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ENVIRONMENTAL IMPACT STATEMENT
FOR THE
GEOTHERMAL LEASING PROGRAM

in compliance with

Section 102(2)(C) of the National Environmental Policy Act of 1969

Prepared by
U. S. Department of the Interior

September 1971

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INTRODUCTORY NOTE

The Secretary of the Interior is charged with the implementation of the Geothermal Steam Act of 1970 (30 U.S.C. §§ 1001-1025 (1970)), which provides for the development of Federally owned geothermal resources. This Draft Statement is intended to comply with the requirements of Section 102(2)(C) of the National Environmental Policy Act (42 U.S.C. § 4332(2)(C) (1970)), with respect to: (1) the adoption of leasing and operating regulations, pursuant to which the program would be administered, and (2) the leasing of Federally owned geothermal resources in three specific areas, with respect to which specific evaluations of potential environmental impact of geothermal development and related activities have been made and are attached to this statement and made a part hereof: (a) Clear Lake-Geysers; (b) Mono Lake-Long Valley; and (c) Imperial Valley.

Specific data may be lacking at this time for particular sites in these areas which might be selected for leasing. Prior to lease-site selection and exploration, environmental evaluations would be possible with respect to land uses and such known resource values as fish and wildlife, aesthetics, and related factors. An adequate description of the nature of the geothermal resources and their potential effect on the environment, including significant hazards, might have to await, in most cases, the completion of the exploration phase of lease operations. Thus, the information in this statement is of a broad nature and is intended to encompass generally the many potential environmental effects that could occur.

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If information were developed after the submission of this environmental statement which indicated that there could be a significant impact upon the quality of the environment from lease operations within the three specific areas covered by this statement, and that impact had not been discussed in this statement, a supplemental environmental statement would be prepared and disseminated in accordance with the provisions of the National Environmental Policy Act. It is recognized that the issuance of geothermal leases in other proposed leasing areas may involve major Federal action significantly affecting the quality of the environment, thus requiring the preparation and dissemination of environmental statements in accordance with the provisions of the National Environmental Policy Act.

The Department would subject each phase of the geothermal-resource development program (leasing, exploration, development) to thorough environmental review to determine whether the proposed actions involved in that phase would require the preparation of separate environmental statements. Starting with the initial leasing action, the Department would seek the input of the interdisciplinary skills from affected local, State, and Federal agencies in conducting the environmental reviews. The Bureau of Land Management would coordinate the environmental evaluations on tracts selected to be leased while the Geological Survey would similarily coordinate the evaluations through the exploration and development phases on the tracts which have been leased under the Geothermal Steam Act. Other concerned agencies as well as other bureaus and officies within the Department would participate in preparing these evaluations.

Where the interdisciplinary evaluations or studies of any phase of the development program reveal that a particular activity may constitute major Federal action significantly affecting the environment, an environmental statement would be prepared and circulated in accordance with Section 102(2)(C) of the National Environmental Policy Act.

Commercial geothermal development in the United States to date is small, existing in only one area in California, and only since about 1960. Worldwide development has existed since about the turn of the century. Exploration and development of the resource are similar to oil and gas production operations except that they deal with water in the gaseous and fluid state, under pressure, produced from the earth through drilled holes. Operating plants for converting the steam to electrical energy consist of low pressure steam-turbine systems similar to those in use in the early 1920's. New technology should expand the use and adaptability of the resource beyond its current limitations.

Impacts on the environment from geothermal steam development are, generally, local in character since the heat must be utilized in close proximity to the point of production. Environmental impacts affecting water, air, and land, and impact caused by noise, it is believed, would be controllable within any reasonable standards which are now, or may be in the future, established by State and Federal agencies and pursuant to provisions for Federal supervision which are incorporated in the regulations attached to the Statement. Environmental impacts on aesthetics, and similar environmental effects, which may be caused by industrial development incident to geothermal resource development, would be subject to control pursuant to regulatory provisions and Federal supervision designed to prevent unsightly development.

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Draft Environmental Statement

1. Administrative action required in connection with proposed action.

2. Proposed Rule Making for leasing and operations on public, acquired, and withdrawn lands for geothermal resource development under the Geothermal Steam Act of December 24, 1970 (84 Stat. 1566). Lands are predominantly in the 11 western States and Alaska.

3. Summary of Environmental Impacts: Climatic, biologic, and geologic environments cover full range of conditions in North America and are not subject to a general description. Lands under consideration are presently used for grazing, forests, mining and other mineral production, fish and wildlife habitat, outdoor recreation, and catchment for water supply.

Development of geothermal resources entails construction of access roads and well sites, drilling and testing of deep wells, conveyance of steam over short distances to electric power plants and by-product processing plants, construction of electric power plants, by-product facilities, electrical transmission lines, and facilities for disposing of waste liquids.

Locally, land would be preempted or restricted from such other uses as wildlife habitat, recreational use, and grazing. Terrain would be modified through construction of roads, wells, pipelines, and industrial facilities.

Noise and noxious gaseous emissions pose problems during testing and production. Possible adverse effects include land subsidence due to production of fluids, and increased seismicity due to production and reinjection of fluid wastes to producing zones.

4. Alternatives considered: (1) The Secretary may decline to promulgate the proposed leasing and operating regulations.

(2) The Secretary may postpone leasing pending further study of the environmental impact.

(3) The Secretary may decline to issue leases in a given area if environmental impacts are considered unacceptable.

Draft Environmental Statement
Geothermal Steam Leasing Program

I. General

The major Federal action described in this statement is: (1) the adoption of leasing and operating regulations pursuant to which the program would be administered, and (2) the leasing of Federally owned geothermal resources in three specific areas having significant potential for geothermal resource development and with respect to which detailed evaluations of potential environmental impact of geothermal development and related activities have been made and are attached to this statement (Appendixes C, D, and E) and made a part hereof. Proposed leasing and operating regulations to implement the Act were published in the Federal Register on July 23, 1971, and are appended hereto as Appendixes A and B, respectively.

Some 1.8 million acres have been identified as of August 1971 as having significant potential for geothermal resource development and have accordingly been classified as Known Geothermal Resources Areas (KGRA's) (Figure 1). Announcements of these classifications have been published in the Federal Register (36 F.R. 5626, 5627, as corrected, 36 F.R. 6118; 36 F.R. 6441, 6442; and 36 F.R. 7319, 7320, as corrected 36 F.R. 7759). Any additional classifications will be published in the Federal Register as soon as possible after they have been made. In areas classified as KGRA's leasing will be by competitive bidding; on other eligible lands leasing will be noncompetitive.

Lands eligible for geothermal leasing (Appendix A, Sec. 3201.1-1) are located principally in the western States and Alaska, but other lands are also eligible for geothermal leasing, including: (1) certain lands administered by the Secretary of the Interior, (2) lands administered through the Forest Service, (3) lands which have been conveyed by the United States subject to a reservation to the United States of geothermal resources.

Lands administered by the Department of the Interior not available for leasing or development, include: (1) lands administered by the National Park Service; (2) lands within a National Recreation Area, a fish hatchery administered by the Department of the Interior, wildlife range, wildlife refuge, game range, wildlife management area, or waterfowl production area; (3) lands reserved for protection and conservation of wildlife species threatened with extinction; (4) Tribally or individually owned Indian trust or restricted lands; and (5) lands which may be temporarily withdrawn from certain or all application for uses pending classification.

The issuance of a lease would represent a short-range commitment for intensive exploration and this may produce a long-range commitment on the part of the Federal government to permit geothermal energy production from Federal lands under proper regulation and environmental control. Because of the wide geographical distribution of lands affected by the leasing program, extreme variability of ecological and geologic factors affecting these lands, and limited experience in geothermal-resource development, it is not practicable to describe in detail in a statement such as this all aspects of the potential environmental impacts.

The policy of the Federal government pursuant to the Geothermal Steam Act of 1970 is to encourage development and use of geothermal resources consistent with the principles of multiple use of land and resources. The proposed leasing regulations require (Appendix A, Sec. 3200.0-6(c)) the Director, Bureau of Land Management, prior to final selection of tracts for leasing, to evaluate as appropriate the potential effect of exploration, development, or production upon the environment and natural resources of the areas affected during each phase of such activities. It is recognized that the issuance of geothermal leases for specific proposed leasing areas may involve major Federal action significantly affecting the quality of the environment. In such circumstances environmental statements would be prepared and disseminated in accordance with the provisions of Section 102(2)(C) of the National Environmental Policy Act of 1969.

II. Environment to be Affected

The Geothermal Steam Act of 1970 defines in Section 3 the public lands potentially available for geothermal leasing. These include principally (Appendix A, Sec. 3201.1) (1) public, withdrawn, and acquired lands administered by the Secretary of the Interior, approximately 451 million acres in 25 States; (2) national forests and other lands administered by the Forest Service, Department of Agriculture, approximately 187 million acres in 45 States and Puerto Rico; and (3) lands containing a reservation to the United States of the geothermal resources.

Most of these public lands are located in the western United States and Alaska, but significant areas exist in other parts of the country. The major known geothermal resource areas are located on the lands in the western United States. The geologic and biologic environment of public lands is diverse and does not lend itself to a general description. Existing land use patterns and management include: mining and mineral leasing operations; timber production; rangeland used under a system of grazing leases; fish and wildlife habitat; and outdoor recreation. These lands include important open space, and watersheds for the streams of the western States. Lands subject to leasing do not include towns and cities, nor are they generally the sites of significant industrial or commercial developments.

Figure 1 shows the location of lands which at this time are either known to be valuable for geothermal resource development or are considered prospectively valuable for geothermal resource development. The law provides that all of the above described lands are, in the discretion of the Secretary of Interior, subject to geothermal leasing, except that where another agency has jurisdiction, concurrence by that agency must be obtained by the Department of the Interior.

III. Program Plan

The proposed leasing and operating regulations issued pursuant to the Geothermal Steam Act of 1970 would provide the framework for exploration, development, and utilization of geothermal resources on Federal lands, consistent with multiple-use management objectives. All activities under the lease will be subject to regulations designed to protect the environment. These regulations are directed primarily at the exploration for and development of the geothermal resources. Surface use of the land is restricted to exploration and development for geothermal resources and for the production, utilization, and conservation of those geothermal resources. A separate permit would be required for any use of the surface for a power-generation plant or commercial or industrial facility and would include such terms and conditions as may be prescribed by the Secretary of the Interior (Appendix A, 3200.0-8). Activities incident to power development, such as electric-power transmission lines and road construction, would be subject to environmental evaluation at the time of application for the rights-of-way and related permits which would be required for such activities.

Provisions of the leasing and operating regulations directed specifically toward environmental protection include the following:

Environmental evaluation -- Section 3200.0-6(a) of the leasing regulations provide for an initial pre-leasing report on resources of the area considered for leasing and the potential impact of operations on the environment. Concerned Federal agencies would be asked to comment on the proposal. If, upon review of any pre-leasing report, it is determined that such action would constitute a major Federal action significantly affecting the quality of the environment, an environmental statement will be prepared and made a supplement to this statement.

Section 3200.0-6(b) requires that for specific tracts offered for leasing the Director shall, when appropriate, evaluate fully the potential effect of the leasing program on the total environment, aquatic resources, aesthetics, recreation, and other resources in the entire area during exploration, development, and operational phases. To aid in this evaluation and determinations, the Director may request and consider the views and recommendations of appropriate Federal agencies, may hold public hearings after appropriate notice, and may consult with State agencies, organizations, industries, and individuals. The Director shall develop special leasing stipulations and conditions when necessary to protect the environment and all other resources.

Industrial facilities -- Section 3200.0-8 limits surface use of the land under lease to production of geothermal resources and related activities. Construction and operation of a power plant or commercial or industrial facility would require a separate permit from the Secretary of the Interior and would be subject to such terms and conditions as he may prescribe, including those designed to safeguard the environment.

Environmental protection -- Section 3204.1 enumerates the specific terms and conditions relating to environmental protection. Paragraph (c) provides that any use of pesticides and herbicides must comply with all rules in this respect issued by the Department of the Interior and the Environmental Protection Agency. Paragraph (c)(2) requires that all operations be conducted in compliance with Federal and State water quality standards and appropriate public health and safety standards. It specifies further that toxic materials shall not be released to any lake, drainage, or underground water. Paragraph (c)(3) requires that all gaseous emissions be in accord with appropriate Federal and State air quality standards. Paragraph (c)(4) requires that the lessee minimize disturbance to vegetation, drainage channels, and stream banks as erosion-control measures. Paragraph (c)(5) requires control of noise emissions from operations so as to prevent harmful effects on operating personnel and the public. Paragraphs (d), (e), (f), and (g) give the authorized government representative the authority to enforce requirements for sanitation and waste disposal, maintenance of aesthetic values, protection of wildlife, aquatic life, and protection of antiquities and historical sites. Specific lease stipulations and, where practicable, Geothermal Resources Operational Orders (GRO) would be prepared to achieve adequate controls on a site-by-site or area-by-area basis.

Waste Prevention -- Section 3204.2 requires the lessee to use all reasonable precautions to prevent waste of geothermal resources and other resources of the leased land.

Compliance Bond -- Section 3206.1 requires separate bonds to insure compliance with the terms of the lease and to insure protection of surface rights. Liability under any bond will not be terminated until all lease terms and conditions have been fulfilled.

Non-compliance -- Section 3243.4 1/ provides for cancellation of the lease after due notice for any violation of the leasing regulations or lease terms.

Cleanup upon termination -- Section 3243.5 1/ requires removal from the premises of materials, machinery, structures, and related equipment within a 90-day period after termination of the lease. Section 3245.1 requires proper clean-up and restoration of the site insofar as is practicable to its original condition before termination of the lease.

Further environmental protection is provided by the proposed operating regulations (Appendix B) as follows:

Regulation of operations -- Section 270.12 provides, among other things, that authorized field officials of the Department shall

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1/ This regulation is improperly included in Subpart 3243 of the proposed regulations and would be incorporated in Subpart 3245 prior to promulgation of the leasing regulations.

inspect and supervise geothermal operations in order to prevent unnecessary damage to natural resources, prevent degradation of water quality, protect other environmental qualities, and prevent injury to life and property. This section would include inspection and supervision of operations to determine whether the operations would cause subsidence of the land surface (an environmental impact which is discussed hereafter in more detail), and, if so, whether the potential subsidence would be unacceptable in the circumstances. This section provides that the authorized field official shall issue orders as necessary to accomplish these purposes. If a lessee submitted an operating plan involving the use of a nuclear fracturing device for production of geothermal steam, the Department would insure that a separate environmental statement were filed before acting on the submittal.

Drilling and abandonment of wells -- Section 270.14 provides that these activities must be done in accordance with lease terms and regulations and further provides that in the case of failure to comply, with respect to the abandonment of wells, the Department is authorized to perform the work needed at the expense of the lessee.

Precautions -- Section 270.30(b) requires the lessee to take all reasonable and necessary precautions to prevent injury or damage to persons or property, or waste of any natural resources, including plant and wildlife, or environmental pollution or damage. Geothermal Resources Operational Orders (GRO) would be prepared to achieve adequate controls on a site-by-site or area-by-area basis.

Disposal of well effluents -- Section 270.41 requires approval by the Department for disposal of well effluents, including without limitation disposal by reinjection, taking into account the potential for increased seismic activity and the potential effects on ground water, streams, plants and wildlife, the atmosphere, and other aspects of the environment.

Pits or sumps -- Section 270.43 provides that use of pits or sumps for discharge of fluids shall be subject to the approval of the authorized field officials of the Department and that in no event shall the contents of a pit or sump be allowed to contaminate streams, ground waters, lakes or rivers; adversely affect the environment, including wildlife and plant life; or damage the aesthetic value of the property or adjacent properties.

Violation of the regulations or lease terms -- Section 270.80 provides that whenever an owner of a lease fails to comply with the provisions of the regulations or lease terms, the Department shall suspend all operations under his jurisdiction and give the lessee notice to remedy the faults or violations. Failure to perform or commence the required remedial action may result in cancellation of the lease.

IV. Evaluation of Environmental Impact

A. PROBABLE IMPACT OF THE PROPOSED ACTION ON THE ENVIRONMENT

The environmental impact of exploration, development, and production of geothermal steam and associated geothermal resources would be dependent upon a number of factors. Among these are the biological, geographic, geologic, physical, climatological, and demographic characteristics of the area to be developed and the mineral resources of the basin, as well as the aesthetic, scenic, recreational, agricultural, industrial, and other potential land uses. Some of the other important factors involving the nature and character of the geothermal resources are the physical and chemical character of the steam and/or brines, the relationship between the geothermal reservoirs and fresh-water reservoirs, and the areal extent and energy content of the geothermal resource.

Geothermal reservoir systems can be divided into two broad categories on the basis of the fluid produced: (1) vapor-dominated ("dry steam") systems, and (2) hot-water systems (Appendix F). The vapor-dominated systems yield steam and other gases with little or no associated water. The hot-water systems yield water, and if the temperature is sufficiently high, some of the water flashes to steam, which can be directed through turbines to generate electricity. The single commercial-scale geothermal power development in the United States at The Geysers, California, is a vapor-dominated system; however, most hot-spring systems in the U.S., including most of the KGRA's, yield fluids that are dominated by hot water rather than by steam.

These two types of systems pose quite different environmental problems. The vapor-dominated systems generally yield relatively pure steam with minor amounts of boron, carbon dioxide, hydrogen, methane, nitrogen, hydrogen sulfide, and ammonia. Analysis of these condensates commonly indicates a water containing predominantly dissolved ammonium and bicarbonate ions. Because the water content is low and most of the water is required for power-plant cooling, there is relatively little waste water to dispose of, and it is generally low in noxious constituents. The gases present in the steam largely are discharged to the atmosphere with the water vapor.

The hot-water systems, on the other hand, generally yield saline waters containing a wide variety of metallic salts and silica; in some of the higher temperature systems the fluid is a highly concentrated brine. Any system for disposal of such waste waters must comply with applicable water-quality standards as provided by the Federal Water Pollution Control Act as amended. Purification or treatment for the removal of contaminants may be practical in some cases; however, it is expected that most residues will have to be disposed of by reinjection into the producing reservoir.

Development and production of geothermal resources involve six phases: exploration, test drilling, production testing, field development, power plant and power line construction, and full-scale operations. Each phase would have differing impacts on the environment depending upon the potential of the geothermal resources and the varying relationships with other actual and potential resources.

Exploration -- The exploration of both known and potential geothermal areas would be designed to locate and define commercial geothermal reservoirs and to evaluate the impact of possible geothermal development upon the environment, including surface and subsurface resources and various land uses. Principal exploration activities include topographic and geologic mapping, geologic field examinations, ground and spring temperature surveys, geochemical studies, geophysical surveys, and shallow drilling for the purpose of sampling superficial ground waters, temperature measurement, and subsurface rock sampling. These exploration activities are surface-oriented investigations subject to control as to potentially significant environmental damage. The movement of field parties over access roads or cross country can be regulated for the protection of resources. Where temporary field camps are needed, they would be established in accordance with permit terms which would be designed to protect the environment. Any shallow drilling required for geophysical exploration would be carried out under the provisions of 43 CFR Subpart 3045.

Test Drilling -- Locations for the drilling of test wells would be selected on the basis of preliminary exploration, approved exploration plan, and other data. These wells provide subsurface geologic data, locate potential productive zones within the geothermal reservoir, help delineate the reservoir limits, and aid in determining the physical and chemical properties of the reservoir and reservoir fluids.

The drilling of test wells would be performed according to prescribed practice to minimize environmental impact (Appendix B, Section 270.34, 270.35). Access roads to the well sites and graded drilling sites would be necessary for the movement of drill rigs and supplies. Such roads would be constructed in accordance with the approved plan so as to control erosion. Restoration would be required if the road is not intended for permanent use (Appendix A, Section 3204.1(h)).

Current drilling equipment, technology, and methods are similar to those used in oil and gas operations, with modifications to suit the specific needs of geothermal drilling. Equipment, such as derricks, substructures, mud-circulation systems, drill strings and casing, well-head equipment, cements, and cementing equipment would be authorized for use only if it has been properly tested, and its use would be supervised by authorized field officials of the Department (Appendix B, Sections 270.11, 270.14, 270.15). During the drilling of a well provisions would be made for the control and disposal of drilling muds and fluids, prevention of blowouts, and containment of reservoir fluids (Appendix B, Sections 270.40, 270.41). Backfilling of mud pits and fluid ponds, use of blowout preventers, and casing and cementing of the well would be required to limit any adverse environmental impact at the immediate well site. If a test well is to be abandoned, the well would be plugged in accordance with a plan approved by the Department (Appendix B, Section 270.44). A well yielding only fresh water could be developed as a fresh-water source (Appendix A, Section 3243.3-3). When field camps are abandoned the camp sites would have to be restored to preoccupancy conditions insofar as is practicable.

Blowouts, in which steam or water escapes uncontrolled, pose a distinct environmental hazard in geothermal drilling. The principal adverse environmental effects of such accidental releases, which are discussed in greater detail in Appendixes C, D, and E, are waste of the resource, noise nuisance, air contamination from gaseous emissions, and possible pollution of surface and ground-water resources. Once a blowout occurs it is troublesome to control because of the difficulty in handling escaping hot fluid; however, unlike similar problems encountered in petroleum drilling, there is essentially no fire hazard in the case of a geothermal accident. To minimize this hazard proper casing design would be required to assure that the pressurized fluid would be confined to the well bore and would be controlled through surface shut-in equipment required by the regulations (Appendix B, Section 270.40).

Production Testing -- Production testing is the transitional phase between exploration and potential development and production of a geothermal reservoir. A well that has penetrated a potentially productive geothermal zone is developed and tested over a period of time to clean out the well and to determine the flow rate, composition and temperature of fluids and gases, recharge characteristics, pressures, compressibility, and other physical properties of the reservoir and reservoir fluids. Testing requires the maximum production of the well followed by various controlled production rates over sufficient time to establish the hydrodynamic properties and/or boundry characteristics of the reservoir. This would involve, among other things, venting of the well. Venting of the well would be done under approved techniques in a manner designed to meet environmental requirements (Appendix B, Sections 270.41, 270.42). All production fluids must be channeled to settling or storage ponds so as not to discharge into local water courses (Appendix B, Section 270.43). The use of settling or storage ponds would contain and localize thermal and chemical discharges to the immediate pond area, which would otherwise cause water pollution. At the end of the test period the ponds would be filled in and replanted. Venting of steam to the atmosphere can create an adverse environmental impact if the steam contains large amounts of noxious gases, such as hydrogen sulfide. When such gases constitute a significant adverse effect, removal would be required (Appendix B, Section

270.41). The noise created by venting steam can also be a problem. The use of special steam mufflers or discharge of steam under water would reduce the noise to levels which would not adversely affect the welfare of operating personnel and the public (Appendix B, Section 270.42).

Test drilling and production testing of geothermal steam resources would have varied impacts upon fish and wildlife, not all of which are completely understood. Most would occur on or adjacent to well sites, although water quality impacts could potentially have farther-reaching influences. The magnitude of particular impacts would be interrelated with fish and wildlife and their habitat within the area of development influences, extensiveness and duration of the entire geothermal development activities and operations, and the effectiveness of control measures. Many of the impact types lend themselves to whole or partial control, and the proposed leasing and operating regulations provide a regulatory framework by which such control could be achieved.

As a specific geothermal development would proceed through test drilling and production testing, physical land modification and commotion would occur. These activities would include such things as construction of roads, ponds, and drill sites and drilling of wells, and would result in loss of wildlife values, including both habitat and human use within the area of influence. Such modifications would physically alter or remove existing wildlife habitat and permanence of these effects would be dependent upon the nature of the particular construction or operational activity and the completeness of control measures. In addition to land modification, the commotion would have displacement effects upon animals and birds in the site vicinity. The degree and permanence of displacement or disturbance would depend upon the scope and type of activity. For example, although the effect on wildlife is not clearly understood or predictable, noise from testing wells would have a disturbing influence upon animals within the site vicinity.

Most areas adjacent to drilling and test operations, but outside of the immediate zones of physical modification, would retain part or all of their fish and wildlife populations and habitat. Where existing public access would be restricted in order to reduce hazards to the public, there would be an accompanying reduction of hunting, angling, and camping opportunity on these lands. The importance of these losses would depend upon the capacity of other available habitat areas to absorb the pressures which are presently absorbed by the geothermal area.

The major potential impact upon fish and wildlife would result from improperly planned or executed handling of geothermal fluids. If controlled releases, spills, seepage or well blowouts were to result in significant additions of toxic or highly saline geothermal waters to streams, ponds, game management areas, etc., adverse impacts would result. These impacts would include the alteration of fishery habitat and waterfowl nesting and feeding areas over the area of influence. If toxic substances, such as boron, sulphides, methane, fluoride, selenium, and others were present in such releases, they also would exert adverse impacts. For example, the present Geysers installation in California at one time added heated fluids, containing boron and ammonia, to Big Sulphur Creek, that may have resulted in a loss of aquatic life. Releases of heated effluents to aquatic habitat would alter aquatic habitat and life, perhaps creating temperatures intolerable to existing fish species and stimulating growths of nuisance algaes. However, the probability of these potential problems occurring at or near any given well site appears to be small, since the proposed geothermal regulations would require controls, including reinjection of problematical brine wastes, to avoid surface water degradation.

Reinjection of geothermal fluids also possesses the potential for adverse impacts upon fish and wildlife; for example, the present major source of water for the Salton Sea in California is surface and subsurface irrigation waste water. If significant quantities of highly saline geothermal waters were added to the sea as a result of improperly planned reinjection techniques, the additions would contribute to degradation of the existing marginal water quality.

If ponds were required as part of the development, they would, depending upon local circumstances, have beneficial impacts upon fish and wildlife resources. If the produced water was free of toxic materials and disease-producing elements, benefits could be significant in the form of increases in aquatic habitat and nesting and feeding areas for waterfowl and marsh birds.

Erosion from roads and the construction activities would predictably result in added siltation of aquatic habitat within the area of project influence. The siltation would be most severe during construction phases, although some might extend into the operational stages. Harmful siltation effects would include coverage of fish spawning and feeding areas and shallowing of streams. The degree of siltation damage to aquatic habitat within the area of influence would be dependent upon the success of erosion control measures.

When the results of the production testing are not favorable for power development, field camps, access roads, ponds, and other property would have to be removed or reclaimed and the area restored to its previous condition insofar as practicable. All well locations would be recorded by the Department of Interior and those wells that are no longer producible or that are not needed for observation or other uses would be plugged to minimize adverse environmental impact (Appendix B, Section 270.44).

In the event that exploratory drilling and production testing indicate that a geothermal field has economic potential for power development, a commitment must be obtained from a customer electric utility to warrant further development. This would be a major decision point in the development and production of the geothermal resources of a given area. Additional permits would be required for construction of industrial facilities on Federal lands and for road and power-line rights-of-way.

Field Development -- Favorable exploration, test drilling, and production testing programs would lead to the drilling of a number of additional wells to develop the field. Essentially the same types of environmental effects would be involved in the field development phase as in the preceding phases. Those environmental protection measures discussed under test drilling and production testing would be systematically applied to the increased activity and drilling during the field development stage. Access roads would be improved to give permanent service. Service and living quarters would be constructed if required, and adequate water sources and sewage disposal facilities would be provided.

Normally several wells spaced over a considerable area are required to provide sufficient energy to supply a single electric generating unit. The spacing of wells is an important reservoir conservation consideration. The spacing of production wells should be wide enough to minimize interference between the wells while assuring the maximum output from the field. Permeability and other reservoir parameters would be analyzed to determine the proper distance between wells (Appendix B, Section 270.15). At this time the construction of a power generating plant normally would be underway also; provisions for its construction would be separately considered (Appendix A, Section 3200.0-8).

Field development in a large field can continue for many years as new wells and additional power-generating units are developed. Since most environmental impacts can be cumulative, for example, water and air pollution, proper care must be exercised at each step. Well-site cleanup thus would be progressive, access roads would be maintained, pipelines connecting producing wells to the power-plant feed lines would be regularly inspected to detect leakage, and well heads would be inspected for exterior corrosion damage or structural weakness to avert blowouts or leakage.

If a field goes out of production all ponds, access roads, and disturbed property would be restored to a natural state insofar as is practicable and all wells plugged to prevent leakage and venting of reservoir fluids.

Power-Plant and Powerline Construction -- Prior to construction of facilities for the actual generation and transmission of electrical power, the activities associated with a new geothermal project are aimed at the evaluation of the geothermal reservoir. Where the information developed during these evaluation phases indicates that production from the reservoir would entail unacceptable adverse environmental effects continuance of the project would not be approved. The installation of power generation and transmission facilities, much of which could not be salvaged or converted to other types of power generation, involves multimillion dollar investiments. Thus, it would be essential to evaluate carefully, at the end of the pre-construction phases and prior to the commitment of such large capital expenditures, all foreseeable adverse environmental effects of the project. For example, such effects as potential air and water pollution, the impact on fish, wildlife, and recreation, and aesthetic degradation, would be re-examined. This would precede the stage where a separate permit for plant construction would be required (Appendix A, Section 3200.0-8).

Power generation and transmission facilities would be constructed in stages to establish the most efficient scope for the project in relation to the associated geothermal reservoir. A geothermal electrical generator, in contrast to a conventional steam-electric installation, has no boiler, firebox, combustion or combustion products. However, it is practicable to transport steam only about one mile. Also, all geothermal power plants installed to date have been small when compared to other types of power plants, not exceeding 110 megawatts at an individual site. It is expected that this pattern of development will continue indefinitely.

Under present technology, above-ground insulated pipes are used to transport the steam from the well to the power plant because of pronounced thermal pipeline expansion and contraction during operation. An underground pipe system is not economically feasible owing to service and equipment requirements.

Transmission facilities accommodating power plants are built above ground. It would be required that all structures, including power-transmission facilities and enclosures for generating plants, be designed to meet existing local architectural standards, to the extent practicable, and should be designed to blend harmoniously with the surrounding environment, and should have a reasonably artistic and pleasant appearance in accordance with Environmental Criteria for Electrical Transmission Systems (1970).

If corrosive fluids are produced by the wells, the equipment for handling such fluids, or inside surfaces of such equipment, must be made of suitable corrosion-resistant materials. This would be normal design practice to assure reasonable life for the equipment; it also is necessary to prevent leaks and spills which could result in contamination of surface waters.

If noxious, foul-smelling or otherwise objectionable gas is present in appreciable quantity in the fluids emitted from a geothermal well, precaution must be taken to prevent such gas from entering the atmosphere (Appendix B, Section 270.41).

It would be required that all access roads, including those related primarily to power generating and transmission facilities, be designed to conform to existing local standards, to the extent practical, and plans would include provision to prevent them from becoming sources of airborne dust, as provided in the general provisions of the leasing regulations (Appendix A, Section 3200.0-6(b)).

If the effluent from a geothermal well is hot water, and this water contains substances that are found to be detrimental to man or the environment, the contaminating substances must either be removed before surface discharge or the fluids must be reinjected (Appendix B, Section 270.41). If no harmful materials are present, or if these materials can be economically removed from the fluids, it is possible that large quantities of water would not have to be disposed of as waste effluent but could be produced as fresh water at the geothermal installation. Conservation and utilization of such demineralized water would be required where such production is economically feasible (Appendix A, Section 3243.3).

<u>Full-Scale Operations</u> -- Most of the potential adverse environmental effects that would be present during the preceding phases would be magnified during full-scale operations. The potential for environmental damage increases with the addition of each new well. Some adverse environmental effects are

unavoidable, such as the potential for air and water pollution as a result of accidental releases; removal of wildlife habitat; restriction on surface use of land in the vicinity of installation; and general aesthetic deterioration through industrial development. The regulations provide for evaluation of each step so that the unavoidable effects are recognized, and each new phase assumes their mitigation.

The ground-water regime in the general area of a geothermal field may be altered irretrievably if appropriate control procedures are not employed. A fresh-water aquifer may occur above a geothermal reservoir which contains hot saline water. Tapping the geothermal strata could result in contamination of the fresh water if one horizon were not kept isolated from the other by properly cementing the casing of either production or reinjection wells. During the earlier stages of a project suitable data must be accumulated and analyzed, and studies made to determine what steps should be taken to prevent or minimize alteration of the area ground-water regime.

Experience in petroleum production indicates that marked changes in reservoir pressure, whether due to pressure reduction from the production of fluids, or to pressure increase due to injection, may in certain types of reservoirs, especially in faulted or fractured rocks, result in instability leading to earthquakes. Such instability due to production alone has been documented in the Wilmington Oil Field, California (Poland and Davis, 1969, p. 205) instability due to injection was documented at the Baldwin Hills Oil Field, California (Hamilton and Meehan, 1970), and at the Rangely Oil Field, Colorado (Healy and others, 1968), and in connection with injection of waste waters at the Rocky Mountain Arsenal, Colorado (Healy and others, 1970). Similar increases in seismic activity have also been noted in association with filling of large surface reservoirs with attendent change in hydrostatic head, including Lake Mead on the Colorado River and Lake Kariba in Africa (Rothe, 1969, p. 215). The role of fluid-pressure changes in triggering earthquakes is not well known, but a causative relation has been established in many areas. In general, such earthquakes have not proven disastrous, but the potential for a major quake cannot be ruled out. In any event earthquakes must be counted as a potential environmental impact associated with geothermal development, and provisions must be made for seismic monitoring before and during major production. If monitoring indicates significant increase in seismicity, particularly in intensity of motion, remedial steps to alleviate stress would have to be initiated promptly.

Subsidence of the ground surface over and around a geothermal reservoir can result from the withdrawal of large volumes of fluids (Poland and Davis, 1969, Hunt, 1970). Subsidence would reach a maximum rate during full-scale operations unless fluid is returned to the reservoir. In some instances it may be practical to reinject the geothermal fluids after extracting most of their heat. Studies would be initiated prior to approval of operating plans to determine the existence of subsidence potential and its probable consequences. If fluids are not reinjected, subsidence measurements would be made during the course of a project, at intervals to be determined by the rate of potential subsidence to determine whether remedial action would be required.

Comprehensive planning beginning with the earliest stages of a project and continuing through full-scale operations can contribute greatly to harmonious layout and design, appropriate utilization of land surface, minimum heat loss, and general efficiency. If there is authorized existing use of the land surface for non-geothermal purposes, the geothermal developer would not be allowed to unreasonably interfere with continued utilization of the surface for such purposes (Appendix A, Section 3200.0-8). Whenever operation of any well or any part of a project is to be discontinued, its deactivation, dismantling or abandonment must be accomplished in an orderly fashion, following procedures such as those described previously.

Noise due to steam ejection or expansion can be severe and can be expected to reach its highest intensity during testing operations. Such noise can range from a low-frequency region to a very high frequency region. Experiments at the Otake Geothermal Power Plants located in the Aso Mountains in Japan have shown that an ordinary expansion chamber muffler is not effective for high-frequency abatment. However, a specially designed muffler effected good noise reduction, even in the high-frequency region, and it did not cause much resistance to steam flow. Venting steam under water also reduces noise effectively.

Drilling and fluid production will involve the same considerations during full-scale operations as during the testing and earlier production operations including prevention of blowouts, sealing of wells, and providing for control of fluid flow from a well. Steam containing no noxious gases generally can be exhausted to the atmosphere without causing significant environmental damage if noise is kept at a moderate level. However, condensing the steam may result in greater heat recovery and augmentation of fresh-water supplies.

Full development of a geothermal field, as with drilling, production testing, field development and power plant and power line construction, would have varied impacts upon fish and wildlife. Most of the impacts would occur on or adjacent to construction and plant sites. Many of the impacts lend themselves to whole or partial control, and the proposed operating regulations provide a regulatory framework by which such control could be achieved.

The most significant potential impacts upon fish and wildlife would result from handling of geothermal fluids. For further details, the reader is referred to the fish and wildlife discussion under "Production Testing".

As a geothermal field would proceed through construction and operation stages of the power plant, pipelines, transmission lines, and any by-product facilities, the loss of wildlife values, which began in the test drilling and production testing stages, would continue within the immediate area of influence. These losses would include both wildlife habitat and its use. Where existing public access would be restricted in order to reduce hazards to the public, there would be an accompanying reduction of hunting, angling, and other recreational opportunity on these lands. The importance of these losses would depend upon the capacity of other available habitat areas to absorb the pressures presently absorbed by the geothermal area.

Transmission lines located in flyways or over nesting and feeding sites would cause some mortality of waterfowl, raptors, and other birds from collision and/or electrocution. The magnitude of this type of loss cannot be predicted but would be expected to be minor.

Electrical-energy generation during full-scale operations would be at its maximum and generally may be expected to continue at approximately the full-scale level for many years. All initial facilities associated with production and conversion of geothermal energy, and by-product production facilities -- e.g., a processing plant for extracting valuable chemicals or minerals from geothermal fluids, and/or facilities for producing and perhaps storing fresh water might serve as a pilot plant for making improvements and additions to the project. Likewise, operation of a plant addition might provide useful data for planning and designing the next addition. Data would be accumulated from the outset by the operator and would be available for designing environmental safeguards as well as for designing other types of improvements.

The by-product potential of some geothermal installations is expected to be of commercial interest. Heat may be extracted from geothermal fluids for purposes other than power generation. It may be feasible in some instances to extract valuable chemicals from the brines produced by geothermal wells. Also, large quantities of fresh water may be produced at some installations. Some of these by-products represent positive, beneficial, environmental influences. At the same time, safeguards must be employed so that waste streams from these by-product plants do not contaminate or adversely affect the environment, for example, by contributing to air or water pollution. Thus, disposal would be supervised to assure that such effects will be prevented.

Closely allied to these environmental considerations is the need to remove substances in geothermal fluids that constitute hazards but whose removal would not be profitable. For example, noxious constituents may be present in the gases that remain after geothermal steam condenses.

Discharge of thermal or saline fluids resulting in pollution of surface streams, lakes, and watersheds must be prevented throughout full-scale operation as well as during the preceding operations. Essentially the same equipment, techniques and procedures described in connection with drilling, field development, and production testing would be employed throughout the remaining productive life of a project. Also, in or near areas prone to earthquakes or landslides, the Department would require that well installations, pipelines, and related facilities be designed and constructed to safeguard against rupture and consequent environmental damage in the event of an earthquake or landslide.

Spills and leaks can be avoided or minimized during full-scale operations by well-conceived design and inspection policies, following the practices described under "Field Development" and such design and inspection would be required by the Department. Corrosion-resistant materials should be used wherever necessary. Instrumentation such as that for preventing overflows may be necessary in some installations such as chemical plants and, if so, they would be required by the Department. Also, a suitable industrial sewer system may be called for. Thorough inspections would be made at regular intervals, covering all facilities, such as pipelines and wellheads, where long continued service with minimal maintenance might result in escape of fluids that could affect the environment adversely.

B. ANY PROBABLE ADVERSE EFFECTS WHICH CANNOT BE AVOIDED

Regulations on leasing and operations provide authority for minimizing, within acceptable standards, the unavoidable adverse effects associated with geothermal exploration, test drilling, development, and operations.

Exploration phase. The adverse impact would normally be limited to temporary disturbance of the terrain and wildlife by vehicle traffic using existing roads and trails. Where holes are drilled for geophysical exploration, such drilling would be regulated under 43 CFR Subpart 3045, which requires restoration of land to its original condition insofar as practicable upon completion of drilling.

Test-drilling phase. Following award of leases, heavy drilling equipment capable of drilling several thousand feet would be required. The need for improvement of existing roads and construction of new roads to provide access for drilling equipment and supplies to the drilling sites constitutes an unavoidable impact. At each drilling site a level area of approximately 1/2 to 1 acre is required for drilling operations; in hilly country this may necessitate considerable grading. This construction would have an obvious aesthetic impact, but it must be carried out under immediate government supervision and under lease provisions drafted with the objective of minimizing adverse impact as provided in Appendix A, Section 3200.0-6.

Significant noise levels could be reached during operations. Noise which would affect human welfare would be prohibited (Appendix B, Section 270.43). Release of harmful fluids to the environment also could occur. In all cases the operations are to be conducted in compliance with State and Federal air- and water-quality standards (Appendix A, Section 3204.1). Should accidental releases of fluids or noxious gases occur, the operating regulations require immediate remedial action under penalty of suspension of operations and could result in cancellation of the lease.

With respect to effects on fish and wildlife, the following unavoidable impacts can be expected, but their relative importance would vary depending upon the particular site. Physical land modification and disturbance effects would involve a loss of wildlife values in the immediate area of a development. Siltation may occur in streams or other bodies within the area of influence with consequential damage to aquatic life. Reduction of hunting and recreational opportunity would occur where existing access would be restricted to protect geothermal facilities and reduce hazards to the public. Transmission lines would result in some mortality of waterfowl, reptors, and other birds from aerial collision and/or electrocution.

Production testing phase. Production testing of a vapor-dominated system requires release of steam at high rates for periods of as long as several weeks or months -- until the flow stabilizes at a uniform level. During this period the noise impact and gaseous emissions are at their maximum level. Where this proves environmentally unacceptable, the Department would specify the degree and method of noise abatement (Appendix B, Section 270.43).

In water-dominated reservoirs, production testing likewise requires production of the formation fluid over an extended period. Water produced would normally be impounded to dissipate the heat before release to the environment. Furthermore, if the water contains toxic materials or would contaminate the environment in violation of State or Federal water-quality standards, it cannot be disposed of to surface waters or usable ground waters. Thus disposal of waste water would be accomplished by: (1) release to saline lakes or the ocean, where such release could be shown to be harmless, (2) reinjection of waste fluid into the producing zone or other underground reservoirs which would not be adversely affected by such injections, (3) evaporation of the water in ponds with subsequent salvage of the mineral content, or (4) demineralization of saline waters with a view to economic recovery of fresh water and/or mineral resources.

The adverse impacts associated with earlier exploration and testing phases would increase in proportion to the scale of development. Currently about 10 wells are needed to supply each generating station. Additional roads and other construction activities would adversely affect the landscape and wildlife. The power plant, steam lines joining wells to plant, and electric transmission lines would also disturb the natural environment. Hazards of air and water pollution through accidents would also increase with scale of activity. In addition to the foregoing at least two new adverse impacts would be introduced during full-scale operation, namely, land subsidence and increased seismic activity. Significant impact would not be expected until major production begins.

Land subsidence occurs because of compaction of the reservoir materials as fluid is removed and reservoir pressure decreases. This is a natural consequence of fluid production and some compaction occurs in any confined system with substantial pressure decline. The amount and distribution of subsidence is a function of pressure decline and physical character of the reservoir materials, especially their compressibility. Land subsidence can be roughly predicted from tests of core material prior to production, but the only precise measure is obtained by measurements of surface altitude before and during production. The impact of subsidence may be negligible in an isolated area, but in a developed area, particularly where rivers and engineering structures such as canals require maintenance of a constant grade, the adverse impact can be very severe. Moreover, wells penetrating compacting sections commonly are severely damaged by the compaction.

One means of alleviating the subsidence problem and at the same time disposing of unwanted waste water is through pressure maintenance by reinjection of such wastes through wells to the producing zone or other reservoir. However, this of itself can lead to the potential adverse impact of increasing seismicity. As noted earlier, experience in several parts of the world has shown that pronounced changes in fluid pressure in confined systems can lead to instability and subsequent earthquakes. Indeed, fluid injection into fault systems has been proposed as a means of triggering earthquakes and thus relieving accumulated strain before a major earthquake occurs. The relationship of fluid-pressure changes to earthquakes is little known, and research in this field has barely begun. To safeguard against this hazard in operations under Federal jurisdiction would require seismic monitoring in all areas of substantial geothermal production prior to and during production. If seismic activity shows signs of increasing significantly as a result of fluid production or reinjection, operating procedures would have to be modified to eliminate any hazard which poses a threat to life or property. Even without reinjection there is a seismic hazard due to production itself, as the rocks rearrange themselves in response to declining reservoir pressure. Production procedures would have to be modified to eliminate any hazard such as described immediately above. Although it is not entirely free of its own adverse effects on the environment, as discussed herein, geothermal development offers possibilities for reducing air and water pollution associated with other types of electric production. Recognition of the problems which may occur and design of effective controls would assist in coping with these problems in an acceptable manner.

C. ALTERNATIVES TO PROPOSED ACTION

The principal alternatives to the proposed action are:

(1) The Secretary could decline to promulgate the proposed geothermal leasing and operating regulations (Appendixes A and B). The Secretary would, however, continue to be under Congressional direction, pursuant to the terms of the Geothermal Steam Act, to formulate geothermal regulations to implement that act.

(2) The Secretary could postpone geothermal leasing pending further study of the environmental impact. This would mean that, on a short term basis, there would be no direct environmental impact on Federal lands. Considerable additional data and information, which would be helpful in further evaluating the environmental effects of geothermal resource development and production, is expected to be generated from exploratory drilling activities under geothermal leases. Such information would not be available for evaluation while geothermal leasing is being postponed.

(3) The Secretary could decline to issue any leases to develop Federally owned geothermal resources. This would mean that there would be no direct environmental impact on Federal lands. Development of non-Federal geothermal resources would not be affected by this type of action. At the present time, the only operating geothermal development in the United States is situated on private lands.

Under this alternative, knowledge of the environmental effects of geothermal development would not be expanded to the same extent as when study is directed to the nature and characteristics of given geothermal reservoirs as disclosed by actual exploration. The design of more sophisticated controls for the expected environmental impact of such development would, in all probability, be affected similarly. In addition, energy needs, which would otherwise be supplied by geothermal development, would have to be met by utilizing other energy sources, e.g. fossil fuel or nuclear plants, which could have greater impact on the environment.

D. THE RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF MAN'S ENVIRONMENT AND MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

Leasing of lands for geothermal resource development would inescapably involve commitment of a portion of the geothermal, water, and land resources of the areas involved. The extent of these commitments and an assessment of their environmental impacts have been described in the proceding sections. However, the relationships between these proposed uses of the environment and the maintenance and enhancement of its long-term productivity must be examined.

Exploration and testing under a geothermal lease to determine the nature and extent of geothermal resources would result in a short-term use of the lands. Where such exploration proves unsuccessful, there would not be any use of the lands for development and production of the resource. In those circumstances, a lease would terminate at the end of its 10 year primary term, unless sooner relinquished by the lessee. As a condition of the authorization for exploratory activities, land disturbed by unsuccessful exploration would have to be restored to its original condition, insofar as practicable, upon termination of that drilling activity.

Where exploration discloses the existence of economically attractive geothermal resources, the development and production of such resources for electric power generation, and, in some cases, mineral by-products could be expected to occur. The geothermal resource normally would be produced at a rate greater than natural replenishment, thus both the geothermal reservoir and the industrial facilities used in production would be retired within the foreseeable future. When the reservoir is no longer capable of sustaining the geothermal operation, the lease would terminate, facilities would be dismantled, and the land would be restored, insofar as practicable, to its original condition.

A. The Resource

By developing geothermal resources, a previously unused source of energy would be tapped to help meet growing energy needs, especially the need for electric power. At present, geothermal energy largely wastes to the atmosphere, and, at this time, no use other than for extraction of heat is known or foreseen.

The generation of base-load power would be the principal use of the geothermal resource; thus the resource would be available, on a relatively long-term basis, to replace comparable power produced by fossil fuel and nuclear plants. Geothermal power could, within a given power network, supply an appreciable portion of the base-load generating requirement, and would be especially attractive for meeting local electric power needs in remote areas lacking in local sources of fossil fuel.

Although the quantity of geothermal resources believed to be available for development and production would only supplement, not supplant, other forms of electrical generation, geothermal energy could, in most cases, replace equivalent electrical power generation from fossil fuel or nuclear plants. The latter types of plants generally have greater adverse environmental effects, e.g. greater release of gaseous, radioactive, and thermal wastes.

Production of chemicals and fresh water as by-products of geothermal energy would represent additional sources of those resources which have not been tapped.

B. Water

Consumption of water resources in power plants and by-product facilities would constitute a depletion of gross water resources available in a given area. To the extent that geothermal fluids are withdrawn from the subsurface reservoir and are not replaced by reinjection or natural recharge, the water consumed would represent a depletion of water in storage.

In some areas, e.g. Imperial Valley, the geothermal fluids that would furnish the water requirements of power plants would be saline water which is not used for any other purpose. The use of such water would not affect water resources available for beneficial use.

Under the proposed controls for waste disposal, degradation of surface and fresh ground waters is not expected to be significant, especially in a long-term sense.

C. Land

Land uses in the vicinity of wells, pipelines, power plants and by-product facilities, and power lines would be changed to industrial use from uses such as for fish and wildlife habitat, recreation, grazing, forests, agriculture, and catchment for water supply. Public access in the vicinity of such industrial facilities would have to be restricted as a safety measure. Development and production of geothermal resources generally is not expected to have any lasting, inhibiting effects on the use of lands in a given area for other purposes after geothermal operations have been concluded.

Should geothermal production result in land subsidence, which is an irreversible process, the subsidence would constitute, a long-term effect on the land resources. Such subsidence would not significantly affect use of the land in most areas except that changes in slope and elevation could affect waterways and engineering works. Such changes would represent a serious short-term impact on engineering structures, but, in the long-term, could be accommodated by engineering modifications, mainly realignment and reconstruction of the affected structures or works.

