LAWRENCE LIVERMORE LABORATORY
University of California, Livermore, California, 94550

UCRL-52450

A REVISED ESTIMATE OF RECOVERABLE THERMAL ENERGY IN THE SALTON SEA GEOTHERMAL RESOURCE AREA

L. Younker
P. Kasameyer

MS. date: April 15, 1978

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

FOREWORD

This work was performed at the Lawrence Livermore Laboratory by Leland Younker of the Department of Geological Sciences, University of Illinois—Chicago and Paul Kasameyer of the Lawrence Livermore Laboratory.

CONTENTS

Abstract	1
Introduction	1
Evaluation of Geothermal Resources	2
Resource Definition	2
Basis for Resource Calculations	4
Revised Estimate	4
Volume Determination	4
Heat Content of the Reservoir	8
Calculation of Recoverable Heat	8
Conversion to Electrical Generating Capacity	9
Comparison with Previous Estimates	10
Estimates Compared and Basis for Comparison	10
Operational Definition of the Resource	10
Calculation of Reservoir Volume	11
Comparison of Results	11
Summary and Conclusions	12
References	13

A REVISED ESTIMATE OF RECOVERABLE THERMAL ENERGY IN THE SALTON SEA GEOTHERMAL RESOURCE AREA

ABSTRACT

We have made a revised estimate of the recoverable thermal energy in the Salton Sea Known Geothermal Resource Area (KGRA) using the strong correlation between the temperature distribution and the magnetic anomaly. Our estimates of the power-generating potential range from 1300 MW-20 years (for indicated resources) to 8700 MW-20 years (for hypothetical resources). These figures are compatible with previously published estimates.

Comparison of various estimation procedures reveals major differences in techniques used to assess reservoir volume. However, authors agree generally on parameters used to convert reservoir volume to recoverable energy. Our conservative estimates justify continued research and development to solve the technical problems that stand in the way of commercialization of the Salton Sea resource.

INTRODUCTION

A sizable area in the vicinity of the Salton Sea has been designated as a Known Geothermal Resource Area (KGRA) by the United States Geological Survey on the basis of measurements of the surface temperature gradient. This is one of six liquid-dominated geothermal resources located within the Imperial Valley (Fig. 1).¹ A limited portion of the Salton Sea has been extensively investigated by drilling and is referred to as the Salton Sea Geothermal Field (SSGF) (Fig. 2).

The entire region is the best known and best characterized water-dominated hydrothermal resource in the North American continent. Past estimates (1975) by the United States Geological Survey² indicated that the Salton Sea KGRA was the highest temperature and the fourth largest KGRA in the United States. They estimated that the Salton Sea region could produce 10% of the total electrical energy recoverable from large, high-temperature hydrothermal resources in the United States.³ Since 1975, exploratory drilling at the KGRAs thought to be larger than the Salton Sea KGRA (Surprise Valley, Long Valley, and Coso) has failed to demonstrate exploitable resources. At Surprise Valley, eight wells have failed to confirm the existence of a hydrothermal resource capable of electricity generation.⁴ At Coso, one well has been completed, and it indicates a maximum temperature of approximately 380°F at a depth of 2100 ft. Below

3000 ft temperature logs indicate a negative thermal gradient.⁵ At Long Valley, interest appears to be shifting to space heating development as evidenced by the latest IGCC estimate of only 250 MWe electrical generating capacity on line by 1990.⁴ Therefore the Salton Sea KGRA is quite likely the largest identified, and certainly the largest proven, hydrothermal resource in the U.S. suitable for electric power generation.

