GL03062

FC USGS AGSO Memo CA 8/7/78

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
Area Geothermal Supervisor's Office
Conservation Division, MS 92
345 Middlefield Road
Menlo Park, CA 94025

→ Circulate to ESL Staff

AUG 10 1978

AUG 7 1978

Memorandum

To: INTERESTED PARTIES

From: Area Geothermal Supervisor

Subject: Plans of Operation for Development, Injection, and Production for 10 Megawatt Power Plant, Magma Power Company, Federal Lease CA-964, East Mesa KGRA, Imperial County, CA
Ref: 1760 CA-964 (POO for EA#113-8)

Magma Power Company has submitted a Plan for Production (PFP), Plan of Development (POD), and Plan of Injection (POI) in accordance with 30 CFR 270.34, for the development of the geothermal resource at East Mesa, KGRA, Federal Lease CA-964, Imperial County, California. The Plans describe the field development necessary for the support of the ten-megawatt (net) power plant, including injection wells, pipelines and attendant facilities. Copies of the Plans of Operation are attached for your review, comments, and files.

In accordance with 30 CFR 270.34 (K), Magma Power Co. has submitted base line data on their leasehold. This base line data consists of a reproduction of Lawrence Livermore Laboratory's April 1977 publication entitled "Imperial Valley Environmental Project: Quarterly Data Report" and is referred to as Appendix I of the Plan for Production. This base line data is not attached, but is available to interested parties upon written request.

Magma Power Company has previously submitted a Plan of Utilization for construction and operation of the ten-megawatt (net) power plant (EA#78-8, approved December 30, 1977). A field inspection was held on the subject lease on July 7, 1977; no additional field inspection is considered necessary for this new proposal. A Geothermal Environmental Advisory Panel (GEAP) meeting was held on October 27, 1977; no additional GEAP meeting has been scheduled, however, if one is considered necessary, you will be informed. You are encouraged to visit the site at your own convenience. Further guidance can be provided by Mr. Bernie Moroz, Reno District Geothermal Supervisor (Tel: (702) 784-5676, FTS: 467-5676). Visitors should inform the above office as to when they propose to be on the site.

Environmental Analysis #113-8 will be prepared by the Office of the Area Geothermal Supervisor to consider the environmental impact of the Development, Injection, and Production Plans of Operation. Comments concerning aspects of any of the three proposed plans must be received no later than August 23, 1978 by:

Area Geothermal Supervisor
Conservation Division
U.S. Geological Survey
345 Middlefield Road, MS 92
Menlo Park, CA 94025
Tel: (415) 323-8111, Ext. 2848

We urge you to send written commentary and will appreciate hearing from you even if you are of the opinion that the existing regulations, lease terms, and operational orders provide adequate environmental protection. All comments will be given full consideration in the preparation of the Environmental Analysis and any subsequent conditions of approval thereafter.

The Area Geothermal Supervisor's Office will not send draft Environmental Analysis (EA#113-8) to all interested parties for review for the proposed actions. Certain parties however, such as the surface managing agency, lessee, and GEAP will receive a copy of the completed EA#113-8. Other interested parties will not receive a copy of the final EA unless such parties comment on the proposed actions in writing or request a copy of the EA pursuant to the Freedom of Information Act. Copies of the Environmental Analysis are available for inspection during normal business hours at the Area Geothermal Supervisor's Office, the appropriate District Geothermal Supervisor's Office, and the appropriate Bureau of Land Management, District Manager's Office.

Reid T. Stone

INTERESTED PARTIES EA#113-8
MAGMA POWER COMPANY
Plans of Operation for Development, Injection, and Production
Federal Lease CA-964
East Mesa KGRA
Imperial County, California

District Geothermal Supervisor
USGS - Conservation Division
Ketzke Plaza, Bldg. D., Suite 137
4600 Kietzke Lane
Reno, Nevada 89502
(702) 784-5676
FTS: 470-5676

USGS- Conservation Division
Conservation Manager, Western Region
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345 Middlefield Road, MS 80
Menlo Park, CA 94025
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USGS-Conservation Division
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Area Geologist, Pacific Area
345 Middlefield Road, MS 80
Menlo Park, CA 94025
(415) 323-8111 Ext. 2053
FTS: 467-2563

Geothermal Environmental Adv. Panel
Attn: Max Crittenden, Chairman
345 Middlefield Road, MS 75
Menlo Park, CA 94025
(415) 323-8111 Ext. 2317
FTS: 467-2317

U.S. Bureau of Land Management
State Director
Federal Office Bldg.
2800 Cottage Way, Rm. E-2841
Sacramento, CA 95825
(916) 484-4676
FTS: 468-4676

U.S. Bureau of Land Management
Attn: Gary Hillier, District Manager
1695 Spruce St.
Riverside, CA 92507
(714) 787-1462
FTS: 796-1462

U.S. Bureau of Land Management
El Centro Resource Area
Attn: David Mari
333 South Waterman
El Centro, CA 92243
(714) 352-5842
FTS: 894-2451

U.S. Bureau of Land Management
Geothermal Specialist
Attn: Theodore W. Holland
Denver Federal Center, Bldg. 50 (D-310)
Denver, CO 80225
(303) 234-5098
FTS: 234-5098

U.S. Fish and Wildlife Service
Office of Biological Services
Attn: L.A. Mehrhoff
Geothermal Advisor - Region 1
4620 Overland Road, Rm. 210
Boise, ID 83705
(208) 834-1931
FTS: 554-1931

U.S. Fish and Wildlife Service
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2800 Cottage Way, R. E-2727
Sacramento, CA 95825
(916) 484-4731
FTS: 468-4731

U.S. Bureau of Reclamation, Region 3
Attn: Wayne Fernelius
P.O. Box 427
Boulder City, NV 89005
(702) 293-7753
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U.S. Department of Energy
Div. of Geothermal Energy, 3rd Floor
Attn: Ronald Toms
20 Massachusetts Ave., NW
Washington, D.C. 20545
(202) 376-1690
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U.S. Environmental Protection Agency
Environmental Monitoring & Support Lab
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State of California
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State of California
Div. of Oil & Gas
Attn: Don Lande
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North Long Beach, CA 90804
(213) 590-5311

State of California
Dept. of Parks & Recreation
State Resources Agency
Attn: Knox Mellon, SHPO
P.O. Box 2390
Sacramento, CA 95811
(916) 445-2358

State of California
Calif. Regional Water Quality Board
Colorado River Basin Region
Attn: Arthur Swajian
73271 Highway 111, Suite 21
Palm Desert, CA 92260
(714)346-7491

State of California
Water Resources Control Board
Attn: Alvin Franks
P.O. Box 100
Sacramento, CA 95801
(916) 322-4548

Imperial County Planning Board
Attn: Richard Mitchell
Imperial County Planning Director
County Services Bldg.
940 Main St.
El Centro, CA 92243
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Imperial Irrigation District
Attn: Helen French
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El Centro, CA 92243
(714) 352-1991

Native Americal Heritage Comm.
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1400 10th St.
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(916) 322-7791

AMAX Exploration
Attn: Larry Hall
4704 Harlan St.
Denver, CO 80212
(303) 433-6151

Aminoil U.S.A.
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P.O. Box 11279
Santa Rosa, CA 95406
(707) 527-5333

Anadarko Production Company
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P.O. Box 1330
Houston, TX 77001
(713) 526-5421

Calif. Energy Company, Inc.
Attn: Paul V. Storm
P.O. Box 3909
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(707) 526-1000

CER
Attn: Joy Hyde
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Las Vegas, NV 89114
(702) 735-7136

Chevron U.S.A., Inc.
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San Francisco, CA 94119
(415) 894-2726

Dresser Industries
MAGCOBAR Division
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Salt Lake City, UT 84108
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Energy and Natural Resources Consultants
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Richardson, TX 75080

Geothermal Power Corp.
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Geothermal Resources Council
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(916) 758-2360

GeothermEx, Inc.
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901 Mendocino Ave.
Berkeley, CA 94707
(415) 524-9242

Getty Oil Company
Attn: Dan W. Sparks
P.O. Box 5237
Bakersfield, CA 93308
(805) 399-2961

Gulf Mineral Resources Co.
Exploration Department
Attn: Glen E. Campbell
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(303) 758-1700

Hydro-Search, Inc.
Attn: Virgil Wilhite
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ICF, Inc.
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Mr. Clyde E. Kuhn
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Lawrence Livermore Laboratory
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Los Angeles, CA 90017
(213) 483-2285

Mr. Jack McNamara
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University of Southern California
Los Angeles, CA 90007
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Occidental Geothermal, Inc.
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(805) 327-7351

Phillips Petroleum Company
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(714) 755-0131

Republic Geothermal, Inc.
Attn: Dwight Carey
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Santa Fe Springs, CA 90670
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Republic Geothermal, Inc.
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San Diego Gas & Electric Co.
Attn: Larry Grogan/J.M. Nugent
P.O. Box 1831
San Diego, CA 92112
(714) 232-4252, Ext. 1715/1903

Southland Royalty Company
Attn: Jere Denton
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(817) 336-9801

Sunoco Energy Development Co.
Attn: C.T. Clark, Jr.
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Dallas, TX 75251
(214) 233-2600, Ext. 515

Thermal Power Company
Attn: K.R. Davis
601 California St.
San Francisco, CA 94108
(415) 981-5700

Mr. Frederick Tornatore
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Union Oil Company of California
Geothermal Division
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Union Oil Center, Box 7600
Los Angeles, CA 90051
(213) 486-7740

V.T.N.
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Mr. Roger Wilde
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MAGMA POWER COMPANY
P. O. BOX 2082
ESCONDIDO, CALIFORNIA 92025
(714) 743-7008

THOMAS C. HINRICHS
VICE PRESIDENT-OPERATIONS

May 25, 1978

U. S. Geological Survey
Office of The Area Geothermal Supervisor
Suite 400, 2465 East Bayshore Rd.
Palo Alto, Ca. 94303

Gentlemen:

The Magma Power Company has submitted to your office a Plan of Utilization covering the installation of a 10,000 Kilowatt Geothermal Generating Plant on Magma's Federal leases in the East Mesa field, Imperial County, California.

The U. S. Geological office of the Area Geothermal Supervisor has prepared an environmental assessment of the Plan of Utilization proposed. This environmental assessment is designated as EA #78. The scope of EA-78 was somewhat limited to the geothermal generating plant itself and the surface disturbances associated with that plant. The purpose of this submittal is to cover the well operations associated with the plant to complete the package required for the overall project.

This submittal incorporates three plans as outlined in Geothermal Resources Operational Order No. 5. These plans are:

1. Plan of Development Operation (Plan of Development) which covers all phases of the additional construction required associated with the production wells to provide the geothermal fluid supply to the generating plant. The drilling of these additional wells has already been approved by USGS and the environmental assessment covering this drilling is referenced as EA #71 dated June 10, 1977. The permits issued by USGS for these wells were exploratory permits and these wells will be utilized as fluid supply for the generating plant along with existing wells 44-7 and 48-7 that were drilled under exploration permits also.

2. Plan of Injection Operation (Plan of Injection). This plan covers the handling of the geothermal fluid after it has yielded its heat in the process of the geothermal generating plant. It includes the pipeline system from the geothermal plant to the injection well area and the operation of the injection wells themselves. Well #46-7 has been drilled and is presently being utilized for testing purposes to determine its suitability for use as an injection well. The environmental assessment associated with the injection wells is designated as EA #53. The testing of the production of 44-7 and 48-7, and injection into 46-7 is presently under way and preliminary results from this testing is incorporated into the data associated with the plan of injection.

3. Plan of Production Operation (Plan for Production). This plan includes the proposed production and injection operations which will be carried out following the completion of the drilling and pipeline construction as outlined in the development and injection plans. This plan also contains a summary of the environmental baseline data which has been collected over the last year in compliance with 30 CFR 270.34 (K).

The format of the submittal has a narrative portion covering a general description and specific details of the three individual plans as outlined in GRO 5 and an attached appendix which includes technical reports, engineering and geological drawings supporting the three plans. Much of the information in the appendix material is referenced in more than one of the specific plans in that similar information is required in the outlines under GRO #5 for the three specific plans.

Please recognize that the well operations of this project are as much a Research and Development program as the generating plant portion. From this we expect to gain specific information on reservoir and well characteristics to enable optimization of production/injection operations to be established for major development.

Very truly yours,

T. C. Hinrichs

TCH:kw

MAGMA POWER COMPANY
P. O. BOX 2082
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(714) 743-7008

THOMAS C. HINRICHS
VICE PRESIDENT-OPERATIONS

PLAN OF DEVELOPMENT

PLAN OF INJECTION AND PLAN OF PRODUCTION

PURPOSE:

To provide geothermal fluid supply for 10,000 Kw Geothermal Power Plant (Ref: U.S.G.S. EA #78)

LOCATION:

R.16E.

Section 7, T16E, R17E
East Mesa KGRA
Federal Lease No. CA964
Imperial County
State of California

OPERATOR:

Magma Power Company
631 S. Witmer Avenue
Los Angeles, Ca. 90017
Field Supt: Mr. E. J. Zajac
Phone: (213) 483-2285

PLAN PREPARED BY:

T. C. Hinrichs, Vice Pres.-Operations
P. O. Box 2082
Escondido, Ca. 92025
(714) 743-7008

SUBMITTED TO:

U.S.G.S.

GENERAL DESCRIPTION

This submittal by the Magma Power Company covers the details associated with well operations for an overall project which Magma is installing on its' Federal Lease CA-964 in the East Mesa KGRA, Imperial County, California. The overall project will be a research and dvelopment oriented project with its goal to determine well operational characteristics, both production and injection and geothermal power generation processing technology. The project incorporates a 10,000 Kilowatt Geothermal Electric Generating Plant incorporating principals of the Magmamax Power Process. From the operation of the facility detailed information on geothermal wells, reservoir characteristics and power conversion technology will be gained to enable appropriate decisions to be made relative to the overall system design for a major geothermal power generating complex in the East Mesa area.

The results of this operation will also be applicable to other geothermal areas in the western United States in addition to the East Mesa area. The reservoir characteristics and temperatures experienced in East Mesa are similar to many other potential geothermal development areas in the western United States.

There are presently three completed wells at the location. Two of these wells will be utilized for productionsupply to the generating plant (44-7 and 48-7) and well #46-7 will be utilized for injection purposes. It is anticipated that two additional production wells will be required and two additional injection wells. The production location in the reservoir will be at the lower depths from approximately 5,500 ft. to 7,500 ft. where the highest temperatures are experienced and the injection will be in shallower zones where temperatures are less, permeability is higher. Concern has been expressed relative to the potential hazards of this typs of operation. It is Magma's conviction that this method of operation may well prove to be the most feasible in that it may be in concert with the actual convective cell operations within the reservoir. Appropriate monitoring during operations of production well water level trends and injection well pressure trends will be the only method to determine the appropriateness of this type of operation. Wellhead facilities and pipelines between the wells and the plants will be designed and constructed under the regulations associated with GRO #6.

Under the CFR Paragraph 270.34 Paragraph (K) it is required that environmental base line data be collected for one year prior to the commencement of the plan for production. Included in this submittal is a summary of that environmental base line data which has been obtained by the Environmental Science Division of Lawrence Livermore Laboratory. The laboratory established an air monitoring system in the East Mesa area in late 1976 and has also established environmental base line data since that period on the various aspects required in the CFR. Our appreciation is expressed to the laboratory for providing this information for utilization by companies such as ourselves.

PLAN OF DEVELOPMENT

A map titled Area Plan showing the overall location of the facilities associated with the project (including the wells) can be found in Appendix A. It is anticipated that two additional production wells will be required for supply to the plant and these will be drilled adjacent to Well 44-7 and 48-7. These additional wells along with existing Wells 44-7 and 48-7 will be producing wells for the facility. An additional well for standby purpose is also anticipated. Reference is made to EA #28 for details associated with the drilling of Wells 44-7 and 48-7 and EA #71 is referenced in regard to the additional wells for the Plan of Development.

The new wells will be directionally drilled from the same drilling pad which was used for Wells #44-7 and 48-7 and the same sump will be utilized. A larger scale drawing detailing the well spacing is included in Appendix B.

Reference is made to Appendix A of Environmental Assessment No. 71 which is Magma's Plan of Operation associated with the drilling of the additional production wells and in that plan of operations all of the details associated with drilling and the general aspects of a plan of operation are included.

Geological and Geophysical Maps. A report prepared by George B. Zebal & Associates is included in Appendix C. This report was written primarily to discuss the matter of the injection of geothermal fluids associated with the project however, much information is in that report relative to the producing reservoir also. Table 4 in Pages 15 thru 17 of the report provides physical data for the producing reservoir sands including such items as reservoir thickness, salinity, porosity and permeability.

Magma is carrying out a short term flow test producing 44-7 with a well pump and injecting to 46-7. Preliminary results associated with this testing is outlined in a report included in Appendix D.

Proposed Manner of Commercial Utilization. The produced resource from the production wells will be directed to Magma's Geothermal Electric Generating Plant for processing to produce electrical power. The electrical power will be purchased by San Diego Gas & Electric Company who in turn have an agreement with the Imperial Irrigation District to deliver the power to IID. The power will be transmitted into IID's 33,000 volt transmission system which traverses the geothermal lease CA-964 of the Magma Power Company.

Surface Equipment Installations. The routing of the pipelines from the production wells to the generating plant is indicated on the area plan map in Appendix A and in more detail on the drawing in Appendix E. This pipeline will be designed and constructed in accordance with GRO #6 and the engineering drawing associated with the details of the pipeline can also be seen in Appendix E.

Proposed Liquid Disposal Program. The geothermal fluid after giving up its heat to the power fluid in the generating plant will be injected back into the reservoir, therefore the details associated with this program are outined in the following plan of injection.

PLAN OF INJECTION

Maps. The area plan in Appendix A indicates the overall location of injection well pipelines and the injection wells relative to the overall project. The drawing in Appendix B indicates a closer detail associated with the actual location of the injection wells. The injection wells in addition to the existing 46-7 will be drilled from the same pad which was used for 46-7 and the existing sump will be utilized during that drilling operation. The wells will be directionally drilled from the 46-7 pad. Details associated with the pipeline and wellhead equipment for the injection wells can be seen in Appendix E.

