant under construction at Cerro Prieto, Mexico.

b. Power Transmission System. A transmission system to collect the power and serve pumping and processing loads of about 30 mw would require about 35 miles of a 69-kv line to serve the pumps on the desalted water delivery and import aqueducts, and a small 230-kv system to collect the power from the individual powerplants.

New substations or, where appropriate, additions to present or planned substations would be required.

c. Injection Wells. It is assumed that geothermal development under the Demonstration Stage would include the drilling of approximately 100 injection wells on the periphery of the geothermal field to inject residual brines from the desalting plants and Salton Sea cooling water for maintenance of reservoir pressures.

Plate No. 7 shows a sketch of the assumed convective currents in a typical geothermal field. This drawing shows that injection wells located on the periphery of thermal anomalies would discharge water into the downward flow of the convective currents. The injection water would eventually flow toward the thermal anomaly, gain heat, and flow upward to the production wells. It is estimated that the injection wells would be drilled to approximately the same depth as the production wells. Further tests and investigations on the injection process may indicate different depths would be required.

d. Water Delivery System. For the purpose of estimating costs, the delivery system for desalted water for stage two would consist of a pumping plant and an eight-mile pipeline that would terminate upstream of drop No. 4 on the All-American Canal. The capacity would be 155 cfs to convey about 100,000 acre-feet of desalted water per year.

e. Import System. An aqueduct from the Salton Sea would transport salt water pumped from the Sea to the Mesa geothermal steam field. The water would be used for desalting plant and powerplant cooling requirements first, and then be delivered to the ground-water aquifers through injection wells. The sea water would be treated before injection.

Photo No. 3. View of 75-mw powerplant under construction at Cerro Prieto, Mexico.

EXPLANATION

- Assumed Geothermal Convection Currents
- - - Isotherms
- Flow of Fluids

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GEOTHERMAL RESOURCE INVESTIGATIONS
IMPERIAL VALLEY, CALIFORNIA
ASSUMED GEOTHERMAL CONVECTION SYSTEM
SCHEMATIC SECTION

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PLATE NO. 7

Interior-Reclamation, B.C., Nev. 10-71

About 125,000 acre-feet of import water would be delivered annually to the steam field. The aqueduct would have a capacity of about 190 cfs, with a 90 percent operation factor to allow for shutdown periods. Two pumping plants would be required to lift the water about 300 feet. The aqueduct would be about 48 miles long.

f. Mineral Disposal. Mineral collection facilities have been included in the conceptual plan. It is believed that some of the minerals would be marketable as usable and economical products. Waste minerals would be hauled to disposal areas.

2. Relationships to Salton Sea Problems

The Salton Sea is the product of floodflows from the Colorado River in 1905 to 1907 which were trapped in the Salton sink. It is being perpetuated by irrigation drainage flows and with some minor contribution from natural runoff. While the drainage flows have some salinity, they are the principal source of dilution of the highly saline Sea. The salinity of the Sea had remained almost constant (about the same as ocean water) until recent years because of the rising surface level. However, the Sea has been experiencing a problem of increasing salinity since its level has stabilized. Evaporation rates are high and with a stabilized inflow and elevation, the salinity will continue to increase at a rapid rate. Allowing it to increase further, most recreational benefits would be lost because it would become uninhabitable for fish and undesirable for water-type recreation activities.

In a joint Federal-State reconnaissance report, dated October 1969, entitled "Salton Sea Project, California," the Department of the Interior, along with The Resources Agency of California, presented a plan for reducing the salinity of the Sea. Basically, the plan would be to isolate a portion of the Sea by diking and allowing water from the Sea to enter the diked area and be concentrated through solar evaporation. Since inflow to the Sea would be of lower salinity, this technique could control the salinity in the major portion of the Sea. The total construction cost of the Salton Sea Project was estimated to be about \$130 million.

Using the Salton Sea as a source of import water, for geothermal development and if no other works are necessary, could result in large cost savings which could be shared among the purposes of controlling the salinity of the Sea and the production of desalted water and power.

A feasibility study of the Salton Sea is currently under way by the Bureau of Sport Fisheries and Wildlife.

3. Cost Aspects

a. Salton Sea Import Concept. To indicate the general magnitude of costs involved and the relative significance of various cost components, subreconnaissance estimates of the conceptual plan utilizing the Salton Sea were developed. Both the initial investment costs and annual costs are summarized on Table 4. These costs include major joint use facilities common to both the production of water and power, which include production wells, injection wells, and facilities for delivery and treatment of import water for cooling and injection.

In order to identify water costs and facilitate considerations of cooperative ventures of Federal and non-Federal entities, it was necessary to distribute the joint costs between water and power. Cost allocation methodology assuring an equitable sharing in the serving of dual-purpose facilities has not been developed to apply to this unique geothermal complex; consequently, tentative assignments were made using available data and current judgments on operating characteristics. In deriving the allocations of costs, the use of facilities method was followed where such common denominators as useful energy available to each of the production processes and volumes of water were recognized. In the Research and Development Stage, economic investigations will explore cost allocation methodology.

The Demonstration Stage based on the Salton Sea conceptual plan would involve an initial investment of some \$209 million of which \$121 million would be an approximate assignment to water production. Annual costs related to water reflecting Federal financing criteria, and a 6 percent interest rate, would amount to about \$11 million or approximately \$116 per acre-foot (36¢ per 1,000 gallons) at a 90 percent plant factor. This includes a prorata share of the cost of power for internal uses which, utilizing the same financing criteria, leads to an average cost of about 3 mills per kwh. On the basis of a 14 percent fixed charge rate for non-Federal financing of 30-year life facilities, and including the savings inherent in joint production of water and power, power costs would approximate 5 mills per kwh at site.

