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MASTER

EXPERIMENTAL GEOTHERMAL RESEARCH FACILITIES STUDY (Phase 0)

31 December 1974

Volume 1

Final Report No. 26405-6001-RU-00

Prepared for

THE NATIONAL SCIENCE FOUNDATION

Grant No. GI-44149

6329000

TRW

DISCLAIMER

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ABSTRACT

The study comprises Phase 0 of a project for Experimental Geothermal Research Facilities, performed by TRW Systems Group under Grant No. GI-44149 of the National Science Foundation's overall program of Research Applied to National Needs (RANN). The study focuses on identification of a representative liquid-dominated geothermal reservoir of moderate temperature and salinity, preliminary engineering design of an appropriate energy conversion system, identification of critical technology, and planning for implementation of experimental facilities. The objectives included development of liaison with the industrial sector, to ensure responsiveness to their views in facility requirements and planning, and incorporation of environmental and socio-economic factors.

The overall project, of which the six-month Phase 0 is reported herein, is phased in accordance with RANN guidelines. This Phase 0 report covers problem definition and systems requirements. Phase 1 will involve design of the experimental facility, and testing of components. Phase 2 will comprise detailed design and construction of an experimental geothermal electrical powerplant at East Mesa, Imperial County, California. Facilities will incorporate capability for research in component, system, and materials technology and a nominal 10 MWe experimental, binary cycle, power generating plant.

ACKNOWLEDGEMENTS

The Phase O Study on Experimental Geothermal Research Facilities was conducted by the TRW Systems' System Integration Laboratory under Project Manager Robert H. Douglass, with Carl E. Hilbers acting as his Deputy for Geothermal Systems, Russell O. Pearson as Principal Investigator, Raoul Choate as Project Geologist, and Lee Leventhal in charge of Plant Engineering.

The following TRW personnel made valuable contributions to the Phase O Study effort:

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Rogers Engineering — Architect-Engineer services involving preliminary design layout and cost estimate.

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1. INTRODUCTION AND SUMMARY

This report presents results of a study sponsored by the National Science Foundation as part of their program of research in utilization of geothermal resources. It focuses on identification of a representative liquid-dominated geothermal reservoir of moderate temperature and salinity, preliminary engineering design of an appropriate energy conversion system, identification of critical technology, and planning for implementation of experimental facilities. The objectives include development of liaison with the industrial sector, to assure responsiveness to their views in facility requirements and planning, and incorporation of environmental and socio-economic factors. The study comprises Phase 0 of a project in "Experimental Geothermal Research Facilities," performed by TRW Systems Group under Grant No. GI-44149 of the National Science Foundation's overall program of "Research Applied to National Needs"(RANN).

A geothermal reservoir has been discovered at East Mesa, Imperial County, California, which uniquely meets criteria established to select a site on which facilities can be developed to conduct research in technology in using liquid-dominated systems of moderate temperature and salinity. Further, it appears that a range of fluid characteristics is available at this site, this providing a spectrum of test fluid parameters to potential experimenters. Engineering studies have indicated a binary energy conversion system as optimum for utilization of fluids produced from existing wells on the site. Industrial advisors to the project have indicated the desirability of the planned experimental facilities, and it has been determined that (1) environmental impact is comparatively low, and (2) there are viable options for utilization of power generated at the site. Finally, it has been determined that ownership of site improvements can and should be vested in a government agency. Options also appear viable in this area.

The overall project, of which the six-month Phase 0 is reported herein, is phased in accordance with RANN guidelines as indicated in the project flow diagram (Figure 1-1). This Phase 0 report covers problem definition and systems requirements. Phase 1 will involve design of the experimental facility and testing of components. Phase 2 will comprise detailed design and construction of an experimental geothermal electrical power plant facility, incorporating facilities for research in component, system, and materials technology, and a nominal 10 MWe experimental binary cycle power generating plant, as shown in Figure 1-2.

Previous studies and investigations have indicated the existence of large potential reserves of geothermal water in the United States which, if utilized, might significantly reduce the need for fossil fuels. In view of the national

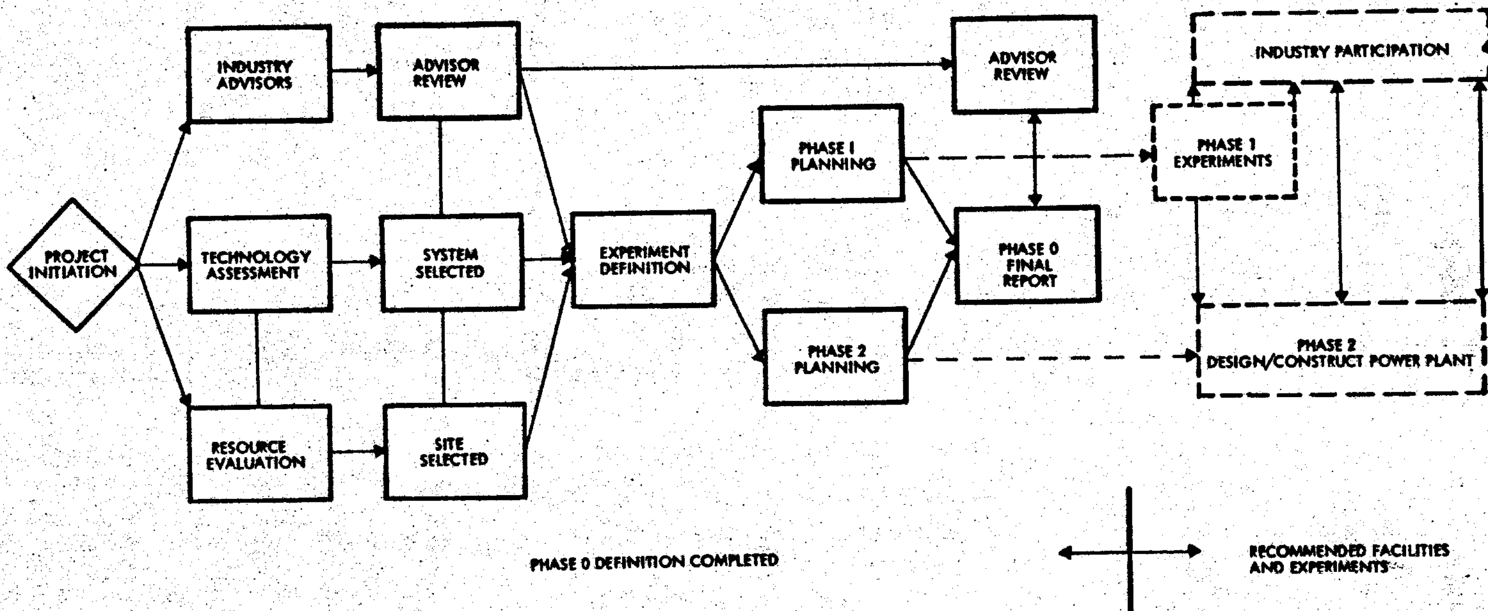


Figure 1-1. Project Flow

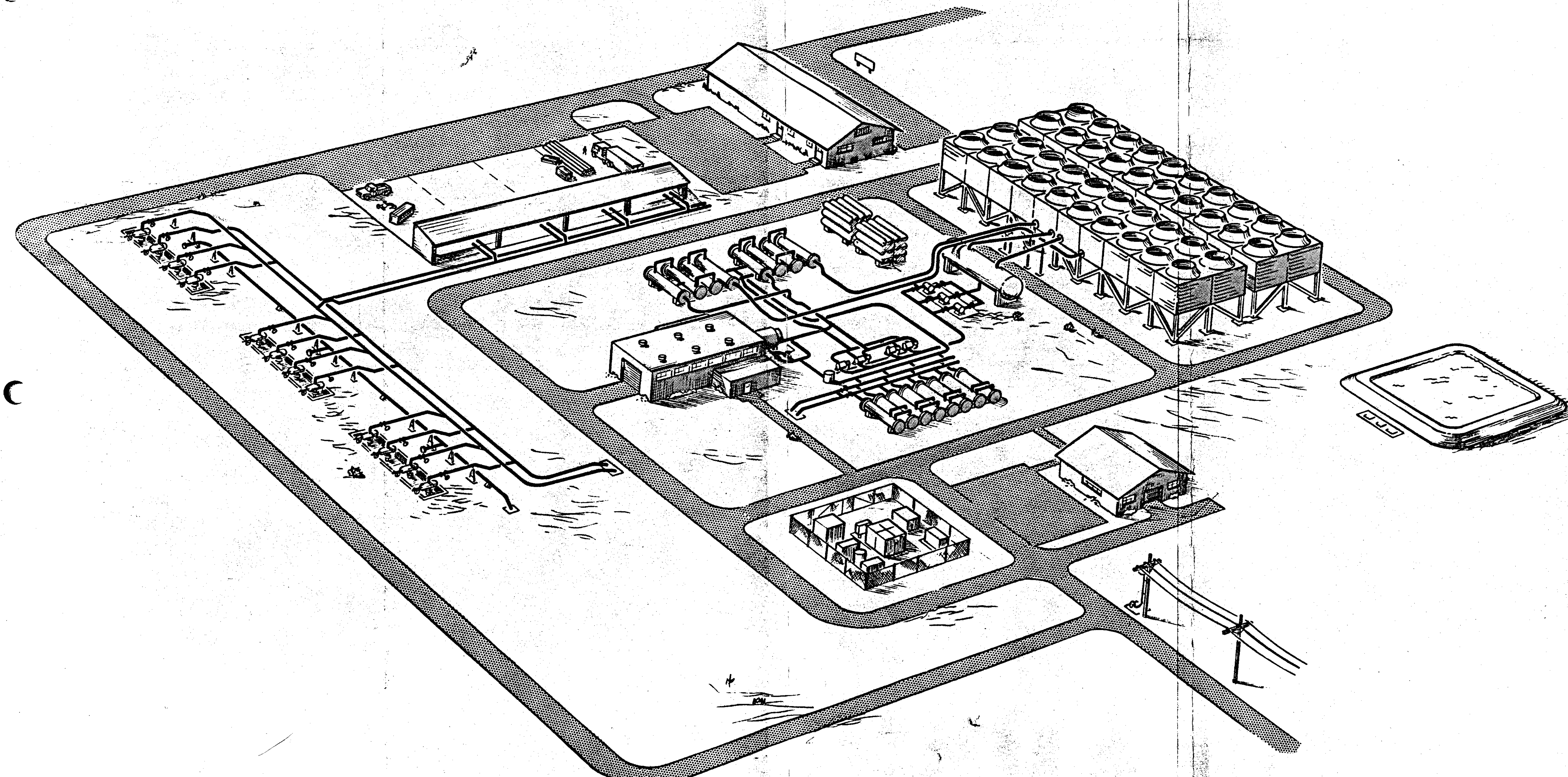


Figure 1-2. Experimental Geothermal Research Facilities

goals for development and utilization of geothermal energy (nominally 20,000 MWe by 1985, thus saving the equivalent of 750,000 barrels of oil per day), current capital investment is comparatively low. Our study, and contact with the industrial sector, indicates that, aside from availability of the resource itself, extant technology for extraction and conversion of geothermal fluid energy is at present inadequate to present low risk to capital. Construction and operation of the planned experimental research facilities, with appropriate industrial participation, would thus hasten the availability of requisite technology to move utilization of geothermal brine reservoirs from experimental to operational phases in a time frame consistent with national objectives.

In recognition of needs for the experimental facilities, the Phase 0 study objectives were to

- Select a representative geothermal hot water resource
- Select an energy conversion system optimally compatible with the properties of the selected resource
- Define utilization system requirements, technical, economic, and environmental
- Identify critical technology
- Plan Phase 1 and Phase 2 experiments
- Develop Phase 1 and Phase 2 implementation plans
- Develop power utility industry participation.

The results of the study are summarized as follows:

- While many areas in the United States are highly prospective for liquid-dominated geothermal reservoirs, only a few are proven. From viewpoints of existing reservoir development and availability of data to the public, the East Mesa site is unique. It is representative of a liquid-dominated reservoir, exhibiting fluid properties of 350°F to 390°F and 3,000 to 25,000 ppm total dissolved solids.
- Assuming proven extraction and conversion technology is available (an overall project objective), representative geothermal hot water resources can cost-effectively compete with oil-fired power plants at a petroleum cost of $8 per barrel or higher.
- A binary cycle energy conversion system using isobutane as the working fluid in a closed Rankine cycle was determined to be the most efficient and cost effective in the representative resource.
- The technology for the binary/Rankine cycle system is as yet not sufficiently developed to institute large scale commercial utilization.
- An experimental test facility is required for the development of critical technology. The facility must accommodate a broad range of research and a variety of system concepts, many of which are promising but extremely developmental. Component and materials technology development is required, however, even for application of more conventional (e.g., binary) systems to geothermal energy conversion.
- To provide credible reliability and economic data for attraction of major capital investment in binary

geothermal power plants, a representative installation of 10 MWe nominal capacity is required. Such a facility, located at East Mesa, might readily be coupled to a major load center.

- The recommended Phase 1 portion of the project will span 18 months at a probable cost of $4,100,000.

- Phase 2 will have a time span of 24 months at a probable cost of $16,930,000. Accordingly, in the ordinary program progression of Phase 2 being initiated at the completion of Phase 1, 44 months will elapse from the start of Phase 1 to completion of the experimental facilities. However, TRW strongly recommends an accelerated schedule in which certain portions of both phases are conducted currently. This accelerated schedule will result in a total program time frame of 30 months — saving a full year.

Project objectives, plus review of data available from 17 potential sites, yeilded the following criteria for site selection, generalized here for brevity:

- The site resource should be broadly representative of liquid-dominated, moderate temperature, and salinity deposits

- A maximum of surface and subsurface geological and geophysical data should be available, and should so characterize the resource as to minimize risk in project implementation

- The site's technical, economic, environmental, political, and institutional situation should be favorable to use of public funds for development of a research facility.

We believe the East Mesa site occupied by the U.S. Bureau of Reclamation (USBR) in Imperial County, California satisfies the criteria uniquely and advantageously. Fluid characteristics (nominally 350°F and 4000 ppm TDS) have been proven by the five deep wells drilled by the USBR. Estimated life (Handy and Choate, independently) of the reservoir is 100 years.

TRW strongly recommends that the existing wells and facilities at the East Mesa site be appropriately altered and augmented to support a federally-sponsored experimental test facility. Development of the site by the USBR is well along; access roads and facilities are in place, a load center for utilizing the experimental facilities electrical output exists, environmental impact is low, and there will be no land use problems in further development of the site. A comprehensive Environmental Impact Report covering use of the site for geothermal energy recovery has been filed by USBR. The above factors involve a significant cost and time saving to the proposed geothermal experimental facility.

The Imperial Valley is a large load center, and the government site is surrounded by private lease holdings in the same geologic formation. This situation gives rise to the following:

- Various options for utilization of power generated of the site, including desalination of water (USBR), as well as insertion into the local power grid, are available.

- The site location makes it highly viable, accessible, and relevant to public and private interests in development of the region's geothermal reservoirs. Rapid transfer of technological development to commercial utilization is facilitated.

- Development of facilities on government land would not entail a third party beneficiary question.

Three basic energy conversion system concepts, and permutations thereof, were studied to select an optimal for known and postulated characteristics of the reservoir, and available cost and engineering data. These included flashed steam, binary, and hybrid systems. In general, an effort was made to avoid configurations where technological breakthroughs were implied, although technological development is required in all cases, as noted in the body of this report.

For the enthalpy and chemistry of the selected reservoir, a binary energy conversion system using isobutane as the working fluid appears optimal. Development of technology for reliability, performance, and economy in binary systems would in our view make such systems logical choices for commercial development on a large scale, in view of the recognized preponderance of moderate temperature geothermal deposits in the United States when compared to high temperature liquid or dry steam reservoirs. Moreover, since the component technology of binary systems is largely common for alternative approaches, research and development on binary systems will have significant impact on a broad spectrum of energy conversion and utilization concepts.

Baseline characteristics for comparison of candidate systems included costing in 1974 dollars, plant output of 50 MWe, use of wet cooling towers, and directionally drilled wells. For the selected binary system, all-up (wells and power plant) costs of $540 per kilowatt were projected, which were the lowest of all candidates considered. Since wet cooling towers are precluded in arid regions, e.g., East Mesa, we have projected binary system costs with dry cooling towers at $1,008 per kilowatt. Costs also were projected for binary systems at 3, 10, 25, and 50 MWe output for comparison. It was determined that all-up cost was roughly linear with output above 10 MWe. Components of 10 MWe (i.e., generator, switchgear and turbine) are the smallest size commercially available which are representative of utility equipment life and operating characteristics. Thus a 10 MWe plant is the smallest whose economics can be reliably scaled for commercial utilization; our recommendation for binary system concept demonstration plant is a nominal output of 10 MWe.

Section 3 of this report presents the systems engineering work, component and materials studies, identification of critical components, and system cost comparisons. Components identifiable as critical include down-hole pumps and heat exchangers. A considerable experimental effort in materials proof testing is required.

To gain the views of the power utility industry as related to the objectives of the study, TRW invited representatives of the Southern California Edison Company, the San Diego Gas and Electric Company, and the cities of Burbank and Riverside to act as Project Advisors. A representative of the Sierra Club was also invited to act as an advisor to provide an early communicative link with the environmentalist community. All invitations were accepted, and an exchange of information and views implemented through briefings, interviews, and correspondence. The views of the Project Advisors are presented in Appendix D. No effort was made to gain a consensual opinion from the advisors as a group. However, a collective expression of needs for technological development to minimize capital risk and meet environmental criteria was elicited. The following comments of Mr. Lyn Rasband of Southern California Edison Company are indicative.

"I think East Mesa, a medium temperature, low salinity reservoir will be representative of a large majority of future geothermal fields. If your (TRW) project is carried to the actual demonstration phase, some badly needed hard-line reliability data could be obtained."

And from Dr. Hamilton Hess of the Sierra Club: "I would see this project as fulfilling a definite need in the exploration of the concept of the utilization of geothermal energy. I believe that the project site is the least environmentally sensitive of the sites that were considered and is therefore the preferable from the environmental standpoint."

Utilization of the completed experimental facilities for maximal benefit to commercial development of geothermal power implies institution of policies and mechanisms to gain industrial participation in research and development performed in the facilities, and rapid and effective transfer of information, subject to certain conditions and restraints indicated below. We include as options:

- Government sponsored work contracted to industrial firms, fully reported in the open literature
- Rental of facilities to industrial firms, under which arrangement rights in data are protected
- Conduct of experimental work in which objectives, data requirements, and success criteria are specified by industrial organizations, e.g., Electric Power Research Institute. This option would appear especially appropriate to acquisition of reliability and economic data essential to industry-wide acceptance of technology as applicable to commercial exploitation.

The above options do not preclude use of the facilities by government research and development organizations, nor by academic and nonprofit institutions. Emphasis on industrial participation is regarded as essential to the project's overall objectives.

Vestiture of title for the East Mesa facilities may be placed, for the present, with the USBR, which currently occupies the site and is a logical choice as lead agency for the planned facility implementation. Transfer of the facility to the Energy Research and Development Agency (ERDA) is suggested as an option. However, a close coupling with USBR is strongly recommended throughout the project because of their previous work at the site, but also to capitalize on the potential for alternative use of the geothermal fluids as well as power generated at the site.

Priorities for experimental work have been identified and clarified by the study. Immediately recognized are needs for technological development in down-hole pumps, heat exchangers, and materials. A general requirement for well completion technology to increase formation permeability and well production rates is observed. Considerable progress in these areas is anticipated in Phases 1 and 2 of the project. Section 5 presents our Recommended Implementation Plan. The reader is also referred to the comments of Mr. James Woodburn, Chief Engineer, Public Service Department, City of Burbank, in Appendix D.

Recognizing the critical nature of the need, the planning has included concurrent Phase 1 and Phase 2 activities as an option. TRW has further established a project team and working relationships with the necessary consultants, equipment manufacturers, and architecture and engineering firm to support an accelerated effort. If implemented, the accelerated effort would result in total project completion within 30 months.

Because of the breadth of scope and the many issues addressed in the study, this introduction cannot do more than indicate results and recommendations. We have attempted to facilitate review of the work by organization of this report into two volumes:

Volume I — Experimental Geothermal Research Facilities

Volume I includes reports of all of the major study efforts and summarized results and recommendations including implementation plans for Phase 1 and 2.

Volume II — Appendices A through I

Volume II presents detailed results of studies and analyses arranged in nine appendices which can be consulted by the reader as desired.

TRW has elected to use units of the English system of measurement throughout the report, rather than metric, since A&E firms, drilling contractors, and the utility industry are all uniform in the uses of the English system.

2. RESOURCE EVALUATION AND SELECTION

A basic problem facing the development of a viable geothermal power industry lies in the location of usable geothermal resources. The geothermal fluid most likely to be used for future power generating systems is hot water of moderate temperature and salinity. Use of dry steam such as is found in the Geysers Field of California, or highly saline waters such as are found in the Niland Field of California, probably will be rare. In this study, we concentrated on geothermal hot water resources of moderate temperature and salinity.

The eleven western states between the Rocky Mountains and the Pacific Ocean form a major geothermal province. Throughout this region, late Tertiary and Recent volcanic rocks are widespread, hot springs are numerous, and many abnormally high temperature gradients occur in oil wells. Also, over 240 good measurements of terrestrial heat flow now exist in the United States and these show a clear division of the country into western and eastern thermal provinces. East of the Rockies, heat flow is comparatively low and uniform, typical of regions that have been inactive geologically since Mesozoic time. In the western states, heat flow is 50% greater than in the east and large variations from this mean are common including some very high values. Such a heat flow distribution is typical of regions marked by extensive volcanic and tectonic activity in Tertiary and Recent times. Such regions have provided all the world's producing geothermal fields to date and provide the best prospects for the future.

The widespread normal and transverse faulting, the volcanic activity and the high heat flow characteristics of the western United States all fit into the global picture of plate tectonics expressing complex events occurring as the North American continental plate overrode the East Pacific Rise, a major sea floor spreading axis.

In the 11 western states, geothermal exploration has been underway for approximately 20 years. Early exploration consisted primarily of surface geological and hydrological mapping and drilling of shallow wells. Lately, surface geophysical surveys have become common, and wells deeper than 2,000 feet have been drilled. Surface geophysical data and one or more deep wells exist in at least 27 locations, and exploration appears to be accelerating. The geothermal resource potential of the western states is detailed in Appendix A.

A primary task of this study was to select a suitable site for an experimental geothermal facility. This task involved a comprehensive review of the geophysical, geological, geochemical, hydrological, and socio-economic data available on both proven and potential geothermal resources. Based on this review, we developed the following set of criteria for selecting the site.

- Strong probability of the existence of a geothermal reservoir
- Existence of a hot water resource of low-to-moderate salinity
- History of exploration and assessment, and availability of geotechnical and reservoir data including
  - Deep wells with geophysical logs
  - Surface geophysical surveys
  - Test data on water temperature and chemical composition
  - Water production tests
- Favorable reservoir characteristics, such as
  - Desirable porosities and permeabilities
  - Large area for many wells and major future development
  - Thick sequence of reservoir strata
  - Good inter- and intra-strata communication permitting efficient full-field development
- No restrictions on the availability and dissemination of all data collected, derived and used in the program
- Amenability to rapid development
  - Minimal land use difficulties with sufficient acreage for the site readily available
  - Minimal environmental problems
  - Minimal political and institutional problems.

These criteria and the site selection process are described more fully in Appendix B.

After applying these criteria to various geothermal sites throughout the western United States, TRW found that the optimum site for the experimental facility is the East Mesa area of Imperial County, California.

East Mesa is uniquely suitable for such a facility. It is a geothermal deposit located in a deep sedimentary basin. The basic feasibility of developing such a deposit has been demonstrated in the Cerro Prieto Field in Mexico. The United States Bureau of Reclamation (USBR) has worked in this area for years, conducting a program of surface geophysical explorations and deep drilling. The existence of a geothermal reservoir with desirable characteristics has been proven. Many of the facilities required to develop the reservoir are already in place, and no major environmental, political and institutional obstacles to development exist.

The East Mesa Field is located in a Known Geothermal Resource Area (KGRA), centered in Section 6, T16S, R17E, approximately seven miles southwest of Holtville (see Figure 2-1). The field has five deep (6,000 to 8,000 feet) wells drilled by the USBR specifically as geothermal tests. Four of these wells (Mesa 6-1, 6-2, 8-1, and 31-1) are planned as geothermal producers; the fifth (Mesa 5-1) is an injection well. There are no hot springs or

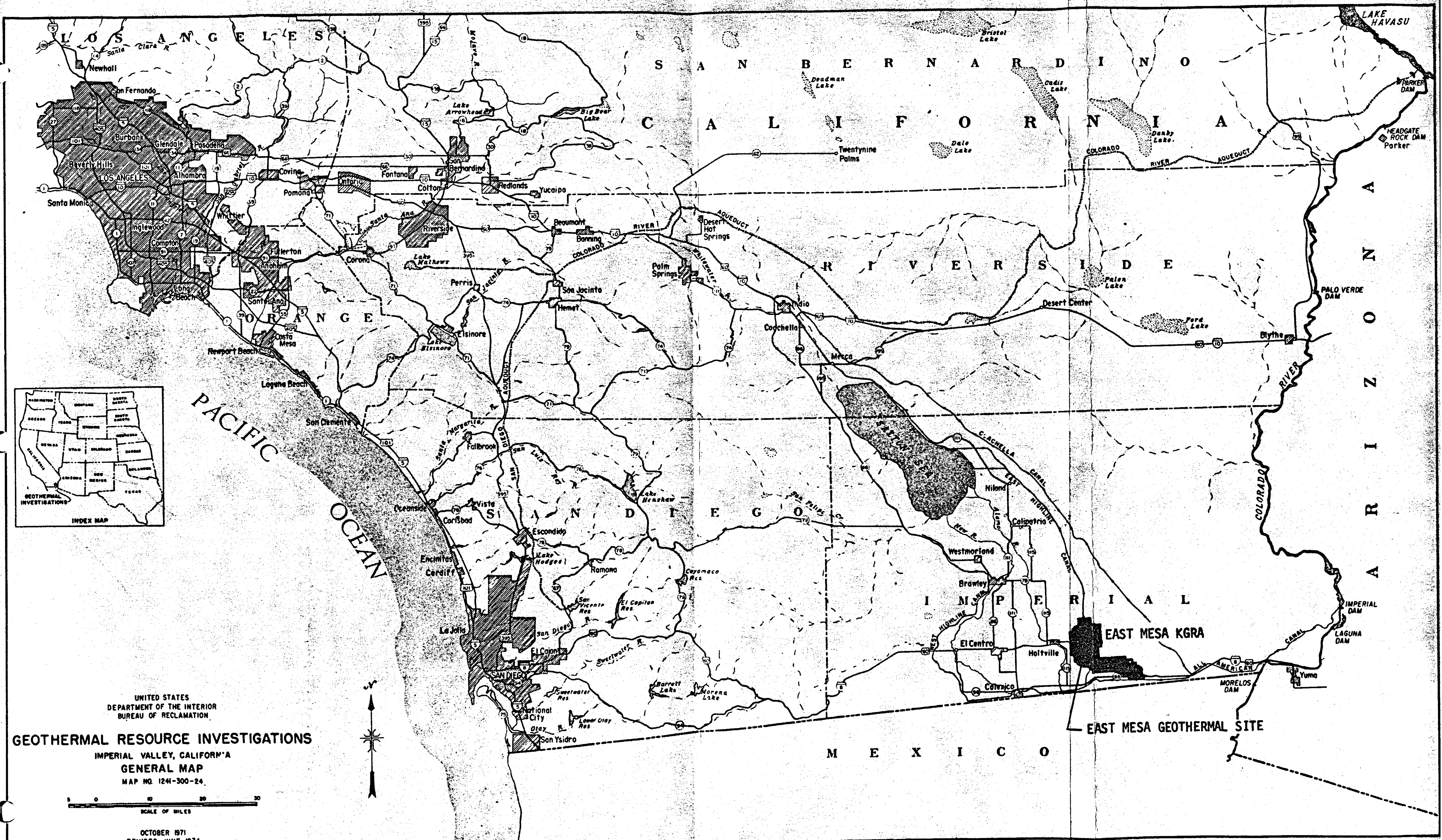


Figure 2-1. Geothermal Resources Investigations General Map

other surface manifestations of geothermal activity at East Mesa.