Injection Fluid Characteristics. The fluid to be used for injection is the produced fluid associated with the project. The fluid will not be changed in any manner except its temperature. It is anticipated that the exited temperature from the generating plant of the fluid to be injected will be approximately 180° farenheit. A slight temperature drop will occur in the pipeline from the plant to the wells and therefore it is expected that the temperature to be injected will be slightly below 180° F. Appendix F has included an analysis of the produced fluids from wells 44-7 and 48-7. It is anticipated that these will be representative of the characteristics of the fluid to be injected.

Characteristics of the Disposal Zone. The report included in Appendix C covers all aspects associated with the injection zone. Table 1 on Page 4 of that report contains a summary associated with the characteristics of the injection zones. In Appendix F an analysis of the zonal water associated with the injection zone is included for a comparison with the produced fluid which will be added to that zone. The TDS of the zonal waters in the injection zone is slightly higher than that of the production zone. Information relative to the injection well performance experienced in the preliminary short term testing is included in Appendix D.

Subsurface Maps, Logs and Well Histories. Magma has submitted to USGS subsurface maps and cross sections as well as well histories and well logs. The cross sectional maps associated with the production and injection zones are included in Appendix G of this submittal.

Injection Well Drilling Program. Reference is made to Magma's Plan of Operation submitted to carry out the drilling of the wells being proposed for injection in this Plan of Injection. Reference is made to Amended EA #53 associated with that Plan of Operations.

Downhole and Surface Injection Equipment. There are no plans to include any equipment other than the well casing itself in the downhole portion of the injection wells. The surface equipment which will be utilized is outlined in Appendix E.

Surveys and Monitoring. Continual recordings of surface pressure and temperature at the injection wells will be carried out. Periodic spinner surveys and downhole temperature and pressure surveys will also be incorporated as part of the monitoring of the injection well performance. Individual well metering will also be incorporated into the engineering aspects of monitoring injection well performance. In conjunction with the production operations since production will be from a different zone than injection the trends of production well water levels and injection well pressure levels will be continuously monitored and plotted to determine if communication between the two zones exists.

Hydrology. In the report filed under Appendix C the regional and local hydrological factors are outlined. These are covered in Pages 9 thru 19 of the report. Also, a report prepared by the John Hess Testing Corporation is included in Appendix H which covers the hydrological aspects associated with the shallow ground water aquafer in the East Mesa area.

PLAN FOR PRODUCTION

Environmental Baseline Data. 30 DFR 270.30 (k) indicates that prior to the submission of a Plan of Production the lessee must collect environmental baseline data for at least one year. The required data to be collected and submitted includes air and water quality, noise, seismic and land subsidence and ecological systems. The requirements associated with collecting this data has been carried out by the Environmental Science Division of Lawrence Livermore Laboratory under a contract from the Department of Energy (previously ERDA). A summary of that environmental data collection is included in Appendix I.

Plan of Production.

A. Power generated from the geothermal generating plant will be sold to San Diego Gas & Electric Company who in turn will provide the power for use by Imperial Irrigation District within their system.

B. Proposed Manner and Rates of Production. The production wells will have shaft driven turbine pumps operated by electric motors at the surface for pumping purposes to the power generation facility. It is anticipated that well production rates will be in the 1,000 to 1,200 gallons per minute.

C. Reservoir Performance Evaluation. The performance of the reservoir will be evaluated by monitoring the trends in the water level in the production wells and the pressure trend in the injection well. Pressure build-up and fall off surveys will be made periodically in the wells and spinner surveys will be periodically carried out in the injection system. Evaluation of communication within the reservoir will be carried out by periodically shutting in production wells and monitoring the pressure in them while other wells are in production service. The Lawrence Berkeley Laboratory Reservoir Assessment Team has agreed to assist Magma in these reservoir determinations.

D. Disposal Method. Reference is made to the plan of injection which is incorporated into this submittal for details associated with the disposal methods.

E. Engineering Details. Reference is made to Appendix E which covers the engineering details associated with the plan of development and injection.

F. Environmental Monitoring. Magma proposes that air quality monitoring be done for a two week period six months after the start up of the facility, monitoring those elements which have been established in the LLL baseline data of ozone, hydrogen sulfide and sulfur dioxide. This would also be done for two week period twelve months following the start up operations of the plant. A two week period would be selected when the plant was in full operation. If during the twelve month monitoring operation there is no evidence of changes from the baseline Magma would propose discontinuing any further monitoring of air quality. Water quality associated with the geothermal operations would be monitored by monthly having the produced fluid analyzed. Groundwater and cooling pond blowdown quality will be analyzed monthly. Noise surveys would be made at specific distances from the plant on a six month basis.

Land subsidence would be monitored by establishing a survey net in the location of the facility and this being tied into the master Imperial Valley network. Surveys to determine if changes occur would be done annually unless evidence indicates there is subsidence occurring. In this event monitoring would be done out by the existing networks of the Bureau of Reclamation and USGS. The ecological system monitoring would be carried out by having a survey done annually to determing if the flora and fauna has been effected by the facility and if after two years no effect is seen this surveying would be dropped.

APPENDIX

A - Area Plan Drawing

B - Drawing - Well Location

C - The Injection of spent Geothermal Fluid - Zebal & Assoc.

D - Preliminary Report of Short Term Testing.

E - Surface Equipment Details

F - Analysis of Reservoir Fluids

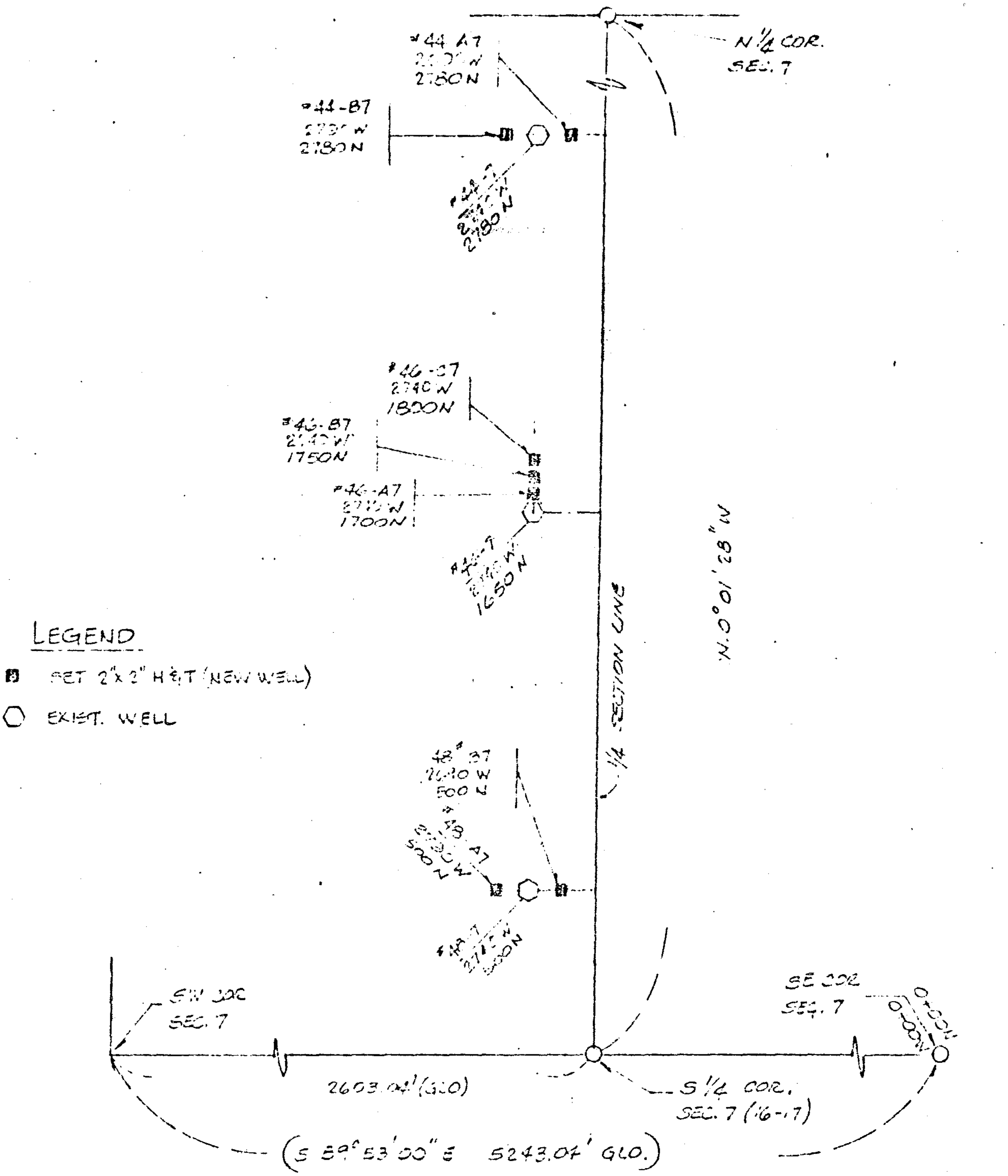
G - Cross Sections of Reservoir

H - Ground Water Report - John Hess Testing Corp.

I - Environmental Base line Data

APPENDIX A

APPENDIX B



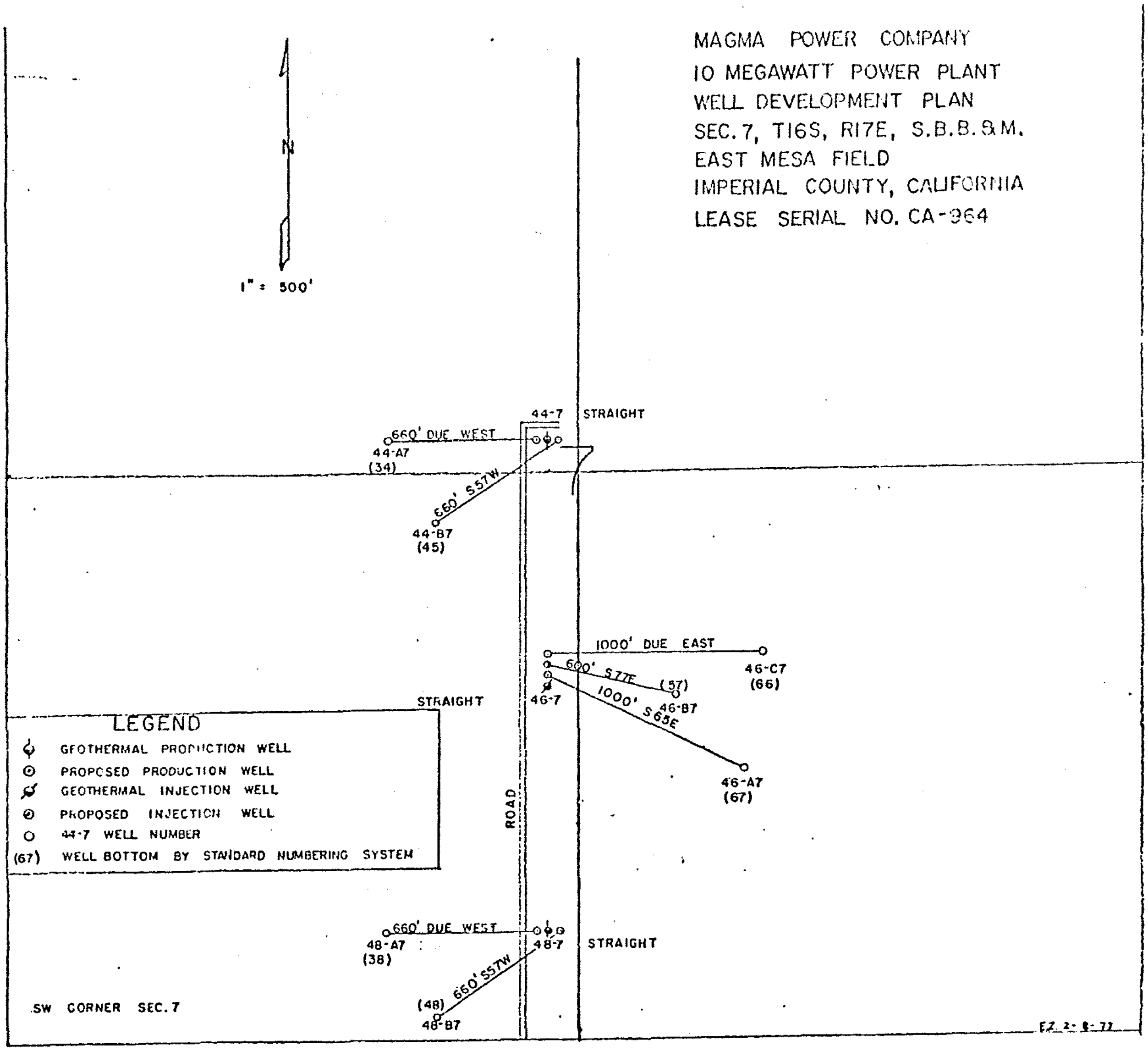
TESCO
TECHNICAL ENGINEERING & SURVEYING COMPANY
(714) 352 - 2716
2170 HWY. 86, EL CENTRO, CA

WELL LOCATION

SEC. 7, T.16S.-R.17E. SBB&M

CLIENT [illegible]

BY: TBJ
DATE: 2/18 [illegible]
CHK'D: [illegible]
REFER: [illegible]
JOB NO. [illegible]



ELL MBER	SURFACE COORDINATES	BOTTOM COORDINATES	REFERENCE	DEVIATION	BOT COORDS FROM SURF	KICK OFF POINT	MAXIMUM ANGLE	VERTICAL DEPTH	MEASU DEPT
				PRODUCTION WELLS					
-7	2500'S 2500'E	STRAIGHT	NW COR.SEC.7 T16S, R17E	-	STRAIGHT	-	-	7000'	7000
-A7	2500'S 2450'E	2500'S 1790'E	"	660' DUE WEST	660'W	4400'	15°49'	7000'	7087.
-B7	2500'S 2550'E	2915'S 2037'E	"	660' S-57-W	415'S 513'W	4400'	15°49'	7000'	7087
-7	2500'E 500'N	STRAIGHT	SW COR.SEC.7 T16S, R17E	-	STRAIGHT			7000'	7000
-A7	2450'E 500'N	1980'E 500'N	SW COR.SEC.7 T16S, R17E	660' DUE WEST	660'W	4400'	15°49'	7000'	7087.
-B7	2550'E 500'N	2000'E 112'N	"	S-57-W	415'S 513'W	4400'	15°49'	7000'	7087.
				INJECTION WELLS					
-7	2500'E 1650'N	STRAIGHT	SW COR.SEC.7 T16S, R17E	-	-	-	-	3000'	3000'
-A7	2500'E 1700'N	3406'E 1278'N	"	1000' S-65-E	906'E 423'S	200'	22°43'	3000'	3188.
-B7	2500'E 1750'N	3085'E 1615'N	"	600' S-77-E	585'E 135'S	600'	15°43'	3000'	3078.
-C7	2500'E 1800'N	3500'E 1800'N	"	1000' EAST	1000' DUE EAST	200'	22°43'	3000'	3188.

APPENDIX C

GEORGE P. ZEBAL AND ASSOCIATES
INDUSTRIAL UTILIZATION OF GEOLOGY

THE INJECTION OF SPENT GEOTHERMAL FLUID, EAST MESA AREA, IMPERIAL COUNTY, CALIFORNIA

Client:

Magma Power Company

4 April 1977

P.O. BOX 1822, NEWPORT BEACH, CALIFORNIA 92663 • (714) 642-5588

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THE INJECTION OF SPENT GEOTHERMAL FLUID,
EAST MESA AREA, IMPERIAL COUNTY, CALIFORNIA

INTRODUCTION

The injection of spent geothermal fluid is an operational requirement for the development of geothermally derived electrical energy in the Imperial Valley. Magma Power Company believes that maximum efficiency and economy will result from injection into shallow, highly permeable aquifiers existing in the East Mesa Area. Additional criteria show that the salinity of the water inhabiting the injection zone is similar to that in the producing reservoir, that injection of spent geothermal fluid can take place without creating surface seepage provided pressure is kept low, and that the dangers of inducing surface subsidence and subsurface seismic activity are eliminated by shallow injection practices.

The ensuing study will examine structural, stratigraphic, physical, geochemical, and hydrological factors relating to the chosen injection zone. Additionally, the porosity, permeability, and salinity (total dissolved solids) of the injection zone will be compared to the producing reservoir on an individual sand as well as overall basis. Finally, the direction of movement of injected spent geothermal fluid will be discussed relative to the geology of East Mesa and to geothermal and hydrological data and models derived by United States Geological Survey, Water Resources Division, and Bureau of Reclamation investigators.

GEOLOGY AND PHYSICAL CHARACTERISTICS OF THE INJECTION RESERVOIR

Structure:

Figure 1 is a structural map of the East Mesa geothermal area contoured on the base of the clay caprock (top of the injection zone). The following paragraphs identify and explain the structural features shown.

The developed portion of the East Mesa Area is structurally an undulating monocline possesing an average strike of N 45°W with dip varying from 2 to 4 degrees to the southwest. Tentative correlations between East Mesa field wells and the Shafer-Bieber Barbara No. 1 well (NW 1/4 NE 1/4 Section 21, T.16.S, R.17 E.) suggests that either southwesterly dip steepens radically to the southeast or southeasterly dip is present (see Figure 1). Gravity data supports the latter conclusion (Biehler, 1971, Figure 1 and Figure 5).

