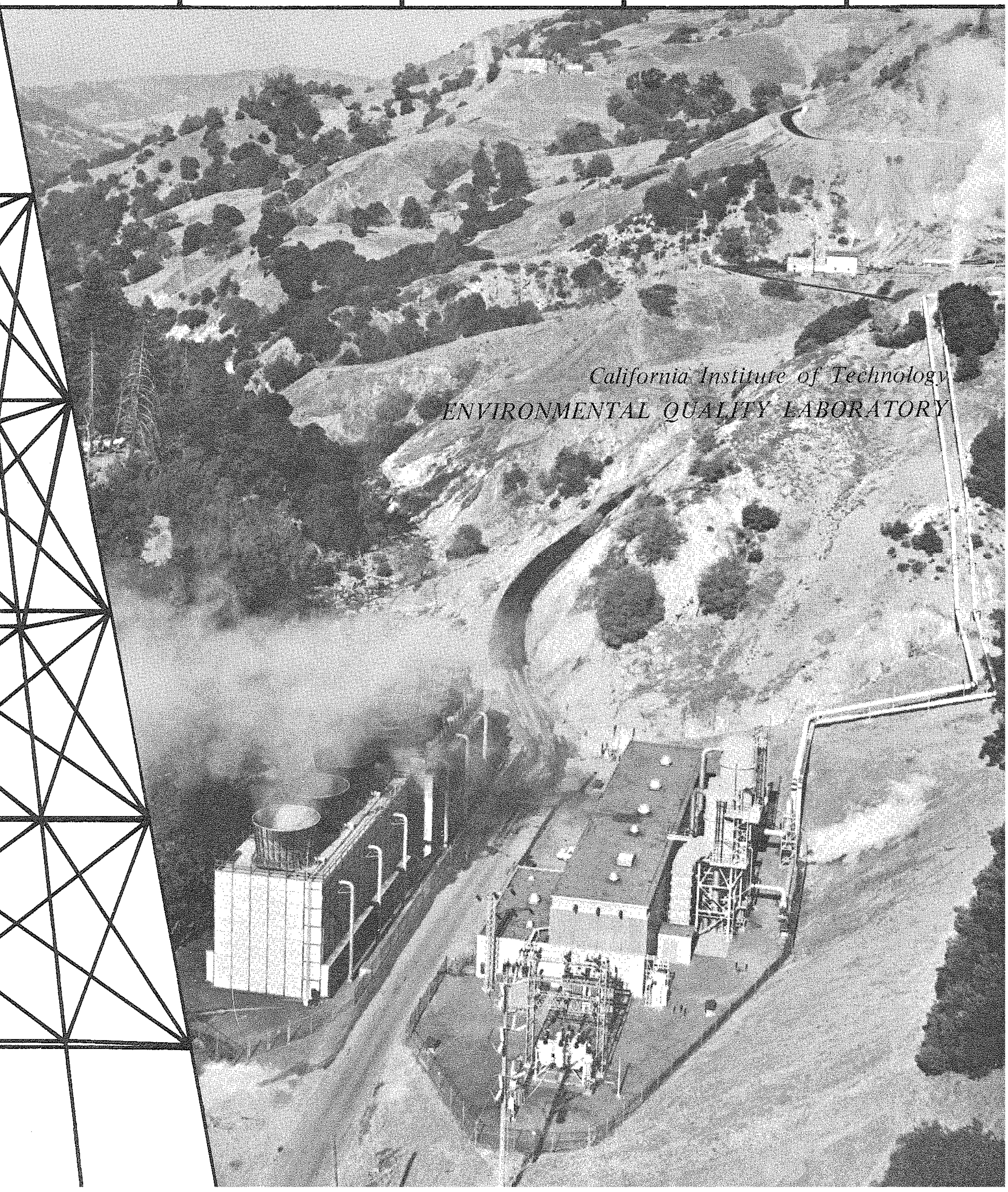
GEOTHERMAL RESOURCES IN CALIFORNIA POTENTIALS AND PROBLEMS

by M. Goldsmith

EQL Report No. 5



California Institute of Technology
ENVIRONMENTAL QUALITY LABORATORY

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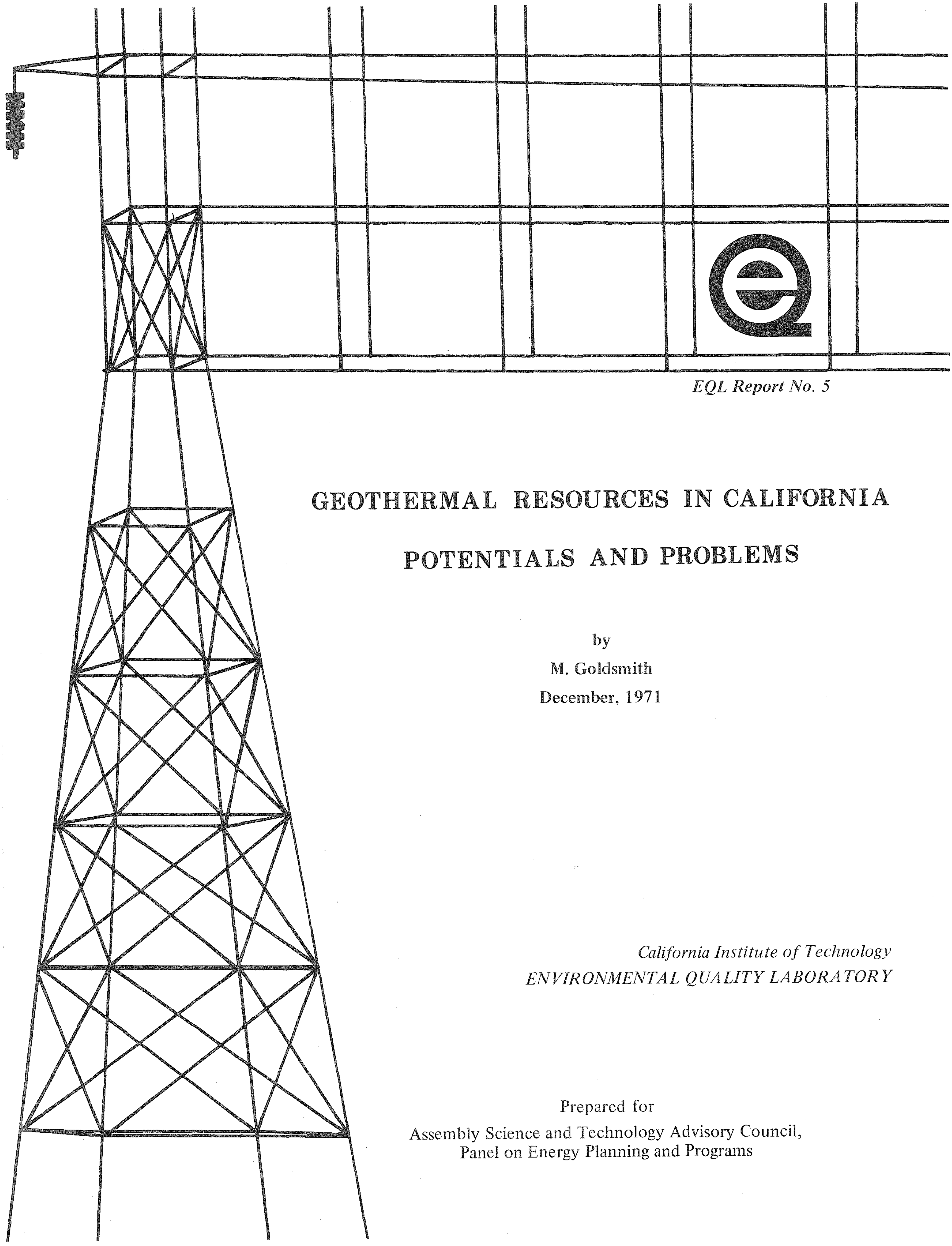

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December, 1971

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ENVIRONMENTAL QUALITY LABORATORY

Prepared for

Assembly Science and Technology Advisory Council,
Panel on Energy Planning and Programs

SUMMARY

The technology, cost and potential of geothermal resources in California are examined. The production of power from dry stream fields is expanding in Northern California, at The Geysers, at costs that compare favorably with alternate means of generation. The possibility exists that economic production of power can be started in the Imperial Valley, but numerous issues remain to be resolved; chief among them is the demonstration that commercially valuable aquifers indeed exist. The production of demineralized water from the geothermal fluids of the Imperial Valley depends, among other things, upon the identification of other sources of water for power plant cooling, or for reservoir reinjection, should it be necessary to avoid subsidence. It would appear that water production, without the income-producing capability of associated power generation, is not economically reasonable.

The pace of geothermal development at the Geysers could probably be accelerated perhaps offering PG&E the opportunity for maintenance of adequate generating reserves should their nuclear construction program be delayed.

The unknown factors and risks involved seem to preclude the Imperial Valley resource from being immediately effective in improving the power generation picture in Southern California. However, in the next decade, geothermal power could provide a useful energy increment, perhaps 10% of peak load. Associated water production could offer relief for the Imperial Valley in its predicted water quality problem.

The pace of public and private development in the Imperial Valley seems incommensurately slow in relation to the potential of the resource.

Geothermal power and water production is not intrinsically pollution-free, but appropriate environmental protection is possible.

GEOTHERMAL RESOURCES IN CALIFORNIA –

POTENTIALS AND PROBLEMS

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A. INTRODUCTION

In the past two years the subject of geothermal power has received increased publicity and attention in governmental and public circles. Owing to the limitations intrinsic to the popular press, the information usually reported is incomplete. Moreover, the thrust of the articles in many cases reflects the biases or interest of the author. For example, a person opposed to the further development of nuclear power will speak in most positive terms of geothermal electric power because it presents a seemingly viable alternative to nuclear development. On the other hand a person concerned with the availability of quality water in the Southwest will tend to emphasize the utility of geothermal resources for the production of high quality water. Other authors are anxious only to entertain, and thus emphasize the spectacular aspects of geothermal development. Additionally, many publications and documents have been written in the technical literature. These usually emphasize one aspect or another of the geothermal development representing the research interests of the author.

The purpose of the present document fits into neither of the two previous categories. This is not a report on a body of physical research that has been accomplished, nor is it intended to advocate one class of geothermal development or another. The present document is addressed to the interested non-specialists and will attempt to describe the nature of the geothermal resource, its extent, and the technology by which it can be exploited. With that background, hypothetical system developments are outlined and their virtues and problems are reviewed. The document attempts to assess the probable cost of electric power and pure water obtained from various types of geothermal areas, and a preliminary assessment of the possible environmental effects is made. Finally, considering the data available to us at this time, the potential of geothermal resources, particularly in the State of California, will be evaluated.

It is hoped that this review and appraisal of geothermal resources will better enable the public, and the executive and the legislative branches of government to perceive the potential role of geothermal power and to enable the government to better determine what its role should be in the development and control of the resource.

B. NATURE OF THE RESOURCE

Improved understanding of the basic forces at work within the earth is giving greater insight into the sources of geothermal energy. From earliest recorded times men have noticed at various places on the surface of the earth manifestations of heat coming from below. These manifestations have included geysers, flows of hot water from springs, or steam issuing from fissures in the earth. At some of these locations men have drilled wells in an effort to tap the resource for useful purposes. In a now increasing number of cases these efforts have met with success and useful quantities of hot steam or hot water are being obtained from the wells.

What is the source of the geothermal heat? It is known that, in general, as one penetrates more deeply into the earth, the temperature of the earth's materials increase. These temperatures are believed to reach very high values in the central part of the earth's interior. The source of this heat is presently thought to be the decay of radioactive elements over long periods of time, as well as frictional (tidal) forces. Studies have been made to see if a working fluid, such as water, could be heated by passing it down a hole drilled into warm regions of the earth, there to be heated and returned to the surface. The heat would then be used, say, for the production of electricity. Two such studies, (Ref. 1 and 2), indicate that it is not presently economically feasible to drill in an arbitrary area and obtain useful quantities of heat.

However, the earth's crust is made up of gigantic plates, of continental size, which move in relation to one another and have fissures between them. The hotter material from the interior of the earth rises in circulation patterns along the joints between these plates. Along uplifted areas, the earth's crust is thinner and it is fractured. Thus in these regions, the heat flow from the interior to the surface is substantially higher than average. This means that basement rocks in those areas are apt to be hotter than would be expected for materials at that depth in other parts of the world. One of these great rift areas is located in the eastern part of the Pacific Ocean and passes up the Gulf of California. In fact, the separation of Baja California from mainland Mexico is attributed to this rift separation between the continental plates. The continuation of this ocean rise is marked, in part at least, by the San Andreas fault zone. Many thermal anamolies are known to exist along this zone.