D. Fish and Wildlife

Geothermal resource development would have certain localized and regional adverse impact on fish and wildlife in the form of loss of wildlife habitat in the immediate vicinity of installations, loss of birds from collision with and/or electrocution on power lines, and possible danger to fish through accidental spills of toxic fluids. In addition, restriction of public access would reduce hunting and related recreational opportunities in the vicinity of installations. A change in the natural setting of lands could result in long range effects on wildlife by rendering some lands undesirable for wildlife habitat purposes.

E. Economic and Social

Geothermal development requires substantial investment in drilling wells, and construction of roads, pipelines, power and by-product plants, and transmission lines. Such investments result in an increased tax base for the area of development. However, the labor-intensive phase is short-term, during field development, and would not result in significant changes in population distribution.

E. ANY IRREVERSIBLE AND IRRETRIEVABLE COMMITMENTS OF RESOURCES WHICH WOULD BE INVOLVED IN THE PROPOSED ACTION

The principal commitment of resources would be the depletion of thermal energy and water from the local geothermal reservoir. Both of these resources are renewable, but not within the life of a specific project. There is no foreseeable alternative use of the stored energy; however, the water developed for use may be significant in some drainage basins.

Compaction and resulting land subsidence that may occur are potential irreparable consequences. If it requires substantial adjustments to accommodate to such changes, the cost and impact will be considered in arriving at decitions.

Some on-site or related ecological features such as plant life and aesthetics would be irreversibly altered. The extent of such alterations would depend upon the particular site and characteristics involved.

Finally, dedication of the land-surface to use for wells, associated surface facilities, power plants, and transmission lines, while not permanent except for minor portions of the permit area, represents an irreversible commitment in the context of human lifetimes. Normally, 25 to 50 years are required simply to amortize the investment in geothermal production facilities at a given field. This would be a localized and human commitment, less pervasive than subsidence and some water uses.

F. DISCUSSION OF PROBLEMS AND OBJECTIONS RAISED BY OTHER AGENCIES

Not applicable to this draft.

REFERENCES

Hamilton, D. H. and Meehan, R. L., 1971, Ground rupture in the Baldwin Hills: Science, v. 172, no. 3981, p. 333-344.

Healy, J. H., Hamilton, R. M., and Raleigh, C. B., 1970, Earthquakes induced by fluid injection and explosion: Techtonophysics, v. 9, p. 205-214.

Healy, J. H., Rubey, W. W., Griggs, D. T., and Raleigh, C. B., 1968, The Denver earthquakes: Science, v. 161, p. 1301-1310.

Hunt, T. M., 1970, Gravity changes at Wairakei Geothermal Field, New Zealand: Geol. Soc. Amer. Bull., v. 81, p. 529-536.

Poland, J. F., and Davis, G. H., 1969, Land subsidence due to withdrawal of fluids: Geol. Soc. Amer. Reviews in Engr. Geology II, p. 187-269.

Rothe, J. P., 1969, Manmade earthquakes: Techtonophysics, v. 9, p. 215-238.

U. S. Department of Interior -- U.S. Department of Agriculture, 1970, Environmental criteria for electric transmission systems: U. S. Govt. Printing Office, 52 ps.

White, D. E., Muffler, L. J. P., and Truesdell, A. H., 1971, Vapor-dominated hydrothermal systems compared with hot-water systems: Econ. Geology, v. 66, p. 75-97.

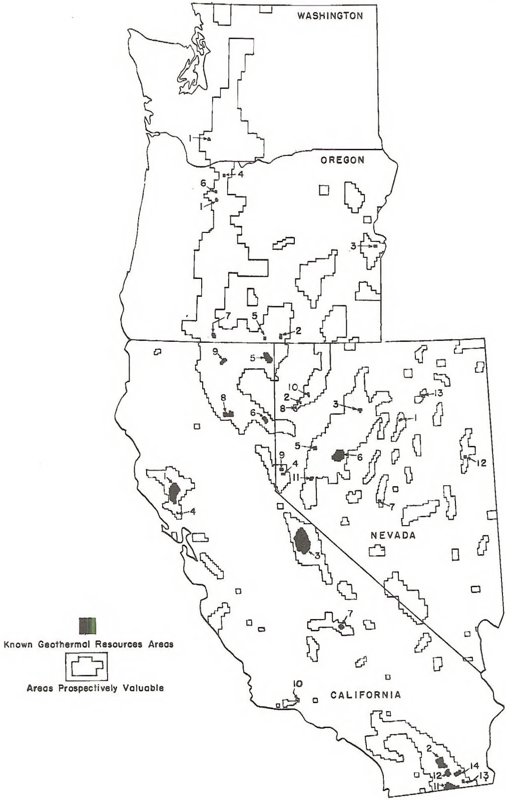
TABLE 1 -- Known geothermal resources areas

(Detailed land descriptions of these areas have been published in the Federal Register, v. 36, p. 5626, March 25, 1971; v. 36, p. 6118, April 2, 1971; v. 36, p. 6441, April 3, 1971; v. 36, p. 7319, April 17, 1971; and v. 36, p. 7759, April 24, 1971.)

No. on figure 1A,1B, or 1C	Name
ALASKA	
1	Pilgrim Springs
2	Geyser Spring Basin and Okmok Caldera
CALIFORNIA	
1	The Geysers
2	Salton Sea
3	Mono-Long Valley
4	Calistoga
5	Lake City
6	Wendel-Amedee
7	Coso Hot Springs
8	Lassen
9	Glass Mountain
10	Sespe Hot Springs
11	Heber
12	Brawley
13	Dunes
14	Glamis
IDAHO	
1	Yellowstone
2	Frazier
MONTANA	
1	Yellowstone

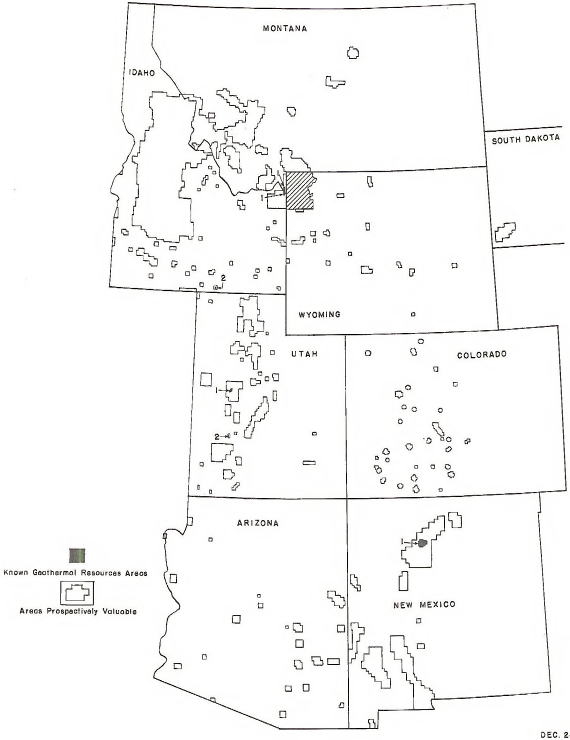
No. on figure 1A,1B, or 1C	Name
NEVADA	
1	Beowawe
2	Fly Ranch
3	Leach Hot Springs
4	Steamboat Springs
5	Brady Hot Springs
6	Stillwater-Soda Lake
7	Darrough Hot Springs
8	Gerlach
9	Moana Springs
10	Double Hot Springs
11	Wabuska
12	Monte Neva.
13	Elko Hot Springs
NEW MEXICO	
1	Baca Location No. 1
OREGON	
1	Breitenbush Hot Springs
2	Crump Geyser
3	Vale Hot Springs
4	Mount Hood
5	Lakeview
6	Carey Hot Springs
7	Klamath Falls
UTAH	
1	Crater Springs
2	Roosevelt
WASHINGTON	
1	Mount St. Helens

FIGURE 1A

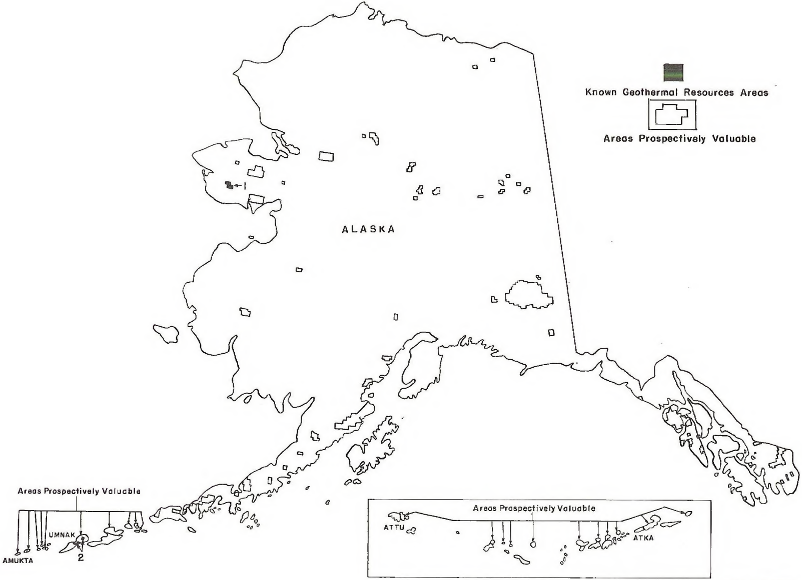


DEC. 24, 1970

FIGURE 1B



DEC. 24, 1970



DEC. 24, 1970

FIGURE 1C

Appendixes A and B

Geothermal Resources Leasing

and

Operations on Public, Acquired

and Withdrawn Lands

Notice of Proposed Rule Making

(Reprinted from Federal Register, July 23, 1971,
Volume 36, Number 142)

federal register

FRIDAY, JULY 23, 1971
WASHINGTON, D.C.
Volume 36 ■ Number 142

PART II

DEPARTMENT OF THE INTERIOR

■

Geothermal Resources Leasing and Operations on Public, Acquired, and Withdrawn Lands

■

Notice of Proposed Rule Making

DEPARTMENT OF THE INTERIOR

Bureau of Land Management

[43 CFR 3000, 3045, 3104, 3200]

GEOTHERMAL RESOURCES LEASING AND OPERATIONS ON PUBLIC, ACQUIRED, AND WITHDRAWN LANDS

Notice of Proposed Rule Making

The purpose of this proposed rule making is to implement the Geothermal Steam Act of December 24, 1970 (84 Stat. 1566). That Act provides for the leasing of public lands for geothermal resource exploration, development, and production.

Environmental statements will be prepared and disseminated in accordance with the provisions of section 102(2)(C) of the National Environmental Policy Act of 1969 (42 U.S.C. Part 4332(2)(C) (Supp. V., 1965–69)), prior to the promulgation of any leasing and operating regulations.

It is the policy of the Department of the Interior, whenever practicable, to afford the public an opportunity to participate in the rule-making process. Accordingly, interested parties may submit written comments, suggestions, or objections with respect to the proposed regulations to the Geothermal Coordinator, Department of the Interior, Washington, D.C. 20240, within 60 days of the date of publication of this notice in the FEDERAL REGISTER.

1. Section 3000.0–5 of Subpart 3000, Chapter II, Title 43 of the Code of Federal Regulations is revised to read as follows:

§ 3000.0–5 Definitions.

As used in this subchapter the following terms shall mean as follows:

(a) "Leasable minerals." (1) Oil and gas. (i) Gas, any fluid, either combustible or noncombustible, which is produced in a natural state from the earth and which maintains a gaseous or rarefied state at ordinary temperature and pressure conditions. (ii) Oil, crude oil, any liquid hydrocarbon substance which occurs naturally in the earth, including drip gasoline or other natural condensates recovered from gas, without resort to manufacturing process.

(b) "Geothermal resources" means geothermal steam and associated geothermal resources which include: (1) All products of geothermal processes, embracing indigenous steam, hot water and hot brines; (2) steam and other gases, hot water and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations; (3) heat or other associated energy found in geothermal formations; and (4) any byproducts derived from them.

(c) "Byproduct" means (1) any mineral or minerals (exclusive of oil, hydrocarbon gas, and helium) which are found in solution or developed in association with geothermal steam and which have a value of less than 75 per centum of the value of the geothermal steam or are not, because of quantity, quality, or technical difficulties in extraction and production, of sufficient value to warrant extraction and production by themselves, and (2) commercially demineralized water.

(d) "Known geothermal resource areas" (KGRA) means an area in which the geology, nearby discoveries, competitive interests, or other indicia would, in the opinion of the Secretary, engender a belief in men who are experienced in the subject matter that the prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose. Any relevant data and information pertaining to the criteria, including without limitation any pertinent engineering and economic data, may be considered in classifying land for inclusion in a KGRA.

(e) "Other leasable minerals." (1) Coal, chlorides, sulphates, carbonates, borates, silicates, or nitrates of potassium and sodium; sulphur in the States of Louisiana and New Mexico; phosphate; and native asphalt, solid and semisolid bitumen and bituminous rock (including oil impregnated rock or sands from which oil is recoverable only by special treatment after the deposit is mined or quarried). (2) Solid (hardrock) minerals; minerals in acquired lands which would be subject to location under the U.S. mining laws if located in the public domain lands.

(f) "Secretary." The Secretary of the Interior or any person duly authorized to exercise the powers vested in that officer.

(g) "Director." The Director of the Bureau of Land Management or any person duly authorized to exercise the powers vested in that officer.

(h) "State Director." The Director of a Bureau of Land Management State office.

(i) "Authorized officer" means any person authorized by law or by lawful delegation of authority in the Bureau of Land Management to perform the duties described.

(j) "Proper BLM office" means the Bureau of Land Management office having jurisdiction over the leased lands or lands subject to lease.

(k) "Commercial quantities" shall mean quantities sufficient to pay a profit after all costs of production have been met.

(l) "Public domain lands." Original public domain lands which have never left Federal ownership; also, lands in Federal ownership which were obtained by the Government in exchange for public lands or for timber on such lands; also original public domain lands which have reverted to Federal ownership through operation of the public land laws.

(m) "Acquired lands." Lands which the United States obtains by deed through purchase or gift, or through condemnation proceedings. They are distinguished from public domain lands in that acquired lands may or may not have been originally owned by the Government. If originally owned by the Government such lands have been disposed of (patented) under the public land laws and thereafter reacquired by the United States.

(n) "Other lands" (1) "Withdrawn lands." Lands which have been withdrawn and dedicated to public purposes. (2) "Reserved lands." Lands which have been withdrawn from disposal and dedicated to a specific public purpose. (3) "Segregated lands." Lands included in a withdrawal or in an application or entry which segregates them from operation of the public land laws.

2. Subpart 3045 of Chapter II, Title 43 of the Code of Federal Regulations is amended by substituting the words "oil and gas, or geothermal resources" for "oil and gas" wherever they appear throughout the Subpart. As revised Subpart 3045 reads as follows:

Subpart 3045—Geophysical Exploration Operations (Oil and Gas or Geothermal Resources)

§ 3045.0–1 Purposes.

The purpose of the regulations in this Subpart 3045 is to establish procedures to be followed in conducting exploration of the public land for oil and gas or geothermal resources. For exploratory operations for other leasable minerals, the lease or permit required by the appropriate regulations must be secured. The regulations in this subpart are not applicable to exploration operations conducted pursuant to oil and gas or geothermal resourses lease, and also are not applicable to the exploration of public domain lands for minerals subject to location under the U.S. mining laws.

§ 3045.0–5 Definitions.

For the purpose of the regulations in this subpart:

(a) "Oil and gas or geothermal resources exploration" means any activity relating to the search for evidence of oil and gas or geothermal resources which requires physical presence upon the land and which may result in damage to public lands or resources thereon. It includes, but is not limited to, geophysical operations, construction of roads and trails, and cross-country transit by vehicle over public domain. It does not include the casual use of public lands for oil and gas or geothermal resources exploration. It does not include core drilling for subsurface geologic information or drilling for oil and gas or geothermal resources; these activities will only be authorized by the issuance of an oil and gas or geothermal resources lease. The regulations in this subpart, however, are not intended to prevent drilling operations necessary for placing explosive charges for seismic exploration, nor do they affect the exclusive right to "drill" for oil and gas or geothermal resources by a lessee upon his leased premises.

(b) "Public lands" means lands owned by the United States and administered by the Bureau of Land Management. It does not include retained mineral interest in lands, title to which has passed from the United States.

(c) "Casual use" means activities that involve practices which do not ordinarily lead to any appreciable disturbance or damage to lands, resources, and improvements. For example, activities which do not involve use of heavy equipment or explosives and which do not involve vehicle movement except over established roads and trails are "casual use."

§ 3045.0–7 Cross-references.

43 CFR 3104.9.
43 CFR 3104.15.

§ 3045.1 Notice of intent to conduct oil and gas or geothermal resources operations.

§ 3045.1–1 Application.

(a) *Forms and where filed.* Any person desiring to conduct oil and gas or geothermal resources exploration operations under the regulations of this subpart shall, prior to entry upon the lands, file with the District Manager of the Bureau of Land Management for the district in which the public lands are located a "Notice of Intent to Conduct Oil and Gas or Geothermal Resources Exploration Operations," on a form approved by the Director.

(b) *Requirements.* The "Notice of Intent to Conduct Oil and Gas or Geothermal Resources Exploration Operations" will contain the following:

(1) The name and address, including zip code, both of the person, association, or corporation for whom the operations will be conducted and of the person who will be in charge of the actual exploration activities.

(2) A statement that the signers agree that exploration operations will be conducted pursuant to the terms and conditions listed on the approved form.

(3) A brief description of the type of operations which will be undertaken.

(4) A description of the lands to be explored, by township and range.

(5) Approximate date of commencement of operations.

§ 3045.2 Completion of operations.

Upon completion of the exploratory operations, there shall be filed with the District Manager a "Notice of Completion of Oil and Gas or Geothermal Resources Exploration Operations." Within 90 days after the filing of such "Notice of Completion," the District Manager shall notify the party who had conducted the operations whether all of the terms and conditions set out by the regulations in this subpart and in the "Notice of Intent to Conduct Oil and Gas or Geothermal Resources Exploration Operations" have been complied with, or whether any additional measures must be taken to rectify any damage to the land, specifying the nature and extent thereof.

§ 3045.3 Bond requirements.

(a) Amount of bond and when filed (see 3104.9).

(b) Termination of period of liability (see 3104.9–5).

3. Sections 3104.9, 3104.9–1, and 3104.-9–5 of Subpart 3104, Chapter II, Title 43 of the Code of Federal Regulations are amended by substituting the words "oil and gas, or geothermal resources" for "oil and gas" wherever they appear throughout. As revised these sections read as follows:

§ 3104.9 Exploration bond.

(a) *Individual.* Simultaneously with the filing of the Notice of Intent to Conduct Oil and Gas or Geothermal Resources Exploration Operations, and before the entry is made on the land, the party or parties filing the "Notice of Intent to Conduct Oil and Gas or Geothermal Resources Exploration Operations" must file with the District Manager a surety company bond in the amount of $5,000, conditioned upon the full and faithful compliance, for each oil and gas or geothermal resources exploration operation, with all of the terms and conditions of the regulations in this subpart and of that notice.

(b) *Nationwide.* A $50,000 nationwide bond.

(c) *Statewide.* A statewide bond in the amount of $25,000 covering all oil and gas or geothermal Resources exploration operations in the same State.

§ 3104.9–1 Riders to existing bond forms.

(a) *Nationwide and statewide bonds.* Holders of nationwide and statewide oil and gas or Geothermal Resources lease bonds shall be permitted to amend their bonds to include exploration activities in lieu of furnishing additional bonds.

§ 3104.9–5 Termination of period of liability.

The District Manager will not give his consent to the cancellation of the bond if an individual bond was submitted, or to the termination of liability if a State or nationwide bond was submitted, unless and until all of the terms and conditions of the "Notice of Intent to Conduct Oil and Gas or Geothermal Resources Exploration Operations" have been complied with. Should the District Manager or any other authorized officer of the Bureau of Land Management fail to notify the party within 90 days from the filing of "Notice of Completion" that all terms and conditions have been complied with or that additional corrective measures must be taken to rehabilitate the land, liability under an individual bond or liability for a particular oil and gas or geothermal resources exploration operation under a State or nationwide bond shall automatically terminate on the 91st day.

4. A new Group 3200 is added to Chapter II, Title 43 of the Code of Federal Regulations to read as follows:

Group 3200—Geothermal Resources Leasing

PART 3200—GEOTHERMAL RESOURCES LEASING; GENERAL

Subpart 3206—Lease Bonds

Subpart 3200—Geothermal Resources Leasing; General

§ 3200.0–3 Authority.

These regulations are issued pursuant to the Geothermal Steam Act of 1970 (84 Stat. 1566), and rights to develop and utilize geothermal resources in land subject to these regulations may be acquired only in accordance with these regulations.

§ 3200.0–5 Definitions.

As used in Group 3200, the term:

(a) "The Act" means the Geothermal Steam Act of 1970;

(b) "Geothermal lease" means a lease issued under authority of the Act;

(c) "Sole party in interest" means a party who is and will be vested with all legal and equitable rights under the lease. No one is, or shall be deemed to be, a sole party in interest with respect to a lease in which any other party has any interest in the lease;

(d) "Interest in the lease" means any interest whatever in a geothermal lease, including, but not limited to: A record title interest; a working interest; an operating right; a claim to any prospective or future advantage or benefit from a lease; a participation in any increment, issue, or profit which may be derived, or accrue in any manner, from the lease based upon, or pursuant to, any agreement or understanding in existence at the time when the offer is filed; and an agreement pertaining to any of the foregoing;

(e) "Supervisor" means a representative of the Secretary under administrative direction of the Director, Geological Survey, through the Chief, Conservation Division, authorized and empowered to regulate operations and to perform other duties prescribed in the regulations in this part, or any subordinate of such representative acting under his direction.

§ 3200.0–6 Preleasing procedures.

(a) When an area is initially considered for geothermal leasing or when the need arises, the Director shall request other interested Bureaus and Federal agencies to prepare reports describing, to the extent known, resources contained within the general area and the potential effect of mineral operations upon the resources of the area and its total environment.

(b) The Director, prior to the final selection of tracts for leasing, shall, when appropriate, evaluate fully the potential effect of the leasing program on the total environment, fish and other aquatic resources, wildlife habitat and populations, esthetics, recreation, and other resources in the entire area during exploratory, developmental, and operational phases. To aid him in his evaluation and selection of tracts he may request and consider the views and recommendations of appropriate Federal agencies, may hold public hearings after appropriate notice, and may consult with State agencies, organizations, industries, and individuals, and shall consider all other potential uses of the land and its natural resources. The Director shall develop special terms and conditions to be included in leases when they are needed to protect the environment, to permit use of the land for other purposes, and to protect other natural resources; any terms and conditions to be included in leases shall be published in the notice announcing the availability of the land for leasing.

§ 3200.0–7 Cross reference.

(a) The regulations governing operations under geothermal leases are found in 30 CFR Part 270.

(b) The regulations setting forth the basic policies for management of the public lands are found in Part 1725 of this chapter.

§ 3200.0–8 Use of surface.

(a) A lessee shall be entitled to use only so much of the surface of the lands covered by his lease as may be found by the Supervisor to be necessary for the production, utilization, and conservation of geothermal resources. Any use of the surface for a power generation plant or a commercial or industrial facility will be authorized only under a separate permit issued by the Secretary for that specific use and subject to all terms and conditions which he may include in that permit. The lessee shall not be entitled to use any mineral materials subject to the Materials Act except as provided by Part 3600 of this chapter.

(b) Operations under other leases or uses on the same lands shall not unreasonably interfere with or endanger operations under leases issued under these regulations nor shall operations under these regulations unreasonably interfere with or endanger operations under any lease, license, claim, permit, or other authorized use pursuant to the provisions of any other Act.

Subpart 3201—Available Lands; Limitations, Unit Agreements

§ 3201.1 Lands subject to geothermal leasing.

§ 3201.1–1 General.

Subject to the exceptions listed below, geothermal leases may be issued for (a) lands administered by the Secretary of the Interior; (b) national forest lands or other lands administered by the Department of Agriculture through the Forest Service; and (c) geothermal resources in lands which have been conveyed by the United States subject to a reservation to the United States of geothermal resources.

§ 3201.1–2 Department of the Interior.

(a) Except as provided in this section, leases may be issued in accordance with the regulations in this part for withdrawn lands, for acquired lands, and for geothermal resources in lands which have passed from Federal ownership subject to a reservation to the United States of the geothermal resources therein where such lands or resources are administered by the Secretary of the Interior.

(b) Notwithstanding any other provision in these regulations, geothermal leases shall not be issued for: (1) Lands which the Secretary has identified or may identify as being necessary to the performance of his or any other Federal agency's authorized functions, and on which geothermal resource development would interfere with such functions in his judgment; or (2) lands respecting which the Secretary has made or may make a finding that the issuance of geothermal leases would be contrary to the public interest. Upon receipt of an application for a geothermal lease affecting lands withdrawn under section 3 of the Reclamation Act of 1902 (43 U.S.C. § 416) or any other appropriate authority, notice thereof and an opportunity to comment thereon shall be given to the head of the agency for whose benefit the withdrawal was made. Where leases are issued under Part 3210 or 3220 for lands neighboring such reserved lands, the lessees shall be required to perform such lease operations and take such measures as are prescribed by the Secretary for the protection of the Federal interests therein. Stipulations for this purpose will be incorporated in any applicable leases.

§ 3201.1–3 Department of Agriculture.

Leases for lands withdrawn or acquired in aid of functions of the Department of Agriculture, for example, lands administered by the Forest Service, may be issued by the Secretary of the Interior only with the consent of, and subject to such terms and conditions as may be prescribed by, the head of that Department to insure adequate utilization of the lands for the purpose for which they were withdrawn or acquired.

§ 3201.1–4 Federal Power Commission.

Leases for lands to which section 24 of the Federal Power Act, as amended (16 U.S.C. 818), is applicable, may be issued by the Secretary of the Interior only with the consent of, and subject to, such terms and conditions as the Federal Power Commission may prescribe to insure adequate utilization of such lands for power and related purposes.

§ 3201.1–5 Patented lands.

(a) Except as provided in paragraph (b) of this section, geothermal resources in lands which have passed from Federal ownership subject to reservation to the United States of the geothermal resources therein may be leased under the regulations in this group subject to the provisions in this part and to such terms and conditions as may be prescribed by the authorized officer to insure adequate protection of the surface and any improvements thereon.

(b) Geothermal resources in lands the surface of which has passed from Federal ownership but in which the minerals have been reserved to the United States shall not be leased under this group unless the question of the title to such resources has been resolved favorably to the United States pursuant to the provisions of section 21(b) of the Act.

§ 3201.1–6 Excepted areas.

Leases shall not be issued for lands which are: (1) Administered under the National Park System; (2) within a national recreation area; (3) in a fish hatchery administered by the Secretary, wildlife refuge, wildlife range, game range, wildlife management area, or waterfowl production area, or for lands acquired or reserved for the protection and conservation of fish and wildlife which are threatened with extinction; or (4) tribally or individually owned Indian trust or restricted lands, within or without the boundaries of Indian reservations.

§ 3201.2 Acreage limitations.

(a). No person, association, or corporation shall take, hold, own, or control at one time, whether acquired directly from the Secretary or otherwise, any direct or indirect interest in Federal leases in any one State exceeding 20,480 acres. Nor may any person, association, or corporation be permitted to convert mineral leases, permits, applications therefor, or mining claims, pursuant to the provisions of section 4 (a)–(f) of the Act into geothermal leases for more than 10,240 acres.

(b) In computing acreage holdings or control, the accountable acreage of a party owning an undivided interest in a lease shall be that party's proportionate part of the total lease acreage. Likewise, the accountable acreage of a party owning an interest in a corporation or association shall be his proportionate part of the corporation's or association's accountable acreage except that no person shall be charged with his pro rata share of any acreage holdings of any association or corporation unless he is the beneficial owner of more than 10 per centum of the stock or other instruments of ownership or control of that association or corporation. Parties owning a royalty or other interest determined by or payable out of a percentage of production from a lease will be charged with a similar percentage of the total lease acreage.

(c) An association shall not be deemed to exist between the parties to a contract for development of leased lands, whether or not coupled with an interest in the lease, nor between colessees, but each party to any such contract or each colessee will be charged with his proportionate interest in the lease. No holding of acreage in common by the same persons in excess of the maximum acreage specified in the law for any one lessee will be permitted.

§ 3201.3 Leases within unit areas.

Before issuance of a geothermal lease for lands within an approved unit agreement, the lease applicant or successful bidder will be required to file evidence that he has entered into an agreement with the unit operator for the development and operation of the lands in a lease if issued to him under and pursuant to the terms and provisions of the approved unit agreement, or a statement giving satisfactory reasons for the failure to enter into such agreement. If such statement is acceptable, he will be permitted to operate independently but will be required to conform to the terms and provisions of the agreement with respect to such operations.

Subpart 3202—Qualifications of Lessees

§ 3202.1 Who may hold leases.

Leases may be issued only to: (1) Citizens of the United States; (2) associations of such citizens; (3) corporations organized under the laws of the United States, any State or the District of Columbia; or (4) governmental units, including, without limitation, municipalities. The term "association" includes a partnership.

§ 3202.2 Statements required to be submitted.

§ 3202.2–1 General.

(a) Each applicant for a lease is required to submit with his application a statement that his interests, direct and indirect, in Federal geothermal leases, and applications, do not exceed the acreage limitations prescribed in § 3201.2, together with a statement of his citizenship.

(b) If the applicant is an association or corporation, the application must be accompanied by: (1) A statement showing that it is authorized to hold geothermal leases; (2) a statement that the officer executing the application is authorized to act on behalf of the association or corporation; and (3) a certified copy of articles of association or incorporation.

§ 3202.2–2 Municipalities.

A municipality must submit evidence (a) that it is authorized to hold a geothermal lease; and (b) that the action proposed has been authorized by its governing body.

§ 3202.2–3 Guardian or trustee.

(a) *Guardian*. If the application is made by a guardian, he must submit: (1) A certified copy of the court order authorizing him to act as guardian and, in behalf of his ward, to enter into contractual agreements and to fulfill all obligations arising under the lease; and (2) statements as to the citizenship and holdings under the Act of himself and of each person under his guardianship for whom the offer or nomination is made.

(b) *Trustee*. If the application is made by a trustee, he must submit a copy of the instrument establishing the trust or a certified copy of the court order authorizing him to act as trustee, in behalf of the beneficiary, as to all obligations arising under the lease; and statements as to the citizenship and holdings under the Act of himself and of each beneficiary.

§ 3202.2–4 Attorney-in-fact.

If an application is filed by an attorney-in-fact, it must be accompanied by evidence as to his authority to act.

§ 3202.2–5 Evidence previously filed.

Where the statements required by § 3202.2 have been previously filed a reference by serial number to the record in which they have been filed, together with a statement as to any amendments will be accepted.

§ 3202.2–6 Death of applicant.

If an applicant or nominator or a successful bidder dies before the lease is issued, the application or nomination will automatically terminate or the bid will be rejected.

§ 3202.2–7 Showing as to sole party in interest.

Each application must be accompanied either by a signed statement by the applicant that he is the sole party in interest, or by a signed statement by the applicant setting forth the names of all other persons who have an interest in the lease and their qualifications to hold a lease.

Subpart 3203—Leasing Terms

§ 3203.1 Primary and additional term.

§ 3203.1–1 Dating of leases.

All geothermal leases will be dated as of the first day of the month following the date on which the leases are signed on behalf of the lessor except that, where prior written request has been made, a lease may be dated as of the first day of the month within which it is so signed. A renewal lease will be dated from the termination of the original lease.

§ 3203.1–2 Primary term.

All leases shall be for a primary term of 10 years.

§ 3203.1–3 Additional term.

(a) If geothermal steam is produced or utilized in commercial quantities within the primary term of a lease, that lease shall continue for so long thereafter as geothermal steam is produced or utilized in commercial quantities, but the lease shall in no event continue for more than 40 years after the end of the primary term.

(b) For the purposes of paragraph (a) of this section, production or utilization of geothermal steam in commercial quantities shall be deemed to include the completion of one or more wells producing or capable of producing geothermal steam in commercial quantities and a bona fide sale of such geothermal steam for delivery to or utilization by a facility or facilities not yet installed but scheduled for installation not later than 15 years from the date of commencement of the primary term of the lease.

§ 3203.1-4 Renewals.

If, at the end of 40 years after the conclusion of the primary term, steam is being produced or utilized in commercial quantities and the lands are not needed for other purposes, the lessee shall have a right to a renewal of the lease for a second 40-year term on such terms and conditions as the Secretary deems appropriate.

§ 3203.1-5 Extensions.

(a) A lease which has been extended by reason of production, or on which geothermal steam has been produced, and which has been determined by the Secretary to be incapable of further commercial production and utilization of geothermal steam may be further extended so long as one or more valuable byproducts are produced in commercial quantities but for not more than 5 years.

(b) The primary term of a lease may also be extended for a period of 5 years and so long thereafter as geothermal steam is produced or utilized in commercial quantities (but for not more than 35 years) where the lessee commenced actual drilling operations prior to the end of the primary term and those operations are being diligently prosecuted at that time.

(c) Any lease on which there has been a suspension of operations or production, or both, under 30 CFR § 270.17 shall be extended for a period equal to the period of suspension.

§ 3203.1-6 Conversion to mineral leases or mining claims.

(a) If the byproducts being produced in commercial quantities are leasable under the Mineral Leasing Act of February 25, 1920, as amended and supplemented (30 U.S.C. sections 181-287), or under the Mineral Leasing Act for Acquired Lands (30 U.S.C. sections 351-359), and the leasehold is primarily valuable for the production thereof, the lessee shall be entitled to convert his geothermal lease to a mineral lease under, and subject to all the terms and conditions of, the appropriate Act upon application at any time before expiration of the lease extension by reason of byproduct production.

(b) The lessee shall be entitled to locate under the mining laws all minerals which are not leasable and which would constitute a byproduct if commercial production or utilization of geothermal steam continued. The lessee in order to acquire the rights herein granted him shall complete the location of mineral claims within 90 days after the termination of the geothermal lease.

(c) Any lease converted under paragraph (a) of this section for the use of the surface of any mining claim location under paragraph (b) of this section for geothermal byproduct minerals affecting lands withdrawn or acquired in aid of a function of a Federal department or agency, including the Department of the Interior, shall be subject to such additional terms and conditions as may be prescribed by that department or agency with respect to the additional operations or effects resulting from such conversion upon the utilization of the lands for the purpose for which they are administered.

§ 3203.2 Lease acreage limitation.

A geothermal lease may not embrace more than 2,560 acres in a reasonably compact area, except where a departure is occasioned by an irregular subdivision. In such event, the leased acreage may exceed 2,560 acres by an amount which is smaller than the amount by which the area would be less than 2,560 acres if the irregular subdivision were excluded. No lease will be issued for less than 1,280 acres, except at the discretion of the Secretary, or where a departure is occasioned by an irregular subdivision. In event of a departure, the leased acreage may be less than 1,280 acres by an amount which is smaller than the amount by which the area would be more than 1,280 acres if the irregular subdivision were added.

§ 3203.3 Consolidation of units.

Two or more contiguous leases issued to the same lessee may be consolidated if the total combined acreage does not exceed 2,560 acres. Except where a departure is occasioned by an irregular subdivision as stated in § 3203.2.

§ 3303.4 Description of lands.

Applications and nominations shall include a description of the lands sought to be included in a geothermal lease. If the lands have been surveyed under the public land rectangular system, each application or nomination shall describe the lands by legal subdivision, section, township, and range. If the lands have not been so surveyed, each application shall describe the lands by metes and bounds, giving courses and distances between the successive angle points on the boundary of the tract, and connected by courses and distances to a monument or to a prominent topographic feature. When protracted surveys have been approved and the effective date thereof published in the FEDERAL REGISTER, each application or nomination for lands shown on such protracted surveys, filed on or after such effective date, shall describe the lands according to the legal subdivision, section, township, and range shown on the approved protracted surveys.

Subpart 3204—Surface Management Requirements, Special Requirements

§ 3204.1 General.

A lessee shall comply with and be bound by the following terms and conditions:

(a) *Equal employment opportunity.* To comply with Executive Order 11246, as amended, 30 F.R. 12319 (1965), and regulations issued pursuant thereto, 41 CFR Chapter 60 and Part 17 of this chapter.

(b) *Public access.* (1) To permit free and unrestricted public access to and upon the leased lands for all lawful and proper purposes except in areas where such access would unduly interfere with operations under the lease or would constitute a hazard to health and safety. Determinations by a lessee to restrict access within the leased area, shall be subject to approval of the Supervisor.

(2) During construction, to regulate public access and vehicular traffic to protect the public, wildlife, and livestock from hazards associated with the project. For this purpose, the lessee shall provide warnings, fencing, flag men, barricades, and other safety measures as appropriate.

(c) *Pollution abatement*—(1) *Pesticides and herbicides.* To comply with all rules issued by the Department of the Interior and the Environmental Protection Agency pertaining to the use of poisonous substances on public lands.

(2) *Water pollution.* To conduct lease operations and maintenance in a manner consistent with Federal and State water quality standards and public health and safety standards. Toxic materials shall not be released into any lake, water drainage, or underground water.

(3) *Air pollution.* To control emissions from operations in accordance with Federal and State air quality standards.

(4) *Erosion control.* To minimize disturbance to vegetation, drainage channels, and streambanks. The lessee shall employ such soil and resource conservation and protection measures on the leased lands as the Supervisor determines are necessary.

(5) *Noise control.* To control noise emissions from operations as directed by the Supervisor.

(d) *Sanitation and waste disposal.* To remove or dispose of all waste generated in connection with the operation in a manner acceptable to the Supervisor. The term "waste" as used in this stipulation means all discarded matter, including but not limited to human waste, trash, garbage, refuse, petroleum products, and waste material resulting from the extraction and processing operation.

(e) *Aesthetics.* To take aesthetics into account in the planning, design, and construction of facilities on the leased premises.

(f) *Wildlife.* To employ such measures as are deemed necessary by the Supervisor to protect wildlife, including fish, and their habitat.

(g) *Antiquities and historical sites.* To conduct activities on discovered, known or suspected archaeological, paleontological, or historical sites in accordance with lease terms or instructions issued by the Supervisor.

(h) *Restoration.* To provide for the restoration of all disturbed lands in a manner approved by the authorized officer; except as provided in 30 CFR Part 270, where approval will be by the Supervisor.

§ 3204.2 Waste prevention.

All leases shall be subject to the condition that the lessee will, in conducting his exploration, development, and operations, use all reasonable precautions to prevent waste of geothermal resources and other resources found or developed in the leased lands.

§ 3204.3 Readjustment of terms and conditions.

(a) (1) Except as otherwise provided by law, the terms and conditions of any geothermal lease may be readjusted as determined by the authorized officer at not less than 10-year intervals beginning 10 years after the date geothermal steam is produced. Each lease shall provide for such readjustments.

(2) The authorized officer shall give notice to the lessee of any proposed readjustment of the terms and conditions of the lease and the nature thereof, and unless the lessee files with the authorized officer an objection to the proposed terms or relinquishes the lease within 30 days after receipt of such notice, the lessee shall be deemed conclusively to have agreed to such terms and conditions. If the lessee files objections, and agreement cannot be reached between the authorized officer and the lessee within a period of 60 days, the lease may be terminated by either party.

(b) Any readjustment of the terms and conditions of any lease of lands withdrawn or acquired in aid of a function of a Federal department or agency may be made only with the approval of that other agency.

§ 3204.4 Reservation to the United States of oil, hydrocarbon gas, and helium.

The United States reserves the ownership of and the right to extract oil, hydrocarbon gas, and helium from all geothermal resources produced from lands leased under the Act. Whenever the right to extract oil, hydrocarbon gas, and helium, from geothermal resources produced from such lands is exercised, it shall be exercised so as to cause no substantial interference with the production of geothermal resources from such lands.

§ 3204.5 Compensation for drainage; compensatory royalty.

(a) Upon a determination by the Supervisor that adjacent or cornering lands owned by the United States are being drained of geothermal resources by wells drilled on adjacent lands, the authorized officer may execute agreements with the owners of adjacent or cornering lands whereby the United States, or the United States and its lessees, shall be compensated for such drainage, such agreements to be made with the consent of any lessee affected thereby. The precise nature of any agreement will depend on the conditions and circumstances involved in the particular case.

(b) Where land in any lease is being drained of its geothermal resources by a well either on a Federal lease issued at a lower rate of royalty or on land not the property of the United States, the lessee must drill and produce all wells necessary to protect the leased lands from drainage. In lieu of drilling such wells, the lessee may, with the consent of the Supervisor, pay compensatory royalty in the amount determined in accordance with 30 CFR Part 270.

§ 3204.6 Patented lands.

The terms and conditions of any geothermal resource lease for lands conveyed by the United States subject to a reservation to the United States of geothermal resources may be readjusted upon notification to the surface owner.

Subpart 3205—Service Charges

§ 3205.1 Payments.

§ 3205.1–1 Form of remittance.

Remittances required under these regulations may be made by cash payment, check, certified check, bank draft, bank cashier's check, or money order. All remittances will be deposited as received.

§ 3205.1–2 Where submitted.

(a) *Rentals on nonproducing leases.* Rentals under all nonproducing leases issued shall be paid at the proper BLM office. All remittances to the Bureau of Land Management shall be made payable to the Bureau of Land Management.

(b) *Other payments.* All royalties on producing leases, communitized leases in producing well units, unitized leases in producing unit areas, leases on which compensatory royalty is payable and all payments under easements for directional drilling are to be paid to the Supervisor. All remittances to the Geological Survey shall be made payable to the U.S. Geological Survey.

§ 3205.2 Service charges.

(a) *Competitive lease applications.* No service charge is required.

(b) *Noncompetitive lease applications.* Applications for noncompetitive leases must be accompanied by a service charge of $50 for each application.

(c) *Assignments.* Applications for approval of an assignment of a lease or interest therein must be accompanied by a service charge of $50 for each application.

(d) *Nominations.* No service charge is required.

§ 3205.3 Rentals and royalties.

§ 3205.3–1 Payment with application.

Each application must be accompanied by payment of the first year's rental of not less than $1 per acre or fraction thereof based on the total acreage included in the application. An application accompanied by a payment of the first year's rental which is deficient by not more than 10 percent will be approved by the authorized officer provided all other requirements are met, but, if the additional rental is not paid within 30 days from notice, the application or the lease, if issued, will be canceled.

§ 3205.3–2 Payment of annual rental.

(a) Annual rental in the amount of not less than $1 per acre or fraction thereof must be paid in advance and must be received by the proper BLM office on or before the anniversary date of the lease. If there is no well on the leased lands capable of producing geothermal resources in commercial quantities, the failure to pay rental on or before the anniversary date shall terminate the lease by operation of law, except as provided by § 3245.2.

(b) If, on the anniversary date of the lease, less than a full year remains in the lease term, the rentals shall be payable in the same proportion as the period remaining in the lease term is to a full year. The rentals shall be prorated on a monthly basis for the full months, and on a daily basis for the fractional month remaining in the lease term. For the purpose of prorating rentals for a fractional month, each month will be deemed to consist of 30 days.

(c) If the term of a lease for which prorated rentals have been paid is further extended to or beyond the next anniversary date of the lease, rentals for the balance of the lease year shall be due and payable on the first day of the first month following the date through which the prorated rentals were paid. If the rentals are not paid for the balance of the lease year, the lease will be subject to cancellation. However, if the anniversary date occurs before the end of the notice period, the rental for the following lease year shall nevertheless be due on the anniversary date and failure to pay the full rental for that year on or before that date shall cause the lease to terminate automatically by operation of law except as provided by § 3245.2. The lessee shall not be relieved of liability for rental due for the balance of the previous lease year.

(d) If the payment is due on a day in which the proper BLM office to receive payment is not open, payment received on the next official working day will be deemed to be timely.

§ 3205.3–3 Escalating rental rates.

To encourage the orderly and timely development of geothermal leases, all leases issued pursuant to the regulations in this Group will include an escalating rental provision as follows: (a) Beginning with the 6 year and for each year of the primary term thereafter until the lease year beginning on or after the commencement of production of geothermal resources in commercial quantities, the rental may be set by the authorized officer as the amount of rental for the preceding year plus an additional amount of not more than the annual rental for the 5th lease year; and (b) if the lease has been extended for reasons other than commencement of production of geothermal resources in commercial quantities, the rental for the 11th year and for each year thereafter until the lease year beginning on or after the commencement of such production may be set by the authorized officer as the amount of rental for the preceding year plus an additional amount of not more than the annual rental for the 10th lease year.

§ 3205.3–4 Fractional interests.

Rentals, minimum royalties, and royalties payable for lands in which the United States owns an undivided fractional interest shall be in the same proportion to the rentals, minimum royalties, and royalties provided for in § 3205.3, as the undivided fractional interest of the United States in the geothermal resources is to the full mineral interest.

§ 3205.3–5 Royalty on production.

Royalty shall be paid at the following rates on geothermal resources produced, utilized, processed, removed, or sold from leases, or reasonably susceptible of sale or utilization: (a) A royalty of not less than 10 per centum and not more than 15 per centum of the amount or value of steam, or any other form of heat or energy derived from production under the lease and sold or utilized by the lessee or reasonably susceptible to sale or utilization by the lessee; (b) a royalty of not more than 5 per centum of any byproduct derived from production under the lease and sold or utilized or reasonably susceptible of sale or utilization by the lessee, except that as to any byproduct which is a mineral named in section 1 of the Mineral Leasing Act of February 25, 1920, as amended (30 U.S.C. 181), the rate of royalty for such mineral shall be the same as that provided in that Act and the maximum rate of royalty for such mineral shall not exceed the maximum royalty applicable under that Act; (c) a minimum royalty of $2 per acre or fraction thereof in lieu of rental payable at the expiration of each lease year for each producing lease, commencing with the lease year beginning on or after the commencement of production in commercial quantities.

§ 3205.3–6 Royalty on commercially demineralized water.

All geothermal leases issued pursuant to the provisions of this group shall provide for the payment to the lessor of a royalty on commercially demineralized water at a rate to be specified in the lease of not more than 5 per centum of the value of such commercially demineralized water that has been sold or utilized by the lessee or is reasonably susceptible of sale or utilization by the lessee.

§ 3205.3–7 Waiver, suspension or reduction of rental or royalty.

(a) The authorized officer may waive, suspend, or reduce the rental or royalty for any lease or portion thereof in the interests of conservation and to encourage the greatest ultimate recovery of geothermal resources if he determines that this is necessary to promote development or that the lease cannot be successfully operated under the lease terms.

(b) An application hereunder shall be filed in triplicate with the Supervisor, and must: (1) Contain the serial number of the leases and the names of the lessee and operator; (2) show the number, location, and status of each well that has been drilled, a tabulated statement for each month covering a period of not less than 6 months prior to the date of filing the application of the aggregate amount of production subject to royalty computed in accordance with the operating regulations, the number of wells counted as producing each month, and the average production per well per day; (3) contain a detailed statement of expenses and costs of operating the entire lease, the income from the sale of any leased products and all facts tending to show whether the wells can be successfully operated using the royalty or rental fixed in the lease; and (4) where the application is for a reduction in royalty, furnish full information as to whether royalties or payments out of production are paid to others than to the United States, the amounts so paid, and the efforts made to reduce them. The applicant must also file agreements of the holders to a permanent reduction of all other royalties from the leasehold to an aggregate not in excess of one-half the Government royalties.

§ 3205.3–8 Application for and effect of suspension of operations and production.

(a) Applications by lessees for suspensions of operations or production, or both, under a producing geothermal lease (or for relief from any drilling or producing requirements of such a lease) shall be filed in triplicate with the Supervisor, who is authorized to act on applications filed pursuant to this section and to terminate suspensions which have been or may be granted. Complete information must be furnished showing the necessity of the relief sought.

(b) A suspension shall take effect as of the time specified in the order of the Supervisor. Rental and minimum royalty payments will be suspended during any period of suspension of all operations and production directed, or assented to, by the Supervisor, beginning with the first day of the lease month in which the suspension of operations and production becomes effective or, if the suspension of operations and production becomes effective on any date other than the first day of a lease month, beginning with the first day of the lease month following such effective date. The suspension of rental and royalty payments shall end on the first day of the lease month in which operations or production is resumed. Where rentals are creditable against royalties and have been paid in advance, proper credit will be allowed on the next rental or royalty due under the lease.

(c) No lease shall be deemed to expire by reason of a suspension of either operations or production only, pursuant to any order or assent of the Supervisor.

(d) If there is a well on the leased premises capable of producing geothermal resources and all operations and production are suspended pursuant to any order of the Supervisor, approval of recommencement of drilling operations will terminate the suspension as to operations but not as to production, and will terminate both the period of suspension of rental and royalty payments provided in paragraph (b) of this section and the period of suspension for which an equivalent extension will be granted. However, as provided in paragraph (c) of this section, the lease will not be deemed to expire so long as the suspension of operations or production remains in effect.

(e) The relief authorized under this section may also be obtained for any leases included within an approved unit or cooperative plan of development and operation.

(f) See 30 CFR 270.17 for regulations concerning action of the Supervisor on applications filed pursuant to this section.

§ 3205.3–9 Readjustments.