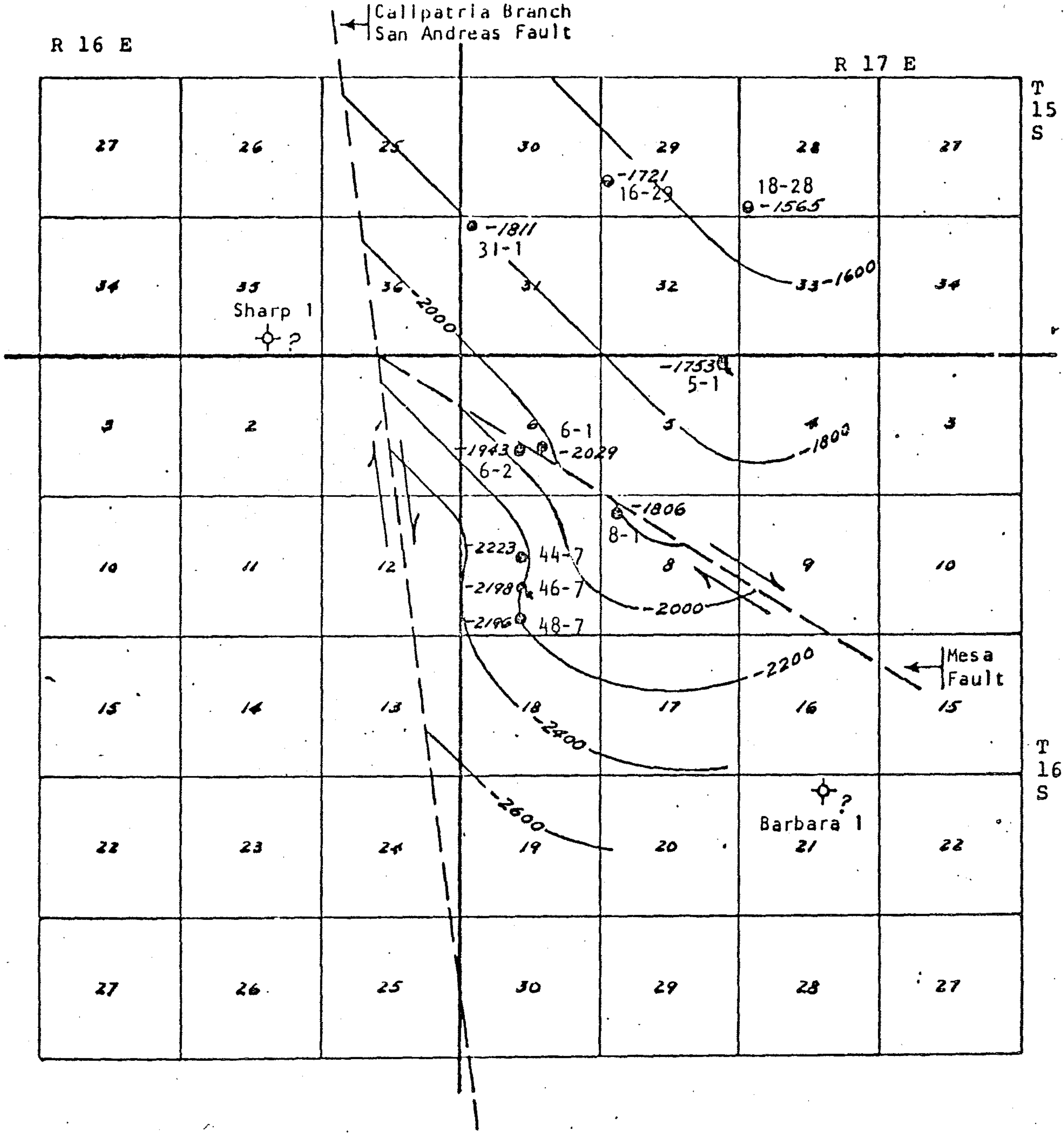

FIGURE 1

STRUCTURAL MAP OF THE EAST MESA AREA

Contours on Base of Caprock

Scale: 1 inch=1 mile

Contour interval=200 feet

The East Mesa geothermal area lies immediately east of a large magnitude fault. The trend and identity of the fault are obscure; however, from geophysical evidence, a fault termed the Holtville fault was proposed at this location (Elders et al, 1972, Figure 1). The trend of the Holtville fault was tentatively established at N 7°W and it was identified as a right-lateral strike-slip fault with a substantial amount of vertical movement. This fault can be corroborated stratigraphically (see Figure 1) because good interwell correlations exist in the East Mesa geothermal field from Bureau of Reclamation (BuRec) Well No. 31-1 (NW 1/4 NW 1/4 Section 31, T.15S., R. 17E.) to Magma Power Co. (Magma) - USA Well No. 48-7 (SE 1/4 SW 1/4 Section 7, T.16S., R.17E) but it is impossible to correlate the Magma Sharp No. 1 well (SW 1/4 SE 1/4 Section 35, T.15S., R.16E.) with any well in the East Mesa field. It is assumed that the fault trace lies midway between the Magma Sharp No. 1 well and the BuRec No. 31-1 well (a total distance of 8,750 feet) and an equal distance west of Magma-USA Well No. 48-7 (hence, 4,375 feet), a major fault having a trend of N 7°W emerges. It is believed that the Holtville fault is actually the Calipatria Branch of the San Andreas fault.

An analysis of microearthquake activity in the East Mesa Area has designated the existence of a right-lateral, strike-slip fault, termed the Mesa fault, having a trend of N 58°W (Combs et al, 1977, p. 24). There is no surface expression of the fault but at depths of 2,000 feet and greater structural maps disclose displacement (see Figure 1).

Stratigraphy:

The stratigraphic section from ground surface to the base of the injection zone consists of clay, sand-gravel, and silt in order of thickness. Overall, the following lithologic percentages obtain: clay = 63%, sand-gravel = 31%, and bedded silt = 6%. It should be noted that many clay beds contain substantial amounts of disseminated silt and thin silty partings and poorly sorted sands are often rich in silt. Cementation of clastic sediments is wholly related to original permeability so that beds of pure silt and poorly sorted, very silty, very fine grained clastic sediments tend to be moderately to well cemented. Cement is exclusively calcium carbonate. Low temprature mineralization, limited to pyrite and hydromuscovite, appears to be more prevelant in silt-bearing zones having low permeabilities. Figure 2 is a graphic log prepared from cuttings as the Magma-USA No. 46-7 well was drilled. This log shows the above characteristics in detail. Figure 3 is the Schlumberger Dual Induction-Laterolog of the same well which can be compared to the graphic well log. Table 1 shows the characteristics of individual sands comprising the injection zone in Magma-USA No. 44-7.

The local continuity of the injection zone at East Mesa is shown in Figure 4, an isopach map of the injection zone sands. From electrical log correlation studies, it is believed that the physical characteristics of individual sand bodies are very similar and stable throughout the area.

TABLE 1
MAGMA POWER CO.-USA 44-7
PHYSICAL DATA FOR INJECTION ZONE SANDS

Depth (in feet)	Thickness (in feet)	Degree of Sorting	Degree of Cementation and Grain Size	Minimum Salinity (in ppm)	Porosity (in %)		Integrated Porosity (feet of pore space)	Permeability (in md)		Integrated Permeability (in darcy-feet)
					Max.	Avg.		Max.	Avg.	
2265-2288	23	Poor	Weakly cemented, silt-fine grain sand	20,561	26.4	23.7	5.2	100	73	1.679
2339-2386	47	Good	Loose medium grain sand	12,522	27.0	25.3	11.9	200	97	4.559
2418-2432	14	Poor	Weakly cemented silt-fine grain sand	17,610	25.0	22.7	3.2	80	48	0.602
2484-2517	33	Good	Loose, medium grain sand	14,693	30.6	26.7	8.8	300	134	4.422
2519-2568	49	Good	As above	12,418	31.4	28.6	14.0	400	209	10.241
2571-2577	6	Poor	Loose, silt-fine grain sand	19,709	25.9	24.2	1.4	90	62	0.372
2602-2623	21	Poor	Weakly cemented, silt-fine grain sand	699	23.1	20.8	4.4	60	26	0.546
2623-2629	6	Good	Loose, medium grain sand	4,342	35.1	33.1	2.0	1,000	750	4.500
2631-2638	7	Poor	Loose, silt-fine grain sand	7,028	22.3	21.8	1.5	40	37	0.259
2752-2731	6	Poor	Well cemented, silt-fine grain sand	19,799	21.1	20.5	1.2	30	25	0.150
2733-2744	11	Poor	As above	13,687	23.9	21.9	2.4	70	37	0.407
2750-2753	3	Poor	As above	10,643	22.3	20.6	0.6	40	23	0.069
2762-2774	12	Poor	As above	12,596	24.4	22.6	2.7	70	54	0.648
2774-2790	16	Good	Loose medium grain sand	10,576	29.2	26.6	4.3	300	149	2.384
2978-2806	8	Poor	Weakly cemented, silt-fine grain sand	14,333	23.1	21.4	1.7	70	39	0.312
2820-2831	11	Very Poor	Loose, silt-medium grain sand	15,448	24.0	23.1	2.8	70	55	0.605
2831-2860	29	Poor	Loose, very fine-coarse grain sand	8,749	30.9	28.3	8.2	400	255	7.395
2866-2892	26	Poor	As above	7,322	29.1	24.9	6.5	200	95	2.470
2964-2975	11	Poor	Weakly cemented, silt-fine grain sand	11,775	21.2	20.5	2.2	30	26	0.286
2999-3013	14	Poor	As above	13,101	24.6	21.5	3.0	100	39	0.546
3018-3021	3	Poor	As above	12,954	22.4	21.1	0.6	30	23	0.069
3100-3133	33	Very Poor	Loose, fine sand - gravel	7,326	25.1	23.5	7.8	100	62	2.046
Total	389						96.4			44.567
Average				12,177		24.8			114	

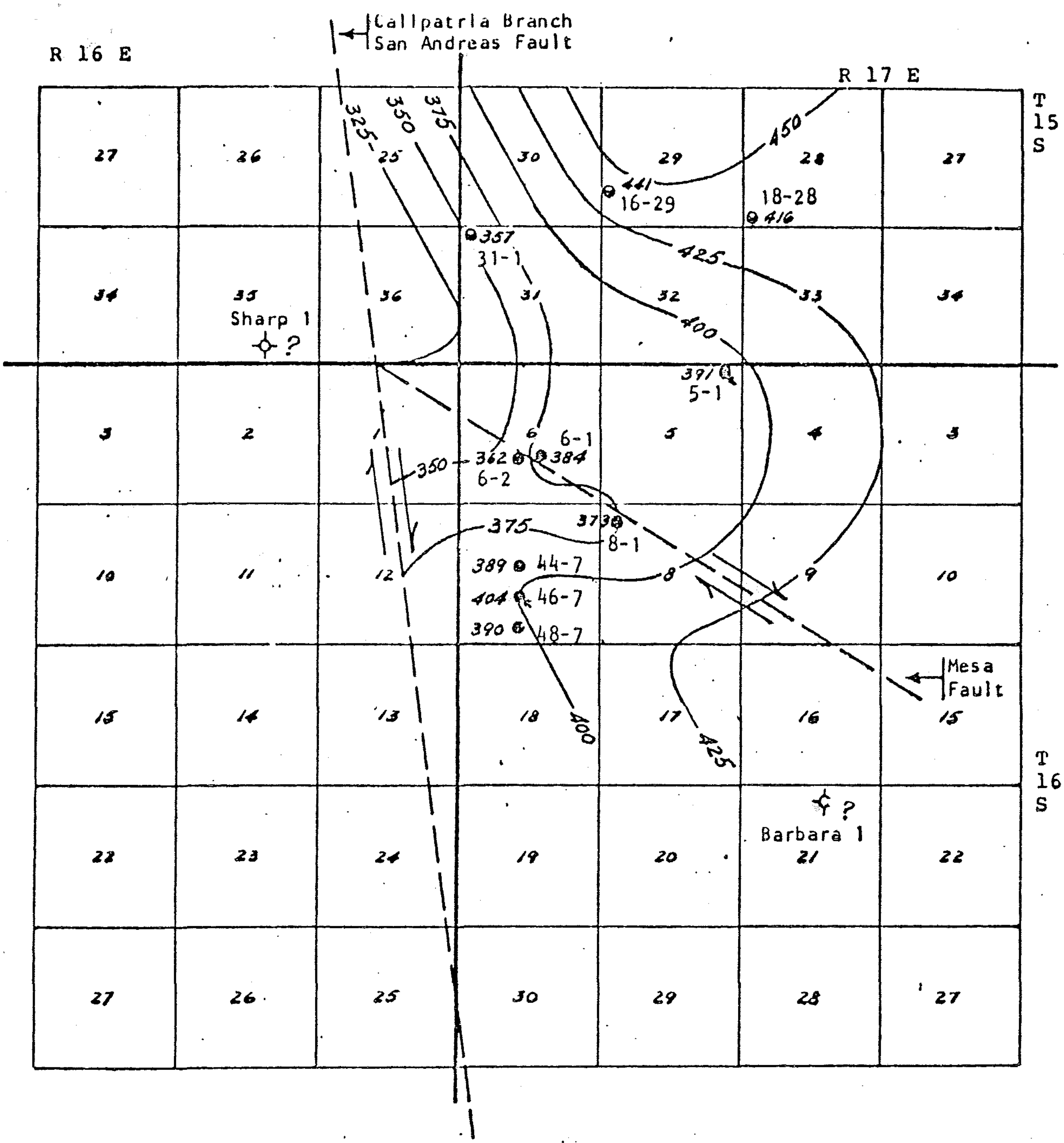

FIGURE 4

ISOPACH MAP OF INJECTION ZONE SANDS

Scale: 1 inch=1 mile Contour interval=25 feet

Regional basinward stratigraphic thickening occurs from northeast to southwest. Tentative correlation of East Mesa geothermal wells with the Shafer-Bieber Barbara No. 1 well also shows thickening to the southeast.

The existence of a substantial clay caprock overlying the geothermal system at East Mesa has been previously documented (Coplen, 1976, Figure 4 and p.26). The thickness and character of the clay caprock can be defined by zoning the stratigraphic section between the ground surface and the base of the injection zone as shown in Table 2.

TABLE 2
STRATIGRAPHIC ZONES IN THE EAST MESA AREA

Zone	Depth* (in feet)	Thickness (in feet)	Sand-Shale Ratio	Percent Sand	Remarks
1	0-1,175	1,175	0.43	30	Ground water zone
2	1,175-2,240	1,065	0.25	20	Clay Caprock
3	2,240-3,100	860	0.83	45	Injection Zone

*Depth data from Magma-USA 46-7 Well.

Local continuity of the injection zone can be demonstrated by correlating the zone through the East Mesa field and presenting the data in the form of a sand isopach map. Figure 4 shows the thickness of sands comprising the injection zone throughout the field.

Physical Characteristics of Injection Zone Sands:

Table 1 shows the pertinent physical characteristics of individual injection zone sands possessing a permeability greater than 10 millidarcys (md). Depth, thickness, minimum salinity, porosity and permeability were taken from the Schlumberger Saraband Log from the Magma-USA 44-7 well (no Saraband Log was run on Magma-USA 46-7). Magma-USA 44-7 lies 1,200 feet north of Magma-USA 46-7; the correlation between individual sands is very good. The degree of sorting, degree of cementation and grain size characteristics were obtained from the graphic well log from Magma-USA 44-7.

From Table 1, it can be seen that the injection zone contains 389 feet of sand having permeabilities greater than 10 md. The maximum porosity is 35.1 percent, the average porosity is 24.8 percent, and the cumulative pore space equals 96.4 feet. Maximum permeability reaches one darcy and the average permeability is 114 md. Cumulative permeability equals 44.567 darcy-feet. In a later section these data will be compared to similar data from the deep producing reservoir in Magma 44-7.

The Schlumberger Saraband Log is derived from a computer program utilizing time-tested empirical equations developed by Schlumberger engineers to aid in the determination of formation and formation fluid characteristics. Factors related to borehole diameter, mud cake, temperature, and formation characteristics created by the clay and silt content are compensated for. The principle advantage offered by the Saraband program is the determination of permeability with an accuracy previously unattainable. The Saraband Log is computed from the following array of logs: Spontaneous-Potential, Dual Induction-Laterolog, Formation Density Compensated Log, Sidewall Neutron Porosity Log, Borehole Compensated Sonic Log, and the Gamma Ray Log. Because this array is required, Saraband Logs are very expensive.

Salinity:

Log interpretations offered by Schlumberger also include formation salinity values. Table 1 shows minimum salinity values per individual sand body. The values vary from a maximum of 20,561 parts per million (ppm) to a minimum of 700 ppm. Average salinity throughout the injection zone amounts to 12,177 ppm. This figure should represent the total dissolved solids (TDS) present in fluid derived from the injection zone reservoir. This average salinity value will be compared to a similarly obtained value for the deep producing zone in Magma 44-7 in the section entitled Hydrology.

Temperature:

The temperature distribution at the base of the injection zone is shown in Figure 5. There are three methods of presenting temperature data as follows:

(1) Isotherm contours of the subsurface temperature at a finite depth plane.

(2) Contours expressing the plane of a finite temperature.

(3) Isotherm contours of a stratigraphic unit.

The latter method was utilized to present the most meaningful picture of the temperature of the injection zone in the East Mesa Area.

Analyses of the stratigraphic and physical characteristics of the late Pliocene and Pleistocene sediments relative to temperature gradients in the East Mesa geothermal system show that the heat flow above the base of the clay caprock is exclusively by conduction. Below the base of the caprock, the heat flow is convective.