Since January 1974, the Lawrence Livermore Laboratory has been working on advanced technologies for the utilization of water-dominated hydrothermal resources. The program has consisted of two basic activities:⁶ technology development, which is concerned with development of efficient, reliable, brine-tolerant conversion systems uniquely designed for the high-temperature brines of the Salton Sea KGRA, and industrial support, which provides technical assistance to joint DOE/industry geothermal utilization programs in developing this KGRA. Progress in solving the technical problems has been reported,⁶ and scenarios for the growth of electric power production developed.⁷

To guide the future development plan, we present in this report an evaluation of the resource potentially available in the Salton Sea KGRA. This revised evaluation is based on an increase in our understanding of the subsurface temperature distribution gained through detailed geological and

Fig. 1. Map of the Imperial Valley showing Known Geothermal Resource Areas (KGRA) and the Salton Sea Geothermal Field.

geophysical studies carried out under the auspices of the industrial support program.^{8,9} We will present the methodology used to evaluate the geothermal resource and compare our results with those of earlier assessments based on widely different

criteria.^{2,3,10,11} While our methods and results differ markedly from those of earlier assessments, we are in essential agreement with other authors that the Salton Sea Geothermal Field is sufficiently large to warrant further efforts toward recovery of its energy.

EVALUATION OF GEOTHERMAL RESOURCES

Resource Definition

California law¹² defines geothermal resources as "the natural heat of the earth, the energy in whatever form, below the surface of the earth present in, resulting from, created by, or which may be extracted from such natural heat, and all minerals in

solution or other products obtained from naturally heated fluids, brines, associated gas and steam . . ." The size of a particular resource must be estimated on the basis of a knowledge of physical properties (temperature, porosity, etc.) and an operational definition that indicates the range of physical properties for which energy extraction is possible.

Fig. 2. Well locations in the Salton Sea Geothermal Field.

Some of the factors that should be considered in defining a resource include:

- Economic feasibility: Can the area be developed with existing technology and existing economic conditions?

- Intended use: Is the resource to be used for electrical generation or non-electrical functions?

- Method of extraction: Do we consider only heat contained in the naturally occurring fluid that can be brought to the surface, or do we also consider the heat in the rock?

- Social/environmental impact: Can the resource be developed without significant environmental risk?

- Fluid quality: Is the fluid quality such as to allow long-term operation of a power plant?

Any formal resource assessment must indicate the degree to which these factors have influenced the results.

For purposes of this report, we are concerned only with resource size. Other factors that may influence the exploitability of the resource have been

ignored. We calculate two resource sizes, one based on naturally occurring fluid that can be brought to the surface and another including additional heat that can be extracted from rocks and brought to the surface. Because we are concerned with electrical generating capability, we restrict our attention to regions where the fluid reaches at least 230°C¹⁰ above a 1000-m depth.

Basis for Resource Calculations

The following steps are used to estimate the size of the geothermal energy resource:

- A volume of "hot" rock and fluid is delineated, based on a specified criterion.

- The heat content of that volume is estimated based on its average temperature.

- The recoverability, or percentage of heat that can be brought to the surface is calculated.

- A conversion efficiency is assumed so that we can estimate the electrical generating capacity.

REVISED ESTIMATE

Volume Determination

We have refined the "leaky transform" crustal spreading model of Elders *et al.*¹³ on the basis of the following pieces of evidence:⁸

- Earthquake epicenter data that reflect the detailed geometry of the presumed plate boundary.

- Correlation of epicenter data and the magnetic anomaly suggesting that both are caused by dike intrusion into the sedimentary section.

- Seismic refraction data that are consistent with a high velocity near the surface (presumably caused by a mixed basalt-sediment layer).

- Well logs that reveal the presence of basalt dikes in the sedimentary section.

- Heat-flow calculations that suggest that crustal dilation of approximately 1 cm/year (with the resulting volume filled by basaltic dikes) could explain the magnitude of the anomaly.

From an analysis of these data, we conclude that the geothermal system in the vicinity of the Salton Sea is produced by intrusions of basaltic dikes into the sedimentary section. Avenues for these dikes to rise to within 1 km of the surface are provided by zones of extension between offset right lateral faults. Heat is transferred to the surface by "mini" convection cells within the dominantly sand reser-

voir. Near the surface, an impermeable caprock reduces the convective component of heat transfer to near zero in most places.