To arrive at annual costs, service lives of wells were assumed to be 10 years; desalting plants and powerplants, 30 years; and conventional conveyance works, 100 years, with appropriate replacements as needed. A breakdown of the major annual components of desalted water costs is as follows:

Table 4
ESTIMATED COST OF DEMONSTRATION STAGE
Salton Sea Concept

Feature	(\$ Millions)	
	Investment	Annual
Production wells and surface plumbing	17.4	2.84
Injection wells and surface plumbing	14.3	2.14
Desalting plant	56.4	6.39
Water import system	55.9	3.54
Desalted water conveyance system	11.0	.72
Powerplant	<u>54.3</u>	<u>4.77</u>
Total Costs	209.3	20.40
<u>Tentative allocation of costs</u>		
Water		
Water production and conveyance	114.3	10.92
Power for desalter and conveyance pumping	<u>6.6</u>	<u>.66</u>
Total Water	120.9	11.58
Power	<u>88.4</u>	<u>8.82</u>
Total	209.3	20.40

Note: Costs are based on 6 percent interest rate.

<u>Item</u>	<u>\$/AF</u>	<u>¢/1,000 gal.</u>
Production wells and injection		
wells at site boundary	22	6.7
Desalting plant at site boundary	55	16.9
Import water for cooling and		
injection	31	9.5
Product water conveyance	<u>8</u>	<u>2.5</u>
 Total	 116	 35.6

The sensitivity of costs as to the source of import water and the point of conveyance of desalted water are apparent in the above breakdown. Over one-fourth of the costs is involved in importing water to the production site for cooling and injection. This will be an important area of cost analysis in the R&D program.

A significant factor which could influence water costs is the water quality benefits of the distilled water product output. Through blending with water of inferior quality, the total output of usable water attributable to the geothermal desalting complex can be increased with important reductions in the average cost of water. Also, potentials of utilizing the highly pure geothermal water product for municipal and industrial supplies locally or through exchanges will need to be considered. No attempt was made to place a value on water quality effects, which in fact, is recognized as one of the most critical problem areas in the Colorado River Basin with international implications. It should be noted that substantial fish and wildlife and outdoor recreation benefits that would result from salinity control are estimated in the previously mentioned Federal-State Salton Sea Project Report of October 1969 to amount to over \$12 million yearly. These benefits have not been accounted for in this cost analysis. Allocations for fish and wildlife and recreation purposes or recognition of a "stretched" supply through blending could reduce water costs.

b. A Range of Water Costs Reflecting Alternative Conceptual Plans. As indicated in an earlier section, there may be several alternative sources of import water for cooling and injection and alternate points of delivery of desalted water. The lowest potential cost of import supplies appears to be local ground water, assuming various technical and institutional problems would be resolved. Import costs would move upward when considering the use of Wellton-Mohawk return flows. The Salton Sea source would

likely be even more expensive than using the Wellton-Mohawk return flows. Unit costs for import water might range from \$10 to \$31 per acre-foot.

Points of delivery and associated conveyance costs would vary significantly from the simple provision of a short gravity section to the All-American Canal as compared to delivery to a point on the Colorado River near Imperial Dam. Such unit costs could range from \$4 an acre-foot to \$20 an acre-foot. Combining the low and high ranges for both import and conveyance systems, and making allowances for the higher quality local ground water, would result in a range of product water from about \$85 to \$130 per acre-foot (26¢ per 1,000 gallons to 40¢ per 1,000 gallons). Again this does not recognize values attributable to the extremely high quality product water output, which could have a significant effect on net costs.

As the research and development program progresses, more detailed studies, technological discoveries, and plan formulation investigations will be undertaken. When compared with the current cost estimates of desalted water from coastal or inland sources, these prospective costs are attractive and show promise for the successful development of a major natural resource.

C. Large-Scale Development

1. General. Well field development under the Large-Scale Development Stage would be similar to the Demonstration Stage with considerably more modules in operation. Experience gained from the Demonstration Stage of development would be utilized in planning features of the Large-Scale Development Stage. Alternatives would be investigated to ensure development of the most feasible plan and to determine the quantity of water that can be or should be developed.

Conceptual alternatives considered for cooling and injection water include the transportation of ocean water from the Pacific coast and from the Gulf of California. Each alignment, however, has certain problems. The Pacific coast alignment would have high rights-of-way costs due to its alignment through developed areas on the coast and high construction costs due to long tunnel alignments. The alignment from the Gulf of California would have international implications, but would have low operation and maintenance costs due to the low lift required. The length of each line would be approximately the same.

Desalted water could be delivered to several points along the Colorado River. The most distant and highest points such as Lake Mead would be the most costly, but would provide the greatest benefits for storage and water quality.

Studies were made on each of the alternates discussed above including several delivery points to the Colorado River. For the purpose of this report, one conceptual plan was selected for a more detailed study and is discussed in the following paragraphs. The plan includes the importation of cooling and injection water from the Salton Sea and the Pacific Ocean and the delivery of desalted water to Lake Havasu. This concept would include the production of desalted water of as much as 2.5 million acre-feet per year. A schematic flow diagram of the Large-Scale Development Stage is shown on Plate No. 8.

It is estimated that a total of 1,800 geothermal wells would be required to form 150 modules for the purpose of producing 2.5 million acre-feet of desalted water per year. Approximately 2,400 injection wells would be required to recharge the ground-water basin with injection water imported from the Pacific Ocean and the Salton Sea. The potential electric power development at full operation would be 10,500 mw. Pumping and processing load requirements are estimated to be 2,000 mw. A drawing showing the conceptual geothermal module and the relationships of modules to each other is shown on Plate No. 9.