The rentals and royalties of any geothermal lease may be readjusted at not less than 20-year intervals beginning 35 years after the date geothermal steam is produced as determined by the Supervisor. In the event of any such readjustment neither the rental nor royalty paid during the preceding period shall be increased by more than 50 per centum, and in no event shall the royalty payable exceed 22½ per centum. Each geothermal lease shall provide for such readjustment. The Supervisor will give notice of any proposed readjustment of rental and royalties. Unless the lessee relinquishes the lease within 30 days after receipt of such notice, he shall conclusively be deemed to have agreed to such terms and conditions. If the lessee files objections, and no agreement can be reached between the authorized officer and the lessee within a period of 60 days, the lease may be terminated by either party.

Subpart 3206—Lease Bonds

§ 3206.1 Types of bonds and filing.

§ 3206.1–1 Types of bonds.

(a) *Lease compliance bond.* The applicant for a noncompetitive lease or the successful bidder for a competitive lease, prior to the issuance of the lease, must furnish a corporate surety bond of not less than $10,000 conditioned on compliance with all the terms of the lease.

(b) *Protection bond.* A lessee will be required prior to entry on the leased lands to furnish and maintain a bond of not less than $5,000 for indemnification for all damages occasioned to persons or property as the result of lease operations.

§ 3206.1–2 Filing of bonds.

A single original copy of the bond on forms approved by the Director must be filed in the proper BLM office. Bonds may be filed with a noncompetitive lease application to expedite action thereon, or within 30 days after receipt of notice by the applicant of the bond requirement, or as required and directed by the authorized officer. For unit bond forms see 30 CFR Part 271.

§ 3206.2 Termination of period of liability.

The period of liability of any bond will not be terminated until all lease terms and conditions have been fulfilled.

§ 3206.3 Operators bond.

An operator, or, if there are more than one for different portions of the lease, each operator, shall furnish a corporate surety bond or bonds in an amount prescribed by the Supervisor.

§ 3206.4 Qualified corporate sureties.

Treasury lists. A list of companies holding certificates of authority from the Secretary of the Treasury under the Act of July 30, 1947 (6 U.S.C. 6-13), as acceptable sureties on Federal bonds is published in the FEDERAL REGISTER annually.

§ 3206.5 Nationwide bond.

In lieu of bonds required under any of the preceding paragraphs, the holder of leases or of operating agreements approved by the Department or holder of operating rights by virtue of being designated operator or agent by the lessee pending departmental approval of operating agreements may furnish a bond the amount of which must be not less than for $150,000 for full nationwide coverage for all geothermal leases.

§ 3206.0 Statewide bond.

In lieu of any of the bonds required by the preceding paragraphs, the holder of leases or of operating agreements approved by the Department or holder of operating rights by virtue of being designated operator or agent by the lessee pending departmental approval of operating agreements, may furnish a statewide bond the amount of which must be at the rate of not less than $50,000 for each unit of coverage.

§ 3206.7 Default.

§ 3206.7-1 Payment by surety.

Where upon a default the surety makes payment to the Government of any indebtedness due under a lease, the face amount of the surety bond and the surety's liability thereunder shall be reduced by the amount of such payment.

§ 3206.7-2 Penalty.

Thereafter, upon penalty of cancellation of all of the leases covered by that bond, the principal shall post a new nationwide bond in the amount of $150,000 or a unit bond, as the case may be, within 6 months after notice, or within such shorter period as the authorized officer of the Bureau of Land Management may fix. However, in lieu thereof, the principal may within that time file separate bonds for each lease.

§ 3206.8 Applicability of provisions to existing bonds.

The provisions hereof may be made applicable to any nationwide or statewide bond in force at the time of the approval of the amendment of this paragraph by filing in the appropriate land office a written consent to that effect and an agreement to be bound by the provisions hereof executed by the principal and the surety. Upon receipt thereof the bond will be deemed to be subject to the provisions of this paragraph.

PART 3210—NONCOMPETITIVE LEASES

Subpart 3210—Noncompetitive Leases; General

Subpart 3210—Noncompetitive Leases; General

§ 3210.1 General.

§ 3210.1-1 Withdrawal of application.

An application may not be withdrawn, either in whole or in part, unless the request is received by the proper BLM office before the lease has been signed on behalf of the United States even though the effective date of the lease is subsequent to the date of filing of the withdrawal, except where a separate conflicting lease has been signed on behalf of the United States covering the land described in the withdrawal.

§ 3210.1-2 Amendment to lease.

If any of the land applied for is open to filing when the application was filed but is omitted from the lease for any reason and thereafter becomes available for noncompetitive leasing, the original lease will be amended to include the omitted land unless, before the issuance of the amendment, the proper BLM office receives a withdrawal of the lessee's application with respect to such land or such omitted lands have been determined to be within a KGRA.

§ 3210.1-3 Determination of priorities.

No lease shall be issued before final action has been taken on (a) any prior application to lease the land, (b) any subsequent application to lease the land that is based upon a claimed preferential right and (c) any petition for the renewal or reinstatement of an existing or former lease on the land. If a lease is issued before final action has been taken on such applications and petitions, it shall be canceled, after due notice to the lessee, where the applicant or petitioner is found to be qualified and entitled to receive a lease of the land. Multiple applications for lease of the same lands received in the mail or delivered on the same day will be deemed to display a competitive interest and to have been simultaneously filed. If the lands are not within any KGRA, the right of priority to a noncompetitive geothermal lease, among those persons simultaneously filing therefor, will be determined by a public drawing.

§ 3210.1-4 Rejections.

If, after the filing of an application for a noncompetitive lease and before the issuance of a lease, or amendment thereto, pursuant to that application, the land embraced in the application becomes included within a KGRA, the application will be rejected as to such KGRA lands.

Subpart 3211—Regular Offers

§ 3211.1 Availability of land.

Lands and deposits subject to disposition under this Subpart which are not within any KGRA will be available for leasing on the 30th day after the effective date of these regulations. All applications to lease the same lands (which are not within any KGRA) which are filed between the effective date of these regulations and 30 days following that time will be considered to have been filed simultaneously, and the respective priority of the various applications will be determined in accordance with § 3210.1-3.

§ 3211.2 Application.

No specific form is required. An application for a lease must be filed in the proper BLM office in duplicate for public lands and in triplicate for acquired lands. An application will be considered filed when it is received in the proper office during business hours. The application must include the following:

(a) The applicant's name and address.

(b) A statement of applicant's citizenship and qualifications.

(c) A complete and accurate description of the lands applied for.

(d) An exploration and development plan which shall include: (1) Map showing topography, drainage pattern, present road and trail locations, present utility systems, proposed road and trail location, proposed well locations, potential surface plant facilities and pipelines, and (2) a narrative statement setting forth his proposed exploration plan and methods. The narrative statement should also describe the measures proposed to be taken to prevent or control fire, soil erosion, pollution of surface and ground water, damage to fish and wildlife or other natural resources, air and noise pollution and hazards to public health and safety both during and after exploration or development activities.

(e) A statement of interest, direct or indirect, in other Federal geothermal leases or applications in the same State. Such total interest may not exceed 20,480 acres.

Subpart 3212—Bureau Motion—Land Previously Leased for Geothermal Resources

§ 3212.1 Releasing of formerly leased lands.

From time to time the authorized officer will publish in the FEDERAL REGISTER, post in each State Office, and provide appropriate news coverage of: (a)

A list of leasing units composed of lands in canceled, expired, relinquished, or terminated leases which are not withdrawn from leasing or not included in a KGRA and which he has determined to be available for leasing, and (b) a request for nominations for leasing. Nominations of tracts should be addressed to the proper BLM office.

§ 3212.2 Leasing units receiving multiple nominations.

If the lands are determined not to be within any KGRA, multiple nominations for such lands within the prescribed period will be considered as simultaneous filings and each nominator will be given the opportunity to qualify for a lease in accordance with Subpart 3211. Where more than one nominator qualifies for a lease, the priority shall be determined by public drawing.

§ 3212.3 Leasing units receiving single nominations.

(a) Tracts receiving only one nomination, which have not been included within any KGRA, will be leased to the nominator, all else being regular.

(b) If no nominations are received a lease may be issued pursuant to an application filed in accordance with these regulations.

§ 3212.4 Nominating procedures.

No specific form is required. Only one complete leasing unit, identified by unit number, may be included in a nomination. Lands not on the published list may not be included in the nomination. The nomination must be accompanied by (a) the first year's advance rental, and (b) a signed statement that the nominator will furnish the information required by these regulations within 15 days after notification that his nomination is the only one for the tract.

§ 3212.5 Rental returned.

If an applicant or nominator withdraws his application or nomination or if his application or nomination to lease is rejected, the advance rental will be returned to him.

PART 3220—COMPETITIVE LEASES

Subpart 3220—Competitive Leases; General

Subpart 3220—Competitive Leases; General

§ 3220.1 General.

(a) Lands within a KGRA, except as provided under § 3201.1-2(b), will be available for leasing on the effective date of these regulations.

(b) The authorized officer will accept nominations to lease, or may on his own motion from time to time call for nominations to lease. Nominations may be withdrawn at any time.

§ 3220.2 Nominations.

(a) No specific form is required.

(b) A nomination must be filed in the proper BLM office in duplicate for public lands and triplicate for acquired lands and must include the following:

(1) The nominator's name and address.

(2) A statement of citizenship and qualifications for lease.

(3) A description of the lands.

(4) A statement of the interests, direct or indirect, held in other Federal geothermal leases or nominations in the same State.

§ 3220.3 Publication of notice of lease sale.

Where the Secretary determines to offer all or any of the nominated land for competitive leasing he will publish a notice of lease sale once a week for 4 consecutive weeks, or for such other period as he may direct.

§ 3220.4 Contents of notice of lease sale.

The notice will state that the successful bidder will be required, prior to the issuance of a lease, to pay his proportionate share of the total cost of publication of the notice which shall be that portion of the total advertising cost that the number of parcels of land awarded to him bears to the number of parcels for which high bidders are declared. The notice will also state the time and place of sale, the manner in which bids may be submitted, the description of the lands, and the terms and conditions of the sale, including royalty and rental rates.

§ 3220.5 Bidding requirements.

(a) A separate sealed bid must be submitted for each lease unit. Each bidder must submit with his bid a certified or cashier's check, bank draft, money order or cash in the amount of one-half of the amount bid together with proof of qualifications as required by these regulations.

(b) All bidders are warned against violation of the provisions of Title 18 U.S.C. section 1860 prohibiting unlawful combination or intimidation of bidders.

§ 3220.6 Award of lease.

All sealed bids shall be opened at the place, date, and hour specified in the notice. No bids will be accepted or rejected at that time, except as otherwise provided in these regulations. Leases will be awarded to the highest responsible qualified bidder. The right to reject any and all bids is reserved. If the authorized officer fails to accept the highest bid for a lease within 30 days after the date on which the bids are opened, all bids will be considered rejected. If the lease is awarded, three copies of the lease will be sent to the successful bidder who shall be required to execute them within 30 days from receipt thereof, to pay the first year's rental, the balance of the bonus bid, and file the required bond or bonds. Deposits on rejected bids will be returned. If the successful bidder fails to execute the lease or otherwise comply with the applicable regulations, his deposit will be forfeited and disposed of as other receipts under the Act. When the three copies of the lease are executed by the successful bidder and returned to the authorized officer, the lease will be executed by the authorized officer and a copy will be mailed to the successful bidder.

PART 3230—RIGHTS TO CONVERSION TO GEOTHERMAL LEASES OR APPLICATION FOR GEOTHERMAL LEASES

Subpart 3230—Rights to Conversion to Geothermal Leases or Application for Geothermal Leases; General

Subpart 3230—Rights to Conversion to Geothermal Leases or Application for Geothermal Leases

§ 3230.1 General.

§ 3230.1-1 Rights to conversion to geothermal leases.

Where lands were on September 7, 1965, subject to valid leases or permits issued under the Mineral Leasing Act of 1920, as amended and supplemented (30 U.S.C. 181-287), or the Mineral Leasing Act for Acquired Lands, as amended (30 U.S.C. 351-358), or subject to valid existing mining claims located on or prior to September 7, 1965, the lessees, permittees, or claimants, or their successors in interest, if qualified to hold geothermal leases, shall have the right, subject to certain limitations as hereinafter provided, to convert such leases, permits or claims to geothermal leases covering the same lands.

§ 3230.1-2 Rights to conversion to applications for geothermal leases.

Where lands were subject to application for leases or permits under the mineral leasing laws referred to in § 3230.1-1 on September 7, 1965, the applicants may, subject to certain limitations as hereinafter provided, convert their applications to applications for geothermal leases having priorities dating from the time of filing such applications under said mineral leasing laws.

§ 3230.1–3 Land in which minerals are reserved to the United States.

Where a right to one of the forms of conversion referred to in §§ 3230.1–1 or 3230.1–2 is claimed as to lands the surface of which has passed from Federal ownership but in which the minerals have been reserved to the United States, final action on any claim to conversion rights under section 4 of the Act shall be held in abeyance until such time as the question of title to the geothermal resources in such lands has been resolved pursuant to the provisions of section 21(b) of the Act.

§ 3230.1–4 Conflicting claims of rights to conversion to geothermal leases.

Where there are conflicting claims of rights to conversion to geothermal leases based upon mineral leases, mineral permits, or mining claims embracing the same land, the date of issuance of the permit or lease or of recordation of the claim shall determine priority.

§ 3230.1–5 Evidence required to qualify for grant of rights to conversion to geothermal leases.

Any person claiming rights to conversion to a geothermal lease must show to the reasonable satisfaction of the authorized officer that substantial expenditures for the exploration, development or production of geothermal steam were made prior to September 7, 1965, on the lands for which a lease is sought or on adjoining, adjacent or nearby lands, including both Federal and non-Federal lands.

§ 3230.1–6 Method of leasing to owners of conversion rights to geothermal leases.

(a) *Lands included within any KGRA*—(1) *Competitive lease.* Where lands have been included with any KGRA, the owner of a conversion right to a geothermal lease for such lands shall be entitled to the issuance of a competitive lease only in accordance with the provisions of subparagraph (2) of this paragraph.

(2) *Preference right.* Lands which have been included within any KGRA shall be leased only by competitive bidding in the manner prescribed in Subpart 3220 of this chapter. Upon the competitive sale, the competitive geothermal lease shall be issued to the person owning the right to conversion to a geothermal lease for such lands if he makes payment of an amount equal to the highest bona fide bid for that lease, and makes payment of the rental for the first year, within thirty (30) days after he receives written notice from the Secretary of the amount of the highest bid.

(b) *Lands not included within any KGRA—Noncompetitive lease.* Where lands have not been included within any KGRA, the owner of a conversion right to a geothermal lease for such lands, if otherwise qualified, shall be entitled to the issuance of a noncompetitive lease for such lands.

§ 3230.1–7 Acreage limitation.

No person shall be permitted to convert to geothermal leases mineral leases, permits, applications therefor, or mining claims for more than 10,240 acres.

§ 3230.2 Qualifications.

Persons who believe they are qualified under the Act to convert mineral leases or permits or valid existing mining claims to geothermal leases and persons who believe they are entitled to convert applications for mineral leases and permits to applications for geothermal leases shall comply with the procedures set forth below.

§ 3230.3 Applications.

§ 3230.3–1 Filing of application.

A written application shall have been filed with the proper BLM office on or before June 22, 1971, pursuant to the notice published in the FEDERAL REGISTER of January 15, 1971, 36 F.R. 623. If such an application has been filed and does not contain the information specified in section 3230.3–2 hereof, such information must be supplied by the applicant within 60 days of the effective date of these regulations.

§ 3230.3–2 Statements required.

(a) An application based on a valid lease or permit referred to in section 3230.1–1 hereof shall include the date of issuance, the State in which the lands are located, and the serial number of the lease or permit. An application based on a mining claim referred to in § 3230.1–1 shall include the name, location, legal description or reference sufficient to identify the lands on the ground, date of location and date and place of recordation of the mining claim (including volume and page) which the applicant seeks to convert to a geothermal lease. An application based on an application for a mineral lease or permit referred to in section 3230.1–1 shall include the date the application for the lease or permit was filed with the Bureau of Land Management and the location of the proper BLM office where the application was filed, and should indicate the serial number assigned to the application.

(b) An application shall include a description of the lands sought to be included in a geothermal lease. If the lands have been surveyed under the public land rectangular system, each application shall describe the lands by legal subdivision, section, township, and range. If the lands have not been so surveyed, each application shall describe the lands by metes and bounds, giving courses and distances between the successive angle points on the boundary of the tract, and connected by courses and distances to a monument or to a prominent topographic feature. When protracted surveys have been approved and the effective date thereof published in the FEDERAL REGISTER, each application for lands shown on such protracted surveys, filed on or after such effective date, shall describe the lands according to the legal subdivision, section, township, and range shown on the approved protracted surveys.

(c) An application shall be accompanied by a detailed statement showing: (1) The expenditures made for the exploration, development, or production of geothermal steam by the applicant on lands for which a geothermal lease is sought or on adjoining, adjacent or nearby Federal or non-Federal lands and the date or dates such expenditures were made, (2) the names and current addresses of the persons who actually performed the aforesaid exploration, development, or production work, (3) the geological, geophysical, and engineering data acquired in such exploration, development, and production which demonstrates, or tends to demonstrate the expenditures claimed, and (4) a map showing the location where the expenditures and improvements were made.

(d) The applicant shall file such additional information with respect to the application as requested by the authorized officer.

§ 3230.4 Conversion to geothermal leases or to applications for geothermal leases.

§ 3230.4–1 Processing and adjudicating applications.

Application for conversion to geothermal leases or to applications for geothermal leases together with all information and data submitted pursuant to § 3230.3–2 hereof and any other pertinent available information or data shall be reviewed by the authorized officer for the purpose of determining whether the required showing has been made, and thereafter the authorized officer shall prepare a proposed determination which shall be submitted to the Secretary.

§ 3230.4–2 Approval.

The authorized officer will make a determination that the applicant has or has not satisfactorily shown that he is entitled to receive the grant of a geothermal lease, or application for a geothermal lease.

PART 3240—RULES GOVERNING LEASES

Subpart 3240—Rules Governing Leases

Subpart 3241—Lease Extensions, Continuations, or Renewal

Subpart 3242—Assignments and Transfers

Subpart 3241—Lease Extensions, Continuation, or Renewal

§ 3241.1 Applications.

An application for lease extension, continuation, or renewal may be filed by the record title holder of the lease, by an assignee of the record title whose assignment has been filed for approval, or by an operator whose operating agreement has been filed for approval.

§ 3241.2 Forms.

An application for extension or renewal must be filed, within ninety days before the expiration date of the lease, on a form approved by the Director or unofficial copies of that form in current use. The application must be accompanied by a service charge of $50 which will be retained as a service charge even though the application is later withdrawn or rejected. The unofficial copies must be exact reproductions, on one sheet of both sides, of the official form.

§ 3241.3 Segregation effect of application.

The timely filing of an application for extension shall have the effect of segregating the leased lands until the final action taken on the application is noted, for public lands, on the tract book, or, for acquired lands, on the official records relating thereto, of the proper BLM office.

§ 3241.4 Rejection.

If, during the 90-day period prior to the expiration date of the lease, the record title holder, assignee of record title, or operator files an application or request for extension, which is not on the prescribed form or unofficial copies thereof, or fails to file the prescribed number of copies, he shall be notified of the defect and allowed 30 days after receipt of notice in which to correct it. If the applicant fails to correct the defect within the time prescribed, the application will be rejected.

§ 3241.5 Expiration by operation of law.

Upon failure of the lessee or other person enumerated in § 3241.1 to file an application for extension within the specified period, the lease will expire at the end of its primary term without notice to the lessee. Notation of such expiration need not be made on the official records, but the lands previously covered by that expired lease will be subject to the filing of new lease offers only as provided in these regulations.

Subpart 3242—Assignments and Transfers

§ 3242.1 Assignments, transfers, interests, qualifications.

§ 3242.1-1 Record title assignments or transfers of leases or undivided lease interests.

(a) The record title of leases may be assigned as to all or part of the leased acreage, except that no assignment will be approved where (1) either the assigned or retained portions created by the assignment would be less than 640 acres, unless the total acreage in the lease being partially assigned is less than 1,280 acres occasioned by an irregular subdivision, as provided in section 3203.2 of this part, in which case the assigned and retained portions may be less than 640 acres by an amount which is smaller than the amount by which the area would be more than 640 acres if the irregular subdivision were added, or (2) an undivided interest of less than 10 percent would be created in the leased acreage.

(b) To obtain approval of a transfer affecting the record title of a geothermal lease, a request for such approval must be made not more than 90 days after the date of the final execution of the assignment by the parties.

§ 3242.1-2 Qualifications.

(a) No assignment will be approved (1) if the assignee or any other party in interest is not qualified to take and hold a lease; (2) if a required bond is not filed; or (3) if the statement of interest required under § 3202.4-1 is not filed.

(b) An assignment to a minor will not be approved.

(c) The assignment must be accompanied by a signed statement by the assignee either (1) that he is the sole party in interest in the assignment, or (2) setting forth the names and qualifications of the other parties holding interests in the lease. Where the assignee is not the sole party in interest, separate statements must be signed by each of the other parties and by the assignee setting forth the nature and extent of the interest of each party and the nature of the agreement between them. These separate statements must be filed in the proper BLM office not later than 15 days after the filing of assignment.

(d) Where an attorney-in-fact or agent signs, on behalf of the assignor or assignee, the instrument of transfer or the application for approval, evidence of the authority of the attorney-in-fact or agent to sign such assignment or application must be furnished to the authorized officer.

(e) In order for the heirs or devisees of the deceased holder of a lease, an operating agreement, or an overriding royalty interest in a producing lease, to be recognized by the authorized officer as the holder of that lease, agreement or interest, the appropriate showing required under the regulations in this group must be furnished to the authorized officer.

§ 3242.2 Requirements for filing of assignments or transfers.

§ 3242.2-1 Place of filing and service charge.

A request for approval of any assignment or other instrument of transfer of a lease or interest therein must be filed in the proper BLM office and accompanied by a nonrefundable service charge of $50. An application not accompanied by payment of such a service charge will not be accepted for filing.

§ 3242.2-2 Number of copies required.

Three copies of all instruments of assignment or transfer, and a single copy of any additional information relating to citizenship or qualifications of corporations must be filed in the proper BLM office.

§ 3242.2-3 Time of filing assignments, transfers of leases, or undivided lease interests.

(a) All instruments of transfer of a lease or of an interest therein, including assignments of working interests, operating agreements, and operating rights, must be filed in the proper BLM office for approval within 90 days from the date of execution of such instrument and must contain all of the terms and conditions agreed upon by the parties thereto, together with evidence and statements similar to that required of an applicant under these regulations in this group.

(b) A separate instrument of assignment must be filed in the proper BLM office for each geothermal lease involving transfers of record title. When transfers to the same person, association, or corporation involve more than one geothermal lease, one request for approval and one showing as to the qualifications of the assignee will be sufficient.

§ 3242.2–4 Forms and statements.

A form approved by the Director, or unofficial copies of that form in current use, must be used for transfers and requests for approval referred to in this section. Unofficial copies used must be exact reproductions on one sheet of both sides of the officially approved one-page form, except that the copies must include: (a) The following statement above the signature of the assignee: "This form is submitted in lieu of the official form and contains all of the provisions thereof as of the date of filing of this assignment;" and (b) the name and address of the printer or other party issuing unofficial reproductions of the official form. The approved form may be used for an assignment which affects a transfer of the record title to all or part of a geothermal lease, but it is not to be used for any other type of transfer. The application for assignment shall be deemed to be approved upon execution by the authorized officer.

§ 3242.2–5 Description of lands.

Each instrument of transfer must describe the lands involved in the same manner as described in the lease.

§ 3242.3 Bonds.

Where an assignment does not create separate leases, the assignee, if the assignment so provides, may become a joint principle on the bond with the assignor. Any assignment which does not convey the assignor's record title in all of the lands in the lease must also be accompanied by consent of his surety to remain bound under the bond of record as to the lease retained by said assignor, if the bond, by its terms, does not contain such consent. If a party to the assignment has previously furnished a nationwide or statewide bond, no additional showing is necessary by such party as to the bond requirement.

§ 3242.4 Approval.

Upon approval, an assignment shall be effective as of the first day of the lease month following the date of filing of the assignment required by this Subpart in the proper BLM office.

§ 3242.5 Continuing responsibility.

(a) The assignor and his surety will continue to be responsible for the performance of any obligation under the lease until the assignment is approved.

(b) Upon approval, the assignee and his surety shall be responsible for the performance of all lease obligations notwithstanding any terms in the assignment to the contrary.

§ 3242.6 Production payments.

If payments out of production are reserved, a statement must be submitted stating the details as to the amount, method of payment, and other pertinent items.

§ 3242.7 Overriding royalty interests.

§ 3242.7–1 General.

(a) Overriding royalty interests in geothermal leases constitute accountable acreage holdings under these regulations.

(b) If an overriding royalty interest is created which is not shown in the instrument of assignment or transfer, a statement must be filed in the proper BLM office describing the interest.

(c) Any such assignment will be deemed valid if accompanied by a statement over the assignee's signature that the assignee is a citizen of the United States, an association of such citizens, or a corporation organized under the laws of the United States or of one of the States or the District of Columbia, and that his interests in geothermal leases do not exceed the acreage limitations provided in these regulations.

(d) All assignments of overriding royalty interests must be filed for record in the proper BLM office within 90 days from the date of execution. Such interests will not receive formal approval.

§ 3242.7–2 Limitation of overriding royalties.

(a) Except as herein provided, an overriding royalty on the value of the output of all geothermal resources, or any of them, at the point of shipment to market may be created by assignment or otherwise: *Provided*, That, (1) the overriding royalty is not for less than one-fourth (¼) of 1 percent of the value of such output, and does not exceed 50 percent of the rate of royalty due to the United States as specified in the geothermal lease, or as reduced pursuant to such lease, and (2) the overriding royalty, when added to overriding royalties previously created, does not exceed the maximum rate established herein.

(b) The creation of an overriding royalty interest that does not conform to the requirements of paragraph (a) of this section shall be deemed a violation of the lease terms, unless the agreement creating overriding royalties provides (1) for a prorated reduction of all overriding royalties so that the aggregate rate of royalties does not exceed the maximum rate established in paragraph (a) of this section and (2) for the suspension of an overriding royalty during any period when the royalties due to the United States have been suspended pursuant to the terms of the geothermal lease.

§ 3242.8 Lease account status; requirements.

Unless the lease account is in good financial standing as to the area covered by an assignment at the time the assignment and bond are filed, or is placed in good standing before the assignment is reached for action, the lease shall be subject to termination in accordance with these regulations.

§ 3242.9 Effect of assignment.

An assignment of the record title of the complete interest in a portion of the lands in a lease shall segregate the assigned and retained portions into separate and distinct leases. An assignment of an undivided interest in the entire leasehold shall not segregate the lease into separate or distinct leases.

Subpart 3243—Production and Use of Byproducts

§ 3243.1 General.

Where the Supervisor determines that production, use, or conversion of geothermal steam is susceptible of producing a valuable byproduct or byproducts, including commercially demineralized water contained in or derived from such geothermal steam for beneficial use in accordance with applicable State water laws, the authorized officer shall require substantial beneficial production or use thereof, except where he determines that:

(a) Beneficial production or use is not in the interest of conservation of natural resources;

(b) Beneficial production or use would not be economically feasible; or

(c) Beneficial production and use should not be required for other reasons satisfactory to him.

§ 3243.2 Prior rights.

The production or use of such byproducts shall be subject to the rights of the holders of preexisting leases, permits or claims covering the same lands or the same minerals.

§ 3243.3 Production and use of commercially demineralized water as a byproduct, production, and use of other sources of water.

§ 3243.3–1 General.

Except as provided in these regulations, the lessee shall have the right to process fluids, including brine, condensate, and other fluids, which are associated with geothermal steam within lands subject to the geothermal lease for the purpose of developing, producing, and utilizing the commercially demineralized water recovered as a result of such processing.

§ 3243.3–2 Prohibition on production of commercially demineralized water.

The lessee shall not be authorized to engage in the primary production of commercially demineralized water from the produced fluids contained in or derived from geothermal steam referred to in § 3243.3–1, where such use would result in the undue waste of geothermal energy.

§ 3243.3–3 Water wells on geothermal areas.

All leases issued under these regulations shall be subject to the condition that, where the lessee finds only fresh water in any well drilled for production of geothermal resources, the Secretary may, when the water is of such quality and quantity as to be valuable and usable for agricultural, domestic, or other purpose, acquire the casing in the well at the fair market value of the casing.

§ 3243.3–4 State water laws.

Nothing in these regulations shall constitute an express or implied claim or denial on the part of the Federal Government as to its exemption from State water laws.

§ 3243.4 Noncompliance with regulations or lease terms.

A lease may be canceled by the authorized officer for any violation of these regulations or the lease terms 30 days after receipt of notice of the violation by the lessee unless the violation has been corrected or is one that cannot be corrected within the notice period, and the lessee has commenced in good faith within the notice period, and thereafter proceeds diligently to correct the violation. A lessee shall be entitled to a hearing on the matter of any claimed violation or proposed cancellation of lease if a request for a hearing is made to the authorized officer within the 30-day period after notice. The period for correction of violation or commencement to correct a violation of regulations or of lease terms, as aforesaid, shall be extended to 30 days after the lessee's receipt of the authorized officer's decision upon such a hearing if the authorized officer shall find that a violation exists.

§ 3243.5 Removal of material and supplies upon termination of lease.

Upon the expiration of the lease, or the earlier termination thereof pursuant to this subpart, the lessee shall have the privilege at any time within a period of ninety (90) days thereafter of removing from the premises any materials, tools, appliances, machinery, structures, and equipment other than improvements needed for producing wells. Any materials, tools, appliances, machinery, structures, and equipment subject to removal shall at the option of the lessor become the property of the lessor on expiration of the 90-day period, or any extension thereof that may be granted because of adverse climatic conditions throughout that period, but the lessee shall remove any or all such property where so directed by the lessor.

Subpart 3244—Cooperative Conservation Provisions

§ 3244.1 Cooperative or unit plans.

For the purpose of more properly conserving the natural resources of any geothermal pool, field or like area, lessees and their representatives may unite with each other or jointly or separately with others, in collectively adopting and operating under a cooperative or unit plan of development or operation of any geothermal resource area, or any part thereof (whether or not any part of that geothermal resource area is then subject to any cooperative or unit plan of development or operation). Applications to unitize shall be filed with the Supervisor who shall certify whether such plan is necessary or advisable in the public interest. The procedure in obtaining approval of a cooperative or unit plan of development, including the suggested text of an agreement, is contained in 30 CFR Part 271.

§ 3244.2 Acreage chargeability.

All leases committed to any unit or cooperative plan approved or prescribed by the Supervisor shall be expected in determining holdings or control for purposes of acreage chargeability. For the extension of leases committed to a unit plan, see Subpart 3203 of these regulations.

§ 3244.3 Communitization or drilling agreements.

§ 3244.3–1 Approval.

(a) The Supervisor is authorized, when separate tracts under lease cannot be independently developed and operated in conformity with an established well-spacing or well-development program, to approve communitization or drilling agreements providing for the apportionment of production or royalties among the separate tracts of land comprising the drilling or spacing unit for the lease, or any portion thereof, with other lands, whether or not owned by the United States, when in the public interest. Operations or production pursuant to such an agreement shall be deemed to be operations or production as to each lease committed thereto.

(b) Preliminary requests to communitize separate tracts shall be filed in triplicate with the Supervisor.

(c) Executed agreements shall be submitted to the Supervisor in sufficient number to permit retention of five copies after approval.

§ 3244.3–2 Requirements.

The agreement shall describe the separate tracts comprising the drilling or spacing unit, disclose the apportionment of the production or royalties to the several parties and the name of the operator, and shall contain adequate provisions for the protection of the interests of all parties, including the United States. The agreement must be signed by or in behalf of all interested parties and will be effective only after approval by the Supervisor.

§ 3244.4 Operating, drilling, development contracts or a combination for joint operations.

§ 3244.4–1 Approval.

(a) The Secretary may on such conditions as he may prescribe, approve operating, drilling, or development contracts made by one or more geothermal lessees, with one or more persons, associations, or corporation whenever, in his discretion, the conservation of natural products of the public convenience or necessity may require, or the interests of the United States may be best served thereby.

(b) The Secretary may approve a combination for joint operations, pursuant to which lessees may combine their interests in leases for the purpose of constructing and carrying on the business of producing geothermal resources, or of establishing and constructing common lines to be used by them jointly in the transmission or transportation of geothermal resources from their several wells or from the wells of other lessees, or to increase the acreage which may be acquired or held under the provisions of the Act relating to competitive leases.

(c) Contracts submitted for approval under this section should be filed with the Supervisor together with enough copies to permit retention of five copies after approval.

(d) The authority of the Secretary to approve operating, drilling, or development contracts or a combination for joint operations, without regard to acreage limitations ordinarily will be exercised only to permit operators to enter into contracts with a number of lessees sufficient to justify operations on a large scale for the discovery, development, production, or transmission, or transportation of geothermal resources, and to finance the same.

§ 3244.4–2 Requirements.

(a) The contract must be accompanied by a statement showing all the interests held by the contractor in the area or field and the proposed or agreed plan of operation or development of the field. All the contracts held by the same contractor in the area or field should be submitted for approval at the same time, and full disclosure of the project made. Complete details must be furnished in order that the Secretary may have facts upon which to make a definite determination in accordance herewith and to prescribe the conditions on which approval of the contracts shall be made.

(b) The application must show a reasonable need for the combination and that it will not result in any concentration of control over the production or sale of geothermal resources which would be inconsistent with the antimonopoly provisions of law.

§ 3244.4–3 Acreage chargeability.

All leases operated under approved operating, drilling or development contracts or a combination for joint operations and interests thereunder, shall be excepted in determining holdings or control for purposes of acreage chargeability.

Subpart 3245—Terminations and Expirations

§ 3245.1 Relinquishments.

A lease, or any legal subdivision of the area covered by such lease, may be surrendered by the record title holder by filing a written relinquishment in triplicate in the proper BLM office. A relinquishment shall take effect on the date it is filed, subject to the continued obligation of the lessee and his surety: (a) To make payments of all accruing rentals and royalties; (b) to place all wells on the land to be relinquished in condition for suspension of operations or abandonment as prescribed by the Supervisor; (c) to restore the surface resources in accordance with all regulations and the terms of the lease; and (d) to comply with all other environmental stipulations provided for by such regulations or lease. A statement must be furnished that all moneys due and payable to workmen employed on the leased premises have been paid.

§ 3245.2 Automatic terminations and reinstatements.

§ 3245.2–1 General.

Except as provided in § 3245.2–2 any lease will automatically terminate by operation of law if the lessee fails to pay the rental on or before the anniversary date of such lease. However, if the time for payment falls upon any day in which the proper office to receive payment is not open, payment received on the next official working day shall be deemed to be timely. The termination of the lease for failure to pay the rental must be noted on the official records of the proper BLM office. Upon such notation the lands included in such lease will become subject to the filing of new lease offers as provided for in Subpart 3212 of these regulations.

§ 3245.2–2 Exceptions.

(a) *Nominal deficiency.* If the rental payment due under a lease is paid on or before its anniversary date but the amount of the payment is deficient and the deficiency is nominal, the lease shall not have automatically terminated unless the lessee fails to pay the deficiency within the period prescribed in a Notice of Deficiency, or by the due date, whichever is later. A deficiency is nominal if it is not more than $10 or one percentum (1%) of the total payment due, whichever is more. The authorized officer shall send a Notice of Deficiency to the lessee on an approved form. The Notice shall be sent by certified mail, return receipt requested, and shall allow the lessee 15 days from the date of receipt to submit the full balance due to the proper BLM office. If the payment called for in the notice is not made within the time allowed, the lease will have terminated by operation of law as of its anniversary date.

(b) *Reinstatements.* (1) Except as hereinafter provided, the authorized officer may reinstate a lease which has terminated automatically for failure to pay the full amount of rental due on or before the anniversary date, if it is shown to his satisfaction that such failure was either justifiable or not due to a lack of reasonable diligence on the part of the lessee; and a petition for reinstatement, together with the required rental, including any back rental which has accrued from the date of termination of the lease, is filed with the proper BLM office.

(2) The burden of showing that the failure to pay on or before the anniversary date was justifiable or not due to lack of reasonable diligence will be on the lessee. Reasonable diligence normally requires sending or delivering payments sufficiently in advance of the anniversary date to account for normal delays in the collection, transmittal, and delivery of the payment. The authorized officer may require evidence, such as post office receipts, of the time of sending or delivery of payments.

(3) Under no conditions will a lease be reinstated if (i) a valid lease has been issued prior to the filing of a petition for reinstatement affecting any of the lands covered by the terminated lease, or (ii) the interest in the lands has been withdrawn, disposed of, or has otherwise become unavailable for leasing. However, the authorized officer will not issue a new lease for lands covered by a lease which terminated automatically until 90 days after the date of termination. (4) Reinstatement of terminated leases is discretionary with the Secretary. The basic criterion in accordance with which this discretion will be exercised is whether the Secretary would be willing to issue a lease if a new lease offer for the same land were under consideration.

Dated: July 15, 1971.

W. T. PECORA,
Under Secretary of the Interior.

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Geological Survey

[30 CFR Part 270]

GEOTHERMAL RESOURCES OPERATIONS ON PUBLIC, ACQUIRED, AND WITHDRAWN LANDS

Notice of Proposed Rule Making

The purpose of this proposed rule making is to implement the Geothermal Steam Act of December 24, 1970 (84 Stat. 1566). That Act provides for the leasing of public lands for geothermal resource exploration, development, and production.

Environmental statements will be prepared and disseminated in accordance with the provisions of section 102(2)(C) of the National Environmental Policy Act of 1969 (42 U.S.C. Section 4332(2)(C) (Supp. V., 1965–69)) prior to the promulgation of any leasing and operating regulations.

It is the policy of the Department of the Interior, whenever practicable, to afford the public an opportunity to participate in the rule-making process. Accordingly, interested parties may submit written comments, suggestions, or objections with respect to the proposed regulations to the Geothermal Coordinator, Department of the Interior, Washington, D.C. 20240, within 60 days of the date of publication of this notice in the FEDERAL REGISTER.

GENERAL PROVISIONS

§ 270.1 Purpose and authority.

The Geothermal Steam Act enacted on December 24, 1970, (84 Stat. 1566) referred to in this part as "the Act", authorizes the Secretary of the Interior to prescribe rules and regulations applicable to operations conducted under a lease granted pursuant to that Act, and for the development and conservation of geothermal steam and associated geothermal resources, the prevention of waste, the protection of the public interest, and the protection of water quality, and other environmental qualities. The regulations in this part shall be administered by the Director through the

Chief, Conservation Division, or his duly appointed representative.

§ 270.2 Definitions.

As used in the regulations in this part, the term:

(a) "Secretary" means the Secretary of the Interior.

(b) "Director" means the Director of the Geological Survey.

(c) "Supervisor" means either a representative of the Secretary (under administrative direction of the Director, exercised through the Chief, Conservation Division, Geological Survey) who is authorized to regulate operations and to perform other duties prescribed in the regulations in this part, or any subordinate of such representative acting under his direction.

(d) "Geothermal lease" means a lease issued under 43 CFR Group 3200.

(e) "Lessee" means the individual, corporation, or association to which a geothermal lease has been issued and its successor in interest or assignee. It also means any agent of the lessee or an operator holding authority by or through the lessee.

(f) "Operator" means the individual, corporation, or association having control or management of operations on the leased lands or a portion thereof. The operator may be the lessee, designated operator, or agent of the lessee, or holder of rights under an approved operating agreement.

(g) "Geothermal resources" means (1) all products of geothermal processes, embracing indigenous steam, hot water, and hot brines; (2) steam and other gases, hot water, and hot brines, resulting from water, gas, or other fluids artificially introduced into geothermal formations; (3) heat or other associated energy found in geothermal formations; and (4) any byproduct derived therefrom.

(h) "Byproduct" means (1) any mineral or minerals (exclusive of oil, hydrocarbon gas, and helium), which are found in solution or developed in association with geothermal steam and which have a value of less than 75 per centum of the value of the geothermal steam or are not, because of quantity, quality, or technical difficulties in extraction and production, of sufficient value to warrant extraction and production by themselves, and (2) commercially demineralized water.

(i) "Waste" means (1) physical waste as that term is generally understood; (2) waste of reservoir energy through inefficiency, improper use of or unnecessary dissipation of reservoir energy; (3) the location, spacing, drilling, equipping, operating, or producing of any geothermal well or wells in a manner which causes or tends to cause reduction in the quantity of geothermal energy ultimately recoverable from a reservoir under prudent and workmanlike operations or which tends to cause unnecessary or excessive surface or subsurface loss or destruction of geothermal energy; and (4) the inefficient transmission of geothermal energy from the source (wellhead) to point of utilization.

(j) "Directionally drilled well" means the deviation of a well bore from the vertical or from its normal course in an intended predetermined direction or course with respect to the points of the compass. Directionally drilled well shall not include those deviated for the purpose of straightening a hole that has become crooked in the normal course of drilling or holes deviated at random without regard to compass direction in an attempt to sidetrack a portion of the hole on account of mechanical difficulty in drilling.

(k) "Geothermal Resources Operational (GRO) Orders." Formal numbered orders, issued by the Supervisor, with the prior approval of the Chief, Conservation Division, Geological Survey, which implement the regulations in this part and apply to operations in an area, region, or any major portion thereof.

(l) "Producible well" means a well which is capable of producing geothermal resources in commercial quantities.

(m) "Commercial quantities" means quantities sufficient to pay a profit after all costs of production have been met.

JURISDICTION AND FUNCTIONS OF SUPERVISOR

§ 270.10 Jurisdiction.

Drilling and production operations, handling and measurement of production, determination and collection of royalty and, in general, all operations conducted on a geothermal lease are subject to the regulations in this part and the applicable regulations contained in 43 CFR Group 3200, and are under the jurisdiction of the Supervisor for the region in which the leased land is situated, subject to the supervisory authority of the Secretary and the Director.

§ 270.11 General functions.

The Supervisor is authorized and directed to carry out the provisions of this part. He will require compliance with the terms of geothermal leases, with the regulations in this part and the applicable regulations in 43 CFR Group 3200, and with the applicable statutes. He shall act on all applications, requests, and notices required in this part. In executing his functions under this part the Supervisor shall ensure that all operations conform to the best practice and are conducted in such manner as to protect the deposits of the leased lands and to result in the maximum ultimate recovery of geothermal resources, with minimum waste, and are consistent with the principles of the use of the land for other purposes and of the protection of the environment. Inasmuch as conditions in one area may vary widely from conditions in another area, the regulations in this part are intended to be general in nature. Detailed procedures hereunder in any particular area will be covered by GRO orders. The Supervisor may issue oral orders to govern lease operations, but such orders shall be confirmed in writing by the Supervisor as promptly as possible. The Supervisor may issue other orders and rules to govern the development and method for production of a pool, field, or area. Prior to the issuance of GRO orders and other orders and rules, the Supervisor may consult with, and receive comments from Federal and State agencies, lessees, operators, and other interested parties. Before permitting operations on the leased land, the Supervisor shall determine if the lease is in good standing, whether the lessee is authorized to conduct operations, has filed an acceptable bond, and has an approved plan of operations.

§ 270.12 Regulation of operations.

The Supervisor shall inspect and supervise operations performed under the regulations in this part to: (a) Prevent waste and damage to formations or deposits containing geothermal resources; (b) prevent unnecessary damage to other natural resources; (c) prevent degradation of the water quality; (d) protect other environmental qualities; and (e) prevent injury to life or property. The Supervisor shall issue such GRO orders as are necessary to accomplish these purposes.

§ 270.13 Required samples, tests, and surveys.

When necessary or advisable, the Supervisor shall require that adequate samples be taken and tests or surveys be made using acceptable techniques, without cost to the lessor, to determine the identity and character of formations; the presence of geothermal resources, water, or reservoir energy; the quantity and quality of geothermal resources, or water; the amount and direction of deviation of any well from the vertical; formation, casing, and tubing pressures, temperatures, rate of heat and fluid flow, and whether operations are conducted in a manner looking to the protection of the interests of the lessor.

§ 270.14 Drilling and abandonment of wells.

The Supervisor shall require that drilling be conducted in accordance with the terms of the lease, GRO orders, and the regulations in this part and 43 CFR Group 3200; and shall require plugging and abandonment of any well or wells no longer necessary for operations in accordance with plans approved or prescribed by him. Upon the failure of a lessee to comply with any requirement under this section, the Supervisor is authorized to perform the work at the expense of the lessee and the surety.

§ 270.15 Well spacing and well casing.

The Supervisor shall approve proposed well-spacing and well-casing programs or prescribe such modifications to the programs as he determines necessary for proper development, giving consideration to such factors as: (a) Topographic characteristics of the area; (b) hydrologic, geologic and reservoir characteristics of the field; (c) the number of wells that can be economically drilled to provide the necessary volume of geothermal resources for the intended use; (d) protection of correlative rights; (e) minimizing well interference; (f) unreasonable interference with multiple use of lands; and (g) protection of the environment.

§ 270.16 Royalties and other payments.

The Supervisor shall determine the value of production accruing to the lessor as royalty, the loss through waste or failure to drill and produce protection wells on the lease, and the compensation due to the lessor as reimbursement for such loss.

§ 270.17 Suspension of operations and production.

(a) On receipt of an application filed in accordance with 43 CFR 3205.3-7 for suspension of operations or production, or both, under a producing geothermal lease (or for relief from any drilling or producing requirements of such a lease), the Supervisor may, if he deems the suspension or relief warranted, approve the application.

(b) In the interest of conservation, the Supervisor may, on his own motion, suspend operations or production, or both, on any geothermal lease.

(c) Where operations or production, or both, under a lease, have been suspended, the Supervisor may approve resumption of operations or production either on his own motion or upon written request by the lessee or his agent.

(d) Whenever it appears from facts adduced by or furnished to the Supervisor that the interest of the lessor require additional drilling or producing operations, he may, by written notice, order the beginning or resumption of such operations.

(e) Any action of the Supervisor under this Section shall be subject to the right of appeal under § 270.81.

(f) See 43 CFR Group 3200 for regulations concerning requests to waive, suspend, or reduce payments of rental or royalty, and extensions of leases on which operations or production have been suspended.

REQUIREMENTS FOR LESSEES

(INCLUDING OPERATORS)

§ 270.30 Lease terms, regulations, waste, damage, and safety.

(a) The lessee shall comply with the lease terms, lease stipulations, applicable laws and regulations and any amendments thereof, GRO orders, and other written or oral orders of the Supervisor. All oral orders (to be confirmed in writing as provided in § 270.11) are effective when issued unless otherwise specified.

(b) The lessee shall take all reasonable precautions to prevent: (1) Waste; (2) damage to any natural resource including trees and other vegetation, fish and wildlife and their habitat; (3) injury or damage to persons, real or personal property; and (4) any environmental pollution or damage.

§ 270.31 Designation of operator or agent.

In all cases where operations are not conducted by the lessee but are to be conducted under authority of an unapproved operating agreement, assignment or other arrangement, a "designation of operator" shall be submitted to the Supervisor, in a manner and form approved by him, prior to commencement of operations. Such a designation will be accepted as authority of the operator or his local representative to act for the lessee and to sign any papers or reports required under the regulations in this part. All changes of address and any termination of the authority of the operator shall be immediately reported, in writing, to the Supervisor.

§ 270.32 Local agent.

When required by the Supervisor, the lessee shall designate a local representative empowered to receive notices and comply with orders of the Supervisor issued pursuant to the regulations in this part.

§ 270.33 Drilling and producing obligations.

(a) The lessee shall diligently drill and produce such wells as are necessary to protect the lessor from loss by reason of production on other properties, or in lieu thereof, with the consent of the Supervisor, shall pay a sum determined by the Supervisor as adequate to compensate the lessor for failure to drill and produce any such well.

(b) The lessee shall promptly drill and produce such other wells as the Supervisor may require in order that the lease be developed and produced in accordance with good operating practices. (See 43 CFR Part 3234.)

§ 270.34 Drilling and development programs.

Prior to commencing any drilling operations on the lease, including the making of locations or well sites, the lessee shall submit, for approval by the Supervisor, a plan setting forth the proposed development program for the area. Each plan for the leased area shall include:

(a) Structural information based on available geologic and geophysical data;

(b) Heat flow and hydrologic information;

(c) The proposed location of each well, including projected bottomhole locations of any directionally drilled wells; and

(d) All pertinent information or data which the Supervisor may require to support the drilling program and development program for the utilization of geothermal resources.

§ 270.35 Subsequent well operations.

After completion of all operations authorized under any previously approved notice or plan, the lessee shall not begin to redrill, repair, deepen, plug back, shoot, or plug and abandon any well, make casing tests, alter the casing or liner, stimulate production, change the method of recovering production, or use any formation or well for brine or fluid disposal without first notifying the Supervisor and receiving written approval of his plan and intention prior to commencing the contemplated work. However, in an emergency a lessee may take action to prevent damage without receiving prior approval from the Supervisor, but in such cases the lessee shall report his action to the Supervisor as soon as possible.

§ 270.36 Well designations.

The lessee shall mark each derrick upon commencement of drilling operations and each producing or suspended well in a conspicuous place with his name or the name of the operator, the serial number of the lease, the number and location of the well. Whenever possible, the well location shall be described by section or tract, township, range, and by quarter-quarter section or lot. The lessee shall take all necessary means and precautions to preserve these markings.

