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**GEOHERMAL DEVELOPMENT AND PRODUCTION
OF ELECTRICITY IN THE SOUTHWESTERN
UNITED STATES**

Technical Report

By
K. R. Nowotny
C. R. Rao

October 1978

Work Performed Under Contract No. EG-77-S-04-3992

New Mexico State University
New Mexico Energy Institute
Las Cruces, New Mexico
and

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U. S. DEPARTMENT OF ENERGY
Geothermal Energy

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ABSTRACT

A computer simulation model (GIRORA-Electric) is developed to study the economics of power generation from high temperature geothermal resources. GIRORA-Electric is a discounted cash flow investment model which evaluates the rate of return on producers' capital investment. This model consists of two major submodels: the exploration and development of a geothermal anomaly by a producer; and the purchase of geothermal fluid by a utility developer. The primary output of the model is a calculated rate of return on the capital investment earned by the geothermal producer. The results of the sensitivity analysis of the model subject to changes in physical and economic parameters are given this report.

Using the results of the economic analysis, the high temperature geothermal sites (temperatures greater than 150°C) in the Southwestern United States are examined for economic viability for power generation. The total amount of power that can be brought on line in the Southwest Region is estimated under three different scenario assumptions.

An econometric model is developed to estimate the total demand for electricity in the Southwest Region. From this demand and supply estimates, the amount of geothermal energy that can be utilized is also estimated.

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INTRODUCTION

Recent research into the viability of geothermal energy in the production of electricity has either investigated the specific characteristics of a single site and evaluated the economics of that site and a concomitant engineering design, avoiding market projections for nation or region-wide supply or ignored site by site characteristics and ascertained gross estimates of nationwide supply supported by a minimum of either geologic or economic information [4,7,9].

Following the lead of MITRE Corporation [5] and with funding from DGE-DOE, research was undertaken to close the gap between micro- and macro-analytics. The focus of the research described herein was to make a region-wide projection of the supply of geothermally produced electricity, building site specific characteristics, through simulation modeling to an analysis of the region wide market for electricity.

The completion of research described herein is by no means the completion of the process of discovery. Each passing month yields additional geologic, engineering and economic information which necessitates a re-evaluation of earlier projections. The purpose of the research was, of course, to formulate policy proposals designed to affect the projections made. The presence of a baseline study, such as this, furthermore provides a benchmark against which progress in policy implementation can be measured.

In this report, the logic underlying the research performed, the tools used, and the results of the research concerning the potential contribution of

geothermal development to electricity production in the Southwest comprised of the states of Arizona, Colorado, Nevada, New Mexico, and Utah, are discussed. First, the underlying philosophy of the research program is described. Next, the sensitivity of profits to changes in physical and policy variables circumscribing the development of geothermal electric power is discussed. Then, site by site profitability as determined by GIRORA-Electric and aggregation of resulting power estimates are described and power-on-line estimate to policy initiatives is discussed. Finally, preliminary estimates of electric power supply and demand conditions are presented. The feed back or impact upon the development of geothermal electric plants is discussed under three possible sets of alternative assumptions. The complete description of the GIRORA-Electric model and the associated computer program (written in FORTRAN IV) is given in the Appendix. We turn first to a discussion of the philosophy underlying the research accomplished concerning the development of geothermal electric power.

RESEARCH PHILOSOPHY

Underlying all considerations of this research was the assumption that electric plants driven by geothermal energy, and the fields which deliver that energy, will be developed by the private or non-Federal government sectors. For the most part, this means private developers in conjunction with regulated electric utilities (although, exceptions may and will likely exist). A concomitant of this assumption is that a geothermal resource will be developed only if it is economic to do so (that is, economic feasibility is necessary, but not sufficient condition). Because private developers and electric utilities are the actors, it is necessary to consider economic feasibility (profitability) from their point-of-view.

The second principal assumption is that geothermal energy is only one of a variety of energy sources at the disposal of an electric utility (or anyone, for that matter, in need of electric power). A concomitant of this second assumption is that geothermal energy must compete in the market place for energy. Because geothermal energy is a marginal energy source, marginal in the sense that it is a relatively small source, and in this region enters the scene chronologically late, it must compete at prices established by other fuels (coal, nuclear, oil, gas, and hydroelectric).

The result of the first two principal assumptions is that if geothermal energy is not profitable for both the geothermal developer and the electric utility, at a price which enables the electric power thus generated to be competitive with that generated by other fuels, the resource will not be developed. This is the bottom line. Given other institutional, attitudinal, and economic factors, a particular resource may not be developed, even if it is economically competitive.

Moreover, even though a particular resource is economically competitive and faces no noneconomic barriers, being a marginal fuel it may not be developed for lack of effective demand. This could occur under two conditions: (1) increases in the price of electricity result in sufficient consumer substitutions to reduce quantity of electricity demanded below some critical level; or (2) general economic growth is insufficient to require the capacity that would be added by a geothermal development. The first condition may have some general applicability, while the second might occur only in remote, sparsely populated areas (due to the portability of electricity).

At each juncture, government policy makers may have an option to affect the environment in which private developers make decisions or perceive opportunities.

It was the aim of the research effort described below (1) to ascertain what elements under the influence of DOE-DGE could efficiently alter the profitability of geothermal resources as perceived by the investors, (2) to identify the magnitude of impact policy action might reasonably be expected to have, and (3) to estimate in a preliminary way the level of market potential for electricity driven by geothermal energy.

Because geothermal energy is not to be had for free, it is an economic resource which should be developed efficiently with due concern for its place in a total energy perspective. Private entrepreneurs cannot discount the value of national balance of payments deficits, or other social concerns when considering the desirability of an investment. It must be DOE-DGE's role to consider this broader perspective and insure the availability of sufficient incentives (or the absence of disincentives) so that private entrepreneurs will perceive geothermal energy as an attractive opportunity.

The criterion for evaluation chosen for this research is the rate-of-return on equity investment. There are a variety criteria which could be used, each having their own special strengths and weaknesses. The one chosen for this research seems most appropriate because of the overall capital intensitivity of the process. It should be added that in the process of ranking geothermal sites, or judging the relative effectiveness of policy actions, any criterion of profitability or economic feasibility would yield approximately the same answer as another, so long as the methodology is consistent.