The system is associated with several geophysical anomalies; however, the magnetic anomaly seems to be the most sensitive indicator of high temperature at depth. Figure 3 shows the magnetic anomaly in the area, and Fig. 4¹⁴ shows the thermal gradient data plotted on the magnetic anomaly map. The field is roughly outlined by the 1800-gamma contour. (1 gamma = 10⁻⁹ Tesla) This relationship can be better seen in Fig. 5, where the surface gradient is plotted versus the magnetic anomaly. Because the surface gradients might be disturbed by shallow convection (and thus not reflect totally the heat distribution at depth), we plot surface gradient versus temperature at a depth of 3000 ft (Fig. 6). From this figure, it is apparent that surface gradients in excess of 0.3°C/m are characterized by temperatures above 230°C at 1000 m depth. Combining this information with Fig. 5 suggests that magnetic values in excess of 1800 gamma are associated with elevated temperatures at depth. This strong correlation between the heat flow anomaly and the magnetic anomaly is due to the fact that both are caused by the presence of relatively young basaltic dikes near the surface.⁸

Fig. 3. Boundary of the Salton Sea KGRA plotted in the magnetic anomaly map of Griscom and Muffler (Ref. 13) with the area bounded by the 1800-gamma contour shaded in.

Figure 3 shows the official KGRA plotted on the magnetic map of Griscom and Muffler.¹⁵ The region contained within the 1800-gamma contour is shaded. This is an area of 58 km²; the official KGRA, has an area of 388 km². Figure 5 indicates that temperatures in the area outlined by the 1775-gamma contour are probably elevated above the regional pattern. The 230°C isotherm would, however, be reached at a greater depth than in the area outlined by the 1800 contour. This is because the dikes within this region are older and have already lost a significant portion of their heat. If we use the 1775-gamma contour to outline the resource, our estimates would approximately double.

The top of the reservoir can be estimated in two ways. One approach would be to use the top to the convecting hydrothermal system. In the Salton Sea,

this approach would result in the inclusion of reservoir rock with temperature too low to be useful for generating electrical power. An alternative approach is to specify a minimum temperature necessary for electrical conversion techniques and to estimate the depth to this temperature in the convecting system. Following Towse,¹⁰ we use 230°C as the minimum temperature that outlines the top of the reservoir. In the drilled portion of the field, 230°C is first reached at depths ranging from 488 m to 1494 m.¹⁰

There are several possible ways to define the bottom of the resource. First, we could estimate the depth at which primary porosity and permeability are reduced by hydrothermal alteration and compaction. Because of the relationship between temperature and self-sealing hydrothermal alteration, we might expect the region of highest temperature

Fig. 5. Observed relationship between the magnetic anomaly and the surface thermal gradient near the Salton Sea Geothermal Field. Values from deep wells (where the gradient is proportional to heat flow through the cap) are designated by circles; values from shallow wells (where gradients may be disturbed by shallow circulation) are designated by squares.

to be characterized by zones of low porosity and permeability. However, well-flow tests within the zones of hydrothermal alteration are as high as tests above the metamorphic zone.¹⁶ This indicates that secondary porosity and permeability in the form of fractures probably control fluid flow in the lower parts of the reservoir. Thus, defining the bottom of the reservoir by the loss of primary porosity and permeability would probably result in an underestimation of reservoir thickness.

Another approach would be to estimate the depth at which igneous dikes become a dominant portion of the section. Seismic refraction data, the magnetic anomaly, and the presence of dike material deep in the wells within the field all suggest that dike material intrudes to within 1 km of the surface. Griscom and Muffler¹⁵ estimate that the region within the elliptical magnetic anomaly has between 10 to 20% dike material. Presumably, the portion of dike material increases with depth. Griscom and Muffler also estimate a dike-plutonic complex at approximately 2.5 km on the basis of the large ridge anomaly that runs the length of the area. Unless this material is extensively fractured, this depth probably represents a maximum depth of the reservoir rock. Using the values for the depth to the top of the reservoir discussed earlier and this depth at the bottom of the reservoir, we expect the maximum

Fig. 6. Graph of surface thermal gradient vs temperature at a depth of 1000 m.

thickness of the reservoir to range from 2 km in the area characterized by the 1800-gamma contour to 1 km in the area characterized by the 1775-gamma contour. Deep wells presently being drilled¹⁷ just outside the area should provide information on deep production rates (depths up to 2.5 km). It is conceivable that on the flanks of the anomaly, or in regions where the igneous material is at greater depths or extensively fractured, the effective reservoir thickness could be greater than that used in our estimate.