If water should flow underground through this heated zone, it will in turn become heated. In some areas, there is connection between the surface and these underground reservoirs and we note surface manifestations (e.g. geysers, hot springs) of the heated body below. It is in these areas that men have explored for geothermal resources. Until fairly recently it was commonly felt that these manifestations were to be found only along fracture zones and the bodies of water beneath the surface were very localized in nature. However, better understanding of the geologic conditions, and the recognition that some of the geothermal fields extended over areas much broader than localized fracture zones, has caused geologists to revise their theories about the nature of the geothermal reservoirs. Without entering into the details of the scientific facts or arguments, it suffices to say that it is now believed that in many cases geothermal reservoirs may extend over considerable areas and have substantial volume.

In the early days of oil exploration, men usually drilled where surface manifestations were present, but we now have elaborate and detailed theories and practices enabling us to find oil even under the bed of the sea. In the same way, geothermal resource exploration is in its early stages; thus attention is concentrated upon areas having surface manifestations. However, with the knowledge that has been gained in modern geology, progress is being made rapidly in devising methods to reveal the presence of geothermal resources where the surface is innocent of its appearance. A clear description of the elements of geothermal phenomona is given in Ref. 3. In Ref. 4 is given a description of how modern geological methods are being used to investigate geothermal resources.

Potential geothermal resources have been identified in many quarters of the world, and are already being exploited in many countries at this time. Electricity is being produced in the United States, Italy, New Zealand, Japan and other places. Additional plants are under construction. Hot geothermal water is being used to heat buildings or parts of cities, most notably in Iceland, but in numerous other locations as well. The question is not whether geothermal resources can be utilized, but rather to what extent and how soon and how widely.

When wells are drilled to tap the geothermal resource, one of several conditions are found. In some cases, the product is dry steam unaccompanied by liquid water. This is the case at one of the earliest of the geothermal steam fields, that of Lardarello in Italy. It is also the case of the Geysers steam field in northern California, which is currently being used to produce electricity by the Pacific Gas and Electric Company. In this case, the subterranean waters are flashed into steam by the hot rocks beneath the surface of the ground, forming a large steam reservoir, often at elevated pressure. This steam will then pass up the well and may be put to useful purpose at the surface.

In other cases, the geothermal wells encounter a reservoir of extremely hot water. Because of the depth and configuration of these reservoirs, the waters are usually found at high pressure. But the well, now open to the surface of the earth, can be used to relieve the pressure on part of the water reservoir. When the pressure is reduced on the very hot water, part of it is evaporated into steam. The steam, in evaporating and expanding, will try to rush up the well pipe and in so doing will entrain a substantial amount of the water. In this case, a flow of mixed steam and water will emerge from the well head, still at a very high temperature although somewhat cooled because of the boiling and expansion process that occurs during the flow through the well. The action in appearance is very similar to that seen in a coffee percolator, where the bubbles of steam drive the flow of water before them. At the well-head, the steam and water may be separated by a simple centrifugal device, sometimes called a cyclone separator. The mixture passes into the separator, which produces water from one pipe, and steam from another. Because the steam and the water are in thermodynamic equilibrium, i.e., both are at the same temperature and pressure, this steam is called saturated. This class of geothermal resource has been found in New Zealand, in Mexico, in the Imperial Valley and other places.

The nature of the water in the subterranean reservoir differs however. In New Zealand the waters have a very low mineral content. There the steam is used to produce electricity, and the water is simply allowed to flow into the sea. New Zealand is an area of abundant rainfall and the geothermal waters are of small value. The geothermal waters found in the Imperial Valley near the Salton Sea, for example, (at the area called Buttes) are of the opposite extreme. Their dissolved mineral content is extremely high, up to 30% by weight. This should be compared to sea water whose concentration of dissolved minerals is about 3.3%. Because of the high mineral content, the steam that is obtained from these wells is corrosive and has proven very difficult to use in electric generating equipment, in small-scale experiments. However, the prime purpose of the Buttes development was to obtain chemicals from the highly saline brines. This remains one of the possible objectives of geothermal resource development, that of obtaining chemicals from the geothermal waters as a prime product or as a by-product from other processes.

Still a different type of water is found at the Cerro Prieto region in northern Baja California. There the waters in the underground reservoir are neither fresh nor highly concentrated in salts. The geothermal water at Cerro Prieto contains approximately 2-1/2% dissolved minerals. This is far too saline for use as potable water or for irrigation purposes, but it is reasonable enough in its properties that the steam obtained from the wells is capable of being used in electric generating equipment. At this time the Mexican government is engaged in the construction of a 75 megawatt electric power plant to use the steam obtained from the Cerro Prieto field.

In the general case, the water that also flows from the separator at the well head is hot, as previously noted. While the steam might be used to generate electricity or for other purposes, the water is not without value. In some cases, of course, it would simply be wasted to the ocean or reinjected into the ground for disposal. As noted, it might also be exploited for its mineral content. Serious consideration has been given to running such water through a desalting plant in order to rid it of its dissolved minerals, thus producing fresh water suitable for agricultural, municipal, or industrial purposes. This is particularly true in the Imperial Valley and other naturally arid areas of the Western United States. It has not yet been found economically desirable to produce fresh water via the desalting process from sea water in California. But because the geothermal waters are already heated, it may be possible to desalt them more cheaply than sea water and thus they might form a valuable resource. The technology and costs of such processes will be considered in later sections of this document.

One thing is certain however. The separated water, if not used, considering its chemical content, cannot be permitted to enter surface streams or shallow aquifers where it might mix with other water supplies. Either a conveyance system must be provided to transport it to the ocean (if this is found permissible) or it must be injected deep into the ground, probably near the level of the producing zone.

In summary then, the nature of the geothermal resource manifests itself in two forms: one, dry steam, and the other very hot water in the ground. In the latter case, the water could be pumped from the well without permitting the pressure to drop, thereby preventing formation of steam. On the other hand, the pressure can be reduced permitting the steam to flash from the water and the mixture to flow from the well where it may then be separated. The case of the underground water reservoir may be further subdivided into fresh, highly mineralized, and intermediately brackish types. This division reflects the utility of the resource and the technical problems to be expected in its use.

C. EXTENT OF RESOURCE.

Several reports have recently been issued that delineate the known geothermal resource areas of the State of California. The data have been accumulated by State and Federal agencies and are published in various forms. The known geothermal resource areas delineated by the United States Geological Survey have been published in the Federal Register and were reprinted by the State of California in a special issue of *Geothermal Hotline* published in July, 1971 (Ref. 5). The total California acreage so delineated amounts to over one million acres, but it should not be assumed that all of these acres embody proven resources. In the report, "Economic Potential of Geothermal Resources in California", issued by the Geothermal Resources Board of the State (Ref. 6), a listing of known geothermal areas in California was included. The State document divided the areas into categories such as those producing power, significant discoveries, potentially significant, and other areas. Other areas include, for example, the various hot springs locations in the State. Potentially significant areas include those where it is strongly suspected that significant geothermal resources exist but where detailed exploration has not taken place. Without extensive exploration it is not possible to make any estimates of the potential value of these areas.

Three areas within the State have received most recent attention and will be discussed in the present document. The first of these is The Geysers area which presently is being exploited for electric power. The second is the Imperial County area which is known to contain significant resources but which has not yet been successfully exploited commercially. The third area is the Mono Lake-Casa Diablo region which, again, has not been exploited commercially.

The Geysers – An excellent review of the history and status of The Geysers field is contained in Ref. 7. At The Geysers, a group of steam-producing companies, headed by the Union Oil Company, drill for and produce steam which is sold to the Pacific Gas & Electric Company. The utility uses the steam to produce electricity and reimburses the steam producers on the basis of kilowatt hours of electricity produced. The first generating unit, Geysers No. 1, went on the line September 1960. It is able to produce twelve megawatts on a continuous basis. This original experimental commercial unit was successful, and through the 1960's PG&E increased its producing capacity until in 1968 a capacity of 83 megawatts was achieved at Geysers. Four separate generating units were used. In 1971, 5 and 6 went on the line with 55 megawatts each. Thus, the total capacity at The Geysers is presently 193 megawatts. PG&E has announced its intention to increase the capacity at The Geysers by approximately 110 megawatts each year until a total of about 600 megawatts is reached. In Ref. 8, PG&E lists their intended increase in total generating capacity for the balance of this decade. Geysers 7 and 8 are listed for 1972, 9 and 10 for 1973, 11 and 12 for 1974, and 13 and 14 for 1975. At that time an installed capacity of over 600 megawatts would be available at The Geysers. An additional 8 geothermal generating units of 53 megawatts capacity each are listed as coming into service through 1979. It is assumed that they would be in the general vicinity of The Geysers field. Thus, in 1979 PG&E intends that 1,000 megawatts, approximately the equivalent of a single modern nuclear power plant unit, would be installed in its system. Statements of PG&E and oil company personnel indicate that the capacity of The Geysers field is at least 1,000 megawatts. In Ref. 6 it is reported that the area of the known steam reservoir is greater than ten square miles and may be as large as twenty square miles. Further exploration may indicate that even this estimate is conservative. At the present time the steam wells are spaced at approximately one per forty acres (recent wells average about 8 MW electrical production each) and some estimates have been made that a spacing of one well for twenty acres may be possible without mutual interference effects. However, interference has been noted in earlier, shallow holes, and conservative estimates would indicate that the greater spacing will continue to be required for all holes.

Thus the present estimate of one thousand megawatts might increase by four fold and the capacity of The Geysers may be as much as four thousand megawatts. The present conservative estimate remains at 1000 MW. Several producers and potential producers are intensively exploring The Geysers area and it is anticipated that the true extent of the field may be more accurately known within the next several years. Additional areas in the vicinity of The Geysers show positive indications of geothermal activity, and continued exploration may verify still further producing areas.

Production at The Geysers consists of dry, slightly super-heated steam, without flow of water from the wells. The steam so produced is collected and passed to the steam generating stations where it is subsequently condensed after passing through the turbine. The resulting water is evaporated in the cooling towers and only a small residual fraction is reinjected into the Earth. Fresh water supply is not a problem in that geographical area. Thus there has been no interest in the production of water using the geothermal resource. Likewise, no minerals are produced by the wells and the operation is strictly one of electric power production. Still in question is the total amount of time that production may be maintained from The Geysers field. Certain shallower aquifers that were tapped in early development have been shown to suffer a depletion with time, and now the deeper producing regions presently being used are beginning to show such depletion and at this time the eventual production capacity is uncertain. For fiscal purposes, the PG&E Company is amortizing their investment over a period of thirty-five years.

Imperial Valley – The second area in California that has received intensive attention is the Imperial Valley. Near the Southeast shore of the Salton Sea, surface manifestations such as fumeroles and mudpots had been noted. In 1927, a well was drilled in that area but it was found that the steam encountered was insufficient to produce power on a commercial basis. However, carbon dioxide gases from the field were used for dry ice production for many years, until flooded out by the increasing level of the Salton Sea. The Imperial Valley has also been explored for oil and in 1957, an exploratory oil well was drilled nearby and encountered hot brine at depths near 5,000 feet. While no oil or gas was discovered, interest was reborn in the exploitation of geothermal resources. Subsequently, additional wells were drilled in the general area known as the Buttes field; a number of these wells were intended for production of minerals from the highly saline brine.

In this area the wells encounter very hot water at depth, which then flashes into a mixture of steam and water as it flows up the well pipe. The percentage of minerals in the water amounts to as much as 25 to 30% by weight. A detailed account of the drilling problems involved in this area is in Ref. 9 by Carel Otte of the Union Oil Company, and a summary of the mineral production situation is given in Ref. 10 by the Morton Salt Company. In spite of the fact that many millions of dollars were invested in well drilling and production equipment, changes in the price structure of chemicals such as potash prevented the successful economic exploitation of the mineral resource. Experiments at producing electric power using steam from these wells were unsuccessful due to the highly corrosive nature of the mineralized brine. Because of this history, further exploration for geothermal resources in the Imperial Valley was inhibited for a number of years. While large quantities of water were obviously present, and heated to high temperatures, the mineral content of the water seemed an insurmountable obstacle to successful commercial exploitation.

