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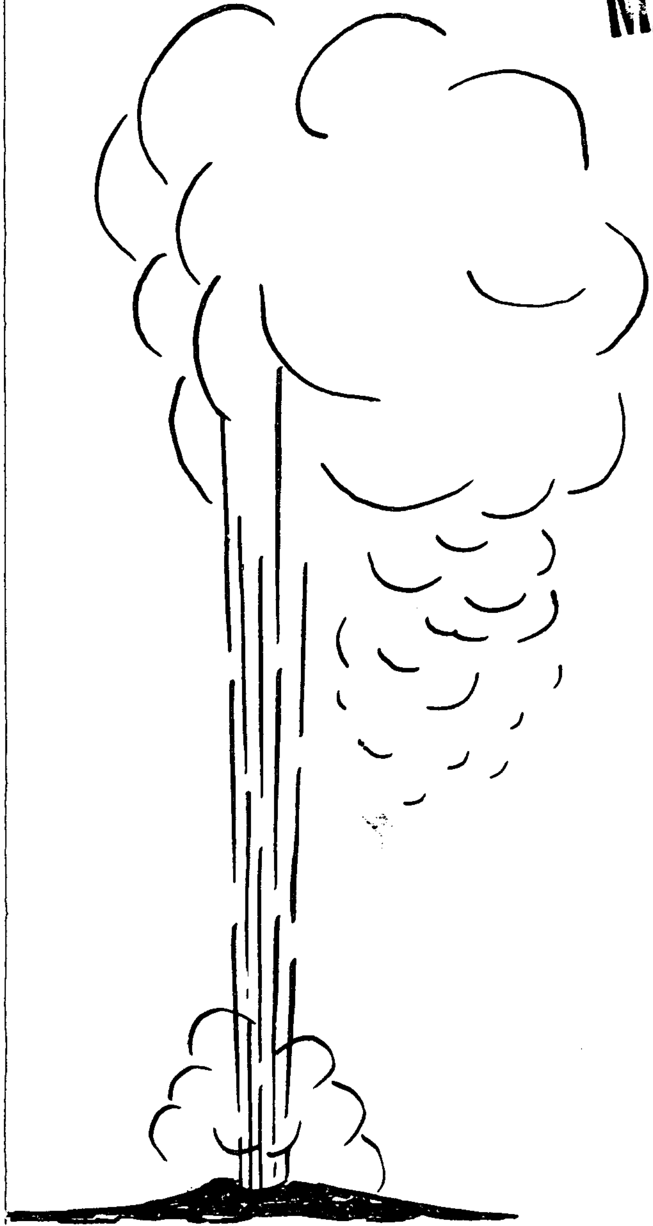

THE DISTRICT SPACE HEATING POTENTIAL OF LOW TEMPERATURE HYDROTHERMAL GEOTHERMAL RESOURCES IN THE SOUTHWESTERN UNITED STATES

Technical Report

By
P. K. McDevitt
C. R. Rao

October 1978

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ABSTRACT

A computer simulation model (GIRORA-Nonelectric) is developed to study the economics of district space heating using geothermal energy. GIRORA-Nonelectric is a discounted cashflow investment model which evaluates the financial return on investment for space heating. This model consists of two major submodels: the exploration for and development of a geothermal anomaly by a geothermal producer, and the purchase of geothermal fluid by a district heating unit. The primary output of the model is a calculated rate of return on 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 in this report.

Using the results of the economic analysis and technological screening criteria, all the low temperature geothermal sites in Southwestern United States are examined for economic viability for space heating application. The methodology adopted and the results are given in this report.

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Introduction

Much of the analysis of geothermal energy potential in the United States in recent years has shifted from the study of electricity generation to non-electric applications. These latter uses are often referred to as direct applications, in contrast to electricity generation which is an indirect application.(1) There are a number of factors which have generated widespread concern for direct applications.

First, recent documentation of geothermal resources in the United States has revealed a large disparity in the endowment of low temperature versus high temperature resource sites. In the Southwest (Arizona, Colorado, Nevada, New Mexico, and Utah), 504 low temperature resource sites ($T \leq 150°$) have now been identified [5, Appendix C]. The sheer abundance of low temperature geothermal resources seems, therefore, to warrant further investigation.

Early estimates of the energy potential offered by low temperature anomalies were promising. The most widely cited of these estimates was Reistad's [12]. Reistad calculated that if all geothermal resources up to 200°, 150°, and 100°C could be used for space heating, 40, 30, and 20 percent, respectively, of total United States energy needs could be met. Although these projections are impressive, some stringent assumptions were employed in the calculations. In particular, many low temperature sites included in these projections could not be harnessed because of the imperfect mapping of resource supply and demand sites.

A second reason for the recent upsurge of interest in direct geothermal applications is that such a large proportion of the nation's energy demands

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(1) A full discussion of potential direct applications may be found in [9].

are for relatively low temperature space heating needs. Again, Reistad estimated that 10,857 x 10^{12} BTU or 18 percent of the 1968 United States fuel consumption was for space heating alone [12]. If geothermal energy proves practical and economical on a broad regional scale, this demand may easily be met. Further energy needs, such as for water heating and cooling, air conditioning, and refrigeration might also be met from low temperature geothermal resources.