The main difference between the Demonstration Stage and the Large-Scale Development Stage would be the addition of the ocean water import system, the delivery system to the Colorado River, and the increased magnitude of operation. The aqueduct systems are described below.

2. Water Delivery System. The aqueduct to Lake Havasu, consisting of a pipeline and pumping plants, would be needed to convey the desalted water from the Imperial Valley to the Colorado River. To deliver 2.5 million acre-feet of desalted water per year, this system was designed to carry about 3,450 cfs. The pipeline alignment is shown on Plate No. 10. A profile of the ground surface along the pipeline alignment is shown on Plate No. 11.

Under this concept, four pumping plants would be required to lift the water from Imperial Valley to Lake Havasu. The first pumping plant would be located near the geothermal development and would pump desalted water collected from all of the desalting plants to the base of the Chocolate Mountains. Three pumping plants would then be required to lift the water for conveyance through several dry desert valleys to Lake Havasu. Standby pumping units would be provided since no regulating reservoirs are included in the system. A 19-foot diameter tunnel two miles long would be required

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GEOTHERMAL RESOURCE INVESTIGATIONS
IMPERIAL VALLEY, CALIFORNIA

**GEOTHERMAL DEVELOPMENT
SCHEMATIC DIAGRAM**

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PLATE NO. 8

TYPICAL GEOTHERMAL WELL FIELD
MODULE PLAN LAYOUT

1000 0 2000 4000 6000 8000
APPROX. SCALE OF FEET

TYPICAL GEOTHERMAL WELL FIELD
WELL MODULES PLAN DETAIL

500 0 1000 2000 3000
SCALE OF FEET

- EXPLANATION**
- BOUNDARY OF GEOTHERMAL WELL MODULES
 - POWER PLANT
 - DESALTING PLANT (2 UNITS)
 - GEOTHERMAL WELL
 - OCEAN WATER
 - POWER
 - ==== DESALTED WATER

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**TYPICAL GEOTHERMAL WELL FIELD
PLAN LAYOUT AND DETAIL**

MAP NO. 1241-300-29
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GEOTHERMAL RESOURCE INVESTIGATIONS
IMPERIAL VALLEY, CALIFORNIA
WATER CONVEYANCE SYSTEMS
LARGE SCALE DEVELOPMENT STAGE

MAP NO. 1241-300-27
SCALE OF MILES

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IMPERIAL VALLEY, CALIFORNIA

WATER CONVEYANCE SYSTEMS
LARGE SCALE DEVELOPMENT
ALINEMENT PROFILE

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in the system. Two major highways would be crossed by this aqueduct: Highway 60 (Interstate 10) between Blythe and Indio, and Highway 95 between Needles and Blythe. The desalted water aqueduct would also cross the existing Colorado River Aqueduct near the town of Rice, California. The alinement was determined from Geological Survey quadrangle sheets.

This conceptual plan includes the delivery of product water to Lake Havasu near Havasu Landing, which is about 16 miles upstream from Parker Dam. This should allow sufficient mixing with the Colorado River water before it reaches the intakes to the Colorado River Aqueduct and the proposed intake to the Havasu Pumping Plant, a proposed feature of the Central Arizona Project. A system of several lake bottom outlets could be added to facilitate mixing operations, if necessary.

Geothermal product water would be cooled to a temperature near 75°F. to avoid environmental and ecological problems. The temperature of flowing water in lake Havasu exceeds 80°F. at certain times of the year. During the winter months when the cooling water temperatures are low, the product water can be cooled to temperatures below 70°F.

3. Ocean Water Import System. The aqueduct from the Pacific Ocean under this concept would convey water to the Imperial Valley geothermal fields for injection into the ground-water basin. This water would be required for ground-water pressure maintenance and prevention of possible subsidence. The ocean water would also be used for cooling purposes in the desalting plants and the powerplants before being injected into the ground as shown in Figure 2. The temperature of the ocean water would vary from about 62°F. in the winter to about 70°F. in the summer, and would be heated to about 290°F. in the product coolers before injection. Some treatment would be required primarily to remove calcium sulfate before injection to prevent subsurface plugging. Use of product water for cooling and/or reinjection purposes would be possible for short shutdown periods to keep powerplants and desalting plants in operation.

The aqueduct would be designed to convey about 2.9 million acre-feet per year of ocean import water 126 miles to Imperial Valley, and would include two 16-foot-diameter pipes. The total capacity would be 4,410 cfs, providing for an operation factor for shutdown time. Plate No. 10 shows the aqueduct alinement and Plate No. 11 shows a profile of the ground surface along the aqueduct alinement.

Under this concept, three pumping plants would be required to lift the water about 1,000 feet from the ocean to the aqueduct's high point at a tunnel inlet in the San Ysidro Mountains. The water would flow by gravity through two tunnels and a pipeline to the geothermal steam fields.

Two 21-foot diameter tunnels were included to avoid traversing two high and rugged ridges. The total length of the tunnels would be about 50 miles. The pipeline and tunnel alignments would generally follow State Highway 94 and U.S. Highway 98 near the Mexican Border to Imperial Valley. Construction of the facilities under stage three of development would take about 10 years to complete.

4. Cost Aspects. Extrapolation of costs to a large-scale development of up to 2.5 million acre-feet would necessarily be conjectural considering that the time frame involved is some 20 years in the future. However, a range of costs can be approximated by using the production costs at site as derived in the Demonstration Stage as a base and by adding estimates of the costs of conventional conveyance systems for importation water and for product water.