Economic factors may reduce the values.¹⁰ The economic depth limit with present conditions would be approximately 1500 to 1800 m. In regions where the 230°C isotherm is relatively near the surface (i.e., ~500 m), the thickness of the usable reservoir would be approximately 1 km. In areas where the 230°C isotherm approaches 1500 m, the usable reservoir would be essentially negligible.

Thus, we conclude that the reservoir in the region of highest temperature (the 1800-gamma region) has a maximum thickness of 2 km and a minimum usable thickness of 1 km. In the region of somewhat lower temperatures (the 1775-gamma region), the reservoir has a maximum thickness of 1 km. The U.S. Department of the Interior has defined several degrees of geological uncertainty for use in resource estimates. Our definitions of these degrees of uncertainty as they relate to the volume of the Salton Sea KGRA are given below:

- *Measured*—area and thickness based on wells within the presently outlined SSGF.
- *Indicated*—area based on the 1800-gamma

contour on land; thickness based on production and temperature data from wells.

- *Inferred (1)*—area based on both 1800-gamma elliptical anomalies; thickness based on production and temperature data from wells.

- *Inferred (2)*—area based on both 1800-gamma elliptical anomalies; thickness based on the depth interval between the 230°C isotherm and the zone of igneous intrusion.

- *Undiscovered* (hypothetical)—area based on 1775-gamma contour; thickness based on depth interval between the 230°C isotherm and the zone of igneous intrusion.

Table 1 shows the range of reservoir volumes calculated for each level of geological certainty.¹⁸ It should be noted that any particular volume estimate includes all volume estimates with a higher degree of certainty.

Heat Content of the Reservoir

A calculation of the heat content of a reservoir region involves an estimation of the average temperature of the region and the specific heat of the fluid and the fluid-rock system. Figure 7 shows the temperature profiles for some of the wells within the field. Assuming that the reservoir starts at 230°C and is 1 km thick, the average temperature is approximately 300°C. If we assume a 2-km-thick reservoir, this average temperature would be slightly higher (~330°C).

Calculation of Recoverable Heat

If we know the reservoir volume (V), porosity (ϕ), heat capacity (C), and temperature drop (ΔT), and

Table 1. Reservoir volume estimates.

	Area		Thickness		Volume, km ³
	Based on:	Value, km ²	Based on:	Value, km	
Measured	Deep wells	13	Temperature and production data	1	13
Indicated	1800-gamma magnetic contour (land)	28	Temperature and production data	1	28
Inferred (1)	1800-gamma magnetic contour (land and sea)	58	Temperature and production data	1	58
Inferred (2)	1800-gamma magnetic contour (land and sea)	58	Depth interval between 230°C isotherm and zone of intrusion	2	116
Hypothetical	1775-gamma magnetic contour	124	Depth interval between 230°C isotherm and zone of intrusion	1-2 ^a	182

^aThe 2-km reservoir is in the area of 1800-gamma contour; the 1-km reservoir is in the area within the 1775-gamma contour and outside the 1800-gamma contour.

Table 2. Range of recoverable heat.

	Volume, km ³	Heat in fluid, 10 ¹⁸ J	Heat in fluid and rock, 10 ¹⁸ J
Measured	13	1.3	3.1
Indicated	28	2.7	6.7
Inferred (1)	58	5.7	13.8
Inferred (2)	116	12.6	30.1
Hypothetical	182	19.0	45.8

Fig. 7. Temperature/depth profiles for the Magma-San Diego Gas and Electric Company wells and some nearest neighbor wells.

the percent drainage of pore water, and the percent of the formation that is permeable (Z), then the recoverable heat in the fluid is given by

$$Q_f = V \times \phi \times C_f \times \Delta T \times R_f \times Z. \quad (1)$$

If, in addition, we estimate the heat capacity of the saturated rock (C_r) and the percent of heat in place that can be recovered (R_p), then the recoverable heat in the fluid-rock system is given by

$$Q_t = V \times C_r \times \Delta T \times R_p \times Z. \quad (2)$$

Table 2 gives the range of recoverable heat in the fluid-rock system for the range of reservoir volumes considered in this report.