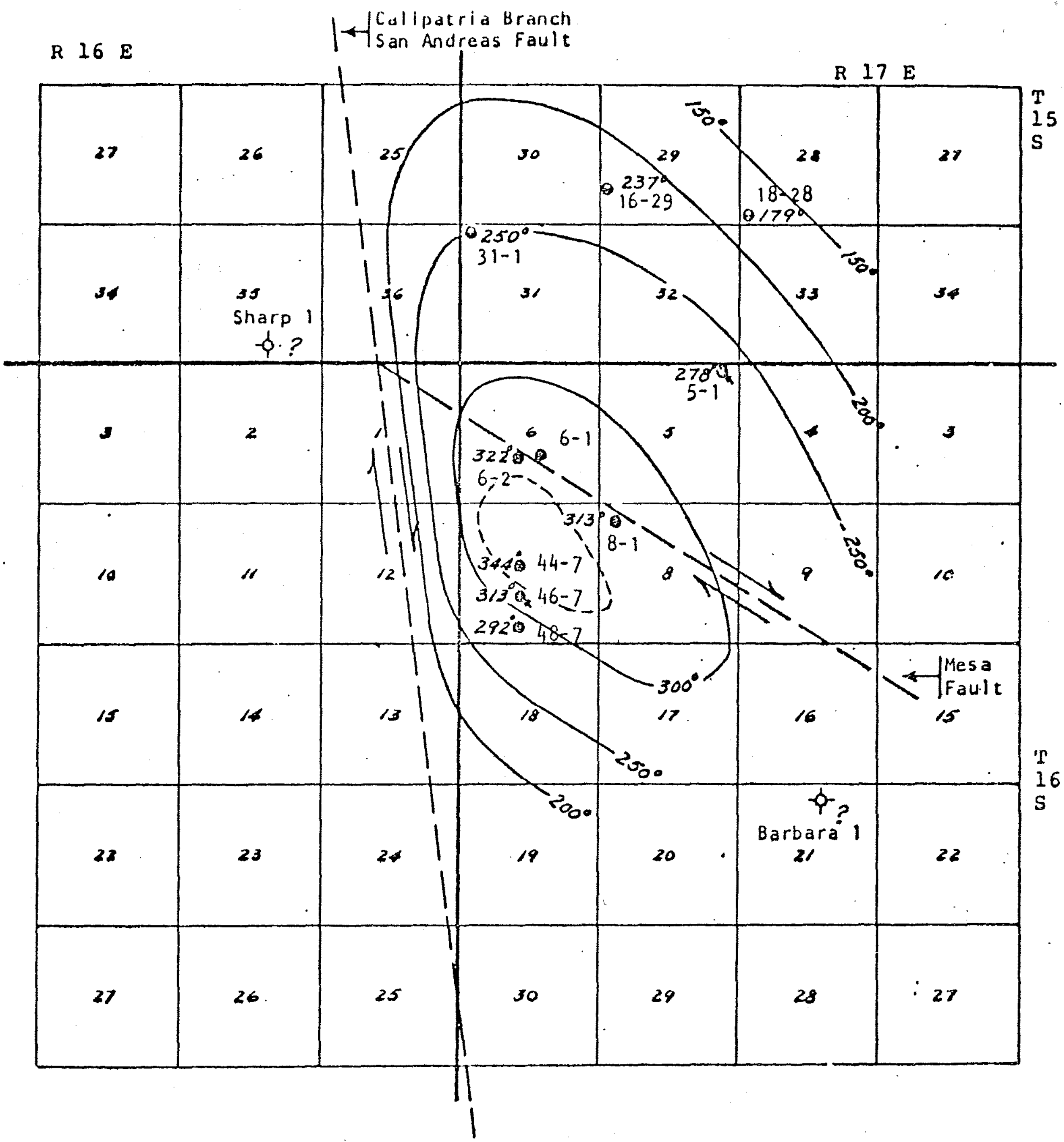

FIGURE 5

ISOTHERM MAP OF INJECTION ZONE TEMPERATURES

Showing Temperatures at Base of Injection Zone

Scale: 1 inch=1 mile Contour interval=50^{O}F

HYDROLOGICAL FACTORS APPLICABLE TO INJECTION

The injection of spent geothermal water at a surface temperature of 180 degrees Fahrenheit (°F) and at a rate of approximately 1,450 gallons per minute (gpm) must consider the following factors:

(1) Premature cooling of the producing geothermal reservoir.

(2) Economics of the injection system.

(3) Formation characteristics.

(4) Potential migration path of injected fluid.

If spent geothermal fluid is injected directly into the producing reservoir, premature cooling will result. This serves to destroy a valuable energy resource. If injection into the producing reservoir is accomplished at sufficient distance from producing wells to theoretically eliminate cooling effects, the combined costs of deep injection wells and an extensive gathering system becomes prohibitive. If super deep wells are drilled for injection purposes, the geothermal convection cell may be prematurely cooled, earthquakes may be induced by high injection pressures, and field development costs would be staggering. These factors suggest injection into shallow zones within the developed area of the geothermal field where porosity and permeability are at a maximum provided that hazards related to surface seepage, surficial subsidence, or the generation of shallow-seated earthquakes are not induced.

REGIONAL HYDROLOGY OF THE IMPERIAL VALLEY

In order to augment the hydrological studies of Magma Power Company in the East Mesa portion of the Imperial-Mexicali Valley, three investigations concerning groundwater and geothermal systems will be utilized. Loeltz et al (1975) discussed the groundwater characteristics and recharge sources for the uppermost 1,000 feet of sediments (hence, above the clay caprock zone). Dutcher et al (1972) applied similar data to deeper horizons to theoretically estimate recoverable reserves of groundwater and geothermal water having TDS values less than 35,000 ppm. Coplen (1976) geochemically investigated geothermal fluid-formation interactions and the hydrogeology of the East Mesa geothermal field to define sources of connate and recharge water.

Discussion of the hydrology of the East Mesa area must be introduced by a brief background discussion of paleohydrologic factors responsible for the evolution of the Imperial-Mexicali Valley, the regional hydrology of the basin, and the source of basin waters.

Paleohydrology:

The last major invasion of marine water into the Imperial Valley basin created the Imperial formation. This invasion occurred during late Miocene-early Pliocene time (approximately 20 million years ago). This time interval was concurrent with the major canyon-cutting activity by the Colorado River (Cooley et al, 1968, p. 101). By early Pliocene time the delta of the Colorado River had isolated the Imperial Valley from further marine invasions. The crest of the delta runs from near Gadsden, Arizona, to Cerro Prieto, Baja California. Its current minimum altitude is 47 feet above sea level. Since then the Salton Trough has continued to be progressively downwarped and as much as 20,000 feet of Pliocene and Pleistocene nonmarine sediments have accumulated. During the remainder of the Pliocene epoch and throughout the Pleistocene a succession of lakes occupied the closed basin. These lakes were freshwater lakes in the sense that they were created and fed by the Colorado River and local watershed streams; in terms of TDS content, they actually contained brackish water. The Pleistocene series of lakes were probably related to glacial stages with evaporation to a playa or salt flat condition during interglacial intervals. Brackish to saline connate water was contributed to lakebed sediments during each stage (Loeltz et al, 1975, p. K25). The maximum elevation attained by any lake was governed by the length of time the Colorado River flowed into the Imperial-Mexicali Valley and by the elevation of the delta crest. It should be noted that the probability of marine invasions are eliminated during glacial stages by lowering of sea level and augmented during interglacial intervals by rising sea levels. Lake Cahuilla was the youngest lake to completely cover the Imperial Valley. The age of the lake conforms to the late Wisconsin glacial stage, 25,000 to 10,000 years before the present (Flint, 1971, p. 560; Loeltz et al, 1975, p. K13). At maximum extent, its shoreline lay at 47 feet above sea level which is exactly equivalent to the present day minimum elevation of the crest of the delta (Loeltz et al, 1975, p. K13).

Vertical Hydraulic Conductivity:

The post-late Pliocene sedimentary column in the Imperial Valley is composed of a bedded series of permeable sand and gravel and relatively impermeable clay and silt (e.g. at East Mesa the sand-gravel to clay-silt ratio for sediments to a depth of 3,000 feet is 0.45 or 31 percent sand-gravel). Bed thicknesses range from a fraction of a foot (usually silt beds or clay partings in sands) to over 100 feet (usually clay). Under the set of conditions the horizontal hydraulic conductivity of an aquifier composed of a heterogeneous series of permeable and impermeable formations is infinitely greater than the vertical hydraulic conductivity. Loeltz states that in the Imperial Valley, "The hydraulic connection between the deposits at great depth and those in the upper part of the reservoir is so poor that the two parts are virtually completely isolated" (Loeltz et al, 1975, p. K14).

Examination of samples from deep wells in the East Mesa area shows that there is a progressive reduction in porosity and permeability with depth to a depth of 6,500 feet. In addition to the effects of compaction, the reduction occurs in the following manner at the following depths:

(1) Loss of gravel at a depth of 1,200 feet (base of floodplain, beach, and near shore deposits).

(2) Progressively greater cementation of silt and poorly sorted, fine grained deposits to depths of 5,200 feet.

(3) Increasing cementation of fine to medium grained deposits, the development of calcite grain-coatings on coarser grains, and crystalline calcite deposits to depths of 6,500 feet.

At 6,500 feet there exists a permeability barrier expressed in the form of the sudden appearance of secondary quartz and kaolinite and a dramatic increase in the volume of crystalline calcite. Below this depth, few sands have porosity values above 15 percent or permeability values greater than 10 md. Above this depth, intergranular porosity is paramount; below this depth, fracture porosity will dictate the flow of fluid. Fracture systems serve to increase vertical hydraulic conductivity and augment operation of theoretical geothermal convection cell systems proposed by White and Dutcher et al (Dutcher et al, 1972, Figure 6).

Horizontal Hydraulic Conductivity:

Regional horizontal variations in porosity, permeability, and salinity occur within the Imperial Valley. The ultimate sink in the closed Imperial Valley basin lies beneath the bulbous southern portion of the Salton Sea where TDS values reach a maximum. From data suppied by Dutcher et al, it can be seen that this area represents a stagnant condition where more than two confined flow systems moving in opposed directions meet (Dutcher et al, 1975, Figure 7; Toth, 1972, p. 484).

Near the basin margins, beach and floodplain gravels throughout the Pliocene and Quaternary stratigraphic section have maximum fluid transmissivities. Transmissivity decreases basinward and with distance from the crest of the Colorado River delta because of decreasing grain size and degree of sorting and increasing volumes of silt and clay in porous sands (Loeltz et al, 1975, p. K15). However, overall horizontal hydraulic conductivity may be balanced by a basinward thickening of porous formations and greater depths to the permeability barrier encountered at East Mesa at depths below 6,500 feet. Geographically, the movement of groundwater contributed by Colorado River underflow from the gaps in the vicinity of Pilot Knob is essentially slightly north of due west to the axis of the Imperial Valley basin and thence northwest into the Salton Trough Sink (Loeltz et al, 1975, p. K23; Dutcher et al, 1972, Figure 7). These flow directions apply equally to both shallow unconfined groundwater systems and deep confined systems.

Source of Recharge Water:

All of the investigators agree that the major source of shallow and deep groundwater recharge in the Imperial Valley is the Colorado River (Dutcher et al, 1972; Loeltz et al, 1975; Coplen 1976). Minor sources include underflow from the Mexicali Valley, intermittent streams draining the Peninsular Ranges and to a lesser extent the Chocolate Mountains, and local runoff. Colorado River underflow takes place through the Cargo Muchacho Mountains-Pilot Knob gap and an area to the south between Pilot Knob and the trace of the Sand Hills Branch of the San Andreas-Algodones fault where the eastern limit of the crest of the Colorado River delta lies. In these areas the stratigraphic thickness of permeable Pliocene and Quaternary deposits is thin relative to that in the central Imperial Valley (less than 5,000 feet versus 20,000 feet in the Salton Trough) (Dutcher et al, 1972, Figure 15). This factor augmented by fracture porosity present along the trace of several major fault systems (Sand Hills and Calipatria Branches of the San Andreas fault, Brawley fault and intervening tensional faults related to differential movement on major right-lateral strike-slip faults) enhances the ability of Colorado River water to overcome the large differential between horizontal and vertical hydraulic conductivity and thereby recharge the entire porous stratigraphic section. The geochemical investigations of Coplen are important for defining this factor in the East Mesa Area (Coplen, 1976, pp. 1-92).

Clay Caprock Zone:

The clay caprock zone existing at East Mesa and previously discussed in the section on stratigraphy is only locally competent. The presence of thick, relatively impermeable clay beds or thermally metamorphosed argillite series have been identified at the Niland and Cerro Prieto Geothermal Fields (Dutcher et al, 1972, p. 19). Both areas also contain surface geothermal manifestations in the form of mud pots in the Mullet Island-Wister area and numerous warm springs in the vicinity of Cerro Prieto volcano and Volcano Pond (Rook et al, 1942, p.18). Figure 1 shows the existence of displacement at the base of the clay caprock on the Mesa fault. Undoubtedly other major strike-slip faults serve to disrupt the regional competence of the clay caprock. Hence, it appears that the injection zone aquifiers are included in the unconfined flow system (groundwater flow distribution controlled by the configuration of the water table) investigated by Loeltz et al (1975).

LOCAL HYDROLOGY OF THE EAST MESA AREA

The local hydrology of the subject area will be discussed in relation to the source of water, salinity, and recharge of specific hydrologic zones.

Hydrologic Zones:

Based on stratigraphy, salinity, and isotope studies of oxygen, carbon, and hydrogen; the East Mesa geothermal area can be hydrologically divided into specific zones as follows (depth data are obtained from the Magma-USA 46-7 well for shallow depths and the Magma 44-7 well for deeper zones):

Zone 1a: Ground surface to 200 feet; dominantly Colorado River water contributed by leakage from the unlined All American, Coachella, and East Highline Canals.

Zone 1b: 200 to 1,175 feet; dominantly Lake Cahuilla connate water invaded by Colorado River recharge water.

Zone 2: 1,175 to 2,240 feet; clay caprock zone with some isolated, lenticular, sand bodies containing nonmigrating connate water from Lake Cahuilla or a pre-Cahuilla lake.

Zone 3: 2,240 to 5,100 feet; connate water from a pre-Cahuilla lake in low porosity zones and Colorado River recharge water in high porosity zones.

Zone 4: 5,100 to 6,530 feet; Colorado River recharge water partially comingled with vertically rising residual brine.

Table 3 shows the average physical characteristics of sands in each zone. The proposed injection zone lies in the upper portion of Zone 3; the producing reservoir is Zone 4. For obvious reasons, the hydrologic zones correlate with the stratigraphic zones defined in Table 2.

Table 4 shows the physical characteristics of sands having a permeability greater than 10 md in the producing reservoir.

Source of Water in Hydrologic Zones:

Coplen conducted a detailed geochemical study of East Mesa Area subsurface waters through the vehicle of oxygen, hydrogen and carbon isotope analyses. The oxygen and hydrogen isotopic compositions of subsurface water samples were reported in parts per thousand difference from Standard Mean Ocean Water. Similar analyses were conducted on waters from Lake Mead, the Colorado River at Winterhaven, California, and the Salton Sea.

A curve was plotted comparing hydrogen isotopic values to oxygen isotopic values (Coplen, 1976, Figure 3). This curve represents an evaporation sequence from pure Colorado River water to the highly evaporated Colorado River water present in the Salton Sea. Subsurface waters from various levels

TABLE 3

PHYSICAL CHARACTERISTICS OF SANDS IN HYDROLOGIC ZONES

Zone	Character of Sand[1]	Average Porosity (in %)	Average Permeability (in md)	Average Minimum TDS (in ppm)
1a	Coarse sand - pea gravel	35%[2]	1,000 md[2]	736 ppm[2]
1b	As above	32%[2]	630 md[2]	1,270 ppm[3]
2	Lenticular fine - coarse sand	NA*	NA*	15,668 ppm[4]
3	Very fine - coarse sand	25%[4]	114 md[4]	12,177 ppm[4]
4	Very fine - medium sand	21%[4]	53 md[4]	6,370 ppm[4]

*Not applicable due to isolation and lenticularity of sands in this zone.

Sources of data:

1. Graphic Well Log from Magma-USA 46-7.
2. Dutcher et al, 1972, p. 16.
3. Loeltz et al, 1975, Table 5.
4. Schlumberger Saraband Log from Magma-USA 44-7.

TABLE 4
MAGMA POWER CO.-USA 44-7 WELL
PHYSICAL DATA FOR PRODUCING RESERVOIR SANDS

Depth (in feet)	Thickness (in feet)	Minimum Salinity (in ppm)	Porosity (in %)		Integrated Porosity (pore space)	Permeability (in md)		Integrated Permeability (in darcy-feet)
			Max.	Avg.		Max.	Avg.	
5187-5264	77	2,821	27.1	21.8	16.8	200	61	4.697
5273-5284	11	8,852	22.9	21.0	2.3	70	40	0.440
5289-5298	9	6,052	26.0	21.7	1.9	200	59	0.531
5300-5321	21	5,980	26.0	22.0	4.6	200	54	1.134
5325-5336	11	5,786	21.2	19.5	2.1	40	21	0.231
5349-5355	6	6,468	19.4	18.3	1.1	20	13	0.078
5385-5424	39	6,196	24.5	21.1	8.2	90	44	1.716
5428-5433	5	7,475	19.0	18.2	0.9	20	14	0.070
5486-5492	6	8,477	19.1	18.7	1.1	20	17	0.102
5507-5527	20	4,912	22.7	20.3	4.1	50	27	0.540
5542-5551	9	8,955	20.5	18.6	1.7	30	16	0.144
5568-5589	21	5,893	24.3	20.3	4.3	80	30	0.630
5591-5602	11	7,338	22.0	19.3	2.1	50	21	0.231
5636-5639	3	5,170	20.8	19.5	0.6	40	27	0.080
5641-5702	61	2,820	26.5	21.8	13.3	200	68	4.148
5709-5723	14	4,047	23.9	21.4	3.0	100	54	0.756
5730-5760	30	4,117	25.2	20.7	6.2	100	38	1.140
5819-5823	4	7,816	20.0	19.2	0.8	20	18	0.072
5832-5862	30	5,247	27.5	22.5	6.7	200	74	2.220
5972-5976	4	7,054	18.8	18.2	0.7	10	10	0.040

(Cont. next page)

TABLE 4 - Continued
MAGMA POWER CO.-USA 44-7 WELL
PHYSICAL DATA FOR PRODUCING RESERVOIR SANDS

Depth (in feet)	Thickness (in feet)	Minimum Salinity (in ppm)	Porosity (in %)		Integrated Porosity (pore space)	Permeability (in md)		Integrated Permeability (in darcy-feet)
			Max.	Avg.		Max.	Avg.	
5983-5992	9	5,270	22.3	20.4	1.8	50	30	0.270
5999-6007	8	5,209	21.3	20.2	1.6	40	26	0.208
6015-6027	12	6,378	23.0	19.9	2.4	60	29	0.348
6033-6053	20	4,505	24.4	20.6	4.1	100	38	0.760
6068-6071	3	6,605	23.9	21.9	0.6	90	57	0.170
6073-6076	3	8,901	20.0	18.8	0.5	30	17	0.050
6088-6092	4	10,485	17.4	16.9	0.7	10	10	0.040
6096-6100	4	6,263	20.2	19.4	0.8	30	20	0.080
6131-6135	4	9,841	19.0	18.4	0.7	20	18	0.070
6143-6147	4	8,450	18.6	18.3	0.7	10	10	0.040
6160-6202	42	3,732	29.2	25.0	10.5	400	153	6.426
6208-6233	25	3,221	30.5	24.6	6.1	500	134	3.350
6236-6257	21	2,056	23.3	20.9	4.4	70	35	0.735
6278-6322	44	4,722	26.5	23.0	10.12	200	67	2.948
6325-6345	20	6,441	21.2	19.8	3.9	40	25	0.500
6350-6364	14	5,034	25.3	21.9	3.0	100	58	0.812
6388-6391	3	6,375	21.1	20.1	0.6	40	27	0.081
6396-6401	5	6,701	20.3	19.7	1.0	30	24	0.120
6404-6409	5	6,231	21.0	19.9	1.0	30	22	0.110
6462-6469	7	7,829	20.1	18.8	1.3	30	16	0.112
6471-6487	16	7,616	23.6	20.3	3.2	80	33	0.528
6498-6515	17	8,022	22.1	19.4	3.3	50	24	0.408

(Cont. next page)

TABLE 4 - (Continued)
MAGMA POWER CO.-USA 44-7 WELL
PHYSICAL DATA FOR PRODUCING RESERVOIR SANDS

Depth (in feet)	Thickness (in feet)	Minimum Salinity (in ppm)	Porosity (in %)		Integrated Porosity (pore space)	Permeability (in md)		Integrated Permeability (in darcy-feet)
			Max.	Avg.		Max.	Avg.	
6517-6520	3	11,058	19.3	18.1	0.5	20	13	0.040
6522-6523	10	6,889	22.1	20.7	2.1	50	35	0.350
7044-7058	14	4,245	23.3	20.1	2.8	60	25	0.350
7134-7138	4	5,357	18.9	18.5	0.7	10	10	0.040
7198-7230	32	8,489	25.3	21.5	6.9	100	50	1.600
7235-7240	5	8,405	18.9	18.2	0.9	20	12	0.060
Total	750				158.7			39.606
Average		6,370		21.2			53	

in East Mesa wells match this curve with minimal scatter. These data convinced Coplen that Imperial Valley groundwater, regardless of the depth factor, consisted wholly of Colorado River water that has undergone various degrees of evaporation. The question arose as to what geological mechanism created the evaporation series. Other investigators had proposed theories related to concentration of salts by membrane filtration of clay-shale beds, by solution of evaporites contained in Imperial Valley sediments, or by extreme concentration resulting from a single, ancient, evaporation event occurring prior to the initiation of the series of Pleistocene lakes (Dutcher et al, 1972, p. 17).