Assuming a rather conservative savings of some 10 percent due to possible advantages of mass production, on-site fabrication, and standardization of the many repetitive processes, the base cost for water production at site would approximate \$70 per acre-foot. This cost must be increased between \$30 and \$80 per acre-foot to include water conveyance systems for import water and product water. The lower figure results from the concept of importing cooling and injection water from the Gulf of California either alone or in combination with local water resources and delivering large blocks of product water to nearby points along the Colorado River such as Imperial Reservoir. The higher figure results from the concept of importing water from the Pacific Ocean and delivering product water to Lake Havasu on the Colorado River. Delivery of product water to Lake Mead would provide greater benefits but would also be more costly.

The total cost to produce and transport product water for the Large-Scale Development Stage is estimated to be between \$100 and \$150 per acre-foot. This is without credit being taken for the major beneficial effects of high quality water as previously discussed such as the opportunities for blending, possible higher valued uses such as municipal and industrial water, and the general enhancement of Colorado River supplies. These costs do not take into consideration possible reductions due to technological advances that could result from stages one and two of the program. In

addition to the potential technological breakthroughs, comparatively minor technical advances can importantly reduce costs. For example, if the 10-year estimated life of the production wells can be improved to 20 or 30 years, costs could be reduced significantly.

As in the Demonstration Stage, the cost of water is very sensitive to the need and source of import water for cooling and injection and to the points of delivery for product water. Since the joint production complex producing both water and power involve imported water, significant cost impacts would also effect power costs though not as severely as water. It is estimated that the power costs for process power and conveyance pumping would be about the same as the costs evaluated in the Demonstration Stage.

Chapter VI ALTERNATE PLANS AND CONSIDERATIONS

In this chapter, several of the alternate approaches will be discussed in further detail. These alternates are of two types: (1) an alternate way of doing specific tasks within the overall conceptual plans, such as transporting the desalted water to different locations; and (2) alternate concepts of approach to larger phases of geothermal development. The discussion of alternates below is broken down into three areas: the destination of desalted water, the source of injection water, and process concepts within the desalting and power systems.

It should be emphasized that these alternates are possible refinements that may lead to lower costs, higher reliability, or more technologically feasible processes. Many unknowns exist with respect to these alternates, and to other alternates not mentioned, just as unknowns exist with respect to the development concepts previously presented. These unknowns would be largely resolved by the proposed research and development program, but some of the unknowns would remain unresolved until undertaking the Demonstration Stage. The final geothermal development plan arrived at after these studies are completed would be primarily dictated by economic and environmental considerations.

The conceptual plans presented in Chapter V represent the selection from several alternatives with regard to delivery of desalted water and importation of cooling and injection water. Also considered were plans to deliver the product water to Imperial Reservoir, Lake Mohave, or Lake Mead, a plan to import injection water from the Gulf of California, and a plan to transport ocean water to the north end of the Salton Sea.

Plate No. 12 shows the alternate conceptual plan locations.

A. Alternate Destinations of Desalted Water

Introducing as much as 2.5 million acre-feet per year of cooled desalted water into the Colorado River at different points would have different effects on the downstream quality of the river's water. Placing the water in Imperial Reservoir would do the least to improve the overall water quality of the river for use in the United States, but would also cost the least. On the other hand, transporting it to Lake Mead would probably have the greatest improvement on the water quality, but would be the most costly of the alternatives. It would have some advantages for power production. Additional studies would be required to determine the downstream impact of introducing

geothermal product water at various points along the river. When the benefits are more clearly defined and costs more precisely known, then an optimum alternative may be better selected.

1. Imperial Reservoir. As a receiving point for desalted water, Imperial Reservoir would require the shortest product water delivery aqueduct, approximately 52 miles in length. The reservoir, however, does not have sufficient storage to handle large deliveries of as much as 2.5 million acre-feet per year, and an offstream reservoir would have to be constructed in order to avoid costly spills at Imperial Dam. Preliminary estimates indicate that annual investment and OM&R costs for conveyance facilities for this alternate would amount to approximately \$20 per acre-foot of water delivered. This would compare with about \$45 per acre-foot for the aqueduct to Lake Havasu. No site for the offstream dam and reservoir for the Imperial route has been determined.

2. Lake Mohave. Delivering desalted water to Lake Mohave would require an aqueduct of approximately 215 miles in length. The product water would be introduced into the lake at a point approximately 16 miles upstream from Davis Dam. Plate No. 12 shows the alinement of the Mohave aqueduct to be the same as the Havasu aqueduct except that the former continues north where the latter turns east toward Lake Havasu. The preliminary estimated annual investment and OM&R costs for conveyance facilities to transport large quantities of desalted water to Lake Mohave would be about \$66 per acre-foot of water delivered.

3. Lake Mead. The aqueduct to Lake Mead would follow the same general alinement as the Mohave aqueduct except that it would continue to the north where the Mohave aqueduct turns east. The Mead aqueduct would be approximately 252 miles in length and would deliver product water to the Lower Basin of Lake Mead. The preliminary estimated annual investment and OM&R costs for conveyance facilities to deliver desalted water to Lake Mead would be about \$82 per acre-foot.

B. Alternate Sources of Injection Water

Injection water would be needed to replace the geothermal brine that is converted to desalted water, thereby preventing the subsidence that could occur if reservoir pressures were not maintained. One concept presented in this report uses water from the Pacific Ocean for this purpose.

Another possible source of injection water that has been considered is the Gulf of California. Adoption of this plan would entail running an aqueduct from the Gulf

through Mexico and into the United States to Imperial Valley. The overall length of such an aqueduct would be about the same as for the Pacific Ocean, South Route, plan, but the total estimated annual investment and OM&R costs for the Gulf plan would be lower (\$29 per acre-foot vs. \$38 per acre-foot for conveyance features only) because of considerably less pumping required.