§ 270.37 Well records.

(a) The lessee shall keep for each well at his field headquarters or at other locations conveniently available to the Supervisor, accurate and complete records of all well operations including production, drilling, logging, directional well surveys, casing, perforation, safety devices, redrilling, deepening, repairing, cementing, alterations to casing, plugging, and abandoning. The records shall contain a description of any unusual malfunction, condition or problem; all the formations penetrated; the content and character of mineral deposits and water in each formation; thermal gradients, temperatures, pressures, analyses of geothermal waters, the kind, weight, size, grade, and setting depth of casing; and any other pertinent information.

(b) The lessee shall, within 30 days after completion of any well, transmit to the Supervisor copies of the records of all operations in a form prescribed by the Supervisor.

(c) Upon request of the Supervisor, the lessee will furnish (1) legible, exact copies of service company reports on cementing, perforating, acidizing, analyses of cores, electrical, and temperature logs, chemical analyses of steam and waters, or other similar services; (2) other reports and records of operations in the manner and form prescribed by the Supervisor.

§ 270.38 Samples, tests, and surveys.

(a) The lessee, when required by the Supervisor, will make adequate sampling, tests and/or surveys using acceptable techniques, to determine the presence, quantity, quality, and potential of geothermal resources, mineral deposits, or water; the amount and direction of deviation of any well from the vertical;

and/or formation temperatures and pressures, casing, tubing, or other pressures and such other facts as the Supervisor may require. Such tests or surveys shall be made without cost to the lessor.

(b) The lessee shall, without cost to the lessor, take such formation samples or cores to determine the identity and character of any formation as are required and prescribed by the Supervisor.

§ 270.39 Directional survey.

The Supervisor may require an angular deviation and directional survey to be made of the finished hole of each directionally drilled well. The survey shall be made at the risk and expense of the lessee unless requested by an offset lessee, and then, at the risk and expense of the offset lessee. A copy of the survey shall be furnished the Supervisor.

§ 270.40 Well control.

The lessee or operator shall: (a) Take all necessary precautions to keep all wells under control at all times; (b) utilize trained and competent personnel; (c) utilize properly maintained equipment and materials; and (d) use operating practices which insure the safety of life and property. The selection of the types and weights of drilling fluids and provisions for controlling fluid temperatures, blowout preventers, and other surface control equipment and materials, casing and cementing programs, etc., to be used shall be based on sound engineering principles and shall take into account apparent geothermal gradients, depths and pressures of the various formations to be pentrated and other pertinent geologic and engineering data and information about the area.

§ 270.41 Pollution.

The lessee shall not pollute the land, water, or air; pollute streams, damage the surface or pollute the underground water of the leased or other land. Federal and State air and water quality standards will be followed unless more stringent requirements are stipulated by the Supervisor. Plans for disposal of well effluents must take into account effects on ground waters, streams, plants, fish and wildlife and their populations, atmosphere, or any other effects which may cause or contribute to pollution, and such plans must be approved by the Supervisor before action is taken under them.

§ 270.42 Noise abatement.

The lessee shall minimize noise when conducting air drilling operations or when the well is allowed to produce while drilling or drilling is being conducted. Welfare of the operating personnel and the public must not be affected as a consequence of the noise created by the expanding gases. The method and degree of noise abatement shall be as approved by the Supervisor.

§ 270.43 Pits or sumps.

Materials and fluids or any fluid necessary to the drilling, production, or other operations by a lessee may, upon approval by the Supervisor, be discharged or placed in pits and sumps. The lessee shall provide pits and sumps of adequate capacity and design to retain all materials. In no event shall the contents of a pit or sump be allowed to: (a) Contaminate streams, artificial canals or waterways, ground waters, lakes or rivers; (b) adversely affect environment, persons, plants, fish and wildlife and their populations; or (c) damage the aesthetic values of the property or adjacent properties. When no longer needed, pits and sumps are to be filled and covered and the premises restored to a near natural state, as prescribed by the Supervisor.

§ 270.44 Well abandonment.

The lessee shall promptly plug and abandon any well on the leased land that is not used or useful. No well shall be abandoned until its lack of capacity for further profitable production of geothermal resources has been demonstrated to the satisfaction of the Supervisor. Before abandoning a producible well, the lessee shall submit to the Supervisor a statement of reasons for abandonment and his detailed plans for carrying on the necessary work. A producible well may be abandoned only after receipt of written approval by the Supervisor. No well shall be plugged and abandoned until the manner and method of plugging has been approved or prescribed by the Supervisor. Equipment shall be removed, and premises at the well site shall be restored as near as reasonably possible to its original condition immediately after plugging operations are completed on any well except as otherwise authorized by the Supervisor. Drilling equipment shall not be removed from any suspended drilling well without taking adequate measures to close the well and protect the subsurface resources.

§ 270.45 Accidents.

The lessee shall take all reasonable precautions to prevent accidents and shall notify the Supervisor within 24 hours of all accidents on the leased land, and shall submit a full report thereon within 15 days.

§ 270.46 Workmanlike operations.

The lessee shall carry on all operations and maintain the property at all times in a safe and workmanlike manner, having due regard for the preservation and the conservation of the property and the environment and for the health and safety of employees. The lessee shall remove from the property or store, in an orderly manner, all scrap or other materials not in use.

§ 270.47 Departure from orders.

The Supervisor may prescribe or approve either in writing or orally with prompt written confirmation, waivers or deviations from the requirements of GRO orders and other orders issued pursuant to these regulations, when such departures are necessary for the proper control of a well, conservation of natural resources, protection of human health and safety, property, or the environment.

§ 270.48 Sales contracts.

The lessee shall file with the Supervisor within 30 days after the effective date thereof copies of all contracts for the disposal of geothermal resources from the lease.

§ 270.49 Royalty payments.

The lessee shall pay all royalties as due under the terms of the lease. Payments of royalties are due not later than the last day of the month following the month in which sales were made, and shall be by check, bank draft, or money order, drawn to the order of the United States Geological Survey. Taxes are not deductible in computing royalties.

MEASUREMENT OF PRODUCTION AND COMPUTATION OF ROYALTIES

§ 270.60 Measurement of geothermal resources.

The lessee shall measure or gauge all production in accordance with methods approved by the Supervisor or may arrange with the Supervisor for other acceptable methods of measuring and recording production. The quantity and quality of all production shall be determined in accordance with the standard practices, procedures, and specifications generally used in industry.

§ 270.61 Determination of content of byproducts.

The lessee shall periodically furnish the Supervisor the results of periodic tests showing the content of the byproducts. Such tests shall be taken as specified by the Supervisor and the method of testing approved by him.

§ 270.62 Value of geothermal production for computing royalties.

The value of geothermal production for the purpose of computing royalty shall be the reasonable value of the product, as determined by the Supervisor. In determining the reasonable value of the product, the Supervisor shall consider: (1) The highest price paid for a majority of the production of like quality in the same field or area; (2) the total consideration received by the lessee for any disposition of the geothermal production; (3) the value of alternate available energy sources; and (4) other relevant matters.

(b) Under no circumstances shall the value of any geothermal production for the purposes of computing royalties be less than:

(1) The total consideration accruing to the lessee from the sale thereof in cases where geothermal resources are sold by the lessee to another party; or

(2) That amount which is the product of the percentage of the value of the end product attributable to the geothermal resource times the total value of such end products in cases where geothermal resources are not sold by the lessee before being utilized, but are instead directly used in manufacturing, power production, or other industrial activity.

§ 270.63 Computation of royalties.

(a) The value of geothermal production, as determined pursuant to § 270.62, shall be apportioned between geothermal steam, heat, and other forms of energy and the byproducts.

(b) The royalties payable shall be the sum of (1) the amount resulting from the multiplication of the value attributable to the geothermal steam, heat, and other forms of energy by the royalty rate set for such forms of geothermal energy in the lease and (2) the amount resulting from the multiplication of the value attributable to byproducts by the royalty rate for byproducts set in the lease.

§ 270.64 Commingling production.

The Supervisor may authorize the lessee to commingle the production from different wells and/or leases with the production of other operators subject to such conditions as he may prescribe.

PROCEDURE IN CASE OF VIOLATION OF THE REGULATIONS OR LEASE TERMS

§ 270.80 Default, termination of lease.

Whenever an owner of a lease fails to comply with the provisions of the regulations or lease terms, the Supervisor shall give a 30-day notice to remedy any defaults or violations. Failure to perform or commence the necessary remedial action within the prescribed time period may result in termination of the lease. Lessee is entitled to request a hearing concerning any claimed default or violation pursuant to section 12 of the Act.

§ 270.81 Appeals.

(a) An appeal from any order issued under authority of the regulations in this part may be filed as set forth in this section. Compliance with any such order shall not be suspended by reason of an appeal having been taken unless such suspension is authorized in writing by the Director or the Secretary (dependent upon the officer with whom the appeal is pending) and then only upon a determination that such suspension will not be detrimental to the lessor or upon the submission and acceptance of a bond deemed adequate to indemnify the lessor from loss or damage.

(b) An appeal to the Director may be taken from any order of the Supervisor by filing the appeal with the Supervisor within 20 days after service of the order. The appeal shall incorporate or be accompanied by such written showing and argument on the facts and law as the appellant may deem adequate to justify reversal or modification of the order. All statements of fact must be made under oath.

(c) The Supervisor shall transmit the appeal and accompanying papers to the Director with a full report and recommendations. The Director shall review the record and render a decision.

(d) An appeal from the Director's decision may be taken by filing the appeal with the Director within 30 days after service of the Director's decision. The appeal shall be accompanied by such written showing and argument on the facts and law as appellant may deem adequate to justify reversal or modification of the decision. Any statement of fact not previously submitted to the Director must be made under oath.

(e) Oral argument in any case pending before the Director or the Secretary will be allowed only in the discretion of that officer at a time to be fixed by him.

REPORTS TO BE MADE BY ALL LESSEES (INCLUDING OPERATORS)

§ 270.90 General requirements.

Information required to be submitted in accordance with the regulations in this part shall be furnished as directed by the Supervisor. Copies of forms can be obtained from the Supervisor and must be filed with that official within the time limit prescribed.

§ 270.91 Application for permit to drill, redrill, deepen, or plug-back.

(a) A permit to drill, redrill, deepen, or plug-back a well on Federal lands must be obtained from the Supervisor before the work is begun. The application for the permit shall state the location of the well in feet, and direction from the nearest section or tract lines as shown on the official plat of survey or protracted surveys; the altitude of the ground and derrick floor above sea level and how it was determined.

(b) The proposed drilling and casing plan shall be outlined in detail under the heading "Details of Work" in the applications referred to herein, and shall describe the type of tools and equipment to be used, the proposed depth to which the well will be drilled, the estimated depths to the top of important markers, the estimated depths at which water, geothermal resources, or other mineral resources are expected; the proposed casing program (including the size and weight of casing), the depth at which each string is to be set, and the amount of cement and mud to be used, the drilling method and type of circulating media (water, mud, foam, air or combinations thereof), the type of blowout prevention equipment to be used, the proposed coring, logging, or other program (such as drilling time log and sample description) to be used to determine the formations penetrated and the proposed program for determining geothermal gradients and the sampling and analysis of geothermal resources.

(c) Each application shall be accompanied by a plat showing the surface and bottomhole locations and the distances from the nearest section or tract lines as shown on the official plat of survey or protracted surveys. The scale shall not be less than 2,000 feet to 1 inch.

§ 270.92 Sundry notices and reports on wells.

(a) Any written notice of intention to do work or to change plans previously approved must be filed in triplicate, unless otherwise directed, and must be approved by him before the work is begun. If, in case of emergency, any notice is given orally or by wire, and approval is obtained, the transaction shall be confirmed in writing. A subsequent report of the work performed must also be filed with the Supervisor.

(b) Casing test: Notice shall be given in advance to the Supervisor or his representative of the date and time when the operator expects to make a casing test. Later, by agreement, the exact time shall be fixed. In the event of casing failure during the test, the casing must be repaired or replaced or recemented as required by the Supervisor or his representative. The results of the test must be reported within 30 days after making a casing test. The report must describe the test completely and state the amount of mud and cement used, the lapse of time between running and cementing the casing and making the test, and the method of testing.

(c) Repairs or conditioning of well: Before the repairing or conditioning of a well, a notice setting forth in detail the plan of work must be filed with, and approved by, the Supervisor. A detailed report of the work accomplished and the methods employed, including all dates, and the results of such work must be filed within 30 days after completion of the repair work.

(d) Well stimulation: Before the lessee commences stimulation of a well by any means, a notice, setting forth in detail the plan of work, must be filed with and approved by the Supervisor. The notice shall name the type of stimulant and the amount to be used. A report showing the amount of stimulant used and the production rate before and after stimulation must be filed within 30 days from completion of the work.

(e) Altering casing in a well: Notice of intention to run a liner or to alter the casing by pulling or perforating by any means must be filed with and approved by the Supervisor before the work is started. This notice shall set forth in detail the plan of work. A report must be filed within 30 days after completion of the work stating exactly what was done and the results obtained.

(f) Notice of intention to abandon well: Before abandonment work is begun on any well, whether a drilling well, geothermal resources well, water well, or so-called dry hole, notice of intention to abandon shall be filed with, and approved by, the Supervisor. The notice must be accompanied by a complete log, in duplicate, of the well to date, provided the complete log has not been filed previously, and must give a detailed statement of the proposed work, including such information as kind, location, and length of plugs (by depths), plans for mudding, cementing, shooting, testing, and removing casing, and any other pertinent information.

(g) Subsequent report of abandonment: After a well is abandoned or plugged, a subsequent record of work done must be filed with the Supervisor. This report shall be filed separately within 30 days after the work is done.

The report shall give a detailed account of the manner in which the abandonment or plugging work was carried out, including the nature and quantities of materials used in plugging and the location and extent (by depths) of the plugs of different materials; records of any tests or measurements made, and of the amount, size, and location (by depths) of casing left in the well; and a detailed statement of the volume of mud fluid used, and the pressure attained in mudding. If an attempt was made to part any casing, a complete report of the methods used and results obtained must be included.

§ 270.93 Log and history of well.

The lessee shall furnish in duplicate to the Supervisor, not later than 30 days after the completion of each well, a complete and accurate log and history, in chronological order, of all operations conducted on the well. A log shall be compiled for geologic information from cores or formations samples and duplicate copies of such log shall be filed. Duplicate copies of all electric logs, temperature surveys, water and steam analyses, hydrologic or heat flow tests, or direction surveys, if run, shall be furnished.

§ 270.94 Monthly report of operations.

A report of operations for each lease must be made for each calendar month, beginning with the month in which drilling operations are initiated. The report must be filed in duplicate with the Supervisor on or before the last day of the month following the month for which the report is filed unless an extension of time for the filing of the report is granted by the Supervisor. The report shall disclose accurately all operations conducted on each well during the month, the status of operations on the last day of the month, and a general summary of the status of operations on the leased lands. The report must be submitted each month until the lease is terminated or until omission of the report is authorized by the Supervisor. The report shall show for each calendar month:

(a) The lease serial number or the unit or communitization agreement number which shall be inserted in the upper right corner;

(b) Each well listed separately by number, and its location by 40-acre subdivision (quarter-quarter section or lot), section number, township, range, and meridian;

(c) The number of days each well was produced, whether steam or hot water or both were produced, and the number of days each input well was in operation, if any;

(d) The quantity of production and any byproducts obtained from each well, if any are recovered;

(e) The depth of each active or suspended well, and the name, character, and depth of each formation drilled during the month, the date and reason for every shutdown, the names and depths of important formation changes, the amount and size of any casing run since the last report, the dates and results of any tests conducted, and any other noteworthy information on operations not specifically provided for in the form.

(f) The footnote must be completely filled out as required by the Supervisor. If no sales were made during the calendar month, the report must so state.

§ 270.95 Monthly report of sales and royalty.

A report of sales and royalty for each productive lease must be filed each month once sales of production are made even though sales may be intermittent, unless otherwise authorized by the Supervisor. Total volumes of geothermal resources produced and sold, the value of production, and the royalty due the lessor must be shown. If byproducts are being recovered, the same requirement shall be applicable. This report is due on or before the last day of the month following the month in which production was obtained and sold or utilized, together with the royalties due the United States. Payment or royalty is to be made pursuant to § 270.49 unless otherwise authorized by the Supervisor.

§ 270.96 Forms or reports.

When forms or reports other than those referred to in the regulations in this part may be necessary, instructions for the filing of such forms or reports will be given by the Supervisor.

§ 270.97 Public inspection of records.

Geologic and geophysical interpretations, maps, and data required to be submitted under this part shall not be available for public inspection without the consent of the lessee so long as the lease remains in effect or until such time as the Supervisor determines that release of such information is required and necessary for the proper development of the field or area.

Dated: July 15, 1971.

W. T. PECORA,
Under Secretary of the Interior.

[FR Doc.71-10321 Filed 7-22-71;8:45 am]

DRAFT

Appendix C

Environmental Evaluation of Potential Geothermal Resources Development in the Clear Lake-Geysers Area, California

September 1971

CONTENTS

CLEAR LAKE-GEYSERS AREA

INTRODUCTION

Location and Climate

The Clear Lake-Geysers area, as shown on figure 2, encompasses about 720 square miles, principally in Sonoma and Lake Counties, California. The area centers about 75 miles north of San Francisco. The land within the area is generally rough and mountainous with peaks reaching a maximum elevation of 4,722 feet at Cobb Mountain. The area is characterized by alternating northwesterly oriented valleys and ridges. Overall relief is about 4,500 feet but the local relief in the mountainous portion is generally on the order of 2,000 feet. The northeastern three-fourths of the area drains to the Sacramento River via Cache and Putah Creeks, while the southwestern quarter drains to the Russian River and thence to the Pacific. A major feature of the drainage pattern is Clear Lake, which occupies some 80 square miles in the northern part of the area, and discharges to Cache Creek.

The average precipitation is about 35 inches per year: nearly all falls as rain from October to April. Due to a strong orographic effect precipitation in the high mountains is as much as 60 inches per year on high points such as Mt. St. Helena. The rainfall received in a single storm can be as high as 10 inches in a 24-hour period, and a large percentage of the rain is generally received in two or three major storms. Generally temperatures range from a low of 20^{o} F. in January to a high of 110^{o} F. in mid-summer. The summer temperatures will fluctuate from over 100^{o} F.

at midday to 45 to 50° F. during the night. During the winter, daytime temperatures of as much as 60° F. will frequently drop to freezing at night. Stream discharge responds quickly to precipitation with maximum flows in the rainy season and little or no flow in the dry season, except in Cache Creek, the flow of which is maintained by an artificial control regulating the discharge of Clear Lake.

Geology

The geologic framework in the Clear Lake-Geysers geothermal area is characterized by a series of northwest-southeast trending fault zones, generally down on the southwest, repeating a gently folded sequence of Mesozoic rocks (Jurassic-Cretaceous, Franciscan Formation). Within this series of tilted and rotated fault blocks lie the Mayacamas Mountains, which are formed by a large horst block and are bounded by structural basins containing Cretaceous shales and siltstones as well as topographic depressions. The Cretaceous sedimentary rocks are considered to be miogeosynclinal in origin and they rest directly upon the locally faulted and sheared rocks of the Franciscan Series. Franciscan rocks exposed in The Geysers-Big Sulphur Creek area of the Mayacamas Mountains, are characterized by a basic core of graywacke, mudstone, and greenstone. The rocks are structurally complicated by thrust faulting, and intruded by ultramatic masses and associated serpentine.

To the northeast in the Clear Lake area, a series of Pleistocene and Quaternary volcanic rocks including rhyolitic flows, tuffs, and lavas lie unconformably on the eroded Franciscan surface or upon the Cretaceous sedimentary rocks. Due to the coincident occurrence of mercury mineralization, areas of borated, carbonated, and ammoniated ground waters, and the location of a major gravity "low", a molten or near-molten body is suggested to be underlying the region as a heat source. This body of magma was probably the source of the Pleistocene volcanic activity in the Clear Lake-Geysers region. Recent landslide debris is common in the area and the geomorphic environment is characterized by a variety of slump blocks and earth-flow features. Surface geothermal activity is evident at Big Sulphur Creek, Castle Rock, and Anderson Springs.

Steam Production

A major steam reservoir occurring in highly fractured Franciscan graywacke at depths of 2,000 to 7,000 feet or more has been established by drilling in an area at least 8 miles long and 2-1/2 miles wide; but geologic evidence of a deep-seated primary heat source extends well beyond the present production at Big Sulphur Creek northward at least to Clear Lake.

Although steam vents and hot springs were discovered at The Geysers as early as 1847, it was not until 1921 that the first geothermal well was drilled along Big Sulphur Creek. By 1925, a total of eight wells had been drilled. The deepest penetration of these early wells was 640 feet; however, no utilization of this power source was made due to economic factors.

Interest in geothermal power generation during the 1950's prompted active leasing in The Geysers area north of Big Sulphur Creek. A total of 11 wells was drilled from 1955 through 1959, the deepest of which was 1,404 feet; and in June 1960 a 12,500 Kw generating plant utilizing 250,000 pounds per hour of steam from four wells was operational. In addition, several wells were drilled in the vicinity of Clear Lake, several townships to the north. They produced sizable flows of thermal fluids and extended the area of geothermal interest.

A total of about 75 wells producing dry steam have been drilled in The Geysers area as of January 1, 1971. Typical chemical analysis of steam condensate from three production wells is shown in the following table. Average well production is about 100,000 pounds per hour with a maximum of 300,000 pounds per hour from a depth of at least 7,000 feet. At least five companies have drilled successful wells along a 7-mile zone following Big Sulphur Creek; three of the companies act jointly to sell steam to Pacific Gas and Electric Company. About 84 Mw of electricity were generated in early 1971; facilities under construction will add 110 Mw to the system in 1971. By the end of 1975, the generating capacity is expected to be over 600 Mw.

The steam at The Geysers contains only about 0.5 percent non-condensable gases. However, small but potentially harmful concentrations of boron, mercury, and ammonia have been found in the steam condensate. For this reason no discharge of condensate is allowed to the waters of Big Sulphur

Composition (in ppm by weight) of steam condensate

from wells in The Geysers field

Constituent	Well: Thermal #7	Well: DX State 3395-1	Well: Sulfur Bank 14
Silica (field)	0.50	0.20	0.50
Calcium	0.20	0.02	0.16
Magnesium	0.06	0.01	0.04
Strontium	< 0.10	~ 0.05	< 0.10
Sodium	0.12	0.10	0.12
Potassium	< 0.10	< 0.10	< 0.10
Lithium	0.002	0.003	0.003
Ammonium	236.00	84.00	354.00
Bicarbonate	775.00	267.00	1153.00
Carbonate	0.06		1.05
Sulfate	7.10	~ 24.00	~ 11.00
Chloride	20±3	1.6±1	17±2
Fluoride	< 0.10	< 0.10	< 0.10
Boron	< 0.01	5.00	0.02
pH (Field)	6.21	5.32	6.03
Specific Conductance (micromhos at 25° C.)	1430.00	546.00	2090.00
Date Collected	10/28/70	10/29/70	10/28/70

Analyst: R. Barnes, U. S. Geological Survey

Creek. Instead, the condensate is injected back into the subsurface, via injection wells. The injection operation has shown no signs of adversely affecting production from steam wells in 18 months of injection operation.

The area of the steam reservoir is known to be greater than 10 square miles in The Geysers field, and may be as large as 20 square miles. Previous estimates of reservoir capacity all have proven to be overly conservative and this estimate may also be conservative. Wells are spaced at one per 40 acres, without harmful interference. Evidence suggests that a spacing of one well per 20 acres may be acceptable and effective in increasing steam production. However, a denser well spacing would be uneconomical and might be harmful to systematic development of the field, without adding appreciably to steam recovery. Extensive areas around the known geothermal field are under lease. Three areas at distances of 20 miles or more from The Geysers have been explored by drilling. Although not commercially productive of steam, each exploratory well has encountered large volumes of hot fluids, suggesting that a sizable area may warrant further exploration.

Vegetation

The predominant vegetative cover is grass-oak, cypress, and chaparral. Grass-oak occupies deep soils on the lower elevations along the foothills and includes blue-oak, black oak, and a grass understory of soft chess, wild oats, ripgut brome, and rattail fescue. Also present are forbs, such as filaree, trifolium, and bur clover, and weeds such as star thistle and tar weed.

The cypress cover, which predominates in many areas, is associated with a single soil, the Henneke series. The vegetation consists predominantly of cypress, leather oak, and manzanita. No forbs or grasses are found in a climax stand of cypress; however, in a subclimax stand, as after a fire, many perennial grasses provide ground cover and large amounts of forage. The following browse plants are found in this association: leather oak, wedge leaf ceanothus, musk brush, toyon, manzanita, and deer brush, as well as several species of perennial grasses.

All other soils and elevation zones are covered with the chaparral type of growth. The primary species in this association are chamise, wedgeleaf ceanothus, mountain mahogany, poison oak, scrub oak, leather oak, live oak, chaparral pea, manzanita, silktassel, red bud, digger pine, knobcone pine, and toyon.

Land Use

The principal economic enterprises in the Clear Lake-Geysers area are agriculture, resorts, recreation, mining, and geothermal power. Agricultural cropping is generally restricted to the level valley lands along the principal streams and on level land surrounding Clear Lake; agriculture in the rest of the area is limited to dry pasture with only minor amounts of irrigated cropland. The mountain lands, owing to steep slopes and long dry periods, are suitable mainly for rangeland

and as wildlife habitat. In general, the forest lands within the area are of poor quality and only minor timbering takes place.

Resort development began more than a century ago with the opening of health spas founded on the natural hot springs that are located principally in Lake County. In recent years the popularity of the spas has declined and those resorts that feature the quiet mountain atmosphere are the most popular.

Mining, especially for mercury, which occurs in association with geothermal waters, was recently a major industry with 15 producing mines in 1969. Most of these mines are now inactive due to a depressed mercury market. Principal mineral production now includes only construction minerals -- sand, gravel, and stone.

The only developed power producing geothermal field in the United States is located at The Geysers in Sonoma County in the southwestern portion of the area. This field is one of only two known dry steam-producing areas in the world.

Federal land fee ownership in the Clear Lake-Geysers area is generally limited to small, isolated tracts of mountain land scattered throughout the area and rarely aggregating more than 2 square miles in a continuous tract. Such public-domain lands total only about 10-15 percent of the area. A notable exception to this is a large continuous tract of National Forestland in the northeast corner of the area, mainly in T.14 and 15 N., R. 8 W., which forms part of Mendocino National Forest.

Other major holdings include the Dry Creek and Middletown Indian Reservations, which are not subject to leasing under the Act, and the bed of Clear Lake, owned by the State of California. Other small Indian holdings and State school lands are scattered throughout the area.

In view of the scattered distribution of lands subject to control under the Federal leasing and operating regulations, Federal policy is expected to have only limited influence in development of the geothermal resources. The development to date of wells and power plants has been entirely on State and private holdings. In this district the main thrust of Federal regulation will be to assure proper development on the government-owned lands, with overall control of development residing with local authorities at the county level.

Fish and Wildlife

Recreational hunting and fishing together make up an important segment f the local economy. The Russian River system supports anadromous fish runs of steelhead trout, silver salmon, and shad. Resident species include rainbow trout, smallmouth bass, crappies, and blue gills, and a variety of non-game species. Clear Lake is a warm water shallow lake of 40,000 surface acres with a 10-month fishgrowing season. The lake's principal game fish species include largemouth bass, crappies, blue gills, Sacramento perch, white catfish, and brown bullheads. It is the largest and most important warm water fishing lake in California, with angling estimated at 200,000 man-days per year.

The Putah and Cache Creeks are tributary to the Sacramento River system. Both streams have smallmouth bass populations. Due to irrigation diversions and flood control facilities neither of these streams have year-long flows to the Sacramento River. Angler use in the study area is slight; although there is significant angling pressure farther downstream.

Black-tailed deer are year-long residents to the study area, frequenting the oak-grasslands, chaparral-covered hillsides, and farmed areas. The deer density is relatively high, averaging an estimated 30 per square mile. Many areas support deer densities as high as 100 per square mile. An estimated deer population of 18,000 would support 45,000 hunter days each year.

Principal small game species are California and mountain quail, western grey squirrels, pheasants, and mourning doves. Quail populations are considered good and would average 20 per 100 acres. Squirrels range extensively in the area and would have densities of about 5 per 100 acres. Doves are in good numbers in both breeding and hunting season. Pheasant populations are limited to the agricultural zones. Furbearers such as coyotes, bobcats, gray foxes, raccoons, and skunks are found in fair numbers.

The only water fowl habitat of any consequence is at Clear Lake. Nesting populations include a few mallards and coots. Also a few wood ducks breed along the streamsides and on farm ponds surrounded by trees. Moderate numbers of mallards, scaups, teals, shovellers, ruddy ducks, and coots winter on Clear Lake. Waterfowl harvest is light and only locally important. Clear Lake is one of the best areas in California to observe western and pied-billed grebes. These birds both winter and nest in the area. The most significant raptors in the area include white-tailed kites and golden eagles.

Environmental Impact of Potential Development

Resource Reconnaissance Stage

The reconnaissance stage of exploration in the Clear Lake-Geysers area has been largely completed. Shallow drilling was begun as early as 1921 and continued intermittently until major production was established in the mid 1950's. Because of the great depth of the major producing zone and complex geology, the principal geophysical exploration has been gravity surveying, which involves occupation of a station with a portable gravimeter for a few minutes, and has had no significant environmental impact.

It is expected that future exploratory work will concentrate on delineating the productive area by deep drilling. Geologic mapping, sampling of natural springs and wells, and additional geophysical work will continue until the field is well defined, but these activities will use existing access routes, and thus the adverse environmental impact of such activities should be negligible.

Test Drilling and Production Testing

This stage of development has also been under way for many years in the Clear Lake-Geysers area and much experience is available on the environmental impact of drilling and testing, particularly in the vicinity of The Geysers Resort (Figure 2) in northeast Sonoma County.

SURFACE EFFECTS

Grading of roads and well sites is the principal surface impact, and this is relatively severe in this area because the mountainous terrain requires extensive cut and fill work. Level spots suitable for well drilling are rare and generally about a half acre of cut and fill is required to provide room for the drilling operations. Road maintenance is complicated by the unstable character of the geologic terrain, which is noted for its susceptibility to landsliding. Increased sediment production is almost assured by the extensive grading; however, the sediment problem is ameliorated to a considerable degree by heavy grass cover on the lower slopes of the hills. Moreover, bare slopes are being covered with straw until reseeding takes hold to reduce erosion.

WATER RESOURCES

Impact on water resources of geothermal drilling and production testing to date has been minimal. Little water is used during drilling except for that required for drilling mud, which is used in drilling the upper part of the well. After setting "surface casing" at about 2,000 feet the holes are commonly completed by air drilling. The steam produced during drilling and testing discharges to the atmosphere;

thus, there is no release of geothermal liquid to surface or ground waters. Where hot water is encountered instead of steam the well is shut in and not produced.

In the mountainous parts of the Clear Lake-Geysers area, superficial ground water from shallow wells is the supply for stock and domestic use. There is little hazard of adversely affecting this source by geothermal drilling and testing. A quite different ground-water resource is the thermal springs of the area, which were the basis for the early health spa development in Lake County. Many, if not all, of these springs represent points of discharge of geothermal waters mixed to varying degree with superficial fresh ground waters. Thus, it is conceivable that geothermal drilling could significantly affect the quantity or quality of discharge of such springs; however, no such effect has been reported to date. Even "The Geysers" springs in the midst of the geothermal field appear to be little affected by the nearby production from the deep geothermal reservoir.

The impact of drilling and production testing on streams is mainly in the form of increased sediment load stemming from clearing and grading operations. To date the scale of geothermal drilling has not caused major downstream impact except insofar as sediment transport may have affected to an undetermined extent the anadromous fish spawning grounds in the tributaries of the Russian River downstream from The Geysers geothermal field.

Additional test drilling and production testing contemplated in the Clear Lake-Geysers area is not expected to have a greater impact than that to date.

AIR

Noncondensible noxious gases emitted from the wells during testing can contribute to air pollution, but the concentrations of such gases are very small and are not expected to be a problem.

Noise

Wells in the Clear Lake-Geysers area use both mud and air as the circulating medium to remove rock cuttings. Mud is used in the upper part of the hole to the depth where the surface casing string is installed, generally at about 2,000 feet. If the well is dry at this point, the operation is converted to air drilling. A moderate noise level is associated with mud drilling, but air drilling involves the higher noise level of the air compressors and the discharge noise of air and cuttings from the return-circulation line. Air compressors can be accoustically shielded to reduce noise, but it is difficult to muffle the return-circulation line because of the abrasive action of the cuttings on muffler baffle plates. Various designs for an adequate muffling system are being tested and it is anticipated that this noise source will be substantially reduced in the near future. The noise associated with the drilling of a particular well is of relatively short duration, lasting on the order of 30 to 45 days. Upon completion of a producing well, the well is tested to determine its productive capacity and to gain valuable information on the reservoir characteristics. This testing period generally lasts a few weeks until the pressure stabilizes. Mufflers are used during the testing phase to reduce the noise to acceptable industrial levels.

A simplified comparative analysis of noise levels generated at The Geysers and from other sources is presented in the following table.

Comparison of Noise Levels Between
The Geysers Area and Other Sources

Source	Level	Distance
Geysers Area		
Drilling operation (air)	126 dB(A)	25 feet
Drilling operation (air)	55 dB(A)	1500 feet
Muffled testing well	100 dB(A)	25 feet
Muffled testing well	~65 dB(A)	1500 feet
Steam line vent	100 dB(A)	50 feet
Steam line vent	90 dB(A)	250 feet
Comparative levels		
Jet aircraft takeoff	125 dB(A)	200 feet
Threshold of pain	120 dB(A)	Average
Unmuffled diesel truck	100 dB(A)	50 feet
Street corner in a large city	75 dB(A)	Average
Residential area at night	40 dB(A)	Average

A time lag of several years generally occurs between the drilling of a well and the completion of power-generating facilities and the hookup of the well to the steam-plant feed line. During this period, the well must be bled continuously to remove the various gases. Failure to remove these gases will result in condensation, flowback down the well, caving of the producing formation, and damage to the well. Bleeding of the wells takes place through 1/4-inch to 3-inch bleed lines, depending upon the quantity of gas present, and these gases pass through appropriately sized mufflers before being discharged to the atmosphere.

Gaseous emissions

During the drilling, testing, and bleeding of test and production wells, various gases including water, carbon dioxide, hydrogen, methane, nitrogen, argon, hydrogen sulfide, ammonia, and boric acid are discharged to the atmosphere. Because of the generally low content of noxious gases in the steam, discharge to the atmosphere has caused no significant air pollution problems. However, each well upon completion should be tested for noxious gases, and if this concentration exceeds acceptable levels, the noxious gases would be removed prior to atmospheric discharge.

VEGETATION

The drilling of test and production wells on Federal lands will result in the controlled clearing and leveling of ground for the well site and the construction of access roads on the property. This practice generally has little detrimental affect on the plant life. Reseeding of the road cuts and drill sites during the rainy season is a standard practice which stabilizes the soil and provides cover where only brush existed.

FISH AND WILDLIFE

Test drilling and production testing of geothermal steam resources in the Clear Lake -- Geysers Area would have varied impacts upon fish and wildlife, which are incompletely understood. Most would occur on or adjacent to well sites, although water quality impacts could potentially have farther-reaching influences. The magnitude of particular impacts would be interrelated with fish and wildlife and their habitat within the area of development influences, extensiveness and duration of the entire geothermal development activities and operations, and the effectiveness of control measures. Many of the impact types lend themselves to whole or partial control, and the proposed leasing and operating regulations provide a regulatory framework by which such control could be achieved.

As a specific geothermal development would proceed through test drilling and production testing, physical land modification and commotion would occur. These activities would include such things as construction of roads, ponds, and drill pads and drilling of wells, and would result in loss of wildlife values, including both habitat and human use within the area of influence. The modification would physically alter or remove existing wildlife habitat and permanence of these effects would be dependent upon the nature of the particular construction or operational activity and the completeness of control measures. In addition to land modification the commotion would have displacement effects upon animals and birds in the site vicinity. The degree and permanence of displacement or disturbance would depend upon the scope and type of activity. For example, although the effect on wildlife is not clearly understood or predictable, it is assumed that noise from testing wells would have a disturbing influence upon animals within the site vicinity.

Most areas adjacent to drilling and test operations, but outside of the immediate zones of physical modification, would retain part or all of their fish and wildlife populations and habitat. Where existing public access would be restricted in order to reduce hazards to the public, there would be an accompanying reduction of hunting, angling, and camping opportunity on these lands. The importance of these losses would depend upon the capacity of other available habitat areas to absorb the pressures which are presently absorbed by the geothermal area.

Probably the major potential impacts upon fish and wildlife would result from improperly planned or executed handling of geothermal fluids. If controlled releases, spills, seepage or well blowouts were to result in significant additions of toxic geothermal waters to drainages, ponds, game management areas, or Clear Lake, adverse impacts would result. These impacts would include alteration of fishery habitat and waterfowl nesting and feeding areas within the area of influence. If toxic substances, such as boron, sulphides, or fluoride were present in such releases, they also would exert adverse impacts. For example, the present Geysers installation at one time added hot fluids containing boron and ammonia to Big Sulphur Creek which may have resulted in a loss of aquatic life. Releases of heated effluents to aquatic habitat would alter aquatic habitat and life, perhaps creating temperatures intolerable to existing fish species and stimulating growths of nuisance algaes. However, the probability of these potential problems occurring at or near any given well site appears to be small, since the proposed geothermal regulations would require controls, including reinjection of problematical brine wastes, to avoid surface water degradation.

If ponds were required as part of the development, they would, depending upon local circumstances, have beneficial impacts upon fish and wildlife resources. If the produced water was free of toxic materials and disease-producing elements, benefits could be significant in the form of increased aquatic habitat and nesting and feeding areas for waterfowl and marsh birds.

Erosion from roads and construction activities could result in added siltation of aquatic habitat within the area of project influence. The siltation would be most severe during construction phases, although some might extend into the operational stages. Siltation effects would include coverage of fish spawning and feeding areas and shallowing of streams. The degree of damage to aquatic habitat within the area of influence would be dependent upon the success of erosion control measures.

AESTHETICS

Scenic Values

The Clear Lake-Geysers area contains scenic areas which will be made more available by the access roads that are constructed for well development. These access roads, once the cuts are replanted, will have a limited adverse impact on natural scenic values. Roadway design in this 35-inch annual rainfall area will require careful planning to minimize erosion and aesthetic degradation, and yet meet basic tranportation needs. Drill sites will be a distinct intrusion but the duration of occupancy is short, 30 to 45 days, and will thus not permanently detract from scenic values. Well-head installations are generally of small size and blend with the surroundings. Replanting of drill sites will also tend to reduce visual impact. Often, only the plume of bled steam marks the site of a well from a distance, and it is doubtful whether this plume will reduce the aesthetic values. Because of the steep topography, the visual site line is short and the geothermal development facilities will not for the most part be visible from any great distance.

Archeological and Historic Values

The Lake County Courthouse in Lakeport is listed in the National Register of Historic Places. The Patwin Indian site located in Long Valley in the northeastern portion of the area has potential for inclusion in the National Register of Historic Places. It is doubtful that geothermal development will take place near these sites.

There are no other known archeological or historical sites within the area. In the event any sites are located during development, these sites should be preserved and the proper agency notified of their existence. Considering the small acreage of land involved in the drilling of a well, it is highly unlikely that any archeological or historical site would be disrupted either by drilling operations or the proximity of drilling operations.

Recreation

The development of geothermal resources should have no adverse influence on the hunting and fishing througnout the area, and camping and water-related activities associated with Clear Lake. On the contrary, the construction of roads will provide additional access to both hunters and fishermen. Geothermal development is not expected to significantly influence the desirability of various resort areas.

MISHAPS

The principal forms of unplanned environmental impacts which may be encountered in drilling and production testing in the Clear Lake-Geysers area include mainly blowouts, forest and brush fires, and landslides.

In any drilling into high-pressure zones, such as a geothermal reservoir, there is a hazard of uncontrolled release of pressurized fluid. Indeed, a steam well that blew out during drilling near The Geysers Resort in 1957 is still discharging steam at a substantial rate in 1971. Efforts to control this blowout at a cost on the order of $1 million have been quite unsuccessful. This mishap has been attributed to an inadequate casing program combined with minor landsliding. Regardless of the cause the impact has been severe and expensive--in the cost of efforts to control the discharge, in the loss of the valuable resource, and in the form of a local noisy impact on the environment.

Presumably minor shifting of the land caused a casing failure that permitted steam to rise to the surface outside the casing, which only extended to 500 feet depth. Thus, attempts to control the casing-head discharge simply resulted in more discharge through the earth around the well. Drilling of another well to relieve the pressure resulted in another commercially productive well without a marked depletion of discharge from the blowout. Under present State drilling regulations, which apply to operations on all but Federal lands, and Federal operating regulations (Appendix A), such a blowout would be unlikely because casing requirements are much more stringent than those that prevailed at the time of the blowout. Under prevailing regulations, if a high pressure zone should be penetrated, resulting in an uncontrolled flow of steam, it would be quickly controllable with required casing-head equipment.

The forest and brush-fire hazard is not peculiar to geothermal development, but simply is increased due to the greater level of human activity and traffic associated with the development. The brush-fire hazard is very severe in the Clear Lake-Geysers area during the dry season, and special fire prevention efforts will be required to avoid disastrous brush fires.

Another potential hazard that poses special problems vis-a-vis geothermal development in the Clear Lake-Geysers area is that of landslides. The drilling and production do not cause landslides, but rather landslides can seriously hamper operations and could conceivable result in casing rupture and perhaps uncontrollable escape of steam. The mountainous lands underlain by rocks of the Franciscan Series (most of the area) are the most susceptible, and landslides are most likely to occur during wet weather when rainfall lubricates the unstable slide surfaces. The most effective preventative measure is to provide soil drainage in susceptible materials to prevent saturation of soil and underlying rocks. To the extent that grading provides such drainage it tends to minimize the landslide problem, but large fills tend to aggravate the problem unless special drain pipes are installed.

Field Development, Power Plant and Power Line Construction Energy Generation, and By-Product Facilities

Once a geothermal field has been tested and proven to have economic value for industrial development, the environmental impact increases and in some aspects changes. Some activities, such as drilling and testing, continue for many years and their impact is simply scaled up, but a whole spectrum of new activities is introduced with the decision to use the resources commercially. Additional wells are required to develop the resource most efficiently, steam lines are built to convey the steam to the power plant, power plants are built to generate electricity, and power lines must be erected to transmit the energy to the point of use. Furthermore, when power generation begins, production from the reservoir imposes stresses on the system beyond those of the testing phase, and such effects as reservoir depletion, land subsidence, and increased seismicity may come into play.

SURFACE

In the Clear Lake-Geysers area the increased surface impact accompanying full-scale electric power development has been largely a scaling factor. Additional fill-in wells have been drilled, necessitating proportionally more cut and fill work on roads and well locations. The first power plant began operation in 1960. As of summer 1971 three plants were in operation and two others were under construction. Roads leading to the power plants have been paved with asphalt. Surface steam lines of 10 to 30-inch, fiberglass and asbestos insulated pipe with characteristic large U-shaped expansion loops connect the wells to the power plants. The greatest distance of any connected well from the power plant is 1,200 feet straight-line in order to minimize pressure and temperature drop in transit. With this restraint, the first three power plants were built within 1 mile from The Geysers Resort (Figure 2), in Sec. 13, T. 11 N., R. 9W. and Sec. 18, T. 11 N., R. 8W. The fourth plant, presently under construction, is near the SW cor., Sec. 7, T. 11 N., R. 8W., about one half mile straight-line from the nearest plant. Each plant is served by several producing wells averaging about 5 Mw per well at a spacing of about 40 acres per well. Thus, in the producing area the terrain is laced with steam pipes radiating out from power plants connected together by high-voltage transmission lines. Brush is cleared for a considerable distance from steam and power lines to minimize the fire hazard to the installations and to improve accessibility.

This type of development pre-empts the surface for some, but not all, other land uses. Grazing or cultivation would be compatible with such development, but wildlife habitat would be severely affected by the clearing and human activity. Hunting must be restricted in the immediate area of development for the safety of personnel involved in the geothermal industry and to avoid damage to structures. A geothermal plant has a nominal tourist value related to its unique design and function, but it would be unusual to think of it as a recreational attraction.

A typical power plant at The Geysers consists of two turbine generators housed in a single building with an adjoining structure housing cooling towers. The typical plants now under construction consist of two 55-Mw units in each plant. The second power plant built, Units 3 and 4 of 28 Mw each, is housed in a building 140 feet by 34 feet and 30 feet high. Adjoining is a cooling tower consisting of three 36 feet by 66 feet cells of the counter flow induced-draft type. The tower is sheathed and decked with 3/8-inch flat cement asbestos board for protection against forest-fire damage. A switchyard, storage building, and high voltage lines complete each facility.

WATER RESOURCES

The impact of full-scale electric-power development on water resources is similar to that of the drilling and testing phase, but on a somewhat more extensive scale. Steam production to date has not had a noticeable effect on ground-water resources, although a reduction in flow and perhaps a change in temperature and/or chemical character of thermal springs in the area may eventually result from extensive steam production.

The impact on surface streams will continue to be mainly in the form of increased sediment yield stemming from clearing and grading operations. As more roads and well sites are constructed new areas will be affected. The early development was confined to the basin of Big Sulphur Creek, but development is now proceeding in the basin of Squaw Creek to the north, and is programmed for Kelsey and Anderson Creeks to the north and west. Squaw Creek is tributary to Big Sulphur Creek, so the impact on anadromous fish there will be additive to that which has already occurred. Kelsey and Anderson Creeks are tributary to Clear Lake and Putah Creek, respectively, which do not have anadromous fish. Although expansion of the producing area results in new sediment loads, the load from older producing areas is progressively reduced as erosion-control techniques and natural revegetation are effected.

An additional problem that comes about with full-scale development is that of handling waste from the power plants. At The Geysers plants the approximately 80 percent of the steam is used for condenser cooling, but the remaining 20 percent, containing natural contaminants, principally ammonium bicarbonate, (NH_3HCO_3) must be disposed of. For the past 1-1/2 years all such waste water has been reinjected under gravity head into a non-producing well without difficulty. The average injection rate is about 400 gallons per minute. In view of the success of this disposal technique, the operators of the field plan to use similar disposal wells for all plant waste-water disposal.

The condensed steam, once exposed to oxygen in the cooling process, becomes severely corrosive to metal and concrete, although it is essentially non-corrosive in the prior closed-system phase. Thus, special metals and anti-corrosive surface treatments must be used between the power-plant condensers and the disposal wells. Leakage is more likely in lines transporting the corrosive water; however, minor leakage does not result in any special hazards, because the waste water is not highly toxic.

Although production in the Clear Lake-Geysers area to date has been mainly steam, hot-water dominated systems exist in parts of the area. If such systems are developed for geothermal energy, provision must be made for disposal of waste water in accordance with applicable water-quality standards.

AIR

Noise

Noise from a fully developed, power-producing field such as The Geysers will be relatively modest. Occasional venting from the wells is through installed mufflers and will not exceed acceptable industrial noise levels at the well site. Minor pipeline or other leaks can be readily repaired and will add little to the background noise level. Any major pipeline breaks will create loud noise for a short period of time until the well valves can be activated to reduce the flow and vent through the well muffler system. Rapid repair of the pipeline will be initiated for economic reasons and thus any associated noise will be of short duration. Minor noise is also associated with power generation but this noise is largely contained within the power plant through the use of acoustical building materials. Fans used in the cooling towers also create some noise but this is confined by the structures to the immediate vicinity of the plant.

Gaseous Emissions

Noncondensible gases are removed from the steam at the power plant and are jetted to the atmosphere under pressure to insure adequate dispersal. Because of the variation in quantity of noxious gases which may be present at various locations in the field, it may be necessary to react these gases rather than allow atmospheric discharge. Analysis of contained gases at each well will provide data on the total quantity of noncondensible gases entering the power plant and will dictate the type of extraction process necessary to maintain air quality standards. The discharge of hydrogen sulfide gas close to the power plant creates not only an odor problem but, because of its highly corrosive nature, can cause considerable damage to various pieces of generating and transmission equipment. Water vapor is discharged from the cooling towers but contains no non-condensible gases and thus creates no immediate problem. The total vented steam and cooling-tower vapor has not contributed to fogging in The Geysers area, nor is this an anticipated problem with increased development of the area.

VEGETATION

No detrimental effect on plant life, due to field development or power plant construction, has been observed in the existing Geysers geothermal field. Future development of the area is not expected to change this situation as the density of the operation in a given area will not increase beyond the productive capability of the field. Landscaping and plantings around the power plants have resulted in the introduction of some non-native plant species but this is not considered a harmful practice. Native grasses have been established at well sites, road cuts, and other areas which required grading or disturbance of the surface vegetation.

FISH AND WILDLIFE

Full development of a geothermal field, as with drilling and production testing, would have varied impacts upon fish and wildlife. Most of the impacts would occur on or adjacent to construction and plant sites. Many of the impacts lend themselves to whole or partial control, and the proposed operating regulations provide a regulatory framework by which such control could be achieved.