About 20 miles south of the international border in the Mexicali Valley, near the volcano of Cerro Prieto, is a steam field currently being prepared by the Mexican government for the production of electricity. Surface manifestations of geothermal activity had been noted by Mexican geologists, and drilling in the area was begun in the 1960's. Commercially exploitable steam and water at high temperature was found at depths of less than 2000 feet. From 1964 onward, production wells were drilled and by 1971 more than 16 producing wells have been installed. Production depths vary, but average about 4500 feet. A typical well will produce 450,000 lbs/hour of steam and water mixture. Approximately 2.75 pounds of water for each pound of steam are produced and the enthalpy of the mixtures varies between 400 and 600 B.T.U./lb. The maximum temperature at depth is 700° F and pressures range up to 1700 psi gauge (Ref. 11). At this time the Mexican government is installing a power plant of 75 megawatts capacity to use the steam that will be produced from this field. The size of the known field approximates 4 square miles (Ref. 3). The Mexican wells are in clusters with spacing between adjacent wells that would correspond to 10 acres per producing well. If the entire 4 square mile field were filled in, as is not presently the case, approximately 250 wells would be installed. If the present average steam production per well was maintained, 120,000 lbs/hr, the capacity of the field is then calculated to be about 1500 megawatts of electrical production. The water that is found at the producing depths at Cerro Prieto is saline in character with approximately 2-1/2% total mineral content. While far too salty for any direct consumptive use, it is an order of magnitude less mineralized than the water found at the Salton Sea area in Imperial Valley.

These facts have served to stimulate further intensive exploration of the geothermal potential of the Imperial Valley area lying away from the Salton Sea, between that body and the Mexican border. Much of this investigation has been carried out by Dr. Robert Rex and his group at the University of California, Riverside. In Ref. 12, Rex points out that the Buttes area has two separate types of geothermal brines beneath it, the deeper being the very hot, hyper-saline brine, while a cooler, less saline brine lies above it. Review of geological and well drilling data indicates that the contact line between these brines dips to the South. Thus, at what would be useful producing depths of perhaps 5,000 feet in the southerly reaches of the Imperial Valley, Rex expects that the less saline brines, similar to those found in the Cerro Prieto field, would be found. The depth of basement in the Imperial Valley is very great, perhaps 20,000 feet, and the basin is considered to be filled with porous, sedimentary formations. In Ref. 13, Rex has estimated the total volume of water contained in the Imperial Valley basin and his estimates indicated that over a billion acre-feet of water are contained in the reservoirs using what he feels to be are conservative assumptions. Less conservative assumptions lead to estimates ranging up to nearly 5 billion acre feet of water. The origin of this water is considered to be meteoric (originating from rainfall), coming from the Colorado River system.

However, simply having a body of water in the ground is not sufficient to provide an exploitable geothermal resource. The water body must be heated, at least in some places. The UCR and the Bureau of Reclamation exploration programs in the area have been directed at the identification of thermal anomalies, that is, areas where the heat flow from the interior of the earth is substantially higher than normal. Modern geophysical exploration methods have been used to conduct these investigations. Gravity measurements, resistivity measurements, as well as shallow drill holes, have been used to produce plots of thermal anomalies. The current status of these investigations has been summarized in Ref. 3. Geophysical surveys have been made of the Imperial Valley area and the heat flows, in the form of thermal gradients, have been measured or estimated.

The methodology that has been used by Rex to determine the total potential of the geothermal resource is straight-forward. He has assumed that any area having a temperature gradient of greater than 6 - 8° F per hundred foot depth represents an area of useful economic potential. This value is chosen on the consideration that for an economic operation, water approximately 600°F or greater should be found at depths of less than 8,000 feet, which represents a limit observed at Buttes and Cerro Prieto for commercial production. The measurements indicate that perhaps 100,000 acres of land lie within these high heat flow anomaly areas. Rex's calculations have assumed that 30 acres per producing well are required. This is contrasted to the Mexican practice where substantially closer well spacing has been employed in the well clusters. If it is assumed that each well is capable of producing 10 megawatts of electricity, one is quickly lead to the conclusion that approximately 30,000 megawatts of electrical potential exists in the Imperial Valley. The 10 megawatt value corresponds to approximately 200,000 lbs/hr of well flow steam and is in excess of that experienced in the Mexican wells where somewhat smaller well diameters are employed as compared to those that would be anticipated for U.S. use. However, formation permeability may be limiting, and these estimates may be optimistic.

It is necessary to view these numbers with caution, however. Until deep exploratory wells are drilled it cannot be certain that these anomalous areas of apparent high thermal gradient indeed extend into producing aquifers or that the water-bearing formations, if actually found, will be capable of producing water through the wells.

At the present time, the majority of public support for geothermal exploration in the Imperial Valley area comes from the Bureau of Reclamation. Funding limitations presently control the pace and scope of the exploratory program. It is anticipated, however, that at least one deep well will be drilled in fiscal year 1972. This will be drilled on Federal lands in the East Mesa area of the Imperial Valley. Because this is a non-agricultural area on Federal lands, problems of potential land subsidence, waste water disposal and other environmental effects are mitigated, making the area more suitable for early exploration.

Mono Lake. Geothermal manifestations have also been noted in the Mono Lake-Long Valley-Casa Diablo area of the Eastern Sierra Nevada regions of California. Shallow wells have been drilled in the Casa Diablo area and hot water was discovered. No commercial exploitation has been carried out. At least one deep well has been drilled in the Mono Lake area by the Southern California Edison Company and its cooperating associates. The well drilled in September of 1971 was found to be both dry and cold. (Ref. 14) Additional holes will be drilled in the immediate future. The potential of this area cannot be assessed at this time.

D. TECHNOLOGY OF EXPLOITATION.

The means by which the geothermal resources are utilized will depend first on the nature of the resource, that is, whether the fluids obtained from the ground are dry steam or a mixture of steam and water. Likewise, the relative values placed on electric power or distilled water will determine which product is to be emphasized and what methods will be used to produce them. Because all of these processes are thermo dynamic in nature, it is required that some form of cooling be utilized. Again, the means of cooling will depend on products desired and on the availability of cooling media, such as local water. This section describes the equipments that are necessary and available for use in geothermal processes.

Dry Steam. Dry steam could be utilized to produce either electric power or to act as the heat source of a desalting plant. The desalting plant would be fed by local waters or sea water. Known dry steam resources in California, however, occur in regions where water is not in short supply. Therefore, it is not considered worthwhile to use geothermal dry steam for the production of water, although the technology is straight-forward. In this case, ordinary desalting plants, as constructed for use with the available feed waters, would simply use the geothermal steam rather than steam generated from another source, such as an oil-fired boiler or low pressure exhaust steam from an electric power plant.

The means of using dry geothermal steam to generate electric power is likewise straight-forward. The steam is usually available at the well head at low pressure as compared to that usually used in fossil or nuclear-powered electric plants. The steam itself seems to require no special treatment except filtering to be sure that no abrasive particles are entrained in the steam and pass through the turbine. This is usually accomplished with rather simple particle collectors.

Because of the low pressure of the feed steam, the turbines themselves differ in design from standard modern power plant practice. For a given power output, the throttling valves, for example, are much larger in size. Likewise, high pressure stages in the turbine are absent. For a given power output, the turbine using geothermal steam is substantially larger than one designed to use high pressure steam; however, the general appearance of the geothermal turbine is that of the low pressure sections of conventional turbines. The largest parts of the turbines are the lowest pressure stages and the exhaust steam piping. Because geothermal steam is low pressure, a great deal more steam is required to produce electricity as compared to a conventional plant. Therefore, for a given output, the exit sections of the turbine may be substantially larger than for conventional practice. This is also influenced by the design back-pressure of the turbine. We should not then expect that the maximum output of geothermal turbines will approach the maximum production of turbines used in conventional plants. While the largest steam turbines presently in use today approximate 1000 megawatts in size, the largest geothermal turbines presently in use are 55 megawatts in size. Designs are available for units of up to 130 MW (Ref. 15).

The steam is expanded through the turbine thereby turning a conventional electric generator. Several means of disposal of the steam passing out of the turbine can be envisioned. The simplest would be simply to discharge into the atmosphere at atmospheric pressure. However, in conventional fossil and nuclear power plants the steam is invariably discharged to a condenser at a pressure very much lower than atmospheric. While condensers are expensive, power plant cost-effectiveness analysis always indicates that it is better to use the condenser, thus extracting greater energy from the turbine, rather than to waste the steam to atmosphere. The same is true for analyses performed on geothermal plants. Therefore the steam will be discharged to a condenser, of which there are several types. A condenser is nothing more than a heat exchanger which condenses the steam into water, which may then be pumped to atmospheric pressure and disposed of, or in conventional plants, returned to the boiler. In the process of condensing the steam, a great deal of heat is released. This heat must be transferred to the atmosphere or some cooling medium. In many cases ocean water, lake water, or water from rivers is passed through the condenser and used to remove the heat. In other cases, a recirculating supply of cooling water passes through the condenser and then to a cooling tower where the heat is rejected to the atmosphere. Aspects of cooling that are pertinent to the geothermal power and water cycle will be discussed in a later part of this section. Thus, it can be seen that the production of electric power from dry geothermal steam is a straightforward engineering problem and has been met successfully, for example, at The Geysers in Northern California as well as other locations in the world.

Power Production from Geothermal Water – As previously explained, if the geothermal resource consists of water at high pressure and temperature deep in the ground, relief of that pressure through the well pipe will cause some of the water to flash into steam and start to drive up the pipe in the manner of a percolator. The steam and entrained water will therefore flow from the well head as a mixture and can then be separated into the steam and water components. This separation process will be caused to occur at some elevated pressure. The steam so produced may then be transported through pipes to a power plant using conventional steam turbine equipment. Here again, the steam pressure is low as compared to conventional fossil and nuclear steam power equipment. This geothermal steam is then expanded through the turbine and into a condenser as previously discussed.

The water that was separated from the steam may be flashed again at a lower pressure producing some additional steam at a pressure intermediate between the first separation and the pressure found in the condenser. This additional steam may be introduced into a low-pressure section of the power turbine, thus increasing the total power output. The residual geothermal water may then be used for desalting purposes, process heating, chemical production or otherwise disposed of. The problem of disposition of geothermal waters will be treated in a later part of this section. A sketch of such a power plant is shown in Plate 1.

Desalination of Geothermal Water – The product of geothermal wells can be used to produce pure water. (If, of course, the geothermal waters are themselves pure, no further treatment is required. It is not expected that this will usually be the case in California.) For discussion, let us assume that the water that has come from the geothermal well, mixed with steam, has been separated into its steam and water components. In the case most often considered, the steam is drawn off to operate a power plant. The water remaining is then introduced into a desalting plant. Desalting is accomplished in one of several ways, among which are membrane processes, distillation processes, and others. Processes such as reverse osmosis do not employ heat as a driving mechanism, and thus the heat that is available in our geothermal brines is of no advantage. Thus, it is usually considered that one of the distillation processes would be used for the desalting of geothermal water. The distillation processes involve the evaporation of part of the feed water and the subsequent condensation of the vapors into pure distilled water. The remainder of the feed stock is either further evaporated and distilled or returned to waste. This is the process commonly associated with the desalting of sea water. A sketch is shown in Plate 2.

The geothermal situation is unique in that the feed waters are already heated. One of the major operating expenses of a conventional desalting plant is supplying the heat to the water. Because this heat is expensive, conventional plants are carefully optimized to maximize the use of the heat. The water is heated and then as it evaporates and is cooled, it passes to subsequent evaporation sections. The coolant used for the condensing of vapors is actually feed water at a lower temperature. Thus the reject heat of one distillation section is used for the heating of another. In the geothermal case, some of this "regenerative" effect will not be required and thus will lead to simpler plant designs. In conventional desalting practice careful trade-offs are made between the cost of energy used and the capital costs of the equipment. Because higher capital costs are required for greater efficiency, these two factors will combine to display an optimum operating condition and design. The same factors apply in the geothermal case. That is, the cost of producing the geothermal waters with their concomitant heat will be balanced against the greater capital cost of using the resource more efficiently. It is expected, however, in the geothermal case that the optimum point will occur for plants of lesser efficiency, although this point has yet to be clearly established.

In the final sections of the geothermal distillation plant, some heat must be rejected either to the atmosphere or some other cooling medium. After much of the water has been removed from the original geothermal brine, the remaining fluid is greatly concentrated and will be disposed of from the plant. This residual brine is called blowdown. In the case of the power plant, the geothermal steam entering is turned into condensate, reject heat, and electricity. In the case of the desalting plant, the intake geothermal fluids are turned into fresh water, blow-down brine and reject heat.

As was pointed out in the first part of this section, the steam that is separated at the head of the geothermal well can also be used to power a desalting plant using feedwaters other than geothermal. Thus it would be quite possible to use the separated geothermal waters in one desalting plant and the geothermal steam in another plant to desalt local contaminated feedwaters.

Electric Power-Closed Cycle Design – It has already been pointed out that in geothermal water wells, the water will flash into a mixture of steam and liquid in passing up the well. In so doing, considerable energy is given up by the geothermal water in propelling itself and evaporating. Another means exists of exploiting the thermal energy. This is to maintain a high pressure on the geothermal water in the well and to pump it out of the well as high temperature water.