The Gulf conceptual plan would have some problems because of the uncertainty of the location of the intake site and the possible complications arising out of international developments. However, because of the apparent significant difference in costs, the plan does merit further study.

Still another alternative being considered for delivery of injection water to the valley is an aqueduct which would begin on the California coast in the vicinity of Camp Pendleton Marine Base in northern San Diego County and would run east to the northern end of the Salton Sea. The water would be discharged into the Sea and removed at the southern end for final delivery to the well field sites. This system would allow for thorough mixing of waters in the Salton Sea and would assist in stabilizing the level of the Sea and its salinity to that of ocean water.

Local ground water would be an attractive source of cooling and injection water considering costs, but several problems may result when the ground water table is lowered. Leakage from the local canals may increase, pumping heads for wells in Mexico may increase, and inflow to the Salton Sea may decrease.

Other alternative plans in the ultimate development of geothermal resources have been considered briefly to date. These include delivery of desalted water to more than one point and possible use of agricultural drainage water as injection water. Drain water used for injection would be a small part of the large-scale requirements and ocean water would still be needed.

C. Alternate Process Concepts in the Desalting and Power Systems

1. Integration of Desalting and Power Systems. In the developmental concepts presented, steam from the wellhead separator is used directly in the desalting plant, and then a clean but slightly lower energy steam is sent from the desalting plant to the powerplant for electrical production. This is contrary to schemes commonly presented whereby the wellhead steam is used in the powerplant and the power and desalting systems are completely divorced from each other.

The integrated concept presented here is preferred for reasons of overall project economy and simplicity; that is, the lowest total cost for water plus power is expected by this approach. Integration achieves these benefits without introducing corresponding disadvantages. The primary benefits for this approach are summarized below.

a. Only a small loss of power potential is experienced by energy degradation of the steam supply in the desalting plant (about 4 percent, due to an enthalpy drop from about 1,200 to 1,192 BTU/lbs. at the turbine inlet).

b. A small gain in actual power production is achieved due to removal of inert gas impurities in the desalting plant, instead of at the powerplant steam jet ejector system, thereby saving the steam required to run the ejectors.

c. The capital cost of the desalting plant proper is reduced by this more efficient use of the geothermal energy, as opposed to the case where only the hot brine from the wellhead separator is processed in the desalting unit and the impurity-laden steam goes directly to the powerplant.

d. Recovery of the inert gas impurities, either for further processing or to avoid environmental degradation, is easier at the high pressure desalting plant than it would be at the low pressure powerplant condenser.

2. Desalting of the Hot Injection Water. The development concept calls for injection of hot ocean and Salton Sea water since the environmental impact on the deep reservoir is minimized when the injection conditions are close to the withdrawal conditions. However, if future investigations show that cold injections would not be deleterious, the desalting of these hot waters in a supplemental desalting unit would be considered in more detail. The advantages of supplemental desalting would be to reduce the number of production and injection wells needed to produce the desired total quantity of desalted water, and also to reduce the amount of injection water that must be treated and transported. The disadvantage of this procedure is that the supplemental desalting unit would resemble a typical sea water desalting plant, and would be expensive. It should be strongly pointed out, however, that the rate of net energy withdrawal from the deep geothermal reservoir is about the same for either case, with or without the supplemental desalting plant for a given total production of water.

3. Desalt Only Ocean Water. Consideration has been given to using hot geothermal brine as a heat source for a conventional sea water desalting unit in the Imperial Valley. The cold, but intact, geothermal brine is then reinjected underground,

and the problems due to its unusual chemical makeup are supposedly avoided. However, these so-called chemical problems would not be avoided in this way, for they would exist in the sea water heater in this case just as they exist in the geothermal desalting unit in the developmental concept. Furthermore, the "conventional" sea water desalting plant required for this case would be much more costly than the equivalent geothermal brine desalting plant.

4. Low Yield, Flash Process for the Desalting Plant. A simple flash process for desalting the hot geothermal brine has been considered for the reasons of its simplicity and inherently low technological risk. However, the product yield from the simple flash process is small, being only about one-fourth to one-third of the hot brine fed to it as opposed to a three-fourths yield for the preferred multieffect process. Thus, more production and injection wells and higher costs would be required with the flash process.

It is anticipated that the technological problems that are associated with the multieffect process would be fully resolved in the research and development program. Furthermore, the cost saving attainable with the multieffect process greatly exceeds the projected cost of the research and development program.

5. Supplementary Electric Energy Production. If further studies indicate that injection of cold water is feasible (see subheading C.2 of this chapter), it may prove to be more economically attractive to produce supplementary electric power rather than the supplementary desalted water discussed in subheading C.2. To accomplish this, the product water leaving the desalting unit at 365°F. (see Figure 1) would be cooled by exchanging heat with a secondary fluid, such as freon, instead of ocean water. The vaporizing secondary fluid would then produce electric energy in a closed loop power cycle. The unheated ocean water would be injected into the reservoir to replace the desalted brine.

D. Summary

As indicated by the brief discussion of this chapter, the developmental concept for the optimum geothermal development plan is by no means fixed. Refinements are certain and some breakthroughs are probable. Part of the objectives of the proposed research and development program is to permit attainment of the potential improvements.

Chapter VII ENVIRONMENTAL CONSIDERATIONS

A. Introduction

This chapter is not an environmental impact statement. It is a general discussion of the major problem areas and possible solutions involving the geothermal development and its effect upon the environment. Complete environmental impact statements will be prepared and submitted for review before proceeding with each phase of the work.