The most significant potential impacts upon fish and wildlife would result from handling of geothermal fluids. For further details, the reader is referred to the fish and wildlife discussion under Test Drilling and Production Testing.

As a geothermal field would proceed through construction and operation stages of the power plant, pipelines, transmission lines, and any by-product facilities, the loss of wildlife values, which began in the test drilling and production testing stages, would continue within the immediate area of influence. These losses would include both wildlife habitat and its use.

Where existing public access would be restricted in order to reduce hazards to the public, there would be an accompanying reduction of hunting, angling, and other recreational opportunity on these lands. The importance of these losses would depend upon the capacity of other available habitat areas to absorb the pressures presently absorbed by the geothermal area.

Transmission lines located in flyways or over nesting and feeding sites would cause some mortality of waterfowl, raptors, and other birds from collision and/or electrocution. The magnitude of this type of loss cannot be predicted and would be expected to be minor.

AESTHETICS

General

The construction of a high tension line through the general Clear Lake-Geysers area may lower its scenic value. With the proper choice of routing and sufficient care in the design of the towers this impact can be minimized.

The surface network of steam-collection pipes and expansion joints extending from wells to power plants detracts from the scenic value of the present Geysers field. Because of the light colored covering on these pipes, they are noticeable for a considerable distance. The present operators have initiated a program for replacing the coverings of steam pipelines so that they blend better with the background, thus reducing the visual impact. It is not feasible to bury the steam lines due to high trenching costs, need for accessibility to the pipelines for maintenance, and difficulty of incorporating expansion joints in a buried pipeline. Other types of piping, such as waste-water pipes, can be buried. Structures such as power plants and cooling towers also detract from the local natural scenic values. Appropriate landscaping and the use of topographic or foliage screening can reduce the visual impact of these structures.

Archeologic and Historical Value

No change is expected from that described earlier.

SOCIAL EFFECTS

Economics

The present (1971) market value of geothermal steam produced in The Geysers area is $5,040 per day, while the value of the electricity produced is $30,240 per day. By 1975, these figures will increase to $36,000 and $126,000, respectively. Annual taxes paid to Sonoma County are $277,694. During Fiscal Year 1970-71, the State of California expects to collect $40,000 in royalties and rentals for State lands, with an increase to $270,000 in Fiscal Year 1974-75. The continued development of geothermal resources in the Clear Lake-Geysers area can be expected to contribute additional funds to the local and State governments. A portion of the salaries paid to employees in the geothermal field can be expected to be spent locally, thereby contributing to the local economy.

Population Distribution

Permanent increases to the local population as a result of geothermal development and power generation will be small. Present power-plant operations at The Geysers require only two resident employees. Drill crews and construction crews will be transient. Small field maintenance crews may be stationed locally or may service the area periodically.

Transportation

An increase in automobile traffic into The Geysers area can be expected. Drill and construction crews, supervisory personnel, State and Federal employees, and others involved in various phases of development and power generation will increase traffic flows. However, existing public roads and access roads constructed by the development companies are capable of handling this type of vehicle increase.

Modification of Land Uses

The development of geothermal resources in the Clear Lake-Geysers area is not expected to modify existing land-use patterns except for the lands directly involved. Present land use in the developed geothermal areas is compatible with the production of steam and power generation.

By-Product Industries

The establishment of by-product industries in conjunction with geothermal steam development is not anticipated in the Clear Lake-Geysers area.

MISHAPS

With the increased activity associated with field development the frequency of unanticipated events is likely to increase but in some respects their severity can be expected to decrease. For example, blowouts, forest fires, and landslides should become lesser hazards as experience is gained in handling such problems, and facilities become available for treating each. The lone blowout that has occurred in The Geysers development has been a continuing nuisance since 1957, but plans are being formulated to utilize the wasting steam in a low pressure turbine. With the clearing that accompanies full-scale power development forest fires become progressively less hazardous. The basic problem of landslides still exists under full development, but increasing capital investment in facilities justifies more expensive engineering efforts to prevent slides.

Another environmental effect that is a negligible problem prior to large-scale production is land subsidence. Any earth material when subjected to stress will compact or deform. Such compaction in a confined reservoir system occurs when stress is applied as in the form of reduction in hydrostatic pressure resulting from fluid production. The amount of compaction of the rock materials is a function of their compressibility, thickness of the zone subject to pressure decline, previous history of consolidation, and the stress applied. The surface manifestation of compaction of the reservoir rocks is subsidence or sinking of the land surface.

In the Clear Lake-Geysers area, the reservoir rocks are highly consolidated metamorphic rocks, and pressure reduction to date reportedly has been minor; thur, compaction and subsidence have not so far proven to be a serious problem. However, as production increases and the producing area is enlarged, pressure reduction should be expected and the likelihood of significant compaction will increase. The only practical technique for alleviating compaction is reservoir-pressure maintenance, which in this case probably would require water injection. If subsidence proves to be a serious problem, fluid injection in excess of the waste-water disposal program may be advisable. For the immediate future, a program of repetitive precise leveling to monitor any land-surface change should be instituted, with remedial measures held in reserve pending assessment of the significance of the problem. The principal impact of subsidence in the Clear Lake-Geysers area would be to the integrity of engineering structures, such as power plants, and particularly wells, which are subject to damage from compressional and shearing strain as the rocks readjust to changing stresses.

Another potential environmental hazard that must be given consideration in the production phase is increase in seismicity due to the geothermal operations. The California Coast Ranges consist of folded and faulted structures, and in general, are recognized as a seismically active area. Change in reservoir pressure, especially increasing of pressure, in a variety of settings elsewhere has caused small earthquakes or microseismisms, so the possibility cannot be dismissed in the Clear Lake-Geysers area. However, the hazard need not be overemphasized. Reservoir pressure changes have been modest in The Geysers field, no high-pressure injection is contemplated, and the immediate vicinity is not notably seismic.

ADVERSE IMPACTS WHICH CANNOT BE AVOIDED

Landscape will be disturbed by grading for roads and wells, and by construction of above-ground steam lines, power plants, and transmission lines.

There will be continued increased industrial activity and traffic in the area because of the geothermal operations.

Siltation would occur in streams or other bodies within the area of influence with consequential damage to aquatic life.

Some level of noise is unavoidable during drilling and testing phases, but during production noise is at a low level.

Noxious gaseous emissions, especially of hydrogen sulfide, are unavoidable, but can be kept at levels harmless to biota and people.

Reduction of hunting and recreational opportunity would occur where existing access would be restricted to protect geothermal facilities and reduce hazards to the public.

Geothermal production may induce seismic activity and cause land subsidence.

Transmission lines would result in some mortality of waterfowl, raptors, and other birds from aerial collision and/or electrocution.

ALTERNATIVES TO PROPOSED ACTION

With respect to any given leasing action, the alternatives to issuance of a lease under the regulations (Appendixes A and B) are:

(1) Postponement of leasing pending further study of the environmental impact. (See discussion under Alternatives in General Statement).

(2) The Secretary could decline to issue any leases to develop Federally owned geothermal resources. (See discussion under Alternatives in General Statement).

THE RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF MAN'S ENVIRONMENT AND MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

Leasing of lands for geothermal resource development would inescapably involve commitment of a portion of the geothermal, water, and land resources of the areas involved. The extent of these commitments and an assessment of their environmental impacts have been described in the preceding sections. However, the relationships between these proposed uses of the environment and the maintenance and enhancement of its long-term productivity must be examined.

A. The Resource

By developing geothermal resources, it is possible to tap a previously unused source of energy to meet growing energy needs, especially for electric power. At present, geothermal energy largely wastes to the atmosphere, and no alternative use other than extraction of heat is known or foreseen. The development of this natural source of energy for beneficial use, therefore, appears highly desirable.

Although geothermal development is expected to supplement rather than supplant other forms of electrical generation, geothermal energy generation, in most cases, would replace equivalent electrical generation by fossil fuel or nuclear plants, which consume valuable natural resources and generally have greater adverse environmental impacts.

B. Water

Consumption of water resources by power plants would constitute a depletion of gross water resources available to the area. However, the geothermal fluids that would furnish the input water to such plants is mineralized steam, not presently used for other purposes. To the degree that such fluid withdrawn from the subsurface reservoir is not replenished by reinjection or natural recharge, the water consumed would represent a depletion of water in storage.

Given the controls envisioned for waste disposal, degradation of surface and fresh ground waters is not expected to be significant.

C. Land

Land uses on Federal leases would be changed from wildlife habitat and recreational use to industrial use in the vicinity of wells, pipelines, power plants, and power lines. Public access in the vicinity of such industrial facilities may be restricted as a safety measure.

If geothermal production results in land subsidence, this being an irreversible process, it would represent a long-term effect on the land resources. Such subsidence in the Clear Lake-Geysers area would not significantly affect any use of the environment except as it affects surface drainage, and possibly power plants, through change in slope. Such changes represent a short-term impact until stabilization has been affected.

D. Fish and Wildlife

Geothermal resource development would have certain localized and regional adverse impact on fish and wildlife in the form of loss of wildlife habitat in the immediate vicinity of installations, loss of birds from collision with and/or electrocution on power lines, and possible danger to fish through accidental spills of toxic fluids, and increased sediment yield to streams. In addition restriction of public access would reduce hunting and related recreational opportunities in the vicinity of installations.

E. Economic and Social

Geothermal development requires substantial investment in drilling wells, and construction of roads, pipelines, power plants, and transmission lines. Such investments result in an increased tax base for the area of development. However, the labor-intensive phase would be short-term, during field development, and would not result in significant changes in population distribution.

IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

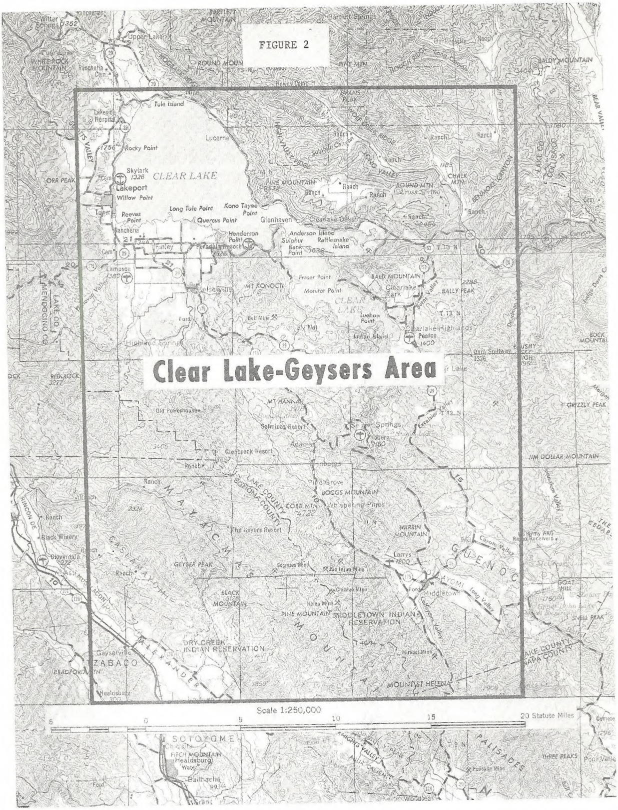
Full development of the Clear Lake-Geysers area would result in withdrawal of thermal energy at a rate considerably greater than the natural terrestrial heat flow. Thus, the power development is based upon utilization of thermal energy stored in the subsurface rocks and fluids over a long period of time. Although the natural heat flow could support a small power development indefinitely, the use of the stored energy must be considered as a commitment of the thermal resources over the time scale of a few centuries.

The mechanism of recharge of water to the geothermal reservoir of the Clear Lake-Geysers area is poorly understood, but evidently is from precipitation on the general area. Thus, the water evaporated in power generation and otherwise lost through geothermal production should also be considered as a water consumption chargeable to the area. However, as water is a renewable resource this charge is not irretrievable.

Compaction that may occur as a result of geothermal production is an irreversible process. The loss of porosity is a commitment of a resource because this is the storage volume for the heat-conducting fluid. The magnitude of this effect, however, is unknown at this time, and indeed may not prove to be significant.

In addition, the capital and labor required in the geothermal development represent an irretrievable commitment of resources. Should the steam be depleted, the wells, pipelines and power generation facilities would have little salvage value.

FIGURE 2


Clear Lake-Geysers Area
Scale 1:250,000
5
0
5
10
15
20 Statute Miles
CLEAR LAKE
Lakeport
Upper Lake
Tule Island
Lucerne
Rocky Point
Willow Point
Long Tule Point
Kono Tayee Point
Quercus Point
Glenhaven
Henderson Point
Anderson Island
Rattlesnake Island
Sulphur Bank Point
Finley
Kelseyville
MT KONOCTI
Fraser Point
Monitor Point
Clearlake Park
Clearlake Highlands
Lampson
Highland Springs
PINE MOUNTAIN
HIGH VALLEY RIDGE
WOLF CREEK RIDGE
BALD MOUNTAIN
BALLY PEAK
ROUND MTN
CHALK MTN
BALDY MOUNTAIN
ORR PEAK
RED ROCK
MT HANNAH
Seigler Springs
Adams
Glenbrook Resort
Old Powerhouse
Pine Grove
BOGGS MOUNTAIN
COBB MTN 4722
Whispering Pines
LAKE COUNTY
SONOMA COUNTY
The Geysers Resort
GEYSER PEAK
BLACK MOUNTAIN
PINE MOUNTAIN
MIDDLETOWN INDIAN RESERVATION
HARBIN MOUNTAIN
Middletown
Long Valley
Coyote Valley
GUENOC
MAYACMAS
DRY CREEK INDIAN RESERVATION
MOUNT ST HELENA
Geyserville
Healdsburg
Cloverdale
ZABACO
ALEXANDER
SOTOYOME
FITCH MOUNTAIN
GRIZZLY PEAK
JIM DOLLAR MOUNTAIN
SNELL PEAK
PALISADES
THREE PEAKS

DRAFT

Appendix D

Environmental Evaluation of Potential Geothermal Resources Development in the Mono Lake-Long Valley Area, California

September 1971

CONTENTS

Title (cont.)

MONO LAKE-LONG VALLEY AREA

INTRODUCTION

Location and Climate

The Mono Lake-Long Valley area, as shown on figure 3, encompasses approximately 1,242 aquare miles, principally in Mono County, California, but extending into Inyo County and including a small area of Madera County in the southwest corner. The area is in east-central California, about 50 miles north of Bishop, California, and approximately 200 miles south of Reno, Nevada. The area actually crosses over into Nevada at the northeast corner. Lee Vining, population 400, the only town in the area, is located on the western edge of Mono Lake at the junction of U. S. Highway 395 and State Highway 120. The low lands within this area consist of Mono Basin and Long Valley. These basins are bounded on the west by the Sierra Nevada and by the Inyo-White Mountain Range along the east. The elevation ranges from approximately 6,400 feet at the shore line of Mono Lake to 11,812 feet on Laurel Mountain near the southern border of the area.

The area includes Mono Lake, a natural lake of 84 square miles, and Lake Crowley, a man-made lake with a capacity of 183,465 acre feet which forms part of the water system of the City of Los Angeles. Mono Lake has no outlet, and its waters are highly mineralized and do not support fish life. Lake Crowley is fresh water and provides excellent sport fishing. Aside from the closed basin of Mono Lake, the principal drainage of the area is to the Owens River system which is diverted for municipal water supply for the City of Los Angeles. Some former tributary flow of Mono Lake is also diverted into the Los Angeles system via Owens Valley.

The Mono Lake-Long Valley Area has a semi-arid climate with temperate summers and cold winters. Maximum temperatures in the summer seldom exceed 90°F, while winter temperatures occasionally drop to -30° F. The annual rainfall averages 10 to 12 inches per year, with more than 60 percent of the precipitation occurring in November, December, and January. The prevailing winds are from the southwest. Mono Lake has an evaporation rate of about 2.5 feet per year resulting in an evaporative loss of 137,000 acre feet per year.

Geology

The Mono Lake-Long Valley area includes two large basins or irregular-shaped depressions connected by a chain of rhyolite, obsidian, and pumice craters which extend southward from Mono Lake in a broad arc. More than 50 volcanic events are represented by this chain of craters, the youngest of which presumably occurred less than 10,000 years ago and possibly as recently as 1,000 years ago. The Sierra Nevada on the west and south and the Benton Range and the Black Mountains on the east of the area are composed of late Paleozoic metasedimentary rocks intruded by mesozoic granite rocks.

Several fumaroles and many hot springs with water temperature up to boiling are located in the basin areas. In addition, there are numerous localities where hydrothermal alteration is evident and many areas where the heat flow is so high that falling snow melts rapidly upon contact with the ground.

Gravity data indicate that Mono Basin and Long Valley are structural depressions as well as physiographic basins and are bounded on all sides by steep faults. Long Valley is considered to be a volcano-tectonic depression caused by subsidence along faults following extrusion of magma from a chamber at depth. Volcanic activity continued from mid-Pleistocene into geologically recent times.

An aeromagnetic survey of the region disclosed a sharp magnetic high over the center of Long Valley. This magnetic anomaly roughly corresponds to a local positive gravity anomaly. The calculated depth to a magnetic body is about 3,000 feet below the valley floor. This mass of dense, magnetic material may represent buried volcanic or intrusive rock, which probably is related to the heat source for the various thermal springs in the vicinity.

The depression containing Mono Lake has been the locus of a great concentration of volcanic activity since mid-Pliocene time and the basin has undergone continued subsidence since the beginning of Pleistocene time 3 million years ago. The depression is bounded by near-vertical faults and probably contains about 300 cubic miles of Cenozoic sediments and volcanic rocks to a depth of 18,000 feet. Paoha and Negit Islands in Mono Lake are of volcanic origin and represent some of the most recent volcanic activity in the area.

Geothermal Exploration

The major exploration efforts in the Mono Lake-Long Valley area to date have been in the vicinity of Casa Diablo Hot Springs in Sec. 32, T. 3 S. R.

28 E. near the Mammoth Creek crossing of U. S. Highway 395. Since the late 1950's some 11 shallow wells have been drilled in this vicinity, all producing hot water.

Four wells drilled at Casa Diablo to depths of about 1,200 feet produced a mixture of saturated steam and hot water. The maximum temperature recorded in the wells ranged from 132° C. to 181° C., the pressure ranged from 7.5 to 39 p.s.i.g., steam produced range from 19,000 to 69,000 lbs./hr., and the hot water produced ranged from 233,500 to 473,000 lbs./hr. The silica dissolved in the well fluids indicates a maximum reservoir temperature of 192° C. The Na/K ratio in the wells indicates a temperature of about 185° C. Chemical analyses of the water and condensate from several test wells are given below.

In the spring of 1971 the California State Lands Commission issued Southern California Edison Company permits and leases to prospect for geothermal resources on seven parcels of State-owned land. Six parcels comprise submerged lands in Mono Lake, and one covers an area of vacant State school land adjacent to the lake. It is proposed to prospect the area for geothermal-energy sources, with the ultimate goal of producing geothermal steam for electrical-power generation. Investigation and evaluation will be dependent upon exploratory drilling projects.

Southern California Edison proposes to locate the initial exploratory well on adjacent Federal upland property and to directionally drill the well to a point under the lake where it is believed that a potential

Chemical constituents of fluids from Casa Diablo wells in ppm (after NcNitt, California Division of Mines and Geology, Special Report 75, 1963)

	Endogenous No. 1[b]	Endogenous No. 2[a]	Endogenous No. 2[b]	Mammoth No. 1[a]	Endogenous No. 4[c]	Endogenous No. 4[d]
Silica	250	278	256	292	200	0.8
Calcium		2		30	4	
Magnesium		Trace		Trace		
Sodium	380	236	375	247	308	5
Potassium	47	62	45	71	32	
Lithium		4		3	0.3	
Iron		5		4		
Aluminum		2		1		
Boron		60		49	11	0.3
Chloride	276	266	276	301	227	5
Sulfate	61	108	62	124	96	2
Hydrogen Sulfide					14	11
Fluoride					20	
Arsenic					0.2	
Ammonia					0.1	0.5
Carbon dioxide					180	205

Analyst: Abbot A. Hanks, Inc., San Francisco

a. Sample taken from wellhead immediately after flowing. Some water flashed to steam.
b. Sample taken from wellhead after cooling. No flashing to steam.
c. Water sample taken during flow test.
d. Condensate of steam sample taken during flow test.

geothermal-energy source exists. A special land-use permit has been issued by the Department of the Interior for the drilling of Federal lands.

No drilling platforms will be placed on the lake, and, in the event of commercial steam production, onshore installations and wellheads will be compact and grouped. Such arrangement will effect a more efficient operation with maximum recovery, and will minimize any impact upon the environment. Exploratory drilling is expected to commence in 1971. If geothermal resources are discovered, it is planned to utilize a small pilot generating unit initially. The pilot facility would be connected to an existing electrical transmission line located along the westerly side of Mono Lake. If development requires the construction of additional transmission facilities, the construction would be accomplished in the most aesthetically acceptable manner.

Vegetation

In the lowland areas where geothermal development is contemplated the vegetation is of semi-desert type and includes sagebrush, rabbitbrush, bitterbrush, as well as blue, needle, and salt grass, and sedge, rush, cattail, and mormon tea. The upland areas are forested, principally with Jeffrey pine, Lodgepole pine, Utah juniper, aspen, and black cottonwood.

Land Use

The principal economic enterprise in the Mono Lake-Long Valley area is grazing of domestic livestock (cattle and sheep). In the vicinity of Long Valley and Lake Crowley, the valley lands support grass and brush (subirrigated) that are usuable for grazing. The mountain lands, owing to steep slopes, shallow soils, and a dry climate, are used primarily for rangeland grazing and as wildlife habitat. The forest lands within the area are of poor quality and only minor timbering takes place.

Extensive recreational facilities exist throughout the Mono Basin and Long Valley. The prime recreational activity is fishing on the large number of streams, lakes, and reservoirs, both on the valley floor and in the Sierra Nevada and foothill area. Other recreations enjoyed in Mono Basin and Long Valley area are hunting, camping, and hiking among the scenic mountains of the area, and winter sports, primarily skiing. Also, nature study, riding, rockhounding, and bottle hunting are popular forms of recreation in this area.

Perhaps the major land use is for watershed as most of the runoff feeds the Owens Valley Aqueduct System of the City of Los Angeles. Some 65 percent of the city supply is obtained from this system.

Mono Lake is saline and, therefore, is not used in the aqueduct system; however, tributary inflow to the lake is diverted to the Owens Valley System and as a result Mono Lake has been receding slowly. Of a mean natural inflow of 216,000 acre-feet per year an average of 76,000 acre-feet per year is now diverted to the City of Los Angeles water supply. The annual evaporation from the lake of about 137,000 acre-feet; this, combined with other withdrawals for local use and reservoir evaporation, results in a small deficit in the waterbalance of Mono Lake on the order of 3,000 acre-feet per year.

Land ownership in the Mono Lake-Long Valley area is quite unlike that in the Clear Lake-Geysers or Imperial Valley area. The southern two-thirds and the northeastern corner of the area is largely within Inyo National Forest and under the management of the Forest Service, Department of Agriculture. In the northern one-third, the Mono Basin, the land is principally public domain under the management of the Department of the Interior. Scattered tracts of privately-owned land, generally not aggregating more than two square miles in a continuous tract, are found in the Mono Basin and on the floor of Long Valley. Other major holdings include the bed of Mono Lake, owned by the State of California, and Lake Crowley, which is under the managementof the City of Los Angeles.

Fish and Wildlife

The two major basins under consideration are Mono Lake and the Owens River in Long Valley. Drainages of the San Joaquin River are in the gross study area, but are presumed outside of potential geothermal development. Fish and wildlife resources on lands lying west of the Sierra crest are not considered herein.

Mono Lake is naturally about twice as saline as sea water. Although not supporting fish life, the lake does maintain groups of five photoplankton and six zooplankton. One species of zooplankton is brine shrimp, which are harvested under license for marketing as a tropical fish food.

Major stream units tributary to Lake Crowley are the Owens River, Mammoth Creek, and Convict Creek. All of these stream systems support significant wild populations of Rainbow, Eastern Brook, and German Brown trout. These populations are augmented by plants of hatchery fish. Trout angling in Mono County in 1963 was estimated to be in excess of 800,000 angler days. It is estimated that at least 300,000 angler days were expended on Lake Crowley and other lakes in the study area. These lakes and streams are the most important trout fishing area in California.

The California Department of Fish and Game maintains a trout hatchery with associated trout-rearing facilities on Hot Creek, a tributary of the Owens River. The U.S. Bureau of Sport Fisheries and Wildlife also maintains a Fishery Research Station at this site. Both of these fish facilities depend upon their water supplies from constant cold water springs.

Virtually all of the study area is considered good mule deer range with densities estimated at 10 to 30 per square mile. The resident mule deer populations are augmented in the winter by migrant deer from the higher snow-clad slopes. Deer population is expected to support 50 hunter days each year per square mile. Wild horses, antelope, and big horn sheep occasionally range on the study area, but should not be considered resident.

Small game species which frequent the area include sage grouse, cottontails, and white-tailed and black-tailed jack rabbits. Sage grouse densities are less than 10 per 100 acres, whereas jack rabbit populations may reach one per acre in peek years. Hunting effort for these species is low.

Despite its high salinity, the 85-square mile Mono Lake receives significant bird use. Many species of shore birds and waterfowl use the lake for resting during migration to and from wintering grounds. Birds found on the lake for extended periods include grebe, phalaropes, terns, and several species of gulls. California and ringbilled gulls nest on islands in Mono Lake. Several creeks attract nesting mallards and cinnamon teal. Lake Crowley attracts some migrant ducks. High numbers of grebes frequent the lake.

Coyote populations are considered high in the study area. Relatively low numbers of bobcats are found, and occasional black bear or mountain lion may range from the hills and mountains.

ENVIRONMENTAL IMPACT OF POTENTIAL DEVELOPMENT

Resource Reconnaissance Stage

The reconnaissance stage of exploration in the Mono Lake-Long Valley area has been underway for some time. Some 11 wells have been completed to depths of as much as 1,200 feet in the Casa Diablo area. The principal geophysical exploration has been gravity surveying, which involves occupation of a station with a portable instrument for a few minutes and has no significant environmental impact.

It is expected that future exploratory work will concentrate on delineating the productive areas by deep drilling. Geologic mapping, sampling of natural springs and wells, and additional geophysical work will continue until the geothermal possibilities are well defined, but these activities will generally use existing access routes, therefore, the adverse environmental impact of such activities should be minor.

Test Drilling and Production Testing

This stage of development is expected to begin in late 1971 and concentrate on defining the economic potential for geothermal development at Mono Lake. Further test drilling is also expected in the Casa Diablo vicinity, if Federal leases are issued.

SURFACE EFFECTS

Grading of roads and well sites, and construction of ponds to contain hot water produced from wells during testing are the principal surface effects expected. In general these are not expected to be a severe impact in the Mono Lake-Long Valley area because the land likely to be developed has gentle slopes and little grading will be required. Sediment production undoubtedly will increase somewhat, but the arid climate and minimum grading required should tend to alleviate this problem.

WATER RESOURCES

Mono Lake is a closed saline lake containing about twice the mineral content of sea water. Although it does not support fish life, it does support a microflora, a microfauna, and a unique species of brine shrimp, which forms part of the food chain of wild fowl, and is harvested commercially for tropical fish food. Release of geothermal waters to Mono Lake could conceivably affect this ecological regime; accordingly, the plan of development for drilling beneath Mono Lake approved by the State Lands Commission and concurred in by the Regional Water Quality Control Board envisions release of geothermal water to Mono Lake only if it can be demonstrated that such waters will not degrade the lake water. It is expected that fluids produced during test drilling and production testing will be disposed of by evaporation from sealed surface ponds or by reinjection to the producing zone.

With respect to fresh waters of the area, the Regional Water Quality Control Board has recommended against discharge of geothermal waters to surface waters of the area. The proposed regulations (Appendixes A and B) as applied to Federal leases similarly prohibit release of geothermal fluids to surface waters or fresh ground water.

The principal impact on the water resources of the area will likely be increased sediment runoff. At Mono Lake this problem probably will not be severe because of the arid climate and gentle slopes. Elsewhere in the area, sediment control requirements of the proposed regulations would prevent the development of a severe sediment discharge problem.

Well drilling and completion practice required by Federal and State regulations is deemed adequate for protection of superficial ground waters from contamination by geothermal waters. Typically, a 20-inch conductor casing is seated at about 50 feet depth in a 24-inch hole with the annular space cemented to land surface; inside that is a 16-inch surface casing in an 18-inch hole to about 350 feet, also cemented to land surface; within that is a 10 3/4-inch casing in a 15-inch hole to 2,000 feet, also cemented to the surface. Finally an 8 5/8-inch casing extending to the producing zone is installed in a 9 7/8-inch hole, with cement extending to the surface. Multiple casing with cement filling each annular space should assure against subsurface corrosion by geothermal brines for many years. If a decision is made to abandon a test well, it will be filled with cement to a sufficient depth to prevent upward movement of brines to superficial ground water bodies.

AIR

Noise

Geothermal well drilling in the Mono Lake-Long Valley area is accomplished with mud circulating systems. As such, the noise from the drilling operations falls within acceptable industrial noise levels. This noise may on occasion be objectionable and special acoustical shields may be required on the drill rigs. Drilling operations generally last about 30 to 45 days for each well, thereby limiting the duration of the noise source. Production testing of the wells, in which 20 to 25 percent of the fluid flashes to steam, generally does not exceed 90 days. Ejection of the steam fraction through appropriate muffling devices can reduce the noise of a testing well to tolerable levels. After testing, the wells are capped and cease to be a source of noise.

Gaseous emissions

Only during the production testing of a well will steam be ejected to the atmosphere in large quantities. This steam contains essentially water vapor plus the non-condensible gases hydrogen sulfide, fluorine, ammonia, and carbon dioxide. The concentrations of noxious gases are small and are not considered harmful. As testing of the wells lasts for only relatively short periods of time, the total quantity of gaseous material emitted to the atmosphere is small. Each well is capped after testing and only a small amount of steam will be vented after the initial test release until power generation is begun.

VEGETATION

The drilling of test and production wells will necessitate the controlled clearing and leveling of ground for the well sites and the construction of access roads with the resultant destruction of some native plant life. Reseeding of the road cuts and drill sites will be required to provide adequate plant cover and to stabilize the soil.

The hot saline fluids produced during well testing are contained in ponds constructed adjacent to the wells. These ponds would be filled and replanted after testing to prevent accidental contamination of surface waters and to eliminate access and usage by various wildlife species.

FISH AND WILDLIFE

Test drilling and production testing of geothermal steam resources in the Mono Lake-Long Valley area would have varied impacts upon fish and wildlife, which are not completely understood. Most would occur on or adjacent to well sites, although water quality impacts could potentially have farther-reaching influences. The magnitude of particular impacts would be interrelated with fish and wildlife and their habitat within the area of development influences, extensiveness and duration of the entire geothermal development activities and operations, and the effectiveness of control measures. Many of the impact types lend themselves to whole or partial control, and the proposed leasing and operating regulations provide a regulatory framework by which such control could be achieved.

As a specific geothermal development would proceed through test drilling and production testing, physical land modification and commotion would occur. These activities would include such things as construction of roads, ponds, and drill pads and drilling of wells, and would result in loss of wildlife values, including both habitat and human use within the area of influence. The modification would physically alter or remove existing wildlife habitat and permanence of these effects would be dependent upon the nature of the particular construction or operational activity and the completeness of control measures. In addition to land modification, the commotion would have displacement effects upon animals and birds such as deer and sage grouse in the site vicinity. The degree and permanence of displacement or disturbance would depend upon the scope and type of activity. For example, although the effect on wildlife is not clearly understood or predictable, noise from testing wells would have a disturbing influence upon animals within the site vicinity.

Most areas adjacent to drilling and test operations, but outside of the immediate zones of physical modification, would retain part or all of their fish and wildlife populations and habitat. Where existing public access would be restricted in order to reduce hazards to the public, there would be an accompanying reduction of hunting, angling, and camping opportunity on these lands. The importance of these losses would depend upon the capacity of other available habitat areas to absorb the pressures which are presently absorbed by geothermal area.

The major potential impacts upon fish and wildlife would result from improperly planned or executed handling of geothermal fluids. The area's existing surface waters are highly mineralized and geothermal fluids would be expected to contain relatively high concentrations of arsenic, boron, and fluoride. If significant additions of geothermal fluids, containing toxic concentrations of these substances, were made to streams, ponds, game management areas, or Lake Crowley, adverse impacts on aquatic habitat, including trout waters and waterfowl areas, would result. Releases of heated effluents would alter the aquatic habitat and life, perhaps creating temperatures intolerable to trout and other fish species and stimulating growths of nuisance algae. However, the probability of these potential problems occurring at or near any given well site appears to be small, since the proposed geothermal regulations would require controls, including reinjection of problematical brine wastes, to avoid surface water degradation.

Reinjection of geothermal fluids also possesses the potential for adverse impacts upon fish and wildlife. For example, the modification of the surface and shallow ground water table, through improperly planned reinjection techniques could adversely affect the trout fishing of the area, which is estimated to be 800,000 angler days annually.

Should a development involve construction of ponds, the ponds could have hazardous or beneficial impacts upon fish and wildlife resources, depending upon local circumstances. If the produced water was of acceptable salinity and free of toxic substances and disease-producing elements, benefits could be significant in the form of increased aquatic habitat and nesting and feeding areas for waterfowl and marsh birds. However, some problems with waterfowl using pond water exhibiting toxic concentrations of trace elements can be foreseen.

Erosion from construction activities could result in added siltation of aquatic habitat within the area of project influence. The siltation would be most severe during construction phases, although some would occur during the operational stages. Siltation effects would include covering of fish spawning and feeding areas and shallowing of streams. The degree of siltation damage to aquatic habitat would be dependent upon the success of erosion control measures.

AESTHETICS

Scenic Values

The Mono Lake-Long Valley area contains numerous scenic attractions such as Devils Postpile National Monument, which is excluded from geothermal development, as well as various volcanic cones, fumaroles, tufa towers, and hot spring areas which may be close to geothermal developments. Test drilling and production testing of wells near these areas could detract from their scenic value. Once drilling is completed, the wellhead equipment will not be readily visible.

Archeological and Historic Values

The theme study on the Works of Volcanism under the National Registry of Natural Landmarks suggests three sites in the Mono Lake-Long Valley area which might qualify as natural landmarks. These include Mono Craters, Black Point Fissures, and Long Valley Caldera. Black Point Fissures lie on State land and responsibility for their protection rests with the State of California. The other two sites are on Federal lands.

Dogtown, the site of an early mining boom town in 1857, has been designated as a State Historical Landmark. Other historic and archeologic sites may be present and in the event any sites are located during development, these sites should be preserved and the proper agency notified of their existance. Considering the small acreage of land involved in the drilling of a well, it is highly unlikely that any archeological or historical site would be disrupted either by drilling operations or the proximity of geothermal operations.

Recreation

Recreational activities including fishing, hunting, camping, hiking, skiing, nature study, riding, and rock hounding will not be significantly influenced by test drilling activities. Scenic values may be impaired due to the presence of drill rigs, but such impairment will be temproary at a specific location. Well access roads may open areas to recreational pursuits that are relatively inaccessible under existing conditions, which would contribute to recreation management problems. Completed wells that are testing will emit a visible steam plume, but again this will be of short duration and will not greatly influence recreational activity. Capped wells will have no influence on recreational pursuits.

MISHAPS

The principal forms of accidental environmental impact likely to be encountered in drilling and production testing in the Mono Lake-Long Valley area are uncontrolled flows of fluid, spills of geothermal brines, and brush and forest fires. In any exploratory drilling in an untested area there is a hazard of such flows of steam, water, or gases such as carbon dioxide or hydrocarbons. The proposed operating regulations for drilling on Federal leases provide safeguards for control of accidental flows in the form of strict casing and completion requirements and installation of blowout preventers. Similar requirements apply to other drilling under the State of California regulations.

The possibility of accidental releases of saline brines, for example, through failure of levees enclosing brine storage ponds or through pipeline leakage must be considered. These possibilities are continuing hazards, but can be minimized through careful supervision and maintenance. Such accidental releases probably would not pose a serious hazard in the Mono Basin because Mono Lake is highly saline and small additional quantities of saline water would not have a significant impact. However, elsewhere in the Mono Lake-Long Valley area release of brines could seriously damage fresh-water resources and pose a threat to fish.

The forest and brush fire hazard is not peculiar to geothermal development, but simply is increased due to the greater level of human activity and traffic associated with development. The brush fire hazard would be modest in the Mono Basin because of sparse vegetation, but elsewhere in the area, particularly during the dry season, special fire prevention efforts will be required to avoid disasterous brush and forest fires.

Field Development, Power Plant and Power Line Construction, Energy Generation and By-product Facilities

Should exploratory drilling in the Mono Lake-Long Valley area prove favorable for economic development of the geothermal resources, the environmental impact will increase and in some aspects will change. Some activities such as drilling and testing continue for many years and their impact is scaled up, but a whole spectrum of new activities is introduced with the decision to use the resources commercially. Additional wells are required for efficient development of the resource, steam lines are built to convey the steam from the point of production to the power plant, power plants are built to generate electricity, and power lines must be built to transmit the energy to the point of use. Furthermore, when power generation begins, production from the reservoir imposes stresses on the system greater than those of the testing phase and such effects as reservoir depletion, land subsidence and increased seismicity may come into play.

SURFACE EFFECTS

In the Mono Lake-Long Valley area the increased impact from full-scale development would result from drilling of numerous wells, construction of pipelines from the wells to points of use, and construction of power plants and transmission lines, facilities for reinjection of spent brine, and possibly by-product plants.

The engineering problem of heat loss from the fluid in transit would be similar to that of The Geysers field, which requires small power plants close to the wells with insulated surface piping. The geothermal development at Cerro Prieto, Mexico, which is a hot-water dominated system, can serve as a model of the type of power-plant development to be expected in the Mono Lake-Long Valley area. At Cerro Prieto some 15 producing wells distributed over an area of about 1 square mile supply steam to a 75-Mw plant at a maximum distance of 1 mile. The fluid produced by the wells consists of about 25% steam and 75% water. A centrifugal-type separator at each well separates the fluid, and the steam is conducted to the power plant in 12- to 34-inch insulated, above-ground pipelines. Except for the feature of water separation, the operation is similar in scale and methodology to any one of the plants at The Geysers field described in Appendix C. At Cerro Prieto the waste water is disposed of by surface discharge, which would not be permitted in most of the Mono Lake-Long Valley area.

Assuming a similar pattern of development to that of Cerro Prieto, one could expect development of several centers of power generation, each with a power plant and network of radiating pipelines to wells. In addition, a pipeline system would be required to collect waste water from the producing wells and to convey it to reinjection wells located strategically throughout the field. Such surface modification would represent a decided change in land use, but not necessarily a severe environmental impact. The proposed development at Mono Lake calls for directional drilling of wells beneath the lake from drilling sites on shore. Full-scale development would entail construction of several small power plants similar to those at The Geysers field around the shore of the lake with appropriate pipeline connections to the plant. Directional drilling would minimize the need for above-ground steam lines because a sufficient number of wells would be drilled from each shoreline drilling site to supply an individual plant. Power lines would be required to connect the power plants to the main transmission line through the area.

WATER RESOURCES

Under full-scale electric development the potential impact on water resources would be in proportion to the scale of activity. As in the earlier exploration phase, the principal hazard would be from accidental release of geothermal fluids to surface waters or shallow ground waters and from increased sediment production. Under the proposed operating regulations of the Department of the Interior and comparable regulations of the State of California, which apply on non-Federal lands, the hazards from leaky well casings and blowouts would be minimal. A more likely risk is from accidental releases from waste-water pipelines, and from brine-storage ponds. Minor leakage would not pose a serious threat to water resources in the Mono Basin because in most of the area the ground water is too saline for many uses, but a large continued leakage for long periods could cause environmental damage to Mono Lake. Elsewhere in the area substantial leakage could pose serious water-pollution problems. The best insurance against this threat is careful supervision of the geothermal development as defined in the proposed leasing and operating regulations for Federal lands. The impact of full-scale development on surface streams would be mainly in the form of increased sediment yields stemming from clearing operations. As more roads and well sites are constructed, additional areas will be affected. Although expansion of the producing area results in increased sediment loads, the loads from older producing areas would be progressively reduced as erosion-control techniques and revegetation take effect.

One new problem that would come about with full-scale development is that of disposing of liquid waste from the power plants. A certain proportion of the geothermal fluid is consumed for condenser cooling in electrical generation. At The Geysers, 80 percent of the steam is used in this way, thus 20 percent of the original water content must be disposed of together with its dissolved mineral content. In a hot-water system, such as in the Imperial Valley area or the Mono Lake-Long Valley area where steam forms 25 percent or less of the fluid production, a proportional amount of waste water must be disposed of -- as much as 80 percent of the original production. Only two possibilities appear feasible for such disposal in the Mono Lake-Long Valley area; (1) reinjection into the producing zone, or (2) discharge to Mono Lake. If discharge to Mono Lake proves feasible under the State of California Water Quality Standards this would be a desirable alternative. However, this course could be elected only if the salinity of the geothermal water is less than or equal to that of Mono Lake, and would not chemically or thermally degrade the lake.

AIR

Noise

During field development, there will be some noise associated with well drilling, but as described earlier, this is of relatively low level and duration. Wells are capped after initial testing so noise from this source should be isolated and, with the use of mufflers, of low-intensity. The construction of power plants and by-product facilities will include noise associated with typical building activity until the facilities are completed. Operating noise for both power plant and by-product plant can be contained within the structures through the use of acoustical building materials. Some noise may be associated with the operation of cooling towers, but this will be noticeable only in the immediate vicinity of the towers.

The potential for loud noise exists if steam lines or wells should corrode and rupture. A well-planned preventive maintenance program can substantially reduce the chance of such occurrences.

Gaseous emissions

Non-condensible gases including hydrogen sulfide, fluorine, ammonia, and carbon dioxide, will be extracted from the steam prior to entry into the generating plant. Each well must be analyzed for gas content and varying field conditions may result in a change in gas concentration. If noxious gases increase, some form of disposal other than atmospheric venting may be required to meet air quality standards.

Water vapor will also be vented from the cooling towers and may contribute to the fog cover which frequently occurs within the basin. Various gases may be generated in a by-product recovery plant. Discharge of such gases must be in compliance with air-quality standards.

Condenser steam

Input steam, after passing through the electric generators, is condensed to the liquid stage and is sent to the cooling towers to reduce the temperature. This condensed steam will contain metal ions and other contaminants which are detrimental to plant and animal life. Excess cooling-tower water and flushing water must be reinjected into the producing formations or ponded for evaporation rather than discharged to the surface drainage system. Waste liquids from the by-product plant would also be reinjected into the producing formations rather than discharged to surface drains. Care must be exercised in combining various waste products, as resultant chemical reactions may lead to the reduction of pore spaces surrounding the injection well and reduction of intake capacity.

VEGETATION

Except for the displacement of plant life in those areas cleared for wells. power plant, pipeline, transmission line, and by-product plant, there will be no adverse affect on adjacent plant life. Reseeding of bare ground and planting of vegetative screenings will stabilize soils and minimize visual impact of surface structures. Ponding of toxic; saline fluids may affect plant life at the edge of such ponds. Aquatic plant life will not be affected, as toxic fluids will either be reinjected to underground formations or will be ponded for evaporation. Regrading of pond sites after abandonment and replacement of topsoil will allow reseeding of these pond areas.

FISH AND WILDLIFE

Full development of a geothermal field, as with drilling and production testing, would have varied impacts upon fish and wildlife. Most of the impacts would occur on or adjacent to construction and plant sites. Many of the impact sites lend themselves to whole or partial control, and the proposed operating regulations provide a regulatory framework by which such control could be achieved.

The most significant potential impacts upon fish and wildlife would result from handling of geothermal brines. For further details, the reader is referred to the fish and wildlife discussion under Test Drilling and Production Testing.

As a geothermal field would proceed through construction and operation stages of the power plant, pipelines, transmission lines, and any by-product facilities, the loss of wildlife values, which began in the test drilling and production testing stages, would continue within the immediate area of influence. These losses would include both wildlife habitat and its use.

Where existing public access would be restricted in order to reduce hazards to the public, there would be an accompanying reduction of hunting, angling, and camping opportunity on these lands. The importance of these losses would depend upon the capacity of other available habitat areas to absorb the pressures which are presently absorbed by the geothermal area.

Transmission lines located in flyways or over nesting and feeding sites would cause some mortality of waterfowl, raptors, and other birds from collision and/or electrocution. The magnitude of this type of loss cannot be predicted but would be expected to be minor.

AESTHETICS

General

Recreational hunting and fishing is enhanced by relatively undisturbed areas. The aesthetic qualities of an area play a large role in the quality of hunting and fishing. Large-scale development or any development that detracts from natural scenic values could have a detrimental and irreversible impact on these activities. Since the economy of Mono County has shifted from mining and minerals to outdoor recreation, this impact could be significant.

An overlook atop Conway Summit provides an excellent view of Mono Lake and surrounding country. Geothermal developments such as pipelines, power plants, power lines, and roads would be visible and could detract from the scenic values. The use of vegetative screening around the various structures and the use of color schemes which blend with the background can reduce the visual impact. Vapor from the cooling towers will be visible and will be difficult to screen. Existing power transmission lines should be used, where possible. Artistically designed, visually compatible transmission towers can reduce the impact of these structures on the scenic values.

Archeological and Historical Values

No change is expected from that described earlier.

SOCIAL EFFECTS

Economics

The development of geothermal power-generating facilities can be expected to contribute tax monies to both the State and county governments. These taxes would be of the same order of magnitude per unit of power output as those in The Geysers area. The construction of a companion by-product recovery plant would also be a source of State and local tax revenue.

Although the quantity of by-product revenue is a variable, it would be comparable to other brine processing facilities. Royalties and rentals would be paid on Federal lease land as well as to private land owners if development takes place on their land. Royalties and rentals are subject to negotiation on private lands. The royalties and rentals are fixed on Federal lands except for bonus sales. Local spending by temporary construction workers and drilling crews may contribute in a small measure to the local economy. It is not expected that permanent employment or employee spending would be great or would have much impact on the local economy due to the small number of employees required for full-scale power production or by-product recovery.

Population distribution

No permanent change in population size or distribution is expected as a result of geothermal developments in the area. Drilling crews and construction workers are transient and temporary housing can be made available for this small number of employees. Power-generating facilities and by-product recovery plants would require only a limited number of employees who can readily be integrated into existing housing facilities.

Transportation

Only minimal increased traffic can be expected as a result of geothermal related activities in the area. Movement of vehicles over untreated access roads can result in the generation of considerable dust. Some form of treatment would be necessary to reduce the impact of this dust on the surrounding environment. Hydrocarbon treatment, chemical treatment, or paving of the roads can solve this problem.

Modification of land uses

The development of this area for geothermal resource values is expected to modify existing land use patterns, especially as it relates to recreational activities. Some portions of the area would be restricted from hunting due to safety factors. Grazing activities may have to be curtailed within the geothermal field to protect cattle and sheep from any danger.

By-product industries

Present data indicate the resource area contains little or no commercially valuable by-product minerals. There is a possibility that demineralized water may be produced to supplement existing supplies in this water-deficient area. In the event the by-product hot water is treated to produce demineralized water, provisions would have to be made to dispose of the remaining mineral salts to prevent degradation of the environment.

MISHAPS

The potential for impact from blowouts and accidental spills of geothermal brines is discussed earlier under Water Resources (p. 22). Other than these, the principal unplanned environmental impacts that are likely in the Mono Lake-Long Valley area are land subsidence and the possibility of inducing seismic activity.

The extraction of fluids from a ground-water reservoir, where withdrawals exceed recharge rate and reservoir pressure declines, may cause land subsidence. In most of the area, ground subsidence will have little impact and may be tolerable. Locally, subsidence may be serious. Most parameters for predicting subsidence, such as anticipated pressure decline, thickness and compressibility of the water-bearing deposits, and lateral extension of fault blocks, are not well known. Subsidence will probably occur if geothermal waters are extracted for an extended period. Both fluid pressures and surface benchmarks would be carefully monitored to determine production effects. Provisions would be made in the monitoring program to differentiate tectonic subsidence from that caused by geothermal development. Subsidence is minimized or prevented by maintaining fluid pressures by either natural or artificial recharge.

Another unplanned potential environmental impact that must be given consideration in the Mono Lake-Long Valley area is increased seismicity induced by geothermal development. The Mono area is known to be faulted and seismically active. Experience in other areas indicates that increased seismic activity, in the form of swarms of micro-earthquakes, has occurred in several areas as a result of fluid injection into confined systems. Similarly, heavy production of fluids from confined systems, which causes land subsidence, has also been related to tectonic activity, such as displacement of fault surfaces as the confined system readjusts to changing stress.

In view of the natural seismicity of the Mono Lake-Long Valley area it would be only prudent to consider the possible effects of pressure changes due to both production and/or reinjection on the seismic regime. Experience with this problem is recent and widely scattered, therefore, it is impossible at this time to predict what might happen in this area under various planning assumptions. A prudent course would be to establish a detailed seismic monitoring program before major production begins; if this indicates significant increase in seismic activity, particularly in intensity of motion, remedial steps to alleviate stress would be undertaken promptly.