In general, it will be necessary for these pumps to be in the well itself. (It should be recognized that it will require substantial power from the power plant to operate such pumps. Therefore, a careful trade-off is needed to determine if it is more efficient to use electric power in this fashion or whether one should simply accept the thermodynamic penalty of having the water propel itself up the pipe by the 'percolator' method.) The hot water then flows from the well at high pressure and is passed through a heat exchanger. Here a part of its heat is transferred to a working fluid which might be water or some other substance. It has been proposed (Ref. 16 and 17) to use isobutane or other organic substances commonly used as refrigerants for this purpose. The geothermal water, now cooled, is returned to the earth through injection wells or otherwise disposed of. The heat exchanger acts as a boiler for the working fluid, which is evaporated and passed through a power turbine to generate electricity. The fluid is then condensed in a condenser and the working fluid, now once again liquid, is pumped to a high pressure and again run through the heat exchanger. This is exactly the fashion in which either a conventional fossil-fired steam boiler or a nuclear power plant operate. The condenser of course must be cooled with atmospheric air or outside water. In Ref. 18 a preliminary design for such a power plant is given. One motivation mentioned for using this cycle is to avoid the deposition of carbonates resulting when some geothermal waters are permitted to flash. The cycle does not avoid the depositions that are possible when saturated solutions of such materials as silica (which comes out of solution upon cooling) are cooled in the heat exchanger. The plant design specifically excludes consideration of the geothermal water supply. Deep well pumps would be required in most areas. No electrically driven pumps are available that can operate where water must be taken from depths of over about 1000 ft. At shallow depths, it is unlikely that sufficiently hot water will be found in most known geothermal areas. It may be found in some areas that waters will rise naturally from greater depth and may be pumped, while a pressure sufficient to preclude flashing is maintained in the well. The Magma Power Company is actively exploring the technology of this method. While the system offers many potential advantages, it is as yet in early development, and firm cost and performance estimates are impossible to make.

Cooling – In each of the power and water production methods discussed it is seen that a means of cooling the plant is required. This is a fundamental requirement of closed thermodynamic cycles and is accomplished in various ways. Generally, one of three types of cooling methods is used. The first is to use the atmosphere as coolant, much as an automobile radiator is cooled by the air. Here in a power plant or water plant, the equivalent of the automobile radiator will have atmospheric air passed through it, thereby heating the air and cooling the fluid within the radiator. Such devices are usually referred to as dry cooling towers. In this case, no water is evaporated into the air and the performance of the cooling tower is a function of the temperature of the air as it is usually measured.

It is also possible to reject heat into the atmosphere using the wet cooling tower. In a wet cooling tower, coolant is circulated through lattice-like construction so that a flow of atmospheric air passes over the fluid droplets. The liquid is cooled by heat transferred to the air directly and by evaporation into the air. Such cooling towers involve a very substantial consumption of water, but, on the other hand, are more efficient than dry cooling towers both in their cost and their cooling capability.

Both classes of cooling tower may be divided into two types. One is the type that uses large fans to force the flow of atmospheric air through the tower (forced draft). The other type (natural draft) relies on the heating of a column of air to cause the air to flow by natural convection, much as hot air flows up a chimney. At The Geysers, forced draft wet cooling towers are used. At the Sacramento Municipal Utility District Rancho Seco nuclear power station, natural draft wet towers will be installed.

Still another method of cooling is to use a source of outside water such as the ocean, river, lake or cooling pond and pass that cool water directly through the condenser and discharge it, heated to some extent, to the body of water from which it came. This is generally the least expensive and most efficient of all cooling methods. However, it is sometimes not possible to utilize it, either because of shortage of water for such purposes or because of the environmental effects of the discharge of such heated waters into the lake or river.

E. SYSTEM SYNTHESIS AND COST.

Power from Dry Steam – This system is relatively well understood, in particular owing to The Geysers experience. No other dry steam field is known in California. At The Geysers, conventional oil field drilling methods are used. In the producing zones, however, compressed air must be substitute for drilling mud. After simple filters are used to remove particulate matter from the well-head steam, the steam passes through insulated pipes to a power plant. The wells vary in their output, but recent deeper wells (Ref. 7) here averaged 8 MW electrical capacity, and a single recent hole is reported to yield 20 MW equivalent.

Pacific Gas and Electric Company buys steam from the producers at the power plant. Conventional condensing turbines are used to drive the generators. The design of these turbines is adjusted to account for the comparatively low temperature and pressure of the geothermal steam. For example, Geysers No. 5 uses steam at 100 psi and 355°F. This can be contrasted to PG&E's Moss Landing fossil plant, which uses steam at 3675 psi and 1000°F. The lower temperatures and pressures lead to lower efficiency, thus geothermal plants consume steam at two to three times the rate of conventional plants. After passing through the turbine, the steam is condensed in a contact condenser. Here the cooling water is mixed with the steam, thereby condensing it. The liquid, coolant and condensate, is them pumped out of the condenser, which operates at vacuum conditions (4" Hg abs), to the forced draft cooling tower. Most of the water condensed from the steam is evaporated by the cooling tower. However, a fraction averaging about 20% (the exact amount depending on the weather) is not, and constitutes tower blow-down. This water contains traces of boron and ammonia, and is not suitable for disposition in the local creeks. Therefore it is delivered back to the steam producer, who disposes of it in injection wells.

The Geysers units being installed (5, 6, 7, 8) are purchased from Toshiba, a Japanese manufacturer, which is also supplying equipment for the Cerro Prieto installation. They are 55 MW capacity each. The size is limited both by transportation difficulties into the area, and by the economical length of steam lines between the wells and the plant. The various units (1, 2) (3, 4) (5, 6) (7, 8) (9, 10) at The Geysers are scattered through the producing area.

Much interesting and useful information concerning the financial and scheduling aspects of The Geysers power plants is contained in PG&E's application to the California Public Utilities Commission for a Certificate of Public Convenience and Necessity for Geysers 9 and 10 (Ref. 19). For example, it is shown that, for this field where circumstances are well understood, a period of only 28 months is required from approval and equipment purchase confirmation to commercial service. The cost breakout is illustrative of several important points.

Land and Land Rights		----------------
*Boiler Plant Equipment		456,000
Structures and Improvements		$ 1,997,000
Turbogenerator Unit		6,191,000
Accessory Electrical Equipment		1,000,000
Miscellaneous Power Plant Equipment		130,000
Communication Equipment		6,000
Engineering, Superintendance		716,000
Construction Plant, Warehouse		81,000
Overhead Construction Cost		1,770,000
	TOTAL	$12,347,000

* Authors note: this refers to steam handling equipment; there is no boiler.

These costs do not reflect sub-stations, transmission lines, or the cost of steam production and transportation. Thus a cost of over $100/kw capacity is involved in the power-plant alone.

In the application, PG&E goes on to estimate the total cost of delivered power to their distribution system. Fixed charges include return and depreciation on the investment, taxes, maintenance, and amount to $2,025,000/year for the two units. With an 80% capacity factor, which is not unreasonable considering the experience at The Geysers, and using a cost for steam of 2.1 mills/kw-hr (plus 0.5 mill for effluent disposal) the total cost of electricity produced is 5.33 mills. In Ref. 7 it is noted that in 1968, the average cost of thermally generated power in California was around 7 mills.

Viewed in another fashion, the per megawatt investment in a Geysers geothermal plant is substantially less than that for a modern fossil plant (whose costs are increasing, in part as a consequence of pollution control equipment) and whose fuel (steam) and operating costs (Ref. 7) are about 85% of those for a modern fossil plant. Thus, conservatively, one can say that for the situation at The Geysers, geothermally produced electricity is somewhat cheaper than that available from fossil plants, and is produced without significant insult to the environment, except possibly in the immediate vicinity.

New nuclear plants are costing in excess of $300/kw, and cost of the nuclear fuel cycle is above 2 mills/kw-hr (projected into the 1970's) (Ref. 20). Thus it appears that geothermal power will be cheaper to produce than nuclear power also, for conditions as at The Geysers.

Power from Flashed Steam – This is the case where a mixture of steam and water flows from the well, as at Cerro Prieto, and as is expected in the Imperial Valley. The two are separated at a well head pressure which, for purposes of calculation, is assumed to be about 125 psi. Selection of optimum operating pressure will depend on the specific characteristics of the steam wells and generating equipment. To date, turbine inlet pressures of 100 psi or less have been chosen by the operators.

The steam flows to a power plant which need not vary in significant detail from those at The Geysers. Thus power generating costs should be essentially equivalent. The differences will occur in the cost of producing the steam, and disposing of the separated water. Without directly applicable experience in the U.S. it would be necessary to estimate such costs from the basic elements. This is often a low-confidence method, as many costly elements are commonly omitted when considering a new technology. Therefore comparative cost estimates will be made. For example, owing to the water disposal problem, it is almost certain that steam costs will exceed those at The Geysers area.

Having no data for wells in the Imperial Valley other than those in the hyper-saline Buttes area, it is necessary to examine the Mexican experience at Cerro Prieto. There is probably no good way to convert a cost value from a government-sponsered Mexican activity to a private development in the U.S. (The data available indicated (Ref. 21) that the cost of the project is $10 million. It is not clear what fraction of the total well field development is included.) The technical information is useful, however.

About half of the present Cerro Prieto wells use 7-5/8" casing, and the others use 11-3/4" casing. The average production of steam is 120,000 lb/hr. The larger casing might flow 200,000 lb/hr. if reservoir permeability is adequate. Still larger production casings do not seem feasible for deep geothermal wells, according to producing company technicians. It is reported that 2.75 lbs water is produced for each pound of steam. For the assumption of 200,000 lb/hr. steam flow, each U.S. well would produce 550,000 lb/hr. of water. Typical geothermal power-plant steam rates (e.g., The Geysers and Cerro Prieto) range from 16.5 to 18.5 lb/kw-hr. For planning purposes a rate of 20 lb/kw-hr. might be assumed. Thus, the typical U.S. well might produce 10 MW of electricity, and 200,000 lb/hr. of condensate and

550,000 lb/hr. of saline water at a temperature of over 300°F. In following sections the disposition of the water will be discussed.

First, it is noted that the net power produced from these hypothetical wells is approximately that known for the recent wells at The Geysers. All other conditions being equal (drilling difficulty, depth, etc.) the cost of steam in Imperial Valley might be the same as the The Geysers, but increased by the amount necessary to reinject or otherwise dispose of the separated saline water. Unfortunately, as with production wells, re-injection wells will vary in capability and cost according to circumstances. As noted above, a typical steam well may produce 550,000 lb/hr. of water. This is equal to 1.6 million gallons per day, or 4.9 acre-ft.

Deep-well injection is a common method for the disposal of oil field brine and industrial wastes. A summary of technology and costs was prepared for the Office of Saline Water (Ref. 22). Water pre-treatment is a key item of expense in many cases, but for geothermal brines perhaps only settling of precipitated minerals will be required. The lowest value suggested for reinjection in the reference is about 20 cents/1000 gallons. If this were to be the case, reinjection will add 1.3 mills/kw-hr to the price of electricity. Clearly reinjection has the potential for being a major cost element in electrical production in the Imperial Valley. No detailed estimates have been made for the disposition of geothermal waste water by transporting it away. However, in Ref. 27, estimates were made for a pipeline/canal system to carry Salton Sea water to the Gulf of California. The capital cost for a line of 500,000 acre-ft./year capacity was estimated at about $60 million. Pumping cost was estimated to be over $3 million annually. For private capital, a total cost in excess of $20/acre-ft. is indicated, less than the cost associated above with re-injection, but it should be remembered that this canal would require right-of-way across Mexican territory.

A method exists for improving the performance of this power cycle. The separated water may be flashed again at a lower pressure, for example, 50 psi. In this case, about 5% of the residual water flashes into steam. This steam is then added to the turbine, increasing flow in the low pressure stages by about 14%. Simple thermodynamic calculations, assuming 90% efficiency of expansion, indicate that turbine output is increased by 11% with this modification. Only a careful plant optimization will enable all factors to be weighed in deciding on the desirability of such a cycle. The study can only be accomplished when firm steam data and design information are in hand.

Power and Water from Flashed Steam – In the cases already considered, the water condensed from the steam used to generate power was assumed to be largely evaporated in the cooling tower. At The Geysers, it has been noted that 80% of the water is so consumed. In the arid Imperial Valley, the number would be closer to 100%. However, the water might be put to some other useful purpose, provided alternate sources of coolant can be found. This condensate may have some impurities that must be removed to permit its use for municipal or agricultural applications. These include boron and ammonia. It is reported, however, (Ref. 23) that condensate from Cerro Prieto wells is free of harmful amounts of boron (0.7 ppm). However, ammonia is high and some treatment will be necessary if the water is to be used for human consumption. In any case, approximately 60,000 acre-ft/yr of water would be produced by a 1000 MW generating plant.