The proposed concept for large-scale development of the geothermal resource requires drilling of deep producing wells and injection wells, as well as the construction of steam powerplants, pumping plants, desalting plants, and conveyance systems with large diameter pipelines. In addition, there would be related facilities of access roads, powerlines, substations, and switchyards. Many distinctly different types of environmental areas are involved, as indicated by the aqueduct route from the coastline of the Pacific Ocean, through the mountains and forests of the San Ysidro and Jacumba Mountain ranges, to the arid deserts of Imperial Valley, California. Facilities would traverse populated urban areas, agricultural lands, and areas essentially undeveloped.

All stages of the development in the Imperial Valley include the extraction of geothermal brines. Past experience at similar water-dominated geothermal power developments at Cerro Prieto, Mexico, and Wairakei, New Zealand, indicates that subsidence can be expected to occur in the Imperial Valley unless provisions are made to maintain reservoir pressures underground. Thus, the prevention of subsidence is an integral part of the proposed developmental concept. Steps are being taken currently to establish a level network to accurately monitor any tendencies for subsidence in the future. Each stage of the development includes a step-by-step program to develop techniques for maintaining reservoir pressures. Water for injection will be imported as required. If the resource is developed for power only, the cost of importing injection water, or making other provisions to reduce subsidence, may adversely affect the development of the much-needed geothermal power. If, however, a comprehensive development program is set up that permits the simultaneous development of both water and power, the combined resources of the entities developing the resource could provide injection and cooling water at greatly reduced unit costs because of the larger amounts of water required.

The brines handled both in production and for injection would be saline. Consequently, should a prolonged spillage or leak in the piping occur, it could cause

this brine to infiltrate the local ground-water table which is some 25 to 40 feet deep. To minimize spillage or leakage, all piping would be above ground so that all flows could be monitored continuously for rapid detection of problems. A system for quickly shutting off of flows would be provided.

B. Imperial Valley

Located in southeastern California, Imperial Valley encompasses some 1,710 square miles of Imperial County. Elevations within the valley range from -234 feet at the Salton Sea to +1000 feet at the foothill boundaries.

Major geographical features of the valley include the Algodones Sand Hills which run northwest-southeast at the eastern boundary of the valley. The Salton Sea is an inland sea that was formed by floodflows of the Colorado River from 1905 to 1907. The Sea has been perpetuated over the years by return flows from irrigation operations and natural runoff.

The major economic development in the valley is agriculture with some 500,000 acres of land irrigated from waters delivered through the All-American Canal system.

Climate in this area is considered as arid desert. The average annual precipitation is only some 2.6 inches, occurring mostly between October and February. The mean annual temperature is 73°F. with temperatures exceeding 100°F. in over 100 days each year. The prevailing winds in the area are generally light from the west or northwest.

Natural vegetation is sparse. The alkali-sink community (occurring mostly in the Salton Sea area) and the more common creosote bush scrub comprise the major vegetation pattern. Certain annual plants are found during years when there are winter rains.

Animal life includes small rodents, badger, kit fox, coyote, bobcat, jack rabbit, and cottontail. Several species of migratory birds including white wing doves, several species of ducks and numerous species of passerine birds frequent the area at various times of the year. Also several resident species of birds are located in the area. These include roadrunners, mourning doves, and resident passerine birds. Many varieties of lizards and snakes inhabit the area. Salt water fish from the Gulf of California have been planted in the Salton Sea and fresh water game and rough fish occupy the irrigation canals. The latter originate from the Colorado River.

C. Environmental Effects

The proposed concept for developing the geothermal resource is divided into three stages: a Research and Development Stage, a Demonstration Stage, and a Large-Scale Development Stage. The effects of each of these stages differ in magnitude, in length of time the effect will be felt, and in the specific areas affected. During each stage of the development, environmental factors would be studied, evaluated, and used to formulate each succeeding stage. A description of these effects for each of the stages follows:

1. Research and Development Stage. The R&D Stage envisions the progressive drilling of approximately five production and approximately five injection wells on Federal lands in Imperial Valley. Progressively larger desalting test facilities, ranging from a 50,000 gallon per day desalting test unit operating in conjunction with a single production well, to a 200,000 to 500,000 gallon per day desalting pilot plant. A 2 to 3 million gallon per day prototype desalting plant would be completed in the sixth year of the R&D Stage. During the first years of the R&D Stage, the technology of deep-well injection of effluent brines will be developed to provide for brine disposal and subsidence prevention. Accordingly, there will be periods when the effluent cannot be sent to the well and must be handled differently. As backup for the disposal wells during the early years, an evaporation pond will be built for taking all brine effluent. The pond will be lined with a suitable impermeable material to minimize the possibility that salts will contaminate the ground water.

The water in the effluent will evaporate from the pond, leaving behind the solids in the disposal pond. The amount of water added to the atmosphere from this source will be infinitesimal compared to the constant evaporation in the valley from the Salton Sea, the irrigation canals, and the irrigation water in the fields. After the evaporation ponds are no longer needed, they will be filled to the original ground surface.

The pilot plant unit would have facilities for removing H_2S gas out of the steam leaving the wellhead separator. The effluent from the removal column, containing dilute sulfide solutions, would be discharged to either the injection well or the evaporation pond.

Silica filtered from the effluent will be discharged to the evaporation pond. In addition, tests will be made of means of redissolving silica with the objective of finding a way of reinjecting the silica into the formation from which it came.

Temporary research and development facilities would change the desert environment considerably in the immediate area of the facilities. After the completion of tests, the facilities would be removed except for some permanent installations, such as wellhead equipment and piping needed for permanent operation. The area disturbed would be revegetated and the facilities needed for the next stage of development would be modified to blend into the desert setting.