ADVERSE IMPACTS WHICH CANNOT BE AVOIDED

Landscape will be disturbed by grading roads and well sites, and by construction of pipelines, power plants, and connecting power lines.

Land use will be changed from recreation, grazing, and wildlife habitat to industrial production in small areas.

Some level of noise is unavoidable during drilling and testing of wells, but noise is at a low level during production.

Some noxious gaseous emissions may be unavoidable, but can be kept at a level harmless to biota and people.

Physical land modification and disturbance effects would involve a loss of wildlife values in the immediate area of a development.

Siltation could occur in streams or other bodies within the area of influence with consequential damage to aquatic life.

Reduction of hunting and recreational opportunity would occur where existing access would be restricted to protect geothermal facilities and reduce hazards to the public.

Transmission lines would result in some mortality of water fowl, raptors, and other birds from aerial collision and/or electrocution.

Some leakage in handling of saline waters is unavoidable, but this can be minimized with careful maintenance.

Production of large volumes of geothermal water can lead to land subsidence if formation pressures are permitted to decrease significantly; however, this effect can be minimized with a properly designed program of pressure maintenance.

Large changes in reservoir pressure might induce increased seismicity in naturally active areas. This can be minimized by careful seismic monitoring combined with prompt remedial action if an increase occurs.

Increased industrial activity and traffic are an unavoidable consequence of development and will increase theopportunity for erosion and sediment production.

The commitment of an undisturbed natural area having high recreation and aesthetic value to industrial development, albeit a clean, relatively small-scale development, while not entirely irreversible, represents a long-term commitment of the scenic resources.

ALTERNATIVES TO PROPOSED ACTION

With respect to any given leasing action, the alternatives to issuance of a lease under the regulations (Appendixes A and B) are:

(1) Postponement of leasing pending further study of the environmental impact. (See discussion under Alternatives in General Statement.)

(2) The Secretary could decline to issue any leases to develop Federally owned geothermal resources. (See discussion under Alternatives in General Statement.)

THE RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF MAN'S ENVIRONMENT AND MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

Leasing of lands for geothermal resource development would inescapably involve commitment of a portion of the geothermal, water, and land resources of the areas involved. The extent of these commitments and an assessment of their environmental impacts have been described in the preceding sections. However, the relationships between these proposed uses of the environment and the maintenance and enhancement of its long-term productivity must be examined.

A. The Resource

By developing geothermal resources it will be possible to tap a previously unused source of energy to meet growing energy needs, especially for electric power. At present, geothermal energy largely wastes to the atmosphere, and no alternative use other than extraction of heat is known or foreseen. The development of this natural source of energy for beneficial use, therefore, appears highly desirable.

Although geothermal development is expected to supplement rather than supplant other forms of electrical generation, geothermal energy generation, in most cases, would replace equivalent electrical generation by fossil fuel or nuclear plants, which consume valuable natural resources and generally have greater adverse environmental impacts.

Production of chemicals and fresh water as by-products of geothermal energy production would represent additions to these resources not presently available, and thus would also be beneficial.

B. Water

Consumption of water resources by power plants and by-product facilities would constitute a depletion of gross water resources available to the area. However, the geothermal fluids that would furnish the input water to such plants are expected to be saline water not presently used for other purposes. To the degree that such fluid withdrawn from the subsurface reservoir is not replenished by reinjection or natural recharge, the water consumed would represent a depletion of water in storage.

Given the controls envisioned for waste disposal, degredation of surface and fresh ground waters is not expected to be significant.

C. Land

Land uses on Federal leases would be changed from wildlife habitat and recreational use to industrial use in the vicinity of wells, pipelines, power plants and by-product facilities and power lines. Public access in the vicinity of such industrial facilities would be restricted as a safety measure.

If geothermal production results in land subsidence, this being an irreversible process, it would represent a long-term effect on the land resources. Such subsidence in the Mono Lake-Long Valley area would not significantly affect any use of the environment except as it affects irrigation and drainage, water transport facilities, and possibly power plants, through change in slope. Such changes represent a serious short-term impact until stabilization occurs.

D. Fish and Wildlife

Geothermal resource development would have certain localized and regional adverse impact on fish and wildlife in the form of loss of wildlife habitat in the immediate vicinity of installations, loss of birds from collision with and/or electrocution on power lines, and possible danger to fish through accidental spills of toxic fluids. In addition restriction of public access would reduce hunting and related recreational opportunities in the vicinity of installations.

E. Economic and Social

Geothermal development requires substantial investment in drilling wells, and construction of roads, pipelines, power and by-product plants, and transmission lines. Such investments result in an increased tax base for the area of development. However, the labor-intensive phase is short-term, during field development, and would not result in significant changes in population distribution.

IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

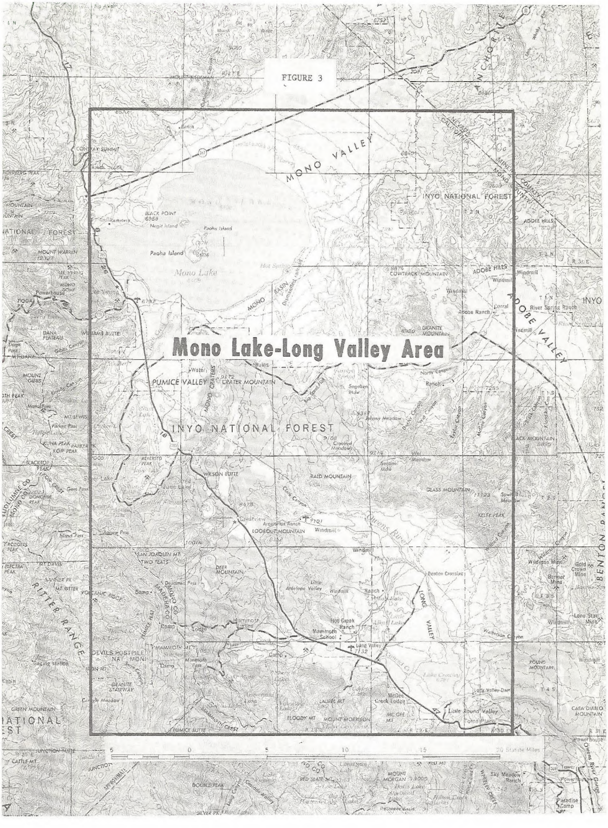
Full development of the geothermal resources of the Mono Lake-Long Valley area would be mainly for electric-power production. The thermal energy stored in the geothermal fluids presumably would be extracted at a rate greater than the natural terrestrial heat flow, thus power development would be based upon utilization of heat stored in the subsurface rocks and fluids over a long period of time. Although the terrestrial heat source will continue indefinitely, the use of the stored energy should be considered as a depletion of the thermal resource over the short term.

The recharge mechanism of the geothermal reservoirs of the area is poorly understood, but is presumed to be from rainfall on the drainage basins tributary to the area. Thus, water evaporated in geothermal production should be considered as a water consumption chargeable to the area. However, as water is a renewable resource, this charge is not irretrievable.

Compaction that may occur as a result of geothermal production is irretrievable in the sense that it is an irreversible process. Loss of porosity is a commitment of a resource because this is the storage volume for the heat-conducting fluid. The magnitude of this effect may prove to be important in this area.

The capital and labor required for the geothermal development represent an irretrievable commitment of those resources, because installations would have little salvage value when the geothermal resources are exhausted.

FIGURE 3


Mono Lake-Long Valley Area
MONO VALLEY
INYO NATIONAL FOREST
Mono Lake
Paoha Island
Negit Island
BLACK POINT
CONWAY SUMMIT
MONO BASIN
ADOBE HILLS
COWTRACK MOUNTAIN
ADOBE VALLEY
Adobe Ranch
River Spring Ranch
PUMICE VALLEY
CRATER MOUNTAIN
MONO CRATERS
GRANITE MOUNTAIN
INYO NATIONAL FOREST
WILSON BUTTE
BALD MOUNTAIN
GLASS MOUNTAIN
KELTY PEAK
Crestview
LOOKOUT MOUNTAIN
SAN JOAQUIN MT
TWO TEATS
DEER MOUNTAIN
Benton Crossing
LONG VALLEY
Hot Creek Ranch
Mammoth School
Mammoth
MAMMOTH MT
DEVILS POSTPILE NAT MON
RITTER RANGE
LAUREL MT
BLOODY MT
MOUNT MORRISON
Little Round Valley
Toms Place
WILLIAMS BUTTE
MOUNT GIBBS
MT LEWIS
KUNA PEAK
MOUNT WARREN
BENTON RANGE
CASA DIABLO MOUNTAIN
ROUND MOUNTAIN
DOUBLE PEAK
MOUNT MORGAN
Sky Meadow Ranch
Paradise Camp
5 0 5 10 15 20 Statute Miles

DRAFT

Appendix E

Environmental Evaluation

of

Potential Geothermal Resources Development in the Imperial Valley Area, California

September 1971

CONTENTS

Title (Cont.)

IMPERIAL VALLEY AREA

INTRODUCTION

Location and Climate

The Imperial Valley area, as shown on figure 4, encompasses 1,710 square miles of Imperial County, California. The area centers about 100 miles east of San Diego. The land within the area is typically flat desert valley. Altitudes range from -234 feet at the Salton Sea to several thousand feet in the mountains bordering the area. The Salton Sea occupies some 90 square miles in the northwestern part of the area. In much of historic time the Salton Sea Sink was a dry lakebed. The present lake was formed when record flood crests of the Colorado River spilled into the Imperial Valley in 1905-1907. Since then the lake has been maintained by flows of natural runoff and irrigation return flows. Both natural and artificial drainage within the area is to the Salton Sea Sink. Natural drainage is principally through the Alamo and New Rivers and artificial drainage is through numerous irrigation canals and drains that traverse the irrigated area.

Under present development, by far the greatest contribution is from irrigation drainage, which is sufficient to maintain the lake level despite an evaporation rate of about 6 feet per year. The mineral content of the drainage return water is high and the salinity of the Salton Sea is increasing. The mineral content is now about equivalent to that of sea water. If it continues to increase, it will threaten an abundant marine sport fishery that has been established in Salton Sea.

The average precipitation on the floor of the Imperial Valley is about 3 inches per year, which falls as rain from August through February. The mean annual temperature is about 70° F with daily maximums in excess of 100 degrees occurring frequently during June, July, and August. January is the coldest month with minimum annual mean temperature of about 37° F. There are about 12 days of frost each year. There is little fog, few thunderstorms, and winds are light to strong from the west and northwest. There is considerable smog which is generated locally from burning stubble fields or which drifts in from the Los Angeles megalopolis when air currents flow southwest.

Geology

Imperial Valley is in a sediment-filled northwesterly trending structural trough called the Salton Trough. The entire depression is filled primarily with clay, silt, and fine-grained sand deposited by the Colorado River as a deltaic deposit, but includes some lakebed deposits. The valley is bordered on the northeast and southwest by mountains underlain by consolidated, largely crystalline rock, but including marine and nonmarine sedimentary rocks.

The Gulf of California marks the intersection of the East Pacific Rise with the North American continent. A high heat-flow associated with the rise extends north throughout the length of the Salton Trough. This high heat flow, locally 4 to 10 times normal, is manifested at the surface in Imperial Valley by two areas of Quaternary volcanic activity and several areas of hot-spring activity. High geothermal gradients in water-saturated sediments, as much as 20,000 feet thick, offer the potential for development of extensive geothermal resources.

The lower part of Imperial Valley at times past was occupied by lakes, the most evident being prehistoric Lake Cahuilla which stood about 50 feet above sea level. The cultivated agricultural land is entirely within the former shorelines of the prehistoric lake. Soils formed on the lakebed sediments have a high proportion of clay and silt as compared to alluvial soils found on higher valley lands to the east and west.

Clastic sediments filling the Salton Trough represent essentially continuous deposition since Miocene time and are estimated to be as much as 20,000 feet thick. These sediments can be grouped in three broad categories, from the surface down: (1) a sequence of mostly non-marine deposits of late Tertiary and Quaternary age derived mainly from the Colorado River; (2) a marine unit (Imperial Formation) of late Tertiary age, and (3) a lower sequence, chiefly non-marine sedimentary rocks of early to middle Tertiary age, but including some volcanic rocks and minor marine sediments.

The sedimentary sequence is pierced on the east side of Salton Sea by geologically modern volcanics which crop out in a row of small conical buttes of rhyolitic obsidian, scoria, and pumice.

Four major active strike-slip faults cut the valley deposits trending generally NW-SE, parallel to the trend of Salton Trough. Several branches of these or subparallel faults have been mapped in Imperial Valley. Among the best known are the San Andreas, Elsinore, Imperial, and San Jacinto Faults. Several major earthquakes have occurred in Imperial Valley in historic times and surface displacement has been noted on some of these occasions. One of the most severe earthquakes in recent years, with a Richter magnitude of

7.1, occurred near Calexico on the Imperial Fault in 1940, and caused measurable land surface displacement of 19 feet. Surface displacement also was observed in earthquakes in 1951, 1966, and 1968.

Geothermal Exploration

The only surface manifestations of thermal activity in the Imperial Valley area are now limited to a few passive carbon-dioxide-rich hot springs and a large number of cool mud pots. However, early descriptions of the area indicate that thermal-spring and geyser activity was greater in the past, in areas now inundated by the Salton Sea.

The possibility of geothermal development was first explored in 1927 when three wells were drilled on Mullet Island for steam. From 1932 to 1954 more than 65 shallow wells (less than 1,000 feet) were drilled along the southeastern border of Salton Sea west of Niland to supply carbon dioxide gas to a dry-ice plant, which operated from 1934 to 1954. In 1957 an exploratory oil test well drilled about 4 miles south of the mouth of the Alamo River yielded large flows of hot brine, and since then 12 additional deep wells have been drilled in that vicinity in an attempt to develop the geothermal resources. Some of these wells have produced several hundred thousand pounds of hot brine per hour at well-head temperatures of 200° C. Reservoir temperature in the Salton Sea area is about 360° C.

Downhole pressure measurements in the geothermal area indicate a normal hydrostatic gradient, suggesting that the reservoir is water saturated, that is, a water-dominated system. The brines thus far encountered in this area contain large amounts of sodium, potassium, calcium, and chloride, as well as unusual contents of heavy metals; the total dissolved solids in many wells exceed 200,000 parts per million--many times the salinity of sea water (about 35,000 ppm). Chemical analyses of two typical brines are shown in the table below. Such hot saline waters are highly corrosive and technical problems of handling the waters have discouraged commercial exploitation of the geothermal energy. The possibility of revenue from saline and metallic by-products, although attractive, has not proven commercially feasible.

Calculated composition (in ppm by weight) of the reservoir fluid produced from the Shell No. 2 Imperial Irrigation District (IID) and Shell No. 1 State of California wells (from Helgeson, Amer. Journal of Science, v. 266, p. 129-166, 1968).

Constituent	No. 2 IID	No. 1 State
Sodium	53,000	47,800
Potassium	16,500	14,000
Lithium	210	180
Barium	250	190
Calcium	28,800	21,200
Strontium	440	
Magnesium	10	27
Boron	390	290
Silica	400	
Iron	2,000	1,200
Manganese	1,370	950
Lead	80	80
Zinc	500	500
Copper	3	2
Silver	<1	<1
Rubidium	70	65
Cesium	20	17
Chloride	155,000	127,000
ΣCO_2	500	5,000
ΣS	30	30
Total Dissolved Solids	259,000	219,500

The Mexican Government is developing a geothermal reservoir at Cerro Prieto, Mexico, about 25 miles southeast of Calexico. Eighteen steam wells have been completed and sufficient energy has been proven to supply a 75 Mw plant under construction. There are two notable differences between the Salton Sea anomaly and that at Cerro Prieto, however. The water produced at Cerro Prieto is relatively dilute, less than 20,000 ppm total dissolved solids and disposal of waste water is less of a problem there.

Temperature probes in an extensive network of shallow wells drilled as part of a research program of the University of California at Riverside have located several areas where temperatures gradients locally are as high as 10° F per 100 feet of depth. The full significance of hot spots will ultimately be determined by deep drilling. The most prominent of these are at Heber, just north of Calexico; at Brawley, about 20 miles north of Calexico; at Glamis, on the Southern Pacific railroad; in the sand dunes east of the Coachella Canal; and on the East Mesa to the east of the East Highline Canal.

From the geologic and hydrologic points of view, the Salton Trough appears to have great geothermal potential. However, for maximum protection of the environment, solutions to these technical problems must be found: disposal of residual geothermal fluids; compaction and land subsidence caused by fluid removal; and possible triggering of earthquakes by geothermal production.

Vegetation

Two predominant natural plant communities are represented in the area: the alkalai-sink, and creosote-bush scrub associations. The alkalai-sink community borders Salton Sea and the agricultural area to the south. The dominant plants are allscale salt bush, four-wing salt bush, and lens-scale salt bush. The upland areas are dominated by creosote bush, except in the sand hills east of the agricultural land, where mesquite is the dominant species.

Land Use

The principal industry and land use in Imperial Valley is irrigated agriculture. Water from the Colorado River, delivered through the All-American Canal System constructed by the Bureau of Reclamation currently supplies some 500,000 acres in the Imperial Valley and Coachella Valleys. In Mexico, the Alamo Canal and ground water pumping supply 400,000 acres in the Mexicali Valley. Highly productive soils and a 365-day per year growing season account for agricultural production of more than 300 million dollars annually. This industry is entirely dependent upon the successful management of the systems for delivery of irrigation water and the disposal of irrigation wastes.

Mineral resources in the Imperial Valley area are varied but production is minor. Production has included salt, calcite, feldspar, fluorite, kyanite, strontium, gold, carbon dioxide, and sulphur. Current production is mainly for construction materials, such as sand and gravel, stone, limestone and gypsum.

Lands outside the irrigated area are largely undeveloped desert suitable mainly for sparse forage and hunting of desert game. Much of the area east of Coachella Canal is reserved for military use as impact ranges. A Federal wildlife refuge occupies a large area of lake and some nearby riparian land near the south end of Salton Sea. Large flocks of migratory birds pass through each year and the area supports a large dove population. In addition, the State of California maintains a waterfowl management area along the southern border of Salton Sea and south of the lake along the Alamo River.

The land-ownership pattern in the Imperial Valley area is quite unlike that of the Clear Lake-Geysers area, and Federal leasing will have a major impact on the direction the development takes. The irrigated land on the valley floor, between the East Highline Canal and the West Main Canal, is essentially all privately owned and Federal leasing regulations will not pertain there, although the Federal government has a vital interest in preventing degradation of Salton Sea by waste waters. The bed of Salton Sea is largely public domain; however, it is unlikely that this area will be subject to geothermal development; the lands in the Federal wildlife refuge are excepted from leasing, and much of the rest of the Federal land is withdrawn from entry as public water reserve or reclamation withdrawals.

The lands east of the East Highline Canal are predominantly in Federal ownership under management of the Department of Interior. On these lands, the proposed leasing and operating regulations will determine the course of development. Any drilling and production will be done under the regulations (Appendix A), and power production and by-product facilities will require separate permission of the Secretary of the Interior.

Fish and Wildlife

There are three major environmental complexes that influence fish and wildlife resources of the Imperial Valley. They are the Salton Sea, the irrigated farmlands, and the desert. The Valley lies for the most part below sea level with the 360-square-mile sea serving as the repository for all surface runoff. The irrigated tracts depend upon the sea to receive irrigation return flows and the sea also receives sewage and industrial wastes.

The sea and adjoining lands are wintering habitat of the Canada, snow and white-fronted geese and a dozen species of ducks. Important ducks are American widgeons and pintails. No other comparable area in the West can boast of the tremendous flocks of shorebirds which each year frequent the Valley. Approximately 180,000 waterfowl winter in the area.

The Salton Sea area supports the highest populations of doves in the West including mourning doves, white-winged doves, and Mexican ground doves. In the summer, gull-billed terns and laughing gulls, which have nested nowhere else in the Western United States are present. Wood, cattle and white-faced ibises, fulvous tree ducks, both white and brown pelicans, and many other interesting birds visit the area. The area attracts birds from Mexico which are not found elsewhere in the United States. Endangered species found in the area include brown pelicans, Yuma clapper rails, and California least terns. The clapper rail nests on the area. The area also contains the native habitat of the road-runner, the Gambel's quail, cactus wren, verdin, and many other desert species.

The coyote, kit fox, raccoon, bobcat and kangaroo rat as well as skunks, muskrats, badgers, cottontails, and jack rabbits are all present.

The Federal government through the U. S. Fish and Wildlife Service established a 32,407 acre refuge in 1930 on Salton Sea. All of these lands are now inundated. In 1947, the Imperial Irrigation District made available for leasing, for waterfowl management purposes, approximately 24,000 acres lying between the sea and private farmlands. The sea continued to rise and less than 2,500 acres remain above water and are administered by U. S. Fish and Wildlife Services as the Salton Sea National Wildlife Refuge. The refuge provides essential fresh water habitat, public hunting, and wildlife study area. About 25,000 recreational days were expended on the refuge in 1970. The use is increasing each year.

The State of California Department of Fish and Game maintains 8,400 acres of land which is designated as the Imperial Wildlife Area. Waterfowl feeding, resting, and hunting areas have been developed. The only fresh water lakes in the Valley are on the area. In 1969, this area provided 32,800 recreational days, mostly hunting and fishing. Future use under present development plans would provide over 140,000 recreational days, mostly fishing.

Fish resources of the area are confined to the Salton Sea, irrigation canals and return flow drainages, and a few pond areas.

The Salton Sea is one of the most unique bodies of water in the world. It lies below sea level and is salty, slightly above that of sea water, and subject to temperatures ranging from the low 50's in winter to a tepid 100 degrees in the summer. The sea is maintained by highly mineralized irrigation return flows. After extensive trial and error planting of ocean fish into the sea, there has been created an excellent fishery for orange-mouth and shortfin corvina and Sargo perch. Mullet are also caught at selected sites. About 500,000 angler days are expended each year. In light of projected increased salinities, ability of the sea to support fish life may not exceed 10 years.

Striped bass, black crappies, channel catfish, and large-mouth bass frequent the main irrigation canal system. The endangered Colorado squawfish is expected to frequent the canal system. The angler use of these canals exceeds 10,000 angler days each year. The California Department of Fish and Game has also developed a warm water fish hatchery in the study area.

ENVIRONMENTAL IMPACT OF POTENTIAL DEVELOPMENT

Resource Reconnaissance Stage

The reconnaissance state of exploration in the Imperial Valley area has been underway for many years and has had minimal environmental impact to date. The geothermal manifestations in the form of geysers and hot-spring activity were first described in 1855. Commercial interest in the geothermal resources dates to 1927 when three exploratory wells were drilled for steam. There was no further significant activity until 1957 when a deep test well (No. 1 Sinclair) encountered very hot brines. This discovery led to considerable exploration activity and 12 deep test wells have been drilled subsequently.

Reconnaissance work over the years has included geologic mapping, gravity and magnetic surveys, electrical earth resistivity surveys, and shallow drilling for temperature and chemical data. The shallow drilling includes 17 500-foot test holes and several dozen 100-foot test holes. One of the most active programs has been a research study conducted by the University of California at Riverside since 1968 which has resulted in the outlining of several geothermal hot spots or prospects including those at Brawley, Heber, Glamis, Dunes, and East Mesa. These geophysical surveys and shallow drillings were conducted mainly on private lands and on existing rights-of-way and no adverse environmental impact has been reported.

It is expected that future exploratory work will concentrate on delineating geothermal prospects by deep drilling. Geologic mapping, sampling of natural springs and wells, and additional geophysical work will continue until the commercial prospects are well defined, but these activities will use existing access routes, and thus the adverse environmental impact from them should be negligible.

Test Drilling and Production Testing

This stage of development has also been underway for many years in the Imperial Valley, with most of such activity in the geothermal area southwest of Niland bordering on the Salton Sea.

SURFACE EFFECTS

Grading of roads and well sites, and construction of ponds to contain hot water produced from wells are the principal surface effects. In general this has not had a severe impact in the Imperial Valley because the land is generally level and little grading is required. Likewise sediment production is a negligible factor because of minimal grading and the arid climate.

WATER RESOURCES

The impact on water resources of geothermal drilling and production testing to date has been modest. One geothermal brine well drilled in 1962 discharged very saline brines to the Salton Sea for a period of 90 days. During this test 250,000 tons of salt were contributed to Salton Sea, which represented an increase of 4.5 percent in the dissolved mineral contribution for that year. Subsequently, the California State Water Quality Board passed a resolution prohibiting discharge of geothermal waste to any channel leading to Salton Sea. The current State water-quality standards provide that effluents discharged toward the New and Alamo Rivers may not average more than 4,000 mg/1 (approximately equal parts per million) and may not exceed 4,500 mg/1 at any time. The comparable temperature standard prohibits raising the river temperature more than 2^{o} F. These regulations effectively prohibit surface discharge of geothermal waters in the area.

Little water is used during drilling, and is mainly required for drilling mud and cleanup around the drilling rigs. Such water is commonly obtained from nearby canals or similar water sources. Drilling in the Imperial Valley is conducted with mud to the full depth of the hole.

The extremely saline character of the geothermal brines in Imperial Valley, including even the more dilute geothermal waters which approximate the concentration of sea water, poses a standing threat to contamination of local ground waters and to the Salton Sea. In most of the agricultural area of the Imperial Valley, the native ground water is too saline for irrigation or human use, so this hazard is somewhat reduced. Nonetheless, it is essential that highly saline geothermal waters not be released to the surface or to shallow ground water, because the entire area already suffers from an excess of salinity, and can ill afford additional contributions.

The present prospects for geothermal development entail disposal of waste by reinjection to the producing zone or by evaporation from surface ponds. Experimental reinjection of brines into the producing zone in the Niland area has shown promising results over a period of as long as 1 year; however, attempts at reinjection into a shallow zone at a depth of about 1,500 feet resulted in plugging of the injection well in a very short period. During a 1-year test, brine produced from a well 8,100 feet deep at a rate of about 640,000 gallons per day was used in a pilot plant, and the residual saline water was reinjected into a nearby well 6,118 feet deep. Except for initially overcoming a well-head pressure of about 200 psi, flow into the reinjection well was under gravity. During the year 190 million gallons of brine was produced, of which 126 million gallons was reinjected, the difference representing evaporation.

Evaporation from surface ponds is feasible for disposing of limited volumes of waste water produced during short tests, but would not be feasible for disposing of waste water under full-scale production because of the land requirement. For example, to evaporate 126 million gallons of fresh water at evaporation rate of 6 feet per year would require a 65-acre pond. Evaporation of brines would require an even greater acreage.

Well drilling and completion practice in the Imperial Valley area is deemed adequate for protection of superficial waters from contamination by geothermal waters. Typically, a 20-inch conductor casing is seated at about 50 feet depth in a 24-inch hole with the annular space cemented to land surface; inside that is a 16-inch surface casing in an 18-inch hole to about 1,200 feet, also cemented to land surface; within that is an 8-1/2-inch production casing in a 10-inch hole to the producing zone depth, also cemented to land surface; and below that is set a 100 to 200 foot section of perforated liner that admits the hot water to the well. Multiple casing with cement filling in each annular space should assure against subsurface corrosion by geothermal brines for many years, but if a decision is taken to abandon a test well, it will be filled with cement to a sufficient depth to prevent upward movement of brines to superficial ground-water bodies.

AIR

Noise

Geothermal well drilling in the Imperial Valley area is accomplished with mud circulating systems. Thus, the noise from the drilling operations falls within acceptable industrial noise levels. In close proximity to high population-intensity areas, this noise may be objectional and special acoustical shields may be required on the drill rigs. Drilling operations generally last about 30 to 45 days for each well, thereby limiting the duration of the noise source. Production testing of wells, in which 20 to 25 percent of the fluids flash to steam, generally does not exceed 90 days. Ejection of the steam fraction through appropriate muffling devices can reduce the noise of a testing well to tolerable levels. After testing, the wells are capped and no longer are a source of noise.

Gaseous emissions

Only during the production testing of a well will steam be ejected to the atmosphere. This steam contains essentially water and carbon dioxide with minor amounts of hydrogen sulfide, oxygen, and nitrogen and a trace of carbon monoxide and hydrocarbons. The concentrations of noxious gases are small and are not considered harmful. As testing of the wells lasts for only relatively short periods of time, the total quantity of gaseous material emitted to the atmosphere is small.

Vegetation

Construction of access roads and well sites will destroy some of the native plant life in the desert areas. As this plant material does not support livestock, the loss will be mainly in the form of reduction of wildlife habitat and browse. Because of the desert conditions, reseeding of well sites is not practical, although in time, native vegetation will return.

The hot saline fluids produced during well testing are contained in ponds adjacent to the wells. These ponds are regraded after testing, but the lack of rainfall and difficult reseeding conditions all but preclude the rapid reclamation of the ponds. In time, native vegetation can be expected to return.

FISH AND WILDLIFE

Test drilling and production testing of geothermal steam resources in the Imperial Valley would have varied impacts upon fish and wildlife, which are only partially understood. Most would occur on or adjacent to well sites, although water-quality impacts could potentially have farther-reaching influences. The magnitude of particular impacts would be interrelated with fish and wildlife and their habitat within the area of development influences, extensiveness and duration of the entire geothermal development activities and operations, and the effectiveness of control measures. Many of the impact types lend themselves to whole or partial control, and the proposed leasing and operating regulations provide a regulatory framework by which such control could be achieved.

As a specific geothermal development would proceed through test drilling and production testing, physical land modification and commotion would occur. These activities would include such things as construction of roads, ponds, and drill sites and drilling of wells, and would result in loss of wildlife values, including both habitat and human use within the area of influence. The modification would physically alter or remove existing wildlife habitat and the permanence of these effects would be dependent upon the nature of the particular construction or operational activity and the completeness of control measures. In addition to land modification, the commotion would have displacement effects upon animals and birds in the site vicinity. The degree and permanence of displacement or disturbance would depend upon the scope and type of activity. For example, although the effect on wildlife is not clearly understood or predictable, noise from testing wells would have a disturbing influence upon animals within the site vicinity.

Most areas adjacent to drilling and test operations, but outside of the immediate zones of physical modification, would retain part or all of their fish and wildlife populations and habitat. Where existing public access would be restricted in order to reduce hazards to the public, there would be an accompanying reduction of hunting, angling, and camping opportunity on these lands. The importance of these losses would depend upon the capacity of other available habitat areas to absorb the pressures which are presently absorbed by the geothermal area.

The major potential impacts upon fish and wildlife would result from improperly planned or executed handling of geothermal brines. If controlled releases, spills, seepage or well blowouts were to result in significant additions of highly saline geothermal waters to drainages, ponds, game management areas, or the Salton Sea, adverse impacts would result. These impacts would include alteration of fishery habitat and waterfowl nesting and feeding areas within the area of influence. If toxic substances, such as boron, arsenic, cadmium, fluoride, selenium, or zinc were present in such releases, they also would exert adverse impacts. Releases of heated effluents to aquatic habitat would alter aquatic habitat and life, perhaps creating temperatures intolerable to existing fish species and stimulating growths of nuisance algaes. However, the probability of these potential problems occurring at or near any given well site appears to be small, since the proposed geothermal regulations would require controls, including reinjection of problematical brine wastes, to avoid surface water degradation.

Reinjection of geothermal fluids also possesses the potential for adverse impacts upon fish and wildlife. For example the present major source of water for the Salton Sea is surface and subsurface irrigation waste water. If significant additions of highly saline geothermal waters were to occur to the sea as a result of improperly planned reinjection techniques, the additions would contribute to degradation of the existing marginal water quality.

Should a development involve construction of salt recovery ponds, the ponds could have hazardous or beneficial impacts upon fish and wildlife resources, depending upon local circumstances. If the produced water was of acceptable salinity and free of toxic concentrations of pollutants and disease-producing elements, benefits could be significant in the form of increases aquatic habitat and nesting and feeding areas for waterfowl and marsh birds. However, water above 36,000 ppm dissolved solids would not benefit waterfowl, and some problems with waterfowl using waste-water disposal pond water exhibiting toxic concentrations of trace elements can be foreseen.

A significant portion of visitor and part-time residence use of the Imperial Valley is directly dependent upon the Salton Sea fishery. Were a degrading effect to occur from geothermal development upon the Salton Sea, resulting in adverse effects upon the fishery, the visitor and part-time residence uses would probably adjust downward, as would sales of gasoline, oil supplies, bait, etc.

AESTHETICS

Scenic values

Test drilling and production testing will have but a temporary impact on scenic values in the area. Drilling rigs are in place for only a short period of time and wells are capped after testing with only the wellhead equipment visible to mark their location. This should not have a deleterious affect on scenic values.

Archeologic and historic values

The Salton Volcanic Domes located along the southeastern shore of the Salton Sea have been assigned a high priority for consideration under the National Registry of Natural Landmarks. These domes occur along a 4-mile buried extension of the San Andreas Fault. Mudpots and steam geysers are associated with the domes and geothermal testing may be contemplated close to them. Test drilling should be conducted far enough away to preserve the integrity of these interesting and significant features.

There are no known archeologic or historic sites within the area. In the event any sites are located during any phase of development, these sites should be preserved and the proper agency notified of their existence. Considering the small acreage of land involved in the drilling of a well, it is highly unlikely that any archeologic or historic site would be disturbed either by drilling operations or the proximity of geothermal wells.

Recreation

The development of geothermal resources should have no adverse influence on boating, fishing, water skiing, hunting, camping and picnicking activities associated with the Salton Sea area. The sand dunes along the eastern edge of the area attract motorcycle and off-the-road vehicle enthusiasts. Access roads to wells in this area should provide additional routes into the sand dune area. Since part of the sand dunes area is proposed as a natural area, the improved access to the area would contribute to the problem of management of the natural area. It may be necessary to fence well-head equipment and ponds to prevent potential injury to people and damage to well equipment and off-the-road vehicles in certain areas. Rock hunting is another recreational activity in certain parts of the area and well-access roads may open new collecting areas.

MISHAPS

The principal unforeseeable environmental impacts which may be encountered in drilling and production testing in the Imperial Valley area are uncontrolled flows of fluid during drilling. In any exploratory drilling in an untested area there is a hazard of such flows of steam, water, or gases, such as carbon dioxide or hydrocarbons. The proposed operating regulations for drilling on Federal leases provide safeguards for control of such accidental flows, in the form of strict casing and completion requirements and installation of blow-out preventers. Similar requirements apply to other geothermal drilling under State of California regulations.

Uncontrolled flows are not considered a severe hazard in the Imperial Valley on the basis of past experience in the area. The producing zone of the Niland area, for example, is under such low pressure that the wells must be mechanically stimulated to induce flow; the head in the producing zone is essentially hydrostatic, and natural lift is provided by expansion of steam in the fluid column once flow has been started. In extensive drilling conducted over many years for petroleum and other resources, high-pressure zones have not been encountered and blowouts have not been a problem, with the exception of a single blowout during the early exploratory drilling at Cerro Prieto, Mexico.

The other principal unforeseen impact might be through accidental release of saline brines, for example, through failure of levees enclosing a brine storage pond or through pipeline leakage. These possibilities are continuing hazards, but can be minimized through careful supervision and maintenance. Because the interval between land surface and the geothermal producing zone at 5,000 feet or more is occupied by laterally continuous strata including substantial thicknesses of marine sediments, the production of brines is not expected to have a direct effect on production of shallow wells or springs with the possible exception of thermal springs, which might be expected to react at some time with a reduction in yield or perhaps a change in chemical character.

Field Development, Power-Plant and Power-Line Construction, Energy Generation, and By-Product Facility

While geothermal drilling and testing in the Imperial Valley area are not expected to have severe environmental impact, full scale development undoubtedly will pose problems that will have to be solved before a major development can be undertaken. The problem of handling and disposing of large volumes of hot brines is probably the key to development in the area. Only a modest proportion of the hot water produced flashes into steam, on the order of 25 percent, and the remaining water must be disposed of. If it can be demonstrated that reinjection of the brines into the producing zone is technically and economically feasible, this would go a long way toward solving several environmental problems. It would solve the problem of waste disposal, and also would reduce the hazards from land subsidence and possibly from earthquakes.

SURFACE

In the Imperial Valley area, increased impact from full-scale development would result from drilling of numerous wells, construction of pipelines from the wells to points of use, construction of power plants and transmission lines, and by-product extraction plants, and facilities for storage and re-injection of spent brines.

The engineering problem of heat loss from the fluid in transit would be similar to that at The Geysers field, which requires small power plants close to the wells with insulated surface piping. The geothermal development at nearby Cerro Prieto, Mexico, can serve as a model of the type of power plant development to be expected in the Imperial Valley area, as the occurrence of the geothermal resources is similar in the two areas. At Cerro Prieto some 15 producing wells distributed over an area of about 1 square mile supply steam to a 75-Mw plant at a maximum distance of 1 mile. The fluid produced by the wells consists of about 25 percent steam and 75 percent water. A centrifugal separator at each well separates the fluids, and the steam is conducted to the power plant in 12- to 34-inch insulated, above ground pipelines. Except for the feature of water separation the operation is similar in scale and methodology to any one of the plants at The Geysers field described in Appendix C. At Cerro Prieto the waste water is disposed of by surface discharge, which would not be permitted in The Geysers area or Imperial Valley.

Assuming a similar pattern of development in Imperial Valley to that of The Geysers and Cerro Prieto, several centers of power generation will probably be developed, each with a power plant and network of radiating pipelines to wells. In addition a pipeline system would be required to collect waste water from the producing wells and to convey it to reinjection wells located strategically throughout the field. Such surface modification would not be incompatible with present land use in the irrigated part of the area. In the desert area east of the irrigated area, it would represent a decided change.

WATER RESOURCES

Under full-scale development of electric power and by-product production, the potential impact of water resources would be in proportion to the scale of activity. As in the earlier exploration phase, the principal hazard would be from accidental release of saline geothermal fluids to the surface waters or shallow ground waters. Under the proposed operating regulations of the Department of the Interior and comparable regulations of the State of California that apply on non-Federal lands, the hazards from leaky well casings and blowouts would be minimal. A more likely risk is from accidental releases from waste-water pipelines, from brine-storage ponds, and from by-product processing plants. Minor leakage would not pose a serious threat to water resources because in most of the area the ground water is too saline for many uses, but if large leakage continued for long periods the saline waters would eventually discharge to surface streams and thence to the Salton Sea. It was noted earlier that any additional salt load would be undesirable because the present load is already a threat to the fishing and recreational resources of Salton Sea. The best insurance against this threat is careful supervision of the geothermal development as contemplated in the proposed leasing and operating regulations for Federal lands.

AIR

Noise

During field development, there will be some noise associated with well drilling, but as described earlier, this is of relatively low level and for short duration. Wells are capped after initial testing so noise from this source should be isolated and, with the use of mufflers, of a low intensity level. The construction of power plants and by-product facilities will have noise associated with typical building activity until the facilities are completed. Operating noise for both power plant and by-product plant can be contained within the structures through the use of acoustical building materials. Some noise may be associated with the operation of cooling towers but this will be noticeable only in the immediate vicinity of the towers.

The potential for loud noise exists if steam lines or wells should corrode and break. A well-planned preventive maintenance program can substantially reduce the chance of such occurrences.

Gaseous emissions

Noncondensible gases including carbon dioxide, hydrogen sulfide, oxygen, and trace amounts of carbon monoxide and hydrocarbons will be extracted from the steam prior to entry into the generating plant. The bulk of the noncondensible gas is carbon dioxide and release of the gases to the atmosphere should cause no pollution problems. Each well must, however, be analyzed for gas content, and varying field conditions may result in a change in gas concentration. If noxious gases increase, some form of disposal other than atmospheric venting may be required to meet air-quality standards.

Water vapor will also be vented from the cooling towers but will not be a source of pollution or cause any meteorological changes in the area.

Various gases may be generated in a by-product recovery plant. Discharge of such gases to the atmosphere must be in compliance with air-quality standards.

Condenser steam

Input steam, after passing through the turbines, is condensed to the liquid stage and is sent to the cooling towers to reduce the temperature. This condensed steam will contain metal ions and other contaminants which if present in high concentration, will be detrimental to plant and animal life. Excess cooling-tower water and flushing water must be reinjected into the producing formations or ponded for evaporation rather than discharged to the surface drainage system. Waste liquids from the by-product plant will also be reinjected into the producing formations rather than discharged to surface drains. Care must be exercised in combining various waste products as resultant chemical reactions may lead to the reduction of pore spaces surrounding the injection well and reduction of intake capacity.

VEGETATION

Because of the scarcity of local native vegetation, the construction of power and by-product facilities and the development of a geothermal field should have little impact on existing plant life. If fresh water is a by-product, a portion will undoubtedly be used in the vicinity of the plants to support imported or local vegetation used for landscaping purposes.

FISH AND WILDLIFE

Full development of a geothermal field, as with drilling and production testing, would have varied impacts upon fish and wildlife. Most of the impacts would occur on or adjacent to construction and plant sites. Many of the impacts lend themselves to whole or partial control, and the proposed operating regulations provide a regulatory framework by which such control could be achieved.

The most significant potential impacts upon fish and wildlife would result from handling of geothermal brines. For further details, the reader is referred to the fish and wildlife discussion under Test Drilling and Production Testing.

As a geothermal field would proceed through construction and operation stages of the power plant, pipelines, transmission lines, and any by-product facilities, the loss of wildlife values which began in the test drilling and production testing stages would continue within the immediate area of influence. These losses would include both wildlife habitat and its use.

Where existing public access would be restricted in order to reduce hazards to the public, there would be an accompanying reduction of hunting, and recreational opportunity on these lands. The importance of these losses would depend upon the capacity of other available habitat areas to absorb the pressures which are presently absorbed by the geothermal area.

Transmission lines located in flyways or over nesting and feeding sites would cause some mortality of waterfowl, raptors, and other birds from collision and/or electrocution. The magnitude of this type of loss cannot be predicted but would be expected to be minor.

AESTHETICS

General

The flat topography and the scarcity of native vegetation will allow the power plant, power lines, steam lines, and by-product facilities to be visible for some distance, particularly from higher vantage points surrounding the valley. If fresh water is available for irrigation at the plant sites, vegetative screenings can be used to reduce the visual impact of the buildings. There should be few steam plumes to indicate the presence of wells or pipelines although vapor from the cooling towers may be visible. The use of aesthetically pleasing transmission towers can reduce the impact of these lines on local scenic values. Geothermal power development will probably not be visible from most of the surface of the Salton Sea and will not detract from the scenic enjoyment of boaters and other water recreation participants. Development in the sand-hills area may have an impact on the recreational use of this area by off-the-road motor vehicle enthusiasts. Although the general desolate nature of the sand hills will be disrupted in the vicinity of the geothermal production, access roads may serve to open additional acreage to this type of recreation, which would contribute to recreation management problems. Aside from the Salton Sea and the sandhills area, there are few highly popular scenic areas within the Imperial Valley area. Geothermal power development should have little impact on the irrigated agricultural portion of the valley or on the local population.

Archeological and historical values

No change is expected from that described earlier.

SOCIAL EFFECTS

Economic

The development of geothermal power-generating facilities can be expected to contribute to tax monies to both the State and county governments. These taxes would be the same order of magnitude per unit of power output as those in The Geysers area. The construction of a companion by-product recovery plant would also be a source of local and State tax revenue. Although the quantity of by-product revenue is variable, it would be comparable to other brine processing facilities. Royalties and rentals will be paid on Federal lease land as well as to private land owners if development takes place on their land. Royalties and rentals are subject to negotiation on private lands. The royalties and rentals are fixed on Federal lands except for bonus sales. Local spending by temporary construction workers and drilling crews may contribute in a small measure to the local economy. It is not expected that permanent employment or employee spending will be great or will have much impact on the local economy, because of the small number of employees required for full-scale power production or by-product recovery.

Population distribution

No permanent change in population size or distribution is expected as a result of geothermal developments in the area. Drilling crews and construction workers are transient and temporary housing is available for this small number of employees. Power-generating facilities and by-product recovery plants will require only a limited number of employees who can readily be integrated into existing housing.

Transportation

Only minimal increased traffic can be expected as a result of geothermal related activities in the area. By-product shipment to various market areas will probably be by rail and an increase in rail traffic may result. A modest increase in truck traffic can also be anticipated. Movement of vehicles over untreated access roads can result in the generation of considerable dust. Some form of treatment will be necessary to reduce the impact of this dust on the surrounding environment. Hydrocarbon treatment, chemical treatment, or paving of the roads can solve this problem.

Modification of land uses

No significant modifications of land-use patterns are expected as a result of geothermal power generation or by-product recovery. Much of the Federal land within the area is not used at the present time, except for scattered recreational uses, and livestock and wildlife grazing. Minor changes in recreation vehicle use in the sand-hills area may occur as a result of geothermal development, although in most cases these two uses will not be incompatible. However, off-road vehicular use could be significantly restricted by surface steam lines. Agricultural or recreational usage on private land will not be affected by development on Federal lands.

By-product industries

The recovery of by-products from the hot saline brines is the only industry which geothermal development will support in addition to power generation. Pilot-plant testing of a recovery facility did not prove economically feasible in the recent past, but a change in the market situation or improvements in technology may well alter this situation in the future. There is also the possibility of recovering fresh water along with other by-products in the brine, but this development also awaits feasible, economic methodology.

MISHAPS

The potential for impact of blowouts and accidental spills of geothermal brines is discussed earlier under Water Resources (p.E11). Other than these, the principal unplanned environmental impacts which may occur in the Imperial Valley area are land subsidence and the possibility of inducing seismic activity.

One of the potential hazards of ground-water development in Imperial Valley, either for geothermal power or for water supply, is the threat of land subsidence. Whenever fluids are extracted from a ground-water reservoir--that is, withdrawals exceed the recharge rate and the reservoir pressures continue to decline--land subsidence may occur. Throughout much of the developed area of the Imperial Valley, subsidence would cause costly damages, mainly through change of grade of irrigation canals and drain ditches. In outlying undeveloped areas subsidence might be tolerated. In either setting, the likelihood of subsidence resulting from the extraction of reservoir fluids must be fully considered, and the hydrogeologic parameters affecting the magnitude, extent, and rate of subsidence should be understood. Subsidence results from the compaction of compressible beds of the aquifer system as effective stresses are increased by fluid-pressure reduction. The magnitude of this subsidence is dependent on the effective stress increase caused by the pressure drop, the compressibility of the deposits, the thickness of the compressible beds, the time the increased stress has been applied, and also on the past stress history--whether the increased stress is being applied for the first time or has been attained or exceeded previously. Although a small part of the subsidence may be elastic in nature and tend to rebound when the stress is removed, most of the change is nonelastic and nonrecoverable. In a confined aquifer system, the effective stress is increased 1 foot (0.43 psi) for each 1 foot of artesian-pressure decline.

Land subsidence caused by the exploitation of oil and gas resources and intensive pumping of ground water is relatively common throughout the world. Recently subsidence has been related to the extraction of geothermal waters at Wairakei, New Zealand, and Cerro Prieto, Mexico. Although the geologic setting of these locations differs considerably, the basic cause of subsidence is the same, the reduction of fluid pressure causing a marked increase in effective stress. At Wairakei, the area affected by subsidence exceeds 25 square miles and the maximum subsidence rate is about 1.3 feet per year. Total subsidence exceeds 10 feet, and, of particular significance, the area of maximum subsidence occurs outside the producing area. Differential subsidence of such magnitude would be intolerable in the irrigated area of Imperial Valley, where irrigation canals and drains have slopes on the order of 5 feet per mile or less. At Cerro Prieto, subsidence has been measured 7 miles outside the well field even before the beginning of extensive production. It is reported that the subsidence there is as much as 7 inches to date. Corresponding effects could be expected to occur in Imperial Valley, unless provisions are made to maintain reservoir pressures. As in oil-field or artesian ground-water production a direct relation exists between subsidence and fluid-pressure decline in a geothermal field. Subsidence can be minimized or prevented by maintaining fluid pressures by either natural or artificial recharge.

Most of the parameters for predicting subsidence in Imperial Valley, such as anticipated pressure decline, thickness and compressibility of the water-bearing deposits, and lateral extent of fault blocks are not well known. Subsidence probably will occur if geothermal waters are extracted for an extended period. Both fluid pressures and surface benchmarks should be carefully monitored to determine production effects. Also, because Imperial Valley is tectonically active and reportedly is subsiding naturally at a rate of about 1 foot per century, provisions should be made in the monitoring program to differentiate tectonic subsidence from that caused by geothermal development. Such a monitoring effort is contemplated by the Division of Oil and Gas, State of California, which has established a subsidence detection program for the

Imperial Valley. An interagency group was convened in June 1971 and plans have been made to establish a network of surface benchmarks and repetitive surface leveling.

Another potential environmental impact that must be given serious consideration in the Imperial Valley area is increased seismicity induced by geothermal development. Imperial Valley is traversed by several major active faults and is known to be one of the most seismically active areas in North America. Earthquakes are commonplace events, and major earthquakes of Richter scale magnitude of 7 or greater occur every few years.

Experience in other areas indicates that increased seismic activity, in the form of swarms of micro-earthquakes, has occurred in several areas as a result of fluid injection into confined systems. Similarly, heavy production of fluids from confined systems, which causes land subsidence, has also been related to tectonic activity, such as displacement on fault surfaces as the confined system readjusts to changing stress.