From the oxygen-hydrogen isotope curve, Coplen showed that a range in intermediate isotopic values (lying between the extreme values represented by pure Colorado River and Salton Sea waters) would conform to the range in values expected from stages in the solar evaporation of a lake that had been rapidly filled and slowly evaporated to dryness (Coplen, 1976, pp. 23-26). Therefore, lake bed sediments should contain connate water having oxygen-hydrogen isotopic values within this intermediate range. High isotopic values represent original connate water and low values are related to Colorado River recharge in extensive permeable zones.

Salinity of Hydrologic Zones:

Isotope data correlate very well with salinity data presented in this report (Tables 1-4). Coplen states that TDS values for East Mesa fluid samples typically lie in the range from 2,000 to 4,000 ppm but some samples are as high as 20,000 ppm (Coplen, 1976, p. 12). The typical values stated by Coplen appear to be low relative to preliminary fluid samples obtained from Magma Power Co. wells and those calculated from electrical logs; the upper range is comparable to maximum values obtained from electrical logs. An explanation for this difference is provided by two factors:

(1) Magma is interested in generating electrical energy, hence in maximum fluid production at the highest possible temperature, so wells were completed over broad intervals; BuRec is interested in desalination, hence completions were based on intervals having low TDS content.

(2) Many fluid samples from BuRec wells were obtained from drill stem tests where small volumes of fluid were recovered (varying from several hundred to over 800 gallons depending upon depth and how rapidly the tool became plugged by loose sand); drill stem tests conducted by Magma show that sample dilution by mud filtrate has occurred in every instance.

Pertinent salinity data are presented for the injection zone in Table 1, for the producing reservoir in Table 4, and for the stratigraphic-hydrologic zones in Table 3.

Laboratory analyses (GHT Laboratories of Imperial Valley, Inc., Brawley, California) of fluids produced from the injection zone in the Magma-USA 46-7 well have an average TDS content of 12,140 ppm (varying from 12,080 to 12,200 ppm). Similar analyses of fluids from the producing zone in the Magma-USA 44-7 well have an average TDS content of 11,670 ppm (varying from 11,100 to 12,200 ppm). These values can be compared to the calculated values obtained from the Schlumberger Saraband Log computer program as follows: average salinity of the injection zone equals 12,177 ppm (from Table 1) and average salinity of the producing zone equals 6,370 ppm (from Table 4).

Salinity values calculated from electrical logs and derived from laboratory analyses compare favorably for injection zone fluids. A major difference exists between analyses of geothermal fluids from the producing reservoir. It is proposed that this anomaly results from the following factors:

(1) The true average salinity of the producing reservoir between depths of 5,100 and 6,350 feet is 6,370 ppm as denoted by minimum salinity values obtained from electrical logs; hence, if the completion of the well had been restricted to this interval, the fluid produced would possess this calculated TDS content.

(2) The actual completion zone extends to the total depth of the well, 7,328 feet; hence, a minor volume of high salinity brine is probably being produced from fractures in the dense, indurated strata encountered below 6,530 feet.

Recharge of Hydrologic Zones:

The preceding hydrologic and isotopic data indicate that a high rate of recharge by Colorado River water is exhibited in Zones 1a and 4 and a moderate rate in Zones 1b and 3. In addition to the hydraulic gradient, it is believed that the existence of one or more of the following structural and stratigraphic factors influence rates of recharge per zone:

(1) The thin stratigraphic section in the vicinity of the gaps adjacent to Pilot Knob is dominantly porous sand wherein vertical hydraulic conductivity approaches horizontal conductivity values.

(2) An unconformity exists along the eastern rim of the Imperial Valley basin wherein Zones 2 and 3 are missing and Zones 1 and 4 receive the entire recharge from the Colorado River.

(3) The migration path of Colorado River recharge water from the gaps adjacent to Pilot Knob into the axis of the Imperial Valley basin crosses several large magnitude faults; fractures along these fault zones may augment vertical hydraulic conductivity and permit the selective entrance of Colorado River water into Zone 4.

MIGRATION PATH OF INJECTED FLUID

The migration path of spent geothermal fluids injected into a zone lying between 2,240 and 3,100 feet in the Magma-USA 46-7 well is related to the following factors:

(1) Injection pressure and volume of spent geothermal fluids to be injected.

(2) Local and regional transmissivity of injection zone formations.

(3) Influence of the Calipatria Branch of the San Andreas fault.

(4) Influence of local and regional structure.

(5) Influence of temperature of injection zone aquifers relative to the temperature of the injected fluid.

The investigations of Dutcher et al and Loeltz et al privide the following pertinent conclusions (Dutcher et al, 1972, p. 2; Loeltz et al, 1975, pp. K19-K23):

(1) Major strike-slip faults do not appear to represent barriers to the horizontal hydraulic conductivity of aquifers.

(2) Maximum transmissivity in shallow aquifers (above 3,000 feet occurs in the southeastern portion of the Imperial Valley (Pilot Knob to Alamo River).

(3) The normal movement of groundwater in the Imperial Valley is westward to the axis of the valley thence northwest toward the Salton Sea.

(4) A groundwater mound resulting from leakage from the All American, Coachella, and East Highline Corals rises to a height of 5 to 40 feet in the East Mesa Area; the movement of groundwater from this mound is principally westward with a minor southwestward component.

(5) Fault-induced fracture systems are advanced as agents for the operation of localized geothermal convection cells; in other words, normal vertical hydraulic conductivity augmented by fracture systems is assumed to provide cold phase recharge and fracture systems are assumed to provide conduits for the ascent of hot phase fluids.

Combining all of the above factors in a careful analysis of both local and regional criteria, a migration path for spent geothermal fluid injected into hydrologic Zone 3 can be identified.

As a function of the existing and long established hydraulic gradient injected fluids cannot migrate to the east or north. In response to the normal movement of groundwater and the structural attitude of the monocline existing in the East Mesa Area, most of the injected fluid will flow to the west. Some of the fluid will migrate to the south and southwest because of the structural dip of the monocline (see Figure 1) and the stratigraphic thickening of sands comprising the injection zone (see Figure 4). And some of the fluid will recharge the cold phase of the East Mesa geothermal convection cell.

Injection practices associated with the secondary recovery of oil and the elimination of surficial subsidence have been studied in depth by the Division of Oil and Gas, State of California. A formula has been established wherein allowable surface injection pressure for relatively unconsolidated sediments equals 0.65 psi per foot of depth less the normal hydrostatic head. Therefore, if the Division of Oil and Gas had jurisdiction in the East Mesa Area, the maximum allowable well head injection pressure would be 487 psi.

Injected fluids migrating to the west will cross the trace of the Calipatria Branch of the San Andreas fault (the Holtville fault). Because of the magnitude of displacement along this fault, it is impossible to stratigraphically correlate the Magma Sharp No. 1 well with East Mesa geothermal wells. However, at a depth comparable to the base of the injection zone in Magma-USA 46-7 (3,100 feet), the temperature recorded at Sharp No. 1 was 170°F. This evidence shows that the Calipatria Branch of the San Andreas fault serves to bound the East Mesa Geothermal Field to the west. Therefore, cold phase fluid recharge to the East Mesa geothermal convection cell along the fault trace must be very substantial to create such a large horizontal temperature gradient.

SURFACE SEEPAGE, SURFICIAL SUBSIDENCE, AND INDUCED SEISMIC ACTIVITY RELATED TO THE PRODUCTION AND INJECTION OF GEOTHERMAL FLUIDS

Every environmental assessment document and every report written by non-industry agencies include sections discussing or predicting the onset of one or more of the subject hazards (e.g., see Dutcher et al, 1972, pp. 50-52). Seldom do these discussions cite factual background data that served to create the problem in cited areas and technically compare these factual data to conditions existing in the Imperial Valley.

Surface Seepage:

The potential hazard related to surface seepage of injected geothermal fluids is a function of the following factors:

(1) Transmissivity of injection zone aquifers.
(2) Effectiveness of vertical hydraulic conductivity.
(3) Influence of fault-induced fracture systems.
(4) Storage capacity of unconfined aquifers.
(5) Normal direction and rate of movement of groundwater.
(6) Influence of injected fluid temperature relative to injection zone temperature.

The transmissivity of injection zone aquifers has been described in terms of porosity and permeability of individual sands and in average data for the entire zone in preceding sections and tables.

Data presented by Loeltz et al indicate that vertical hydraulic conductivity is poor in the Imperial Valley (varying from hundreths to thousandths of the horizontal hydraulic conductivity) due to the heterogeneous nature of the sedimentary column (Loletz et al, 1975, pp. K14-K15). Salinity values and the isotopic data presented by Coplen (1976) demonstrate that the clay caprock in the East Mesa Area is locally competent. However, this factor may be negated by the presence of major strike-slip faults and fault-induced fracture systems. Fault zone permeability and the stairstep displacements of aquifers and aquiclides can provide avenues of escape for water from aquifers that may be locally confined. Therefore, it appears that the injection zone aquifers are regionally unconfined but the vertical hydraulic conductivity is low.

Northeast of the Salton Sea a linear series of springs parallels the San Andreas fault. Despite the existence of a groundwater mound along the East Highline Canal in the East Mesa Area, no springs issue from the trace of the Calipatria Branch of the San Andreas fault. Therefore, it is concluded that the storage capacities of unconfined aquifers in the East Mesa Area are large (equal to the porosity; hence, 25 to as much as 40 percent) and the westerly movement of groundwater is at a rate sufficient to preclude surface seepage.

The fluid to be injected will have a temperature of 180^{o}F; reservoir temperatures in the injection zone attain a maximum of 344^{o}F. The higher density of cooler injection water will stimulate injection; therefore, injection pressures at the well head will basically relate to overcoming friction losses in the casing and formation. For this reason, injection pressure can be held below the allowable pressure defined by the Division of Oil and Gas, i.e., 487 psi.

Therefore, it is concluded that under normal operational practices no surface seepage problems will be created in the East Mesa Area by injecting spent geothermal fluid into the aquifer represented by hydrologic Zone 3.

Surficial Subsidence:

Subsidence occurs due to lowering of the piezometric surface in unconsolidated or semiconsolidated formations in an unconfined reservoir. Subsidence can also occur in a confined reservoir having similar formation characteristics when the withdrawl rate exceeds the rate of recharge.

The isotope data of Coplen demonstrates that the producing zone for geothermal fluid in the area being developed by Magma Power Co. at East Mesa is almost wholly Colorado River water and that the more permeable aquifers in the injection zone also are dominated by Colorado River recharge water (Coplen, 1975, Figure 4). The East Mesa area lies athwart the major pathway of Colorado River underflow entering the Imperial Valley from gaps adjacent to Pilot Knob. Isotope data also shows that the recharge by Colorado River water is more extensive in hydrologic Zone 4 (producing zone) than Zone 1b (unconfined groundwater zone).

If a convection cell of the type and magnitude theoretically defined by Dutcher et al is operating in the East Mesa geothermal area, recharge by ascending plumes of hot geothermal water will be an important mechanism (Dutcher et al, 1972, Figure 8).

These factors indicate that recharge by Colorado River water and convecting geothermal water is of sufficient magnitude in the deep producing reservoir at East Mesa to withstand withdrawl of fluid for geothermal purposes. Obviously, the reinjection of spent geothermal water has no influence on surficial subsidence but will aid in the recharge of a geothermal convection system.

The principal cause of future subsidence problems in the East Mesa area will be related to the proposed lining of the All American and East Highline Canals. This will eliminate leakage into the unconfined groundwater reservoir and perhaps initiate minor subsidence problems.

Induced Seismic Activity:

Macroseismic activity (earthquakes greater than Richter magnitude 3.0) has never been attributed to the production of geothermal fluid or petroleum but reports of microearthquake activity abound in the literature. Perhaps all geothermal areas are associated with faults and the convective cell theory requires fault induced fractures for its operation. Hence, microseismic activity is not unexpected. The Hubbert-Rubey effective stress concept proposes that earthquakes are initiated by increased pore pressure, therefore, the removal of fluids from deep geothermal reservoirs may serve to inhibit macroearthquake activity.

Conversely, evidences of macroearthquake activity related to fluid injection are well documented by citing examples occurring at the Rocky Mountain Arsenal near Denver and the Rangely Oil Field in western Colorado (Healy et al, 1968; Raleigh et al, 1976). Never stated are the facts that in both instances very high injection pressures were utilized. In the case of the Rocky Mountain Arsenal high injection pressures were used because of the volume of fluid being injected (the average injection rate was 17 acre-feet of fluid per month for 19 months); at Rangely, the low average porosity and permeability of the Weber sandstone (12% porosity and one md permeability) encouraged high pressure injection of water for secondary recovery purposes. The critical data for earthquakes induced by injection are shown in Table 5. It should be noted that, in both cases, the maximum reservoir pressure due to injection greatly exceeded the least stress for initiating fractures.

The microearthquakes investigated at East Mesa have focal depths ranging from 6,500 to 16,500 feet (Combs et al, 1977, p. 31). In association with almost continuous microseismic activity, these earthquakes are proposed as stress release mechanisms limiting the accumulation of strain at focal depths; hence, they are self-limiting in magnitude.

Finally, low pressure, shallow injection programs into highly porous and permeable strata at the upper limit of a geothermal convection cell are, by definition, incapable of inducing earthquakes ranging in focal depths from 6,500 to 18,000 feet. Some of the injected fluid may migrate into the base of the convection cell but the migration will operate under locally normal pressure-temperature conditions.

TABLE 5
CRITICAL DATA FOR EARTHQUAKES INDUCED BY INJECTION

Data	Rangely	Denver
Reservoir formation	Sandstone	Granite
Depth to injection reservoir	6,200 ft.	12,000 ft.
Average porosity of reservoir	12%	(Fractured)
Average permeability of reservoir	1 md	(Fractured)
Original reservoir pressure	2,465 psi	2,900 psi
Maximum reservoir pressure due to injection	4,205 psi	5,640 psi
Least stress for initiating fractures	3,725 psi	5,200 psi
Maximum magnitude of earthquakes	3.1	5.3
Focal depth of earthquakes	6,550-11,500 feet	14,750-18,000 feet

Sources of data:

1. Healy et al, 1968, pp. 1306-1309.
2. Raleigh et al, 1976, pp. 1233-1235.

SUMMARY

Magma Power Company proposes to inject spent geothermal fluid into a shallow zone present at a depth of 2,240 to 3,100 feet at East Mesa. The preceding sections have discussed the technical, economic, and hazard-reducing features of shallow injection. These data can be summarized as follows:

(1) The injection zone lies on an undulating monocline having an average strike of N 45°W and dip varying from 2° to 4° to the southwest.

(2) The subject geothermal area lies immediately east (approximately 4,400 feet distant) of a large magnitude, right-lateral, strike slip fault having a strike of N 7°W which probably represents the Calipatria Branch of the San Andreas fault (plus a substantial amount of vertical displacement); studies of microearthquake activity and lack of surface definition show that the fault is inactive in the East Mesa Area.

(3) The developed geothermal area is traversed by the seismically active, Mesa fault having a trend of N 58°W with right-lateral, strike-slip movement but no surface or well bore definition; micro-earthquakes to magnitude 2.9 and almost constant nanoearthquake and microseismic activity are believed to be related to verticaly migrating water in a local convective geothermal cell.

(4) Historically, earthquakes with magnitudes greater than 3.0 have never occurred in the East Mesa Area; high temperature gradients associated with the convective geothermal cell limit the onset of larger magnitude earthquakes by containing strain to shallow depths and shallow low pressure injection practices eliminate the possibility of inducing earthquakes such as those at Denver and Rangely.

(5) The injection zone (2,240 to 3,100 feet in Magma-USA 46-7 well) consists of interbedded clay, sand, and silt with a sand-shale ratio of 0.83 (45% unconsolidated sand); there are 389 feet of sand having a permeability value greater than 10 md; the average porosity equals 24.8%, average permeability is 114 md, and the average TDS content is 12,177 ppm; there is 96.4 feet of water-bearing pore space containing 96.4 acre-feet of water having an average temperature of 328°F and the cumulative permeability amounts to 44,567 darcy-feet.