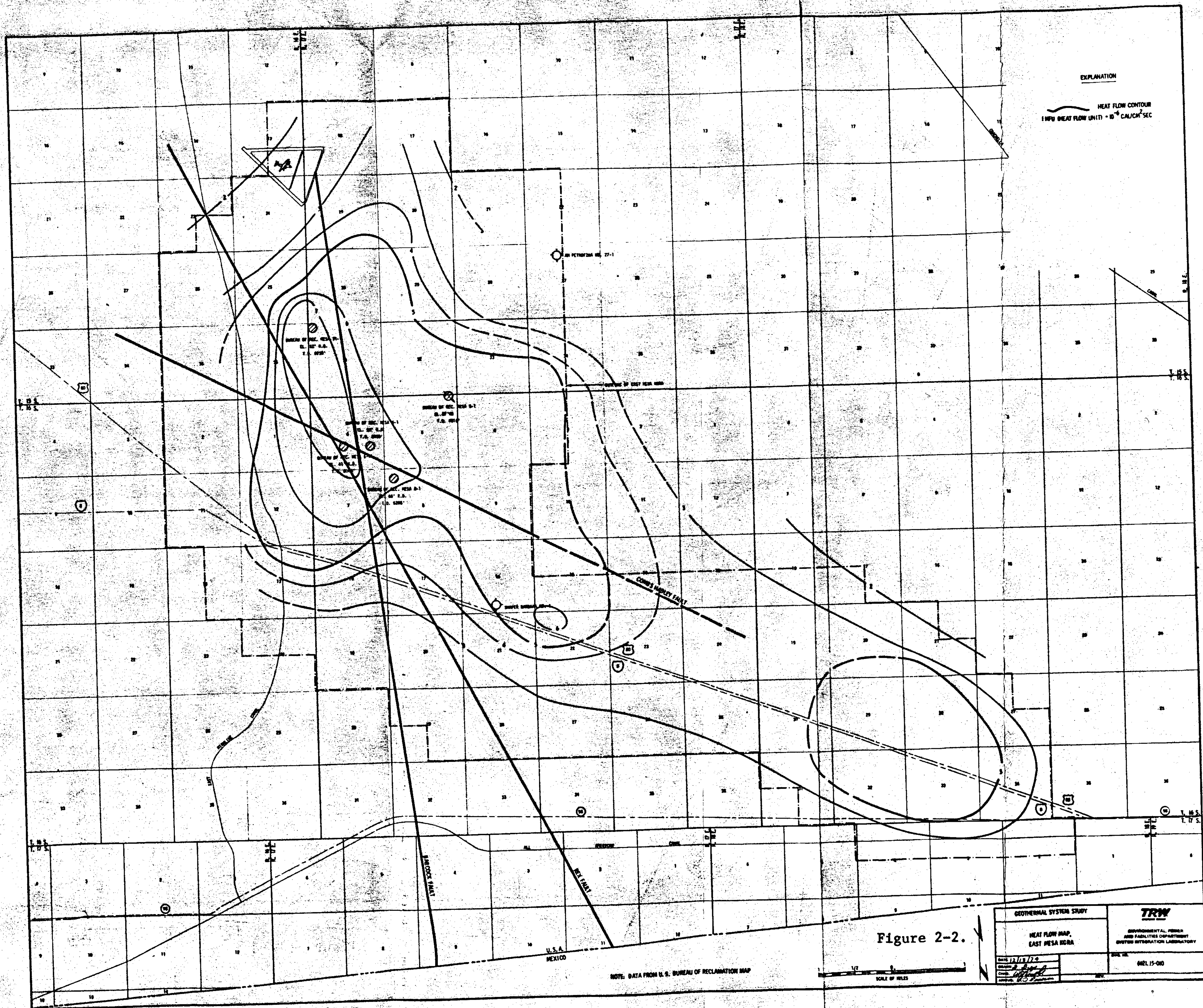
The field lies on the east flank of the Salton Trough, the continental extension of the East Pacific Rise. The surface at East Mesa is barren and featureless alluvium and dune sand. The nearest crustal outcrops are Tertiary volcanics approximately 25 miles to the east and northeast.

The subsurface of East Mesa is a deltaic sequence of sands, silts and clays becoming compacted to sandstone, siltstone and claystone with depth. No stratigraphic marker beds, either lithological or paleontological, have been identified and no well-to-well correlations have been found on the geophysical logs. This lack of correlations has made determination of the geologic structure of the area particularly difficult. Seismic refraction data indicate that the basement is at least 11,000 feet deep.

Surface geophysical exploration techniques have been used successfully in the East Mesa area. Virtually every technique used has shown an anomaly over the geothermal field. Thermal data obtained from shallow test holes have been of prime importance in discovering and delineating this field. Figure 2-2 depicts heat flow contours derived from the thermal measurements as well as the locations of the wells. Note that the geothermal field lies on the heat flow maximum. Other geophysical techniques, such as gravity, electrical-resistivity, microearthquake activity, and seismic-noise, indicate anomalies coincident with the field as shown in Figure 2-3. Major faulting in the field has been postulated (see Figures 2-2 and 2-3).

Figure 2-4 presents temperature profiles of the East Mesa geothermal wells. Note that for all wells, the profile steepens below 2,500 feet. This change in profile probably denotes a change in heat transfer mechanism, conductive transfer occurring above 2,500 feet and convective transfer below. For wells lying on the heat flow maximum (that is, Mesa 6-1, 6-2, and 8-1), temperatures at depths below 2,500 feet average 350°F, which is high enough to be exploitable; temperatures at the same depths in wells off the heat flow maximum (Mesa 5-1 and 31-1) are lower, nominally 275°F.

Geophysical data obtained from logs of the geothermal wells were combined by the Saraband computer method to determine various reservoir characteristics, including sandstone-shale lithology, porosity, permeability, water saturation, and water quality. The Saraband program output is foot-by-foot data, which were combined to determine average values of porosity, permeability and water quality over approximate ten foot intervals; these are displayed in Figure 2-5 for the Mesa 6-1 well. The intervals of apparent zero porosity in Figure 2-5 indicate clay. Note that the clay content is considerably greater in the conductive heat transfer zone above 2,500 feet. Sand predominates


EXPLANATION
HEAT FLOW CONTOUR
1 HFU (HEAT FLOW UNIT) = 10^-6 CAL/CM^2 SEC
COMBS HANLEY FAULT
U.S.A.
MEXICO
NOTE: DATA FROM U.S. BUREAU OF RECLAMATION MAP
SCALE OF MILES
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HEAT FLOW MAP,
EAST MESA KGRA
TRW
ENVIRONMENTAL, POWER
AND FACILITIES DEPARTMENT
SYSTEM INTEGRATION LABORATORY
DATE 12/13/74
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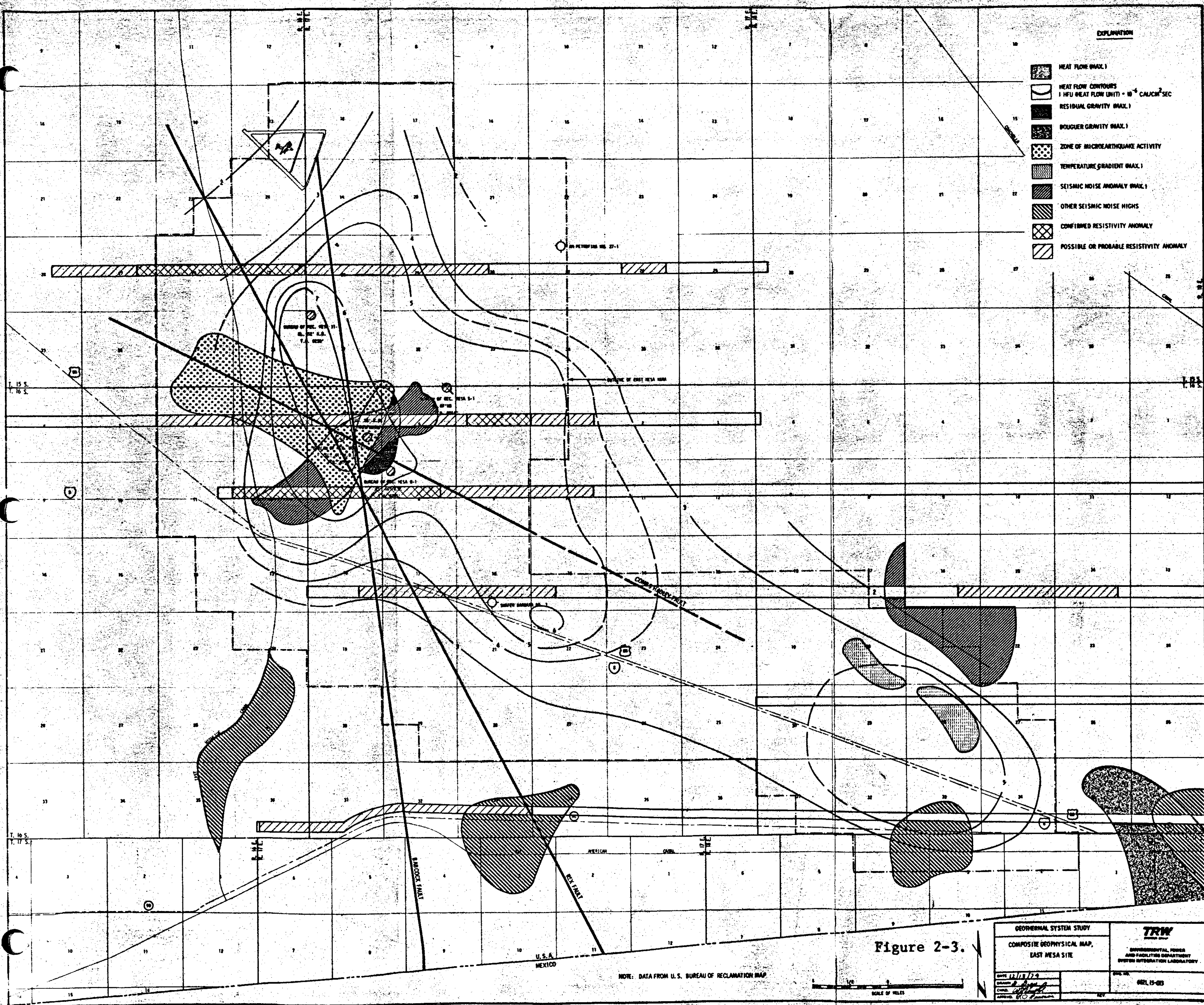
Figure 2-2.


EXPLANATION
HEAT FLOW (MAX.)
HEAT FLOW CONTOURS
1 HFU (HEAT FLOW UNIT) = 10^-6 CAL/CM^2 SEC
RESIDUAL GRAVITY (MAX.)
BOUGUER GRAVITY (MAX.)
ZONE OF MICROEARTHQUAKE ACTIVITY
TEMPERATURE GRADIENT (MAX.)
SEISMIC NOISE ANOMALY (MAX.)
OTHER SEISMIC NOISE HIGHS
CONFIRMED RESISTIVITY ANOMALY
POSSIBLE OR PROBABLE RESISTIVITY ANOMALY
T. 15 S.
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T. 17 S.
BABCOCK FAULT
U.S.A.
MEXICO
AMERICAN CANAL
NOTE: DATA FROM U.S. BUREAU OF RECLAMATION MAP
SCALE OF MILES
GEOTHERMAL SYSTEM STUDY
COMPOSITE GEOPHYSICAL MAP,
EAST MESA SITE
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Figure 2-3.

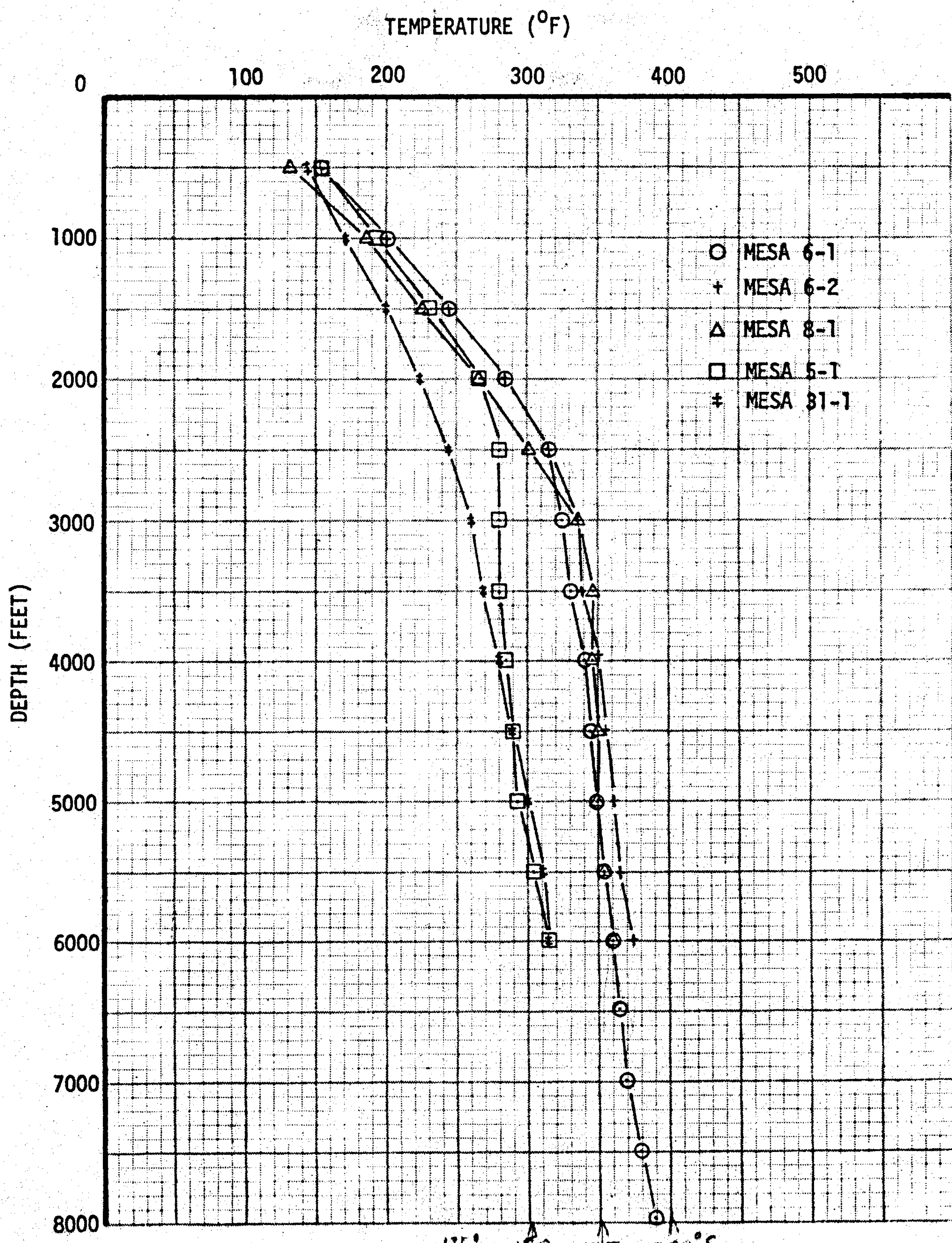


Figure 2-4. East Mesa Geothermal Well Temperature Profiles

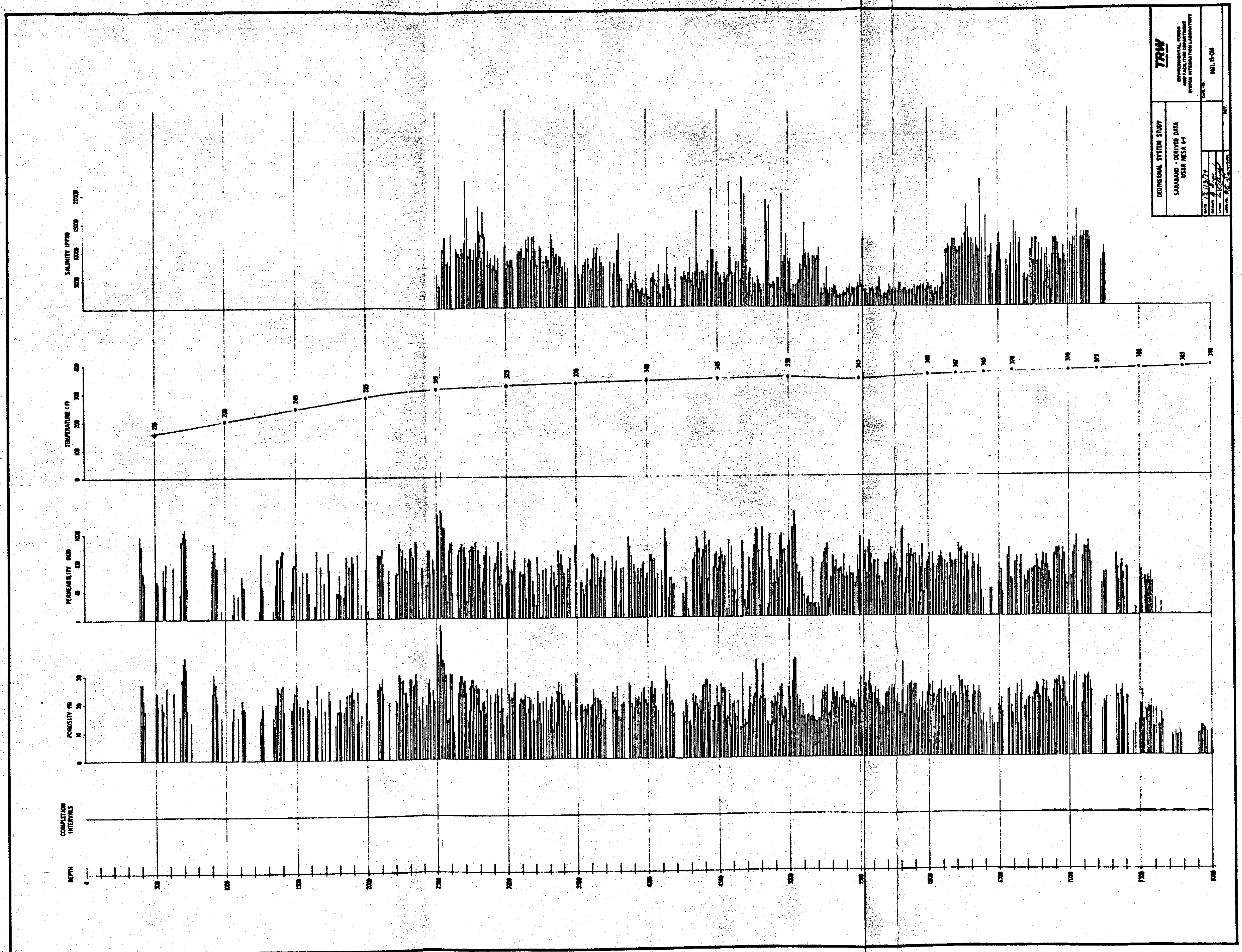


Figure 2-5. Saraband - Derived Data USBR Mesa 6-1

from 2,500 to 7,000 feet; below this, the clay content again becomes significant. Bulk porosity is approximately 20 percent from 2,500 to 7,000 feet and diminishes below that depth.

In the Saraband process, permeability is derived empirically from the porosity data and therefore may be subject to question at any one specific locality, such as East Mesa. The general Saraband-derived permeabilities of 50 to 100 millidarcies are in general agreement with permeabilities provided by other investigators (Rex et al, 1972). However, permeability values derived from drill stem test data are considerably lower than the Saraband values.

Permeability decreases below 7,000 feet in Mesa 6-1 and becomes less than one millidarcy below 7,600 feet. Water production below this depth has been attributed to fracture rather than intergranular permeability.

The water table at East Mesa is shallow — less than 20 feet — and the subsurface section is 100 percent water saturated. In Mesa 6-1, water quality (defined as the total dissolved solids by weight) below 2,500 feet is 4,000 to 5,000 parts per million (ppm) decreasing to approximately 3,000 ppm below 5,000 feet. Of particular interest is the abrupt increase in dissolved solids to 10,000 ppm at 6,100 feet. This depth is marked by two 12-foot clay beds. Thus, two geothermal reservoirs may exist at East Mesa — a fresher water body of approximately 3,000 ppm lying above a more saline body ranging from 10,000 to 25,000 ppm. Other wells in the area, however, are not deep enough to determine whether this postulated deeper reservoir exists.

Analysis of water quality in the geothermal field wells and in outlying wildcat oil wells indicates that water above 6,000 feet becomes fresher (salinity decreases) as distance from the area of maximum heat flow increases. Water in the area of maximum heat flow, as evidenced by the Mesa 6-1 and 6-2 wells, is more highly mineralized, i.e., contains more ions other than Na^+ and Cl^-, than water away from the heat flow maximum.

In summary, the geothermal reservoir at East Mesa appears to lie at depths between 4,200 and 6,200 feet. This 2,000-foot interval (or reservoir) represents the best tradeoff between water temperature, water quality, and formation stability. Furthermore, it affords a host rock section thick enough to provide the water flow needed for the power generating system.

Environmental considerations, notably subsidence, are a very real concern at the East Mesa site. A first and second order level network has been established in the Imperial Valley by several governmental agencies and this network is resurveyed periodically. Also, subsidence monitoring instrumentation is being installed within the geothermal field, consisting of two tiltmeters and two extensometers placed in drill holes previously used for thermal measurements.

Appendix B contains details on the geology, geophysics, geochemistry and hydrology of the East Mesa Field.

The East Mesa Field can be a prolific geothermal producer if developed properly. Theoretical calculations indicate that the life of the field can be extended beyond 100 years if the produced water is reinjected into the reservoir. Based on the limited data available, the expected flow rate from a single well is at least 0.7 gallons/minute/foot of producing section, with a pressure drawdown of 1,700 psi. If the producing section is 1,500 feet, the minimum expected flow from one well is 1.5 x 10^6 gallons/day. (See Appendix C for details.)

However, additional testing is required to establish reservoir extent and continuity, including static and flow pressure measurements, pulse testing, and testing for interference among adjacent wells. For the purpose of water cycling, the injectivity characteristics of the formation should be determined, and additional temperature surveys are desirable. Also, it may be advantageous to study mathematical models of the volumetric sweep efficiencies of water reinjection to determine the efficiency of cycling operations as a function of well location and spacing. Information from these tests and surveys can be used to select the optimum location of injection wells, to refine values of porosity and permeability, and to improve estimates of reservoir pressure. USBR plans to conduct a production and injection test program in the East Mesa Field in the near future.

Water flow rates and recoverable heat are two important characteristics in evaluating the Field's potential as a geothermal energy source. Because of the limited production history and test data available, estimating flow rate (i.e., reservoir productivity) is difficult. Nevertheless, productivity estimates have been made by three different methods:

- Drill stem tests
- Direct flow data
- Theoretical calculations.

Drill stem tests indicate an average productivity of 0.7 gallons/minute/foot for a pressure drawdown of 1,500 psi. Available direct flow data indicate that perforation of an additional 200-foot section in Mesa 6-1 will increase production to 1.10 gallons/minute/foot. Furthermore, theoretical calculations by Darcy's Law for radial flow indicate productivities of 0.56 gallons/minute/foot for the steady-state condition and 0.67 gallons/minute/foot for the pseudo steady-state condition, assuming no water influx across the outer boundary of the reservoir volume.

In general, the data now available indicate that a potential flow rate of 0.7 gallons/minute/foot of producing section is a conservative estimate, and a flow rate of 1.0 gallons/minute/foot appears entirely reasonable, considering the uncertainties in the permeability determinations. As noted previously, nominal permeabilities of more than 100 millidarcies are obtained from the geophysical well logs through the Saraband process; the limited drill stem test data show nominal permeabilities of one millidarcy.

If production reduces the reservoir pressure to below the fluid vapor pressure, fluid production would be in the vapor phase and considerable additional heat could be extracted from the host rock as heat of vaporization. Production rates would be low however, because of the low pressures involved.

Estimating hot water reserves requires knowledge of the reservoir size and recharge characteristics. Since the characteristics of the heat recharge from the heat source as as yet unknown, this factor is neglected and only water recharge is included. For this study, the reservoir is considered to be bounded by a thermal gradient of $8^{o}F/100$ feet. The area so defined is approximately ten square miles. With an average producing section of 1,500 feet and an average bulk porosity of 20 percent, the reservoir fluid in place totals 6.25×10^{11} gallons.

In the absence of recharge or reinjection, the volume of recoverable fluid is determined only by liquid expansion, with a corresponding decrease in pressure. For a pressure decline of 2,000 psi, recoverable reserves are 5×10^{9} gallons, about two years expected flow from five wells.

Therefore, any practical means of long-term production from the East Mesa Field will require reinjection of the produced water. Heat is contained in the host rock as well as the water stored in the pore volumes and the total heat is equivalent to an effective total of three pore volumes of fluid. A very conservative estimate of the heat fraction that could be recovered by convective heat transport is 25 percent. In theory, all this water should be recovered at the initial reservoir temperature, although additional investigation of the reservoir volume swept by the reinjected water is required.

Accordingly, with reinjection, but without heat recharge, a recoverable hot water reserve of 4.7×10^{11} gallons of hot water may exist at East Mesa. At an anticipated production rate of 3×10^{9} gallons/year, this reserve will supply the test facility for well over 100 years.

This reserve is sufficient to supply 60 megawatts for a commercially-viable power plant life of 30 years. Note that the indicated recoverable reserve figure is very conservative. For example, heat recharge, heretofore neglected, certainly occurs and will increase the effective recoverable reserves and power output, perhaps by several multiples. Indeed, a basic purpose of the test facility is to shed light on the realistic power potential of geothermal reservoirs of which East Mesa is typical.

Details on the East Mesa Field are provided in Appendices B and C.

3. ENERGY CONVERSION SYSTEM SELECTION AND ASSESSMENT

This section summarizes technology assessments and candidate geothermal systems and subsystems that are based on studies described in the appendices. It describes an energy conversion system for electrical power generation that uses moderate temperature (300 to 400°F) and salinity (<20,000 ppm total dissolved solids) geothermal well fluids. The selected and optimized system is based on the East Mesa environments and reservoir characteristics. It affords the most benefit at the least cost, with acceptable environmental impact.

This section also identifies and recommends critical technology developments and experiments to demonstrate reliability and economics favoring commercial development.

3.1 GUIDELINES AND CONSTRAINTS

The following design requirements, constraints and considerations were used in the parametric characterization and comparative evaluation of candidate energy conversion systems.

3.1.1 Study Parameters

The following demand, well fluid, and environment parameters were used in selecting candidate systems and in analyzing their performance characteristics and costs:

- Power plant size

Size	Applicability
1 to 3 MWe	• One well production • Electrical collection concepts • Near small distant load center (i.e., Alaska)
10 MWe	• Geothermal interest identified nominal demonstration plant • Near small distant load centers (i.e., Long Valley, Raft River, Hawaii)
25 MWe	• Midpoint cost scaling • Potential binary cycle turbine size limitation
50 MWe	• Approximates field well fluid collection module practical size (20 acre spacing) • Near a large load center (i.e., East Mesa, Niland, Heber)

- Well fluid temperature: 300 to 400°F
- Individual production well flows: 1000 to 1500 GPM
- Condensing temperature: 100 to 130°F.

3.1.2 Reservoir Characteristics

Recommended system selection is based on East Mesa reservoir characteristics identified in Section 2 and summarized as follows:

- Producing Zone. The optimum well-fluid producing zone is between 5200 to 6200 feet. The selection is based on the representative low salinity, high porosity, and high permeability characteristics exhibited by USBR well Mesa 6-1.
- Well Fluid Temperature of 350°F. This selection is based on the average zone temperature of the three representative USBR wells: 6-1, 6-2, and 8-1.
- Formation Pressures. East Mesa reservoir formation pressure is hydrostatic.
- Well Fluid Salinity. The USBR chemical analyses indicated in Table 3-1 are selected as representative for design evaluation.
- Reservoir. Productivity is estimated at 1000 GPM per well.

Table 3-1. Well Fluid Chemical Analyses (USBR Water Analyses)

Item	Low Salinity	Moderate Salinity
Well	6-2	6-1
Zone (feet)	5456-5957	6809-7982
pH	6-7	6-8
	ppm	ppm
Na	725	6,263
K	83	782
Ca	8.5	642
Mg	0.8	2.8
HCO_3	749	204
SO_4	182	17.3
Cl	793	11,053
SiO_2	301	163
Fe	2.6	1
B	16.7	15.3
F	–	1.07
PO_4	–	0.17
Li	11	–
SO	6	–
S	0.8	–
TDS (~)	2,880	19,145
H_2S	–	1 ppm

3.1.3 Environments

The following data were used to establish thermal environment guidelines in the evaluation of cooling (plant heat rejection) subsystems.