As will be noted in the next section, the simulation model used to evaluate geothermal electric projects uses the rate-of-return as the basis for comparison rather than the price of electricity. This is due to our assumption that geothermal energy must compete at the margin with established fuels. The price of electricity is then an independent rather than dependent variable. Moreover, using a rate-of-return on equity as the dependent variable focuses our attention

on the profit motive of the developer. The developer can invest in geothermal energy, or any other income yielding prospect. If the rate-of-return on geothermal energy is not high enough (at a price where it can effectively compete), the developer will place investments elsewhere.

SENSITIVITY OF PROFITS TO POLICY PARAMETERS

Having developed and calibrated GIRORA-Electric (calibrated with other models of the genre), the next step was to determine the sensitivity of the output, rate-of-return (R), to changes in policy parameters. This was done by first establishing an estimate of R, given a "baseline" set of policy, geophysical, and market parameters. The "Baseline" parameters are not here held to be "typical" or "characteristic." Resource areas in the Southwest Region could be characterized as being of a wide variety of temperatures, salinity, distance to demand areas, etc. On the other hand, all will be confronted, given the nature of electricity markets, with similar market parameters and, of course, federal policy parameters. Table 1 lists the more important parameters for the "baseline" case.

The "base case" value of R maximizes at a 50 MW utility plant and increases as resource temperature increases from about 7% per annum at 150°C to within excess of 100% per annum at 250°C. (The 150°C - 250°C range was chosen due to the fact that over 90 percent of resource sites in our 5-state area qualifying as electric sites lie in this range.) This is shown in Figure 1. Subsequent sensitivity analysis is, therefore, performed only upon plants of 50 MW capacity.

At 230°C, when the depletion allowance is at zero, R is approximately 26% per annum ("base case" data). Increasing depletion to a value of 22 percent increases R to approximately 28% per annum at 230°C of $\frac{\Delta W}{R} = 7.69\%$. This is not an altogether promising result. This result is also illustrated in Figure 1.

Table 1
Base Case Values
Geothermal Energy Producers

Variable		Value
BR:	Bond Rate	0.085
CRRT:	Investment Tax Credit Rate	0.12
FR:	Flow Rate	585,794 lb/hr
TEMP:	Initial Downhole Temperature	190°C
EPK:	Equity Proportion of Capital	0.30
DPK:	Debt Proportion of Capital	0.70
λ :	Royalty Rate	0.10
Z:	Depletion Allowance Rate	0.00
EXP:	Exploration Period	0 years
DVP:	Development Period	8 years
TXRT:	Income Tax Rate	0.50
IRR:	Internal Rate of Return	0.15
Electric Utility		
Variable		Value
CAP:	Capacity	50,000 Kilowatts (Net)
LF:	Plant Factor	0.80
UF:	Plant Use of Power (Proportion)	0.18
PB _e :	Base Price of Electricity (Busbar)	0.021 (\$/kwh; current \$)
$\dot{P}$:	Escalation Rate of Base Price	0.05
EK:	Equity Proportion of Capital	0.50
DK:	Debt Proportion of Capital	0.50
UR:	Regulated Return to Equity	0.12
BR:	Bond Rate	0.085
TXRT:	Income Tax Rate	0.50

Figure 1: "Base Case" and Depletion Sensitivity

A more interesting result is shown in Figure 2. This concerns the policy variable Investment Tax Credit Rate (CRRT). When CRRT is at the "base case" level, R increases monotonically from left to right. But when CRRT is increased from its "base case" level, 12% to 16%, this monotonic relationship changes. At temperatures between 185°C and 200°C, there exist higher R values than in the temperature range 200°C to 230°C. This is due to the higher capital intensity of the binary plant. There exists, then, a differential increase or effect as between binary and flash plants since CRRT has its principal impact on the cost of plant and equipment. The 33% increase in CRRT results in as much as more than a doubling of R at 190°C whereas at 230°C, the increase in R is only about 18.5%. This is probably a significant result in that it is precisely those lower temperature sites, which are most abundant, that will require the most assistance for development that respond most readily to the investment tax credit. A correlative and similar result is shown in Figure 3 for the sensitivity of R to the Bond Rate (BR).

The sensitivity of R to a variety of other variables is shown in Figures 4 through 7, and the results are summarized in Table 2.

After observing the variability of R with changes in individual independent variables, we must also consider the range of R as several variables are changed simultaneously. This gives a range for expected values of R under a variety of circumstances.

Considering such a range is a more reasonable approach to forecasting than simple point estimates. This is because the future cannot be predicted with any precision and thus those factors which might impact geothermal development cannot be predicted with any great precision. Looking at a range, however, permits us to realistically analyze the likely effects of policy initiatives.

Table 3 lists the parameter values for what is here discussed as "pessimistic" and "optimistic" and a "baseline" R for each potential electric site (estimate for

Figure 2: Investment Tax Credit Sensitivity

Figure 3: Bond Rate Sensitivity

Figure 4: Royalty Rate and Electricity Base Price Sensitivity

Figure 5: Plant Load Factor Sensitivity

Figure 6: Flowrate Sensitivity (Temperature = 225°C)

Figure 7: Sensitivity to Length of Exploration and Development Periods (Temperature = 225°C)

Table 2
Summary of Sensitivity Analysis
at Base Case Values and at 225°C

Variable	Range	$\frac{\Delta R}{R}$	Range of R (% per ann.)
MW	200 - 50	+ 38.2%	17% to 23.5%
Depletion	0.0 - 0.22	+ 10.6%	23.5% to 26%
CRRT	0.12 - 0.16	+ 27.7%	23.5% to 30%
Royalty	0.1 - 0.0	+ 4.3%	23.5% to 24.5%
Base Price of Elec.	0.21 - 0.031 Mills/KWH	+ 29.8%	23.5% to 30.5%
Plant Load Factor	0.5 - 0.8	+ 147%	9.5% to 23.5%
Producer $\frac{\text{Debt}}{\text{Equity}}$	2 1/3 - 1	- 10.2%	29.5% to 26.5%
Flowrate	$0.2 \times 10^6 - 0.45 \times 10^6$	+ 160%	7.5% to 19.5%
Exploration Period	1 year - 10 years	- 6.3%	24% to 22.5%
Development Period	2.5 years - 10 years	- 43.8%	36.5% to 20.5%
Bond Rate	0.085 - 0.065	+ 4.3%	23.5% to 24.5%
Bond Rate at 190°C	0.085 - 0.065	+ 59.3%	13.5% to 21.5%
Plant Use of Power	0.18 - 0.03	+ 415%	23.5 to 121.0%
Temp. at 50 Mw	150°C - 230°C	+ 264%	7% to 25.5%