Conversion to Electrical Generating Capacity

If we assume a value for conversion efficiency (ϵ), the electrical generating capacity in MW-20 years for the fluid is given by:

$$P_f = \epsilon Q_f / c, \quad (3)$$

where c is a constant equal to 6.311×10^{14} J and Q_f is the recoverable heat in J from Eq. (1). Similarly, the electrical generating capacity for the fluid and rock system in MW-20 years is given by:

$$P_t = \epsilon Q_t / c \quad (4)$$

Table 3 shows the range of values for the reservoir volumes considered.

Table 3. Electricity generation.

Category	Volume, km ³	Fluid, MW-20 years	Fluid and rock, MW-20 years
Measured	13	250	590
Indicated	28	500	1300
Inferred (1)	58	1100	2600
Inferred (2)	116	2400	5700
Hypothetical	182	3600	8700

COMPARISON WITH PREVIOUS ESTIMATES

Estimates Compared and Basis for Comparison

The major estimates compared with our own include those of the USGS,^{2,3} Towse,¹⁰ and Biehler and Lee.¹¹ In comparing these estimates, four questions must be addressed:

- What is the operational definition of the resource?
- How was reservoir volume determined?
- What values were assumed for the parameters necessary to convert to energy in place?
- What assumptions were made to convert from energy in place to electrical generating capacity?

Tables 4 and 5 compare the parameters used to estimate the recoverable heat in the fluid and in the fluid and rock system for the various studies. All estimates agree on heat capacity, recoverability, and efficiencies to within a factor of two. It is therefore to be expected that most of the variation in estimates comes from the operational definition of the

geothermal resource or the method of calculating the reservoir volume.

Operational Definition of the Resource

All estimates define the resource as the recoverable heat in the ground; differences in the estimates occur because of different ideas as to what is recoverable. Biehler and Lee's¹¹ estimate and our own do not consider economic, technical, and social limitations. Towse's¹⁰ estimate and our own include only regions with a temperature higher than 230°C. The USGS^{2,3} and Biehler and Lee definitions include that heat which is in a convecting hydrothermal system. Towse and the USGS consider economic limitations to the resources. Towse calculates that costs will limit well depths to the upper 300 m of the reservoir. The USGS indicates that the hypersaline brines make the Salton Sea field uneconomical at this time. All estimates except that of Towse include heat extracted from the rock matrix as well as from the water.

Table 4. Resource estimates for the area within the Salton Sea KGRA (parameters for heat in fluids).

	Heat in place			Recoverable heat	
	Porosity, %	Heat capacity, cal/cm ³ °C	Temperature minus reference, °C	Yield, %	Permeable zones, %
USGS (Refs. 2 and 3)	—	—	—	—	—
Towse (Ref. 8)	20	0.9	340°-0°	80	59
Biehler (Ref. 9)	20	0.9	340°-0°	80	Not needed
This work	20	0.9	330°-25° (2-km reservoir)	80	59
			300°-25° (1-km reservoir)		

Table 5. Resource estimates for the area within the Salton Sea KGRA (parameters for heat in rock and fluid).

	Heat in place		Recoverable		Conversion efficiency, %
	Heat capacity, cal/cm ³ ·°C	Temperature minus reference, °C	Permeable zones, %	Recovery, %	
USGS (Refs. 2 and 3)	0.6	340°-15°	50	50	12
Towse (Ref. 8)	—	—	—	—	16
Biehler (Ref. 9)	0.7	340°-0°	100	100	10
This work	0.7	330°-25°	59	50	12
		(2-km reservoir)			
		300°-25° (1-km reservoir)			

Calculation of Reservoir Volume

Table 6 compares the volume estimates made by the various authors and gives the basis for the reservoir volume calculation in each case.

Biehler and Lee¹¹ and the USGS^{2,3} determine the volume of the hydrothermal system in different ways. The USGS estimate is based on the surface area with hydrothermal manifestations or geothermal wells, and an assumed depth of 3 km for the bottom of any convecting system. Biehler and Lee assume that the gravity anomaly is caused by silica deposition and hydrothermal alteration of the sedimentary section and indicates the region of convecting hot brines. Using the gravity anomaly as an indicator of total excess mass, they calculate reservoir volume as the quotient of excess mass and density contrast. In their report, they use three values

for density contrast, producing three energy estimates in the ratio of 0.67 to 1 to 2. We have used values from their intermediate estimate in this report.