- Air Temperatures. Table 3-2 presents a climatological summary for El Centro which is 20 miles west of the East Mesa area.
- East Highline Canal. This canal, approximately 2 miles west of the USBR test site, may be a candidate for use as a thermal sink within these constraints:
  - Maximum water temperature of 84°F was recorded in August of 1974
  - Canal salinity of 800 to 950 ppm total dissolved solids
  - Maximum allowable temperature rise of 2°F

Table 3-2. Climatological Summary for El Centro, Imperial County, California
(Elevation: -50 feet. Latitude: 32 47'N. Longitude: 115 34'W)

Temperature Summary

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Highest*	86	89	102	109	114	120	122	122	118	112	96	92	122
Mean daily maximum**	69.7	72.7	80.8	87.6	96.2	103.7	109.3	107.5	103.4	92.6	80.2	77.1	90.1
Mean daily**	54.2	57.5	64.2	70.4	78.4	85.1	92.4	91.9	88.2	75.1	62.8	56.1	72.9
Mean daily minimum**	38.8	42.2	47.6	53.2	60.7	66.5	75.4	76.2	68.9	57.7	45.3	40.6	56.1
Lowest*	16	23	33	33	44	49	59	58	52	39	26	24	16

*Based on 18 years of record

**Based on 14 years of record

- Summer normal flow of 2500 second feet (cu ft/sec)
- Winter minimum flow (rainy season) of 200 second feet
- Cutouts for repair, canal dry average of one week/year
- Closed loop thermal extraction only with no process water extraction or effluent pollution

- Ground Water. Ten shallow wells have been drilled encompassing USBR wells 6-1 and 6-2. Representative water tables vary from 7 to 22 feet and water temperatures approximate 90°F.

3.1.4 Environmental Impact

The demonstration of geothermal power as a feasible energy source is significantly affected by its environmental acceptability. Hence, a demonstration geothermal system must accommodate environmental impact considerations. Appendix H summarizes the environmental guidelines that must be factored into geothermal designs and processes.

In considering the various candidate geothermal energy conversion systems, we found that the process flow design concepts have a major environmental impact. The binary energy process flow of the selected cycle conversion system has minimum adverse environmental impact.

The binary cycle is a closed flow process (no effluents to dispose of); all geothermal materials from deep well (fluids and noncondensible gases) extraction are reinjected to ground. Reinjection of the geothermal fluids affords other advantages: it provides for subsidence control and extends geothermal reservoir life. To avoid possible seismic disturbances, reinjection will be carried out at a point removed from fault zones.

Environmental impact of the geothermal plant will depend substantially on design options associated with various subsystem functions: extraction, brine transmission, reinjection, cooling, and electrical transmission. The adverse effects of these functions generally are short term and minor. Major adverse effects of subsystems can be mitigated by good design or avoided altogether by using suitable design options.

The environmental guidelines described in Appendix H indicate that minimizing the environmental effects of cooling facilities should receive special consideration. The wet cooling approach requires substantial water; the use of ground water poses a major subsidence problem; the removal and consumption of the required water from local streams cannot be allowed because of agricultural demands in the area. Heat exchangers supplied by local water and dry cooling techniques are candidate subsystem design options that can mitigate these adverse effects.

Drilling and exploration will have major effects on the environment. These effects include air-bound emissions of fugitive dust and steam, the noise from the effluent discharge, and the negative aesthetics of drilling rig and equipment. Fortunately, drilling and exploration are of short duration, and their adverse effects can be mitigated by suitable precautions, such as precipitators and silencers for the effluent steam discharge. However, because of the remoteness of the test area, mitigation measures probably will not be required.

As Phase 1 of the geothermal project progresses, activities will be constrained by the California Environmental Quality Act of 1970. It requires that local agencies evaluate the consequences of any proposed project on the environment. In Imperial County (and other counties with geothermal resources), local agencies require completion of a special application for exploratory geothermal drilling, and another approval scheme for a permit to undertake a geothermal project. Both of these permits require an environmental impact statement.

In applying for a permit to conduct exploratory drilling, a project report relating to the proposed drilling activities is required. The statement for exploratory drilling is drafted by the Imperial County Planning Department. We expect that exploratory drilling will be approved readily because East Mesa has been the site of the USBR geothermal projects in the past, and environmental impact reports have been drafted by the USBR* and approved.

In applying for a permit to construct and operate a geothermal power plant at the proposed site, the Planning Department of Imperial County requires an environmental impact report. The USBR has provided an environmental statement for a similar geothermal project in this area before; therefore substantial information on impact assessment exists. Our investigation found that the area is generally insensitive to environment impact, and that the proposed geothermal projects will cause no significant adverse effects provided the design includes suitable mitigation provisions. We anticipate that we will be able to rely substantially on USBR impact reports in drafting an environmental statement for the Experimental Research Facilities and in demonstrating the environmental acceptability of these activities.

3.1.5 Advisor's Views and Comments

To gain the views of the power utility industry, TRW invited representatives of the Southern California Edison Company, the San Diego Gas and Electric Company,

*Department of the Interior, Bureau of Reclamation, 1) Environmental Statement, Final Deep Geothermal Test Well, Geothermal Resource Investigations, Imperial Valley, California; FES 72-9, April 1972. 2) Supplement to the Final Environmental Statement on Proposed Deep Geothermal Test Well; FES 73-5, February 1973.

and the cities of Burbank and Riverside to act as project advisors. A representative of the Sierra Club also was invited to act as an advisor. The views of the project advisors are presented in Appendix D; our tradeoff optimizations and implementation planning are responsive to the advisors' views.

In summary, the utility companies consider the following problem areas the major retardants to industrial development of geothermal power (in order of priority):

- Methods or systems for determining the expected longevity and recoverable energy from geothermal reservoirs.
- Definition of a true geothermal resource. A reliable estimate of availability of geothermal energy based on true produceability.
- Development of reliable/economical production equipment: e.g., heat exchangers (most important), downhole pumps, high quality steam separators.
- Tradeoff analyses and techniques for evaluation of long-range economics.

The advisors also generally recognized the following requirements to justify a power plant at specific geothermal sites:

- Near a small distant load center (examples: Mammoth, Raft River, Alaska, Hawaii)
  - Proven reserves: 10 to 15 MWe (30 years)
- Near a large load center (examples: East Mesa, Niland, Heber)
  - Proven reserves: 50 MWe (30 years)
  - Potential reserves: 200 to 400 MWe
- Remote from a large load center (examples: Central Nevada)
  - Potential reserves: 1000 to 2000 MWe

The advisors unilaterally emphasized that accelerated construction and operation of the planned experimental research facilities, with appropriate advanced hardware technology demonstrations, is required to encourage industry commercial developments in a time frame consistent with national objectives.

3.2 CANDIDATE ENERGY CONVERSION SUBSYSTEMS

An energy conversion subsystem is required to convert the heat energy (enthalpy) of a geothermal well fluid into electric power. The following summary describes the synthesis of candidates and parametric performance characterizations. The performance characteristics are in sufficient detail for input to the comparative cost analyses of Section 3.6.

Several energy conversion concepts were initially screened on the basis of geothermal resource applicability and development status. Three thermodynamic processes were considered for the conversion of energy in East Mesa geothermal well water to electricity:

- Flash process wherein high temperature, high pressure well water is throttled adiabatically, producing a mixture of steam and water at lower pressure and temperature. The steam is used directly in a turbine; the remaining water may or may not be flashed again.

- Binary process wherein well water is used without change of phase to heat and vaporize a secondary working fluid in a Rankine cycle.

- Hybrid combination of the flash and binary processes wherein the water remaining after flashing is used to heat the working fluid in the binary portion of the process.

Other concepts were eliminated from consideration because of limited definition and development status. Note that the recommended experimental test facilities are configured to support future developments of these concepts, which include:

- Helical screw expander (Sprankle)
- Bladeless turbine (Possell)
- Keller Roto Oscillating Van (KROV)
- Impulse turbine (Austin)
- Biphase engine (Elliott)

3.2.1 Candidate Concepts and Options

Further examination of the three basic thermodynamic processes selected for study led to the options shown in Table 3-3. Figures 3-1, 3-2, and 3-3 are overviews, respectively, of the Concept A flashed steam cycle, the Concept B binary cycle, and Concept C hybrid binary-steam cycle.

Table 3-3. Candidate Energy Conversion Concepts and Options

CONCEPT	OPTION	DESCRIPTION
A	A-1	SINGLE FLASH - STEAM
	A-2	DOUBLE FLASH - STEAM
	A-3	SINGLE FLASH WITH REHEAT - STEAM
B	B-1	BINARY FLUID - WATER
	B-2	FINARY FLUID - BUTANE
	B-3	BINARY FLUID - ISOBUTANE
	B-4	BINARY FLUID - ISOPENTANE
	B-5	BINARY FLUID - PENTANE
	B-6	BINARY FLUID - HEXANE
C	C-1	HYBRID - BEST COMBINATION OF OPTION A-1 PLUS ONE OPTION OF CONCEPT B

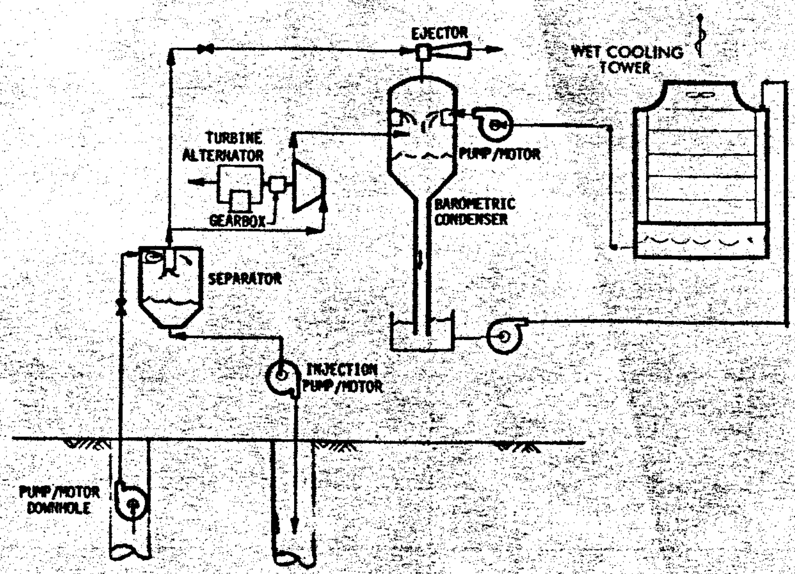
3.2.2 Comparative Concept Analyses

This section summarizes performance characteristics of candidate concepts and options. The analytical procedure, including results with varying temperatures, is presented in Appendix E.

Costs of providing the well are a major portion of overall system costs. Thus, comparative characteristics were developed to minimize well flow rates. To facilitate comparisons on this basis, we defined system efficiency as the net plant electrical output over the available energy in the well water measured between wellhead and the design condensing temperatures.

A realistic comparison of different cycles and fluids requires that certain operating conditions and plant parasitic loads be defined. These need not be exact, because small changes in, say, condensing temperature or cooling tower fan power, that have significant impact on efficiency are unlikely to affect the relationship between the cycles or fluids.

OPTION A-1
DOUBLE FLASH



OPERATION

WELLWATER AT A PRESSURE ABOVE SATURATION IS INTRODUCED INTO A FLASH CHAMBER THAT ACTS AS A CENTRIFUGAL SEPARATOR OF STEAM AND WATER. THE SEPARATED STEAM IS EXPANDED THROUGH A PRIME MOVER (TURBINE) COUPLED TO AN ELECTRIC GENERATOR. TO PREVENT EXCESSIVE WEAR ON THE TURBINE BLADES, THE STEAM MAY GO THROUGH ONE OR MORE MOISTURE SEPARATING STAGES. THE LOW PRESSURE SIDE OF THE TURBINE IS MAINTAINED BY A CONDENSER EQUIPPED TO REMOVE THE NONCONDENSABLE GASES FROM THE STEAM. AFTER THE STEAM IS REMOVED, THE REMAINING WATER IS REINJECTED TO PREVENT FIELD SUBSIDENCE AND TO MAINTAIN RESERVOIR PRESSURE. THE INJECTION WELL IS LOCATED REMOTELY FROM THE PRODUCING WELL TO AVOID THERMAL INTERACTION.

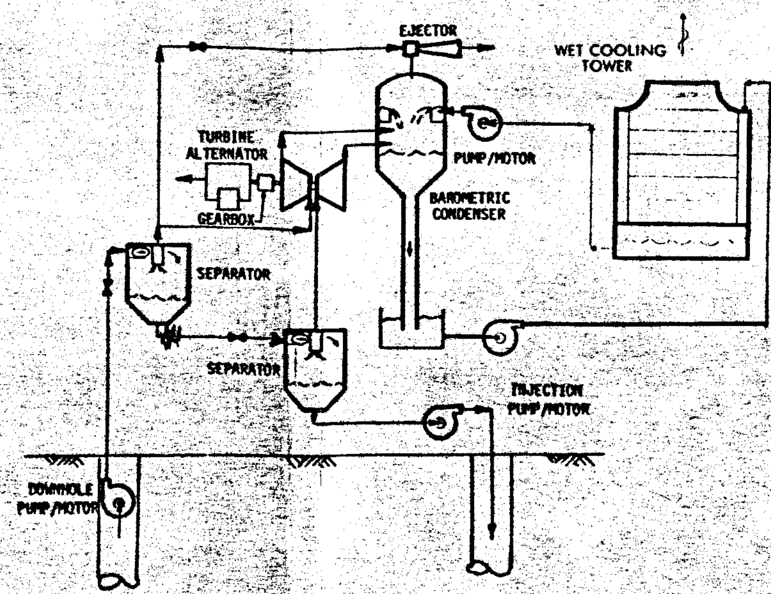
EQUIPMENT

RELATIVELY SIMPLE AND COMMERCIALLY AVAILABLE TURBINES WILL HAVE STANDARD AXIAL FLOW WHEELS SIMILAR TO THOSE USED FOR THE LAST STAGES IN A FOSSIL OR NUCLEAR FUELED STEAM POWER PLANT. EITHER A DIRECT CONTACT OR A SURFACE CONDENSER CAN BE USED. STEAM EJECTORS OR VACUUM PUMPS MAY BE USED FOR REMOVING NONCONDENSABLES TO REDUCE THE BACK PRESSURE AT THE TURBINE EXHAUST. FOR DIRECT CONTACT OR BAROMETRIC CONDENSERS, THE NONCONDENSABLES INCLUDE DISSOLVED GASES PLUS AIR ADDED BY COOLING WATER. FOR SURFACE CONDENSERS, THE ONLY NONCONDENSABLES ARE THOSE FLASHED WITH THE STEAM, CONSISTING OF GASES DISSOLVED IN THE GEOTHERMAL WATER. AFTER FLASHING, THE PRESSURE OF THE REMAINING WATER IS LOW AND INSUFFICIENT TO REINJECT THE WATER EMERGING FROM THE FLASH CHAMBER. A REINJECTION PUMP IS THEREFORE REQUIRED WITH A HEAD RISE SUFFICIENT TO OVERCOME THE REINJECTION WELL HEAD AND CASING RESISTANCE. TURBINE OIL AND GENERATOR PROCESS COOLING SYSTEMS ALSO ARE REQUIRED.

FEATURES

- FIELD EXPERIENCE IN MEXICO, NEW ZEALAND, AND JAPAN
- SIMPLICITY

OPTION A-2
SINGLE FLASH



OPERATION

THE BASIC OPERATION IS SIMILAR TO OPTION A-1; HOWEVER, THE WATER LEAVING THE SEPARATOR UNDERGOES A SECOND FLASH IN A SECOND SEPARATOR OPERATING AT A LOWER PRESSURE. THE RESULTING STEAM IS EXPANDED THROUGH A LOW PRESSURE TURBINE THAT IS MOUNTED ON THE SAME SHAFT AS THE HIGH PRESSURE TURBINE. THE SHAFT IS COUPLED TO A SINGLE GENERATOR. THE REMAINING WATER IS REINJECTED INTO A WELL. THE LOW PRESSURE SIDE OF BOTH TURBINES IS MAINTAINED BY A SINGLE CONDENSER EQUIPPED TO REMOVE NONCONDENSABLE GASES.

IMPLEMENTATION IS HIGHLY DEPENDENT ON THE SALINITY OF THE GEOTHERMAL FLUID. IF THE SALINITY IS LOW (BELOW 5000 PPM), STEAM FROM THE SECOND FLASH IS RELATIVELY CLEAN AND DOES NOT CARRY OVER EXCESSIVE CORROSIVE PRODUCTS INTO THE TURBINE. IF THE SALINITY IS HIGH, CARRYOVER MAY BE DIFFICULT TO AVOID. TURBINE WHEELS HAVE BEEN WORN AWAY IN EARLY ATTEMPTS TO IMPLEMENT THIS OPTION.

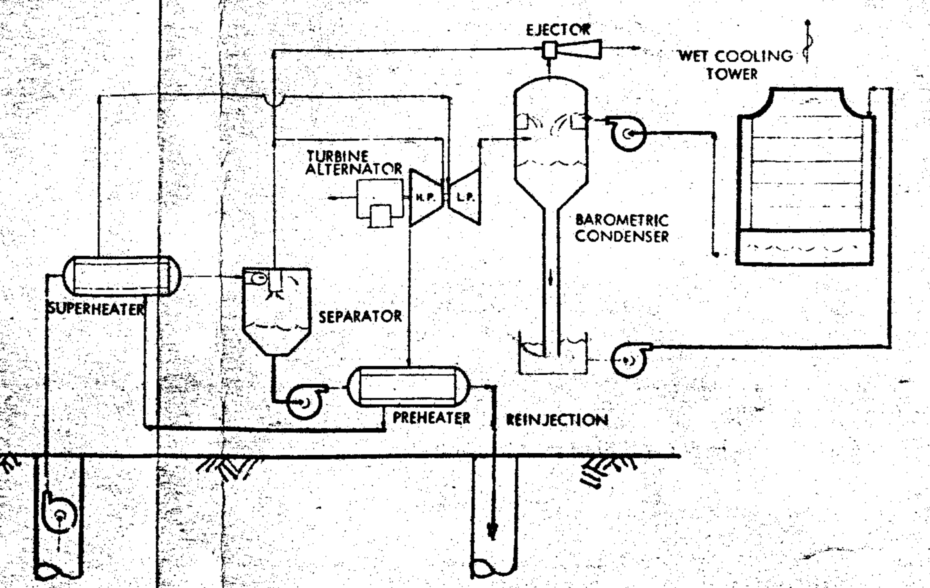
EQUIPMENT

SIMILAR TO CONCEPT A-1 WITH ADDED SEPARATOR AND LOW PRESSURE TURBINE.

FEATURES

- EFFICIENCY IS APPROXIMATELY 30% GREATER THAN OPTION A-1
- SYSTEM INSTALLED COST (PLANT AND WELLS) APPROXIMATELY 10% LESS THAN OPTION A-1

OPTION A-3
SINGLE FLASH WITH REHEAT



OPERATION

THE BASIC OPERATION IS SIMILAR TO OPTION A-1; HOWEVER, THE STEAM OBTAINED FROM THE FLASH SEPARATOR IS ONLY PARTIALLY EXPANDED THROUGH A A TURBINE. THE EXHAUST STEAM IS REHEATED WITH DIRECT WELL FLOW THROUGH TWO SEPARATE HEAT EXCHANGERS (PREHEATING AND SUPERHEATING), AND IS EXPANDED THROUGH A LOW PRESSURE TURBINE. IT IS MOUNTED ON THE SAME SHAFT AS THE HIGH PRESSURE TURBINE AND THE SHAFT IS COUPLED TO A SINGLE GENERATOR.

EQUIPMENT

SIMILAR TO CONCEPT A-1 EXCEPT THAT TWO HEAT EXCHANGERS MUST BE ADDED TO PREHEAT AND SUPERHEAT THE STEAMS EXHAUSTING FROM THE HIGH PRESSURE TURBINE. THESE HEAT EXCHANGERS MOST LIKELY WOULD BE OF THE TYPE USED AS FEED WATER HEATERS. SHELL AND TUBE HEAT EXCHANGERS HAVE BEEN USED MOST OFTEN BY UTILITY COMPANIES THAT USE TREATED WATER ON BOTH PASSAGES: ON ONE SIDE, THE CONDENSATE AND ON THE OTHER, STEAM REMOVED FROM THE TURBINE STAGES. IN THE GEOTHERMAL APPLICATION, ONE SIDE IS FAIRLY CLEAN EXHAUST STEAM , BUT ON THE OTHER SIDE IS THE GEOTHERMAL FLUID CONTAINING SOLIDS AND GASES. SCALING AND FOULING MUST BE AVOIDED TO PREVENT CORROSION AND PASSAGE BLOCKING, AND TO MAINTAIN EFFECTIVENESS ON THE HEAT TRANSFER SURFACES.

FEATURES

- LESS EFFICIENT THAN OPTION A-2
- GREATER COST THAN OPTIONS A-1 OR A-2

Figure 3-1. Concept A - Flashed Steam Cycle Overview

OPERATION

PRESSURIZED WELL WATER IS PASSED THROUGH A SERIES OF HEAT EXCHANGERS. THESE ACT AS BOILER AND SUPERHEATER, TRANSFERRING MAXIMUM ENERGY TO THE WORKING FLUID. THE HIGH PRESSURE WORKING FLUID IS EXPANDED THROUGH A TURBINE COUPLED TO A GENERATOR TO PRODUCE ELECTRICITY.

THE LOW PRESSURE WORKING FLUID VAPOR EXHAUSTING FROM THE TURBINE IS CONDENSED AND RETURNED TO THE HEATERS AT HIGH PRESSURE USING APPROPRIATE PUMPS. THE WORKING FLUID MAY COME OUT OF THE TURBINE EXHAUST WITH SOME SUPERHEAT, I.E., A TEMPERATURE HIGHER THAN THE CONDENSING TEMPERATURE CORRESPONDING TO THE EXHAUST PRESSURE. IN THIS CASE, WHERE THE EXIT QUALITY IS HIGHER THAN UNITY, SOME OF THE HEAT CAN BE RECOVERED BY A RECUPERATOR OR REGENERATOR. REMOVING THE SUPERHEAT BY THE CONDENSATE PRODUCES SAVINGS IN TWO AREAS: LESS HEAT HAS TO BE REMOVED IN THE CONDENSER AND LESS HEAT HAS TO BE ADDED IN THE ECONOMIZER. THESE HEAT SAVINGS MAY REDUCE WELL FLOW REQUIREMENTS FOR A GIVEN POWER OUTPUT.

CONCEPT B OPTIONS USE DIFFERENT WORKING FLUIDS RESULTING IN DIFFERENT SYSTEM EFFICIENCIES AND WELL WATER FLOW REQUIREMENTS.

EQUIPMENT

EQUIPMENT INCLUDES A SINGLE STAGE RADIAL FLOW TURBINE OR A MULTIPLE STAGE AXIAL TURBINE, DEPENDING ON THE WORKING FLUID SELECTION AND THE EXPECTED MOISTURE DURING EXPANSION. A WORKING FLUID FEED PUMP, SURFACE HEAT EXCHANGERS FOR HEATING AND CONDENSING THE WORKING FLUIDS, AND SURGE AND STORAGE TANKS ARE ALSO NEEDED.

THE RADIAL FLOW TURBINE IS PREFERRED FOR HYDROCARBON WORKING FLUID BECAUSE THE EXPANSION RATIO IS NOT HIGH. IN A SINGLE STAGE MACHINE, A HIGHER TURBINE EFFICIENCY MAY THUS BE OBTAINED. THE WORKING FLUID FEED PUMP IS REQUIRED TO RAISE THE WORKING FLUID PRESSURE FROM THAT IN THE CONDENSER TO THAT REQUIRED FOR THE TURBINE INLET. THE PUMP ALSO IS NEEDED TO OVERCOME THE PRESSURE DROP THROUGH THE HEAT EXCHANGERS. HEAT EXCHANGERS ARE REQUIRED FOR REGENERATORS, ECONOMIZERS, BOILERS, SUPERHEATERS, AND THE CONDENSER.

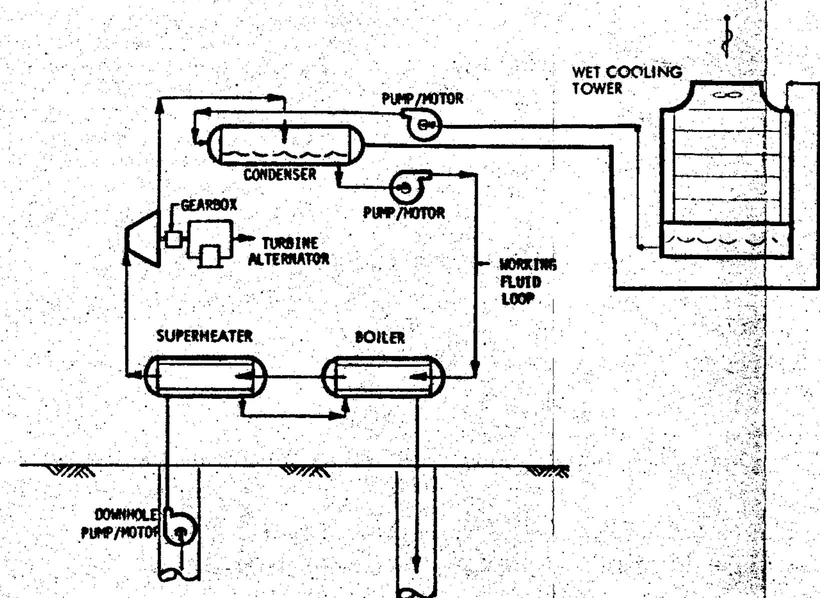
CONFIGURATIONS OF THE HEAT EXCHANGERS MAY VARY THROUGHOUT THE CYCLE, EACH TAILORED TO THE FUNCTIONS PERFORMED AND TO THE CORRESPONDING PRESSURE AND TEMPERATURE REGINES. A HOT WELL IS NEEDED TO COLLECT CONDENSATE AND TO PROVIDE A POSITIVE HEAD TO THE FEED PUMP, THEREBY AVOIDING CAVITATION. A SURGE AND STORAGE TANK IN THE WORKING FLUID LOOP MINIMIZES PRESSURE SURGES IN THE WORKING FLUID LINES AND SUPPLIES MAKE-UP FLUID FOR SMALL LEAKS. THE SURGE AND STORAGE TANK MAY BE COMBINED WITH THE HOTWELL. A REINJECTION IS NOT REQUIRED, THE DOWNHOLE PUMP CAN BE SIZED TO YIELD THE REQUIRED FLOW RATE, AND TO RAISE THE PRESSURE TO OVERCOME THE DROP THROUGH THE HEAT EXCHANGERS AND THE REINJECTION WELL.