Table 3
Values of Choice Variables and
Parameters: Optimistic and
Pessimistic Market Scenarios

	"Pessimistic"	"Optimistic"
LF	60%	75%
PB	21 mils/KWH	30 mils/KWH
P	5%	6.5%
D/E Utility	1	1
D/E Producer	1.5	1.86
Utility's Return	15%	12%
TXRT	48%	48%
BR	8.5%	7.5%
CRRT	12%	12%
FR	250,000 lb/hr	400,000 lb/hr
T°	230°C	230°C
Royalty Rate	10%	5%
Depletion	0%	22%
Exploration	5 years	5 years
Development	8 years	5 years
R	3%	300%

base temperature over 150°C) in the Southwest Region. In Tables 4 through 8, megawatt estimates are given for each site under the conditions specified by sets of parameter values. A required return to equity of 15 percent is assumed. Those sites which do not receive a required return under a given set of parameter values are rated at zero megawatts. The estimates are given at three levels, namely, pessimistic, baseline, and optimistic.

If a positive megawatt value is shown, it is the maximum thirty-year usable energy estimate of the resource given estimated temperature and volume. (In many cases the volume is a default value from U.S.G.S. Circular 726, thus making the "optimistic" estimate possibly conservative.) The optimistic case is the maximum probable energy that could be obtained under any circumstances. Table 9 summarizes the megawatt estimate for the Southwest Region from Tables 4 through 8.

AGGREGATED POWER-ON-LINE ESTIMATES

Under conditions of minimum competition for development inputs (drilling rigs, labor, casing, pipe, etc.), and given the projected scenarios for development of individual sites, a time phasing of power-on-line can be constructed for the region. This is illustrated in Figure 8. Figure 8 contains three basic projections for this time phasing; one, "optimistic," one "baseline," and one "pessimistic." Each is the region-wide aggregation of megawatt estimates for the five states for each year according to site by site projections. The range between the two extreme projections represents the most highly probable range for the development of geothermal electricity production, given minimum competition for development inputs.

For a planning outlook, however, this perspective must be modified. The range illustrated in Figure 8 could be realized only if sufficient resources are devoted to the production of drilling rigs and the training of

Table 4

Electric Power Estimates
in Megawatts for Arizona

Site	Temp °C	Estimates Power in Megawatt		
		Pessimistic	Baseline	Optimistic
Power Ranch	184	0	0	50
Clifton H.S.	160	0	0	50
Verde H.S.	150	0	0	50
Statewide (Kingman)	50-200	0	0	0
White Mountains, (Flag- staff)	210	0	100	1000
Yuma	150-180	0	50	50
Hyder Valley	200	0	50	500
Wilcox*	205	0	0	100
Springerville*	210	0	100	500
Tucson*	60-120	0	0	50
Safford	210	0	100	100
Total		0	400	2450

* Indicates that the resource is hot dry rock.

Table 5

Electric Power Estimates
in Megawatts for Colorado

Site	Temp °C	Estimates Power in Megawatt		
		Pessimistic	Baseline	Optimistic
Mt. Princeton/Cotton- wood Creek	170-200	0	100	100
Poncha Springs	175-200	0	0	200
Cebolla Hot Springs	145	0	0	200
Total		0	100	500

Table 6

Electric Power Estimates
in Megawatts for Nevada

Site	Temp °C	Estimates Power in Megawatt		
		Pessimistic	Baseline	Optimistic
The Needles Rocks	200	0	245	245
Surprise Valley	185	0	0	45
South Smoke Creek Desert	200	0	65	65
Anaho Island	185	0	0	45
Dyke Hot Spring	200	0	245	245
Baltazor Hot Spring	185	0	0	45
Bill Creek Reservoir	200	0	65	65
Bog Hot Springs	170	0	0	40
Howard Hot Springs	200	0	65	65
Pinto Hot Springs	185	0	0	45
Cordero Mercury Mine	185	0	0	45
Hot Sulphur Spring	185	0	0	180
The Hot Springs	170	0	0	40
Humboldt Wells	200	0	245	245
Mineral Hot Springs	185	0	0	90
San Emidio Desert	200	0	245	245
Gerlach, N.E.	200	-	-	-
Double Hot Spring/Black Rock Hot Spring	200	0	735	735
Gerlach	200	0	370	370
Colona	185	0	0	45
Fly Ranch	185	0	0	45
Fly Ranch, N.E.	185	0	0	45
Trego	185	0	0	45
MacFairlane's	185	0	0	45
Sulphur	185	0	0	45
Rye Patch	185	0	0	540
Colado	185	0	0	180
South Eugene Mountains	185	0	0	180
Golconda	185	0	0	-
Hot Springs (Tipton) Ranch	200	0	245	245

Table 6 (Continued)

Site	Temp °C	Estimates Power in Megawatt		
		Pessimistic	Baseline	Optimistic
Hot Pot	185	0	0	45
Sand Dunes	185	0	0	-
Winnemucca Mountain	90	0	0	-
Leach Hot Springs	200	0	735	735
Kyle Hot Springs	200	0	245	245
Battle Mountain	185	0	0	-
Smith Creek Valley	200	0	245	245
Beowawe Geysers	245	1220	1220	1220
Horseshoe Ranch Spring	185	0	0	45
Hot Springs Point	185	0	0	180
Duff Creek	185	0	0	45
Darrough's Hot Spring	185	0	0	45
Elko Hot Springs	185	0	0	-
Walh Hot Springs	185	0	0	45
Bruffey's Hot Springs	185	0	0	45
Kolbe Hot Springs	185	0	0	45
Spenser Hot Springs	185	0	0	45
Carlin	185	0	0	-
Sulphur Hot Springs	200	0	490	490
Monte Neva Hot Springs	185	0	0	180
Ruby Lake	200	0	245	245
Cherry Creek Hot Spring	170	0	0	40
Steamboat Spring/Huffaker	215	0	400	400
Steamboat Spring/Huffaker	60	0	0	-
Moana Spring/Lawton	60	0	0	-
Comstock Mining District	155	0	0	38
Washoe Valley	60	0	0	-
Desert Peak	215	0	665	665
Brady's Hot Springs	215	0	265	265
Huxley	200	0	65	65
Eagle Salt Works	215	0	-	-

Table 6 (Continued)