Towse's¹⁰ estimate and our own choose reservoir surface areas based on geophysical correlations with the locations of successful geothermal wells. Towse used Combs's¹⁹ temperature gradient contours to define the reservoir area. Kasameyer and Younker⁸ point out the inaccuracies of those contours within the drilled field. In this report, we use the correlation between the magnitude of the magnetic anomaly and surface gradient and include an area beneath the Salton Sea in the reservoir.

Comparison of Results

Table 7 gives the resource estimates for the area within the Salton Sea KGRA both for the fluid and

Table 6. Resource estimates for the area within the Salton Sea KGRA (volumetric parameters).

	Area		Thickness		Volume, km ³
	Based on	Value, km ²	Based on	Value, km	
USGS (Refs. 2 and 3)	All geothermal manifestations	54	Top of reservoir to 3 km	2	108
Towse (Ref. 8)	Combs' geothermal gradient map (6° F/100')	307	Economic limitations	0.3	94
Biehler (Ref. 9)	Volume from gravity anomaly		No limit		255
This work	Magnetic anomaly contour				
	Smallest	1800-gamma (land)	Temperature and production data	1	28
	Largest	1775-gamma	Depth to zone of intrusion	1-2	182

Table 7. Resource estimates for the area within the Salton Sea KGRA.

	Volume, km ³	Fluid		Fluid and rock	
		Recoverable heat in place, 10 ¹⁸ J	Electricity, MW-20 years	Recoverable heat in place, 10 ¹⁸ J	Electricity, MW-20 years
USGS (Refs. 2 and 3)	108	—	—	22	4,200
Towse (Ref. 8)	94	11	2,900	—	—
Biehler (Ref. 9)	255	53	8,400	111 ^a	17,600 ^a
This work	28-182	3-19	500-3,600	7-46	1,300-8,700

^aCorrected for error in recoverability.

the fluid and rock systems. We include reservoir volume in the table to emphasize that the major dif-

ferences in the estimates stem from the methods used to calculate this quantity.

SUMMARY AND CONCLUSIONS

Comparison of recent estimates of the geothermal resource in the vicinity of the Salton Sea reveals differences; however, the authors all agree that the resource is substantial. The major differences in the estimates come from the method of determining the reservoir volume and whether heat removal from the rock is assumed possible.

The spatial extent of the zone of elevated temperature in our revised estimates is based on the strong correlation of the thermal anomaly and the magnetic anomaly. The prime uncertainty in our calculations of the reservoir volume comes from the estimate of reservoir thickness used.

Agreement between authors on the choice of parameters needed to convert reservoir volume to recoverable heat and electrical generating capacity probably reflects a lack of experience in production of geothermal fluids and a reliance on "standard" values rather than a complete understanding of the problems of heat extraction from geothermal resources.

The next refinement in resource assessment will require:

- More meaningful site-specific estimates of energy conversion parameters based on detailed well tests.

- Production data from deep wells to establish the lower limit of the reservoir.

- Shallow temperature surveys within the sea to further test the heat flow-magnetic correlation.

In our estimates, values for electrical generation potential from the fluid and rock system range from 1300 MW per year (over a 20-year period) for indicated resources to 8700 MW per year (over a 20-year period) for undiscovered hypothetical resources. Assuming 12,900 barrels of oil per MW-yr this one resource is equivalent to as much as 3.4 billion barrels of oil.

Our estimates are conservative. A high proportion of our resource area has been investigated by deep drilling (approximately 1/2 of the 1800-gamma contour on land). In addition, our resource definition excludes areas surrounding known producers (Sinclair 3, Sinclair 4, Landers 1, Landers 2, Landers 3, Kalin Farms 1, Dearborn 1, Dearborn 2). The Sinclair wells are located in the SSGF. The other wells are located between Westmoreland and the southern boundary of the KGRA. These are all wells within the geothermal system in which the necessary high temperatures are reached at depths greater than those considered in our estimate. In spite of the conservative stance, we are able to estimate hypothetical resources as equivalent to over eight 1000-MW nuclear power plants operating for 20 years. Thus, our estimates strongly support continued research and development to solve the technological problems associated with the commercialization of the Salton Sea KGRA.