If it is used, some alternative means of cooling the condensers will be required. One possibility is to use a source of poor quality water for the cooling towers. The waste geothermal brines are too high in mineral content for such a purpose. However, irrigation waste water or brackish water from shallow wells might be suitable. If we simply take the condensate flow to approximate the cooling water requirement, an estimate of total water consumption can be made. The condensate flow is equal to the steam rate, about 18.5 lbs/kw-hr. Thus a water supply of 55,500 gallons/mw-day is required. One thousand megawatts of generating capacity would require 62,000 acre-ft/year. This would require that the contact-type condenser be replaced by more conventional surface condensers. Both the total plant cost and performance would be adversely affected, but not significantly so. The total agricultural waste water flow in Imperial Valley is close to one million acre-ft annually. Thus, in principle, water is available for cooling, and the distilled water condensate could then be used for fresh water supply. However, interruption of the flow of waste water means that the major source of water for the Salton Sea would be eliminated. In that case, the Sea would steadily shrink in size, until a new equilibrium size is reached. The whole question of the future of the Salton Sea is cloudy (Ref. 24). If a major investment is made to halt the increasing salinity of the Sea, interrupting its water source would be most difficult. If, on the other hand, no effort is made, and the Sea becomes unusuable for recreation, its disappearance is less of a catastrophe. See also Ref. 25.

All this assumes that the waste water flow can be routed to the region of the power plants in an economical fashion, without having an adverse effect on present activity in the Imperial Valley. The availability of large quantities of brackish well water is not established but some small supplies are known to exist (Ref. 26). Thus, as a by-product of power plant operation, using waste water or brackish well water for cooling, a supply of desalted water can be obtained. In a later section, the possible requirements for such water in the Imperial Valley will be calculated.

Another possibility for cooling is once-through flow. This requires substantially largers quantities of water, but only heats the water instead of evaporating it. Using our example plant, it is found that for 1000 MW production, in excess of 2 million acre-ft flow per year is required, assuming a 20°F temperature rise in the flow stream. This is about twice the amount of water required by a nuclear power plant, owing to the lower efficiency of the cooler geothermal steam. No such river flow exists in the Imperial Valley, and it is unlikely the All-American Canal flow (2.5-3 million acre-ft/yr) could be used for such a purpose. However, Salton Sea water could be circulated through the system and returned to the Sea. The question of what would happen to the Sea's temperature and evaporation rate has been examined (Ref. 27). For the thermal load from 1000 MW, the effect on the Sea would be negligible (perhaps a mean temperature rise of 1°F) assuming that the heated discharge were well diffused into the Sea. However, for more massive power production, the effects will become more noticeable. Only detailed calculations would show if present environmental standards could be met. The composition of Salton Sea water would also lead to operational problems in a cooling system, thus it is unlikely that this is a viable alternative. The operational problems of piping water to and from the power plants scattered through the Valley also militate against this solution.

Yet another alternative is available. That is to use air-cooled (dry) condensers for the power plant. Again, in this way the distilled water condensate can be saved. Direct air-exchange cooling towers are commonly used in chemical industries, but have found less application for power production. The largest existing installation has the capacity to serve about a 100MW geothermal power plant. The capital cost of the equipment is substantially higher than for evaporative cooling towers, and the power cycle using air towers is less efficient. This comes about because the evaporative tower uses a sink at wet-bulb temperature, while the air tower must reject heat at dry bulb temperature. In desert regions these temperatures can differ by 30 or 40 degrees F. This lower effectiveness of direct air exchangers is particularly costly for an intrinsically inefficient cycle, such as is the case for geothermal steam. Simple cycle efficiency estimates indicate that an air exchanger, on a hot summer day, would be able to support a 6 psia condenser pressure (50°F air-steam temperature difference). This compares to the 2 psia possible with watercooled towers. The reduced efficiency thereby causes a 23% reduction in electrical output per unit of well flow.

The capital costs of dry air exchangers have not been calculated in detail for a geothermal electric plant. However, Professor Washburn of Sacramento State College has estimated the cost (Ref. 28) of producing electricity in nuclear plants using air towers. Unfortunately, unit equipment costs were not tabulated. However, Leung and Moore (Ref. 29) and Smith and Larinoff (Ref. 30) published estimates indicating a cooling tower system to cost \$35 - \$45/kw for a nuclear plant. Again, simple cycle calculations indicate that for equivalent electrical output, a geothermal plant will reject approximately twice the heat rejected by a nuclear plant, using air condensers. Therefore, the capital cost associated with air coolers in the geothermal case could amount to \$80/kw. This would be a very substantial addition to power generation cost. It also ignores the special problems and costs that might be brought about by the adverse chemical content of the steam and condensate. However, this expedient would be necessary only if one wished to preserve the condensate, and the costs would be attributable to water production. The technology and economics of water production will be treated in subsequent paragraphs. In rough terms, however, the use of air exchangers, if charged to power, would probably increase the capital and energy costs per kw-hr to values equalling or exceeding those expected for fossil plants.

Let us examine the cost factors involved in conserving condensate as outlined above. If one substitutes waste water for condensate in the cooling tower, the largest cost factor will probably be to transport the waste water to the plant. This cost cannot be estimated without having plant locations specified and waste water sources identified. If well water* is used, the same comments apply. However, an appraisal was made of such a well water source for level control of the Salton Sea (Ref. 26). The outlook was discouraging as to the availability of substantial quantities of well water.

The use of waste water is a good possibility however, provided the caveats regarding the effect of this action on the Salton Sea are kept in mind. It is unlikely that the transportation costs for the waste water would exceed \$10/acre-ft, and this is the major cost attributable to water production.

If the expedient of air cooling towers is used, the additional cost must be attributed to water production. The extra equipment cost for 1000 MW electrical production might amount to \$70 million. If capital is annualized at a rate of 12% (interest, amortization), the annual cost is \$8.4 million. The decreased efficiency of production increases steam supply costs by 30% (a 23% efficiency reduction). Using the figure of 2.1 mills/kw-hr for steam at The Geysers (without adding in the 0.5 mill charge for condensate reinjection) plus the 1.3 mill/kw-hr figure for brine reinjection previously derived yields a value of 3.4 mills/kw-hr for steam supply. This is the value to be increased by 30%. Thus a cost of about 1

* brackish water unsuitable for agricultural purposes.

mill/kw-hr must be paid for by water production. In a year (assuming 100% load factor) the efficiency loss would cost \$8.77 million. This is added to the annualized cost of the equipment for a total of \$17.2 million. In this case, 62,000 x 1.30 = 80,000 acre-ft/year of water is produced. This is a water cost of \$215/acre-ft. It is unlikely that any such water supply would be economically attractive. Clearly, the expedient of using waste water in a cooling tower is a preferable solution. All these estimates ignore the costs that may be necessary to remove harmful residuals, such as boron, ammonia, dissolved hydrogen sulfide, from the product water.

None of the above considerations pertain to the stream of hot mineralized water that is separated from the well flow. This water may be desalted by a variety of techniques. However, because the water is already hot, evaporative processes appear most attractive. At the present time, a test facility to develop the technology of desalting geothermal waters of the type expected from the Imperial Valley is underway under the sponsorship of the Office of Saline Water. A winning proposal for portions of this work (Ref. 31) outlines a plant configuration which utilizes much of the technology being developed for sea water desalting. However, it differs in that the feed water need not be heated, the chemical scaling problems are different, and a source of ocean water is not available for cooling. In the Envirogenics design, the flow of hot brine enters the plant at 450°F, which corresponds to about 400 psi wellhead pressure. The producing companies claim that only exceptional wells can be produced at that pressure and temperature. Optimum operating conditions will probably call for a lower temperature and pressure. In this case, the overall production of the plant can be maintained, but larger heat transfer surfaces will be necessary. The cost of such a plant is impossible to estimate accurately at this early date, when so little of the actual development has been accomplished. The conceptual plant is somewhat simpler than a sea-water desalter, but operates at higher pressure. As a rule of thumb, a large (50 million gpd) sea water plant might cost \$1/gallon per day capacity. For illustration, this figure can be used for a geothermal desalter. Because the water is apt to be produced by a public agency, the cost of interest is lower than for the case of an investor-owned public utility. Using a value of 10% annually for amortization and interest, capital charges might amount to \$0.30/1000 gallons, assuming high utilization (90%). Operating charges have been estimated in various studies of sea water converters to approximate \$0.10/1000 gallons. What need not be paid for in the geothermal case is the heat (usually as low temperature steam) which the sea water plant requires. This can amount to 10-15 cents per thousand gallons, but does not enter into the geothermal plant calculation. Thus, fresh water might be produced from the well brine flow at a cost of 40 cents/1000 gallons. This is approximately equivalent to \$130/acre-ft. Remember that the power plant has paid for the original well production. The power/water plant now has to pay only for reinjection of 20% of the brine.

Either the cost of electricity could be decreased about 1 mill/kw-hr, or the price of water could be decreased by 20 cents/1000 gallons, or the savings can be allocated between them. If water was credited with the whole amount, fresh water might cost only 20 cents/1000 gallons, or $65/acre-ft. By agricultural standards, either is expensive water, but in the case of the Imperial Valley, the situation is improved because this distilled water could be used for blending with the existing canal water, whose quality is deteriorating. It should be noted that this cost does not provide for the possible requirement for water reinjection; that subject will be treated in the following section.

How much water would be available? The Envirogenics design indicates 82% fresh water recovery from the assumed (2% mineral) brine. Conservative assumptions regarding Imperial Valley water would suggest larger values (3-1/2%). Higher mineral concentrations might lead to reduced yields, owing to concentration limitations. As previously noted, a Cerro Prieto type situation yields 550,000 lb/hr of brine per 10 MW electricity production. Thus, for 80% yield, fresh water production of 130,000,000 gallons per day or 145,000 acre-ft/yr is associated with 1000 MW of generating capacity. It must be noted that this water production rate greatly exceeds that of any desalting plant that has been constructed. The Office of Saline Water is presently planning a demonstration project for a 50 million gpd sea water desalting plant.

Supplemental Water for Reinjection – Owing to the withdrawal of geothermal water for power or fresh water production, land subsidence may possibly become a serious problem in some areas. Owing to the configuration of the water distribution and drainage system in the Imperial Valley, this could be particularly serious if it should occur there. A possible means of preventing subsidence is injection of water into or near the producing zones in such a fashion that production is not adversely affected. Lack of detailed knowledge of reservoir conditions precludes definitive statements as to the necessity or practicality of this action. If, however, it is to be done, the question of the source of the injected water must be addressed. Because it is possible that subsidence may occur in the Imperial Valley (natural subsidence goes on at the rate of about 1 cm/yr, owing to tectonic action) and because it is in the irrigated sections of the Valley that most harm could be done, the discussion will center on that area. Many, if not most, other geothermal areas would be unharmed by subsidence.

The most likely source, of course, are the waters remaining from the geothermal production process. Water from the production wells, or desalting plant or cooling tower blowdown will have to be disposed of in some fashion, and reinjection is the most likely.

However, some of the original water will have been consumed, either as steam, distilled water or by evaporation. It is this balance that might have to be make up for by an outside source.

It has already been noted that in some areas of the Imperial Valley, irrigation waste water is present. Some of the problems involved in reinjecting such waters include the possible pre-treatment required to remove organic material, and the transportation problem. The Valley has a complex net of water distribution and drainage canals. To move water across the pattern may be difficult and expensive. Also, as mentioned, this water maintains the Salton Sea, an asset of considerable importance for recreation. Without specifying particular locations, it is not possible to make cost estimates for waste water use.

Likewise, some supplies of shallow, ground water are available. The only water that could be made use of in the geothermal cycle would be sub-agricultural-quality brackish sources, but the extent and location of even these are not established. No well-founded estimate of cost can be made, but the acre-ft cost of reinjection water can be added directly to the acre-ft cost of distilled or cooling water that is withdrawn from the geothermal stream. Thus, if the outside water is delivered for \$10/acre-ft, the price of the distilled water is increased by \$10/acre-ft, as there is roughly a one-to-one correspondence between them. This cost would have to be added to the equivalent electrical production, if it were making up for coolant evaporation.

The only known, assured source of reinjection water is the ocean. Fortunately, the Gulf of California is separated from the Imperial Valley by less than one hundred miles, and the maximum elevation between them is only about 30 feet. This does not mean that obtaining the water will be cheap, or even possible. The Gulf lies within the Republic of Mexico. That country would have to grant permission for the water withdrawal and the right-of-way over its territory. Granted that permission was given, the problem is still not trivial. Crossing the irrigated areas of the Mexicali Valley would involve serious problems of interference with on-going activity. The extensive salt flats at the head of the Gulf and the extreme tidal range will make for great problems in water intake design. No layout for such a water transport system has been made. However, In Ref. 27, estimates are given for the cost of a pipeline/canal system to transport water in the other direction, from the Salton Sea to the Gulf. A system for transporting 100,000 acre-ft/yr was estimated to cost about \$30 million; for 500,000 acre-ft/yr, about \$60 million. Even at the large flow rate, capitalization costs amount to over \$12/acre-ft, and operating cost must be added to this figure. It is probably that pre-treatment before flowing in the canal will be necessary to prevent fouling, and more extensive treatment before injection will be needed. Costs are presently unknown. It is unlikely, however, that the sea water could be made available for less than $20/acre-ft, and the number could be considerably higher.