FEATURES

- ONLY GEOTHERMAL BINARY CYCLE PLANT IN RUSSIA (1 MWE)
- 32% GREATER EFFICIENCY THAN DOUBLE FLASH STEAM CYCLE CONCEPT A-2
- 75% GREATER EFFICIENCY THAN SINGLE FLASH STEAM CYCLE CONCEPT A-1

Figure 3-2. Concept B - Binary Cycle Overview

WET COOLING TOWER OPTION



FEATURES

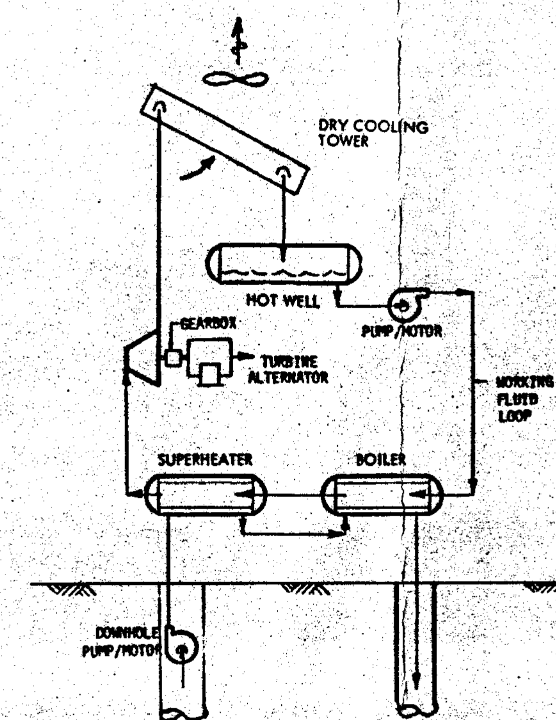
- LOW CONDENSING TEMPERATURE YIELDS HIGH EFFICIENCY
- REQUIRES MAKE-UP WATER

WORKING FLUID OPTIONS*

OPTION	WORKING FLUID	EFFICIENCY (%)	WELLWATER (10^6 LB/HR)
B-1	WATER	6.22	2.176
B-2	BUTANE	8.89	1.525
B-3	ISOBUTANE	9.83	1.378
B-4	ISOPENTANE	7.73	1.753
B-5	PENTANE	7.65	1.772
B-6	HEXANE	7.76	1.745

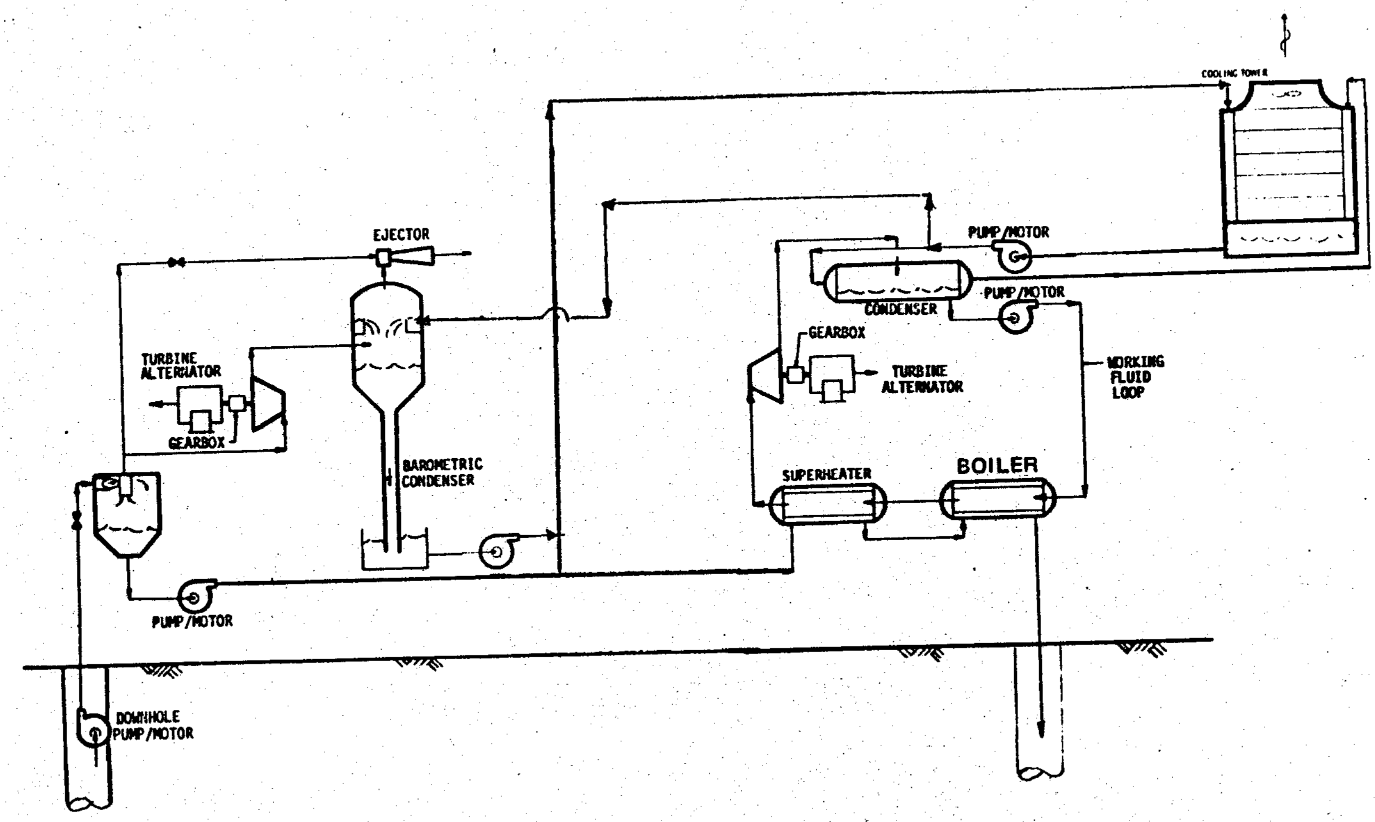
* SUB-CRITICAL CYCLE, 350°F WELLWATER, 102°F CONDENSING TEMPERATURE, WET COOLING TOWER, 10 MWE DELIVERED

DRY COOLING TOWER OPTION



FEATURES

- HIGH CONDENSING TEMPERATURE LOWERS EFFICIENCY
- NO MAKE-UP WATER NEEDED, MINIMIZING ENVIRONMENTAL IMPACT AND PRECLUDING SUBSIDENCE



DESCRIPTION

CONCEPT C IS A HYBRID CONCEPT THAT COMBINES OPTION A-1 WITH ONE OF THE CONCEPT B OPTIONS, THE EQUIPMENT REMAINING THE SAME AS FOR A-1 AND THE B OPTION. THE HYBRID CONCISTS OF A SINGLE FLASH STEAM CYCLE PLUS A BINARY CYCLE WITH THE WORKING FLUID HEATED BY THE LOW TEMPERATURE, SEPARATED WATER. TWO DISTINCT TYPES OF POWER PLANTS ARE REQUIRED WITH SEPARATE PIECES OF EQUIPMENT THAT ADD COMPLEXITY. WHERE WELL WATER TEMPERATURES EXCEED 450°F, THE NUMBER OF WELLS AND/OR THE WATER FLOW MAY BE REDUCED. HOWEVER, THE HIGH LEVERAGE COSTS OF THE POWER PLANT MAY BE SHIFTED FROM THE WELLS TO THE CONVERSION EQUIPMENT.

Figure 3-3. Concept C - Hybrid Binary Cycle Overview

Initial system selection analyses were based on the following:

- Pumped well fluid temperature: 350°F
- Condensing temperature: 102°F
- Reinjection: 90 psi with 40 percent pump efficiency
- Down-hole pump load: 2.3 Btu/lb pumped (0.45 HP/gpm)
- Wet cooling tower pump loss: 0.018 Btu/Btu condensed
- Turbine efficiency: 0.85
- Generator efficiency: 0.98
- Separator efficiency: 0.95
- Maximum secondary fluid turbine inlet temperature: 20°F below well fluid temperature
- Regenerator efficiency: 0.80 (binary cycles, when used)
- Condenser coolant temperature rise: 15°F
- Miscellaneous losses: 2 percent of net output

Results of these analyses, shown in Table 3-4, were used to develop comparative system costs, and led to the selection of isobutane as the working fluid. Certain cycle operating conditions were changed to comply with site requirements: e.g., a dry cooling tower was selected to prevent subsidence and make the plant independent of variable cooling water supplies in the locality. This results in a maximum condenser temperature of 130°F. Isopentane can provide power at a higher efficiency (lower geothermal water flow required) than isobutane. However, it operates in the supercritical region, and, on expansion, it goes through the saturated liquid region, increasing vapor quality as it expands. Isopentane requires that the turbine wheels be erosion resistant and maintain their geometry for the life of the system to operate at design efficiency. Only a small penalty in efficiency results from the choice of isobutane.

The binary cycle using isobutane as a working fluid was analyzed considering different turbine inlet temperatures and pressures (see Appendix I). The selected operating parameters for the recommended Phase 2 10 MWe gross powerplant are indicated in Table 3-5. Figure 3-4 is a schematic of the recommended powerplant, showing temperatures, pressures, and flows throughout the system.

We recommend that the turbine inlet temperature be investigated in Phase 1 to find ways to reduce the size of heat exchangers and the required well flow, and possibly to eliminate the regenerator. The effects on cycle efficiency, condenser size, and overall plant cost of these optimizations will have to be evaluated.

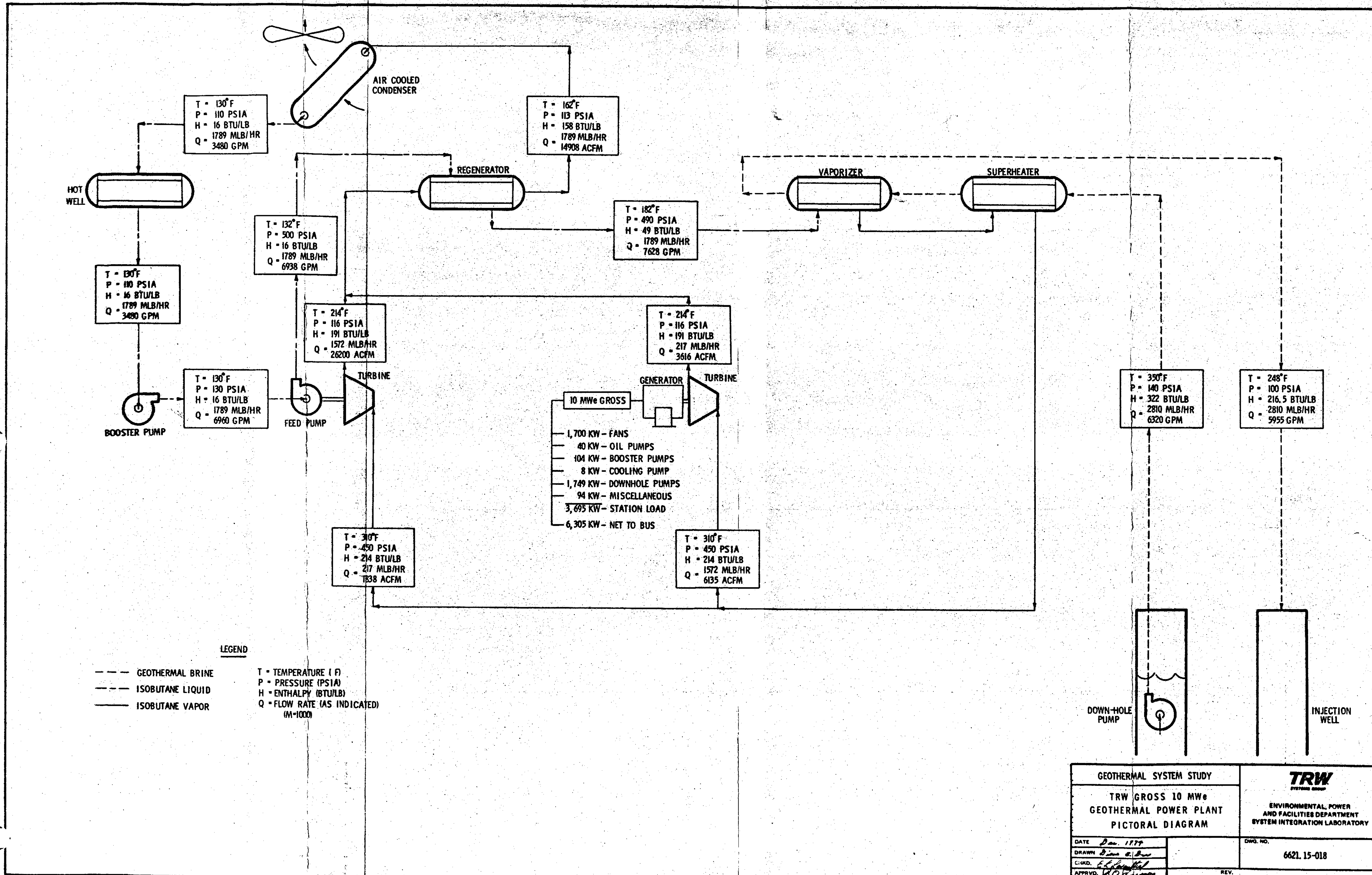


Figure 3-4. 10 MWe Power Plant Schematic

3.3 CANDIDATE SUBSYSTEM CONCEPTS

The following assessments address cooling, pumping, and electrical technologies that are common to each of the energy conversion concepts investigated. Various approaches are analyzed and recommendations are made for the Phase 2 powerplant design. Also critical technology developments and experiments are identified for Phase 1 implementation.

3.3.1 Process Cooling

Each candidate energy conversion concept analyzed requires a means of cooling the plant. This is a fundamental requirement of closed thermodynamic cycles and may be accomplished using local waters, or by wet and/or dry cooling methods. System performance (i.e., power cycle efficiency) is sensitive to condensing temperature, which establishes turbine exhaust back pressure. Therefore, it is desirable to reject system heat at the lowest feasible temperature to minimize system size and cost.

The features of each approach and the rationale leading to selection of a dry cooling tower are described in the following paragraphs.

3.3.1.1 Local Waters

The least expensive and most efficient of all cooling methods is the use of local waters passed directly through the condenser and returned to the source reservoir remote from the supply location. The East Mesa source for this water could be ground water (shallow wells) or local streams (e.g., East Highline Canal).

If ground water were used for a 10 MWe powerplant, upwards of 50 wells widely scattered through the area would be required for the removal of condenser waste heat. The cost of wells, pipelines, pumps, and power would be high and the environmental impact considerable.

The use of the East Highline Irrigation Canal is subject to certain constraints.

- Maximum temperature rise allowed is 2°F (in the summer).
- Stream must be kept clean with no increase in solid contents.
- No hot spots must be created by water returning to the canal.
- Canal flow is variable, with occasional shutdowns during winter months.

Waste heat removed from a 10 MWe powerplant would raise the temperature of the canal water in the summer by 0.6°F. This temperature rise is considered tolerable by the IID and a considerably higher temperature is desirable during winter. Canal cooling water can be supplied and returned by buried pipes for a distance of about 2 miles between the test site and the canal. Pumping is required at the supply, and return lines are provided with a downstream temperature distribution diffuser.

Although the use of canal water appears potentially attractive for a 10 MWe plant, this type of cooling source is not readily available at most geothermal resource areas and would not support further power-plant developments in the East Mesa area. Therefore, this approach was eliminated from further consideration in developing a representative experimental facility.

3.3.1.2 Wet Cooling

Wet cooling towers transfer heat to the atmosphere by evaporation and are more efficient in both cost and performance than dry cooling towers. Wet cooling towers can provide cold water to the condenser year-round, since even on a hot summer day the water temperature can reach wet bulb temperature. On a hot summer day, the wet bulb temperature will be about 87^{o}F. Thus, turbine back pressure can be maintained (with the aid of noncondensable removing equipment for the flashed steam concepts) at a value corresponding to a temperature of about 100^{o}F. This is equal to 1 psia for the flash steam concepts and 25 psia for option B4 (isopentane).

The main disadvantage of wet cooling towers is that the amount of water that must be evaporated equals the latent heat of the vapor that is condensed. That can be substantial and must be made up from a continuous supply. In concept, water can be taken from the cycle, and this can be subtracted from water that should be reinjected to avoid subsidence. For Concept B, water can be withdrawn from the production well stream after it has gone through the working fluid heaters, or from an alternate source, such as ground water or local streams (canals).

Neither of these sources is very desirable since the geothermal source water would have to be flushed, which could create a number of problems. One problem is environmental pollution by the addition of salts to the ground in an area that has been fighting the problem of excess salinity in the soil for years. This problem is caused by the peculiarities of the terrain contour and composition, and the run-off of irrigation waters. The use of ground water would cause a major subsidence problem: for a 10 MWe plant on a July or August day, approximately 6 acre feet of water would be evaporated resulting in a decline in the water table and a 4 percent subsidence of about 0.5 inch per day of operation. The permanent removal of such amounts of water from the local streams cannot be allowed because the area depends on this water for irrigation and the removal of water from the stream would reach a maximum when the removal for irrigation is maximum.

Another alternative for supplying water for wet cooling is large spray ponds. These have been found environmentally unattractive because of their extremely large size. Water losses are larger than for cooling towers. In addition to the evaporation due to the heat added by the process, wind-caused evaporation and entrainment also contribute to water losses.

For these reasons, wet cooling methods were eliminated from further consideration.

3.3.1.3 Dry Cooling

To avoid the problems discussed for local waters and wet cooling, the use of air for the removal of waste heat was considered. Two possible approaches are direct and indirect cooling.

In direct cooling, air is blown directly through the condenser. In the indirect method, air is blown through a water cooler and the cooled water is used in the condenser for waste heat removal.

In either of these approaches, powerplant efficiency is highly dependent on air temperature and varies considerably from winter to summer. To flatten out the power output fluctuations due to these temperature changes, the powerplant can be designed for a mean summer air temperature. Such a powerplant would have a reduced power output on hotter days, and during the winter, a number of fans can be shut down to reduce the air and maintain a more even turbine exhaust back pressure.

The direct air-cooled condenser approach is the least expensive. Subsequent Phase 2 design studies will consider wet/dry cooling towers, with special attention to impact on subsidence. Subsidence is not a problem with dry cooling towers; however, acceptable impact may be obtained with wet/dry cooling towers with measurable benefit on powerplant operation and system costs.

The cooling options for the turbine lube oil coolers and the generator coolers have received minimum attention because they represent very minor system heat loads. Forced air or circulating water oil coolers can be considered for this function. In the case of the generator, hydrogen cooling may even be considered for the lowest power output option. Normally, generators producing less than 25 MWe are air cooled; however, to prevent any problems from corrosive gases and vapors emanating from the geothermal wells, hydrogen cooling is considered for a 3 MWe generator. The hydrogen can be circulated through an air or water-cooled coil to remove the heat produced by generator.

3.3.2 Downhole Pumps

Geothermal well production may be accomplished by pumping or by permitting the well to flow naturally. Self-produced natural flow is obtained by allowing the water to flash into a mixture of steam and liquid. However, considerable energy is given up by the geothermal water in vaporization and in propelling itself. Therefore, considering the moderate enthalpy of East Mesa well fluids, we recommend that the well fluids be pumped to pressure the maximum attainable temperature to the point of utilization. Additional justification for this approach, i.e., maintaining system pressures above saturation, is that carbonate deposition is avoided in the wells and surface transport system.

Recommended pump discharge pressures and cavitation avoiding setting depths with 50 percent safety margins are indicated in Figure 3-5. The indicated pump depth is with reference to the draw-down level considering the productivity index of the well.

The geothermal fluid pumping requirements are likened to present oil well pumping technologies. However, existing applicable nonmixing liquid, oil pumping techniques (i.e., electric submergible and lineshaft pumps) exhibit limited temperature corrosion experience with geothermal fluids. The development status of various pumps are compared in Figure 3-6.

Electric submergible pumps are recommended for this application for the reasons noted in Figure 3-6. However, further optimizations are recommended during Phase 2 to minimize well casing sizes (less than 9-5/8 inch outside diameter and parasitic power requirements and to maximize availability (i.e., reduce impellor erosion impacts).

3.3.3 Electrical Subsystem

The configuration of the electric power generating station will be similar to other utility power stations and will conform to standard practices of the power utility industry (see Figure 3-7).

All local auxiliary equipment, such as pumps, fans, motor loads, and housekeeping loads, will be fed from stepdown transformers. Before and during start up, these loads will be energized from the 33 KV grid system. After start up, the generator will be brought on-line. It will then supply power to these loads as well as to the grid system.

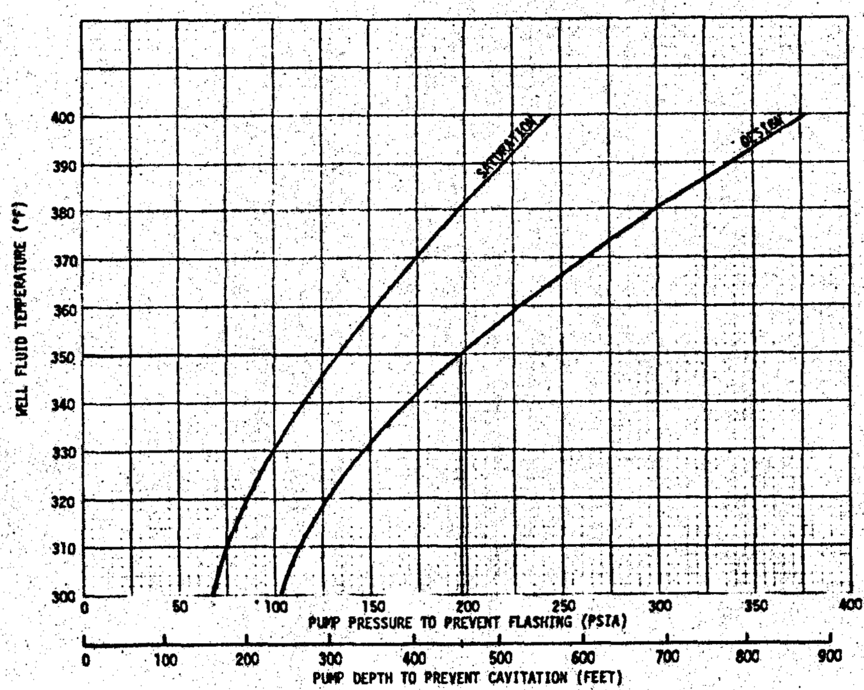
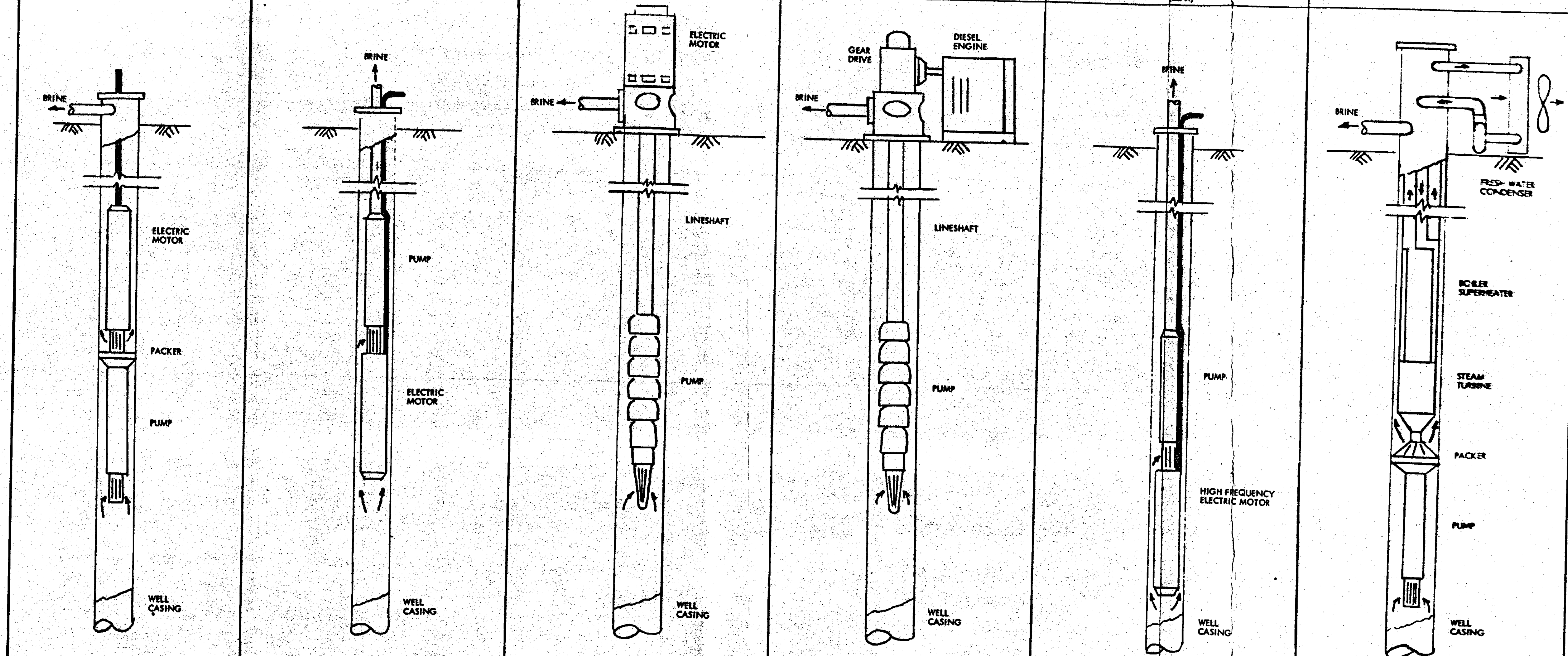


Figure 3-5. Geothermal Pump Requirements



	COMMERCIALLY AVAILABLE				NSF GRANT DEVELOPMENT	
	ELECTRIC SUBMERGIBLE		LINESHAFT			
	CABLE SUSPENDED	TUBING SUSPENDED	ELECTRIC MOTOR DRIVE	RIGHT ANGLE GEAR DRIVE	HIGH FREQUENCY ELECTRIC SUBMERGIBLE (LEAR)	STEAM TURBINE
PROS	• MAXIMUM FLEXIBILITY - INSTALLATION - MAINTENANCE CHANGE OUT - SETTING DEPTH ADJUSTMENTS	• LOWEST INVESTMENT COST • NO SETTING DEPTH LIMITATION • OFF-THE-SHELF 1000 GPM, 375°F CAPABILITY	• LIMITED EXPERIENCE WITH 375°F BRINES • MOTOR IN COOL AMBIENT	• VARIABLE SPEED FLOW RATES 400 TO 1500 GPM • MOTOR IN COOL AMBIENT	• VARIABLE SPEED • MINIMUM WELL BORE DIAMETER • DESIGN GOAL 500°F BRINES	• LOWEST PARASITIC POWER REQUIREMENT • DESIGN GOAL 450°F BRINES
CONS	• NO EXPERIENCE WITH 350°F CORROSIVE BRINES • MOTOR IN HOT AMBIENT	• LONG-TERM OPERATION EXPERIENCE LIMITED TO 325°F • MOTOR IN HOT AMBIENT	• HIGHER COST THAN ELECTRIC SUBMERGIBLE • SETTING DEPTH LIMITED ~800 FEET • WELL BORE DIAMETER LARGE COMPARED WITH ELECTRIC SUBMERGIBLE	• HIGHEST COST • SETTING DEPTH LIMITED ~800 FEET	• MAXIMUM PARASITIC POWER REQUIREMENT • HIGH RPM - NPSH REQUIRES DEEP SETTING - ACCELERATED IMPELLOR EROSION IMPACT	• MAXIMUM WELL BORE DIAMETER • HIGH RPM - NPSH REQUIRES DEEP SETTING - ACCELERATED IMPELLOR EROSION IMPACT • MINIMUM FLEXIBILITY INSTALLATION AND DEPTH ADJUSTMENTS
DEVELOPMENT REQUIREMENTS	• DEMONSTRATED LONG TERM OPERATIONAL CAPABILITY • HIGH TEMPERATURE BRINE IMPROVEMENTS - MOTOR BEARINGS - SUSPENSION CABLE - MOTOR COOLANTS	• DEMONSTRATED LONG-TERM OPERATIONAL CAPABILITY • HIGH TEMPERATURE BRINE IMPROVEMENTS - MOTOR BEARINGS - MOTOR COOLANTS	• DEMONSTRATED LONG-TERM OPERATIONAL CAPABILITY • APPLICATION IMPROVEMENTS - SHAFT ALIGNMENT - BEARINGS AND LUBRICATION - MINIMIZE WELL BORE DIAMETER	• DEMONSTRATED LONG-TERM OPERATIONAL CAPABILITY • APPLICATION IMPROVEMENTS - SHAFT ALIGNMENT - BEARINGS AND LUBRICATION - MINIMIZE WELL BORE DIAMETER	• PROJECTED COMMERCIAL AVAILABILITY 3 TO 4 YEARS • MINIMIZE "CON" IMPACTS ABOVE	• PROJECTED COMMERCIAL AVAILABILITY 2 TO 3 YEARS • MINIMIZE "CON" IMPACTS ABOVE

Figure 3-6. Geothermal Downhole Pump Technology

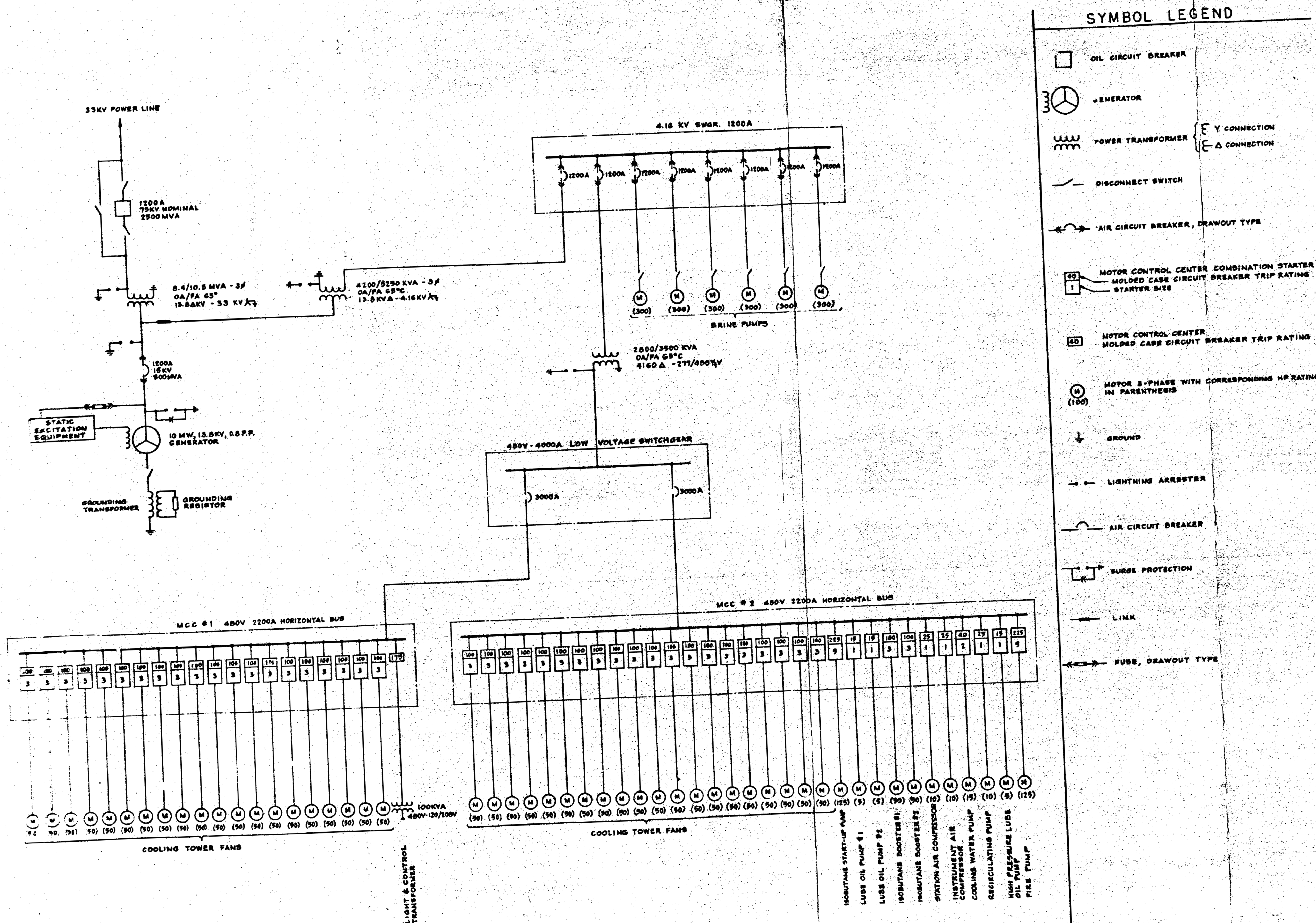


Figure 3-7. 10 MWe Power Plant Schematic

All the electrical equipment required is presently available from industrial manufacturers. Standard design or off-the-shelf equipment will be selected to the maximum extent.