(6) At East Mesa there exists a continuous reduction in porosity and permeability with depth as the result of induration supplied by calcite cement and grain-coatings; the East Mesa producing reservoir zone (5,187 to 7,240 feet in the Magma-USA 44-7 well) contains 750 feet of sand having permeability values greater than 10 md; the average porosity is 21.2%, average permeability is 53 md, and the average TDS content is 6,370 ppm; there are 158.7 feet of water-bearing pore space containing 158.7 acre-feet of water having an average temperature of 370°F and the cumulative permeability equals 39,606 darcy-feet.

(7) Isotope and hydrologic studies show that all subsurface water present in the deltaicly dammed, closed, Imperial-Mexicali Valley basin is Colorado River water; isotope variations correlate with salinity variations wherein the most saline water occurs as formation connate water associated with evaporation stages of a series of late Pliocene-Pleistocene brackish water lakes and the least saline water is related to youthful groundwater recharge by underflow from the Colorado River through gaps in the vicinity of Pilot Knob.

(8) Maximum recharge rates for water derived by underflow from the Colorado River occur in stratigraphic-hydrologic Zones 3 (the injection zone) and Zone 4 (producing reservoir) as a function of porosity, permeability, nonlenticularity of individual sand bodies (high transmissivity), and the hydraulic gradient.

(9) The migration path for injected fluid will follow the normal hydraulic gradient; hence, the major volume of fluid will flow due west parallel to the local structural strike toward the axis of the Imperial Valley basin, a minor volume will spread south and southwest in response to local structural attitudes, and a minor volume will probably enter the deep geothermal convective cell.

(10) Water quality control requirements that necessitate the reinjection of spent geothermal fluids result in predictions of the onset of the following hazards: seepage of injected fluid into the unconfined groundwater zone or to the surface, surficial subsidence, and induced seismic activity.

(11) The production and injection programs proposed by Magma Power Company in the East Mesa Area will have the following effects on these hazards:

(a) The potential surface seepage of injected fluid represents the only real hazard; the following factors combine to negate this hazard:

- High formation transmissivity versus low vertical hydraulic conductivity.
- Insuring that surface injection pressure does not exceed standards set by the Division of Oil and Gas, State of California.
- Temperature differences between injected fluid ($180^{\circ}F$) and injection zone fluids (greater than $300^{\circ}F$) stimulates injection due to the water density factor.

(b) Surficial subsidence is negated because of the following factors:

- High recharge rates due to high transmissivity and hydraulic gradient in the producing zone.
- The shallow injection program.

(c) The seismic hazard is eliminated by interplay of the following factors:

- Minor reduction of pore pressure in the producing zone (probably offset by high temperature recharge from the geothermal convection cell).
- The nature of the injection program and the transmissivity of the zone causes fluids to be spread laterally rather than concentrated locally.

.Elevated temperature gradients limit the accumulation of strain to shallow zones, hence limit the magnitude of potential earthquakes.

CONCLUSIONS

The principal conclusions derived from this study of pertinent geological, physical, and hydrologic parameters related to a shallow injection program in the East Mesa Area tend to demonstrate that the plan is technically and economically sound for the following reasons.

On a one to one basis (one injection well to one producing well), the permeability of the injection zone (cumulative permeability equals 44.557 darcy-feet) relative to that of the producing zone (cumulative permeability equals 39.606 darcy-feet) is so great that there is no argument that the injection of large volumes of fluid can successfully take place.

If spent geothermal fluid is injected directly into the producing reservoir or into superdeep formations below the producing reservoir, premature cooling will serve to destroy a valuable energy resource.

The TDS content of the fluid inhabiting the injection zone is approximately the same as the fluid from the producing zone.

Despite the existence of major strike-slip faults in the Imperial Valley, regional horizontal hydraulic conductivity is high and vertical hydraulic conductivity is very low.

The migration path of injected fluid will conform to the existing direction of flow of groundwater in the East Mesa Area, namely, due west to the axis of the basin and thence northwest toward the Salton Sea.

The only potential environmental hazard relates to surface seepage. This problem is eliminated by insuring that well head injection pressure does not rise above the pressure standard set by the Division of Oil and Gas formula.

From an economic standpoint, a shallow injection program geographically located in the area undergoing geothermal development is preferred to alternate plans because of the following cost-generating factors:

(1) Road net and noncentralized facilities.

(2) Drilling and casing costs.

(3) Length of gathering system and expansion of pumping requirements.

(4) Potential premature cooling of the geothermal reservoir.

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APPENDIX D

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720
Telephone 415/843-2740

January 18, 1978

Mr. Tom Hinrichs
Imperial Magma
Post Office Box 2082
Escondido, California 92025

Dear Tom:

Enclosed is the data from the Paroscientific quartz guages on 48-7 and 46-7. The pumping of 44-7 which began on September 29th at about 1:30 p.m. produced a drawdown in 48-7 as seen in the plot. But there was no corresponding drawdown, buildup at 46-7. Note that the full-scale is 1 psi. The small jump in the 46-7 data on the 28th was not related to the pumping test. This data has not yet been run through our computer program (recall that the rate varied considerably during the test). Finally, it should be clear that although communication is absent for this short test, it may appear during injection over an extended period into the shallow zone.

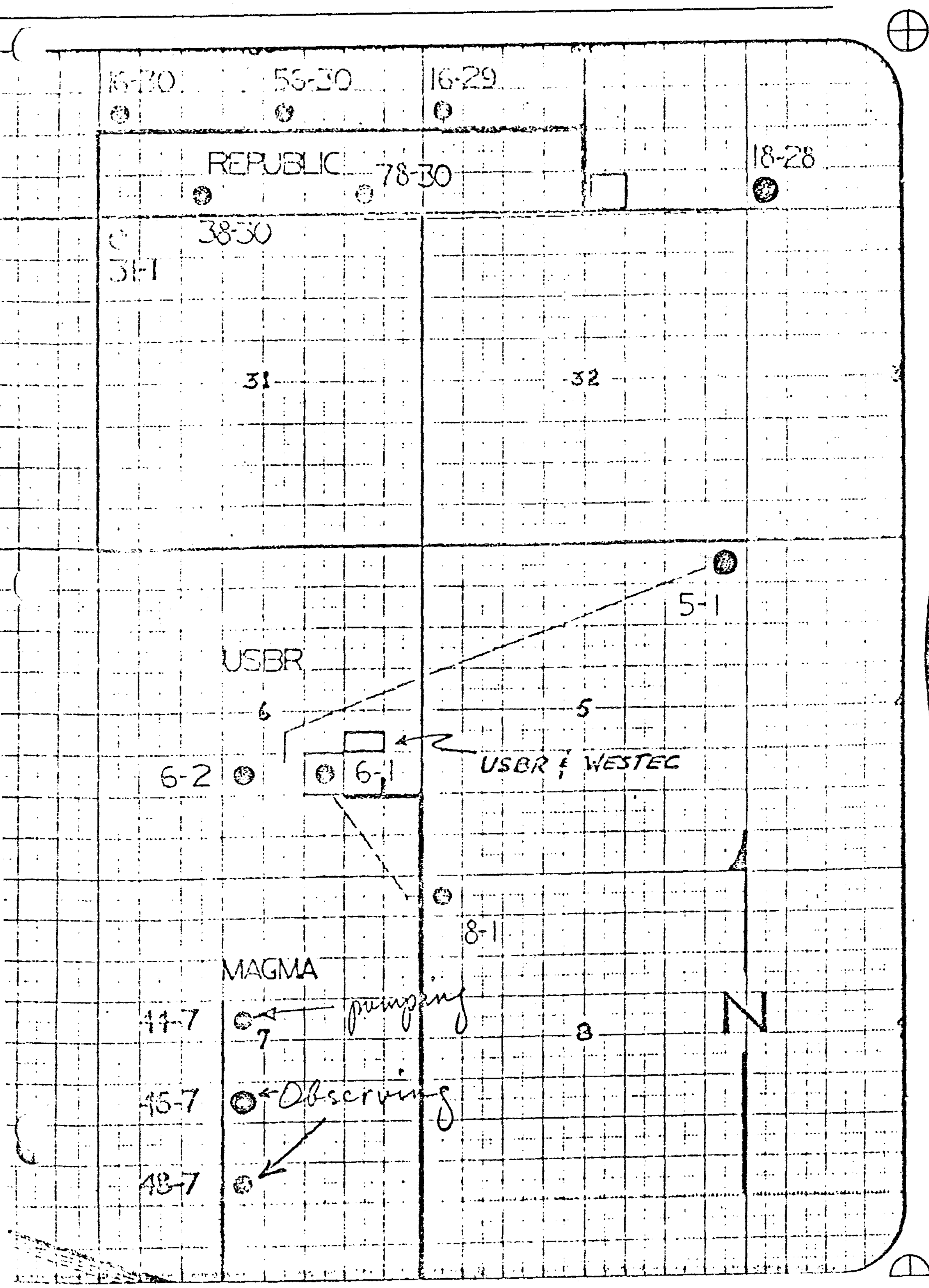
Our final analysis will be complete soon and I'll send you the results at once.

Yours truly,

Ron Schroeder

Ron Schroeder

RS/lta



16-30
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USBR
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USBR & WESTEC
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MAGMA
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pumping
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48-7

APERTURE)

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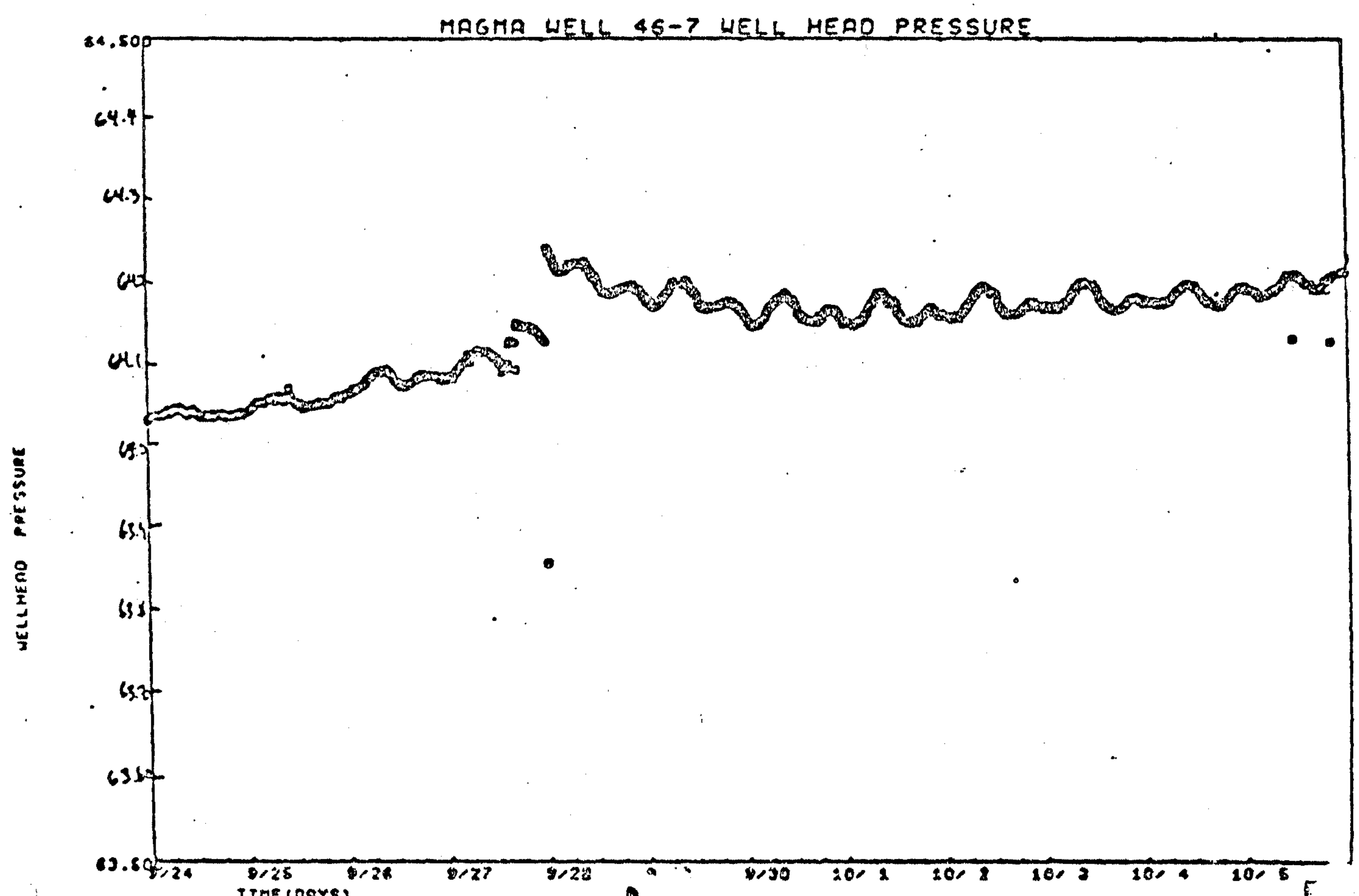

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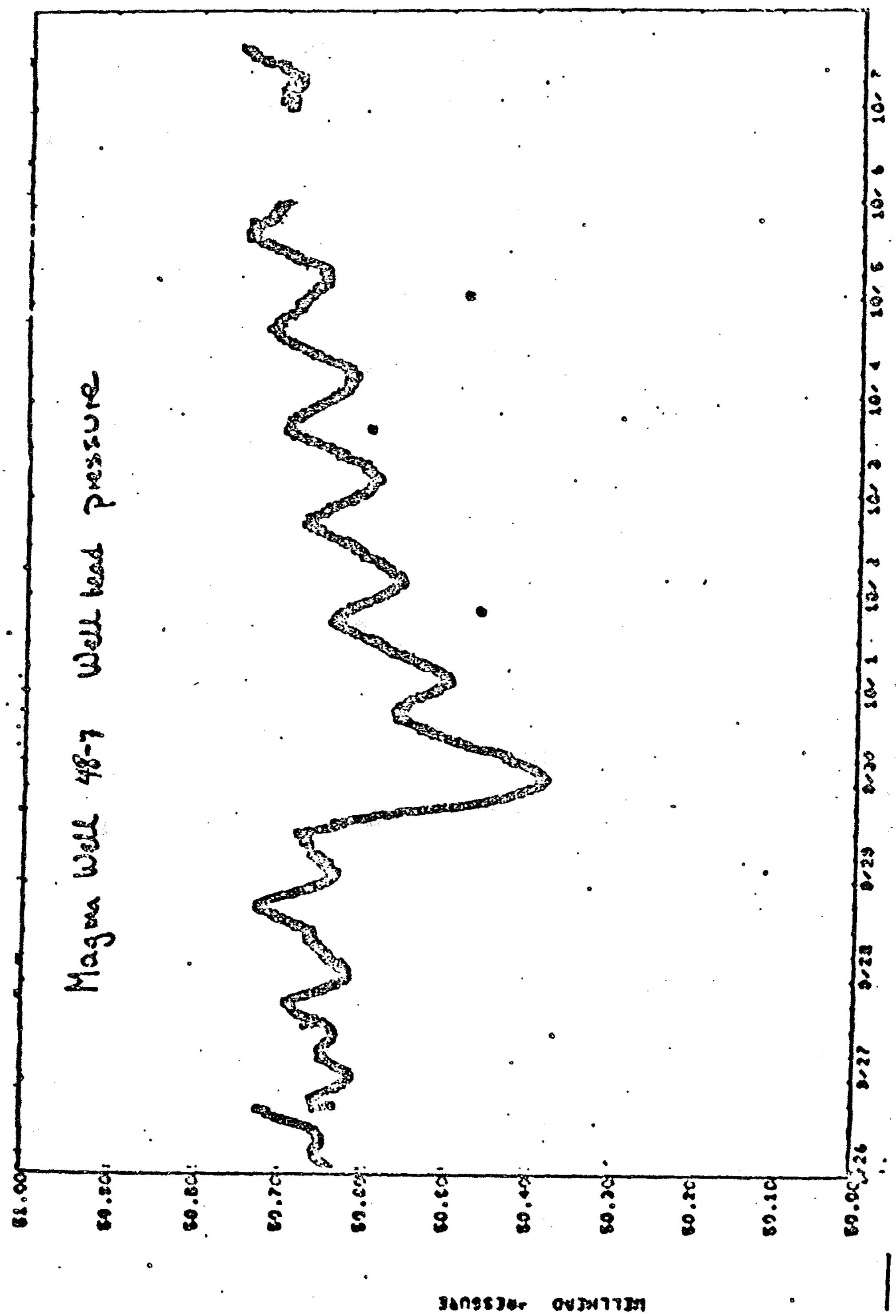