Site	Temp °C	Estimates Power in Megawatt		
		Pessimistic	Baseline	Optimistic
Hot Springs Mountains	215	0	265	265
Hazen	200	0	65	65
Brady's Hot Springs	215	0	-	-
Carson Sink/Alkali Flat West Side	200	0	65	65
Carson Sink/Alkali Flat East Side	200	0	65	65
Lone Rock	185	0	0	45
Soda Lake/Upsal Hogback	215	0	400	400
Soda Lake/Upsal Hogback	215	0	-	-
Stillwater	215	0	530	530
Carson Lake	185	0	0	65
Lee Hot Springs	185	0	0	63
Eight Mile Flat	185	0	0	63
Stillwater	215	0	-	-
Dixie Hot Springs	200	0	245	245
Sou Hot Springs	185	0	0	135
McCoy Springs	185	0	0	135
Hyder Hot Spring	200	0	145	145
Senator	185	0	0	-
Dixie Comstock Mine/ Humboldt Marsh	185	0	0	135
IXL	170	0	0	-
Buffalo Hot Springs	185	0	0	135
Jersey Valley	200	0	145	145
Wabuska Hot Springs	170	0	0	40
Wabuska Hot Springs	170	0	0	-
Wilson Hot Springs	170	0	0	40
Hind's Hot Springs	155	0	0	-
Dead Horse Wells/Wedell Spgs	170	0	0	165
West Gabbs Valley	170	0	0	165
Sodaville Springs	140	0	0	-
Fish Lake Valley	260	390	390	390

Table 6 (Continued)

Site	Temp °C	Estimates Power in Megawatt		
		Pessimistic	Baseline	Optimistic
Silver Peak Hot Springs	200	0	63	63
Silver Peak Hot Springs	200	0	-	-
Southern Clayton Valley	170	0	0	40
Warm Springs	170	0	0	45
Railroad Valley/Pancake Range	170	0	0	45
Hot Creek Canyon	170	0	0	45
Hot Creek Valley	155	0	0	38
Lunar Crater	185	0	0	130
Caliente Hot Springs	65	0	0	-
Sarcobadus Flat/Beatty	65	0	0	-
TOTALS		1610	9478	13600

Table 7

Electric Power Estimates
In Megawatts for New Mexico

Site	Temp °C	Estimates Power in Megawatt		
		Pessimistic	Baseline	Optimistic
Lightning Dock	170	10	20	100
Kilbourne Hole	155	10	20	50
Radium Springs	~	0	0	50
Valles Caldera	260	1900	2000	2000
Lower Frisco H.S.	150	0	0	50
TOTALS		1920	2040	2250

Table 8

Electric Power Estimates
in Megawatts for Utah

Site	Temp °C	Estimates Power in Megawatt		
		Pessimistic	Baseline	Optimistic
Roosevelt	230	300	500	500
Cove Fort	200	0	200	200
Thermo	185	0	100	100
West Cove Ft.	200	0	200	200
North Cove Ft.	200	0	200	200
TOTALS		300	1200	1200

Table 9
Electric Power Estimated
In Megawatts for the Five States

State	Estimated Power in Megawatts		
	Pessimistic	Baseline	Optimistic
Arizona	0	400	2450
Colorado	0	100	500
Nevada	1610	9473	13600
New Mexico	1920	2040	2250
Utah	300	1200	1200
Totals	3830	13128	20000

Figure 8. Time-Phased Scenarios Under Conditions of Minimum Competition

geothermal drilling teams. An obvious policy recommendation is that DOE-DGE should assure an environment in which such resources may be readily available.

However, in the presence of development resource competition one could expect a time phasing more along the lines of that presented in Figure 9. Assuming that the provision of development resources grows at a more or less constant rate, the slope of the initial growth phase must be less steep while the period of maximum output is more extended. Since it is likely that some competition for development resources will exist, we will assume for the sake of policy analysis that the power-on-line time phasing suggested in Figure 9 is the relevant case. It must be kept in mind, however, that this time phasing is subject to policy initiatives.

POLICY ANALYSIS AND RECOMMENDATIONS

The final step is to consider the sensitivity of the time-phased aggregations to changes in policy parameters. In order to accomplish this, however, the logic of these aggregations must be reviewed. The aggregations are precisely that, the sum of the parts which are site specific estimations of power and the time-phasing of those sites.

The three cases illustrated for the time-phased aggregations are the result of an essentially "go" or "no-go" decision for each site. The "Optimistic" boundary is the result of a "go" decision for all sites within the region, as a brief review of Tables 4 through 8 will show. Thus, the upper bound of our range of likely power-on-line estimates can increase or change only subject to the following conditions: (1) the volume or temperature estimates are altered, or (2) as noted earlier, the supply of development resources is increased or decreased. Thus, the effect of DOE-DGE policy can only be to raise the middle estimate and lower boundary of the range or to alter the rate of development by ensuring timely supply of development resources.

Figure 9. Time-Phased Scenarios Under Some Competition for Development Resources

The policy parameters indicated previously, then, can only affect the position of two of the three estimates, the "base line" and the "pessimistic" projections for power-on-line, in Figure 9. The following policy analysis is, therefore, directed at the sensitivity of these lower two estimates to changes in policy parameters.

It must be recalled that the lower estimates are the results of the confluence of a variety of negative influences on the rate-of-return (R). Moreover, as a result of this confluence, the "pessimistic" case results in zero or lower estimates for R for all sites having down hole temperature of 200°C or lower. If the "go" - "no-go" decision point for a site is at an approximate of R of, say 15 percent per annum, substantial increases in R are necessary for sites below 230° C. in the pessimistic scenario. Given the very low E of R with respect to either the depletion allowance or the royalty rate, it should not be surprising that substantial changes in either of these policy variables will not noticeably affect the lower bound or the "baseline" case of our estimated range. Eliminating the royalty rate or establishing a 22 percent depletion allowance will accomplish two things: (1) increase the probability that the actual power output will fall within the given range, and (2) increase the profitability of these sites which will be developed in any event. This second result is not meant to indicate criticism. Increasing the cash flow of geothermal enterprises could inspire developers to take on riskier geothermal projects. The impact of this activity cannot, however, be measured at this time.

A further word about result (1) above is necessary. An estimated range of high and low prospect for geothermal development in the Southwest Region has been illustrated. We are saying that it can be expected that, with no assistance beyond what currently exists, the development path for geothermal energy will

fall within the indicated range. It cannot be said with any certainty what the likelihood is that this will occur. The likelihood may be a 60 percent probability or a 90 percent probability. We are only saying the probability is somewhat greater than 50% that the actual development path will fall within that range. We cannot be more certain than that until more precise estimates of reservoir volume and the distribution of flowrates is obtained. With this information, it would then be meaningful to assign probability weights to other parameters and through Monte Carlo simulation techniques, estimate a probability value for the range and also probability values for paths within that range. In the absence of such information we can specify that magnitude of movement, but not the magnitude of the change in probability distribution.