3.4 GEOTHERMAL FLUID COLLECTION

This section summarizes the recommended means of drilling and completing the deep wells that are required to provide geothermal fluid for the test facility. Environmental and field life considerations dictate that the produced water be reinjected into the reservoir. Consequently, both producer and injector wells are required. Factors considered include vertical vs directional drilling (directional wells are preferred based on lower cost and environmental impact); casings that allow adequate water flow and capability for testing down-hole pumps at minimum cost; and well completion methods that allow testing of the reservoir flow capability at minimum cost.

3.4.1 Fluid Collection Options

Two means of fluid collection have been considered in this study: vertical wells with overland piping to a central facility and directionally drilled wells from the central facility. See Figure 3-8. Two principal factors entered into the selection: cost and environment. Costs of the two options are itemized in Figure 3-8, Option A directional costs are approximately 20 percent less than Option B vertical. The significant reason for the cost difference lies in the elimination of expensive insulated overland piping in Option A. Eliminating this piping also results in less environmental disturbance. Accordingly, TRW recommends that directional drilling be used in the fluid collection system.

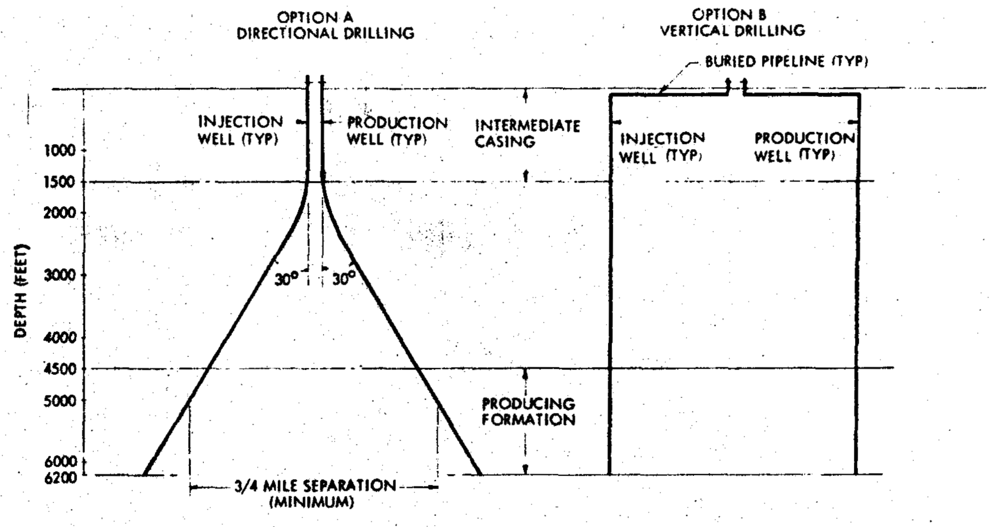
TRW further recommends that in the initial development, a conservative program of equal numbers of water producer and water injector wells be adopted. Figure 3-8 shows this producer/injector ratio. As more knowledge of the reservoir is obtained, the more efficient ratio of three producers to two injectors will probably prove desirable.

Reinjection of the produced water is necessary because environmental concerns regarding waste disposal are eliminated, subsidence is prevented (the level network and instrumentation used to monitor subsidence at East Mesa are described in Section 2 and in Appendix B), and field life is increased significantly (see Appendix C).

TRW suggests a conservative 20-acre production and injection well spacing, with injectors being located a minimum of 0.75 mile from producers. These desirable distances are, of course, subject to change based on field operational history.

3.4.2 Drilling

Directional drilling of a geothermal well is complicated somewhat because the direction and angle of the hole cannot be measured at high temperature. Accordingly, the hole must be diverted at a shallow depth where the temperature is relatively



ITEM	UNIT COST ($)	PRODUCTION UNITS	PRODUCTION COST $K	INJECTION UNITS	INJECTION COST $K	PROJECTION UNITS	PROJECTION COST $K	INJECTION UNITS	INJECTION COST $K
DRILL RIG	130/HR	1300	169	1300	169	1200	156	1200	156
THIRD PARTY SERVICE	L.S.	--	89	--	89	--	89	--	89
CONDUCTOR CASING	29.47/LF	250	7	250	7	250	7	250	7
INTERMEDIATE CASING	18.69/LF	1500	28	1500	28	1500	28	1500	28
FLOW CASING	16.46/LF	5400	89	6900	114	4700	77	6200	102
PERFORATIONS	40/LF	1000	40	1000	40	1000	40	1000	40
BURIED PIPE (INSULATED)	61.50/LF	--	--	--	--	1800	111	1800	111
SUB-TOTALS		1	422	1	447	1	508	1	533
TOTALS		2	$869,000			2	$1,041,000		

Figure 3-8. Fluid Collection Options

low. Once the intermediate casing is emplaced, deviation of the hole can begin and the hole deflected by 1 degree in the required direction for every 10 meters of advance. Thus, the hole can be deflected by 25 to 30 degrees before production casing is installed. TRW will install vertical intermediate casing to 1500 feet before deviation. This also is in keeping with the California Division of Oil and Gas requirement that cemented surface casing be used for at least 10 percent of the total depth. A 30 degree deviation from the vertical is planned for both producer and injector wells (see Option A, Figure 3-8).

Typical sizes and ratings of the drilling rig that might be used are:

Depth capability:	4500 to 7500 feet
Draw works power:	550 horsepower
Pump size:	2 sets, 7.5 x 15 in.
Pump power:	530 horsepower/set
Derrick:	Standard type
Rotary table:	20.5 in. diameter

An electric, rather than diesel rig drive will be used to reduce environmental effects. Also because of environmental considerations, containerized mud tanks will be used in lieu of ponds. However, the existing USBR pond will be used for discharge in the initial flow testing of the wells, and a pipe will be installed from the experimental facility to the pond for that purpose. The drill sites will be constructed so that four holes may be drilled from a single site by skidding the rig.

A drilling time of 30 to 45 days per hole is anticipated, followed by 10 days for completion and testing. These times are comparable to those reportedly encountered by USBR at East Mesa and the Chevron Oil Company at Heber. Costs per well, tabulated in Table 3-6, include costs anticipated for the experimental test facility wells and projected costs for future commercial drilling. The costs contain an item for third party services, which is detailed in Table 3-7.

3.4.3 Casing Program

The casing used in the USBR East Mesa wells is shown in Figure 3-9. Note that the 7-5/8 inch diameter production casing is not necessarily the optimum diameter; rather it was the only diameter available at the time of completion. The casing program that TRW plans to use on the experimental facility wells is also shown in Figure 3-9. As shown, 13-3/8 inch intermediate casing will be set to a depth of 1500 feet to allow the installation of high net positive head suction (NPHS) pumps, such as the Sperry and Lear models. The production casing diameter will be 9-5/8 inches, which is large enough to handle the required water flow. One well, however, will use 8-5/8 inch diameter production casing as a test of the flow capacity of this less costly configuration. Casing lengths will be joined by buttress thread and coupling joints, thereby achieving a smooth ID.

3.4.4 Well Completion

The experimental facility wells will be completed by selective zone perforation, rather than by using slotted liner as in the USBR wells. The specific perforation intervals will be selected from low salinity, highly permeable and porous sands located by geophysical logging of the holes. Enough geological section, approximately 1500 feet, will be perforated to sustain the required 1000 gpm flow. Extrapolation of data from the USBR wells to the proposed site indicates that sufficient sand section will be available. In the interests of cost savings TRW recommends initially perforating at 2 shots/foot and reservoir testing. Perforation will be increased to 4 shots/foot, if necessary, which essentially simulates an open hole.

The USBR wells have required stimulation by nitrogen injection to achieve two phase flow after shutdown. No such stimulation problems are anticipated in the proposed wells; there will be approximately six times the perforated zone of the USBR

Table 3-6. Geothermal Well Cost Estimates

ITEM	DESCRIPTION	UNIT COST ($)	EXPERIMENTAL TEST FACILITY – PRODUCTION – UNITS	EXPERIMENTAL TEST FACILITY – PRODUCTION – COST $K	EXPERIMENTAL TEST FACILITY – INJECTION – UNITS	EXPERIMENTAL TEST FACILITY – INJECTION – COST $K	PROJECTED COMMERCIAL – PRODUCTION – UNITS	PROJECTED COMMERCIAL – PRODUCTION – COST $K	PROJECTED COMMERCIAL – INJECTION – UNITS	PROJECTED COMMERCIAL – INJECTION – COST $K
1	Drill Rig	3120/Day	45	140	45	140	30	94	30	94
2	Third Party Services	L.S.	1	89	1	89	1	89	1	89
3	Conductor Casing									
	16" O.D. @ 86#	27.39/LF	--	--	--	--	250	7	--	--
	20" O.D. @ 94#	29.47/LF	250	7	250	7	--	--	250	7
4	Intermediate Casing									
	11 3/4" O. @ 54#	16.09/LF	--	--	--	--	1000	16	--	--
	11 3/8" O.D. @ 61"	18.69/LF	1500	28	1500	28	--	--	1000	19
5	Flow String									
	8 5/8" O.D. @ 44#	15.36/LF	--	--	--	--	6000	92	--	--
	9 5/8" O.D. @ 47#	16.46/LF	5500	90	6900	114	--	--	6900	114
6	Perforations									
	2 Shots/LF	20/LF	--	--	--	--	800	16	800	16
	4 Shots/LF	40/LF	1000	40	1000	40	--	--	--	--
	TOTALS			394		418		314		339

NOTES:
1) Wells Directionally Drilled (30°) to 6,200 Ft.T.D.
2) Producer/Injector Ratio 3:2
3) September 1974 Costs

Table 3-7. Well Drilling Third Party Service Costs (Directionally drilled (30 deg) well with 9-5/8 Inch Production to 6200 Ft. T.D. With 45 Day Drilling and Test Period; September 1974 Costs)

Service	Estimated Cost
Mud services	$20,000
Coring and laboratory log (3 at 30 ft)	8,000
Schlumberger logging	15,000
Cementing	25,000
Bits, reamers, stabilizers, and hole-openers	12,000
Drill stem tests	3,000
Services (welding, casing head, fishing tool)	2,000
Total	$89,000

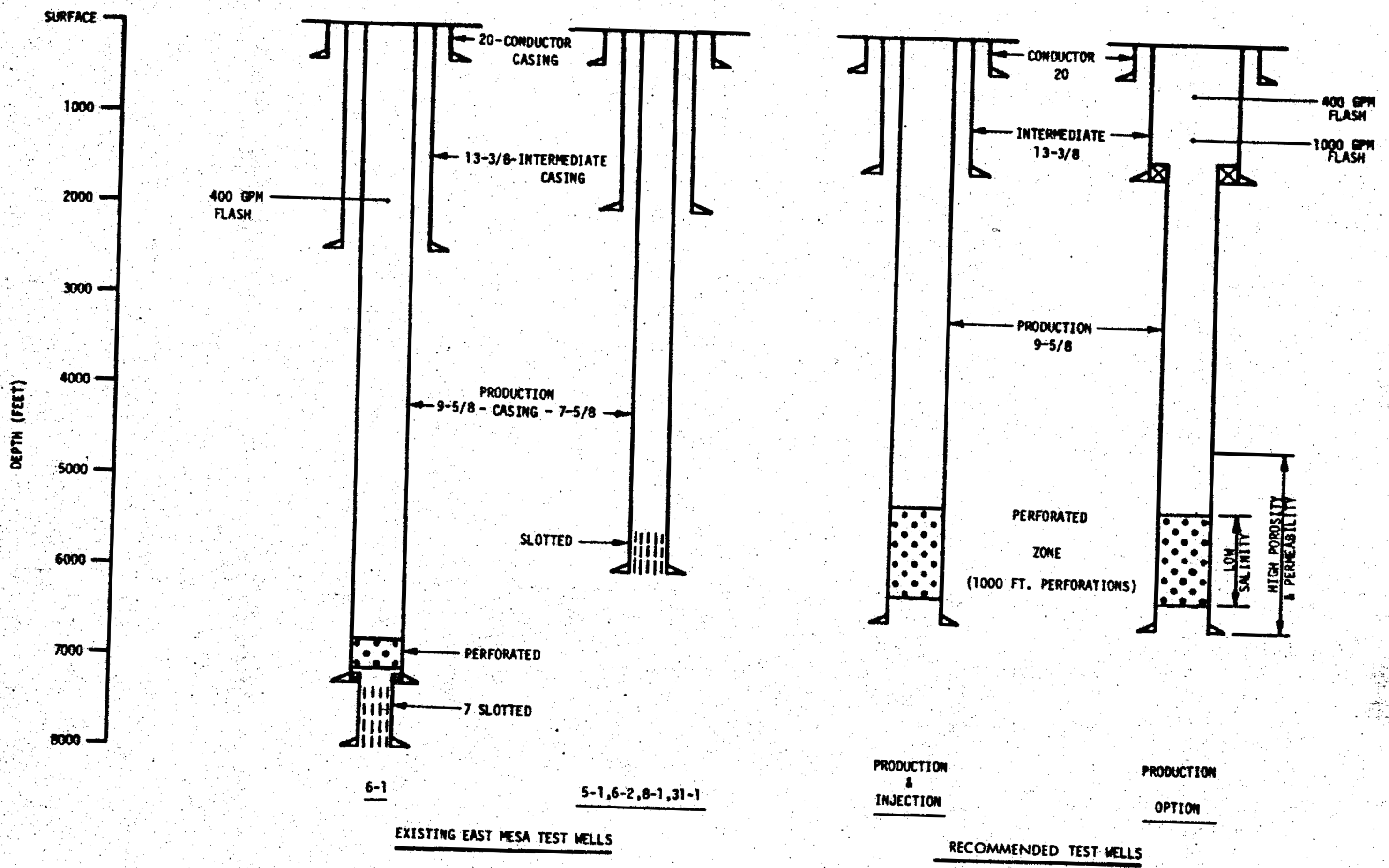


Figure 3-9. Well Casing Programs

wells. However, the experimental facility wells initially will be produced slowly to consolidate the geologic section. Accordingly, TRW suggests a variable speed pump (such as Peerless gear-driven lineshaft with a capacity of 400 to 1500 gpm) be installed and used in the initial production.

3.5 MATERIALS AND CORROSION FACTORS

The following assessment of materials-related requirements and problems and the material recommendations are generally based upon a study which is summarized in Appendix F. The study included the collection of data on geothermal plant operations, desalination studies, laboratory R & D studies, chemical engineering studies and petroleum engineering studies. During the course of the investigation, private conversations were held with representatives of industrial and academic groups as well as government agencies in order to obtain first-hand information.

The overall system requirements are stated below, followed by a discussion of the basis for material evaluation, and a listing of candidate materials by system component. An attempt has been made to identify problems and to recommend the action required to provide the required engineering data, see Section 3.5.4. The most critical problems identified are the lack of data concerning the environmental stress cracking behavior of polymers, the need for establishing the parameters for scale formation and/or salt precipitation for the East Mesa brines and the confirmation of the applicability of corrosion data reported in the literature to the slightly acidic East Mesa brines. It is strongly recommended that test programs be initiated to resolve these problem areas.

3.5.1 System Requirements

The materials used in the construction of a geothermal powerplant must meet extremely severe operation requirements. They must provide long-term operation with a minimum of maintenance or replacement in a very corrosive environment under varying conditions of temperature, pressure, fluid velocities, and, possibly fluid composition. The governing parameters for material selection are associated with the driving fluid and the working fluid. A minimum material-fluid interaction is desired.

3.5.1.1 Driver Fluid (Hot Brine)

The driving fluid is a hot brine which may contain as much as 20,000 ppm of contaminants at temperatures up to 400°F. The main brine constituents are Na and Cl with significant amounts of K, Ca, HCO_3, SO_4, and SiO_2. The chemical analysis is given in Table 3-1. The water is slightly acidic, typically pH=6.7. The fluid will contain solids as well as noncondensables and will move at high velocities with pressures up to 250 psi. The main failure modes of materials modes associated with the hot brine are corrosion, stress corrosion, scaling of surfaces and fouling.

3.5.1.2 Working Fluid

The selected working fluid is isobutane, a low molecular-weight hydrocarbon (paraffin), which was chosen on the basis of thermodynamic properties, cost, availability, stability, and compatibility with component materials. Isobutane is readily available in tank-car quantities at a relatively low price (less than $0.60 per gallon, delivered). It is known to be compatible with common metallic materials including those which are candidates for the various system components for the proposed geothermal plant.

Cracking (decomposition to lower molecular weight hydrocarbons) and isomerization occurs at high temperatures so that isobutane is stable at the temperatures of interest (up to $400^{\circ}F$). Isobutane is insoluble in water or brine.

3.5.1.3 Material Failure Modes

The primary failure modes anticipated in materials used for geothermal energy components are corrosion, stress corrosion-type failures, scaling and fouling. These mechanisms are influenced by the type of corrosive medium, its concentration, temperature, pressure, phase, velocity, the presence of entrained solids and gases, the presence of electrically coupled dissimilar metals, structure geometry, and time of exposure.

Corrosion failures include general corrosion (uniform attack), pitting corrosion, crevice corrosion, intergranular corrosion, and galvanic (dissimilar metal) corrosion.

Stress corrosion-type failures include stress corrosion of metals, environmental stress cracking of polymers, static fatigue of glass and ceramics, hydrogen embrittlement of alloys, erosion-corrosion, and fretting corrosion.

Scale formation on surfaces exposed to brine can affect the heat transfer coefficient of heat exchangers, act as sites for local corrosion, and can cause fouling of flow passages. Scale can form by local oxidation of a metal surface or precipitation and growth of insoluble compounds of Ca, Mg, and Na.

3.5.2 Summary of Materials Behavior in Hot Brine

Mild steels are prone to corrosion in brines. High temperatures, brine velocities, and O_2 concentrations aggravate the attack, especially in regard to pitting corrosion and erosion-corrosion. In-leakage of air must be avoided in the fluid passages. Some type of coating may have to be provided in areas where corrosion attack is severe. It is possible that the formation of scale on mild steel components will increase their resistance to corrosion attack. Some testing should be performed to determine the behavior of mild steels in the slightly acidic brines found in the East Mesa region.

Alloy steels and high strength steels behave in a way similar to mild steels in hot brine. Again, protection may be required in critical areas. In addition, care must be exercised to ensure that stress-corrosion cracking or hydrogen embrittlement does not occur. Normally, proper selection of heat treatments (lower strength steels are more resistant) and process control so that impurities, such as hydrogen, are not absorbed, and careful design to maintain subcritical stress levels in the components obviate such problems.

Corrosion-resistant stainless steels (CRES) are superior to mild steels, alloy steels, and high strength steels in corrosion resistance. CRES is, however, prone to pitting and crevice corrosion, especially at low brine velocities. Molybdenum bearing CRES is better than non-molybdenum bearing CRES. As with mild steels, the presence of O_2 accelerates corrosive attack. CRES is more expensive than mild steels due to its nickel and chromium contents.

Copper and copper alloys exhibit good corrosion resistance in hot brine, especially if the O_2 content is low. High fluid velocities can cause erosion-corrosion attack, especially at lower temperatures. Erosion due to entrained solids (sand, etc.) can be a problem. Brasses are susceptible to stress corrosion cracking if H_2S or NH_3 are present.

Aluminum alloys are highly susceptible to corrosive attack in brines; severe pitting occurs, especially if CO_2 is present. Galvanic coupling to more noble metals must be avoided if aluminum alloys are to be used. It is recommended that aluminum alloys should not be used in the proposed East Mesa geothermal plant.

Titanium and titanium alloys exhibit excellent resistance to corrosion, pitting corrosion, and erosion-corrosion in hot brines. Crevice corrosion occurs in alloys, but some of the newer grades of low alloy titaniums show excellent resistance to this form of attack. Titanium has a high strength which means that thinner sections can be used for component design, thus making it economically competitive with cupro-nickels and CRES. High strength titanium alloys must be protected from stress corrosion attack.

Organic (polymeric) materials have been generally limited to a maximum of $200^{\circ}F$ in hot brine environments. These materials have been used as protective coatings in desalination plants with varying degrees of success. Erosion is a problem, especially in thermoplastic materials. Environmental stress cracking has been encountered in many plastics in hot brine. More information is required, especially in the behavior of thermosetting plastics, before these materials can be recommended for use in the proposed system.

Inorganic materials have been used successfully in hot brine applications for a number of years. Cement pipe liners have been used up to $280^{\circ}F$; studies are under way to improve their performance to allow $400^{\circ}F$ service. Sulfate attack can occur if H_2S is present. Crushed limestone is unacceptable in hot brine applications.

3.5.3 Material Selection for System Components

Candidate construction materials are given below by system components for the proposed powerplant at East Mesa. The materials selected are based upon results of the study summarized in Appendix F, with emphasis on experience gained in the New Zealand and Cerro Prieto geothermal plants. It should be noted that these two plants are operated on alkaline brines while East Mesa brine is slightly acidic. Some tests should be performed to determine if nickel cladding or other methods of protection of mild steel components is required for East Mesa brine. In addition, a chemical analysis of the noncondensables, species and amount, must be performed to establish the concentrations of CO_2, H_2S, NH_3, O_2, etc. The presence of these gases can affect material and plant performance and life. Because a binary cycle system is the prime candidate for the East Mesa site, only components for this type of system are listed.

3.5.3.1 Bores and Well-Head Equipment

Down-hole conditions are extremely severe but experience has shown that mild steel and cement are adequate for most applications. Copper alloys are not suitable due to their poor erosion-corrosion resistance. CRES may be used for valve trim while Ni-resist (austenitic cast irons) alloys (or equivalent) can be used on valve and pump housings. Austenitic cast irons should always be stress relieved. It is important that in-leakage of oxygen be prevented. Exposed edges of the casing must be protected by use of grouting because aerated ground water near the surface can cause problems. In order to prevent down-hole clogging by mineral scale formation, the fluid velocity and pressure should be maintained at high levels. This indicates that down-hole pumping is very desirable.

3.5.3.2 Pipelines

Mild steel is suitable for brine and steam pipelines. Elbows and areas of flow directional change should be protected by use of a protective coating. It is not clear at this time what type of coating is best and whether any polymer can withstand long term service at high temperatures under severe erosion conditions. Expansion joints can be bellows type or expansion loops. CRES may be used for the bellows but at a low stress level to avoid stress corrosion cracking. The exterior of all pipes should be painted to reduce atmospheric corrosion. Pipes and tubes on the working fluid side can be mild steel of conventional design. Ni-resist castings can be used for fittings.

3.5.3.3 Turbine

If a binary cycle is used, the turbine will operate on a hydrocarbon and standard materials will be adequate.

3.5.3.4 Heat Exchangers

Heat exchanger housings exposed only to working fluid can be constructed of standard mild steels, low alloy steels, or corrosion-resisting casting alloys. The heat exchanger tubes and housing exposed to brine should be constructed of a titanium alloy or 316 CRES. If titanium is used care should be exercised to prevent galvanic coupling to steel components. Headers should be CRES or Ti to prevent oxides from forming, exfoliating, and flowing into the tubes causing a blockage. If mild steel tubes are used in the heat exchanger, they must be protected on the brine side by a protective coating. One possibility is an electroless nickel coating on the inside of the tubes. However, this combination of materials would have to be investigated to prove fabricability, uniformity, and performance.

3.5.3.5 Valves, Controls, Pumps

Nickel-iron cast alloys (Ni-resist) with 316 CRES trim is recommended for valve construction. CRES, nickel, and monel are acceptable for individual valve components. Critical parts should be made more noble with respect to the valve housing. Similarly, pump housings should be austenitic cast iron, and impellers and shafts made from 316 CRES and monel, respectively. Stress levels should be kept low to minimize problems with stress corrosion.

3.5.3.6 Auxiliary Equipment

Experience at the New Zealand plant showed that above ground auxiliary components presented very troublesome maintenance problems. Tarnishing of silver and copper electrical contacts, blackening of lead-pigmented paints, stress corrosion of spring materials in gauges and recorders, and corrosion of exposed lines have been encountered. However, much of the problem is related to H_2S in the atmosphere which should be absent in the proposed East Mesa plant. If atmospheric corrosion presents a problem, corrective measures include the use of aluminum for electrical conductors, use of K-monel or stainless steel springs, use of titanium oxide pigmented paints, chromium plating of instrument and telephone components, and gold plating of electrical contacts.

3.5.4 Critical Materials Problems and Recommended Research

During the course of the literature survey, several problems were identified for which data is not available. These are listed below with recommended action.

a) The applicability of existing geothermal corrosion and scaling data to the slightly acidic brines of East Mesa must be established. Nearly all existing data is based upon alkaline brines. It is recommended that a comprehensive corrosion test program be initiated immediately. The effects of temperature and fluid velocity on candidate materials, especially mild steels, should be determined. In addition, the conditions for scale formation should be established. Stress corrosion tests should be performed on CRES, titanium, and high strength materials at high temperatures.

b) Environmental stress cracking or severe erosion occurs in most organic materials at temperatures above 200°F. A program is recommended to test candidate polymeric materials under temperature-stress-brine exposure conditions and under high-velocity flow conditions at temperatures up to 400°F. It is important that a suitable liner material for mild steel be found, especially if protective scale formation does not occur.

c) Inorganic protective coatings are still in the development stage. In the event that polymeric coatings are unsuitable at 400°F, an inorganic erosion-corrosion resistant coating will be needed to protect mild steel and copper bases metal components. It is recommended that various metal and ceramic coatings, such as electroless Ni, nickel cladding, flame-sprayed oxides, etc., be tested with East Mesa brine under high-flow velocity conditions at 400°F. The test specimens should simulate an elbow or other flow directional change area in the system.

d) It is unclear at this time whether precipitation of salts could occur for East Mesa brines in the proposed system. The third heat exchanger will operate at relatively low temperatures (exit temperature possibly as low as 180°F) and the temperature just prior to reinjection will be still lower. The conditions for precipitation should be established by test and, if necessary, prevention methods included in the system.

3.6 SYSTEM SELECTION AND OPTIMIZATION

The aforementioned technology assessments and performance characterizations were used to provide a basis for comparative concept evaluations and selection of an optimum representative geothermal powerplant system as described herein.

Several methods of comparing systems and evaluating variables have been identified and used in other geothermal power studies, e.g., "figures-of-merit" incorporating efficiency, unit costs and delivered energy costs either singly or in combination. The figure-of-merit used in this study is based solely on estimated 1974 system unit costs, which reflect system efficiency and eliminates the uncertainties of future escalation and costs of financing. The estimates are based on vendor quotes where possible and by scaling other costs of analogous plant equipments from the utility, chemical, and petroleum industries. The reader is cautioned against indiscriminate comparison of costs with different variables and cost bases.