It has been suggested by Pomeroy, Rex, and others that the Salton Sea salinity could be controlled by removing an amount of water from it each year. This amount is presently estimated to be 140,000 acre-ft. This will suffice once the salinity increase is brought under control; a larger rate is necessary initially. For the maintenance phase, however, this removal rate will keep the salinity at a reasonable value, and the level of the Sea will be about 5 ft below its present height. This amount of water would make up for the condensate from 2000 MW of electrical production. While a useful idea, it does not cope with the original adjustment period for the Sea, nor would it provide for the very extensive geothermal developments sometimes suggested. If, however, reinjection were required in only parts of the Imperial Valley, this may prove to meet the need. The cost of pre-treating the salty, organically rich water to prevent well plugging will perhaps be high. However, that cost, plus the transport and reinjection could be shared by the beneficiaries, the Salton Sea users and the power consumers. Pending detailed study, made with reference to particular situations, all these concepts of obtaining non-geothermal water for reinjection are high speculative.

F. ENVIRONMENTAL EFFECTS.

Land Use

The production of geothermal power or water will involve a number of environmental effects. The most obvious items are embodied in the intrusion of an industrial operation into non-industrial land areas. For example, a geothermal well is drilled in the same fashion as an oil well. Problems included noise and the appearance of drill rigs. Once drilled and in production, the geothermal well can be made unobtrusive and hopefully will offer no severe environmental problems. However, the well products must be collected by pipe and transported to the using plant, often over distances of up to a mile. These insulated pipes are costly to install below ground, and the tendency will be to run them above the surface. Such pipes can be obtrusive. The power and water plants are typically industrial, with a not unreasonable noise level, but noticeable, and with cooling towers. Thus commercial and residential usage would be generally incompatible with a geothermal field.

Waste Water

More general and destructive environmental effects are possible, but fortunately are capable of being controlled. When developing a field yielding a steam/water mixture, there is the matter of disposal of surplus waters. In some instances, these wastes will be high in mineral content, and cannot be discharged into surface waters. Unless very well mixed, even ocean discharge could lead to severe local effects (Ref. 32), if the plant waste differed substantially from ocean water.

Let us review the magnitude of the problem. It is assumed that plant condensate, being distilled water, will be used all or in part, for consumptive purposes. Even when this is done, however, as at The Geysers, (the condensate water is used for cooling tower make-up) the surplus water generated contains trace chemicals which preclude its discharge into the local streams. The water often requires further treatment, or at The Geysers, is reinjected into the ground, in deep wells. There, about 20% of the condensate is reinjected. For 100 MW of generating capacity, this amounts to over 1 million gallons/day. One large injection well can accommodate this flow.

The more difficult problem arises when the geothermal wells produce hot water, rather than dry steam. In this case the water may be highly mineralized. For example, at the Buttes Field, near Salton Sea, the water contains over 20% salts, an extremely high value. At Cerro Prieto, in Mexico, the waters contain about 2% salt (ocean water contains 3.3% salts).

As has been calculated, for conditions like Cerro Prieto, for an equivalent electric plant of 1000 mw size, salt water is produced at a rate of approximately 150 million gallons/day, or over 150,000 acre-ft annually.*

Before disposal, the water might be concentrated in evaporation ponds, or used as feed water to a desalting plant. In either case, limits exist to the concentration factor, thus the disposal of the brines is a problem requiring careful consideration. In most inland areas, transport of the brines to the ocean would be difficult and costly, therefore other methods must be sought (Ref. 22 and 33). The problem has been specifically examined for the Salton Sea district (Ref. 34). The method that appears most promising is disposal into injection wells. An injection well is drilled to a depth where a porous formation will accept the water. To avoid contamination to ground waters, these may involve depths of several thousand feet.** After overcoming original well-head pressure, it is often found that the water is literally poured down the hole.*** This method is widely used for disposal of oil well brines and industrial wastes. One must take care to avoid aquifers that connect to areas where the waste will do harm, e.g., sources of agricultural or potable water. This is not thought to be a problem in geothermal areas. A potentially serious problem in injection well operation is the deposition of minerals from the water in the pores surrounding the well. Such deposition can cause rapid impediment to well flow.

It is unlikely that geothermal waste will be disposed of in California other than by well injection. In Mexico, at Cerro Prieto, the water simply flows in ditches to the Gulf of California, via the Rio Hardy. The present flows already affect the Rio Hardy, and it is anticipated that additional development will require the construction of a special waste canal to the Gulf. This course is not open in the Imperial Valley, which is land-locked and drains to the Salton Sea. It is already forbidden by the Regional Water Quality Control Board to discharge geothermal waste to the Sea or its tributaries. This is necessary to preserve the already threatened Sea from an uncontrolled increase in salinity. The same considerations will probably hold for the Mono Lake region.

Subsidence

A closely associated problem is that of land subsidence. If large quantities of fluids are removed from the underground reservoir, the land surface may sink, with sometimes disastrous consequences. This happened in the Wilmington oil field. It is, however, an

* for 2% brine, 12,000 tons/day of salts would result if the water was evaporated away. This poses a monumental solid disposal problem, and constitutes a real environmental danger.

** for the prevention of subsidence, where necessary, the water would probably be injected into the producing zone.

*** this is often made easier by the greater density of the concentrated and cooled brine.

unusual occurrence. If the aquifer consists of fractured rock, subsidence is unlikely. If it is a very porous medium, which can collapse when the water is withdrawn, subsidence can occur. The problem is sometimes coped with in oil field practice by injecting water into the reservoir. Thus the disposal of geothermal wastes by injection may also be necessary to prevent subsidence. This effect is potentially very serious, and might have to be met by importing water for reinjection in a drained agricultural area such as Imperial Valley. An elaborate survey network is already being laid out in the Imperial Valley so that possible subsidence resulting from future geothermal development can be quickly detected. Subsidence has already been reported at the geothermal field at Wairakei in New Zealand and at Cerro Prieto, (Ref. 35) but that at Cerro Prieto may not be connected with geothermal production.

Seismic

Experience in Colorado, and some on-going experiments there, have indicated that seismic activity can be stimulated by the injection of water deep underground. The seismic effects of water withdrawal and reinjection in geothermal fields will be peculiar to the particular area, and cannot be stated to be or not to be a problem at this time. There is even speculation that the induced micro-seismicity relieves strain on faults and tends to prevent major earthquakes.

Air Pollution

Noxious gases are often a by-product of geothermal wells. At The Geysers, for example, the oder of hydrogen sulfide (H_2S) is prevalent. It exists in the steam with other gases, most notably carbon dioxide. The non-condensable gases constitute from 0.2% to 1.8% of the steam flow at The Geysers (Ref. 36). Of this 82.5% is CO_2, 6.6% methane, 1.4% hydrogen, 1.2% inerts, 4.5% H_2S and 3.8% ammonia. What do these small percentages mean? For one thing the materials of a turbine, condenser or water plant must be chosen to avoid corrosion problems. Thus the PG&E condensers must be lined with stainless steel. The non-condensable gases must be separated from the steam or water flow to insure proper operation of condensers. This is simply done, and at The Geysers the eject gas is discharged to the atmosphere. Some gases dissolve in the condensate. This is the case for H_2S, where a portion dissolves in the condensate and later escapes to the atmosphere when the condensate water is evaporated in the cooling tower. If we assume that only one-half percent of the steam flow, on the average, is non-condensable gas, the above figures indicate that H_2S is present in the steam to the amount of 225 parts per million (PPM). If a total of 1000 MW of power were produced there, this would require 430 million lbs/day of steam. Thus 97,000 lb/day of H_2S will be released. This is roughly equivalent to the amount of sulfur released by a fossil-fueled power plant of the same size, burning low-sulfur oil.

Technology is available to prevent the release of these gases, if it is found to be necessary, as is probable if extensive fields are developed. PG&E and Union Oil Company are presently investigating methods of emission control at The Geysers. The question is one of practicality and cost.

In the following, an estimate is made of the hydrogen sulfide that might be found in a field yielding hot water, as in the Imperial Valley. The data from Cerro Prieto will be taken as representative, (Ref. 21). It has been reported that H_2S exists to the amount of 0.26% by weight in the steam. Other data supplied by the geothermal project at UCR indicates substantially smaller values, with wide variations between individual wells. Let us consider the higher value, however. Assuming a likely steam rate (20 lb/kw-hr), a 1000 MW plant would lead to the production of 1,180,000 lb/day of sulfur. This number exceeds that experienced from fossil plants burning high sulfur fuel. Thus, it is seen that noxious gas control is apt to be an essential part of geothermal power production. To say that geothermal power intrinsically involves no air pollution in incorrect. With controls, however, it need not cause air pollution.

Heat Rejection

A possibly significant environmental effect to be expected in routine operation of a geothermal power plant is heat rejection. All power production cycles using thermal energy must reject heat, and the less efficient they are, the greater is the heat rejection. As previously pointed out, geothermal steam is available at low pressure and temperature, as compared to that from conventional boiler or nuclear plants. Thus the heat rejection will be high. This is clearly indicated by the comparative steam rates (which can be roughly equated to comparative heat rejection) given in Ref. 36 for The Geysers and a modern fossil plant. The rate for Geysers 3 and 4 is given as 18.53 lb/kw-hr, while Moss Landing 6 and 7 is shown as 6.68.

Let us examine the heat rejection quantitatively. For 100 psi inlet conditions, and a water tower-cooled condenser, thermodynamic calculations show that 3630 MW of heat are rejected by a 1000 MW geothermal electric plant (a 1000 MW nuclear power plant rejects approximately 2000 MW of heat). This number means little unless we have a basis for comparison. Data exists for the total 24 hour average solar heat received in a desert area in summer (Ref. 37). This number, called the solar insolation, is 720 MW/square mile. Thus the 1000 MW power plant produces heat equivalent to that received by 5 square miles of desert from the sun. If ten such plants or their equivalent were installed in the Imperial Valley (and the total geothermal potential there has been estimated to be at least that large - Ref. 13), the total heat added to the 1000 sq. mi. area of the Valley would be 5% of the total summer solar heat. The effect of this heat on the local weather is unknown at this time.

If air-cooled condensers are used, the reject energy will be larger and will go directly to heating the atmosphere. How this heated air would distribute itself and affect the local climate will require detailed consideration of local conditions. If water cooling towers are used, the temperature would be affected to a lesser extent, but substantial quantities of water would be evaporated, thus influencing the humidity. Considering the heat rejection rate, and for typical cooling tower performance, up to 50,000 acre-ft/yr of water will be evaporated by a 1000 MW plant. Ten such plants will evaporate 500,000 acre-ft/yr. Presently, approximately 1.5 million acre-ft pass into the atmosphere through evapotranspiration in the Imperial Valley each year by agriculture and another 1 million evaporates from the Salton Sea. This added burden of water vapor is a small fraction (~20%) and in times past, more water has been used in Imperial Valley than is presently the case. Coincidently, this increment corresponds roughly to this cooling tower use. Thus no overall detrimental effects should be expected. Local effects are very possible, and deserve detailed examination. On balance, for the Imperial Valley as a whole, the variations in heat absorption that presently occur owing to the state of the field (e.g., plowed, in full leaf) would tend to be greater than the effects of the power plant heat. Likewise, the real humidity variations that occur in the area seem mostly a function of air mass movement. Thus permanent valley-wide effects are unlikely. However, in the immediate vicinity of the plants, considerable environmental effects are possible, and appropriate investigations should be carried out.

Well Blow-out

In any well drilling operation involving high pressure fluids, the possibility of a well blow-out must be taken into account. Blow-outs occur in a variety of ways. The classic oil well blow-out is one type. This same class of accident occurred during the drilling of one of the early production wells at Cerro Prieto. Standard oil field methods were used to bring the well under control. Days were required to accomplish this, however, while the well geysered steam and salt water. Such a blow-out might flow as much as 10 acre-ft/day. Clearly, such a release of salt water in an agricultural area would pose a major environmental problem. Means of affecting prompt blow-out control must be provided, and are called for by state regulation.