In view of the natural seismicity of the Imperial Valley area it would be only prudent to consider the possible effects of pressure changes due to both production and/or reinjection on the seismic regime. Experience with this problem is recent and widely scattered, therefore it is impossible at this time even to predict what might happen in Imperial Valley under various planning assumptions. A prudent course would be to establish a detailed seismic monitoring program before major production begins; if this indicates significant increase in seismic activity, particularly in intensity of motion, remedial steps to alleviate stress should be undertaken promptly.

ADVERSE IMPACTS WHICH CANNOT BE AVOIDED

Land use would be changed from irrigated agriculture to power and by-product production in small areas of private lands. In the desert portion of the area, mainly Federal land, the change would be from undeveloped land to industrial sites.

Some level of noise is unavoidable during drilling and testing of wells, but noise is at a low level under production.

Some noxious emissions are unavoidable, but can be kept at a level harmless to biota and people.

Some leakage in handling of saline brines is unavoidable, but this can be minimized with careful maintenance.

Physical land modification and disturbance effects would involve a loss of wildlife values in the immediate area of a development.

Reduction of hunting and recreational opportunity would occur where existing access would be restricted to protect geothermal facilities and reduce hazards to the public.

Transmission lines would result in some mortality of waterfowl, raptors, and other birds from aerial collision and/or electrocution.

Production of large volumes of geothermal water can lead to land subsidence if formation pressures are permitted to decrease significantly: however, this effect can be minimized with a properly designed program of pressure maintenance.

Large changes in reservoir pressure might induce increased seismicity in naturally active areas. This can be minimized by careful seismic monitoring combined with prompt remedial action if an increase occurs.

ALTERNATIVES TO PROPOSED ACTION

With respect to any given leasing action, the alternatives to issuance of a lease under the regulations (Appendixes A and B) are:

(1) Postponement of leasing pending further study of the environmental impact. (See discussion under Alternatives in General Statement.)

(2) The Secretary could decline to issue any leases to develop Federally owned geothermal resources. (See discussion under Alternatives in General Statement.)

THE RELATIONSHIP BETWEEN LOCAL SHORT-TERM USES OF MAN'S ENVIRONMENT AND MAINTENANCE AND ENHANCEMENT OF LONG-TERM PRODUCTIVITY

Leasing of lands for geothermal resources development would inescapably involve commitment of a portion of the geothermal, water, and land resources of the areas involved. The extent of these commitments and an assessment of their environmental impacts have been described in the preceding sections. However, the relationships between these proposed uses of the environment and the maintenance and enhancement of its long-term productivity must be examined.

The Resource

By developing geothermal resources it will be possible to tap a previously unused source of energy to meet growing energy needs, especially for electric power. At present, geothermal energy largely wastes to the atmosphere, and no alternative use other than extraction of heat is known or foreseen. The development of this natural source of energy for beneficial use, therefore, appears highly desirable.

Although geothermal development is expected to supplement rather than supplant other forms of electrical generation, geothermal energy generation, in most cases, would replace equivalent electrical generation by fossil fuel or nuclear plants, which consume valuable natural resources and generally have greater adverse environmental impacts.

Production of chemicals and fresh water as by-products of geothermal energy production would represent additions to these resources not presently available, and thus would also be beneficial.

Water

Consumption of water resources by power plants and by-product facilities would constitute a depletion of gross water resources available to the area. However, the geothermal fluids that would furnish the input water to such plants is saline water not presently used for other purposes. To the degree that such fluid withdrawn from the subsurface reservoir is not replenished by reinjection or natural recharge, the water consumed would represent a depletion of water in storage.

Given the controls envisioned for waste disposal, degradation of surface and fresh ground waters is not expected to be significant.

Land

Land uses on Federal leases would be changed from desert wildlife habitat and recreational use to industrial use in the vicinity of wells, pipelines, power plants and by-product facilities and power lines. Public access in the vicinity of such industrial facilities would be restricted as a safety measure.

If geothermal production results in land subsidence, this being an irreversible process, it would represent a long-term effect on the land resources. Such subsidence in Imperial Valley, would not significantly affect any use of the environment except as it affects irrigation and drainage works, and possibly power plants, through change in slope. Such changes represent a serious short-term impact on engineering structures, but can be accomodated for by engineering modifications, mainly realignment and reconstruction of the affected structures.

Fish and Wildlife

Geothermal resource development would have certain localized and regional adverse impact on fish and wildlife in the form of loss of wildlife habitat in the immediate vicinity of installations, loss of birds from collision with and/or electrocution on power lines, and possible danger to fish through accidental spills of toxic fluids. In addition restricting of public access would reduce hunting and related recreational opportunities in the vicinity of installations.

Economic and Social

Geothermal development requires substantial investment in drilling wells, and construction of roads, pipelines, power and by-product plants, and transmission lines. Such investments result in an increased tax base for the area of development. However, the labor-intensive phase is short-term, during field development, and would not result in significant changes in population distribution.

IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

Full development of the geothermal resources of the Imperial Valley would encompass extraction of thermal energy, dissolved mineral matter, and fresh water from thermal brines. The thermal energy stored in the brines presumably would be extracted at a rate greater than the natural terrestrial heat flow, thus power development would be based upon utilization of heat stored in the subsurface rocks and fluids over a long period of time. Although the terrestrial heat source will continue indefinitely, the use of the stored energy should be considered as a depletion of the thermal resource over the short term. The dissolved mineral matter is not believed to be renewable and should be classed as a depletion of that resource if it is utilized.

The mechanism of recharge to the geothermal reservoirs of the Imperial Valley is poorly understood, but is presumed to be from rainfall on the drainage basins tributary to the Imperial Valley. Thus, water evaporated in geothermal production should be considered as a water consumption chargeable to the area. However, as water is a renewable resource, this charge is not irretrievable.

Compaction that may occur as a result of pressure decline is an irreversible process. Loss of porosity is a commitment of a resource because this is the storage volume for the heat conducting fluid. The magnitude of this effect may be important in this area.

The capital and labor required for the geothermal development represent an irretrievable commitment of those resources, because installations would have little salvage value when the geothermal resources are exhausted.

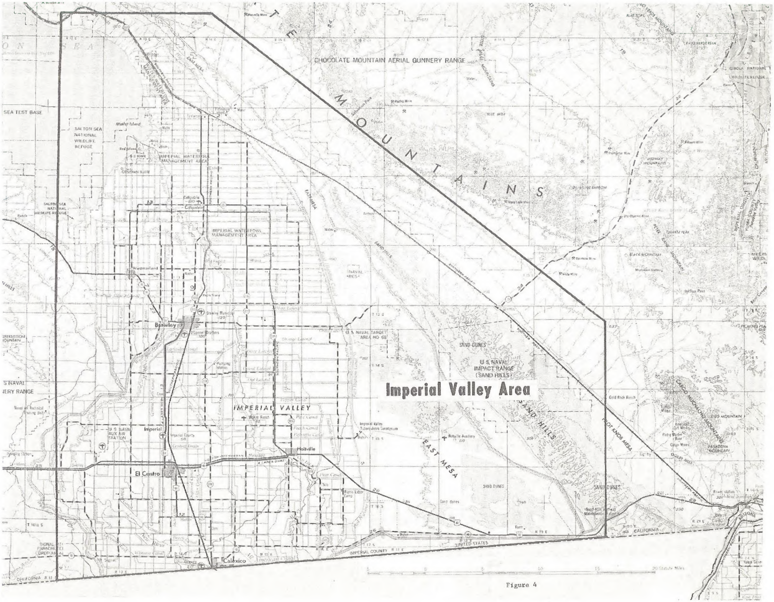

Imperial Valley Area
CHOCOLATE MOUNTAIN AERIAL GUNNERY RANGE
SALTON SEA NATIONAL WILDLIFE REFUGE
IMPERIAL WATERFOWL MANAGEMENT AREA
IMPERIAL VALLEY
Westmorland
Brawley
Imperial
El Centro
Holtville
Calexico
U.S. NAVAL TARGET AREA NO. 68
SAND DUNES
U.S. NAVAL IMPACT RANGE (SAND HILLS)
SAND HILLS
EAST MESA
PILOT KNOB MESA
CALIFORNIA
UNITED STATES
IMPERIAL COUNTY

Figure 4

Appendix F

Vapor Dominated Hydrothermal Systems

Compared with Hot-Water Systems

by

D. E. White, L. J. P. Muffler, and A. H. Truesdell

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Vapor-Dominated Hydrothermal Systems Compared with Hot-Water Systems[1]

D. E. WHITE, L. J. P. MUFFLER, AND A. H. TRUESDELL

Abstract

Vapor-dominated ("dry-steam") geothermal systems are uncommon and poorly understood compared with hot-water systems. Critical physical data on both types were obtained from U. S. Geological Survey research in Yellowstone Park. Vapor-dominated systems require relatively potent heat supplies and low initial permeability. After an early hot-water stage, a system becomes vapor dominated when net discharge starts to exceed recharge. Steam then boils from a declining water table; some steam escapes to the atmosphere, but most condenses below the surface, where its heat of vaporization can be conducted upward. The main vapor-dominated reservoir actually is a two-phase heat-transfer system. Vapor boiled from the deep (brine?) water table flows upward; most liquid condensate flows down to the water table, but some may be swept out with steam in channels of principal upflow. Liquid water favors small pores and channels because of its high surface tension relative to that of steam. Steam is largely excluded from smaller spaces but greatly dominates the larger channels and discharge from wells. With time, permeability of water-recharge channels, initially low, becomes still lower because of deposition of carbonates and $CaSO_4$, which decrease in solubility with temperature. The "lid" on the system consists in part of argillized rocks and CO_2-saturated condensate.

Our model of vapor-dominated systems and the thermodynamic properties of steam provide the keys for understanding why the major reservoirs of The Geysers, California, and Larderello, Italy, have rather uniform reservoir temperatures near 240° C and pressures near 34 kg/cm² (absolute; gases other than H_2O increase the pressures). Local supply of pore liquid and great stored heat of solid phases account for the physical characteristics and the high productivity of steam wells.

We suggest that vapor-dominated systems provide a good mechanism for separating volatile mercury from all other metals of lower volatility. Mercury is likely to be enriched in the vapor of these systems; the zone of condensation that surrounds the uniform reservoir is attractive for precipitating HgS.

A more speculative suggestion is that porphyry copper deposits form below the deep water tables hypothesized for the vapor-dominated systems. Some enigmatic characteristics of these copper deposits are consistent with such a relationship, and warrant consideration and testing.

Introduction

ALTHOUGH hot springs throughout the world have been studied for centuries, direct knowledge of their subsurface relationships was lacking until commercial and research drilling was initiated in the 20th Century. With a few notable exceptions (Allen and Day, 1927; Fenner, 1936) little significant scientific data were available prior to 1950.

Efforts to produce electricity from natural steam were first successful in the Larderello region of Italy, starting about 1904. Drilling from 1920 to 1925 showed that large quantities of natural steam could also be obtained at The Geysers in California, but economic development was not feasible until 1955. At both The Geysers and Larderello, wells deeper than a hundred meters or so[2] and near centers of surface activity were found to yield slightly superheated steam (Burgassi, 1964). Some wells on the borders of the active systems[3] produced hot water

[1] Publication authorized by the Director, U. S. Geological Survey.

[2] The metric system is used throughout this paper. Some readers may find useful the following conversion factors:

Length:	1 m = 3.281 ft; 1 km = 3,281 ft = 0.6214 mi.
Temperature:	(°C × 9/5) + 32 = °F.
Pressure:	1 kg/cm² = 0.9678 atm = 0.9807 bars = 14.22 psi. All pressures absolute, with 0.78 kg/cm² added to gage pressure for Yellowstone Park, and 1.03 kg/cm² added to gage pressure at sea level and geothermal areas at low altitudes.
Heat:	1 cal = 3.9685 × 10^{-3} BTU; 1 cal/gm = 1.80 BTU/lb.

[3] A geothermal system includes a source of heat within the earth's crust (regional heat flow or local igneous intrusion) and the rocks and water affected by that heat. When geothermal systems involve circulating waters, they are also

and steam in noncommercial quantities and pressures (Allen and Day, 1927, p. 82); the characteristics of such wells have not yet been adequately described.

From 1946 to 1970 approximately 100 geothermal systems throughout the world were explored at depth by drilling. Initially, the objective of this search was to discover areas yielding dry steam, as at Larderello and The Geysers. This effort, however, soon revealed that most hot-spring systems yield fluids that are dominated by hot water rather than by steam.

New Zealand first demonstrated that a source of dry steam was not essential for the generation of geothermal power. At Wairakei, subsurface hot water at temperatures up to 260° C is erupted through wells to the surface; some of the water flashes to steam as temperature and pressure decrease to the operating pressure, commonly from 3 to 6 kg/cm^2. This steam, generally 10 to 20 percent of the total mass flow, is separated from the residual water and directed through turbines to generate electricity. The high energy potential of subsurface water has also been demonstrated in Mexico, Iceland, Japan, USSR, El Salvador, the Philippines, and the United States.

A few systems, other than Larderello and The Geysers, yield vapor with little or no associated liquid water. These include the Bagnore and Piancastagnaio fields near Monte Amiata southeast of Larderello (Burgassi, 1964; Cataldi, 1967), and probably the Matsukawa area of northern Honshu, Japan, (Saito, 1964; Hayakawa, 1969; Baba, 1968), the Silica Pit area of Steamboat Springs, Nevada (White, 1968b), and the Mud Volcano area of Yellowstone National Park, considered in this report.

Hot-water systems have attracted nearly all of the research drilling in natural hydrothermal areas. The first two research holes in the world were drilled by the Geophysical Laboratory of the Carnegie Institution of Washington in the hot water systems of Yellowstone Park in 1929–30 (Fenner, 1936), and seven of the eight research holes drilled at Steamboat Springs, Nevada, in 1950–51 (White, 1968b) were in a hot-water system. The eighth was in the small vapor-dominated Silica Pit system, subsidiary to the larger water-dominated area.

Although research drilling by the U. S. Geological Survey in Yellowstone National Park during 1967 and 1968 was aimed mainly at a better understanding of the hot-water systems of the major geyser basins, a specific effort was made to find and drill a vapor-dominated system. The Mud Volcano area was found to be such a system and is described here.

In spite of long and extensive commercial development at Larderello and The Geysers, the origin and nature of the systems that yield dry or superheated steam, and why they differ from the abundant hot-water systems, are not nearly so well understood. Facca and Tonani (1964), for example, seem to deny that Larderello and The Geysers differ significantly from Wairakei, New Zealand, and the other water-dominated areas. Marinelli (1969) states that Larderello is a hot-water area. James (1968) and in less detail Elder (1965) and Craig (1966) have instead proposed that the reservoirs are filled with steam maintained by boiling from a deep water table.

We submit, in agreement with James (1968), that fundamental differences do exist between two main types of natural hydrothermal systems; each type is recognizable by geologic, physical, and geochemical criteria. However, in contrast with James (1968) and others, we consider that steam and water must coexist in the reservoirs of these systems that yield dry steam at the surface.

Acknowledgments

We are much indebted to our associates, R. O. Fournier, John Haas, Warren Nokleberg, and J. T. Nash, for their helpful suggestions and review of this manuscript. Gunnar Bodvarsson has been especially helpful in clarifying the properties of coexisting liquid and vapor and in pointing out important differences in specific resistance to flow of liquid water and steam.

Summary of Characteristics of Hot-water Systems

Hot-water systems are usually found in permeable sedimentary or volcanic rocks and in competent rocks such as granite that can maintain open channels along faults or fractures. Total discharge from typical systems ranges from several hundred to several thousand liters per minute (lpm), with individual springs commonly discharging a few lpm to several hundreds of lpm. Where near-surface rocks are permeable and the surrounding water table is relatively low, much or all of the circulating hot water escapes below the ground surface, and little or none is discharged from local surface springs. For example, nearly 95 percent of the water at Steamboat Springs, Nevada, escapes in such a way (White, 1968b). On the other hand, where spring outlets are at or below the level of the surrounding water table, all hot water of the system is likely to be discharged in local visible springs.

The spring systems that discharge at low to moderate temperatures are commonly similar chemically

called hydrothermal systems. The hot part of each hydrothermal system is commonly emphasized, but in its broader meaning the marginal parts involve convective downflow of cold water, and are also included. A hot spring area is the surface expression of a geothermal system and contains hot springs, fumaroles, and other obvious hydrothermal phenomena.

to nearby ground waters, but the near-boiling hot waters of moderate to high discharge are nearly always characterized by relatively high contents of alkali chlorides, SiO_2, B, and As (table 1, anals. 4, 8, and 10; White and others, 1963, Tables 17 and 18). In confusing contrast, some gassy springs of low discharge may differ greatly from these chloride-rich waters in physical and chemical characteristics. Surrounding ground is commonly bleached and hydrothermally altered to a porous siliceous residue that may be mistaken for hot-spring sinter. The bleached ground may contain native sulfur, white, yellow, and orange sulfate minerals, and clay minerals, especially kaolinite; vegetation is generally sparse or absent. Chemical analyses of such springs (table 1, anal. 9; White and others, 1963, table 20) contrast strikingly with those of higher discharge; chloride is generally less than 20 ppm, sulfate is the dominant anion, pH is usually between 2.5 and 5, and Fe, Al, Ca, and Mg are abundant relative to Na and K.

Where these two contrasting types of springs coexist in the same general area, topographic relationships and results of shallow drilling and augering indicate that the nearly neutral to alkaline chloride springs are from the main water body, occurring where the water table intersects the ground surface. Where the water table is low, acid springs may result from boiling at this water table. Some steam condenses in cooler ground and in pools of rain water, perched ground, and previously condensed steam.

H_2S that evolves with the steam reacts near the surface with atmospheric oxygen to form sulfuric acid, thus accounting for the high sulfate contents and the low pH's characteristic of these waters. Bacterial oxidation of intermediate forms of sulfur may be involved (Schoen and Ehrlich, 1968). The acid dissolves available cations from the surrounding rocks, which are adequate sources for the reported constituents (White and others, 1963, table 20).

The geochemistry of chloride is critical in understanding the differences between the coexisting neutral-chloride and acid-sulfate waters, as well as the differences between vapor-dominated systems and hot-water systems. Most metal chlorides are highly soluble in liquid water, and the low content of Cl in most rocks can be selectively dissolved in water at high temperatures (Ellis and Mahon, 1964, 1967). The common metal chlorides, however, have negligible volatility and solubility in low-pressure steam (Sourirajan and Kennedy, 1962; Krauskopf, 1964). The only chlorides with sufficient volatility to account for significant transfer of Cl in steam at low temperatures and pressures are HCl and NH_4Cl, both of which are minor constituents of most hot-spring systems. The very low Cl content of the perched acid springs associated with some hot-water systems is thus consistent with near-surface attainment of acidity from oxidation of H_2S, rather than by vapor transfer of HCl from initially acid sources.

The temperatures of many explored hot-water systems increase with depth to a "base" temperature (Bodvarsson, 1964a, 1970) that differs with each system that has been drilled deep enough. Temperatures at Wairakei, New Zealand, rise to a maximum of 260° C near 450 m of depth but increase little if any more at further explored depths (Banwell and others, 1957, p. 52–56), and at Steamboat Springs, Nevada, the temperatures in six drill holes were near 170° C at depths close to 100 m, but deeper drilling found no higher temperatures even though major channels were intersected below 150 m (White, 1968b). In such an area, meteoric water (Craig, 1963; White, 1968b) evidently penetrates to considerable depths along permeable channels of a huge convection system; the water is heated to its base temperature by rock conduction, perhaps augmented slightly by magmatic steam. It then rises in the core of the spring system, losing only a little heat because of its relatively high rate of upflow through wallrocks of low thermal conductivity. As the hot water rises the hydrostatic pressure decreases, and eventually a level is attained where pressure is low enough for boiling to begin.

Of about one hundred hot-water systems throughout the world that have now been explored by drilling, fewer than 30 are known to exceed 200° C in temperature and only about 10 demonstrably exceed 250° C. The liquid of the two reservoirs known to exceed 300° C is brine rather than relatively dilute water. The Salton Sea system has about 250,000 ppm of dissolved salts and a maximum temperature of about 360° C (Helgeson, 1968). The Cerro Prieto system, about 90 km to the south in Baja California, Mexico, has a salinity of about 17,000 ppm and temperatures as high as 388° C (Mercado, 1969).

Hot-water systems have a high potential for self-sealing (Bodvarsson, 1964b; Facca and Tonani, 1967) by means of deposition of minerals in outlet channels. SiO_2 is the most important constituent for the self-sealing of high-temperature systems because quartz is so abundant and its solubility increases so much with temperature (Fournier and Rowe, 1966). Quartz dissolves rather rapidly at high temperatures; when quartz-saturated waters are cooled, quartz precipitates rather readily down to about 180° C but with increasing sluggishness at lower temperatures. The SiO_2 content of many waters, after cooling, greatly exceeds the solubility of quartz and may even exceed the solubility of amorphous SiO_2. Near the surface where temperatures are near or below

Table 1.--Chemical analyses of waters associated with vapor-dominated and hot-water geothermal systems

Name	1/ The Geysers	2/ The Geysers	3/ GS-7	4/ Spring 8	5/ Mud Volcano	6/ Mud Volcano	7/ Y-11, Mud Volcano
Location	Calif.	Calif.	Steamboat, Nev.	Steamboat, Nev.	Yellowstone, Wyo.	Yellowstone, Wyo.	Yellowstone, Wyo.
Water type	HCO_3-SO_4	Acid-sulfate	HCO_3-SO_4	Cl-HCO_3	Acid-sulfate	HCO_3-SO_4	HCO_3-SO_4
System type	Vapor-dom.	Vapor-dom.	Vapor-dom.	Hot water	Vapor-dom.	Vapor-dom.	Vapor-dom.
SiO_2	66	225	14	293	540	215	
Al		14		0.5	146		
Fe		63		0.05	17		
Mn		1.4		0.05			
As				2.7			
Ca	58	47	6.3	5.0	14	28.7	28
Mg	108	281	0	0.8	11	16.4	0.47
Na	18	12	9.3	653	16	74.3	105
K	6	5	4.5	71	17	47.5	12.6
Li			0	7.6		.20	.18
NH_4	111	1,400		<1	26	.18	3.2
H		9.5			43		
HCO_3	176	0	21	305		298	258
CO_3	--	--	--	--	--	--	
SO_4	766	5,710	24	100	3,149	65.3	74
Cl	1.5	0.5	0.5	865	Tr.	13.5	9.6
F			0	1.8	1	2.0	
Br				0.2			
NO_3			Tr.	--			0.2
B	15	3.1	1.3	49		.6	0.1
H_2S	0	--	2.4	4.7	0		
Total reported	1,330	7,770	83	2,360	3,980	761.7	491.4
pH	neutral	1.8±	6.5	7.9	Strong acid	7	8.5(?)
Temperature °C	100	Boiling?	161	89.2	65	58.5	131.7

1/ Witches Cauldron, White and others, 1963, p. F47, modified from Allen and Day, 1927.

2/ Devils Kitchen, White and others, 1963, p. F46, modified from Allen and Day, 1927.

3/ White and others, 1963, p. F47. Condensate in apor-filled hole.

4/ . . . Do . . . . p. F40.

5/ Allen and Day, 1935, p. 427; described as "Big Sulphur Pool" 0.3 km N of Mud Volcano; location indicates Old Sulphur Cauldron of fig. 4, 60 m SSW of Y-11 drill hole.

6/ Spring discharging from sinter, E. bank of Yellowstone River 0.5 km SE of Y-11 drill hole; has deposited sinter in recent peat, if not now. Analyzed by Mrs. Roberta Barnes.

7/ Erupted from Y-11 drill hole Sept. 22, 1969 after hole had caved to 28 m depth (table 1); collected by R. O. Fournier, analysis by Mrs. Roberta Barnes. pH not representative of in-hole environment because of CO_2 loss, storage in plastic with clays.

Note: The word apor should read vapor in footnote 3.
Reference to Table 1 in footnote 7 should read Table 4.

100° C, the excess silica in such waters may precipitate as chalcedony, opal, and cristobalite (White and others, 1956). Self-sealing by silica minerals is likely to be slight in hot-water systems that do not exceed 150° C, but as maximum temperatures increase above this value, the potential for self-sealing increases greatly.

Calcite, zeolites, and some other hydrothermal

Table 1.--Chemical analyses of waters associated with vapor-dominated and hot-water geothermal systems (continued)

Name	8/ Norris Basin	9/ Norris Basin	10/ Well 4	11/ Well 5	12/ Cerboli A,	13/ Well MR-1
Location	Yellowstone, Wyo.	Yellowstone, Wyo.	Wairakei, N.Z.	Wairakei, N.Z.	Italy	Matsukawa, Japan
Water type	$Cl(HCO_3)$	Acid sulfate	Cl	HCO_3 SO_4	SO_4 $HCO_3(Cl)$	$SO_4(HCO_3)$
System type	Hot water	Hot water	Hot water	Vapor-dom.(?)	Hot water	Vapor-dom.(?)
SiO_2	529	109	386	191		635
Al		2.4			Trace	29
Fe		0.8			Trace	508
Mn						
As	3.1					
Ca	5.8	2.2	26	12		
Mg	0.2	0	<0.1	1.7	5.0	8.7
Na	439	2.0	1,130	230	56.6	264
K	74	3.0	146	17	32.0	144
Li	8.4		12	1.2		
NH_4	0.1	30	0.9	0.2	19.0	
H		14				
HCO_3	27	--	35	670	89.7	37
CO_3	--	--	0(?)			
SO_4	38	758	35	11	137.4	1,780
Cl	744	15	1,930	2.7	42.6	12
F	4.9		6.2	3.7		
Br	0.1					
NO_3	--					
B	12	6.9	26	0.5	13.9	61.2
H_2S	.0		1.1	0		Trace
Total reported	1,890	943	3,750	1,140	396.2	3,478.9
pH	7.5	1.97	8.6	6.7		4.9
Temperature °C	84.5	90	228±	High	~300	~240

8/ Dr. Moray's Porkchop, 60 m southwest of Pearl Geyser (White and others, 1963, p. F40).

9/ Locomotive Spring, 55 m WSW of Norris Basin drill hole of Fenner (1936); seeping discharge (White and others, 1963, p. F46).

10/ Typical of shallow Wairakei system; 375 m deep with maximum temperature of 245°C (Banwell and others, 1957). Analysis by Wilson; also contains 11 ppm free CO_2 (Wilson, 1955; quoted in White and others, 1963, p. F40).

11/ Western part of Wairakei field (Wilson, 1955, quoted in White and others, 1963, p. F47). Similar to some waters of vapor-dominated systems; 467 m deep, maximum 217°C at 271 m.

12/ Deepest well of hot-water field on So. border Larderello steam fields (Cataldi and others, 1969). Orig. anal. in ppm, supplied by R. Cataldi, 1970.

13/ Well 945 m deep, produced steam, some water for 1 year before drying; this anal. while still wet; condensate of steam 50 ppm H_2S and 6.2 ppm S (Nakamura and Sumi, 1967; Hayakawa, 1969).

minerals are also effective in producing self-sealed margins of some hot-water systems, but generally less so than the silica minerals. Self-sealing is likely to be most extensive where temperatures decrease most rapidly. These marginal parts are of secondary interest for production drilling, and they have not been

Table 2.--Analyses of gases associated with vapor-dominated and hot-water geothermal systems, in volume percent

	Total vapor, including H_2O		Gases, excluding H_2O					
	1/ The Geysers, California	2/ Larderello, Italy	3/ The Geysers, California (1), recalc.	4/ Larderello Italy (2), recalc.	5/ Y-11 Mud Volcano, Yellowstone	6/ Mud Volcano Yellowstone	7/ Y-9, Norris, Yellowstone	8/ Spring Norris Yellowstone
H_2O	98.045	98.08						
CO_2	1.242	1.786	63.5	93.02	98.4	98.90	91.5	97.40
H_2	0.287	-0.037	14.7	} 1.92 (H_2 + CH_4)	<0.01	0.00	0.9	0.00
CH_4	0.299		15.3		Tr.	0.10	0.1	0.20
C_2H_6					0.0		0.0	
N_2	} 0.069 (N_2 + A)	0.0105	} 3.5 (N_2 + A)	0.54	0.8	} 1.00 (N_2 + A)	5.1	} 1.60 (N_2 + A)
A					0.013		0.08	
H_2S	0.033	0.049	1.7	2.55	0	0.10	1.4	0.75
NH_3	0.025	0.033	1.3	1.72				
H_3BO_3	0.0018	0.0075	0.09	0.39				
O_2	———	———	———	———	0.2	0.00	1.0	0.05?
Total	100.002	100.003	100.09	100.14	99.42	100.10	100.08	100.00

1/ Well 1, The Geysers (Allen and Day, 1927, p. 76).

2/ Average vapor from producing wells (Burgassi, 1964), recalculated from analysis in gm per kgm; 2,850,000 kg produced per hour; also contains 1 cm^3 total rare gases per kg.

3/ Recalculated from 1/, without H_2O.

4/ Recalculated from 2/, without H_2O.

5/ Collected July 10, 1968, by R. O. Fournier, when hole was still open to 316 ft (table 3).

6/ Gas from same spring as anal. 5 of table 1 (Allen and Day, 1935, p. 86).

7/ Collected by R. O. Fournier, Sept. 18, 1969, and analyzed by D. Byrd, U.S. Geol. Survey; gas separated from water; nearest drill hole to springs of anal. 8 and 9, table 1.

8/ Gas from unnamed acid-sulfate spring "near Congress Pool," perhaps Locomotive (table 1, anal. 9). Allen and Day, 1935, p. 86, 469.

Note: Reference to Table 3 in footnote 5 should read Table 4.

cored and studied in much detail except in research drilling in Yellowstone Park (unpublished data).

For similar geochemical reasons, most hot-water systems with subsurface temperatures of 180° C or higher (White, 1967a) have hot springs or geysers that deposit sinter (amorphous silica precipitated on the ground surface by flowing hot water). Waters that deposit sinter nearly always have SiO_2 contents of at least 240 ppm, equivalent to a quartz-equilibration temperature of 180° C. Because the solubility of amorphous SiO_2 is so much higher than that of quartz, a quartz-saturated water at 180° C must cool to about 70° C in order to precipitate amorphous silica. If the water becomes sufficiently concentrated in SiO_2 by evaporation, as on the borders of pools and in erupted geyser water, precipitation can occur at somewhat higher temperatures.

The existence of sinter, as distinct from travertine ($CaCO_3$) and siliceous residues from acid leaching, is evidence for a hot-water system with present or past subsurface temperatures of more than 180° C.

Summary of Characteristics of Vapor-dominated ("Dry-steam") Systems

The near-surface rocks of Larderello, Italy, and The Geysers, California, are relatively tight and incompetent, and evidently do not permit large quantities of meteoric water to penetrate deep into their systems (White, 1964). Even in these areas, however, isotopic data indicate that most of the water is of surface origin (Craig and others, 1956; Craig, 1963).

Surface springs at The Geysers[4] typically have

[4] "The Geysers" is an unfortunate misnomer. The area has never had true geysers, which are restricted to the hot-water systems (White, 1967a).

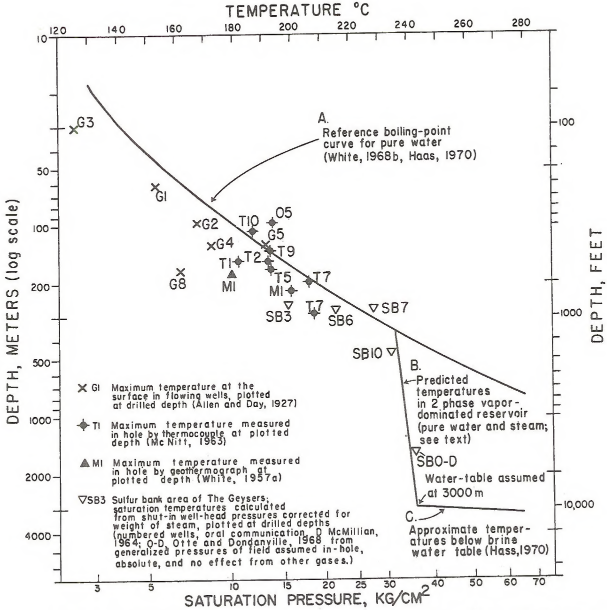

Fig. 1. Measured and calculated temperatures from The Geysers, Calif., with some theoretical curves. The reference boiling-point curve for pure water, curve A, differs in shape from its usual representation because of the logarithmic scale for depth. Note that curves B and C are *temperature-deficient* and *pressure-deficient* relative to curve A.

very low discharge, totaling little more than 100 lpm (Allen and Day, 1927). Most of the springs are strongly acidic (pH from 2 to 3). The few neutral springs (Table 1, anal. 1) have chloride contents of less than 2 ppm, similar to local rain water. A careful search of the creek that flows through the area was made on the chance that undetected chloride springs might be seeping into the creek (White, 1957a, p. 1651). However, throughout an area of at least 30 square miles surrounding The Geysers, the surface and ground waters are no higher in chloride than normal cold streams.

Chloride contents have not been included in reports on natural springs associated with the original vapor-dominated Larderello fields, but available descriptions of spring activity, dominated by mud pots and fumaroles, suggest the presence of sulfate waters low in chloride. However, present springs are not low in pH (R. Cataldi, written commun., 1970), perhaps because of the neutralizing action of abun-

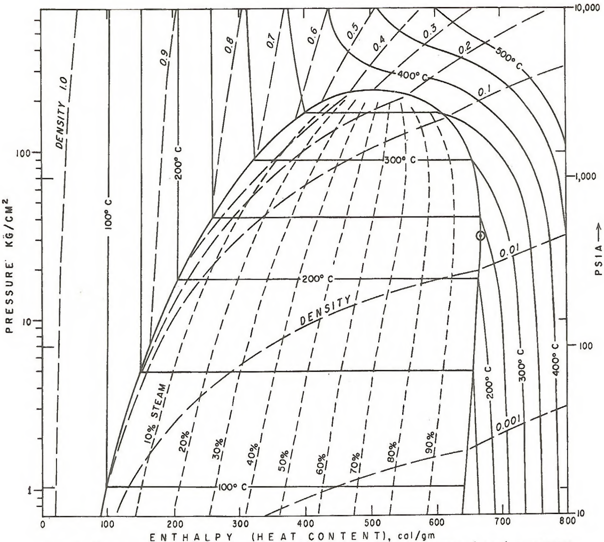

FIG. 2. Pressure-enthalpy diagram for pure water and vapor, showing contours of equal temperature, density, and mass proportions of steam to water (computed from Keenan and Keyes, 1936). Open circle indicates maximum enthalpy of saturated steam, 670 cal/gm at 236° C and 31.8 kg/cm².

dant NH_3 absorbed from the gases. Some springs and wells of the Carboli area just south of the vapor-dominated fields (Cataldi and others, 1969) contain some chloride (42.6 ppm, Table 1). Although this Cl content is not notably high, it is consistent with the abundant water and old travertine which suggest that Carboli is a hot-water system.

In general where surface springs are all low in chloride and subsurface thermal waters are similarly low (< 20 ppm) a vapor-dominated system is indicated. The Cl content of steam is normally less than 1 ppm, but near-surface waters involved in condensation of the steam commonly contain a few ppm of Cl because, with little or no discharge, Cl can be selectively concentrated.

Typical wells at Larderello (Burgassi, 1964) produce dry or slightly superheated steam with 1 to 5 percent of CO_2 and other gases (Table 2, anal. 2). Liquid water evidently occurs in some noncommercial wells on the borders of the fields. Shut-in wellhead pressures in typical steam wells tend to increase with depth up to a maximum of about 32 kg/cm² (Penta, 1959; Burgassi, 1964). Increased productivity reported at greater depths evidently is not due to significantly higher initial pressures. Ferrara and others (1963) list the temperatures of two Larderello wells as 251° C, but all other cited wells are 240° C or lower (depths not given).

Typical wells at The Geysers also produce dry or superheated steam containing gases similar to those in the Larderello field (Table 2, anal. 1). Pressures up to about 35 kg/cm² were measured in the deeper wells (500 psi, Otte and Dondanville, 1968), but whether pressures were at the well-head or in-hole, and gage or absolute were not specified.

Figure 1 shows the maximum temperatures measured or calculated for individual shallow wells in The Geysers field. For a variety of reasons each point is individually unreliable and is probably not identical with the original ground temperature at its plotted depth. Nevertheless, temperatures of shallow wells (< 350 m) do show a rather close relationship to curve A, the reference boiling-point curve for hydrostatic pressure of pure water. A few points plot above this curve, indicating pressures above hydrostatic but below lithostatic.

All of the early shallow wells at The Geysers were drilled in or near fumaroles, hot springs, and hydrothermally altered ground that provided evidence of surface discharge of thermal fluids. Figure 1 suggests, and our model (to be discussed) assumes, that liquid water condensed from rising steam fills much of the pore spaces; this condensed water provides a major buffering control over temperatures and pressures in the zone of upflowing fluids. McNitt (1963) concluded from other data that a near-surface zone is water saturated; we support his general conclusions but disagree on the nature of the evidence.

Although available data are scanty, temperatures at The Geysers increase irregularly with depth, probably along or near the hydrostatic boiling-point curve, until temperatures near 236° C (and pressures near 32 kg/cm²) are attained, with only slight additional increases approximately along curve B of figure 1 to explored depths. In the Sulphur Bank area of The Geysers (Otte and Dondanville, 1968), about 1½ km west-northwest of the original field, wells range from 450 m to more than 2,000 m in depth and are remarkably uniform in temperature (close to 240° C) and in pressure (about 35 kg/cm²), as shown in Figure 1. Otte and Dondanville state that "the fluid exists in the reservoir as superheated steam," but the reported temperatures and pressures indicate approximate saturation. No specific data for individual wells are available.

No data have been published to indicate that wells in the central parts of any vapor-dominated field have penetrated a deep water-saturated zone or a water table. In such a penetration, in-hole pressures should increase downward through the water-filled parts of shut-in wells instead of remaining near 32 kg/cm². This evidently does occur in parts of the Italian fields (R. Cataldi, written commun., 1970), but detailed relationships are not yet available. The expected temperature-depth relationships below the deep water table are shown in Figure 1, curve C. This curve has an increasing slope with depth and all points on it are also deficient in pressure with respect to external water pressures, probably to depths of 2,000 m or more below the water table.

Table 3.--Pressures and temperatures in a two-phase reservoir in which steam is the continuous phase. Top of reservoir assumed to be 236°C 31.8 kg/cm², and 360 m deep (from hydrostatic boiling-point curve).

Depth meters	Pressure, kg/cm² (bottom hole)	Temperature °C
360	31.8	236.0
500	32.0	236.1
1,000	33.5	239.0
1,500	34.3	240.3
2,000	35.1	241.6

Note: Second line of column 3 should read 236.3.

James (1968) noted that initial temperatures and pressures of the Larderello steam fields were close to the temperature (236° C) and pressure (31.8 kg/cm²) of saturated steam of maximum enthalpy (670 cal/gm; indicated on Fig. 2). James reasoned that enthalpies up to this maximum can be obtained in undisturbed steam reservoirs by evaporation at a subsurface water table. Higher temperatures (and pressures) can exist below but not *at* the water table. He reasoned that if saturated steam at 350° C and 68.7 kg/cm², for example, with an enthalpy of only 612 cal/gm (Fig. 2), formed deep in a system and rose up to levels of lower hydrostatic pressure, part of the steam would increase in enthalpy as it continued to rise while the rest would condense to liquid water and remain behind. For a pure water system, this separation of liquid from vapor continues until the pressure at maximum enthalpy is attained.

The enthalpy of saturated steam near its maximum, however, is not very sensitive to changes in temperature and pressure (Fig. 2). James suggested that the top of a natural vapor-dominated reservoir is likely to have a temperature near 236° C and a pressure near 31.8 kg/cm² but that, because of the weight of steam in a deep reservoir, the temperature near a boiling water table may be as much as 240° C at a pressure near 34 kg/cm². Table 3 shows expected depth-related variations in temperature and pressure of a pure water system in a homogeneous, vapor-dominated reservoir.

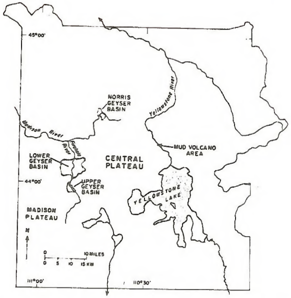

FIG. 3. Index map of Yellowstone National Park, Wyoming, showing location of Mud Volcano area and the major geyser basins.

The scanty available data suggest that temperatures and pressures may exceed the limits suggested by James because of the effects of dissolved salts and the partial pressures of other gases. In addition, although the maximum enthalpy of steam does seem to buffer these systems at temperatures near 236° to 240° C and pressures near 32 to 34 kg/cm², we see no fundamental reason why the available heat supply may not form somewhat more steam than can escape at these pressures through available channels. In this paper we shall assume James' suggested range in temperatures and pressures as the most probable, but we emphasize that more precise data are essential in understanding the detailed characteristics of these systems.

Recorded temperatures of the vapor-dominated reservoirs are significantly lower than in some hot-water fields, which range up to 388° C (Mercado, 1969). The Carboli field on the southern edge of the Larderello steam fields is notable in being the only described field in the Larderello region that produces more water than steam by mass and thus is a hot-water system. Its maximum temperature is about 300° C (Cataldi and others, 1969), which clearly exceeds all temperatures reported from the vapor-dominated areas.

The Mud Volcano Area, Yellowstone Park

General Setting.—The Mud Volcano area is located along the Yellowstone River about 8 km north of Yellowstone Lake (Fig. 3). Bedrock of the area is rhyolitic ash-flow tuffs erupted approximately 600,000 years ago (R. L. Christiansen and J. D. Obradovich, 1969, written commun.). Glacial gravels and sands of Pinedale age (about 25,000 to 12,000 years B.P.) mantle the bedrock except near the center of the area.

Thermal activity in the Mud Volcano area consists almost entirely of vigorously bubbling mud pots, acid-sulfate springs, and steam vents concentrated on north-northeast lineaments. Total discharge is only about 80 lpm (Allen and Day, 1935, p. 58) from an area of 2½ km². There are no chloride-rich springs like those of the major geyser basins, even along the Yellowstone River, which is the local base level for the water table of the area. Instead, acid-sulfate and nearly neutral bicarbonate-sulfate springs occur along the river (anals. 5 and 6, Table 1). A little silica is being deposited by evaporation from algal mats at two of these nearly neutral springs, and opal-cemented Holocene alluvium is common along the riverbanks. Although none of the present springs has enough silica to deposit hard sinter from flowing water on the surface (generally requiring at least 240 ppm SiO_2), three small areas of old sinter occur as much as 3 m above river level. This indicates that sometime in the past 12,000 years silica-rich water, presumably also rich in chloride, discharged at the surface in the Mud Volcano area.

Acid-sulfate springs similar in discharge and chemistry to the Mud Volcano springs occur locally where H_2S is abundant in high ground of the major Yellowstone geyser areas (anal. 9, Table 1). However, in contrast to drill hole Y-11 in the Mud Volcano area (anal. 7, Table 1), all drill holes in the geyser basins tapped water rich in chloride and similar to waters from the geysers and the principal flowing springs (anal. 8, Table 1).

Y-11 was drilled by the U. S. Geological Survey at the north end of the Mud Volcano area, 75 m north-northeast of Old Sulphur Cauldron. Figure 4 shows the locations of the hole and the "tree line," inside of which trees do not grow because temperatures are too high. Also shown are two heat-flow contours mapped by snowfall calorimetry (White, 1969). The 900 μcal/cm² sec (microcalories per sq cm per second) contour is probably within 20 percent of the existing total conductive and convective heat flow. This heat flow is about 600 times the world-wide average conductive heat flow of the earth (Lee and Uyeda, 1965). The 5,000 μcal contour is less precisely located, but total heat flow obviously increases rapidly southeast from Y-11 drill hole.

Near-surface Ground Temperatures.—Relationships between heat flow, depth, and temperature determined in shallow auger holes near Y-11 clarify some principles of major significance to the vapor-

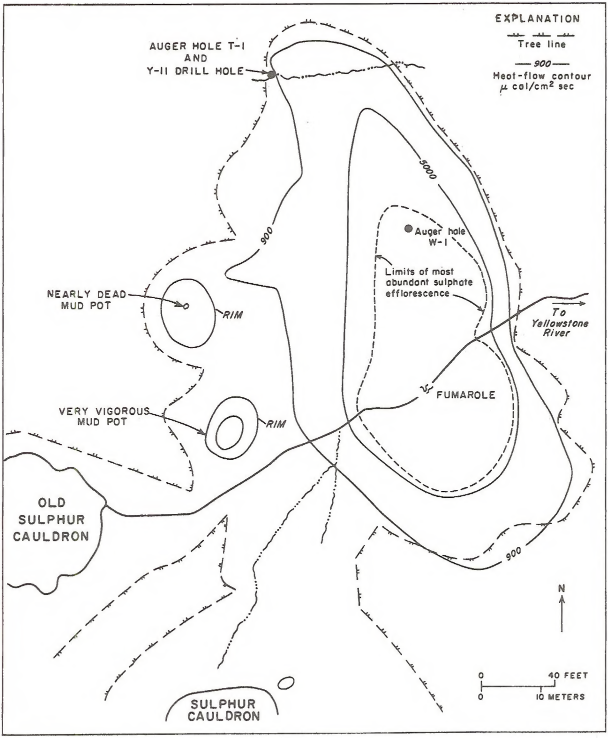

FIG. 4. Sulphur Cauldron area, north end of Mud Volcano area, showing location of Y-11 drill hole relative to heat flow and other features.

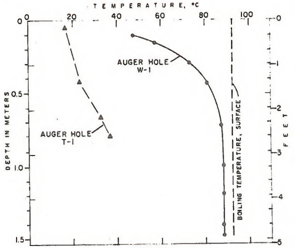

FIG. 5. Temperature-depth curves in shallow auger holes in ground with dispersed upflow of steam and other gases.

dominated systems. Hole T-1 (Fig. 5) was augered on the Y-11 site just prior to drilling, and hole W-1 was augered 35 m to the southeast (Fig. 4). The near-surface temperature at any given depth increases abruptly to the southeast, correlating with increasing heat flow.

Temperatures in W-1 increased rapidly with depth to about $\frac{3}{4}$ m, where they leveled off at 88.2° C. From 1.0 to 1.55 m there was no temperature change. Consequently, heat cannot be transferred by conduction through this interval, and *all* heat that flows out at the surface must be transferred in steam and other gases through the no-gradient zone. Total heat flow at the surface of W-1 auger hole has not been measured by snowfall calorimetry, but extrapolation of data on Figure 4 suggests a heat flow of perhaps 10,000 μcal/cm^2 sec.

The leveling off of temperatures in W-1 at 4.1° C below the boiling temperature of pure water (92.3° C at this altitude) is due to the high content of CO_2, H_2S, and other gases in the rising vapor. The vapor pressure of water at 88.2° C is 491 mm of Hg, but the atmospheric pressure averages about 572 mm of Hg. Thus 14 percent of the total vapor pressure results from the partial pressures of other gases. At a depth where the temperature is 85° C, 25 percent of the total pressure is due to residual gases (143 mm of 572 mm of total Hg pressure); similarly, 50 percent consists of other gases at 75° C, 90 percent at 40° C, and 97.7 percent at 15° C.

The depth at which the temperatures level off is dependent on the heat flux from below, the thermal conductivity of the soil, the air-ground interface temperature, and the amount and nature of precipitation of the preceding few days or weeks. If the rate of upflow of steam increases sufficiently, a surface fumarole is produced. If, in contrast, the rate of upflow decreases, complete condensation occurs at a greater depth appropriate to the thermal conductivity heat flow, and surface temperature.

In the steam-gas mixture in W-1 auger hole, no steam condenses between a depth of 1.0 m and the bottom of the hole because of the absence of a tem-

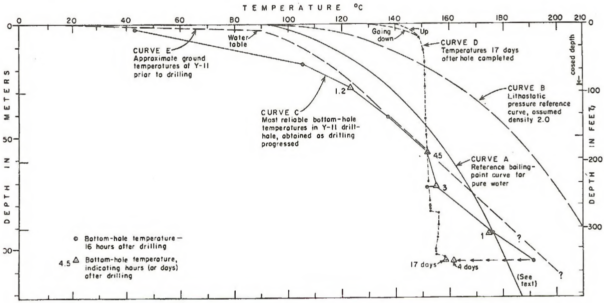

FIG. 6. Temperatures in Y-11 (Sulphur Cauldron) drill hole, Mud Volcano area, Yellowstone Park, Wyoming.