3.6.1 System Selection

The performance characteristics presented in Table 3-4 were used as a basis for developing candidate concept equipment and system unit costs. The following criteria were used to provide comparative concept commonality:

a) 50 MWe delivered energy plant outputs to provide a basis for comparison with other electrical generation methods. Additionally, the 50 MWe unit costs are expected to be representative of the range of geothermal powerplants from 25 to 50 MWe.

b) Wet cooling towers (i.e., 102°F condensing temperature) to provide an initial optimum performance cost comparison of all candidates, independent of environmental impact influences.

c) Directionally drilled wells, with 20 percent spares, to 6200 feet with 1000 feet of perforations. Producing well flows of 1000 GPM (350°F well fluid) and injection wells 1500 GPM. Casing program with 9-5/8 inch outer diameter production and injection strings.

The initial candidate system unit cost estimates are presented in Table 3-8 with the following observations:

a) The double flash steam system appears more cost effective than single flash. Increased efficiency results in lower well costs offsetting the higher powerplant cost of double flash.

b) The binary cycle with isopentane or isobutane working fluids is more cost effective than either of the flashed steam systems.

c) The fluid collection (wells) costs are significant, 45 to 65 percent of total system costs with pumped well fluids at 350°F.

Preliminary reliability-maintainability analyses were performed as described in Appendix G. Based on an overview of complexity and potential critical items in each concept option, the following order of preference is indicated:

a) Concept B — Binary cycle

b) Concept A-1 — Single-flashed steam cycle

c) Concept C — Double-flashed steam cycle

The selected representative system employs a binary cycle energy conversion system with isobutane as the working fluid.

3.6.2 System Optimizations

The selected system approach was optimized considering ranges of well fluid temperatures, condensing temperatures, powerplant sizes and energy collection approaches. The comparative system cost summaries are indicated in Figure 3-10 and the cost sensitivity optimization displays and conclusions are indicated in Figure 3-11.

Table 3-8. 50 MWe Candidate Concept Unit Cost Estimates

Item	Steam Cycle ($/KWe)		Binary Cycle ($/KWe)	
	Single	Double	Isobutane	Isopentane
Fluid Collection				
*Production wells	(30) 254.5	(23) 195.1	(13) 110.3	(12) 101.8
Injection wells	(21) 168.2	(15) 120.0	(12) 96.0	(11) 88.0
Down-hole pumps	40.5	31.1	24.3	21.6
Injection pumps	12.0	8.8	--	--
Wellhead/piping	8.8	6.6	5.2	4.7
Exploration/engineering design	63.6	47.2	36.8	33.1
Subtotal	547.6	408.8	272.6	249.2
Power Plant				
Power house	15.0	20.0	15.0	15.0
Turbine/generator	104.5	153.0	72.6	71.0
HX/cond	70.8	72.9	96.3	94.5
**Cooling subsystem	48.5	47.0	54.0	50.0
Substation/electrical	25.3	25.3	25.3	25.3
Engineering/Design	36.0	43.4	35.9	34.9
Subtotal	300.1	361.6	299.1	290.7
Totals	847.7	769.9	571.7	539.4

*Directional wells, 20 percent spares, 6200 ft T.D., 350°F, W/1000 ft perforations, producing 1000 GPM/well, injection 1,500 GPM/well

**Wet cooling tower, 102°F conditional temperature

POWER SYSTEM UNIT COSTS*

CENTRAL PLANT

1,000 GPM PRODUCTION WELLS
20% SPARE WELLS

	UNIT COSTS ($/KWE)			
	3 MWE	10 MWE	25 MWE	50 MWE
BRINE COLLECTION				
PRODUCTION WELLS	(2) 269	(4) 160	(10) 160	(18) 145
INJECTION WELLS	(2) 254	(3) 114	(6) 91	(12) 91
DOWN HOLE PUMPS	45	27	27	24
WELLHEAD/PIPING	12	6	6	5
EXPLOR/ENGINEERING	35	18	17	16
SUB-TOTAL ($/KWE)	580	325	301	281
POWER PLANT				
POWER HOUSE	25	20	15	15
TURBINE/GENERATOR	120	105	78	78
HX/COND.	170	160	140	140
COOLING	96	88	80	80
SUBSTATION/ELEC	30	28	25	25
ENGINEERING	60	55	46	46
SUB-TOTAL ($/KWE)	501	456	384	384
SYSTEM TOTAL ($/KWE)	1081	781	685	665

* 1974 COST ESTIMATES WITHOUT CONTINGENCY OR ESCALATION.

CENTRAL PLANT

1,500 GPM PRODUCTION WELLS
20% SPARE WELLS

	UNIT COSTS ($/KWE)			
	3 MWE	10 MWE	25 MWE	50 MWE
BRINE COLLECTION				
PRODUCTION WELLS	(2) 269	(3) 12	(7) 113	(12) 97
INJECTION WELLS	(2) 254	(3) 114	(4) 65	(8) 65
DOWN-HOLE PUMPS	45	20	18	16
WELLHEAD/PIPING	12	6	4	4
EXPLOR/ENGINEERING	35	16	12	11
SUB-TOTAL ($/KWE)	580	277	212	193
POWER PLANT				
POWER HOUSE	25	20	15	15
TURBINE/GENERATOR	120	105	78	78
HX/COND	170	160	140	140
COOLING	96	88	80	80
SUBSTATION/ELEC	30	28	25	25
ENGINEERING	60	55	46	46
SUB-TOTAL ($/KWE)	501	456	384	384
SYSTEM TOTAL ($/KWE)	1081	733	596	577

ELECTRICAL COLLECTION

1,000 GPM PRODUCTION WELLS
NO SPARES
3 MWe MODULES

	UNIT COSTS ($/KWE)			
	3 MWE	9 MWE	24 MWE	48 MWE
BRINE COLLECTION				
PRODUCTION WELLS	(1) 135	(3) 135	(8) 135	(16) 135
INJECTION WELLS	(1) 127	(3) 127	(8) 127	(16) 127
DOWN-HOLE PUMPS	23	23	23	23
WELLHEAD/PIPING	6	6	6	6
EXPLOR/ENGINEERING	17	10	10	10
SUB-TOTAL ($/KWE)	308	301	301	301
POWER PLANT				
POWER HOUSE	25	25	25	25
TURBINE/GENERATOR	120	120	120	120
HX/COND	170	170	170	170
COOLING	96	96	96	96
SUBSTATION/ELEC	30	30	30	30
ENGINEERING	60	22	9	5
SUB-TOTAL ($/MWE)	501	463	450	446
SYSTEM TOTAL ($/MWE)	809	764	751	747

CONDITIONS:

- BINARY/ISOBUTANE CYCLE
- 350°F BRINE
- 110°F CONDENSING TEMPERATURE
- DIRECTIONAL WELLS TO 6,200-FOOT DEPTH
- 1974 COST ESTIMATES WITHOUT CONTINGENCY OR ESCALATION

DELIVERED ENERGY COSTS**

CENTRAL PLANT

- 1,000 GPM WELLS
- 20% SPARES
- 50 MWe

[illegible] COLLECTION

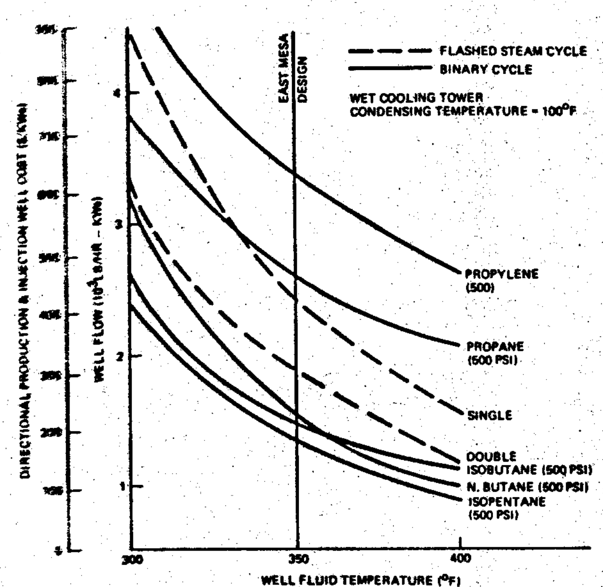
- [illegible] GPM WELLS
- [illegible]
- [illegible] MWe MODULES)

	CENTRAL PLANT		[illegible] COLLECTION	
ITEM	WELLS	POWER PLANT	WELLS	POWER PLANT
INVESTMENT (1974 COSTS)	265	338	[illegible]	446
ESCALATION @ 12% (YR)	64	122	[illegible]	161
CONTINGENCY 20%	53	68	[illegible]	89
SUB-TOTAL ($/KWE)	382	528	[illegible]	696
EXPLOR/ENGINEERING	16	46	[illegible]	5
ESCALATION @ 12% (YR)	2	6	[illegible]	1
CONTINGENCY 20%	1	9	[illegible]	1
SUB-TOTAL ($/KWE)	18	61	[illegible]	7
SYSTEM TOTAL ($/KWE)	400	589	[illegible]	703
PLANT FACTOR	85%	85%	[illegible]	75%
FIXED CHARGE RATE	21%	18.5%	[illegible]	18.5%
FIXED CHARGES (MILLS/KW)	11.28	14.63	[illegible]	19.80
20%/YR O & M (MILLS/KWH)	1.07	1.58	[illegible]	2.14
SUB-TOTAL (MILLS/KWH)	12.35	16.21	15.47	21.94
SYSTEM TOTAL (MILLS/KWH)	28.56		[illegible]	

** PUBLIC UTILITY PROJECT START 1975

Figure 3-10. Comparative System Cost Summaries

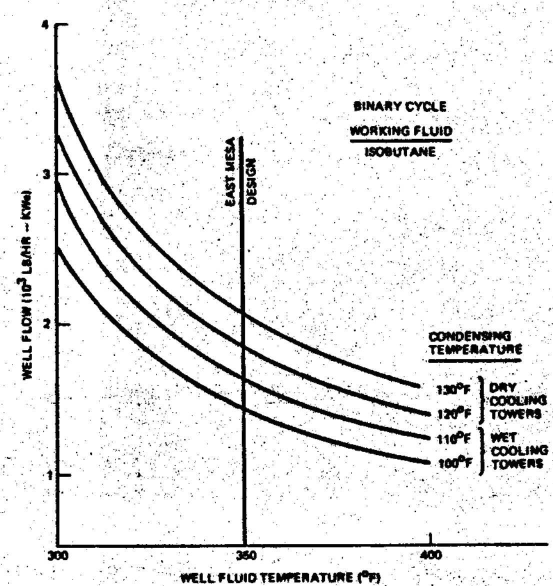
PARAMETRIC COST SENSITIVITIES



A. ENERGY CONVERSION CONCEPT WELL COST/FLOW SENSITIVITY TO TEMPERATURE

CONCLUSIONS

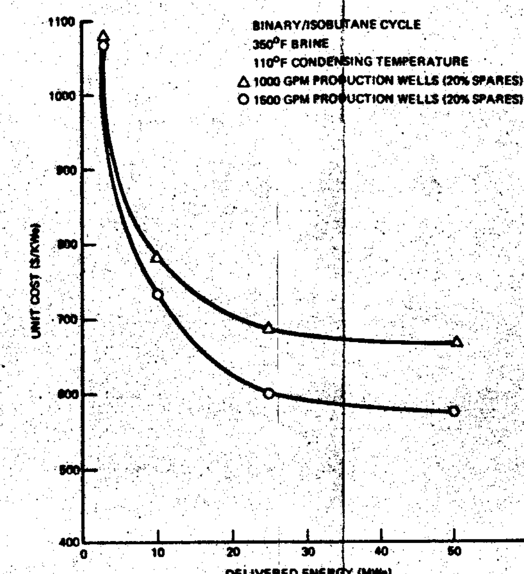
- BINARY CYCLE WITH ISOPENTANE, ISOBUTANE OR BUTANE AS WORKING FLUIDS IS MORE COST EFFECTIVE THAN FLASHED STEAM CYCLES
- ISOBUTANE AND ISOPENTANE ARE LEAST SENSITIVE TO OFF-DESIGN WELL FLUID TEMPERATURES



B. WELL FLOW SENSITIVITY TO CONDENSING TEMPERATURE

CONCLUSIONS

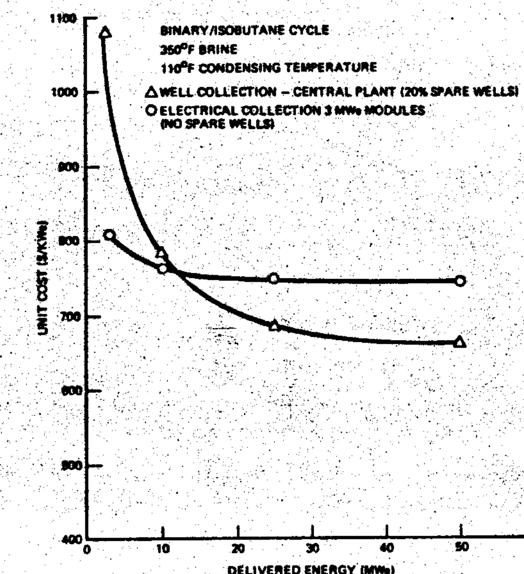
- WELL FLOWS (i.e. COSTS) INCREASE APPROXIMATELY 18% PER 10°F CONDENSING TEMPERATURE
- SLIGHT ADVANCE IN COOLING TOWER TECHNOLOGY YIELDS SIGNIFICANT IMPROVEMENT IN PERFORMANCE



C. SYSTEM COST SENSITIVITY TO SIZE AND WELL FLOWS

CONCLUSIONS

- UNIT COSTS OF SMALLER PLANTS ARE (3 TO 10 MWe) AFFECTED ADVERSELY BY COSTS OF SPARE WELLS AND NON-LINEAR TURBINE GENERATOR AND ANCILLARY EQUIPMENT
- COST SCALING FROM 25 TO 50 MWe PLANTS IS LINEAR WITH PROPORTIONAL SPARE WELLS
- COST SCALING FROM 10 TO 50 MWe PLANTS IS LINEAR CONSIDERING NON-PROPORTIONALITY OF SPARE WELLS
- 50% INCREASE IN INDIVIDUAL WELL FLOWS DECREASES TOTAL SYSTEM COSTS BY 10%, INDICATING DESIRABILITY OF MAXIMIZING INDIVIDUAL WELL PRODUCTION



D. SYSTEM COST SENSITIVITY TO ENERGY COLLECTION OPTIONS

CONCLUSIONS

- ELECTRICAL COLLECTION CONCEPT IS APPROXIMATELY 10% MORE COSTLY THAN WELL FLUID COLLECTION ON INSTALLED COST BASIS
- PROJECTED DELIVERED ENERGY COST OF ELECTRICAL COLLECTION IS APPROXIMATELY 30% HIGHER THAN FIELD COLLECTION, CONSIDERING INCREASED MULTIPLE UNIT MAINTENANCE AND DOWNTIME

Figure 3-11. Parametric Cost Sensitivities

4. PRELIMINARY UTILIZATION PLAN

A primary objective of the recommended geothermal power generation experiments is to encourage utility industry commercial applications with relatively proven utilization technology. It is therefore necessary to provide timely dissemination of research findings and technology development descriptions to relevant public or private sector communities. Recommendations are:

- Immediate dissemination of significant experiment trends and results by means of bi-monthly progress reports to interested subscribers.
- Progress report briefings at geothermal symposiums and conferences. Based on the past year's experience, quarterly public briefings may be anticipated.

4.1 USER GROUPS

The specific near-term user groups are identified as municipal and private utilities. It is recommended that the current participating advisors' interest and participation be solicited for subsequent Phase 1 and Phase 2 planning activities and experiments.

Utilization of the completed experimental research facilities for maximal benefit to commercial development of geothermal power also implies institution of policies and mechanisms to gain industrial participation in research and development performed in the facilities, and rapid and effective transfer of information, subject to certain conditions and restraints indicated below. We include as options:

- Government sponsored work contracted to industrial firms, fully reported in the open literature
- Rental of facilities to industrial firms, under which arrangement rights in data are protected
- Conduct of experimental work in which objectives, data requirements, and success criteria are specified by industrial organizations, e.g., Electric Power Research Institute. This option would appear especially appropriate to acquisition of reliability and economic data essential to industry-wide acceptance of technology as applicable to commercial exploitation.

The above options, of course, do not preclude use of the facilities by government research and development organizations, nor by academic and nonprofit institutions. But emphasis on industrial participation is regarded as essential to the project's overall objectives.

4.2 USER MARKET

This section summarizes user market economic analyses indicating cost competitiveness and potential disposition of test generated power. It is recommended that these initial efforts be extrapolated, during Phases 1 and 2, to develop a plan for identifying and stimulating interest, and beneficial program involvement with other power companies in representative geothermal resource areas.

4.2.1 Economic Projections

The ultimate test of geothermal power generation economic viability is to compare and demonstrate competitiveness with oil fueled powerplants to achieve the national oil saving goal.

The assumptions used in developing this comparison, shown in Table 4-1, are summarized as follows:

a) Unit Costs — All unit costs are projected to plants coming on line in 1974. The geothermal plant unit costs include 1974 cost estimates derived in the study. Oil fueled plant unit costs are optimistically low and were obtained from the recent literature, i.e., "Power Engineering" August 1974.

b) Plant Factor — The geothermal plant factor is considered conservatively low at 85 percent in view of past experience at the Geysers and Cerro Prieto of greater than 90 percent. The oil fueled plant factors are considered optimistic in view of the national averages.

c) Annual Fixed Charges (AFC) — Estimated AFC's for municipal and private utilities.

d) Fuel Costs — Fuel costs were derived from the recent literature. The most unpredictable cost is that of fuel oil.

It is observed that geothermal power production at East Mesa appears competitive with oil fueled plants on both capital ($/KWe) and delivered energy (mills/KWH) cost basis.

4.2.2 Disposition of Generated Power

The Imperial Irrigation District (IID), a publicly owned utility, is the sole supplier of electric energy to the Imperial

Table 4-1. Projected Economic Comparisons

Delivered Energy Costs

	MUNICIPAL UTILITY		PRIVATE UTILITY	
	WELLS	PLANT	WELLS	PLANT
INSTALLED COST ($/KW)	387	574	387	574
ENGINEERING COST ($/KW)	11	36	11	36
UNIT COST ($/KW)	398	610	398	610
PLANT FACTOR (%)	85	85	85	85
A.F.C. (%)	16	13.5	21	18.5
O & M ($ YR)	2	2	2	2
A.F.C. (MILLS/KWH)	8.55	10.41	11.22	15.16
O & M (MILLS/KWH)	1.04	1.54	1.04	1.54
ENERGY COST (MILLS/KWH)	9.59	11.95	12.26	16.70
SYSTEM (MILLS/KWH)	21.54		28.96	

CONDITIONS:

- 50 MWE PLANT 1974 COST ESTIMATE
- 350°F LOW SALINITY BRINE
- ISOBUTANE BINARY CYCLE
- AIR COOLED CONDENSER (120°F CONDENSING TEMPERATURE)
- 26 at 9-5/8 BORE, 1500 GPM PRODUCTION WELLS
- 17 at 9-5/8 BORE, 2250 GPM INJECTION WELLS

Annual Fixed Charges

	MUNICIPAL UTILITY		PRIVATE UTILITY	
	30 YEAR	10 YEAR	30 YEAR	10 YEAR
RETURN RATE (COST OF CAPITAL)	8.00	8.00	13.00	13.00
DEPRECIATION/ AMORTIZATION	1.25	3.75	1.25	3.75
LOCAL AND GOV'T TAXES	3.00	3.00	3.00	3.00
ADMINISTRATIVE EXPENSES	1.00	1.00	1.00	1.00
INSURANCE	0.25	0.25	0.25	0.25
FIXED CHARGES	13.5%	16%	18.5%	21%

* ESTIMATED FIXED PORTION OF REVENUE REQUIREMENT FOR 1974

Oil Vs Geothermal

ITEM	MUNICIPAL UTILITY		PRIVATE UTILITY	
	OIL	GEO-THERMAL	OIL	GEO-THERMAL
PLANT SIZE (MWE)	1000	50	1000	50
1980 UNIT COST ($/KWE)	300	610	300	610
PLANT FACTOR (%)	80	85	80	85
FIXED CHARGE RATE (%)	13.5	13.5	18.5	18.5
FIXED CHARGES (MILLS/KWH	5.78	10.41	7.92	15.16
OPERATIONS AND MAINTENANCE (MILLS/KWH)	0.86	1.54	0.86	1.54
FUEL COST (MILLS/KWH)	* 14.90	9.59	** 20.18	12.26
ENERGY COST (MILLS/KWH)	21.54	21.54	28.96	28.96

* OIL AT $ 8.32/BARREL
** OIL AT $11.27/BARREL

NOTE: CURRENT LOW SULFUR (0.5%) No. 6 RESIDUAL OIL RANGES FROM $15 TO $20/BARREL

Valley in which the recommended East Mesa test site is located. The IID power sources are indicated in Figure 4-1.

Figure 4-1 also shows the IID power transmission grid. The IID, with foresight, provided a 33 KV transmission service into the USBR test site with potential for future feed into the transmission grid of geothermal generated power. The transmission pole line is within 1000 feet of the study-recommended NSF test site and has the capability to absorb up to 30 MWe of site generated power. Up to 50 MWe could be absorbed with increased transmission voltage modifications to the IDD substation.

Assuming that IID would pay 5 mills/KWH for NSF facilities developed power and 6 MWe available at 85 percent plant factor, $223,380 per year revenue would be obtained from Phase 2 operation to provide supplemental testing goods and services.

Imperial Irrigation District Sources of Power

District Owned		Nameplate Rating in Kilowatts
El Centro Steam Plant		186,000
Brawley Diesel Plant		
Diesel	12,000	
Gas Turbine	22,500	
Total Diesel Plant		34,500
Coachella Gas Turbines		40,000
Hydroelectric Plants		
Pilot Knob	33,000	
Drop No. 2	10,000	
Drop No. 3	9,800	
Drop No. 4	19,600	
Double Weir	560	
Turnip	420	
Total Hydroelectric		73,380
Total District Owned		333,880
Other Power Sources		
U.S. Bureau of Reclamation		
Glen Canyon (CRSP	23,200	
Davis Dam	30,000	
Total USBR		53,200
APS Yucca Plant	25,000	25,000
Total Other Sources		78,200
TOTAL ALL SOURCES		412,080

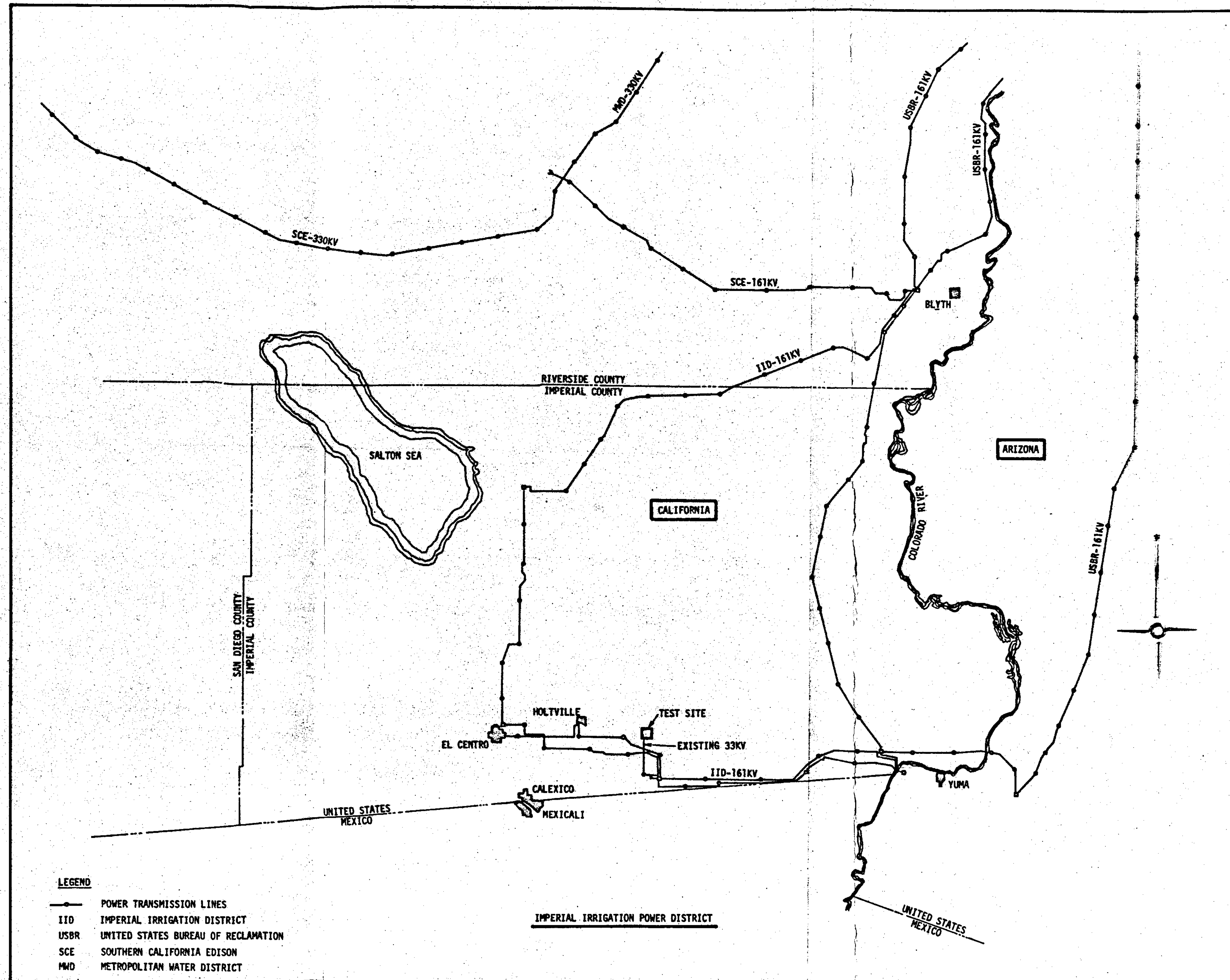


Figure 4-1. Imperial Irrigation District Power Sources and [illegible]

5. RECOMMENDED IMPLEMENTATION PLAN

A primary goal of the NSF geothermal program is to encourage commercial development of geothermal electrical power generation. To achieve this objective, facilities are required for geothermal testing and research under actual field conditions, and for fielding the technology needed to demonstrate feasibility of commercial development. Accordingly, TRW recommends an Experimental Geothermal Research Program that will provide an experimental research facility with a power generating capacity to 10 MWe. The facility will use the moderate temperature, low salinity liquid-dominated geothermal resources at East Mesa.

The implementation plan presented in this section is recommended as the best approach to achieving program objectives. It is structured in accordance with the NSF RANN phased project approach as stated in the Project Independence Geothermal Task Report. The plan calls for two phases: Phase I involves systems definition and subsystem (component) experimentation; Phase II involves the actual design and construction of the experimental research facilities.

As presently envisioned, Phases 1 and 2 will be consecutive efforts, totalling 44 months. However, substantial time and cost savings are available to the NSF by conducting the two phases concurrently, with Phase 2 beginning 6 months after start of Phase 1.

Therefore, TRW recommends an accelerated Phase 2 program that provides a total schedule span of 30 months and a total estimated cost of $21 million. This option pares 14 months off the schedule and results in a cost savings of 14 percent, which is realized because of a reduction in the escalation impact (see Figures 5-1, 5-2, and 5-3).

This section presents our approach to promoting commercial development, our planning rationale, our implementation plan for Phases 1 and 2, followed by a statement of work for each phase.