Another class of blow-out has occurred at The Geysers. Here the formation through which the well passes is unstable (Ref. 7). Attempts to cap the flow cause steam to escape into the ground and threatens to cause an eruption from the ground. Thus the flow continues and attempts at control are being made. This physical situation is akin to that found in the Santa Barbara Channel oil field, where control of the oil well tends to cause seepage from fractures in the sea-bed. Again, such a possibility must be avoided by careful well design. California State oil drilling regulations seem to offer good protection on this point.

G. RESOURCE POTENTIAL.

Of the several geothermal areas identified in California, only two have received extensive exploratory attention; the first of these is the area of The Geysers in Northern California and the second is the Imperial Valley in Southern California. Let us first examine the potential for power production of The Geysers field, which is currently being developed by Union Oil and PG&E. In Ref. 19, PG&E indicated its intentions for power plant construction during the balance of the decade of the 70's. They list geothermal units through Geysers 14, to be installed in the Fall of 1975, and which lead to a total of approximately 600 MW of geothermal electric production. During this same time frame, it is their intention to install 735 MW of fossil power and 2120 MW of nuclear power. During the balance of the decade they indicate an intention to install 4400 MW of additional nuclear capacity. On this basis then, the 600 MW of geothermal capacity appears noticable, useful, but relatively small. If on the other hand, The Geysers field is more extensive than presently positively established (if for example the estimate of 4000MW capacity is found to be realizable), it is conceivable that it could replace half or more of the installation of nuclear capacity presently in planning stages by PG&E. It is worthwhile to note, however, that unless considerably more extensive exploration is carried out to identify areas presently not verified as economically and technically attractive geothermal fields (if indeed they exist), geothermal resource cannot substantially replace nuclear power in PG&E's plans.

It is interesting to note in the listing of projected power plants that the first of the now planned nuclear plants is to be on line in Spring of 1977. With current construction lead times it is highly unlikely that this date can be met. If the electrical load continues to grow at a rate that would have necessitated this addition, then it is conceivable that further exploitation of the geothermal resource will enable the gap in generating capacity to be filled, thus overcoming the effects in delays of nuclear plant construction.

Several factors serve to inhibit more aggressive development of The Geysers geothermal field. First, the utility is already making a substantial investment in money in the area, and the utility is accustomed to investing money in plants whose useful lifetime can be accurately predicted in advance. In the case of the geothermal field, however, if the field should lose its capacity to produce, the investment would become useless; and it is not possible to accurately predict this period of useful production.

Second, if PG&E has only 600 MW capacity at The Geysers, out of a system capacity of over 15,00 MW, the possibility of loss of geothermal field productivity does not seriously affect their ability to supply their customers. Consider the reliability problem if they were employing 4000 MW of geothermal capacity. It could be argued that field productivity would not drop precipitously, but would gradually wane over several years. This is small comfort however, as the leadtime for new nuclear plants is now nearly ten years. Thus, for major exploitation of geothermal resources, developed, proven reserves will be required to insure system reliability. This emphasizes the need for aggresive exploration for additional producing areas, and not simply for exploitation of known areas.

Thus it is to be expected that the utility would have a natural reluctance to invest too much of its money and to rely too heavily for generating capacity on this somewhat uncertain resource at this time. Projected load growth* for the P G and E system indicates that even with completion of a two-unit nuclear plant (2300 MW) subsequent to Diablo Canyon, and continuous installation of geothermal capacity at the present rate, system reserves are not as great as desirable. Then in a realistic sense, one cannot state that intensive development of The Geysers field would enable P G and E to postpone the installation of nuclear units subsequent to Diablo Canyon 1 and 2 until even the end of this decade. Rather, geothermal is simply an addition to the generating mix for P G and E, and may permit a reduced pace of nuclear plant installations in the future.

Turning now to the Imperial Valley, the picture becomes even less clear. Here no proven economic production area has been positively identified. Moreover, no intensive program for clearly identifying and determining the extent of such an area is contemplated which would yield such results in the next year or two. The largest published estimates of the generating capacity of the Imperial Valley, those of Professor Rex, indicate a generating potential of 20,000 MW. Growth projections of electric demand in the Southern California area indicate that such a supply will satisfy expected needs for the next 10 to 20 years. However, other planned electric generating capacity expansions cannot be deferred at this time in the expectation of geothermal development because no proven geothermal capacity exists at this time in Southern California. No reasonable utility planner could at this time factor geothermal capacity into his overall planning strategy nor will he be able to do so until an intensive exploration program is conducted. It is still unclear when such an aggressive exploration program will be initiated, and by whom.

Even if the program is successful, utilities would probably proceed with development in a most deliberate fashion, for reasons of system reliability. Until the capacity and duration of yield of the fields are well understood and proven, the developments of the resource must be carefully paced.

* As in various PUC submissions.

It is interesting also to see how potential geothermal fresh water production might match increasing water requirements in the Imperial Valley area. It is known that the California Aqueduct system will supply the general needs of Southern California (apart from the Imperial Valley area) for the next 20 years or perhaps longer. However, no California Aqueduct water is intended to be used in the Imperial Valley and it is known that quality of the water being used by the Imperial Irrigation District from the Colorado River is steadily deteriorating. It is certain that this steady deterioration will have a deleterious effect on agriculture. For example, at this time the water drawn from the Colorado River at the Imperial Dam contains dissolved solids to the amount of about 900 parts per million. By the year 2000, projections of the Colorado River Board indicate that this figure will increase to in excess of 1300 parts per million. It is known that the farmers in the Mexicali Valley are already suffering from inferior water quality at the level of 1200 parts per million, that which is delivered to them at the Morelos Dam. The expected increase in water salinity at Imperial Dam is shown in Figure 1 as a function of time. Let us now assume that the desalted geothermal waters would be used for blending with existing irrigation waters to maintain the total dissolved content at a reasonable level for agricultural purposes. If we further assume that a reasonable level is 900 parts per million, and that the total use of water by the Imperial Irrigation District remains at 2.7 million acre feet annually, one can then plot the amount of distilled water needed, as a function of time, to maintain favorable water conditions. This plot is shown in Figure 2. It is seen that by the year 2000, 900,000 acre feet annually of distilled water would be required for blending. We have seen that nearly 60,000 acre feet of water would be produced annually by simply conserving the condensate of a 1000 MW power plant. Thus, if electrical generating capacity in the Imperial Valley should actually amount to 20,000 MW by the year 2000 then an ample supply of distilled condensate would be available for water blending to maintain the quality of water in the Imperial Valley, although the supply of waste water for cooling would be stretched. As previously calculated, if a desalting plant is associated with the electric plant to process the waste brines from the well after the flashing process, perhaps 145,000 acre feet per year of fresh water would be associated with 1000 MW of generating capacity, in addition to the 60,000 acre feet already discussed. Therefore, it is seen that potentially an additional water supply of nearly 3 million acre feet annually could result.

It should be remembered that the geothermal power plant itself produced the first increment, and, given the availability of cooling water, this water increment is available at fairly low cost. It should also be remembered that the second and larger increment must be produced by a distillation plant dedicated to the production of water, and this water may be fairly expensive as estimated in previous sections.

In summary then, present geophysical evidence indicates that the possibility for supplementing Southern California electrical growth over the next 10 or 20 years might be met by the geothermal resources of the Imperial Valley and that if such a development took place the associated water production could maintain the quality of water in the presently irrigated areas of the Imperial Valley until the end of the century and beyond. Also it is possible that a supply of additional water equivalent to or exceeding the capacity of the California Aqueduct as it flows into the Southern California area could be created for transport to water-short areas. There is an evident incompatibility between the potential of the Imperial Valley resource and the availability of public funds to conduct geothermal explorations in the area.

H. POSSIBLE ACTIONS.

At this time the State of California has taken the ordinary actions usually considered within its purview to promote the exploitation of geothermal resources. The State has a geothermal leasing law, and leases have been granted. The Division of Oil and Gas, responsible for well drilling regulation, has provided a mechanism for approval of drilling. In exploring the reasons for the slow pace of development, no one has pointed to the State being an obstacle.

The same statement cannot be made with regard to the Federal government. At this time, one year after the Federal geothermal leasing was signed into law, no Federal leases have been granted. Even the guidelines are not yet firmly established. Exploration companies, utilities, and local government agencies have pointed to this delay as a real problem, as over half of potentially productive areas appear to lie under Federal lands. A feeling has grown in some quarters that the Federal government wishes to produce both power and water from Federal lands, and not release the geothermal resource to private development. This seems contrary to the spirit of the Federal leasing law, and is denied by Federal officials.

The Federal exploration program, while it has been the prime supporter of geophysical research in the Imperial Valley, is hampered by reduced levels or delays of funding. The OSW desalination research program is proceeding with minimum monies. Other studies, dozens of them, have pointed out the growing urgency for development of new power and water resources, but the creaking machinery of the Federal government seems unable to rise to the challenge.

The only action that seems open to the State Legislature in this matter is to memorialize The Congress to direct funds and a demand for action to the responsible agencies.

Some other suggestions have been made, on which opinions might well vary. These relate to economic, not technical, matters and judgments are expected to differ.

One such suggestion is that legislation should force unitization of geothermal fields, in order to promote orderly development. Unitization is voluntarily entered into in many oil-producing areas, and effectively is the law for water pumped from aquifers.

Another speculation has been offered. If a public utility is unable to enter into an exploration or production agreement in a geothermal area, does its right to condemnation, previously applied to surface rights, extend to sub-surface geothermal rights. An objection to such a condemnation is that the value of the condemned resource is uncertain (how long will the field produce, for example). This argument has been countered by the suggestion that payment be made on as-produced basis. The usefulness of these suggestions might be explored by the State Legislature through hearings.

It has been suggested that potential anti-trust action has inhibited accelerated development of geothermal fields. While oil producing companies may feel this pressure, it is also true that PG&E has had to face this possibility in expanded future development at The Geysers. It is conceivable that State legislation could clarify the issues.

Utility management, properly conservative, may be reluctant to invest too much and rely too heavily on a generating source who longevity is uncertain. Perhaps some assurance that capital recovery would still be possible, in the event field productivity dropped, would help overcome this natural reticence.

It is also clear that geothermal development can have environmental impacts. However, in passing environmental protection regulation, great caution should be observed. For example, if land subsidence should occur, obviously an area such as the irrigated portions of the Imperial Valley must be protected. Blanket prohibition of subsidence is not sensible, however, for it would be a non-problem in many areas. Likewise, the escape of noxious odors must be carefully controlled in some areas, but residential standards need not be applied to industrial areas. For example, even farm activities lead to odors that would be unwelcome to urban residential areas. No one suggests that fertilizer application should be curtailed for that reason, however. The State should assure that a miasma of Federal, State, and local regulation is not permitted to develop which could needlessly inhibit the development of the resource. On the other hand, geothermal development is not without its potentially harmful effects. It is not intrinsically non-polluting, thus environmental protection will be required.

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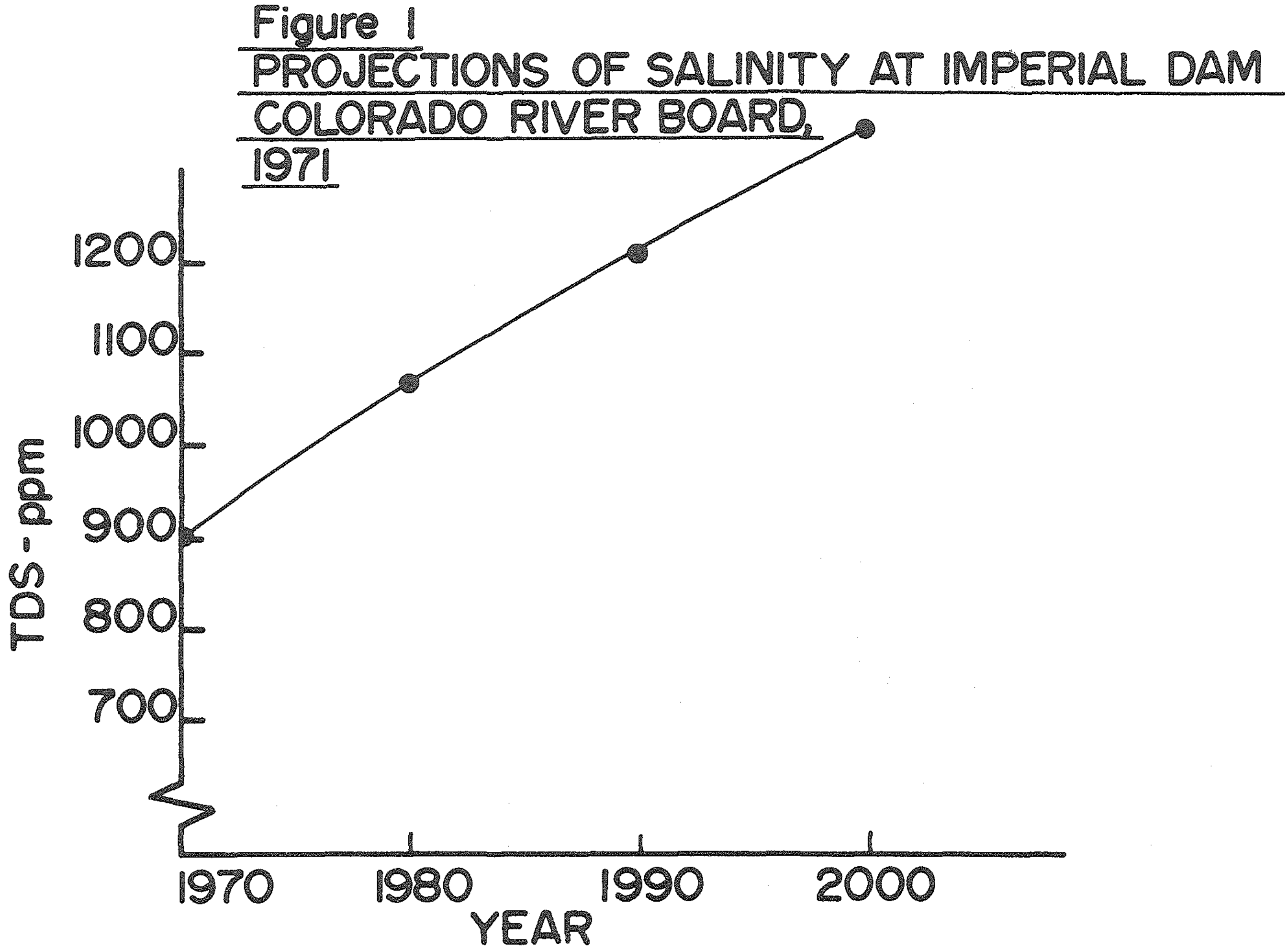