Noise from the testing of steam wells has been an inherent trait in geothermal developments in other countries. Effective measures will be taken to muffle the noise, and, after tests are complete, the wells will be capped and the noise will be substantially reduced. Noise associated with the powerplants and desalting plants will be effectively muffled through the use of acoustical building materials.

There would be a certain amount of noncondensable gases which would have to be removed from the steam before it is passed to the generating stations. These gases include carbon dioxide, hydrogen sulfide, ammonia, and trace amounts of carbon monoxide and other hydrocarbons. It is proposed to remove the gases from the first stage of the desalting process, compress them, and reinject them into the ground in injection wells. No air pollution problems are anticipated from this method of disposal. Various chemical treatment processes could also be used to dispose of noxious gases.

The present plan is to reinject residual brine into the ground at conditions as close as possible to the material taken out with respect to chemistry, temperature, and concentration. This would have minimum impact underground. This problem will be thoroughly studied in the research and development program.

Waste mineral solids would be hauled to disposal areas. Disposal sites have not been selected but would be located to have minimal effect on the environment. Some mineral solids would have economic value and would present no disposal problems.

Due to the topography and sparseness of native vegetation, most test facilities would be visible for some distance. Appropriate architectural and landscaping techniques would be used to minimize visual impact. Steam plumes associated with powerplants and test wells during testing would no doubt be visible for some distance. Most development would be on remote, sparsely used Federal land within the valley, and the esthetic impact of the facilities with respect to the number of people affected would be minimal.

A possible adverse effect could be ground vibration around the wellheads as wells are producing. This vibration, if it occurs, should be limited to the immediate area of the wellhead and would be unnoticeable to the general public.

2. Demonstration Stage. The Demonstration Stage would have many of the environmental effects of the R&D Stage plus others related to its larger scope. This stage would require the drilling of approximately 72 production wells and 100 injection wells grouped in six modules of 12 production wells each around a desalting plant and a powerplant. A considerable amount of piping would be required to carry steam and brine from the wells to the powerplant and desalting plant, carry product water to the point of delivery, and import water for cooling and injection. Most of the piping would be above ground to permit early detection of leaks and spills. Techniques for minimizing leakage and spills developed during the R&D Stage would be used. A limited number of small lined emergency brine ponds may also be required.

Several sources of cooling and injection water are being considered for this stage of the development: local shallow ground water, imported Salton Sea water, and imports from the Wellton-Mohawk Drain. Pretreatment methods developed during the R&D Stage would be employed to minimize adverse chemical effects of the injection water on the aquifer. Minerals produced by pretreatment would be disposed of by sale (if possible) or by transporting to suitable disposal areas.

Importing Salton Sea water for cooling and injection may be the only economically feasible way to reverse the increasing salinity of the Sea. Preliminary studies indicate that removing 125,000 acre-feet per year of water could stabilize the salinity of the Sea near the salinity of the ocean, thereby preventing the gradual annihilation of the present fish population. Results from the proposed developmental concept will be coordinated with the Salton Sea Task Force which is currently studying ways of stabilizing the salinity of the Sea.

Water from the Salton Sea would be brought to the East Mesa by an aqueduct beginning at a point on the northeast side of the Sea near the end of the East Highline Canal. From there, it would extend east until reaching the Federal lands on the east side of the East Highline Canal where it would turn south toward East Mesa, generally paralleling the canal. It would be wholly within the Imperial Valley. Elevations along the pipeline route range from approximately -234 feet at the Salton Sea to about 100 feet at East Mesa.

If cooling and injection water is brought in from the Wellton-Mohawk Drain approximately 200,000 acre-feet of desalted water and 800 mw of power could be produced. Since the salinity of this source of water is less than the Salton Sea, less

pretreatment for injection would be required. The conveyance for the Wellton-Mohawk water would cross the Colorado River and roughly parallel the alignment of the All-American Canal through an unpopulated area.

If ground water is used for cooling and injection, several wells would be drilled approximately 500 feet deep. The wells would be located from two to six miles from the plant site in an undeveloped area on Federal lands. Subsidence caused by ground-water pumping, if it occurs, would be restricted to the immediate area of the ground-water well field and should have little adverse effect on the ecology.

Steam from the powerplants would be condensed by heat exchange with imported water prior to injection of the imported water. The cooling water would be recycled in cooling towers which would emit constant plumes of steam. If Salton Sea water is used in the cooling towers, salt drift could result which would deposit salt on the surrounding area. Research on suppressing salt drift will be undertaken as an integral part of the development program. Cooling towers would probably require periodic cleaning to remove salt encrusted from the vaporization of the cooling water.

Desalted water produced in the Demonstration Stage would be delivered by canal to the All-American Canal or by pipeline to Imperial Dam. The water would be cooled to avoid adverse ecological problems. Power produced could be integrated into the existing electrical networks in the area by adding short transmission lines from the production area to nearby connection points.

3. Large-Scale Development. The large-scale development of the geothermal resource would have a significant impact on the area. Depending on the amounts of water and power produced, large numbers of production and injection wells would be drilled; numerous desalting plants, powerplants, roads, service and maintenance buildings, switchyards, electrical transmission lines, and water conveyances would be constructed. During construction, as many as 5,000 workers could be employed at any one time. After construction is completed, it is estimated that as many as 1,000 employees could be required to operate and maintain the facilities. This represents a significant increase in the present population of the area. No new communities are anticipated, however, as it is felt that existing cities and towns could absorb this increase with some growth. Such an increase would require a certain increase in existing commercial and recreational facilities.

Lessons learned in the preceding stages of development in such areas as construction practices, reseeding procedures, accident prevention, and architectural design will be used to minimize visual impact of the development. Subsidence control measures, waste disposal, and cooling procedures, noxious gas removal, and other operating techniques developed during the Demonstration Stage will be employed to reduce other adverse environmental effects.