5.1 PROMOTING COMMERCIAL DEVELOPMENT

Promoting commercial development of geothermal electrical power generation requires that both the experimental research facility and the experiments defined be responsive to the needs of industry, expressed and implied. These needs, as expressed by advisors from municipally and privately owned utilities and the Sierra Club, are summarized as follows:

- Viable geothermal resource evaluations and exploratory techniques
- Demonstrated reliability and economics of extraction and utilization technologies, e.g., down-hole pumps, heat exchangers, binary cycle thermodynamics.
- Accelerated transition from study and analysis to advanced hardware development and technology demonstrations

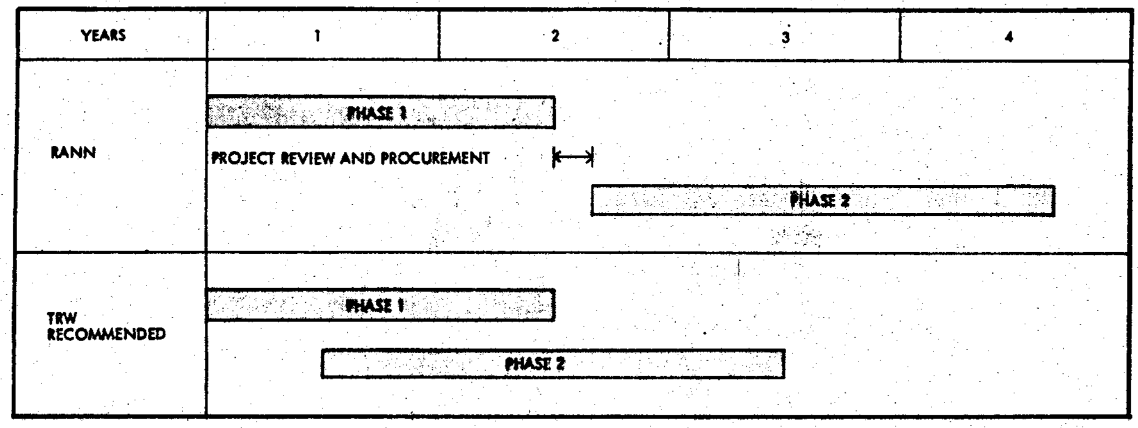


Figure 5-1. Consecutive and Concurrent Phase 1/Phase 2 Schedules

TASK	DESCRIPTION	ESTIMATED COST(S)
1A	FACILITY DESIGN	48,800
1B	CONSTRUCT ACCESS ROADS	56,770
1C	PREPARE TEST AREAS	84,000
1D	CONSTRUCT LAB BUILDING	124,720
1E	INSTALL ELECTRICAL SERVICE	371,670
1F	INSTALL PIPELINE TO POND	60,400
2A	WELL COMPLETION ENGR	60,000
2B	WELL 6-1 MOD & TEST	130,500
2C	WELL 6-2 MOD & TEST	124,600
2D	DRILL WELLS 6-3 & 6-4 & TEST	1,010,900
2E	DRILL WELLS 6-5 & 6-6 & TEST	1,051,340
2F	MOD WELL 6-3 & MAX FLOW TEST	41,440
2G	RESV'R ANALYSES & REPORT	50,440
3A	SPERRY PUMP TEST WELL 6-1	33,300
3B	LEAR PUMP TEST WELL	34,260
3C-1	CORROSION TESTS 6-1	95,400
3C-2	CORROSION TESTS 6-2	43,600
3C-3	CORROSION TESTS 6-3	44,900
3D	SCALE CLEANING R&D 6-3	120,750
4A	SYSTEMS OPTIMIZATION ANALYSES	47,700
4B	PHASE 2 DESIGN CRITERIA	22,570
5	ENVIRONMENTAL IMPACT STATEMENT	66,000
6	UTILIZATION BRIEFINGS	19,800
7	PHASE 2 PLANNING	50,400
8	PROGRAM MANAGEMENT	270,000
	MOST PROBABLE COST	4,064,260
	15% CONTINGENCY	609,639

Figure 5-2. Phase 1 Schedule and Cost Estimate

TASK	DESCRIPTION	MONTHS AFTER START OF PHASE 1 (7–30)	ESTIMATED COST($)
1A	POWER PLANT DESIGN		1,086,000
	ORDER DRILL RIG & CASING		
	ORDER TURBINE/GENERATOR		
1B	CONSTRUCTION SUPERVISION		200,000
1C	RELIABILITY ANALYSES		50,400
2A	DRILL PRODUCTION WELLS(6)		2,956,890
2B	DRILL INJECTION WELLS(2)		1,045,670
2C	INSTALL WELLHEAD/PIPING		195,120
2D	INSTALL DOWN-HOLE PUMPS(6)		595,300
3A	INSTALL BRINE DISTRIBUTION		276,020
3B	INSTALL ISOBUTANE SYSTEM		3,309,930
3C	INSTALL TURBINE/GENERATOR		5,311,350
3D	INSTALL STATION POWER		881,472
3E	INSTALL GENERAL FACILITIES		408,456
4	ENVIRONMENTAL IMPACT STATEMENT		74,400
5	UTILIZATION BRIEFINGS		93,000
6	PROGRAM MANAGEMENT		446,400
		MOST PROBABLE COST	16,930,410
		15% CONTINGENCY	2,539,560

Figure 5-3. Accelerated Phase 2 Schedule and Cost Estimate

5.2 PLANNING RATIONALE

TRW's planning rationale for achieving program objectives, emphasizing industry needs, is as follows:

- Resource Measurement and Evaluation. Existing USBR wells will be modified early in Phase I by additional perforations and down-well pumps to accelerate project test capability and reservoir measurement and evaluations. New producer/injector well pairs (6-3/6-4 and 6-5/6-6) will be drilled to support reservoir definition and evaluations. New findings will be correlated with predictions derived from previous explorations at East Mesa to verify exploratory techniques and evaluation.

- Experiments. Phase 1 subsystem (component) experiments must emphasize system concepts and technology experiments that demonstrate reliability and economic viability of commercial development.

  The following critical technologies have been identified as providing leverage with respect to the binary cycle energy conversion concept:

  — Down-hole pumps

  — Well completions for increased well flows

  — Materials corrosion and erosion

  — Heat exchangers

  — Working fluid and turbine optimizations.

  The experimental binary cycle power plant of 10 MWe gross output generating capacity is representative of equipment life and operating characteristics of utility companies. This plant size is large enought to demonstrate scalable technical and economic viability requiring them to encourage commercial development.

- Experimental Research Facilities. Although the Phase 1 test facilities must address the specific needs of this project, sufficient well bore size, additional test spaces, well fluid manifolding and power service will be provided to accommodate other technology demonstrations involving

- Direct contact heat exchangers
- Steam separators
- Advanced down-hole pumps
- Materials
- Processes (heating, refrigeration, chemical extraction).

The East Mesa reservoir exhibits a low salinity (3000 ppm) zone at 5000 to 6000 foot depths and a higher salinity (25,000 ppm) zone at 6000 to 7000 feet. It is desirable to develop this unique feature and to provide test facilities with access to each of these brines. This is done by modifications to existing wells 6-1 and 6-2. By providing sufficient power reserve, brines can be heated to 500°F, resulting in a versatile geothermal brine research and test facility.

- Program Acceleration. Early completion of the facilities is vital to encourage industry participation in geothermal development. An overall program based on the NSF/RANN phased approach requires at least 44 months. Much of this time is devoted to in-line project review and procurement between Phases 1 and 2, and to in-line lead times. For instance, the lead time for Phase 1 drill rigs and casing is approximately 6 months; an Phase 2 turbine/generator lead time is approximately 18 months. An accelerated program is required to provide operational demonstration by 1978 if we are to meet our 1985 national goal.

5.3 PHASE I INTEGRATED EXPERIMENTAL RESEARCH FACILITIES

The NSF experimental research facilities will be located in Imperial County, California (see Figure 5-4). This site was selected because

- Reservoir characteristics are typical of fields of moderate temperature (350° to 400°F), low salinity (3000 ppm to 25,000 ppm) brines.
- The site is not under lease, thereby minimizing acquisition difficulties.

The East Mesa test site now has five deep wells drilled specifically for geothermal purposes by the USBR. Total depths, completion intervals, and completion types are indicated on Figure 5-5. The 5-1 well is a water injection well; the other four are used for producing hot brines. Figure 5-6 is an aerial view of the East Mesa area showing USBR test wells and facilities, and the recommended location of the NSF experimental research facility.

5.3.1 Coordinated Use of USBR Facilities

The USBR is planning a test program during January through March of 1975 that calls for free flowing production of wells 6-1 and 6-2 to the pond, then pumping from the pond into the injection well.

We recommend that the proposed NSF project incorporate well modifications and supplementary pumped production tests of these USBR wells to provide early test facility capabilities and reservoir evaluations. Modifications involve perforating additional reservoir sections to increase flow rate. The 6-1 well will be perforated in the deeper, high salinity section. The 6-2 well penetrates a shallower section; additional perforations will increase

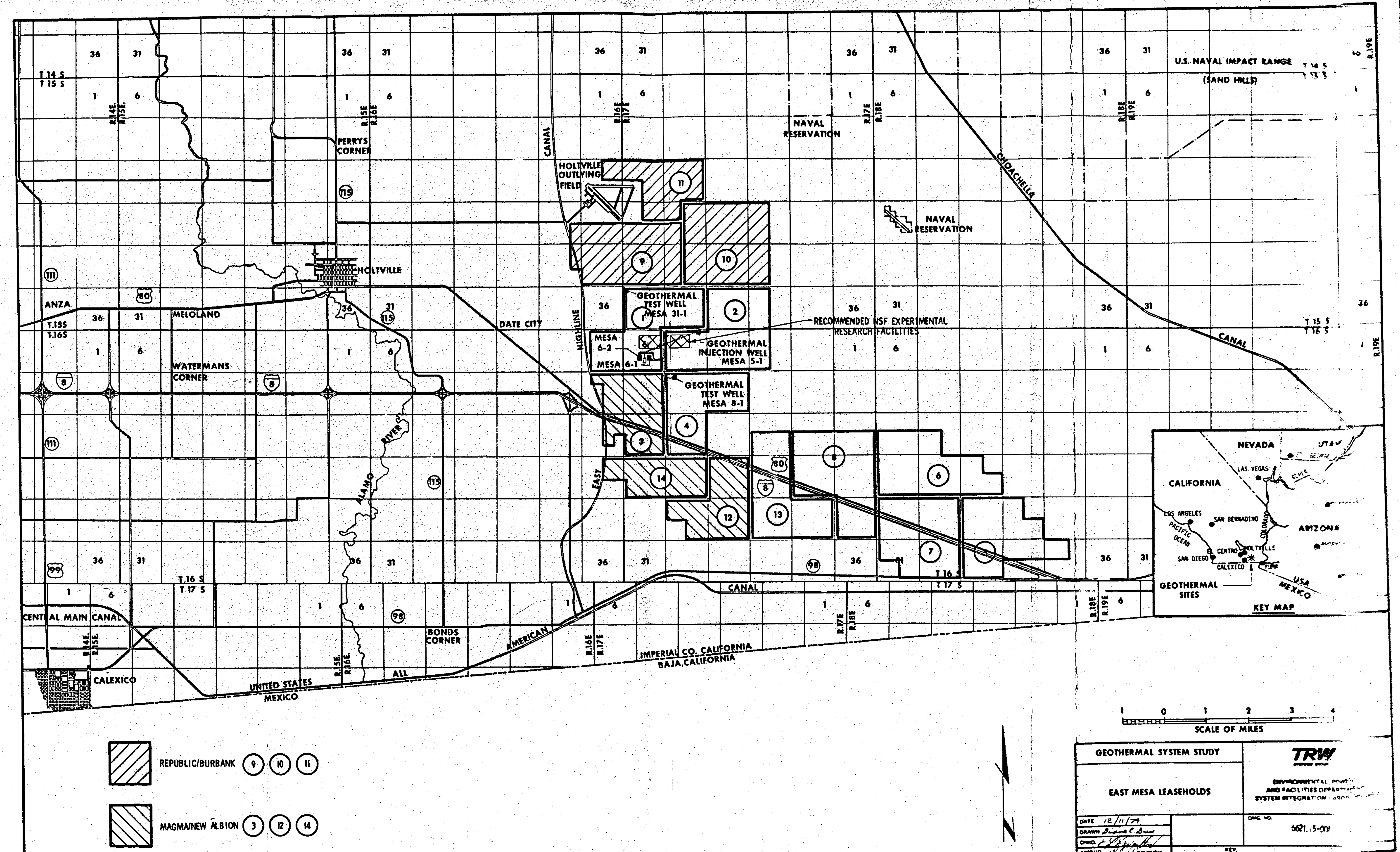


Figure 5-4. East Mesa Leaseholds

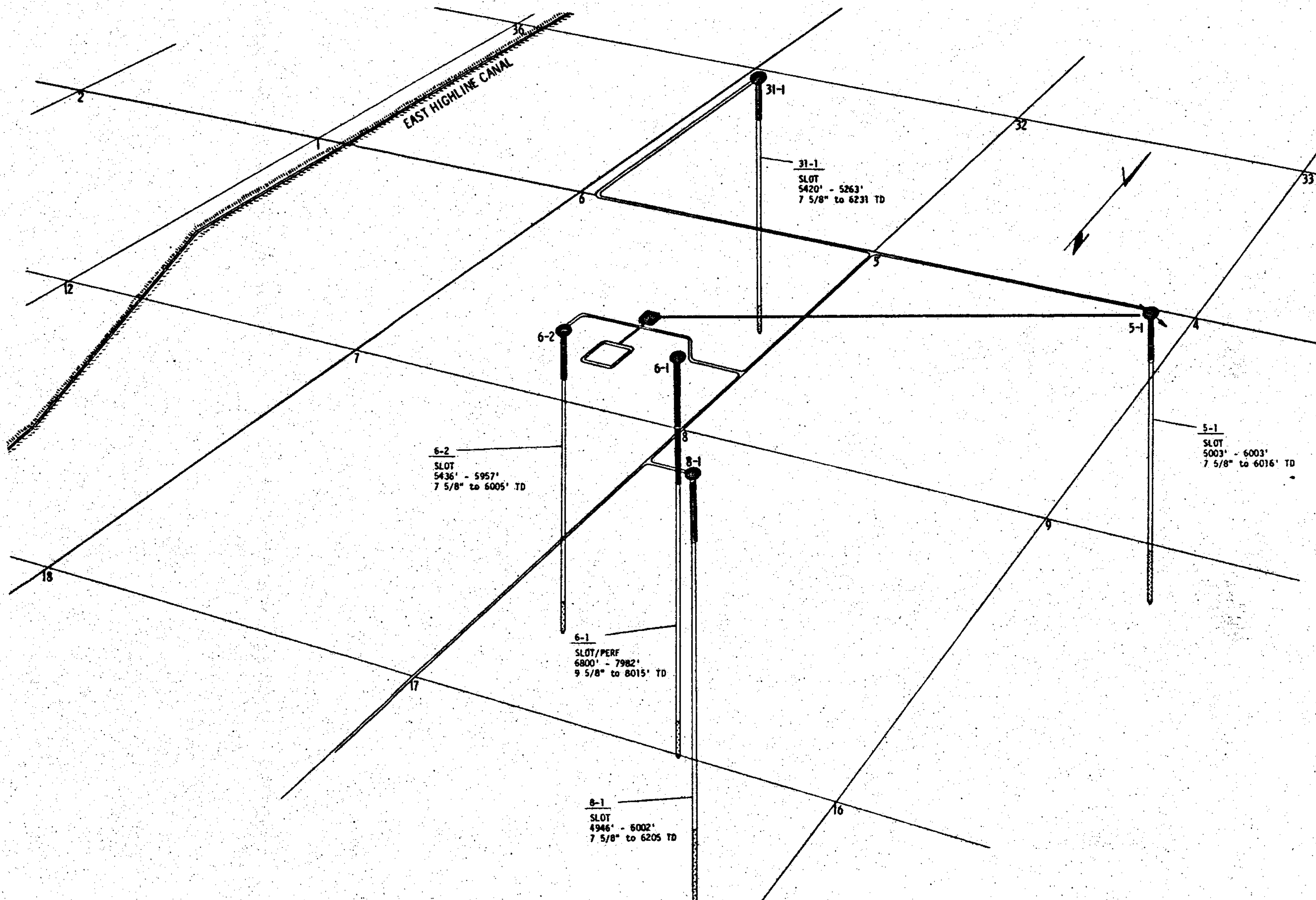


Figure 5-5. USBR Test Wells

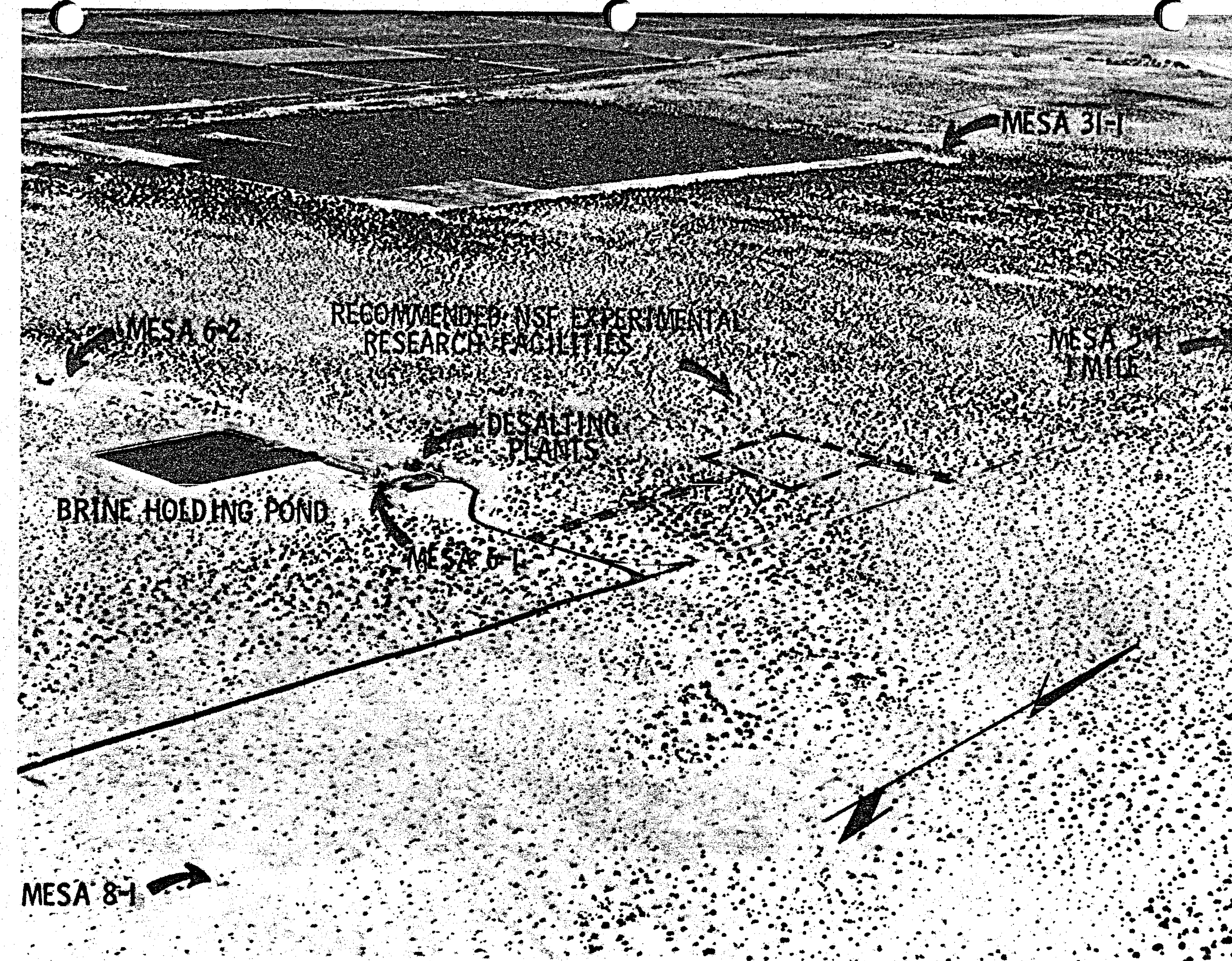


Figure 5-6. Aerial View USBR East Mesa Test Site

volumes of this low salinity brine. These modified wells will permit time-shared use, high and low salinity (3000 ppm to 25,000 ppm) brine tests of components prior to completion of NSF production wells 6-3 and 6-5.

Both free-flowing and pumping production tests are recommended. The pump tests require a high volume, electric-submergible down-hole pump to increase flow rates to 1000 GPM. Pond discharge bypass plumbing interconnections will permit direct injection into well 5-1.

Specific tests will involve producing the wells at various rates for various time intervals, and monitoring the decrease in pressure (pressure drawdown). The increase in pressure (pressure recovery) at the cessation of production also will be noted. Tests such as these, together with the USBR tests and porosity and reservoir thickness data from the geophysical logs, will yield data on reservoir permeability and continuity. They also will yield a measure of hot water reserves, reservoir life, and recoverable heat. The test program will emphasize monitoring any unexpected changes in water temperature and/or salinity.

5.3.2 Experimental Test Facility

The site recommended for the NSF experimental research facility is immediately north of and adjacent to the USBR experimental desalting facilities (see Figure 5-7). The site affords the following:

- Directionally drilled production wells will confirm the predicted geothermal anomaly center and heat flow contours
- Proximity to USBR will allow shared use of existing USBR facilities, chemical laboratories, and test wells to reduce costs. For instance, the USBR brine holding pond will allow well flow and rework brine collection.
- The site is close to roads, power transmission lines, and other utilities.

The recommended Phase 1 experimental test facilities include the following (see Figure 5-8):

- Four Wells — There will be a common location (see Figure 5-9) and directionally drilled to minimize environmental impact. The wells will be drilled in this order:
  - 6-3, a producer (9-5/8 inch outer diameter producing string)
  - 6-4, an injector
  - 6-5, a producer (8-5/8 inch outer diameter producing string)
  - 6-6, an injector.

  The bottom hole locations are in conformance with a 20-acre spacing, and the injection wells are separated from the producing wells by 0.75 miles (now thought to be optimum for East Mesa-type fields). The surface locations allow wells 6-3 and 6-4 to be completed and tested while the remaining wells are being drilled.

  Figure 5-9 details well drilling and recommended casing programs for the test wells. The production casing string is hung from

13-3/8 inch outer diameter intermediate casing at 1500 feet to accommodate future large diameter and high NPSH requirements of down-hole pumps (e.g., Sperry steam turbine and Lear HF electric submergible pumps). The perforated interval (1000 feet) is in the low salinity, high permeability, high porosity zone to obtain 1000 GPM or greater flows.

Well 6-3 will have a variable speed diesel driven gearhead, lineshaft pump with maximum 1500 GPM capability. Well 6-5 will have a high temperature electric submergible pump with 1000 GPM capability.

Having two pairs of producer/injector wells will allow concurrent reservoir engineering and technology development testing on a non-interference basis. In addition, one production/injection well pair can be used as a spare to support Phase 2 electric power plant operation.

- Four Test Areas — These are sized to permit adjacent test activities on a non-interference basis. Although only two test areas are required for Phase 1, two additional areas will be provided for concurrent use by other commercial or government agency users. Each test area will have its own brine supply and return connections and power supplies. Power service and space of each test area will be adequate for high temperature (350° to 500°F) brine testing of components.

- Laboratory and Office Building — An air conditioned building will be provided.

- Services and Utilities — The existing USBR 33 KV electrical transmission service will be extended to the NSF facility. The electrical substation shown in Figure 5-8 and described in Appendix I will be installed. Service (4.16 KV to 15,000 KVA) will be provided to well areas (electric drilling service), well cellars, and test areas.

  A buried pipeline connection to the existing USBR pond will be installed for bringing in wells as they are drilled (see Figure 5-5).

5.4 PHASE 2 EXPERIMENTAL RESEARCH FACILITY

The recommended energy conversion system for demonstrating the technical and economic viability of generating electrical power, using East Mesa brines, is a binary cycle with isobutane as a working fluid. Figure 5-8 is a preliminary design layout which contains features as follows:

- Siting. The plant will be oriented in the direction of the prevailing winds to place the air-cooled condenser downwind. The condenser will be elevated 20 feet so that the top of the condenser will be at a higher level than the plant proper. The differential elevation will allow the condenser air-heat plume to be dissipated with a minimum recycle of warm air.

  All spark creating devices will be placed upwind from the prevailing wind and 75 feet from the nearest isobutane vapor containing pipelines and equipment.

  Plant access will be oriented to existing roads. Plant roads will loop around the powerplant buildings, providing easy access to all equipment. Both access and plant roads will support heavy duty vehicles if they are used sparingly. The site will be sloped at the minimum necessary grade to dissipate isobutane across the site and