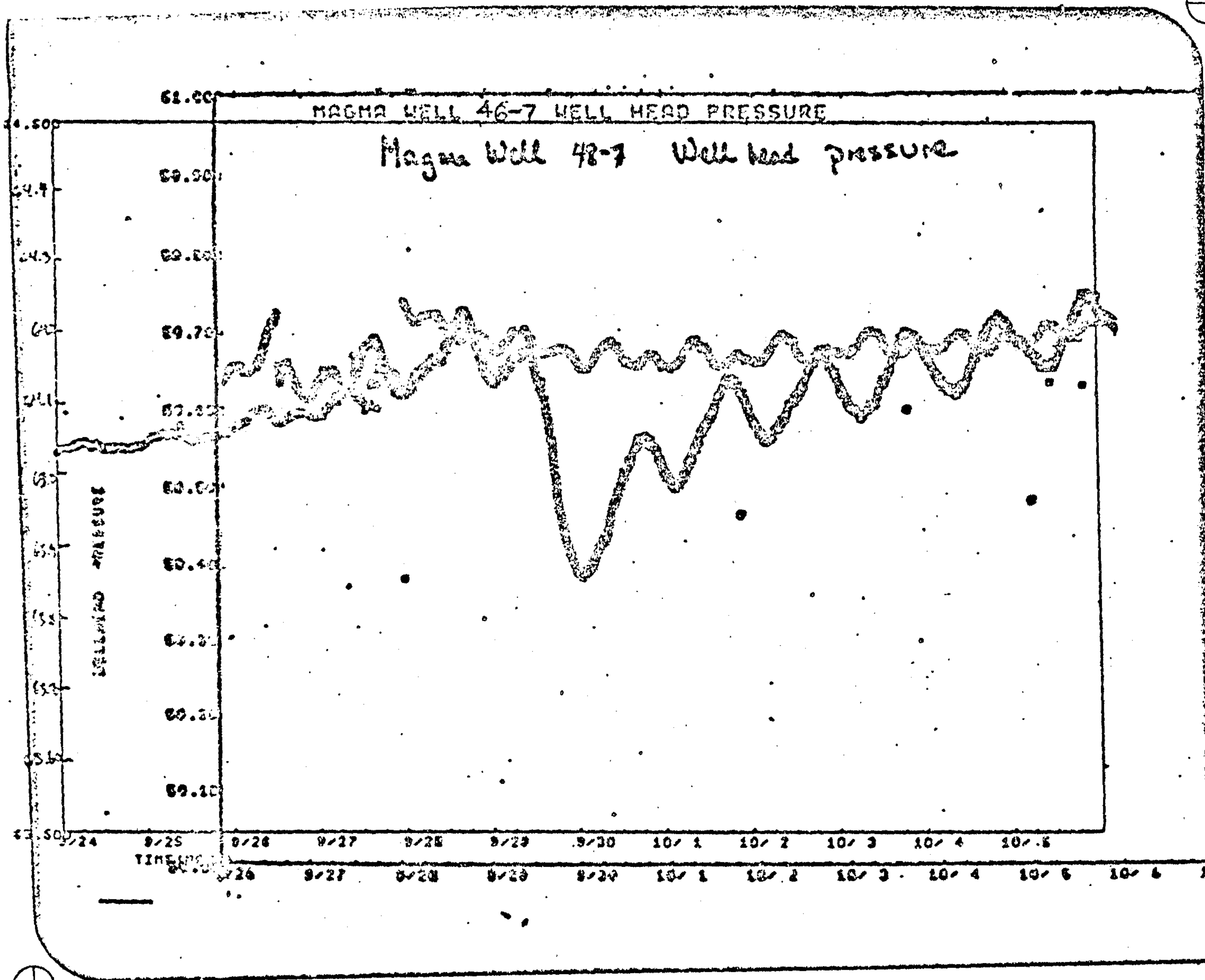
MAGMA WELL 46-7 WELL HEAD PRESSURE
Magma Well 48-7 Well head pressure
WELLHEAD PRESSURE
TIME
61.00
60.90
60.80
60.70
60.40
60.10
9/24
9/25
9/26
9/27
9/28
9/29
9/30
10/ 1
10/ 2
10/ 3
10/ 4
10/ 5
10/ 6

APPENDIX E

APPENDIX F

PRODUCTION ZONE

GHT LABORATORIES OF IMPERIAL VALLEY, INC
116 SO 5th STREET BRAWLEY CALIFORNIA 92227
344-2532

LABORATORY NO.	D 10958	REPORTED	3-24-78
FOR	Imperial Magma	SAMPLED	
SAMPLE	Brines (2)	RECEIVED	3-10-78
IDENTIFICATION	#1) 1A - 2-18-78 44-7 595 ml, 900 g.p.m. #2) 2 - U.S. Magma 44-7 340 p.s.i., 355° F, 458.5 g.p.m.		

Based on sample --- drawn by this laboratory ☐

delivered to us . . . ☒

RESULTS OF ANALYSIS

See Attached Sheet.

GHT LABORATORIES OF IMPERIAL VALLEY

Robert A. Reynolds

ROBERT A. REYNOLDS

GHT LABORATORIES OF IMPERIAL VALLEY, INC.
106 SO. 8th STREET, BRAWLEY, CALIFORNIA 92227
344-2532

D 10958 3-24-78

Imperial Magma

Brines (2) 3-10-78

#1) 1A - 2-18-78 44-7
595 ml, 900 g.p.m.
#2) 2 - U.S. Magma 44-7
340 p.s.i., 355° F.
458.5 g.p.m.

	#1	#2
LITHIUM (Li)	9.3 Mg/L	9.7 Mg/L
SODIUM (Na)	2845 Mg/L	2881 Mg/L
POTASSIUM (K)	285 Mg/L	315 Mg/L
CALCIUM (Ca)	71 Mg/L	90 Mg/L
MAGNESIUM (Mg)	1.4 Mg/L	1.6 Mg/L
STRONTIUM (Sr)	12.8 Mg/L	12.2 Mg/L
BARIUM (Ba)	Trace 1.2 Mg/L	Trace 0.7 Mg/L
CHROMIUM (Cr)	Trace 0.3 Mg/L	N.D. < 0.3 Mg/L
MANGANESE (Mn)	1.92 Mg/L	4.2 Mg/L
IRON (Fe)	25 Mg/L	9.3 Mg/L
COBALT (Co)	N.D.<0.04 Mg/L	N.D. < 0.04 Mg/L
NICKEL (Ni)	4.6 Mg/L	2.1 Mg/L
COPPER (Cu)	0.05 Mg/L	0.03 Mg/L
ZINC (Zn)	0.23 Mg/L	0.36 Mg/L
SILVER (Ag)	Trace 0.02 Mg/L	Trace 0.02 Mg/L
GOLD (Au)	N.D. <0.09 Mg/L	N.D. <0.09 Mg/L
CADMIUM (Cd)	TRACE 0.004 Mg/L	N.D. <0.004 Mg/L
MERCURY (Hg)	0.011 Mg/L	0.012 Mg/L
BORON (B)	7.5 Mg/L	7.7 Mg/L
ALUMINUM (Al)	Trace 0.3 Mg/L	N.D. < 0.2 Mg/L
SILICA (SiO_2)	257 Mg/L	261 Mg/L
LEAD (Pb)	Trace 0.05 Mg/L	Trace 0.03 Mg/L
ARSENIC (As)	.158 Mg/L	.255 Mg/L
ANTIMONY (Sb)	N.D. < 0.05 Mg/L	N.D.< 0.05 Mg/L
BISMUTH (Bi)	0.036 Mg/L	N.D.< 0.010 Mg/L

Robert A. Reynolds

GHT LABORATORIES OF IMPERIAL VALLEY, INC.
1?5 SO 8th STREET, BRAWLEY, CALIFORNIA 92227
344-2532

D 10958 3-24-78

Imperial Magma

Brines (2) 3-10-78

	#1	#2
TOTAL SULFUR (S)	22 Mg/L	27 Mg/L
SELENIUM (Se)	N.D.<0.05 Mg/L	N.D.<0.05 Mg/L
FLUORIDE (F)	2.78 Mg/L	3.00 Mg/L
CHLORIDE (Cl)	4310 Mg/L	4290 Mg/L
BROMIDE (Br) IODIDE (I)	NOT ENOUGH SAMPLE	
SULFATE (SO_4	64 Mg/L	79 Mg/L
BICARBONATES (HCO_3)	519 Mg/L	539 Mg/L
pH	5.8	6.1
TOTAL DISSOLVED SOLIDS	8170 Mg/L	8040 Mg/L
SPECIFIC CONDUCTANCE (MICROMHOS/CM)	15,900	15.7
AMMONIA (NH_3)	18.0 Mg/L	20.6 Mg/L

Robert A. Reynolds

ROBERT A. REYNOLDS

INJECTION ZONE

GHT LABORATORIES OF IMPERIAL VALLEY, INC.
[illegible] STREET BRAWLEY CALIFORNIA [illegible]
344-2532

LABORATORY NO.	D 8533	REPORTED	3-3-77
FOR	[illegible]	SAMPLED	
SAMPLE	BRINES (2)	RECEIVED	2-17-77
IDENTIFICATION	1 2 WELL #46-7		

Based on sample --- drawn by this laboratory ☐

delivered to us . . . ☒

RESULTS OF ANALYSIS

SEE ATTACHED SHEET

GHT LABORATORIES OF IMPERIAL VALLEY

Robert A. Reynolds

ROBERT A. REYNOLDS

4

.GHT LABORATORIES OF IMPERIAL VALLEY, INC.
1?? SO. ?th STREET, BRAWLEY, CALIFORNIA 92227
344-2532

D 8533 REPORTED: 3-3-77

MAGMA POWER

BRINES (2) RECEIVED: 2-17-77

1
2

ALL REPORTED IN MG/L	1	2
pH	8.3	8.5
TOTAL DISSOLVED SOLIDS	12,080	12,200
CALCIUM (Ca)	64	58
SILICA (Si)	144	130
BORON (B)	6.50	6.75
CHLORIDE (Cl)	6,810	6,645
IRON (Fe)	0.11	0.14
POTASSIUM (K)	150	150
LITHIUM (Li)	6.1	6.2
MANGANESE (Mn)	ND<0.10	ND<0.10
SODIUM (Na)	4,800	4,900
AMMONIA (NH4)	ND<0.5	ND<0.5
SULFUR (S)	ND<0.05	ND<0.05
STRONTIUM (Sr)	13.6	14.2
BARIUM (Ba)	1.25	1.41
CARBONATES (CO3)	31	37
BICARBONATES (HCO3)	370	358
SULFATE (SO4)	147	177

Robert A. Reynolds
ROBERT A. REYNOLDS

5

APPENDIX G

APPENDIX H

GROUNDWATER STUDY

MAGMA ELECTRIC COMPANY

EAST MESA PROJECT SITE

IMPERIAL COUNTY, CALIFORNIA

TABLE OF CONTENTS

Page

..TERIALS ENGINEERING
..ED SOIL MECHANICS
..CULTURAL INVESTIGATIONS
..ING AND HYDROLOGY

760 N. FOURTH STREET
TELEPHONE: 352-2518
MAIL: P. O. Box 642

ESTABLISHED: 1953

John D. Hess Testing Corporation

ENGINEERS • GEOLOGISTS • CHEMISTS
EL CENTRO, CALIFORNIA 92243

AMERICAN SOCIETY OF CIVIL ENGINEERS
AMERICAN SOCIETY FOR TESTING & MATERIALS
AMERICAN CONCRETE INSTITUTE
INTERNATIONAL SOCIETY OF ROCK MECHANICS
ASSOCIATION OF ENGINEERING GEOLOGISTS
INTERNATIONAL SOCIETY OF SOIL MECHANICS & FOUNDATION ENGINEERS
AMERICAN SOCIETY OF AGRICULTURAL ENGINEERS

November 9, 1977

Mr. Tom Hinrichs
Magma Electric Company
P. O. Box 2082
Escondido, CA 92025

Subject: Groundwater Study, East Mesa Project Site, Imperial County, California, Our Lab. No. 12575

Dear Tom:

Transmitted herewith is our report covering a groundwater study of your East Mesa site.

Recommendations are made pertinent to stability and seepage control, employing clay, plastic type membrane and soil cement linings.

Yours truly,

JOHN D. HESS TESTING CORPORATION

REGISTERED GEOLOGIST
JOHN DAWSON HESS
NO. 1703
EG-544
STATE OF CALIFORNIA

John D. Hess
Registered Engineering Geologist, EG-544
Engineering Geologist, 1706

Harry E. Putman
Registered Civil Engineer, CE-10156

mh

1. LOCATION

The proposed project will occupy a portion of the south 1/2 of section 7, T. 16 S., R. 17 E., S.B.B.M. and section 12, T. 16 S., R. 16 E. (Imperial County). The main plant portion of the project, however, will occupy a portion of section 7.

2. SITE CONDITIONS

The project site is typical of desert sandy arid topography, of low to moderate dune relief with numerous sand hummocks or low hills scattered throughout the area. Due to the close proximity of the water table (less than 10 feet in most instances), a considerable amount of greasewood and mesquite brush occurs throughout the area. At the present time, one unpaved service road extends north to the area from old Highway 80.

3. PROJECT DESCRIPTION

The project is designed to use geothermal energy in the generation of electrical power. The design net generating capacity will be approximately 10,000 kilowatts.

Physical features will include three lined water reservoirs with a total storage capacity of 100 million gallons, three production wells, two injection wells, heat exchangers, turbine generator, pumps, and condensers. An equipment and operational metal structure will be constructed.

4. BACKGROUND OF INVESTIGATOR

The following is a brief summary of the educational and working experience of the investigator insofar as groundwater hydrology studies are concerned.

Undergraduate and Graduate:

A. Education in the field of geology, engineering geology, and civil engineering. Majored in groundwater.

B. Employed by the U. S. Bureau of Reclamation, 1950 - 1951, as a geologist with the hydrology section, San Joaquin Valley District. Assisted in the collection of hydrological data for the design of the San Luis West Side Project. Prepared maps dealing with geochemistry of groundwater.

C. Research engineer for the Imperial Irrigation District, 1951 - 1953. In charge of groundwater hydrology studies, drainage investigations, laboratories, drill crews, etc. Prepared reports dealing with East Mesa groundwater conditions with particular reference to seepage from the All American and Coachella Canals. Completed extensive studies on groundwater geochemistry, tracing origin, and movement of waters. Published reports.

D. President, John D. Hess Testing Corporation, 1953 to the present. The firm has undertaken and completed numerous groundwater, drainage, and canal seepage studies for the local municipal governments, farmers, landowners, etc. Hydrological studies have also been undertaken for several foreign countries, both on this continent and in the Middle East.

5. GROUNDWATER CONSIDERATIONS

A. General History and Hydrological Background

There have been several published reports prepared covering East Mesa groundwater conditions. The reader is referred to the Appendix Section of this report for a list of major references cited.

The All American Canal was completed in 1942. By 1948, the Coachella Canal had also been completed. Both of these canals are presently unlined and were dug in "clean" sandy highly permeable type soils.

The completion of the All American Canal, which permitted the diversion of Colorado River water to Imperial Valley by an All American route rather than through Mexicali Valley by the Alamo Canal, greatly increased the opportunity for recharge to the groundwater system. In February, 1942, the All American Canal became the sole means for diverting Colorado River water to the Imperial Valley. Six years later, the Coachella Canal was completed and thereafter supplied water to the lower part of Coachella Valley.

The canals are major sources of recharge because (1) they are unlined; (2) they are as much as 200 feet wide; (3) they flow across many miles of sandy terrain, especially in the eastern part of Imperial Valley; and (4) the water surface in the canals is much higher than the general groundwater levels along their alignment. In the Sand Hills area of the East Mesa, the stage of the All American Canal is about 80 feet above precanal groundwater levels; the difference between precanal levels and canal stage is similar at the head of the Coachella Canal and northward.

The rate of leakage of water from these canals cannot be determined precisely. However, the records of measured canal flows corrected for diversions and evaporation losses give a rough estimate of the rates of leakage. In 1948, the Imperial Irrigation District assumed responsibility for operation of the All American Canal and the upper 50 miles of the Coachella Canal; since that time, the canal flow, diversions, and evaporation losses have been recorded. Water losses in selected reaches of the All American Canal and the upper end of the Coachella Canal has been compiled by the Imperial Irrigation District.

Errors in measurement probably account for a large part of the annual variations in the leakage rates. The plotted values are residual differences in canal flow in the reaches and, therefore, include the net effect of any errors in measurement. The annual flows in the upper end of the All American Canal generally are three to four million acre-feet, and at the head of the Coachella Canal, they are about 0.5 million acre-feet. A small percentage of error in flow measurement, therefore, can account for much of the year-to-year variations in computed rates of leakage.

The total quantity of leakage from the All American Canal between Pilot Knob and the East Highline Canal and from the Coachella Canal in the reach above the 6A check can be estimated as follows. The average annual rate of leakage from the All American Canal from 1941, when the canal was first used for conveying large flows to Imperial Valley, to 1950 probably was about the same as the average annual rates for the first three years. The rates were about 90,000 acre-feet per year for the reach Pilot Knob to Drop 1 and about 130,000 acre-feet per year for the reach Drop 1 to East Highline Canal, or a total of about 220,000 acre-feet per year. From 1950 to 1967, the leakage from the two reaches was about 140,000 acre-feet per year. Through 1967, therefore, the total leakage from the All American Canal between Pilot Knob and East Highline Canal was nearly 4.5 million acre-feet. The leakage from the Coachella Canal in the reach above the 6A check averaged nearly 150,000 acre-feet per year; thus, from 1950, when the canal was first used to near capacity, through 1967, leakage amounted to about 2.7 million acre-feet. The groundwater recharge to the East Mesa as a result of leakage from these canals thus was about seven million acre-feet through 1967.

The leakage caused groundwater ridges to form beneath the canals almost immediately, and in time, the tops of the ridges intercepted the canals. The leakage also spread horizontally, thereby causing water levels over large areas to rise many tens of feet. Eventually, much of the recharge due to the leakage, especially from the All American Canal caused additional discharge to drains and areas of natural discharge, rather than continuing to add to the quantity of groundwater stored in the system.

Along the All American Canal, the water-level rise generally was more than 40 feet, and along the Coachella Canal, it was about 40 feet near the head of the canal and gradually increased northward to more than 70 feet. Throughout most of the length of the East Highline Canal, the change in groundwater levels was small.

In 1948, the Imperial Irrigation District initiated an observation well installation program. Hundreds of 1½ to 2-inch diameter, galvanized pipes were installed at selected locations throughout irrigated portions of the Valley as well as the East Mesa, Bard, and Winterhaven areas. Wells were hand dug with augers or advanced by air jetting; the latter method being used throughout the East Mesa. Total depths of wells varied depending upon depth to groundwater or zone of saturation.

Groundwater levels were monitored by a regular staff of well readers. For a great many years, depth to water readings were made every three months. Hydrological data was tabulated and plotted on profile grids.

In 1952, an extensive report was prepared by the writer dealing with canal seepage and hydrological conditions throughout the East Mesa.

The Soil Conservation Service also carried on extensive hydrological investigations throughout Imperial County between the years 1948 and 1952. Some of the data considered in the preparation of this report was developed by the SCS.

There is no secret to the fact that shallow groundwater conditions which presently prevail throughout the East Mesa are due to seepage from the All American and Coachella Canals. A profuse amount of hydrological data supports this conclusion.

Studies show that once water was placed in the two arterial canals (1942 and 1948), seepage commenced and a large groundwater wave or ridge gradually moved outward from the canals. By far, the Coachella Canal appears to have played the greater part in rising groundwater conditions throughout the entire East Mesa.

Flood and sprinkler irrigation have resulted in the development of significant groundwater mounds underlying the East Mesa experimental farms.