Figure 1
PROJECTIONS OF SALINITY AT IMPERIAL DAM
COLORADO RIVER BOARD,
1971
TDS - ppm
1200
1100
1000
900
800
700
1970
1980
1990
2000
YEAR

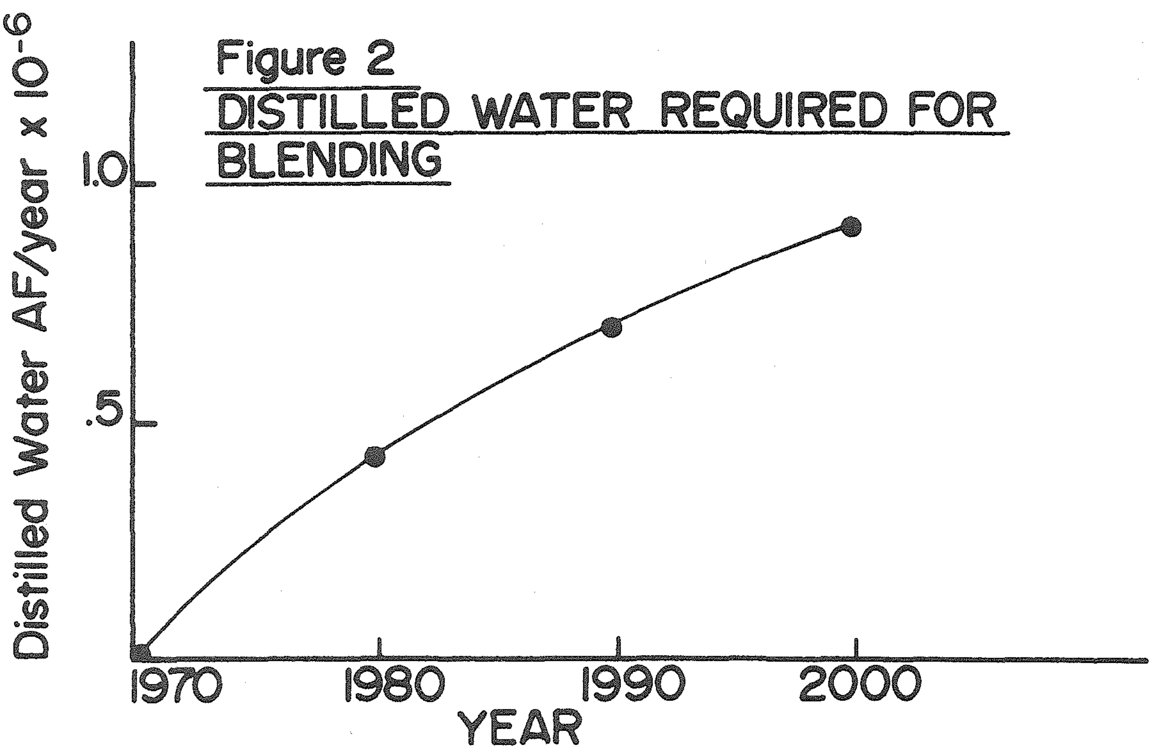
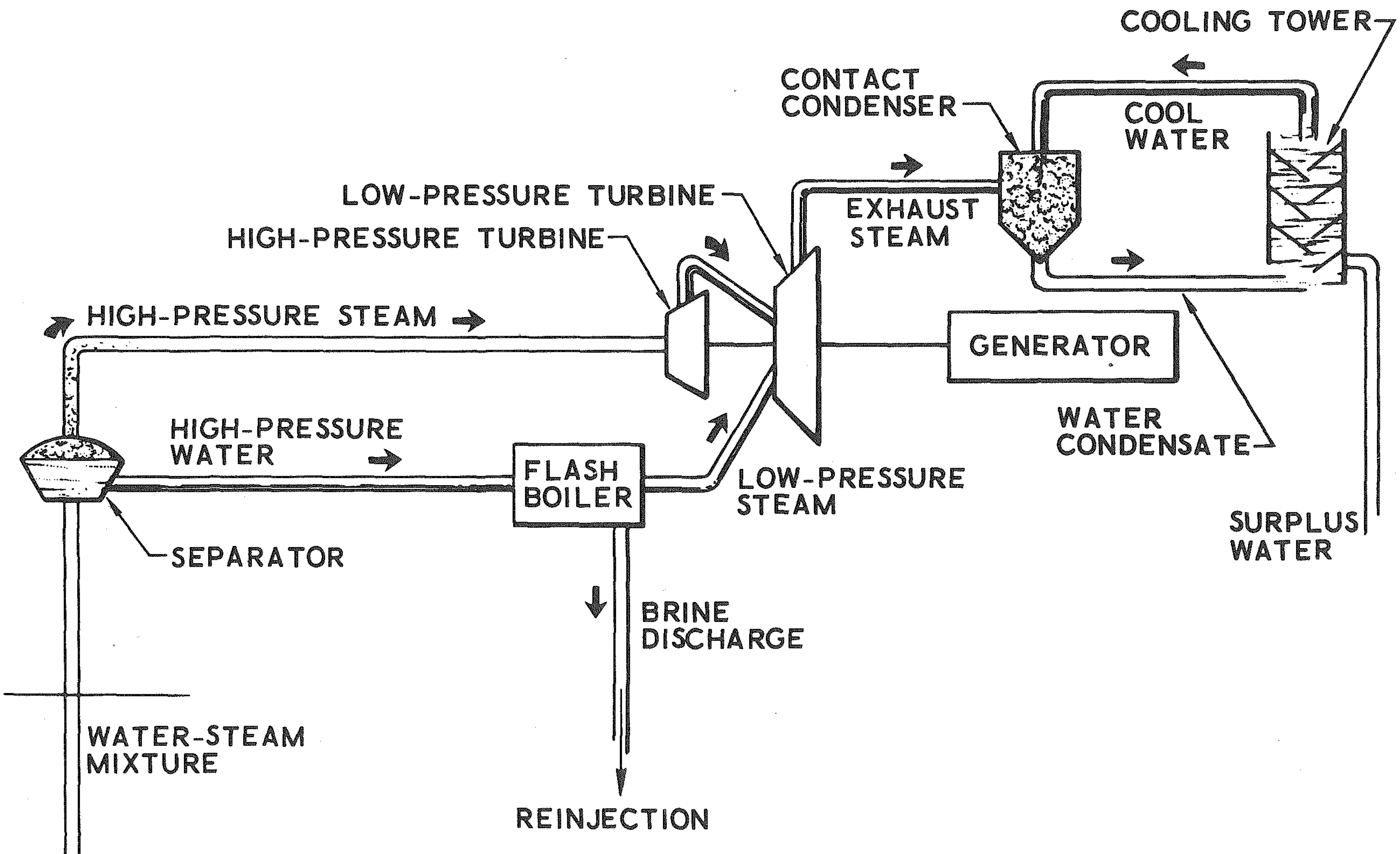


Figure 2
DISTILLED WATER REQUIRED FOR
BLENDING
Distilled Water AF/year x 10⁻⁶
1.0
.5
1970
1980
1990
2000
YEAR

PLATE 1

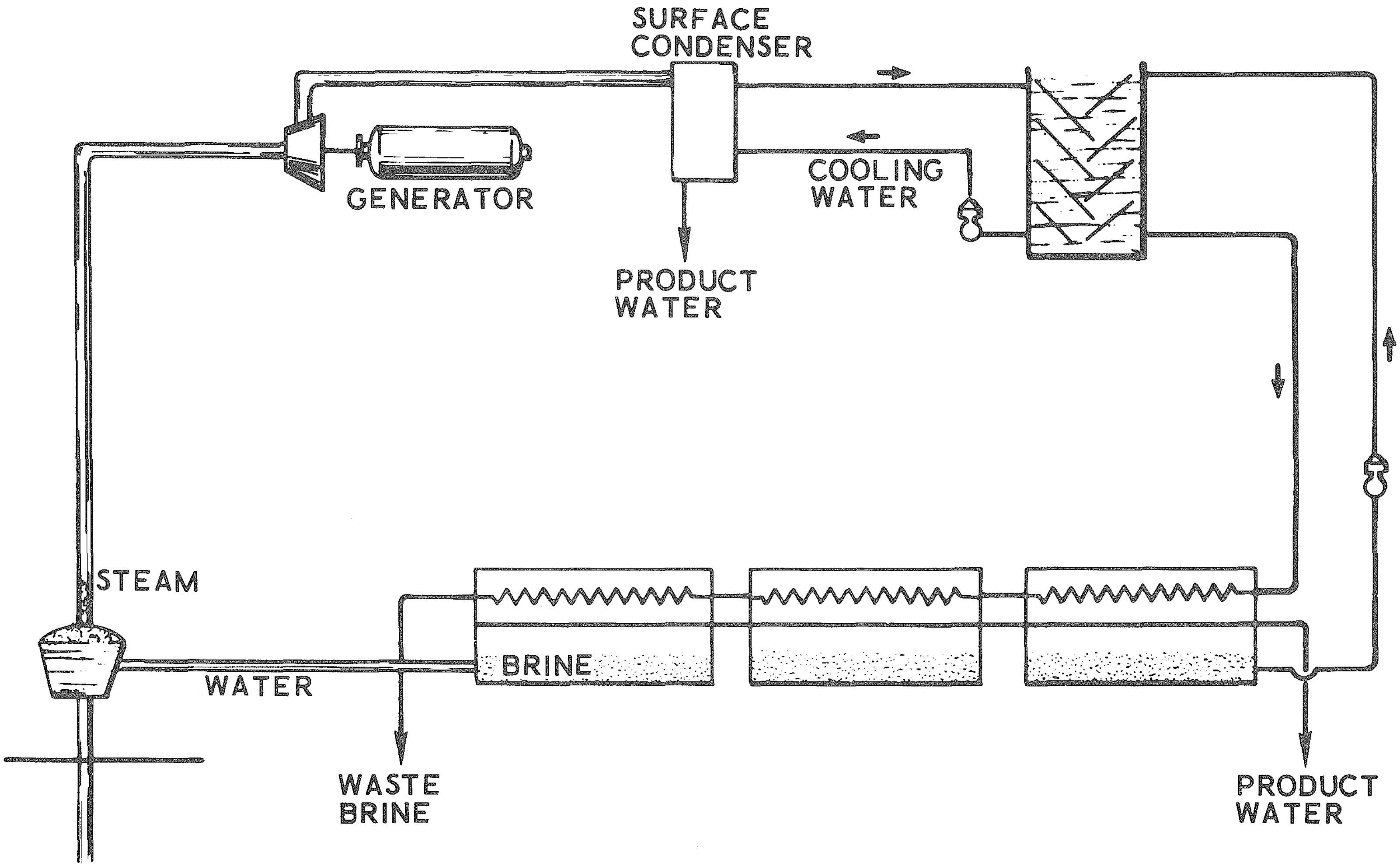
Geothermal Power Plant



Courtesy of the Aerospace Corp.

PLATE 2

Geothermal Water/Power Plant



Courtesy of the Aerospace Corp.

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