In contrast with the two policy parameters mentioned above, an increase in the investment tax credit of 4 percentage points (say, from 12 percent to 15 percent) or a fall in the bond rate by 2 percentage points (from 8.5 percent to 6.5 percent) would add perhaps 7,000 megawatts of power on to the total found under the "baseline" case in Table 9, and perhaps 4800 megawatts to the "pessimistic" case. The lower two estimates would experience a shift as illustrated in Figure 10.

The occasion for this result is that under the original "pessimistic" case, no site with a temperature below 230° C was "on-line" due to the insufficient profit level, nor were sites below 190° C in the "baseline" case. Most of such sites would use a binary cycle plant which is more capital intensive than flash cycle plants. It is the former plants which would receive the relatively greater incentives from changes in the investment tax credit rate and the bond rate.

A combination of both an increase in the investment tax credit rate by 4 percentage points and a decline in the bond rate by 2 percentage points would

Figure 10. Time-Phased Scenarios With Policy Incentives

perhaps add another 2000 megawatts to the "pessimistic" case and bring the "baseline" case approximately to the maximum. In short, it could be said with a great deal of certainty that altering those two policy parameters in the amounts indicated could result in production of 11,000 to 20,000 megawatts of geothermally generated electricity on-line by about the year 2020 within the region. There is almost no doubt that by the year 1990, almost 6,000 megawatts of electricity could be on line. In the absence of these two policy initiatives, the probability that only 3000 MW would be on line is equal to that 5000 MW being on line. It should be added here, at least parenthetically, that any policy action which reduced the cost-of-capital to both the geothermal producers and the electric utilities in an amount equivalent to the policy actions indicated would have a similar result.

REVIEW AND SUMMARY OF POLICY ANALYSIS

Under "optimistic" conditions for development, almost all resource areas within the Southwest Region will probably develop. Under "pessimistic" conditions, in the absence of financial incentives on the part of government agencies, only those sites with temperature greater than 230°C are likely to develop. To insure the speedy development of geothermal resources, DOE-DGE should concentrate its efforts on those activities which will enhance the viability of low temperature electric sites. Any activity which will lower the cost-of-capital by an amount equivalent to an increase in the investment tax credit rate by four percentage points and to a decrease in the bond rate by two percentage points would result in an additional 5,000 to 7,000 megawatts of electricity generated from lower temperature sites in the Southwest Region by the year 2015. This would be a significant addition to the Southwest's electrical generating capacity.

THE MARKET FOR ELECTRICITY

As noted under the "Research Philosophy" section above, even if all other conditions are favorable for the development of a geothermally powered electric plant, the demand for the additional capacity may not exist. Because geothermal energy is a "marginal" power source, in the absence of sufficient demand, utilities will probably not substitute geothermal plants, e.g., for coal fired plants.

In order to estimate the potential utility of geothermal powered electric plants, it was then necessary to accomplish two tasks. First, it was essential to estimate the relationship between the quantity of electricity demanded and other causal factors, and project those causal factors to the year 2020 to estimate electricity needs through the time period. Second, it was necessary to ascertain the planned capacity within the region to determine whether or not a deficiency might develop. We turn first to a discussion of electric energy consumption and its projection.

ELECTRIC ENERGY CONSUMPTION

Economic theory tells us that the quantity purchased of any commodity is a positive function of income, the number of consumers, and the prices of substitutes and a negative function of price. In addition, the consumption of any commodity should also be a positive function of the consumption of complementary products. In order to economically estimate the relationship between the quantity of electricity and other assumed causal factors, it is necessary to specify a mathematical relationship between the variables. This was done following Mount, Chapman, and Tyrrell [6].

We begin by specifying that Electricity Consumption is a function of its own price, the price of natural gas (a substitute), per capita income, population and the stock of electricity-using consumer durables. We furthermore

specify a model that constrains electricity consumption to a constant elasticity of growth with respect to its causal variables. This may appear restrictive, but (1) observation of long run trends suggests such an assumption, (2) the resulting model yields a good fit with historical data, and (3) it is the common practice.

$$QE_t = ae^{\lambda t} PE_t^{\beta_1} PNG_t^{\beta_2} PCI_t^{\beta_3} POP_t^{\beta_4} \quad (1)$$

where QE_t = Quantity of electricity consumed in year t
 PE_t = Average Price of Electricity in year t
 PNG_t = Price of Natural Gas in year t
 PCI_t = Per capita Income in year t , constant \$
 POP_t = Population in year t
 $a, \lambda, \beta_1, \beta_2, \beta_3$, and β_4 are the constants to be estimated
 e = Natural logarithm constant

For the purposes of estimation, equation (1) is transformed to the linear equation (2). The short-run elasticity of QE with respect to each variable is $\beta_i/(1-N)$. Equation (2) was estimated using pooled cross-section and time series data. Estimation of β_1 using strictly time-series data can result in multicollinearity due to

$$\ln QE_t = \ln a + \lambda t + \beta_1 \ln PE_t + \beta_2 \ln PNG_t + \beta_3 \ln PCI_t + \beta_4 \ln POP_t \quad (2)$$

the strong trend element in all independent variables. Estimation using strictly cross-section data yields no reason for confidence in projection through time. The variable λ is introduced to account for the adjustment of consumers to consumption levels through time and insures homoskedasticity of estimated parameters.

Table 10 presents the results of the regression analysis and a test calibration of the estimated model.