The new environmental effects for this stage are primarily related to bringing in large quantities of cooling and injection water, and conveying desalted water and power to distant points of delivery. The routes of these conveyance features have not been determined at this time. The conveyances would be permanent features of the landscape. The nature of the desert area, together with a reseeding program, should aid the area temporarily disturbed during construction to return rapidly to its natural state.

Delivery of substantial quantities of high-quality desalted water to the Colorado River will markedly improve the quality of the water in the river, permitting the use of the water directly in municipal systems without expensive pretreatment. An improvement in the quality of water used for agriculture could result in lower unit consumption and improvement of crop yields.

The proposed geothermal resource development program has been staged to permit solving problems in small increments while they are more manageable and applying the lessons learned in succeeding stages. Every effort will be made to avoid large-scale irreversible commitments until they have been thoroughly researched on a smaller scale.

Chapter VIII FINDINGS AND CONCLUSIONS

A. Findings

Geothermal explorations in Imperial Valley, California, have indicated the existence of a substantial energy reservoir as hot brine at relatively shallow depths in the valley sediment deposits. The sediments have depths to 20,000 feet and are saturated with mineralized water having a salinity range estimated between 600 and 260,000 ppm. In areas and depths of interest for development by the Bureau of Reclamation, the estimated salinity ranges from 3,000 to about 30,000 ppm.

Preliminary estimates by the Geological Survey indicate that 1.1 billion acre-feet of water are usable and recoverable at feasible drill hole depths in the Imperial Valley.

Based on data available to date, it is estimated that it may be possible to develop as much as 2.5 million acre-feet of desalted water per year from geothermal well fields in Imperial Valley.

B. Conclusions

1. It is concluded that geothermal water development has a potential for augmentation of the Colorado River from sources within the basin.

2. An orderly program of geothermal resource investigations should be accomplished involving Bureau of Reclamation and Office of Saline Water expenditures of about \$16 million over a 7-year period. Other Federal and State agencies will participate with investigations and funds, but the extent of their contributions is not known at this time. The investigation program would delineate geothermal well fields, identify the extent of the resource, and develop the technology for desalting geothermal brines.

3. The Federal Government should protect and insure the optimum development of the geothermal resource to provide a source of high quality water for augmentation of the Colorado River together with associated electric power generation, mineral extraction, and other resource uses. It is premature at this time to outline a firm approach to the production and marketing of any commercial power that may be involved; however, it is anticipated that some form of joint endeavor with non-Federal power suppliers will be formulated.

GLOSSARY OF TERMS

Blowout Preventer

A hydraulically operated arrangement of gates, rams, and a rubber bag installed in a stack at the casing head to control high pressures encountered by chance during drilling.

Christmas Tree

A wellhead assembly of control valves to facilitate production and testing.

Desalted Water

High quality water produced from the desalting plant. Total dissolved solids commonly range from 20 to 50 parts per million.

East Pacific Rise

A branch of the worldwide network of oceanic spreading centers. The East Pacific Rise has been traced as running along the axis of the Gulf of California, and entering the United States under the Imperial Valley. Its route after that is unknown as the trail is obscured by the continental crust.

Geothermal Anomaly

An area of high heat as indicated by contouring thermal gradients.

Geothermal Gradient

The rate of change in temperature with depth, commonly expressed in "degrees Fahrenheit per 100 feet."

Geothermal Resource

The heat generated from the interior of the earth and recoverable in some medium such as hot ground water or steam.

Gravity Survey

Measuring the changes in densities within the earth. Bodies in a geothermal environment having a density contrast may be created by metamorphism due to heat or cementation due to deposition of silica or calcium carbonate.

Module

As used in this report, a module is a group of 12 producing wells arranged in an octagon-shaped pattern. It includes one desalting plant and one powerplant.

Ocean Water

Water pumped from the Pacific Ocean for powerplant and desalting plant cooling purposes and injection into the geothermal reservoirs to maintain ground-water reservoir stability.

Permeability

The permeability of a rock or sediment is a measure of its ability to transmit fluid, such as water, under a hydropotential gradient.

Porosity

The porosity of a rock or soil is its property of containing interstices, or voids, and may be expressed quantitatively as the ratio of the volume of its interstices to its total volume. It may be expressed as a decimal fraction or as a percentage.

Porosity, Effective

Effective porosity refers to the amount of interconnected pore space, the space available to fluid transmission. It is expressed as a percentage of the total volume occupied by the interconnecting interstices.

Residual Brine

Brine fluids remaining after desalting. Concentration of salts.

Resistivity Survey

Introducing electrical current into the ground and measuring the distribution of electric current below the surface. Surveys are performed in search for water-bearing formations, stratigraphic traps in oil fields, and conductive ore bodies.

Spreading Center

A geological feature usually in the form of a sea floor ridge thousands of miles in length. It is caused by the circulating pattern of the molten rock in the mantle just below the crust of the earth. The upwelling of molten rock causes spreading or rifting of the crust, thus creating movement of large masses of land. There is believed to be a network of spreading centers covering the entire earth but occurring mostly under the oceans.

Temperature Recovery

The return of a well to equilibrium with the various temperatures of the formations that were penetrated. Circulation of drilling mud cools the formations immediately adjacent to the well bore. In the Imperial Valley, it requires from 10 to 20 days for a well or test hole to reach equilibrium.

Terrestrial Heat Flow

The transmission of heat through a rock media is expressed in heat flow units (HFU). $1\text{HFU} = 1 \times 10^{-6} \text{ cal cm}^{-2} \text{ sec}^{-1}$.