The space heating potential of geothermal energy was also examined by Kunze and Richardson, who combined Reistad's geothermal supply estimates with some energy demand projections combined at the Stanford Research Institute [10]. The objective of this exercise was to determine the proportion of estimated 1985 space heating needs that could be met with geothermal energy. Ignoring some admittedly pertinent economic considerations, they estimated that roughly 35 percent of the projected space heating needs could be geothermally supplied. Again, however, the locational problem of matching supply and demand sites was ignored.

A final explanation for heightened interest in low temperature geothermal resources is that present and future low temperature energy needs are not efficiently served by existing technology using traditional fossil fuels. For example, Hardy and Chiang employed an "efficiency of fuel utilization co-efficient" of 0.65 to acknowledge the inefficiency of using fuel oil for space heating in South Dakota [4]. Others have estimated the heating efficiency of natural gas to be only 75 percent [6]. These compare unfavorably with the 100 percent efficiency of geothermal energy.

For these reasons, at least, the district space heating supply potential of low temperature hydrothermal geothermal resources in the Southwestern United States will be examined in this report. Those pertinent locational and economic considerations which have been ignored in previous efforts will be explicitly recognized and fully incorporated. In order to achieve this objective, the report is organized as follows:

1. A complete assessment of the regional resource endowment will be compiled. The resource base will be divided into two groups, including those which are usable and those which are not usable given current recovery and production technologies.
2. An economic simulation model, GIRORA, will be employed to evaluate the financial feasibility of existing resources.
3. The significance of numerous energy policy variables and geophysical resource characteristics will be assessed through a number of GIRORA modeling exercises.
4. A financial analysis of the technologically usable resource sites will be conducted to identify those resources which offer a minimum acceptable level of profitability.

The cumulative results of these findings will provide, for the first time perhaps, a realistic estimate of the regional district space heating supply potential of low temperature geothermal resources in the Southwest.

A Technological Screening of the Regional Low Temperature Resource Endowment

A complete baseline inventory of known low temperature anomalies as well as their estimated energy supply potential is presented in Appendix A. This information is summarized more succinctly in Table 1. This table contains a distribution by state of the low temperature resources and their corresponding energy supply potentials.

The spatial distribution of resources is clearly not balanced. For example, 328 of the 504 (65 percent) known anomalies are located in Nevada. Each of these resource sites is designated with a dot (·) in Figure 1, which conveys a visual impression of the regional endowment. If the energy supply potential of these resources is calculated in MBtuh, a full 78 percent of the

TABLE 1

Distribution of Low Temperature Geothermal Resources by State

State	Number of Resource Sites	Estimated Supply Potential in MBtuh
Arizona	40	1892
Colorado	45	1460
Nevada	328	30423
New Mexico	46	2969
Utah	45	2201
Total	504	38945