REFERENCES

1. L. H. Godwin, L. B. Haigler, R. L. Rioux, D. E. White, L. J. P. Muffler, and R. G. Wayland, *Classification of Public Lands Valuable for Geothermal Steam and Associated Geothermal Resources*, U.S. Geological Survey, Washington, D. C., Circular 647 (1971).
2. J. L. Renner, D. E. White, and D. L. Williams, "Hydrothermal Convection Systems," in *Assessment of Geothermal Resources of the United States*, U.S. Geological Survey, Washington, D. C., Circular 726 (1975).
3. M. Nathenson and L. J. P. Muffler, "Geothermal Resources in Hydrothermal Convection Systems and Conduction-Dominated Areas," in *Assessment of Geothermal Resources of the United States*, U.S. Geological Survey, Washington, D. C., Circular 726 (1975).
4. Interagency Geothermal Coordinating Council, *Geothermal Energy Research, Development and Demonstration Program Second Annual Report*, U. S. Department of Energy, Rept. DOE/ET-0039/1, IGCC-3 (April 1978).
5. R. M. Galbraith, *Geological and Geophysical Analysis of Coso Geothermal Exploration Hole No. 1 (CGEH-1), Coso Hot Springs KGRA, California*, University of Utah Research Institute, IDO/78-1701.b.4.2 (May 1978).
6. A. Austin, A. Lundberg, L. Owen, and G. Tardiff, *The LLL Geothermal Energy Program, Status Report, January 1976-January 1977*, Lawrence Livermore Laboratory, Rept. UCRL-50046-76 (1977).
7. D. Ermak, *Potential Growth of Electric Power Production from Imperial Valley Geothermal Resources*, Lawrence Livermore Laboratory, Rept. UCRL-52252 (1977).
8. P. Kasameyer and L. Younker, "Temperature Gradient Analysis," in *The LLL Geothermal Energy Program, Status Report, January 1976-January 1977*, Lawrence Livermore Laboratory, Rept. UCRL-50046-76 (1977).
9. L. Younker and P. Kasameyer, "Salton Sea Geothermal Resource: Source of the Anomaly," *EOS, Transaction of the American Geophysical Union* **57**, 1017 (1976).
10. D. Towse, *An Estimate of the Geothermal Energy Resource in the Salton Trough, California*, Lawrence Livermore Laboratory Rept. UCRL-51851 (1975).
11. S. Biehler and T. Lee, *Final Report on a Resource Assessment of the Imperial Valley*, University of California, Riverside, DLRI Rept. No. 10 (1977).
12. State of California, "Geothermal Operations," Public Resources Code, Chapter 4, Division 3, Subchapter 4, Section 1970, paragraph e.
13. W. A. Elders, R. W. Rex, T. Meidav, P. T. Robinson, and S. Biehler, "Crustal Spreading in Southern California," *Science* **178**, 15 (1972).
14. T. Lee and L. Cohen, "Onshore and Offshore Measurements of Temperature Gradients in the Salton Sea Geothermal Area California," University of California at Riverside, UCR/IGPP-77/22 (1977).
15. A. Griscom and L. J. P. Muffler, *Salton Sea Aeromagnetic Map*, U.S. Geological Survey, Washington, D. C., Map GP-754 (1971).
16. L. B. Owens, Lawrence Livermore Laboratory, private communication (Dec. 1977).
17. J. L. Smith, C. F. Isselhardt, and J. S. Matlick, "Summary of 1976 Geothermal Drilling—Western United States," *Geothermal Energy* **5** (5), 8 (1977).
18. U.S. Department of Interior, *New Mineral Resource Terminology Adopted*, press release (April 15, 1974).
19. J. Combs, "Heat Flow and Geothermal Resource Estimates for the Imperial Valley," in *Cooperative Geophysical-Geochemical Investigations of California*, University of California, Riverside, CA (1971).

SKM