Seepage through porous soils can be reduced through the development of biological gums and seals. This "false" lining condition has developed along the entire reaches of both canals. The extent that the biological process plays in the reduction of seepage has never been established, however, it was clearly brought to light that chain dragging of a section of the All American Canal to remove extensive growth, not only eliminated the growth, but also permitted adjacent groundwater levels to rise sharply. Since that time, canal clearing operations have been limited to superficial cleaning programs, leaving the soil and interfaced organic matter untouched as much as possible. The writer estimates that a 25 percent reduction in seepage due to gum seal development, can occur within five years after canal or reservoir completion. This value is thought to be conservative.

B. Present Groundwater Conditions

Groundwater gradients have become sufficiently steep that seepage mounds have travelled with fairly rapid progress across the eastern two-thirds of the East Mesa. In the northern portion of the Mesa, seepage waters have ponded or become perched on a shallow clay horizon which is superimposed by sand. Throughout the southern half of the Mesa, the thick clay layer is not present and, therefore, this perched condition does not exist.

Depths to groundwater throughout the project site vary, depending upon the topographic relief. For the most part, however, depths vary from three to eleven feet. At the present time, the groundwater elevation lies at approximately elevation 20. Groundwater levels fluctuate a certain amount, especially in those areas adjacent to the canals. As a general rule, high groundwater levels occur during the winter months or during the time when canal is at its low flow. This points to the fact that there is a 6-month time lag between canal to groundwater high levels. Within the study area, however, observation data collected over the past 28 years shows a maximum rise in groundwater level of seven feet (1948 - 1976).

Groundwater profiles indicate that seepage from the arterial canals have played a major, if not a total part, in the rise of groundwater levels throughout the East Mesa. Seepage has simply developed a steep groundwater wave which has gradually migrated toward the East Highline Canal. As can be seen by the profile sheets, groundwater gradients are steep until they approach the western portion of the East Mesa, or near the East Highline Canal.

Due to decrease in groundwater gradients near the East Highline Canal, flattening of surface/ground slope, hydraulic head superimposed by the East Highline Canal, as well as the abrupt change in horizontal permeability due to aerial changes in soil texture, groundwater has become somewhat ponded and stagnated behind the East Highline Canal. Indications are that evapotranspiration, and other losses are about equal to input to the point where further groundwater rise will not likely occur. Chemical analyses indicate that the water is not of Colorado River origin, or if it is canal water originally, it is canal water which has been modified due to mixing or concentration.

The East Highline Canal marks the eastern border of agricultural lands in the Imperial Valley. It also separates the agricultural soils from cohesionless sands and gravels which occur throughout the East Mesa.

The Soil Conservation Service conducted a study over the period 1948 to 1950 to evaluate various methods of estimating the amount of canal seepage occurring within a given reach of a canal system. Piezometers were installed in and adjacent to a number of canals, one of which was the East Highline Canal. Results of the East Highline Canal piezometer studies indicated that flow line gradients were away from the canal to the west and east indicating water loss to the underlying sediments and parent groundwater. The studies further indicated that the greatest volume of seepage was down gradient or to the west.

Very recent test drilling along a line west of the Magma facility, beginning from a point 270 feet west of the East Highline Canal and extending 1.5 miles to the west, indicated that the soils vary between sand, sandy loam, sandy clay, silty sand, and clay. Depths to groundwater or zone of saturation along this east-west line varies from 9½ to 11 feet, which is typical of most areas throughout the Valley.

Electrical conductance measurements were made on water secured from each of the four test borings. The results are:

Location	Distance from EHL	Conductance, $K \times 10^6$	TSS, Ppm
Sta. 1	270 Feet	1568	1004
Sta. 2	0.5 Miles	1848	1183
Sta. 3	1.0 Miles	4500	2880
Sta. 4	1.5 Miles	5448	3486
Colorado River Water			850

From the above data, there is little reason to doubt that the East Highline Canal is contributing seepage water and diluting the underlying saline parent groundwaters. Although the soils are lighter in texture throughout this area of the Valley than the heavier clayey type soils elsewhere, nevertheless, the dilution is quite evident and apparent.

Tile drainage grid systems have been installed in most of the cultivated fields immediately to the west of the project site and the East Highline Canal. These tile systems are designed to maintain a satisfactory groundwater level, and to maintain an ever improving salt balance within the soil profile. As a general rule, tile grid systems are more effective in the lighter type soils, the type which exists throughout the area immediately west of the Magma project.

Seepage from the East Highline Canal gradually results in the development of a very shallow mounding water table condition to the west of the canal. Although many of the cultivated fields west of the canal have conventional tile grids installed at six-foot depths, nevertheless, this did not alleviate the high shallow groundwater conditions which resulted due to canal seepage. It was not until the installation of an interceptor drain that effective lowering of the water table occurred throughout areas west of the EHL.

In 1968, the Imperial Irrigation District installed approximately 10,000 linear feet of 14 through 24-inch diameter tongue and groove concrete pipe with gravel envelope along a line paralleling the west edge of the East Highline Canal. At various locations along the drain line, pump sumps have been installed to recover seepage water and return it to the East Highline Canal. The length of interceptor drain adjacent to the study area consists of approximately 993 feet of 14-inch and 145 feet of 16-inch lines (1150 feet nominal).

Discharge at sump DP-21 (west of project area) was metered at 865 acre-feet for the year 1976. Average daily flow has been established at 730 GPM from this sump. Depth of drain installation is eight feet below the natural surface.

Interceptor drain water quality tests, made at various times by the Imperial Irrigation District, show an average total soluble salt content of 982 parts per million or 1.34 tons/acre foot (Colorado River water T.S.S. approximately 810 Ppm). The slight excess salinity over and above the Colorado River water value is probably due to salts leached from the soil profile or water contribution from the underlying more saline parent groundwater.

Groundwater quality has been considered within the area to be developed as well as any possible changes in quality which might occur due to seepage from the reservoirs. To begin with, the quality of the upper groundwater zone is very poor insofar as industrial, agricultural, or potable uses are concerned. The total soluble salts exceed 4700 parts per million. The water is high in percent sodium, boron, fluoride, and falls into the sodium chloride class type water (AAC water is calcium sulfate type water).

Water quality studies conducted a number of years indicate that the upper shallow groundwater is very saline to brackish throughout many areas of the East Mesa, especially the central sections of the Mesa lying between the Coachella and East Highline Canals. Periodic sampling and tests have shown that as the groundwater mound encroaches westward, there is a dilution of the brackish-saline waters. It is suspected that the brackish salts were derived due to dilution or resolution of evaporate salts incorporated within old clay lake beds. To the south, near the All American Canal, as well as the southeast portion of the Mesa, the thick clay bed is absent. Deep wells drilled near the All American Canal reveal an abundance of excellent quality fresh water. The source is believed to be from early Colorado River overflows into the area. Chemical quality, in some instances, exceeds the present quality of All American Canal (Colorado River) water (450 to 600 Ppm TSS).

The high salinity of the groundwaters in the southwest section of the Mesa as well as the areas abutting against the East Highline Canal is probably due to a combination of events, which are: (1) saline parent water, (2) concentration due to evapotranspiration, (3) mixing of saline parent water with canal water, or (4) a combination of the foregoing.

The three project reservoirs will be designed and lined for minimum seepage. Permeability tests conducted on soil cement specimens as well as native clay type soils from nearby clay pits indicate that the total seepage from the reservoirs can be kept to well within 58,000 gallons per day or less. The design thickness (soil cement and clay) required to obtain this minimum loss value were based upon laboratory permeability tests. Should a butyl rubber lining be used, then, of course, seepage would be essentially nil.

6. POST GEOTHERMAL PLANT CONSIDERATIONS

Some concern has been voiced concerning what effect any post construction reservoir seepage will have on parent groundwater elevations and water quality, not only in the immediate vicinity of the plant but also, down gradient and beyond the west edge of the East Highline Canal.

Tests have established that the quality of the groundwater in the vicinity of the proposed plant site is poor and unacceptable insofar as any agricultural or industrial uses are concerned. Therefore, a "designed" or calculated seepage to the parent groundwater (Colorado River water) will do nothing more, from a chemical standpoint, than dilute the total soluble salts and make the water more acceptable.

Recent tests covering the salinity content of the shallow groundwaters within the construction area shows a T.S.S. content of approximately 4700 Ppm. Tests conducted on recovered groundwater samples during the period 1951 through 1952 show the following total soluble salts in tons/acre-foot (1.0 TAF = 735 Ppm).

Well Location	TAF, 1951 - 1952
SW Corner Sec. 7 (Magma site section)	5.41
SE Corner Sec. 7	12.12
NE Corner Sec. 7	12.56
NW Corner Sec. 7	19.00
W¼ Corner Sec. 6 (North of Magma site section)	13.55
Center Sec. 6	13.90
Center Sec. 6	24.05
E¼ Corner Sec. 6	5.11
E¼ Corner Sec. 6 (250' west)	6.31

Further, tests made by the Soil Conservation Service in 1947 showed boron and fluoride values both of high magnitude, and unfit for agricultural or potable uses. Boron values have been found as high as 5 Ppm with fluoride values running as high as 1.15 Ppm

Geochemical plotting of water analyses information indicates that a small quantity of East Mesa parent groundwater presently migrates down gradient and into the cultivated portions of the Valley. However, due to abrupt change in soil permeability and transmissibility, location of interceptor drain, changes in surface slope, as well as the magnitude of hydraulic head imposed by the East Highline Canal, it is considered unlikely that the small contribution added by seepage from the reservoirs will do much more than have only a local effect on the groundwater quality and will not induce any significant effect on the potential groundwater elevations in the cultivated areas west of the East Highline Canal. It is thought that, should any seepage water reach the EHL, this volume would be passed to the deep interceptor drain which parallels the EHL. That water which escapes the interceptor conduit will be totally or partially intercepted by the deep warren drain which also parallels the EHL west bank.

The final selection of a lining material is not within the scope of this report. However, due to the high permeability rate of the raw soil (one percent of reservoir volume/day), some type of a suitable lining will be needed.

Originally, soil cement and clay reservoir linings were considered for minimum seepage. By using a thick step plate lining of soil cement, seepage could be limited to approximately 58,000 gallons per day.

Consideration has been given to permit the reservoirs to seep in a volume required for make up water addition to maintain a given level of salinity. The amount of seepage or make up volume was computed in the order of 400,000 gallons per day. This volume of seepage to the shallow underlying water table will place the entire project in jeopardy. In fact, within a very short period of time, surface water would appear with the result that the structural integrity of the project would be in question (shallow bearing foundations, etc.). Therefore, this approach for salt balance control is not recommended.

A loss of 58,000 gallons per day would dissipate without harmful effects or ponding.

A butyl rubber lining, of course, would keep seepage to essentially zero. Butyl is a tough, thick rubbery material which is basically aquatic plant puncture proof and will not deteriorate due to sunlight or ultraviolet expo-sures.

APPENDIX

AND

SUPPORTING DATA

SELECTED LIST OF REFERENCES CITED

1. "Plants as Indicators of Groundwater", U.S.G.S. Water Supply Paper No. 577, 1927.

2. "Imperial East Mesa Groundwater Studies, 1947 to 1952", Unpublished report for IID prepared by John D. Hess, Research Engineer.

3. "Geohydrologic Reconnaissance of the Imperial Valley, California", U.S.G.S. Prof. Paper 486-K, 1975.

IID EAST MESA GROUNDWATER OBSERVATION WELL HYDROLOGY DATA

IID Well No.	Record Length	Depth to Water Surface Last Reading	Change in Water Surface Elevation, Total Record Period
6612	1948 - 1973	7.43 Feet	+1.70' Change
6601	1948 - 1968	1.27 Feet	+1.27' Change
5636	1948 - 1972	7.97 Feet	+7.10' Change
5625	1948 - 1973	12.13 Feet	+6.90' Change
6707	1949 - 1976	9.16 Feet	+5.80' Change
6706	1948 - 1962	30.42 Feet	+2.40' Change
5731	1948 - 1973	31.33 Feet	+6.20' Change
5730	1949 - 1976	29.74 Feet	+5.90' Change

LOG OF WELLS

IID Well No.	Depth	Lithology - Log
5730	0 - 30'	Sand
	30 - 32'	Clay
	32 - 40'	Sand & gravel
5731	0 - 30'	Sand
	30 - 31'	Clay
	31 - 40'	Sand
6706	0 - 26'	Sand
	26 - 40'	Clay
6707	0 - 28'	Sand
5625	0 - 16'	Sand
	16 - 24'	Clay
	24 - 30'	Sand
5636	0 - 10'	Sand
	10 - 11'	Clay
	11 - 20'	Sand
6601	0 - 5'	Clay
	5 - 10'	Sand
6612	0 - 16'	Sand
	16 - 20'	Clay

Wells installed by IID during period of 1948 - 1949. Installation by air jetting method. $2\frac{1}{2}$" steel pipe installed and bottom 10' perforated.

LOG OF SOIL PROFILE

TEST BORING NO. 1 LOCATION 60' S of Pear Canal (concrete lined) & approx. 27
W of EHL Canal west bank.

WATER TABLE 9 FT. INITIAL 9 FT. approximately two hours later.

DEPTH FEET FROM	DEPTH FEET TO	% FIELD MOISTURE	DESCRIPTION	STANDA[RD] PENETRAT[ION] BLOWS/F[T]
0	2½		Moist, sandy loam. The surface is covered with an alfalfa crop.	
2½	5½		Moist, sandy loam with silt and clay stratas.	
5½	9½		Moist, medium fine to coarse sand with a small amount of gravel to 3/4" dia. Wet to saturated sand at 9½'.	
9½	14		Saturated, medium fine sand.	
			Water level at 9' at the end of drilling, augers removed, and at 9' approximately two hours later.	
			EC Recovered Water: 1568.18 millimhos EC X 10^6 @ 25°C. Total Soluble Salts: 1004 Ppm.	

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LOG OF SOIL PROFILE

Test Boring No. 2 Location 50' N of Pear Canal (concrete lined) & ¼ mile W of EHL Canal.

Water Table 10½ Ft. Initial 6½ Ft. approximately 1½ hours later.

Depth, Feet From	To	% Field Moisture	Description	Standard Penetration Blows/Ft.
0	3		Moist, sandy loam. The surface is covered with an alfalfa crop.	
3	7		Moist/wet sandy loam with numerous sandy clay layers. Wet/saturated zone at 6 - 7'.	
7	10		Wet, sandy clay with fine sand lenses.	
15	16		Wet/saturated fine silty sand with several thin sandy clay lenses.	
			Water level at 10½' at the end of drilling, augers removed, and at 6½' approximately 1½ hours later (refer to 3 - 7' zone above).	
			EC Recovered Water: 1848.22 millimhos EC X 10^6 @ 25°C Total Soluble Salts: 1183 Ppm.	

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LOG OF SOIL PROFILE

TEST BORING NO. 3 LOCATION 150' S of Pear Canal (unlined) & 1 mile W of EHL

WATER TABLE 11 FT. INITIAL 8½ FT. approximately one hour later.

DEPTH FEET FROM	TO	% FIELD MOISTURE	DESCRIPTION	STANDARD PENETRATION BLOWS/FT
0	4		Moist, sandy loam. The surface is covered with an alfalfa crop.	
4	8		Moist/wet sandy loam with several sandy clay layers.	
8	12		Wet/saturated sandy loam.	
12	14		Wet, stiff clay.	
14	18		Wet/saturated fine silty sand.	

Water level at 11' at the end of drilling, augers removed, and at 8½' approximately one hour later (refer to 8 - 12' zone above).

EC Recovered Water: 4500.05 millimhos EC X 10^6 @ 25°C
Total Soluble Salts: 2880 Ppm.

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LOG OF SOIL PROFILE

TEST BORING NO 4 LOCATION 100' N of Pear Canal (concrete lined) & 1½' W of E

WATER TABLE 11½ FT. INITIAL 8½ FT. approximately ½ hour later.

DEPTH FEET FROM	DEPTH FEET TO	% FIELD MOISTURE	DESCRIPTION	STANDA PENETRAT BLOWS/F
0	4		Moist, sandy loam. The surface is covered with an alfalfa crop.	
4	9		Moist/wet sandy loam.	
9	12½		Wet, saturated sandy loam.	
12½	14		Wet, stiff clay.	
14	18½		Wet, saturated fine silty sand.	
			Water level at 11½' at the end of drilling, augers removed, and at 8½' approximately ½ hour later (refer to 9 - 12½' zone above).	
			EC Recovered Water: 5447.51 millimhos EC X 10^6 @ 25°C Total Soluble Salts: 3486 Ppm.	

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[illegible] Electric Company
East Mesa Project Site
Imperial, California

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John D. Hess Testing Corporation

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[illegible] 9 20-77

MARK: Groundwater shallow test hole @ N. well site. D-W approximately 4.0 feet. Sampled Sept., 1977.

CHEMICAL ANALYSIS OF WATER

	Parts Per Million	Reacting Values Milliequivalents	Character Formula Percent	
[illegible] (Ca)	8.0	0.40	.53	
[illegible] (Mg)	14.6	1.20	1.58	Cations
[illegible] & Potassium (Na)	1700	73.90	96.99	
[illegible]	27	0.69	0.91	100%
[illegible] (HCO3)	171	2.80	3.65	
[illegible] (CO3)	18	0.60	0.78	Anions
[illegible]	638	13.3	17.34	
[illegible] (Cl)	2130	60.0	78.23	100%
[illegible]				
[illegible] (BO_3)				
[illegible] Silica (SiO_2)				
[illegible]				
[illegible]				
[illegible]				
[illegible]				
[illegible] Salts	4731 (from conductance)			
[illegible] AS $CaCO_3$				
[illegible] AS $CaCO_3$				
[illegible] AS $CaCO_3$				
[illegible] M.E.				
[illegible] Phenolphthalein				
[illegible] AS $CaCO_3$				
[illegible] AS $CaCO_3$				
[illegible] AS $CaCO_3$				
[illegible] AS $CaCO_3$				
[illegible] AS $CaCO_3$				
[illegible]				
[illegible] Value		152.89 Me		
[illegible]	Sodium chloride			

Groups		Chemical Properties			
[illegible]	%	Primary Salinity	%	Hydrogen Ion pH	
[illegible]	%	Secondary Salinity	%	Conductance, Kx10⁻⁶C25°C	7393
[illegible]	%	Primary Alkalinity	%		
[illegible]	%	Secondary Alkalinity	%		
[illegible]		Sodium	%		

Respectfully Submitted,
John D. Hess Testing Corporation

By ____________
John D. Hess, Director

APPENDIX I IS SEPARATE DOCUMENT
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