Table 4.--Temperatures, pressures, and other data from Y-11 (Sulphur Cauldron) drill hole, Mud Volcano area, Yellowstone National Park, Wyoming

Underlined data considered most reliable

Date and time 1968	Observation depth, m	Temperature, °C		Depth to water m	Total pressure kg/cm^2	Comments
May 15 8:35A	2.0	43.0 ?				Drilled to 6.1 m, set 4 in. casing, and cemented on May 14; on cement at 2.0 m, temp. probably minimum.
12:10	8.3	(36.0)		2.3		80 min. after circulation ceased; good water level 1 hr. after circulation ceased.
3:25	18.1	87.0			0.85	Drilled 18.3 m; pressure all gas.
16 8:15A	17.3	104.4	105.4	2.3	1.17	Do.
8:23		106.4			1.08	Gas only; 91°C at water level.
1:25P	27.7	123.3			2.05	1.2 hrs. since circulation; could have erupted; drilled, set 27.4 m 3 in. casing and cemented.
17 8:00A	13.7	73.0				On cement; temperature probably minimum.
4:45P	(41.8)	(116.1)		5.2		Drilled 41.8 m; lost circulation 37.2-41.8 m.
18 7:50A	41.4	137.0	137.1	4.9		Gas pressure from outside rods, 1.56 kg/cm^2 temperature at water level inside rods 73°C.
8:08A		137.2				
1:00 P	(57.0)	(120.3)		4.7		Lost circulation 41.8-57.0 m; temp. 1-1/2 hrs. after circulation.
19 10:40A	56.9	152.4	151.9	4.6		23 hrs. after circulation.
11:00		151.4				
20 7:54A	57.0	151.4	151.9			45 hrs. after circulation.
8:05	57.0	153.4				
8:12		150.9				
8:22		151.9		0.3		Water level fluctuating.
2:00P	72.2	154.5			0.8	3 hrs. after circulation, pressure fluctuating; water discharged outside of rods; drilled 72.3 m.
21 7:45A	72.2	151.1	151.6		3.5-3.6	Gas pressure; note temp. decrease since May 20. Drilled to 93.6 m; erupted after pulling core; nearly all steam after much initial water.
7:57		152.0				
12:20P	93.4	174.3			5.8 then to 4.1	Temp. 40 min. after eruption; some water with steam at 4.1 kg/cm^2.
3:45P		1?4.7			7.8 down to 5.9	Leaking steam at 7.8 kg/cm^2, then down to 5.9 kg/cm^2, some water.
3:50					4.4	Pressure on side valve, outside drill rods.
22 8:00A	93.4	175.7	175.9		10.1 down to 8.0	Leaking vapor only.
8:12		176.1				Vapor and a little water; drilling increasingly difficult >100 m. Violent eruption at 105.7 m, initially much water (drill water?), then mostly steam.
23 8:15A		191.6	191.4		12.7 to 11.2	Leaking vapor only. Drill rods in hole a few feet off bottom; exact depth not noted.
8:30A	105.7	191.1				
~11:00A					5.3	Rods pulled, pumping cold water down outside rods throughout; pressure with open hole >27.4 m. Hang up at about 33.6 m, erupted to clear--powerful steam eruption but little water.
27 Not noted	105.5	161.1	161.3		5.3	Note major permanent changes in temperature and pressure after rods out of hole.
		161.4			5.4	
June [illegible] 10:00A	~105		158.6		5.3 to 5.4	Thermistor temperature series plotted on fig. 6. Temperature generally steady and reproducible down to 84.1 m, fluctuating somewhat at greater depths, up to 4°C at bottom (maximum is plotted).
10	96.3				5.0	R. O. Fournier attempted to sample; filled with vapor to existing bottom.
28	39.0				4.6	Blocked; no access to greater depths; no water to 39.0 m.
Sept. 1969 21	28.0		131.7		3.2 to 3.5	Attempting thermistor series; initial temperature at top 75°C, increasing to 107°C with leakage of gas. Hole filled with gas to cave at 28.0 m just below casing; thermistor wedged and lost. Erupted gas, mud, and water, and collected water sample.
						Pumped in 5 sacks of cement at pressures up to 11.3 kg/cm^2.

perature gradient. As steam rises above a depth of 1 m, however, a little starts to condense as a temperature gradient first becomes evident. The gradient increases upward as the surface is approached, so more water vapor can condense. The residual gases are progressively concentrated upward as H_2O

is condensed, the velocity of upflow consequently decreases, and a correspondingly smaller proportion of the total heat is transported by water vapor. Convective transport of heat at the air-ground interface must be largely in the residual gases, but water vapor, even though a minor constituent, is still a significant transporter of heat because of its high heat of vaporization (588 cal/gm at 15° C), relative to heat content of other gases.

The water vapor that condenses between 1.0 m and the surface at W-1 percolates downward against the flow of steam. The ground is unsaturated with liquid at the bottom of the auger hole and probably to the local water table (2.3 m in Y-11 drill hole). Below the water table at W-1, pressures must exceed atmospheric, and temperatures probably rise along or near the hydrostatic boiling point curve of Figure 6.

The near-surface temperature gradient in auger hole W-1 of Figure 5 is much higher than in T-1, as we should expect from the heat-flow contours of Figure 4. Projection of the T-1 gradient downward to the water table at 2.3 m suggests that temperatures were slightly below boiling at this depth. It appears that only a little water vapor and other gases were rising at the Y-11 site prior to drilling, and most heat was being transferred from the water table to the ground surface by conduction.

Physical Measurements Made During Drilling of Y-11.—Data from Y-11 are summarized in Table 4, and bottom-hole temperatures are plotted in Figure 6. The bottom-hole temperatures considered to be most reliable are connected by a solid line. Much effort was made to obtain reliable data from Y-11 as drilling progressed, in part because of the paucity of such data from the large commercial vapor-dominated systems. Because of the high cost of drilling and other factors, available data from the commercial systems are entirely restricted to completed wells, and almost no data are obtained at shallow and intermediate depths as drilling progresses.

In the recent holes drilled in Yellowstone National Park, temperatures measured at each temporary bottom, just before resumption of drilling (generally after overnight shut-down of about 16 hours), provided reasonable approximations of pre-drilling ground temperatures; they are far superior to temperature profiles measured in completed holes (White, Fournier, Muffler, and Truesdell, unpublished data). Measured bottom-hole temperatures in Y-11, however, are less reliable than in the other holes but are considered to be within a few degrees of original ground temperature. At depths less than 27.4 m, rapid drilling plus the setting of two strings of casing prevented acquisition of reliable data. From 37.2 to 79.3 m, all drill water was lost into the ground, and at greater depths only about 50 percent returned to the surface. Despite the apparent high permeability and loss of drill water, however, the temperature of 151.9° C at 57.0 m depth is probably reliable because it was repeated on successive days with no disturbance by drilling.

A temperature profile made in the open hole 17 days after completion is shown on Figure 6 (curve D). It differs greatly from the temperature profile obtained as drilling progressed. The temperatures from 12.2 to 83.5 m were almost constant, rising only 2° or so, to 153° C at 83.5 m. At greater depths, rapid fluctuations of 1° to 5° were observed. These fluctuations were not due to instrumental defects and were far too large and too rapid to be caused by only a vapor phase; coexistence of steam and water is thus indicated from 83.5 to 103.7 m. The pressure of saturated steam at 153° C is 5.3 kg/cm^2, which is very close to the measured well-head pressure, 5.4 kg/cm^2. The temperature of 158.2° C at 103.7 m, however, is not consistent with the well-head pressure, unless liquid water was present near the bottom of the hole. From drill records, we conclude that water was probably entering the hole from depths as shallow as 58 m or less, while an upward flow of steam dominated the central part of the casing. Detailed relationships that existed during the thermistor measurements between 83.5 and 103.7 m cannot be deciphered completely. Evidently some steam was flowing in near 84.2 and 103.7 m. Water seeping down from higher levels did not accumulate extensively but was either forced out into permeable walls or was evaporated by the higher temperature steam. At shallow depths in the hole, horizontal and vertical temperature gradients were so high that most water vapor condensed and residual gases were concentrated, as in auger hole W-1. The condensed water trickled down the walls of the casing.

On several occasions during the drilling of Y-11, we were unable to prevent the hole from erupting for short intervals. The eruptions differed notably, however, from those in holes in the hot-water systems of the geyser basins. In drill holes in permeable rocks, with adequate water supply, and a temperature of 160° C, for example, only 11 percent of the total liquid water vaporizes to steam when erupted (at constant enthalpy) to atmospheric pressure (Fig. 2). The remaining 89 percent of the erupted mass is liquid; the large content of liquid water produces effects that are similar to those of the early stages of geyser eruptions. During an eruption of Y-11, however, the local supply of liquid water was soon nearly exhausted and steam became completely dominant. We estimated that the steam was associated with less than 10 percent of liquid water by weight. Although at no time did the hole discharge dry steam free of liquid water, we are confident that a dry discharge would have occurred if the eruption had been permitted to continue or if the hole had been cased a little deeper. (The hole was uncased below 27.4 m, and the bottom-hole temperatures indicate an original dominance of liquid water in pore spaces to depths of about 73 m; curves C and E, Fig. 6.)

The pressure of 12.7 kg/cm² measured in the drill rods on May 23 at the greatest drilled depth represents the approximate total pressure at the drill bit, assuming vapor-filled drill rods raised the usual 3 to 4½ m above bottom (1 to 1½ lengths of drill rods), and neglecting the weight of the vapor. If 3.7 m off bottom is assumed, with liquid water filling the hole below the rods, the calculated bottom-hole pressure was about 13.1 kg/cm² (with a possible range from about 12.8 to 13.6 kg/cm²). The pressure at the bottom of an open hole 105.8 m deep and filled with water everywhere just at boiling should be 10.5 kg/cm². Thus, the excess pressure above hydrostatic was about 2.6 kg/cm² or 25 percent. The fact that temperatures and pressures are higher than those of a simple hydrostatic control is important and must be consistent with any satisfactory general model of the vapor-dominated systems.

Liquid-dominated and Vapor-dominated Parts of the System.—In Y-11 drill hole, water-saturated ground evidently extended from the water table at 2.3 m down to a depth of about 73 m. At 72.2 m, the bottom-hole temperature measured 3 hours after drilling ceased was 154.5° C; 18 hours later it had dropped 3° C. We believe that this change was due to the cooling effect of drill water continuing to drain down the hole and into channels that had formerly been dominated by vapor. The pre-drilling ground temperature probably was not attained at this drilled depth and was probably about 165° C (Fig. 6, curve E); flow of water down the hole prevented a normal temperature recovery.

The hole was definitely in vapor-dominated ground at a depth of 93.4 m. At this depth an unanticipated eruption through the drill rods first discharged abundant drill water and then changed rapidly to wet steam with only traces of liquid water. Such a change in behavior is not particularly significant in tight rocks of a hot-water system when the water available for immediate eruption is exhausted; the behavior is similar to that of a geyser as it changes from its main eruptive phase to a steam phase (White, 1967a). However, permeability was so high at all depths below 37 m in Y-11 that little or no drill water returned to the surface. Lack of permeability clearly does not explain the observed eruptive behavior; a limited supply of *available liquid water* provides the only reasonable alternative. If all lost drill water had remained in nearby permeable ground, the eruption likewise could not have been so nearly dry. The drill water must have percolated down former vapor-filled channels to become unavailable in supporting the eruption.

Forty-six days after completion of the hole, measurements made by an in-hole sampling device (Fournier and Truesdell, 1970) demonstrated that the hole was filled with vapor to 96.4 m, where caving had occurred. Presumably all drill water was then exhausted and all inflowing pore water from higher levels either evaporated completely or escaped downward through former vapor-filled channels.

From these data we can conclude that vapor pressure in the hot core of the system below about 76 m is now significantly above hydrostatic pressure (Fig. 6). Some vapor is being forced upward and outward into the cooler walls. The excess driving pressure above hydrostatic presumably is dispersed in overcoming the frictional resistance to flow of vapor along narrow channelways, which become increasingly clogged upward and outward with liquid water condensed from steam; some of the gases other than steam dissolve in this liquid condensate. If many large free-flowing channels vented to the surface as fumaroles and mud volcanoes, the high vapor pressures in excess of hydrostatic obviously could not be maintained.

Another factor that may be of major importance in impeding the escape of vapor is the formation of montmorillonite and kaolinite, which are the dominant alteration products in rocks and fracture fillings of Y-11 drill core from about 15 to 58 m. Montmorillonite and kaolinite also occur sporadically at greater depths but are generally less abundant than other hydrothermal minerals and unaltered rock silicates. The condensed steam is saturated with CO_2 and other gases from the rising vapor. This carbonated water, represented by analyses 6 and 7 of Table 1, is highly effective in altering feldspars and other silicates to clay minerals, and in leaching cations from the rocks. Pyrite is also relatively abundant through the same general interval, from 18 to 61 m, but is sporadic at greater depths. Much sulfide from the rising H_2S evidently dissolves in the condensate and becomes fixed, combining with Fe of the rocks.

The hot vapor-dominated core of the system evidently is not sharply separated by a single fluid interface from the cooler liquid-dominated walls. We conclude that, in the core of the system, the largest fractures and open spaces are mostly or entirely filled with vapor but open spaces of similar dimensions in the margins of the system are largely filled with liquid water, except for dispersed clays and vapor bubbles that sporadically rise through the water.

General Model of Vapor-dominated Geothermal Systems

A vapor-dominated geothermal system must normally develop from water-saturated rocks. This statement may be unconvincing for young volcanic rocks (how do we ***know*** that such rocks were ever water-saturated?) but is irrefutable for old marine sediments that are now far below the regional water table, as in Tuscany and The Geysers. A new regime is initiated with the introduction of a local potent source of heat at depth (probably a body of magma). Much heat is transferred via conduction and circulating water into surrounding rocks that have some permeability. Because of thermal expansion and resulting decrease in density of the heated water, a ***hot-water*** convection system is then initiated. Most rocks seem to be sufficiently permeable to persist as hosts for hot-water systems; the rate of flow of water remains high enough and the supply of conducted heat below the circulation system remains low enough for most of the water flowing through the system to remain liquid. Near-surface temperatures in the hotter systems, however, are high enough for some boiling to occur as the water rises to intersect the boiling point curve (A of Fig. 6). The depth where boiling first occurs in the rising water depends mainly on the temperature of the water.

Many hot-water systems are to a major extent self-regulating. With more heat flow, the upflowing

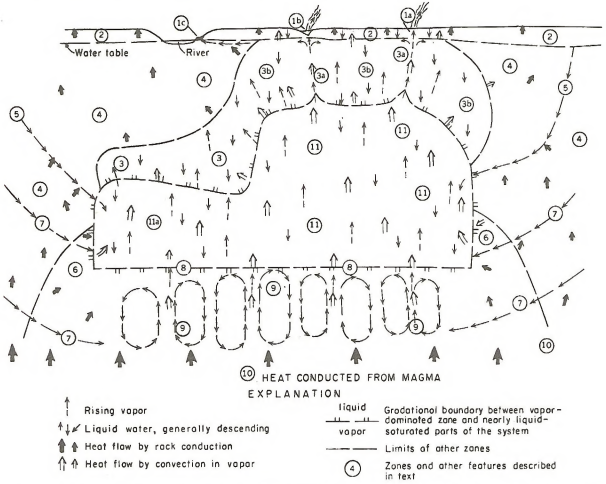

FIG. 7. Model of dynamic vapor-dominated geothermal reservoir surrounded by water-saturated ground. The most significant parts of the model, inward and downward by number, are: 4) zone of conductive heat flow; 3) zone of condensation of steam (conductive and convective heat flow equally important); 11) main vapor-dominated reservoir, with convective upflow of heat in steam in larger channels, and downflow of condensate in small pores and fractures (surface tension effects); 9) deep zone of convective heat transfer, probably in brine; 10) deep zone of conductive heat flow (too hot for open fractures to be maintained). Other features are discussed in text.

water becomes hotter and lower in density and viscosity; the pressure drive for recharge increases, and the increased rate of through-flow removes most of the additional heat. This self-regulation, however, may be limited by insufficient permeability.

With sufficiently potent heat supply or, for any reason, a decreasing rate of recharge of water, a hot-water system of limited permeability may start to boil off more water than can be replaced by inflow. A *vapor-dominated system* then starts to form. Direct evidence for the assumed initial dominance of liquid water is lacking for the major vapor-dominated systems. Hot-spring sinter constitutes the clearest evidence, and is so interpreted for the Mud Volcano system. However, sinter is deposited only from very hot water that flows so rapidly to the surface that little SiO_2 precipitates en route. In addition, the early hot-water stage of these systems of high heat flow and low permeability is likely to have been brief and their thin sinter deposits (if any) are likely to be destroyed by erosion.

Figure 7 is our tentative general model of a well-developed vapor-dominated system. Different parts, discussed below, are keyed by number on the figure.

(1) Fluids that discharge at the surface provide much of the evidence for a vapor-dominated system. Fumaroles (1a) are generally at temperatures near surface boiling or somewhat lower. High-chloride springs are completely absent; associated springs and mud pots are generally acid, high in sulfate, and low in discharge (such as 1b of Fig. 7, and anals. 2 and 5, Table 1), and they deposit little if any sinter. Surrounding ground may be bleached and lacking in vegetation. Some springs not so strongly influenced by oxidation of H_2S (or containing enough NH_3 absorbed from gases) are nearly neutral in pH and are dominated by bicarbonate and sulfate without much chloride (1c, Fig. 7, and anals. 1 and 6, Table 1).

(2) Zone 2 lies between the ground surface and the water table.[5] Where hot enough, steam and other gases rise above the water table, as in auger hole W-1 of Figure 5. At the water table heat transfer is nearly all convective, but as the temperature gradient increases upward and water vapor condenses, near-surface heat transfer becomes largely conductive.

(3) Zone 3 inhibits the free escape of rising vapor. The zone is nearly saturated with liquid water derived largely from condensing steam rich in CO_2. Montmorillonite and kaolinite form by reaction of this CO_2-saturated condensate with rock silicates. Clay minerals and condensed water clog most pore spaces and channels, impeding but in many places not prohibiting the escape of residual uncondensed gases. Temperatures in this zone may be similar to those along the hydrostatic reference curve A of Figure 6. Near major channels of upflowing steam (3a, Fig. 7), temperatures and pressures are somewhat above hydrostatic, and conductive heat flow and condensation of steam are consequently high; at least part of the condensate is swept upward to the water table or to surface springs, mud pots, and mud volcanoes. A crude steady-state rate of upflow is determined by pressure gradients, dimensions of the channels, strength of wallrocks, and impedance provided by condensate and suspended clays. Other parts of zone 3 (3b, Fig. 7) are dominated by downflowing condensate and some surface water, with temperatures that are likely to be somewhat lower than those along reference curve A of Figure 6. As temperature gradients in general increase outward and upward through zone 3, more of the heat of vaporization in the rising steam can be transferred by conduction, so water vapor is continuously condensing and the rate of mass flow of vapor therefore decreases upward. A part of the heat in rising vapor is transferred through local horizontal gradients to heat the downward-percolating condensate, which must absorb heat as it descends into hotter ground. The dashed line bounding the outer part of zone 3 marks the gradation in mode of heat transfer from dominantly convective to dominantly conductive.

The lower limit or "pinch-out" of zone 3 is at a depth where the hydrostatic pressure of water in the reservoir margins exceeds the total vapor pressure of steam and gases in the reservoir. Below this depth, vapor can no longer effectively penetrate the reservoir margin.

Wells drilled into parts of zone 3 may produce liquid dominantly, but if drilled and cased into deeper parts they probably yield wet steam and some water when first produced (as in Y-11 drill hole). If an uncased section of hole intercepts channels of upflowing steam and zones of cooler downflowing condensate, the temperature and pressure of the steam will commonly dominate the hole. This occurred in Y-11 below 72 m.

(4) Zone 4 is characterized mainly by conductive heat flow, with heat being supplied from condensing steam within zone 3. Wells bottomed in zone 4 may fill with water, and may erupt hot water and some steam, but discharge rates are likely to be low and the wells noncommercial.

(5) Representative channels of intermediate-level recharge are deep enough at points of entry for hydrostatic pressure to exceed the vapor pressure of

[5] In sands and gravels the water table is easily recognized. In clays, however, the water table is poorly defined, but we consider it to be the level at which water is maintained in a shallow open hole. The zone of saturation can rise as much as 10 m above this level, owing to surface tension in the clays. Hydrostatic pressure increases downward only below the water table as defined in the open hole.

about 31 to 35 kg/cm^2 in the main reservoir (zone 11).

Channels of inflow tend to be enlarged by solution of SiO_2 as the inflowing water is heated by conduction (indicated by heat-flow arrows in Fig. 7). Channels are diminished, however, by deposition of $CaCO_3$ and $CaSO_4$, which are rather unusual in *decreasing* in solubility with increasing temperature (see, for example, Holland, 1967). In all rocks with recharge waters relatively high in $CaCO_3$ and $CaSO_4$, channel permeabilities are especially likely to *decrease* rather than increase with time. These considerations may be important in understanding Larderello, which involves anhydrite-bearing limestone and shales, and The Geysers, where mafic lavas and serpentine are associated with graywacke and shale.

(6) Zone 6 consists of reservoir margins where temperatures decrease *toward* the reservoir. The depth of the top of zone 6 is not easily predicted. If there were no convective heat flow, the depth would be near that of the 240° C isotherm of the original conductive gradient from the surface to the magma chamber. If 600° C is assumed at 4 km, for example, and the rocks are homogeneous, 240° C would be at 1.6 km depth. The development and downward penetration of the main vapor-dominated reservoir as excess pore water is vaporized result in extensive convective modifications of temperature that greatly change the relationships. Convective cooling from downflowing meteoric water increases this depth, and a shallower intrusion at higher temperature decreases it. These reservoir margins contain channels of inflowing water at pressures that are close to hydrostatic and much greater than ~33 kg/cm^2 of the reservoir. Sharp pressure and temperature gradients decreasing toward the reservoir must therefore exist in zone 6. In contrast to zone 3, heat is transmitted through zone 6 by conduction (and inflowing H_2O) to the reservoir. The temperatures of zone 6 grade downward into, and are maintained by conduction from zone 10.

(7) Channels of inflowing water are narrowed by precipitation of calcite and anhydrite as zone 6 is approached; clogging of channels by these minerals of decreasing solubility may be offset entirely or in part by solution of quartz, which increases in solubility as long as the liquid water continues to rise in temperature. At the outer edge of zone 6, however, pressures and temperatures in the recharge channels attain their maxima; with further flow toward the reservoir, boiling commences and *temperature declines* as the pressure drops to that of the reservoir. The fluid in these channels is now a two-phase mixture of steam and water. Specific resistance to flow (resistance per unit of *mass*) of steam is much greater than that of liquid water, and specific flow resistance of a two-phase mixture is greater than a linear combination would indicate (I. G. Donaldson and Gunnar Bodvarsson, oral commun., 1970). Because of evaporative concentration by boiling and because of decreasing temperature, quartz and other minerals are now deposited, further impeding the flow of the two-phase mixture. The result of all of these processes is to decrease the rate of recharge through the deeper channels.

(8) The deep subsurface water table recedes as long as the heat supply is sufficient for net loss of liquid water and vapor from the system to exceed net inflow (water table shown in Fig. 7 is horizontal, but it may be very irregular in detail). As mentioned above, recharge tends to decrease with time as resistance to flow of H_2O through individual channels increases. As the water table recedes and liquid water in the reservoir is largely replaced by vapor at nearly constant pressure throughout the reservoir, the driving pressure on the deeper channels of inflow increases, offsetting in part the increasing impedances. A crude steady state may be attained in some systems, especially as rate of heat flow eventually starts to decline.

(9) With time, if not initially, the water boiling below the deep water table becomes a brine as recharging water boils off and as dissolved substances of low volatility are residually concentrated. Vapor from brine is superheated with respect to pure water at the same pressure. Steam boiling from 25 percent NaCl brine at 35 kg/cm^2, for example, is superheated by about 12° C with respect to saturated steam and pure water (254° vs 242° C, Haas, 1970). The critical temperature of a salt solution increases above that of pure water (374° C) as salinity increases; that of a 1 percent NaCl solution is about 384° C (Sourirajan and Kennedy, 1962, p. 134); that of a 10 percent solution is about 480° C; and that of a 25 percent solution is about 675° C. Thus, brine can be a very effective agent for convectve transfer of heat and dissolved matter at temperatures much above 374° C. Note that Figure 7 has no vertical scale; the depth of zone 9 may be 1,000 m or more, and through all or most of this depth, pressures are *lower* than hydrostatic pressures outside the system (Fig. 1, curve C, increases downward in slope).

(10) Conductive heat flow from the magma predominates deep under the reservoir where rock plasticity due to increasing temperature prevents the maintenance of open channels. On the outer margins of zone 10 where convective disturbance is not so severe, conductive heat flow predominates to higher levels than under zone 9, grading upward without distinct boundaries into zones 6 and 4. The amount of convective circulation may eventually de-

crease beneath the vapor-dominated reservoir by decreased permeability from deposition of minerals, and possibly as a stable salinity gradient becomes established.

11) The main vapor-dominated reservoir contains *liquid water and vapor coexisting,* except possibly in major channels of steam discharge and locally just above the brine water table. Steam and other gases rise in the largest channels where resistance to flow is lowest. Steam starts to condense on the outer borders of the reservoir and continues to condense from all vapor escaping into zone 3, where temperatures decrease outward and provide a thermal gradient for conductive transfer of the heat of vaporization of steam. The condensate from zone 3 percolates down into the reservoir, favoring narrow channels and pore spaces between mineral grains because of surface tension and the lower specific resistance to flow of liquid water relative to steam.

Edwin Roedder (personal commun., 1970) has suggested that our model for vapor-dominated systems is similar in many respects to recently-developed remarkable devices that have been called "heat pipes" (Eastman, 1968). These devices may be "several thousands of times more efficient in transporting heat than the best metallic conductors." They consist of a closed chamber with inside walls lined by a capillary structure or wick, and saturated with a volatile fluid. Heat is transferred by vapor from the hotter to the cooler end, where the vapor condenses. The liquid condensate returns by capillary action to the evaporator section; temperature gradients in the pipe may be extremely low. The top end may be the hotter, with capillary return of liquid (to some limited height) being opposed by gravity. Our natural "heat pipes" are not completely closed systems, and their depth has no theoretical limit because gravity assists rather than opposes the return flow of condensate.

Parts of the subsurface reservoir such as 11a of Figure 7 may be isolated from direct outflow of vapor and may be representative of parts of the Larderello and The Geysers systems that have no apparent direct discharge in fumaroles. Pressures throughout the reservoir are controlled primarily by the total vapor pressure at the boiling water table, modified by frictional resistance to the upward flow of vapor and by the weight of the vapor. Near the top of the reservoir the vapor may be greatly enriched in CO_2, H_2S, and other gases that are not flushed out of the system as actively as near the top of the main reservoir (11). Much water vapor condenses below the boundary of the vapor-dominated reservoir near 11a. In contrast to the flushed part of the main reservoir, significant thermal gradients exist in the poorly flushed parts. Consequently,

Table 5.--Saturation temperatures of water calculated for ideal steam-gas mixtures at constant vapor pressure, 31.8 kg/cm^2.

Percent steam	Percent other gases	Pressure, kg/cm^2	Saturation temp., °C
100	0	31.8	236
99	1	31.5	235.5
98	2	31.2	234.9
95	5	30.2	233.1
90	10	28.6	230.1
80	20	25.4	223.7
70	30	22.3	216.9
50	50	15.9	200.1
30	70	9.5	176.8
10	90	3.2	134.7
5	95	1.6	113.0
1	99	0.3	68.0

some steam can condense and other gases are residually concentrated. Pressure of the remaining water vapor requires lower saturation temperatures, as shown in Table 5. This table suggests that temperatures in isolated parts of the reservoir differ little from 236° C until the residual gases are enriched above 5 percent. With higher residual gas contents, temperature gradients and conductive heat flow increase.

The above-described relationships may explain the relatively high pressures and low temperatures of the vapor-dominated fields of Bagnore and Piancastagnaio near Monte Amiata (Burgassi and others, 1965; Cataldi, 1967). Initial pressures were 22 to 40 kg/cm^2 and gas contents of the vapor were as high as 96 percent, but reported temperatures did not exceed about 150° C (Burgassi, 1964; Burgassi and others, 1965; Cataldi, 1967). Pressures and gas contents of the vapor decreased rapidly with production.

Similar reasoning indicates that high contents of gas in vapor coexisting with liquid water at a temperature near that of the maximum enthalpy of steam can result in total vapor pressure significantly above 31.8 kg/cm^2 at 236° C (Table 6). These data indicate that, as contents of other gases increase in the vapor phase at constant temperature of liquid and vapor, total pressures must increase. The least

Table 6.--Total vapor pressures of steam-gas mixtures coexisting with liquid water at 236°C

Vol. percent gas in vapor	H_2O pressure kg/cm^2	Pressure other gases, kg/cm^2	Total pressure, kg/cm^2
0	31.8	0	31.8
1	31.8	0.3	32.1
2	31.8	0.7	32.4
5	31.8	1.7	33.5
10	31.8	3.5	35.3
20	31.8	7.9	39.8
50	31.8	31.8	63.6

Note: Pressures 32.4 and 39.8 in column 4 should read 32.5 and 39.7 respectively.

actively flushed extensions of The Geysers field that have recently been discovered are likely to have higher gas contents and initial pressures than the original field.

Table 6 also suggests a possible triggering mechanism for some hydrothermal explosions and phreatic eruptions (Muffler and other, 1970) in gas-rich hot-spring and volcanic systems where escape of vapor and flushing of residual gases are inhibited by barriers of low permeability. Local accumulatons of gas-rich vapor can attain pressures that exceed hydrostatic and perhaps even lithostatic, finally resulting in rupture and explosive eruption.

The tentative model described above has additional support from thermodynamic calculations and comparison of actual production data with production predicted on the basis of our model (manuscript in preparation). We are hopeful that the model will prove to be of value in predicting the behavior of individual wells, in detecting interference between wells, in detecting inhomogeneities within the reservoir, in calculating reserves of steam in the original vapor-dominated reservoir, and in detecting a major influence by increased boiling below the water table as a result of declining reservoir pressures.

Speculations Relating Vapor-dominated Systems and Ore Deposits

Some mercury deposits may have formed in the upper parts of vapor-dominated systems. We also suggest, more tentatively, that porphyry copper deposits may have formed in the deep brine zones hypothesized to underlie vapor-dominated reservoirs.

Mercury Deposits.—Many mercury deposits appear to have formed near the surface in relatively recent time. Furthermore, mercury deposits occur on the periphery of two active vapor-dominated geothermal systems: The Geysers in California and Monte Amiata in Italy (White, 1967b; Dickson and Tunell, 1968). Recent geothermal exploration for extensions of The Geysers field disclosed dry steam 2½ km to the west under the Buckman mercury mines. Other wells yield dry steam near Anderson Springs, only 1½ km from the Big Chief and Big Injun mercury mines (White, 1967b), which are 10 km southeast of the original steam field. A number of other mercury mines in the district are within 3 km of steam wells.

Vapor-dominated systems of high gas content, previously discussed, have recently been discovered from 3 to 10 km south and southwest of the major Monte Amiata mercury mine (Burgassi and others, 1965; Cataldi, 1967), the largest Italian mercury deposit. No vapor-dominated reservoir has been found to prove a genetic relation to the mercury deposits, although abnormally high temperatures (63° C at 440 m depth) and notable concentrations of CO_2 and H_2S characterize these Italian deposits (White, 1967b). Dall'Aglio and others (1966) have shown that mercury occurs in anomalous amounts (> 1 ppm) in stream sediments in and around the Larderello-Monte Amiata fields. The anomalies in some stream drainages may be related to specific mercury deposits, but many clearly are not. These widespread anomalies instead seem more directly related to the geothermal fields and their broad anomalies in temperature gradient (Burgassi and others, 1965, Fig. 7).

Krauskopf (1964) has emphasized the high volatility of mercury, which provides an attractive mechanism for separating this metal from most others. The vapor-dominated geothermal systems, as we now understand them, provide a mechanism for shallow, moderately high temperature vapor-phase separation of mercury from other metals. Mercury is known to occur in vapor from The Geysers steam field (White, 1967b, p. 590, and unpub. data), and large mercury anomalies have been found in Yellowstone Park in mudpots of the Mud Volcano area and elsewhere, that are maintained by steam flow and condensation (W. W. Vaughn, U. S. Geol. Survey, written commun., 1969). Especially attractive is the possibility that Hg and H_2S dissolve in the steam condensate of zone 3 of our model (Fig. 7), precipitating as HgS as temperature decreases and as the pH of the condensate increases from reaction with silicates.

We do not claim that *all* mercury deposits form in this way. The Sulphur Bank and Abbott mines east of The Geysers, for example, are associated with discharging thermal chloride waters that may be, respectively, metamorphic and connate waters being forced out of their source rocks by lithostatic pressure (White, 1957b, 1967b). During peak mineralization at high temperatures, similar water was almost certainly being discharged, perhaps with more abundant vapor than now.

Porphyry Copper Deposits.—The possibility that porphyry copper deposits may be forming in the zone of boiling brine below vapor-dominated systems (zone 9 of Fig. 7) should be tested in these systems by looking for copper minerals in core and cuttings from the deepest drill holes. The model provides attractive possibilities for explaining many aspects of these deposits:

1. Recent isotope studies (Sheppard, Nielsen, and Taylor, 1969) demonstrate that water of meteoric origin probably is dominant over water of other origins during mineralization stages.

2. Temperatures of filling of fluid inclusions are most commonly above 250° C and exceptionally range up to 725° C (Edwin Roedder, oral and written commun.). The salinities of many inclusions are exceedingly high, probably ranging up to 60 percent of total fluid by weight. However, many inclusions are largely vapor, probably indicating boiling of the saline fluid at the time of entrapment.

3. Fluid relationships and the geologic setting of Copper Canyon, Nevada, are considered to be generally similar to porphyry copper deposits (J. T. Nash, written commun., 1970). Extensive fluid-inclusions studies by Nash and Theodore (1970) demonstrate that a) temperatures are most commonly in the range of 315° to 375° C; b) salinities of the ore fluids are commonly in the order of 40 percent (or higher, if $CaCl_2$ is abundant), with highest salinities in and near the porphyry intrusion and with lower salinities (2 to 15 percent) in peripheral gold-bearing deposits; c) vapor bubbles were trapped in many inclusions, demonstrating the prevalence of boiling or near-boiling conditions. The copper deposits are largely dispersed in the intruded rocks adjacent to the porphyry, and thus are within the spectrum of deposits that have been called porphyry copper deposits (Lowell and Guilbert, 1970).

4. High-salinity brines can develop from residual concentration of dilute (or saline) recharge water, providing a satisfactory system for transferring heat, metals, sulfur and CO_2 from the large magma body that presumably underlies the small multiple porphyry intrusions of most deposits. The critical temperature of water increases with salinity; with sufficient contents of alkali and calcium chlorides, water can remain liquid at temperatures as high as those of the magma body. Copper and other metals could be derived from the local porphyries, a larger underlying magma chamber, and from surrounding rocks.

5. The return flow of condensate through the vapor-dominated reservoir is relatively dilute, but is normally saturated in SiO_2 (with respect to quartz, 440 ppm at 240° C, Fournier and Rowe, 1966). Reevaporation of this water may account for much of the abundant hydrothermal quartz of porphyry copper deposits.

6. Condensate from the discharge areas of vapor-dominated systems is high in sulfate. Some and perhaps much of this condensate may drain downward to the deep water table and account for the abundant anhydrite of many porphyry copper deposits.

7. The most commonly quoted range in depth for the tops of porphyry copper deposits is from 1,000 to 3,000 meters (Lowell and Guilbert, 1970). The shallower depths seem too low for attaining the indicated temperatures and salinities, but may be possible in a brine below a shallow vapor-dominated reservoir (Fig. 1, curve C, can be at shallower as well as greater than plotted depth).

8. If porphyry copper deposits were indeed formed at depths of 1,000 to 3,000 meters, if most of the water of the ore fluids is of surface origin, as indicated by isotopes, and if near-magmatic temperatures and excess heat flow were maintained close to the surface for thousands of years, some type of hydrothermal activity *must* have characterized the then-existing ground surface. Hot-water systems are numerically far more abundant than vapor-dominated systems, and may be the surface expression of some kinds of ore generation (White, 1967b, 1968a), but dissolved salts are *dispersed* by discharging water, and extreme salinities are not ordinarily attained. The highest salinity yet known in active hot-water systems is about 25 percent, characterizing both the Salton Sea and the Red Sea geothermal brines (White, 1968a). Chemical evidence indicates strongly that the high salinities of these two systems result from the solution of NaCl-rich evaporites. We doubt that evaporites are also involved in the generation of all porphyry copper deposits; some other mechanism for attaining extreme salinity is indicated. Our proposed mechanism for residual concentration of salts by boiling below vapor-dominated systems is a feasible and attractive possibility.

9. The postulated water below a vapor-dominated reservoir may be characterized by high positive temperature and salinity gradients extending downward from the deep water table (Fig. 1), thereby providing a favorable environment for upward transport and

deposition of copper sulfides and pyrite. Temperatures in the water-dominated zone must increase toward the source of heat, presumably an igneous intrusion; actual gradients are highly dependent on the extent of convection in this zone. Formation of vapor bubbles probably occurs largely near the base of penetration of water of the system, where temperatures are highest relative to pressure. Salinity is thereby increased by residual concentration near the base, where permeability is low enough to inhibit convection. On the other hand at higher levels near the deep water table, dissolved salts are being diluted by three processes: (a) *condensation* of dilute water from steam bubbles rising in the brine, as pressures decrease to about 34 kg/cm², as discussed above; (b) downward percolation of *condensate* of steam from the upper margins of the vapor-dominated reservoir; and (c) entry of *new water* recharging the system; this water is likely to be considerably more dilute than the average deep water.

Porphyry copper deposits should be reexamined with consideration of these speculations on temperatures and salinities. If temperatures and salinities do increase sharply downward, our model may provide a new understanding of mode of transport and deposition of the ore minerals. Both decreasing temperature and decreasing salinity upward should favor precipitation of copper sulfides because of the decreasing stability of copper chloride complexes. Introduction of the ore metals may normally occur during a late stage in the total activity after very high salinities have been attained from residual concentration by boiling, and perhaps after the deepest permeable fractures (zone 9 of Fig. 7) have extended downward into a partly cooled major magma chamber.

Porphyry copper deposits should also be examined to determine whether the primary deposits were limited in upward development by a subsurface water table (8 of Fig. 7). Copper and other base metals have low volatilities and could not be transferred into the vapor-dominated reservoir. Pyrite and cinnabar are likely to be characteristic of the zone of condensation (zone 3), and pyrite can also form within the reservoir (zone 11) by reactions involving H_2S and Fe of the rocks. However, pyrite is likely to be much more abundant below the brine water table. Thus, where the original upper limit of copper mineralization and the level of the former brine water table are exposed in the present topography, the water table may be indicated by an anomalous upward *decrease* in supergene oxidation, where pyrite was initially so scarce.

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Menlo Park, California,
July 15; Aug. 22, 1970

REFERENCES

Allen, E. T., and Day, A. L., 1927, Steam wells and other thermal activity at "The Geysers," California: Carnegie Inst. Washington Pub. 378, 106 p.

——, 1935, Hot springs of the Yellowstone National Park: Carnegie Inst. Washington Pub. 466, 525 p.

Baba, Kenzo, 1968, On the temperature and pressure measurements of the geothermal well Matsukawa No. 4: Japan Geol. Survey Bull., v. 19, no. 11, p. 725–728.

Banwell, C. J., Cooper, E. R., Thompson, G. E. K., and McCree, K. J., 1957, Physics of the New Zealand thermal area: New Zealand Dept. Sci. and Indus. Research Bull. 123, 109 p.

Barnes, H. L., and Czamanske, G. K., 1967, Solubilities and transport of ore minerals, *in* Barnes, H. L., Editor, Geochemistry of Hydrothermal Ore Deposits: New York, Holt, Rinehart, and Winston, Inc., p. 334–381.

Bodvarsson, Gunnar, 1964a, Physical characteristics of natural heat resources in Iceland, *in* Geothermal Energy I: United Nations Conf. New Sources Energy, Rome, 1961, Proc., v. 2, p. 82–90.

——, 1964b, Utilization of geothermal energy for heating purposes and combined schemes involving power generation, heating, and/or by-products, *in* Geothermal Energy II: United Nations Conf. New Sources Energy, Rome, 1961, Proc., v. 3, p. 429–436.

——, 1970, Evaluation of geothermal prospects and the objectives of geothermal exploration: Geoexploration, v. 8, p. 7–17.

Burgassi, Renato, 1964, Prospecting of geothermal fields and exploration necessary for their adequate exploitation performed in the various regions of Italy, *in* Geothermal Energy I: United Nations Conf. New Sources Energy, Rome, 1961, Proc., v. 2, p. 117–133.

——, Cataldi, R., Mouton, J., and Scandellari, F., 1965, Prospezione delle anomalie geotermiche e sua appricazione alla regione Amiatina: l'Industria Mineraria, v. 16, p. 1–15.

Cataldi, R., 1967, Remarks on the geothermal research in the region of Monte Amiata (Tuscany-Italy): Bull. Volcanol., v. 30, p. 243–270.

——, Ferrara, G. C., Stefani, G., and Tongiorgi, E., 1969, Contribution to the knowledge of the geothermal field of Larderello (Tuscany, Italy). Remarks on the Carboli area: Bull. Volcanol., v. 33, no. 1, p. 1–27.

Craig, H., 1963, The isotopic geochemistry of water and carbon in geothermal areas, *in* Nuclear geology on geothermal areas, Spoleto: Consiglio Nazionale delle Ricerche, Laboratoria de geologia nucleara, Pisa, p. 17–53.

——, 1966, Superheated steam and mineral-water interactions in geothermal areas: Am. Geophys. Union Trans., v. 47, p. 204–205.

——, Boato, Giovanni, and White, D. E., 1956, Isotopic geochemistry of thermal waters: Natl. Acad. Sci., no. 400, p. 29–38.

Dall'Aglio, M., DaRoit, R., Orlandi, C., and Tonani, F., 1966, Prospezione geochemical del mercurio—distribuzione del mercurio nelle alluvioni della Toscana: Industria Mineraria, v. 17, p. 391–398.

Dickson, F. W., and Tunell, George, 1968, Mercury and antimony deposits associated with active hot springs in the western United States, *in* Ridge, J. D., Editor, Ore deposits of the United States 1933–1967 (Graton-Sales volume), v. 2: New York, Am. Inst. Mining Metall. Petroleum Engineers, Inc., p. 1673–1701.

Eastman, G. Yale, 1968, The heat pipe: Scientific American, v. 218, p. 38–46.

Elder, J. W., 1965, Physical processes in geothermal areas, *in* W. H. K. Lee, Editor, Terrestrial heat flow: Am. Geophys. Union Mon., ser. 8, p. 211–239.

Ellis, A. J., and Mahon, W. A. J., 1964, Natural hydrothermal systems and experimental hot-water/rock interactions: Geochim. et Cosmochim. Acta, v. 28, p. 1323–1357.

——, 1967, Natural hydrothermal systems and experimental hot water/rock interactions (Pt. II): Geochim. et Cosmochim. Acta, v. 31, no. 4, p. 519–538.

Facca, Giancarlo, and Tonani, Franco, 1964, Theory and technology of a geothermal field: Bull. Volcanol., v. 27, p. 143–189.
——, 1967, The self-sealing geothermal field: Bull. Volcanol., v. 30, p. 271–273.
Fenner, C. N., 1936, Bore-hole investigations in Yellowstone Park: Jour. Geol., v. 44, no. 2, pt. 2, p. 225–315.
Ferrara, G. C., Ferrara, G., and Gonfiantini, R., 1963, Carbon isotopic composition of carbon dioxide and methane from steam jets of Tuscany, *in* Tongiorgi, Editor, Nuclear geology on geothermal areas, Spoleto 1963: Pisa, Consiglio Nazionale Delle Ricerche, Laboratorio di Geologia Nucleare, p. 277–284.
Fournier, R. O., and Rowe, J. J., 1966, Estimation of underground temperatures from the silica content of water from hot springs and wet-steam wells: Am. Jour. Sci., v. 264, no. 9, p. 685–697.
——, and Truesdell, A. H., 1970, A device for measuring down-hole pressures and sampling fluids from geothermal wells: Jour. Sci. Instruments [in press].
Haas, J. L., Jr., 1970, The effect of salinity on the maximum thermal gradient of a hydrothermal system of hydrostatic pressure and near boiling: Econ. Geol., in press.
Hayakawa, M., 1969, Anomalous heat flow in Japan: Bull. Volcanol., v. 33, no. 1, p. 57–68.
Helgeson, H. C., 1968, Geologic and thermodynamic characteristics of the Salton Sea geothermal system: Am. Jour. Sci., v. 266, p. 129–166.
Holland, H. D., 1967, Gangue minerals in hydrothermal deposits, *in* H. L. Barnes, Editor, Geochemistry of Hydrothermal Ore Deposits: New York, Holt, Rinehart, and Winston, Inc., p. 382–436.
James, Russell, 1968, Wairakei and Larderello; geothermal power systems compared: New Zealand Jour. Sci. and Technology, v. 11, p. 706–719.
Keenan, J. H., and Keyes, F. G., 1936, Thermodynamic Properties of Steam: New York, John Wiley and Sons, 89 p.
Krauskopf, K. B., 1964, The possible role of volatile metal compounds in ore genesis: Econ. Geol., v. 59, p. 22–45.
Lee, W. H. K., and Uyeda, S., 1965, Review of heat flow data, *in* W. H. K. Lee, Editor, Terrestrial heat flow: Am. Geophys. Union, Geophys. Mon. 8, p. 87–190.
Lowell, J. D., and Guilbert, J. M., 1970, Lateral and vertical alteration-mineralization zoning in porphyry ore deposits: Econ. Geol., v. 65, p. 373–408.
Marinelli, G., 1969, Some geological data on the geothermal areas of Tuscany: Bull. Volcanol., v. 33, no. 1, p. 319–334.
McNitt, J. R., 1963, Exploration and development of geothermal power in California: Calif. Div. Mines and Geology Spec. Rept. 75, 45 p.
Mercado, Sergio, 1969, Chemical changes in geothermal well M-20, Cerro Prieto, Mexico: Geol. Soc. America Bull., v. 80, p. 2623–2629.
Muffler, L. J. P., White, D. E., and Truesdell, A. H., 1971, Hydrothermal explosion craters in Yellowstone National Park: Geol. Soc. America Bull. [in press].
Nakamura, Hisayoshi, and Sumi, Kiyoshi, 1967, Geological study of Matsukawa geothermal area, northeast Japan: Japan Geol. Survey Bull., v. 18, no. 2, p. 58–72.
Otte, Carel, and Dondanville, R. F., 1968, Geothermal developments in The Geysers area, California [abs.]: Am. Assoc. Petroleum Geologists Bull., v. 52, p. 575.
Penta, Francesco, 1959, Sulle Origini del Vapore Acqueo Naturale e Sull' attuale Stato delle Relative Ricerche (Ricerche per "forze Endogene"): La Ricerca Scientifica, v. 29°, num. 12, p. 2521–2536.
Saito, Masatsugu, 1964, Known geothermal fields in Japan, *in* Geothermal Energy I: United Nations Conf. New Sources Energy, Rome, 1961, Proc., v. 2, p. 367–373.
Schoen, Robert, and Ehrlich, G. G., 1968, Bacterial origin of sulfuric acid in sulfurous hot springs: Internat. Geol. Cong., 23d, Prague, v. 17, p. 171–178.
Sheppard, S. M. F., Nielsen, R. L., and Taylor, H. P., Jr., 1969, Oxygen and hydrogen isotope ratios of clay minerals from porphyry copper deposits: Econ. Geol., v. 64, p. 755–777.
Sourirajan, S., and Kennedy, G. C., 1962, The system H_2O-NaCl at elevated temperatures and pressures: Am. Jour. Sci., v. 260, p. 115–141.
White, D. E., 1957a, Thermal waters of volcanic origin: Geol. Soc. America Bull., v. 68, no. 12, p. 1637–1658.
——, 1957b, Magmatic, connate, and metamorphic waters: Geol. Soc. America Bull., v. 68, p. 1659–1682.
——, 1964, Preliminary evaluation of geothermal area by geochemistry, geology, and shallow drilling, *in* Geothermal Energy I: United Nations Conf. New Sources Energy, Rome, 1961, Proc., v. 2, p. 402–408.
—, 1967a, Some principles of geyser activity, mainly from Steamboat Springs, Nevada: Am. Jour. Sci., v. 265, p. 641–648.
——, 1967b, Mercury and base-metal deposits with associated thermal and mineral waters, *in* Barnes, H. L., Editor, Geochemistry of Hydrothermal Ore Deposits: New York, Holt, Rinehart, and Winston, Inc., p. 575–631.
——, 1968a, Environments of generation of base-metal ore deposits: Econ. Geol., v. 63, no. 4, p. 301–335.
——, 1968b, Hydrology, activity, and heat flow of the Steamboat Springs thermal system, Washoe County, Nevada: U. S. Geol. Survey Prof. Paper 458-C, p. C1–C109.
——, 1969, Rapid heat-flow surveying of geothermal areas, utilizing individual snowfalls as calorimeters: Jour. Geophys. Research, v. 74, no. 22, p. 5191–5201.
——, Brannock, W. W., and Murata, K. J., 1956, Silica in hot-spring waters: Geochim. et Cosmochim. Acta, v. 10, p. 27–59.
——, Hem, J. D., and Waring, G. A., 1963, Chemical compositions of subsurface waters, *in* Data of geochemistry: U. S. Geol. Survey Prof. Paper 440-F, 67 p.
Wilson, S. H., 1955, Chemical investigations, *in* Grange, L. I., Editor, Geothermal steam for power in New Zealand, chap. 4: New Zealand Dept. Sci. and Indus. Research Bull. 117, p. 27–42.

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