Using this estimation of the relationship between the quantity of electricity consumed and the causal variables, the next step was to project the quantity

Table 10

Results of the Forecasting Model

$$QE = (1.39)PE^{-.134} PNG^{-.095} PCI^{.234} POP^{1.978} a^{.009c}$$

Percentage of Variance Explained = 100%

Year	Actual (GWN)	Calibration Predicted (GWN)	% error
1961	21.900	21.824	-0.35%
1962	23.500	23.646	0.62%
1963	25.700	27.713	0.05%
1964	27.481	27.210	-0.99%
1965	28.760	28.835	0.26%
1966	29.800	29.910	0.37%
1967	31.519	31.605	0.27%
1968	33.730	33.879	0.44%
1969	37.879	37.709	-0.45%
1970	41.079	40.944	-0.33%
1971	44.679	44.665	-0.03%
1972	49.740	49.491	-0.50%
1973	54.538	54.822	0.52%
1974	57.203	57.524	0.56%
1975	59.221	58.939	-0.46%

of electricity demanded through the year 2020. This of course involves, first, the projection of causal variable values through 2020, thus engaging the researcher in a guessing game concerning the future. For example, although it is doubtful that the population of the United States will grow much more rapidly than one percent per annum at any time in the future, migration may result in population increases within the area of 1.2 to 1.5%. Real per capita income may grow at a rate of between 2.5% to 3.5%. The range of likelihood around these potential growth rates is fairly small and so 1.35% annual population growth was assumed and a 3% annual growth rate was assumed for real income.

The range of uncertainty for projections in the growth of electricity consumption is due then to uncertainty concerning the price of electricity and the price of natural gas. In 1976, National Economic Research Associates (NERA) in a study for the Arizona Nuclear Power Project [1] used company data to arrive at higher and lower level estimates for real price escalations in electricity and natural gas. NERA estimated a range in real price escalation for electricity of about 1% - 3.5% per annum and in natural gas of about 1.8% - 5% per annum. These are consistent with other estimates. We have, therefore, produced four projections for electricity consumption using (1) a higher growth rate in price for electricity and also a high rate for natural gas, (2) high for electricity, low for gas, (3) low for electricity, high for gas, and (4) low for gas and electricity. These are designated in Table 11 as I, II, III, and IV, as well as illustrated in Figure 11.

These projections have been translated into Megawatts of required capacity and illustrated in Figure 5 according to the following formula. The number for GWH has been translated into MW by multiplying GWH by $10^6/8760$. This average MW figure has been multiplied by 1.5 in order to account for peak loading. Another 0.15 has been added for reserve capacity.

Table 11
Sensitivity Analysis Parameters
For Projections Of Electricity Consumption

CASE	I	II	III	IV
PCI	3.0%	3.0%	3.0%	3.0%
POP	1.35%	1.35%	1.35%	1.35%
FE	3.5%	3.5%	1.0%	1.0%
PNG	5.0%	1.3%	5.0%	1.3%

Figure 11. Projections of Demand for Electricity in the Five State Region

Electric utilities have been polled within the region and capacity increments already in the planning or building state ascertained. There are currently some 20,708 MW on line and by 1986, an additional 16,083 MW are planned. Assuming that approximately ten percent of the increment is for replacement and that, on average, power plants consume 18 percent of power produced, and an additional ten percent is lost in transmission, planned effective capacity for 1986 is 25,965 MW, where it is currently 15,282 MW. If it is further assumed that the current proportion of export to sales remains constant at about 26 percent, the effective planned domestic (within the subject 5 states) capacity in 1986 is about 19,214 MW. Given reasonable growth projections as illustrated in Figure 12, this capacity should carry the region up to about 1990-1995. Depending upon replacement needs, additional capacity may be required prior to 1990. By the year 2020, this region may require an additional 30,000 MW (NET) of electric capacity for domestic consumption alone, and perhaps another 10,000 to 15,000 MW (NET) for export. Power plants driven by geothermal steam could provide 15-30 percent of the region total electric capacity if it can become an economically viable alternative.

Figure 12. Projections of Required Plant Capacity in the Five State Region

REFERENCES

1. K. P. Anderson, Sales and Load Growth of Participating Companies, Arizona Nuclear Power Project. 1974-1978, New York: National Economic Research Association, 1976.
2. Edison Electric Institute, Report on Economic Growth in the Future, New York, 1976.
3. J. Johnston, Econometric Methods, New York: McGraw-Hill Book Co., 1972.
4. Jet Propulsion Laboratory, Program Definition for the Development of Geothermal Energy, Pasadena, California Institute of Technology, 1975.
5. J. N. Gupta, and J. G. Leigh, GELCOM: A Geothermal Levelized Busbar Cost Model, Mitre Corporation Report No. M78-17, January 1978.
6. T. C. Mount, L. D. Chapman, and T. J. Tyrrell, Electricity Demand in the United States: An Econometric Analysis, Oak Ridge, Tennessee, Oak Ridge National Laboratories, 1973.
7. Stanford Research Institute, Economic Analyses of Geothermal Energy Development in California, Vol. I and II, Menlo Park, 1977.
8. L. C. Taylor, "The Demand for Electricity: A Survey," The Bell Journal of Economics 6:1, 74-110.
9. United States Comptroller General, Domestic Energy Resource and Reserve Estimates - - Uses, Limitations and Needed Data, 1977
10. United States Geological Survey, Circular 726, 1975.

APPENDIX

Geothermal Algorithm for Electric Power Generation (GIRORA-Electric)

The model which follows posits the very simple economic idea that an investment should be made if the present value of all net income streams is equal to the investment required to generate them when discounted at an interest rate appropriately high.¹ If the amount of an investment is known, and the net income streams are known, the rate-of-return can be calculated. This model attempts to calculate the internal rate-of-return to a producer from a geothermal field for which electricity production is planned. This model can easily be modified to fit any type of energy production from a geothermal field.

The basic equation is of the simple form for discounting cash flows:

$$\text{Investment} = \sum_{t=1}^T (\text{Net Income}_t) (1 + R)^{-t} \quad (1)$$

where Net Income = (Total Revenues) - (Total Operating Cost) - (Taxes)

Total Revenues = (Price) (Quantity Output)

Total Operating Cost = A Percentage of Investment

R: Rate-of-Return

t: Each year, $t = 1, 2, \dots, T$.

T: Expected life span of the Investment

However, this rather fundamental notion is modified somewhat in GIRORA-Electric due to the fact that some investments are made throughout the life of the project and thus must also be discounted to the present for proper evaluation. This yields the equation,

$$\sum_{t=1}^T (\text{Investment}_t) (1 + R)^{-t} = \sum_{t=1}^T (\text{Net Income}_t) (1 + R)^{-t} \quad (2)$$

¹For a discussion of this principal, see Fred R. Glahe Macroeconomics (New York: Harcourt, Brace, Jovanich, Inc., 1973), pp. 91-95

which reduces to

$$\sum_{t=1}^T (\text{Investment}_t) (1 + R)^{-t} = 0 \quad (3)$$

If we set $(1 + R)^{-1} = b$, then

$$\sum_{t=1}^T (\text{Investment}_t - \text{Net Income}_t) b^t = 0 \quad (4)$$

Equation (A.4) is a polynomial with T roots. Assuming a monotonic function there will be one real (non-imaginary) root (b) which permits a solution for the equation. This root can be found iteratively by Newton's technique.² Fortunately, GIRORA-Electric has generated only monotonic functions.