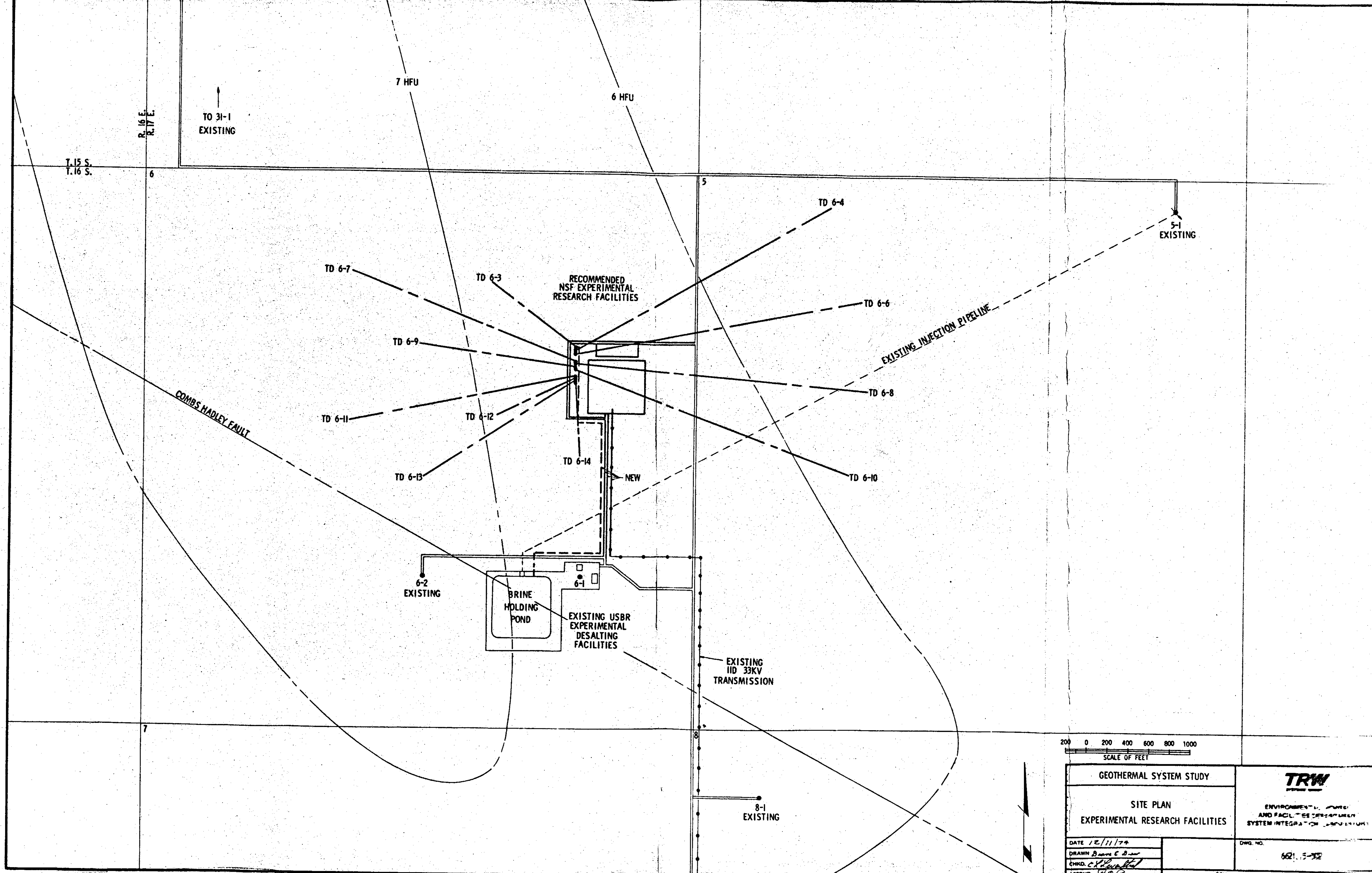


Figure 5-7. Experimental Research Facilities Site Plan

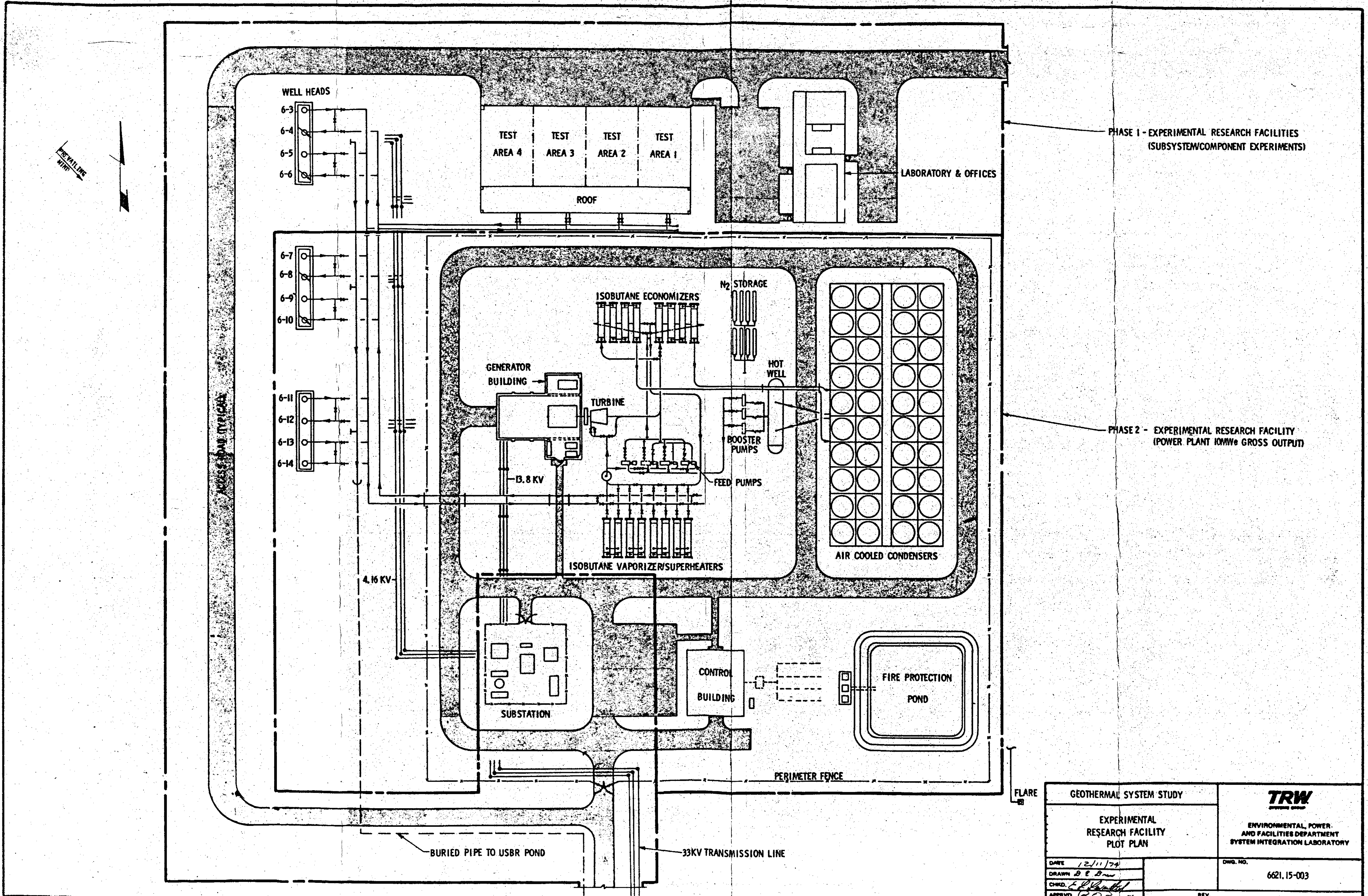
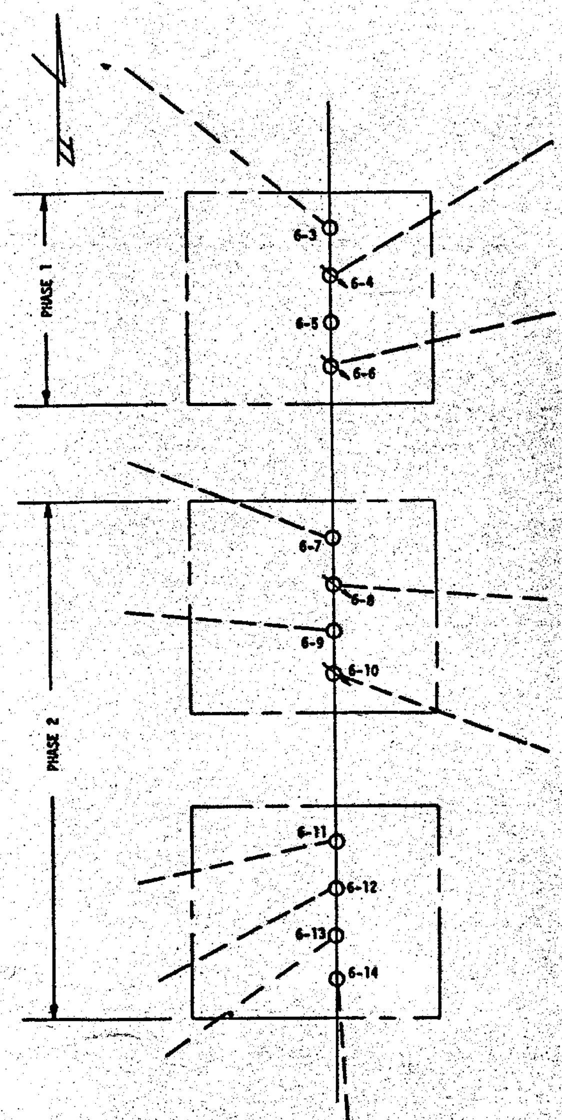
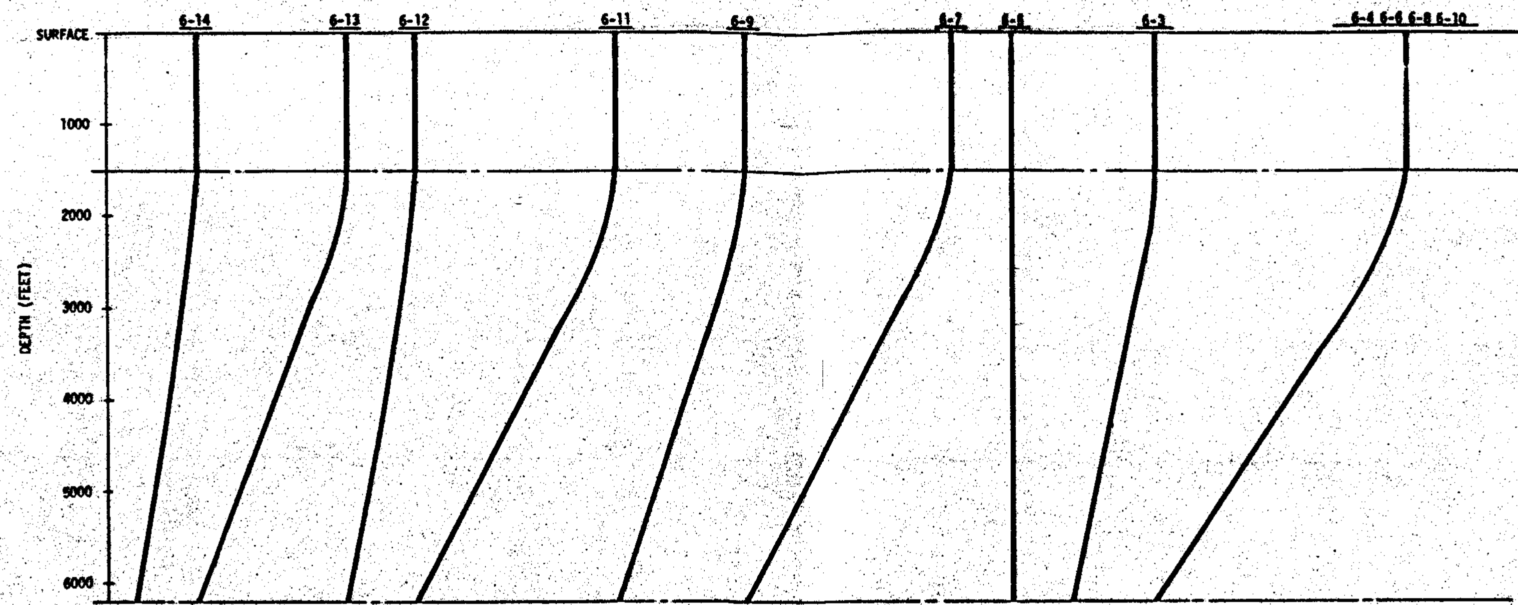


Figure 5-?. Experimental Research Facilities Plot Plan



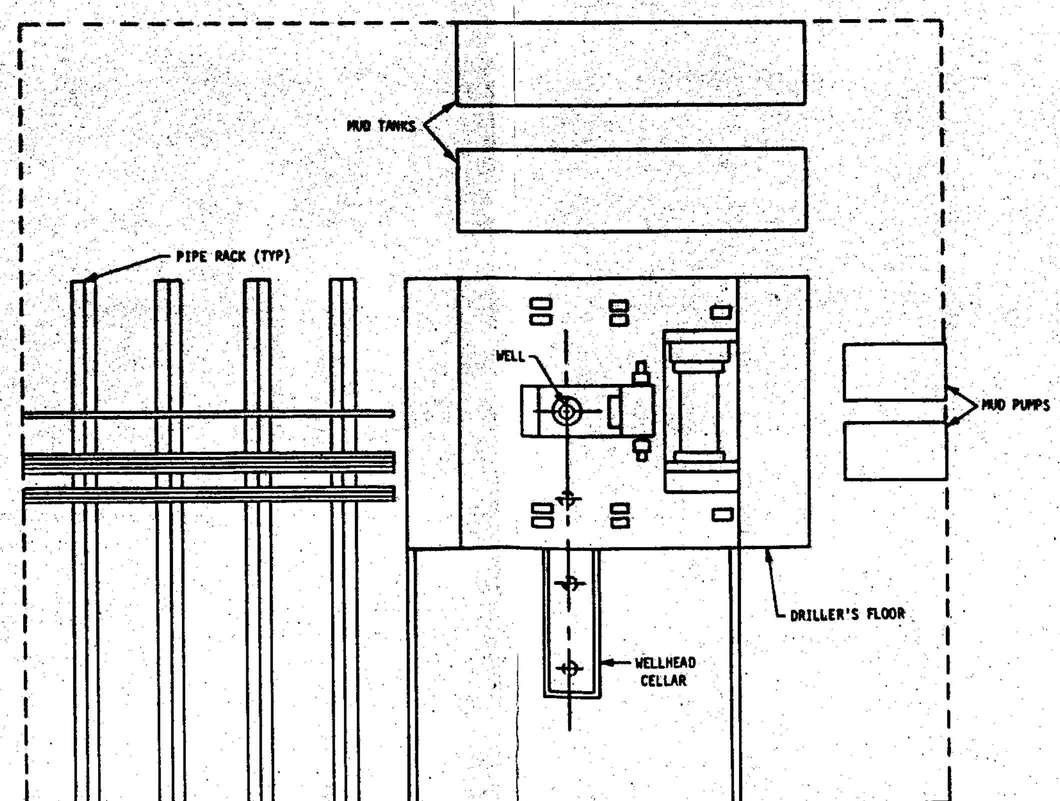
DRILLING PATTERN



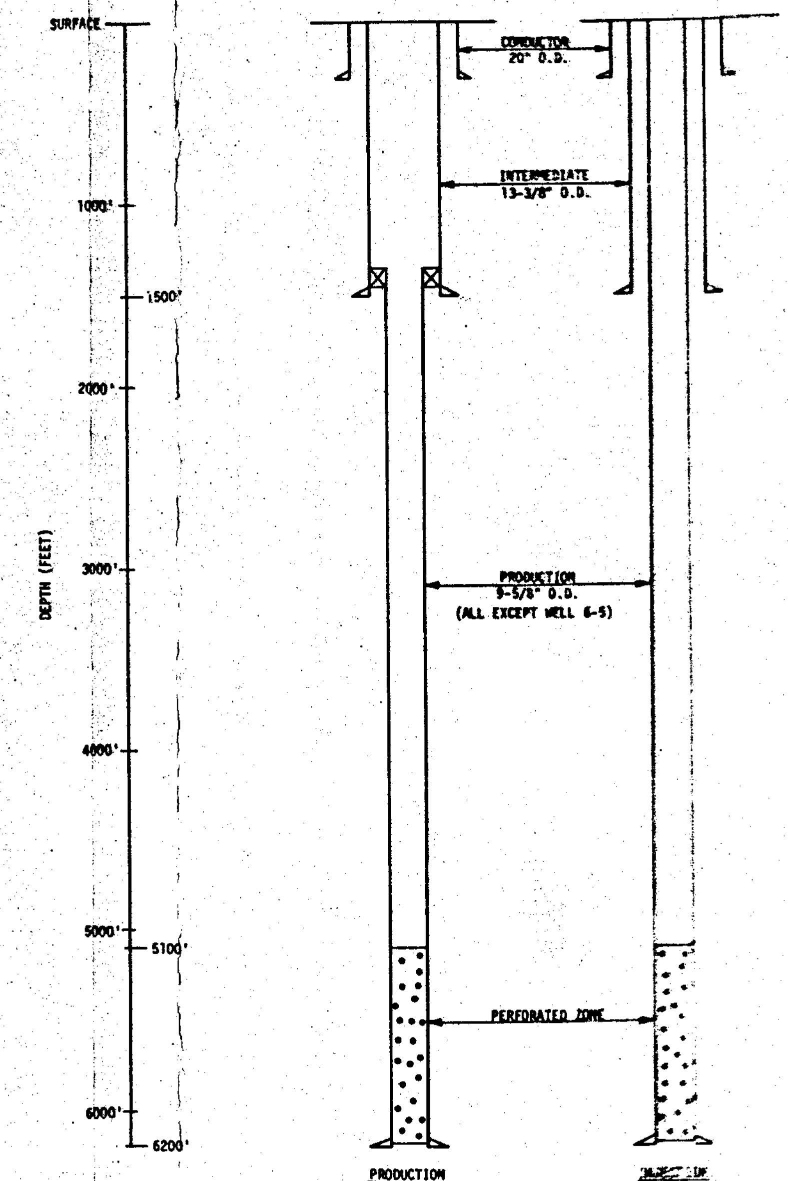
WELL NO.	6-3	6-4	6-5	6-6	6-7	6-8	6-9	6-10	6-11	6-12	6-13	6-14
TYPE	PROD	INJEC	PROD	INJEC	PROD	INJEC	PROD	INJEC	PROD	PROD	PROD	PROD
PHASE	1	1	1	1	2	2	2	2	2	2	2	2
20" CONDUCTOR (FT)	250	250	250	250	250	250	250	250	250	250	250	250
13 3/8" INTERMEDIATE (FT)	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
9 5/8" PRODUCTION (FT)	4800	6900	* 4700	6900	5300	6900	5000	6900	5300	6900	5000	4800
TOTAL DRILL (FT)	6300	6900	6200	6900	6800	6900	6500	6900	6800	6900	6500	6300

*8-5/8" PRODUCTION CASING

CASING PROGRAMS



TYPICAL DRILL RIG ARRANGEMENT



CASING PROGRAMS

GEOTHERMAL SYSTEM STUDY	TRW
WELL DRILLING DETAILS	
DATE 12/11/74	DWG. NO.
DRAWN	
CHKD.	
APPRVD.	REV.

Figure 5-9. Well Drilling Details

away from the large structures in the direction of the prevailing wind.

Sewage will be handled through a small septic tank and leaching field behind the control building. All collection and flows will be by gravity head.

A storage pond will provide water for fire protection and a water treatment system for potable supply. The plant area will be fenced, with major access through one 30-foot double swing gate. An interior parking area will be provided for operating personnel and visitors.

- Plant Operation. The instrumentation of the power plant has been laid out to allow complete control and monitoring from a central control room. Provision will be made locally at key points in the system for installation of precision instruments. This will ensure an accurate heat balance.

In addition to normal powerplant instrumentation, instruments and controls will be provided for operation as an experimental installation. At each critical point, a connection will allow use of a test or calibration gauge. Instruments and controls will allow unattended operation after a manual startup. Any out of tolerance condition will be detected and will cause an automatic shutdown. The annunciator will give a "first-out" indication so that the cause of the shutdown may be easily traced.

Energy input to the plant will be derived from hot brine pumped from the geothermal production wells. The hot brine will pass through the tubes of the brine-isobutane vaporizer-superheater then will return to the injection wells. Instrumentation will indicate brine flow rate, pressure, and temperature at the entrance to and exit from each heat exchanger branch as well as from the plant.

This information will be used to evolve a good preventative maintenance program for the heat exchangers.

The hot well will receive the condensed isobutane from the air cooled condenser, which is elevated to provide a suction heat esceeding the NPSH requirement for isobutane booster pumps. From the hotwell, the isobutane will be pumped to the suction of the main feed pumps by two identical booster pumps driven by explosion-proof electric motors. The booster pumps will raise the pressure of the isobutane sufficiently to accommodate the feed pump HPSH requirements. The layout of the booster pumps permits the installation of a third pump at a later date. The capacity of each booster pump is over one-half the full flow required for the feed pumps.

The isobutane loop will be fed by two identical feed pumps with provisions for the installation of a future third pump. The pumps will be turbine-driven, each capable of delivering one-half the total flow of isobutane to the main turbine at design pressure. The feed pump turbines will be driven by isobutane gas. The turbine characteristics in the working range are such that the pump will maintain a constant discharge pressure independent of varying flow rates. Both pumps and pump turbines will have oil lubrication seals to prevent isobutane leakage.

The turbines that drive the feed pumps will receive vapor from the line to the main turbine. A pressure control in this line will regulate the speed of the feed pumps to maintain a constant pump discharge pressure. The exhaust conditions will be the same as for the main turbine.

The isobutane startup pump will be driven by an explosion-proof electric motor, with pump capability to supply the isobutane flow for one feed pump turbine at its rated capacity and design pressure. The pump will have double mechanical seals to prevent isobutane leakage. The station power requirements for cold startup of the powerplant will provide the isolation of the two feed pumps and the startup pump.

The eight economizer heat exchangers will transfer heat from the turbine exhaust to the liquid condensate. The liquid will pass through the shell side and the vapor through the tube side of the heat exchanger. From the vapor and liquid side, these vessels are connected in 4 parallel, 2 series arrangement.

The eight brine/isobutane liquid-vapor heat exchangers will be connected in 4 parallel, 2 series arrangement. These units will vaporize and superheat the power fluid (isobutane) to the throttle conditions at the generator-turbine. Heat from the geothermal brine water passing through the tubes will heat the isobutane passing through the shell side of the heat exchangers. The paralleling feature will allow any group of two heat exchangers to be isolated from the system for maintenance. The remaining heat exchangers can be operated in series by closing the appropriate valves.

The turbine is a single stage unit. The isobutane will enter the turbine through a separately mounted main stop valve, check valve, and control valve. The generator output will be 10 MWe at 13,8 KV and 3600 rpm. The turbine-generator output can be regulated manually and auto-manual from a remote station by the operator. The flow of isobutane to the turbine can be controlled directly from the turbine panels. The controls will include tachometer pickup, bearing vibration pickup, alarms and signals of shutdown of the unit. The turbine will be provided with rate control equipment and sufficient feedbacks from other control systems for automatic limit of rate of load change to avoid an imbalance in the control system.

Facilities will be provided to take power into the plant from the step-up transformer to supply startup power. Once on-line, the generator will provide all the required station power and the load on the generator will be brought to the desired level by a governor control until full output power is reached. A 9000 rpm gas expander turbine will be directly connected to a gear reducer to reduce the speed to 3600 rpm. The 3600 rpm gear reducer output shaft will be directly connected to the generator. The gas expander turbine-generator combination will recover the energy on expansion of the power fluid (isobutane vapor) through the turbine.

A dry mechanical draft cooling tower will remove heat of vaporization from the isobutane gas and cause it to condense. A standard mechanical draft dry cooling tower will be used. It is a highly reliable, well proven method of disposing unusable heat energy with minimum thermal environmental pollution. The hot exhaust gases will be in a closed loop; after passing through the regenerator, they will enter the cooling tower (condenser). The cooling air will be circulated by induced draft fans. The condensate discharge from the condenser will have the necessary head to permit adequate gravity flow to the hotwell.

Piping and isolation valves will permit nitrogen purging of the system by parts or sections and will connect pressure system vents. This will include an automatic flare burner for burning isobutane expelled from the system.

Additional equipment required is an instrument and control air system.

It will be backed by an emergency nitrogen system.

All process instrumentation will be pneumatic except the governor control system. Pneumatic instrumentation will make the system inherently explosion proof. To adapt the plant to remote monitoring or control, transducers may be added to convert the pneumatic signals to electronic. Final control valve operators will be pneumatic except for the electro-hydraulic governor system. The governor will require the high speed response possible with hydraulics. All important alarm conditions will be monitored by a "first-in" annunciator system for ease in troubleshooting. Plant protection will be provided in that any equipment approaching unsafe level will automatically trip, causing plant shutdown. Examples are overspeed or excess vibration on any rotating equipment, high lube oil or bearing temperatures, or loss of level in the isobutane condensate hotwell.

A separate building will house the generator, machine shop, and mainteneance area. Instrument air and hydraulic oil systems also will be enclosed in this building.

The control building will house the control room, switchgear, maintenance shop, and living quarters for one or two people. The control room and living quarters will be air-conditioned.

5.5 INTRA-AGENCY COORDINATION

TRW's recommended implementation plan is based on information obtained from these government agencies

- United States Bureau of Reclamation (USBR)
- United States Geologic Survey (USGS)
- Bureau of Land Management (BLM)
- Imperial Irrigation District (IID).

Because the proposed project will require interfaces with these agencies, we recommend that NSF coordinate specific aspects of this implementation plan with these agencies prior to project start:

- <u>Lease Set Aside</u>. Request BLM and USBR for set aside of available leaseholds 1 and 2 of Figure 5-4.
- <u>Environmental Impact Statement (EIS)</u>. USBR-approved EIS permits nine test wells of which only four have been drilled. Coordinate with USBR for installation of four new wells on approved USBR/EIS.
- <u>Time Share Existing Wells</u>. Coordinate with USBR to accommodate NSF project tests and proposed well perforation modifications. (Note: Preliminary discussions of recommended plans have been held with USBR, Boulder City, Nevada; however, planning funding and operational details require NSF/USBR intra-agency resolution.)
- <u>Power Connections</u>. Coordinate Phase 1 site power requirements and Phase 2 power supply plans with IID.
- <u>Subsidence</u>. Coordinate drilling and injection plan with cooperative USGS/USBR site subsidence monitoring net planned for the USBR site.

5.6 STATEMENT OF WORK

5.6.1 Phase 1 Statement of Work

<u>Task 1 — Experimental Test Bed Development</u>

The experimental test facilities shown in Figure 5-8 will be constructed.

Development of the facilities will include

- Facility design
- Construction of access roads
- Site preparation (test areas and yard piping)
- Construction of a laboratory and office building
- Installation of electrical transmission line and substation
- Construction of a buried pipeline connecting the test bed to the USBR pond.

Task 2 — Reservoir Measurement and Evaluation

Drawdown pressure recovery and injection continuity tests will be performed using modified existing USBR wells 6-1, 6-2 and 5-1 and new NSF wells 6-3, 6-4, 6-5 and 6-6. These tests will determine reservoir permeability and continuity. Test results, together with porosity and reservoir thickness data from the geophysical logs, will provide a measure of hot water reserves, reservoir life, and productivity indexes, which will be input to Phase 2 fluid collection and well designs.

Concurrently, brine chemical analyses, pressure tests, and related measurements will be performed to define fluid characteristics, which will be required for Phase 2 power plant design.

Additionally, interference tests will be conducted by producing from one well and monitoring other wells for changes in pressure and temperature. Tracers will be used to measure reservoir water movement. Data from these tests will be used in determining reservoir continuity and life, and in particular, optimum bottom hole separations. Phase 1 tasks will be to do the following:

- Perform engineering design of well modifications and install new wells.
- Perforate existing well 6-1 in the high salinity section between 6000 and 7000 feet, and provide it with an electrical submergible 1000 GPM pump. Perform reservoir testing.
- Perforate existing well 6-2 in the low salinity section between 5000 and 6000 feet, and provide it with an electric submergible 500 GPM pump. Perform reservoir testing.
- Drill wells 6-3 and 6-4, and perforate both between 5000 and 6000 feet. Install variable speed diesel driven, gearhead, lineshaft pump (temperature upgraded) with maximum 1500 GPM pumping capability in well 6-3 at a 900 foot depth. Install wellhead and piping, and perform reservoir engineering tests at 1000 GPM flow.
- Drill wells 6-5 and 6-6, and perforate both between 5000 and 6000 feet. Install 1000 GPM high temperature electric submergible pump in well 6-5 at a 900 foot depth. Install wellhead and piping, and perform reservoir engineering tests.
- Provide additional perforations in well 6-3, and perform reservoir engineering tests to determine maximum flow capability to 1500 GPM.
- Perform reservoir engineering analyses and prepare report defining reservoir characteristics (temperature, pressure and salinity), estimated reservoir reserves and life, and optimum flow well characteristics, spacing, bore size, perforation zones and pump setting depths.

Correlate test results and analyses with predictions derived from previous East Mesa explorations. Recommend improved and confirm existing exploration techniques and evaluation methods.

Task 3 — Subsystem and/or Component Experiments

Experiments will be performed on critical subsystems and components to establish optimum design requirements and criteria for Phase 2 powerplant design. Down-hole pump (temperature upgraded line-shaft and electric-submergible) and well completion experiments will be performed in Task 2. In addition, the following pumps under NSF advanced technology development will be tested:

- Steam turbine pump (Sperry)
- HF electric submergible pump (Lear).

Corrosion and scaling effects in the heat exchanger, which are critical to economic and operational effectiveness of a geothermal binary system, will require

- Coupon Tests to determine the optimum heat exchanger materials and configurations to protect against geothermal well fluid corrosion, erosion and scaling. Test equipment will include sample material tubings with representative diameters configured to pass geothermal well fluid exchanger rated flows from wells 6-1, 6-2, and 6-3. The tubing will be externally cooled representative of operational requirements.

- Scale Cleaning to develop scale prevention and cleaning methods for problem configurations and materials identified in coupon tests.

Task 4 — Systems Definition Analyses

Powerplant systems will be defined and analyzed based on Phase 1 experiments and findings. Working fluid and turbine optimizations that can reduce capital or operating costs will be performed

- Other fluids, such as R-318 and cyclobutane, show promise and will be investigated. Coefficients for the Starling equations will be derived.

- The performance of mixtures of various compounds will be studied.

- Off-design point performance will be studied to evolve a design that exploits the increased performance resulting from lower winter condensing temperatures.

- Computational techniques that treat turbine efficiencies as a function of cycle parameters will be refined (specific speed, operating pressure, working fluid, etc.).

- Direct contact heat exchangers (mixing water and working fluid) will be studied to eliminate costly and fouling-prone surface heat exchangers.

- Tradeoffs will be performed to determine optimum turbine configuration and fluid expansion conditions. Single stage radial turbines versus multiple stage axial turbines will be compared based on performance, efficiency, size, and cost. An optimum combination of working fluid, turbine configuration, and heat transfer equipment will be derived.

- Design criteria for Phase 2 powerplant design will be prepared based on reservoir measurements and evaluations (Task 2) and subsystem (component) experiments (Task 3).

Task 5 — Environmental Impact Report

The California Environmental Quality Act of 1970 requires these tasks:

- Preparation of a project report to be submitted to the Imperial County in applying for a permit for geothermal exploratory drilling at the proposed site.
- Assessment of the environmental impact of the proposed geothermal power plant facilities, and preparation of an Environmental Impact Report preparatory to approval of the geothermal project by Imperial County.

Task 6 — Utilization Briefings

The research outputs and technology developments of Phase 1 will be disseminated to relevant public or private communities. Briefings will be presented at Geothermal symposiums and conferences. Based on the past year's experience, quarterly public briefings are anticipated.

Task 7 — Phase 2 Implementation Planning

Phase 2 planning will be conducted concurrent with resource evaluations and experiments. Cost, engineering, and schedule information will be provided for the Phase 2 plan.

Task 8 — Program Management

A program manager will be assigned to direct, monitor, and control the project and serve as the TRW interface with NSF. A site operations manager and support personnel as required will be assigned to reside at the site within two months after project start.

Coordination meetings will be held quarterly with NSF. Agendas for these meetings will be submitted to NSF two weeks before the scheduled date. Recommendations and action items resulting from these meetings will be documented and minutes provided to NSF within a week after the meetings.

A formal briefing will be presented to the NSF Program Manager summarizing the major project conclusions in conjunction with the submittal of the final report.

Phase 1 Schedule and Costs

The Phase 1 schedule and estimated costs are shown in Figure 5-2. Costs are based on September 1974 costs, with 5 percent allowance for miscellaneous, 6 percent for contractor's fee, and 12 percent per year for escalation. A 15 percent contingency is indicated.

5.6.2 Preliminary Phase 2 Statement of Work

A preliminary design of an experimental binary cycles powerplant with 10 MWe gross output generating capacity (Reference Appendix I) has been developed to identify Phase 2 design and construction tasks, costs, and schedules. Phase 2 includes the following major tasks:

Task 1 — Engineering

Task 2 — Wells and brine collection system construction

Task 3 — Powerplant construction

Task 4 — Environmental impact statement

Task 5 — Utilization briefings

Task 6 — Program management.

The Phase 2 schedule and estimated costs are shown in Figure 5-3. The accelerated schedule option calls for Phase 2 to begin 6 months after start of Phase 1 and for the two phases to run concurrently.