GIRORA-Electric simulates all investment, revenue, and cost flows for a specified resource site, and inputs the flows to equation (3) and solves for R.

Investment, revenue and cost flows are divided into two sectors, a geothermal developer sector, and an electric utility sector. The geothermal developer's revenues are operating costs as perceived by the electric utility. The electric utility demand for geothermal fluid (or steam) is derived from the demand for electricity. Once a quantity of electricity has been specified, given resource characteristics, the quantity of fluid or steam is automatically specified. The price of the geothermal energy is the highest price consistent with the competitive price of electricity and the electric utility's regulated rate-of-return (both which are assumed to be known). The description of GIRORA-Electric begins with a description of the Electric Utility Sector.

Electric Utility Sector

The model first identifies the principal components of cost to the electric utility for each year (t) of electricity production: capital costs (CC_t),

²For a description of the mathematical technique involved, see C. C. T. Baker, Dictionary of Mathematics, (New York City, Hart Publishing Co., 1966), p. 206.

operating costs (OMC_t), income taxes (ITX_t), property taxes (PTX_t), and energy costs (ENC_t).

Capital costs are a function the investment (K) required for a specified level of capacity in kilowatts (CAP).

$$K = (CAP) (CAPC) \quad (5)$$

CAPC: capacity cost in dollars per KW; an input parameter

Capital costs are also a function of the regulated return to equity (ER), the bond rate (BR), the debt to equity ratio, and depreciation ($DEPR_t$).

$$E = (EK) (K) (ER), \text{ (equity costs),} \quad (6)$$

$$D = (DK) (K) (BR), \text{ (debt costs),} \quad (7)$$

$$DEPR_t = (DEP_t) (K), \text{ (depreciation),} \quad (8)$$

and therefore

$$CC = E + D + DEPR \quad (9)$$

where, EK: equity share of capital; an input parameter,

DK: debt share of capital; an input parameter

$$(EK = 1-DK)$$

$$DEP_t: \text{depreciation rate in year } t; \quad (10)$$

$$DEP_t = (T + 1 - t) / \sum_{t=1}^T t,$$

where T is the length of time for electricity production. The model provides for a fast write-off option.

Operating costs are a function of total investment and escalate through time.

$$OMC_t = (OC_t) (K) \quad (11)$$

$$OC_t = (OCB) (1 + \dot{OC})^t \quad (12)$$

OC_t : operating percent of investment in year t; input variable

OCB: base rate; input variable,

$\dot{OC}$: escalation rate; input variable

Likewise, property taxes are a function of investment.

$$PTX = (PTP) (K). \quad (13)$$

PTP: property tax rate; input variable

Before income taxes are calculated, total revenues must be known. They are, of course, a function of the price of electricity (PE_t) and the quantity of electricity (QE), which is a function of plant capacity. PE_t is specified as an exogenous busbar price of electricity which is determined by the market and escalates over time.

$$PE_t = (PB) (1 + \dot{P})^t \quad (14)$$

PB: Base busbar price of electricity; input variable.

P: escalation factor; input variable

$$QE = (CAP) (8760) (LF) (1-UF) \quad (15)$$

LF: Plant factor; an input variable,

UF: Plant use of power; an input variable.

Income taxes and energy costs must be determined simultaneously, because the price of the geothermal energy (PHW_t) is an element of both and moreover, PHW_t is the output of the utility sector for the model. The quantity of geothermal energy is determined by electricity plant requirements.

$$QHW = (CAP) (8760) (LF) \quad (16)$$

$$ENC_t = (PEW_t) (QHW) \quad (17)$$

$$ITX_t = \{TXRT\} \{[(PE_t) (QE)] - [OMC_t] - [PTX] - [ENC_t] - [D] - [DEPR_t]\} - \{[CRRT] [K_{t=1, t=2, t=3,}]\} \quad (18)$$

TXRT: income tax rate; input variable

CRRT; investment tax credit rate; input variable

Therefore,

$$PHW_t = \frac{(TXRT) (DEPR_t) + (CRRT) (K_{t=1, t=2, t=3,}) - (CC_t)}{(QHW) (1-TXRT)} + \frac{(PE_t) (QE) - (CMC_t) - (PTX)}{(QHW)} \quad (19)$$

The price of energy in year (t) from (15) and the quantity of energy from (12), that is, ENC_t (equation 17), become total revenue for the geothermal energy producer.

Geothermal Energy Producer Sector

We will recall equation (17) ENC_t for the producer, REV_j , or total revenues.

$$REV_j = ENC_t \quad (20)$$

First, a discussion of the time period involved is necessary. The producer's time horizon is different from that of the electric utility. The years t are elements of T , while the years j are elements of J . $J - T = PPY$, the "pre-production years." PPY is composed of two periods. The exploration period (EXP) and the development period (DVP), and thus $EXP + DVP = PPY$. Thus, the determinative direction is $EXP + DVP + T = J$. EXP is the period during which only exploratory wells are drilled. The development period begins with the drilling of the first production well.

The producer's activity is modeled somewhat differently from the utilities because the output of the simulation is a rate of return on the producer's equity. Thus, the first order of business is to determine what the level of the investment is in each year of the project. The producer's investment (PNV_j) is a share of the total investment in year J (PPK_j).

$$PNV_j = (EPK)(PPK_j) \quad (21)$$

$$PPK_j = (LNV_j) + (DNV_j) + (IDC_j) + (OPNV_j) \quad (22)$$

EPK: Equity portion of capital; an input variable,

LNV_j: Leasing investment in year j , in \$,

DNV_j: Drilling investment in year j , in \$,

IDC_j: Interest cost during construction in year j , in \$,

OPNV_j: Other producer investments in year j , in \$,

Total investment by the producer, cumulative to year j is

$$PK_j = \sum_{i=0}^j PKK_i \quad (23)$$

We will first describe the calculation of each element of PKK_j , beginning with DNV_j .

$$DNV_j = \left[\left(\frac{NPW_j}{PSS} \right) (ADDP) (CPFP) \right] + \left[\left(\frac{NIW_j}{ISS} \right) (ADDI) (CPFI) \right] \quad (24)$$

NPW_j : New producing wells in year j.

PSS : Production Well Success ratio,

$CPFP$: Cost per foot, producing wells,

NIW_j : New injection wells in year j,

ISS : Injection well success ratio (= 1 usually),

$ADDI$: Average depth of injection wells,

$CPFI$: Cost per foot of injection wells.

The calculation of the elements of DNV_j is shown below.

$$NPW_j = RPW_j - RPW_{j-1} \quad (25)$$

RPW_j : required producing wells, $RPW_j = 0$ when $j < EXP + 1$.

$$RPW_j = \frac{RFR_{CAP}}{FR} \quad (26)$$

FR : Flowrate in lb/hr per producing well,

RFR_{CAP} : required flowrate for rated capacity in lb/hr.³ (27a)
(CAP is stated here in MW, not KW, and is net of UF.)

$$RFR_{50} = 1374.912e^{-0.01379 (TEMP)} \quad (27b)$$

$$RFR_{100} = 2667.012e^{-0.01372 (TEMP)}$$

³ Bechtel Corporation, Advanced Design and Economic Considerations for Commercial Geothermal Power Plants at Heber and Niland, California. SAN-1124-2, San Francisco, California, 1977.

$$RFR_{150} = .3959.226 e^{-0.013655 (TEMP)} \quad (27c)$$

$$RFR_{200} = 5251.44 e^{-0.01359 (TEMP)} \quad (27d)$$

Temperature decline is estimated, and resulting need for increased flow rate, thus producing wells, is modeled in the following way:

$$Temp = \frac{T_0}{360} [358.344 e^{-0.00144(Time)}], \text{ for CAP} = 50MW \quad (28a)$$

$$Temp = \frac{T_0}{360} [357.474 e^{-0.00233(Time)}], \text{ for CAP} = 100 MW \quad (28b)$$

$$Temp = \frac{T_0}{360} [357.12 e^{-0.00322(Time)}], \text{ for CAP} = 150 MW \quad (28c)$$

$$Temp = \frac{T_0}{360} [357.769 e^{-0.00411(Time)}], \text{ for CAP} = 200MW \quad (28d)$$

T_0 : downhole temperature of brine in °F, an input variable.

$$NIW_j = RIW_j - RIW_{j-1} \quad (29)$$

RIW_j : required injection wells in year j .

$$RIW_j = RPW_j (PIR)^{-1} \quad (30)$$

PIR : required ratio of producing wells to injection wells, in year j , an input variable.

After initiation of power generation, NPW_j and NIW_j will generally take on a value of 0 or 1, but are arbitrarily allocated during DWP.

The remaining elements of PKK_j are discussed below:

$$LNV_j = [(DPAC)(ACPW)(NPW_j)] + [(DPAC)(ACIW)(NIW_j)] \quad (31)$$

$DPAC$: dollars per acre leasing cost; input variable,

$ACPW$: acres per producing well; input variable,

$ACIW$: acres per injection well; input variable.

$$OPNV_j = EXPN_n + PIPN_j + ONV_j \quad (32)$$

$EXPN_j$: exploration investments, year j ,

PIP_j: piping investments, year j,

ONV_j: other investments, year j.

$$\text{EXP}_j = f(\text{EXPN}) \quad (33)$$

$$\text{EXPN} = (\text{EXD})(\text{CAP}) \quad (34)$$

EXD: dollars per unit of capacity (electric needed for exploration, on average; input variable.

$$j > \text{EXP}, \text{EXP}_j = 0$$

EXPN: total exploration investment in \$

(Note: $\text{EXPN} = \sum_{j=0}^{\text{EXP}} \text{EXP}_j$, where the distribution function is chosen arbitrarily)

$$\text{PIP}_j = (\text{PIP})(\text{DNV}_j) \quad (35)$$

PIP: average percentage of drilling investment required for piping and similar field developments.

$$\text{ONV}_j = (\text{OPE}_j)(\text{DNV}_j) \quad (36)$$

$$\text{OPE}_j = (\text{OPEB})(1+\text{OPF})^j \quad (37)$$

Equations (A.37) and (A.38) calculate estimate additional investments in field development which are related to drilling expenses.

$$\text{IDC}_j = [\text{BR}] [\text{DPK}] \left\{ \sum_{i=0}^j \text{LNV}_i + \sum_{i=0}^j \text{DNV}_i + \sum_{i=0}^j \text{OPNV}_i \right\} \quad (38)$$

$$\text{IDC}_j = 0 \text{ for } j > \text{PPY}.$$

DPK: debt portion of capital; $\text{DPK} = 1 - \text{EPK}$.

Thus, total revenues and all elements of investment have been calculated. What remain are uncapitalized elements of cost. OMCP_j are operating and other current outlays.

$$\text{OMCP}_j = [(\text{OCP}_j)(\text{PK}_j)] + [(\text{BR})(\text{PK}_j)(\text{DPK})] + [\text{PTXP}_j] \quad (39)$$

$$OCP_j = (OCPB)(1+OCP)^j \quad (40)$$

OCP_j: operating percentage of investment outlay,

OCPB: base percentage; input variable,

OCP: escalation factor.

PTXP_j: property taxes.

$$PTXP_j = (PTPP)(PK_j) \quad (41)$$

PTPP: property tax rate; input variable.

Income taxes are as follows:

$$ITXP_j = \{TXRT\} \{[(REV_j)(1-\lambda)(1-Z)] - OMCP_j - [(Y)(DNVD_j)]\} \\ - \{[CRRT][(1-Y)(\sum_{i=j-2}^j DNVD_i)]\} \quad (42)$$

$$DNVD_j = \sum_{i=1}^j DNVD_i (DEPRP_{j-i+1}) \quad (43)$$

$$DEPRP_j = (D + 1 - j) / \sum_{j=1}^D j \quad (44)$$

D: period chosen for depreciation; input variable

λ: royalty rate, input variable,

Y: percentage tangible investment, input variable,

Z: depletion allowance, input variable,

DNVD_j: depreciation allowance in year j, \$

DEPRP_j: depreciation rate in year j. Program contains fast write-off option.

Finally, the model solves for R, the rate of return to equity for the geothermal energy producer from the Jth degree polynomial given by

$$\sum_{j=1}^J \{[(REV_j)(1-\lambda) - (OMCP_j) - (ITXP_j)]\} e^{-Rj} = 0 \quad (45)$$

The R thus solved is one criterion for ranking geothermal resource sites and for comparing the outcomes of policy variable changes.