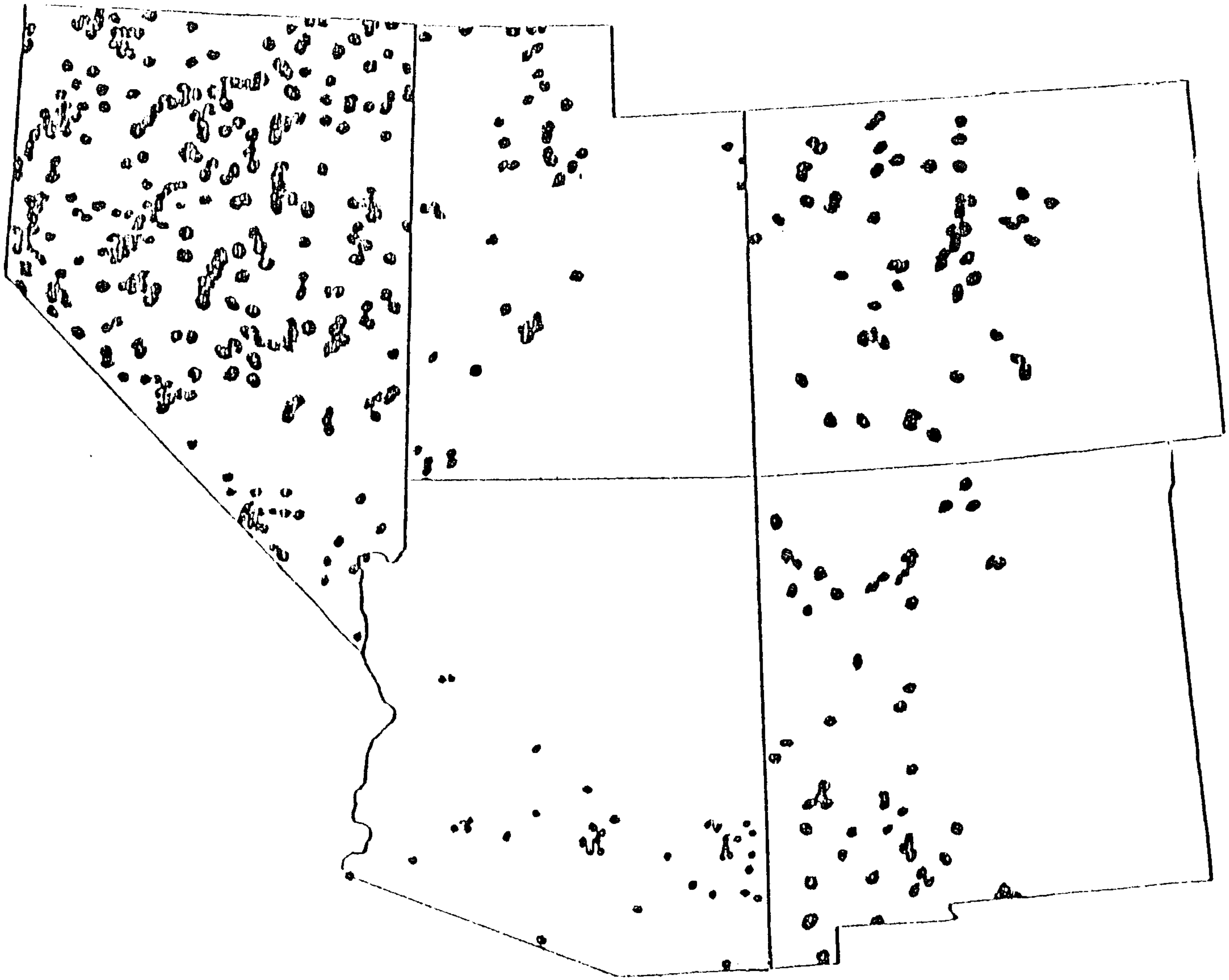

Figure 1 Low Temperature Sites in Southwestern Region

total is located in Nevada. Thus, the state with the smallest population has been the most abundantly blessed with low temperature geothermal resources.

The large number of resource sites and the estimated energy potential designated in Table 1 present a misleading impression of the true potential for space heating with geothermal energy in the Southwest. Given the nature of the resource and the state of production technology, many of these resources offer little if any current space heating potential. The first task which must be undertaken, therefore, is to eliminate from further consideration any resource which, for one reason or other, is not a feasible supply site for district space heating applications.

Accordingly, the initial inventory of low temperature resource sites is subjected to a technological screening.(2) The objective of this exercise is to divide the population of sites into two samples. The first sample consists of sites which are currently usable given the existing state of production technology in the industry. Those sites which fall in the second subgroup are resources which, for one reason or another, are not considered usable given the present state of "know how." As production techniques advance, of course, these latter resources may in time become of substantive importance.

The criteria which were employed to partition the total resource base were threefold. The first is the temperature of the resource. A minimum resource temperature is required for effective space heating just as a minimum temperature is required for electricity generation from hotter resources. Earlier space heating experiences in Klamath Falls, Oregon; Boise, Idaho; and other places were consulted in designating a minimum temperature.

The second criterion is the distance between the geothermal resource and the nearest user market. This consideration is intended to exclude from further study all resources which are not sufficiently proximate to a market to be realistically employed.

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(2) This methodology was first employed by Farah and Williams. See [8].

The final criterion employed for partitioning low temperature resources is the size of the potential market. A minimum feasible market size, which is measured in terms of population, is defined. As there is or is not a market of sufficient size within the designated distance, a resource is or is not considered usable.

The values for the technological screening criteria are presented in Table 2.

The technological screening described above was designed to group geothermal sites on the basis of objective benchmarks. Insofar as these criteria (temperature, distance, and demand) accurately differentiate between the currently feasible and infeasible, then some rough measure of the technological supply potential of low temperature resources in the Southwest is known. This estimate is certainly more realistic than earlier estimates, e.g., by Reistad, in that the locational configuration of supply and demand sites are explicitly recognized.

The results of the preliminary technological screening are informative. The origianl case of candidate sites has been reduced from 504 to just 82. These latter resources are those designated with an asterisk (*) in Column 3 (Comments) of Appendix A. The number of sites remaining and the corresponding estimate of energy supply potential by state are presented in Table 3 below and are mapped in Figure 2.

Both Table 3 and Figure 2 convey a noteworthy impression: of the original 504 sites, only 16 percent are feasible for district space heating given current production expertise. Thus, a rough but realistic evaluation of the regional geothermal supply potential considerably depresses earlier estimates. A set of histograms presented in Figure 3 effectively portrays the reduction in the aggregate supply potential attributable to the technological screening.

TABLE 2

Preliminary Values for Technological Screening Criteria

Distance	$\leq$ 50 Miles
Market Population	$\geq$ 1000 persons
Resource Temperature (T)	$65° \leq T \leq 150°$ C

TABLE 3

Distribution by State of Low Temperature Geothermal Resources Which Pass Initial Technological Screening

State	Number of Resource Sites	Estimated Supply Potential in MBtuh
Arizona	12	1045
Colorado	24	588
Nevada	14	662
New Mexico	19	1724
Utah	13	1580
Total	82	5599

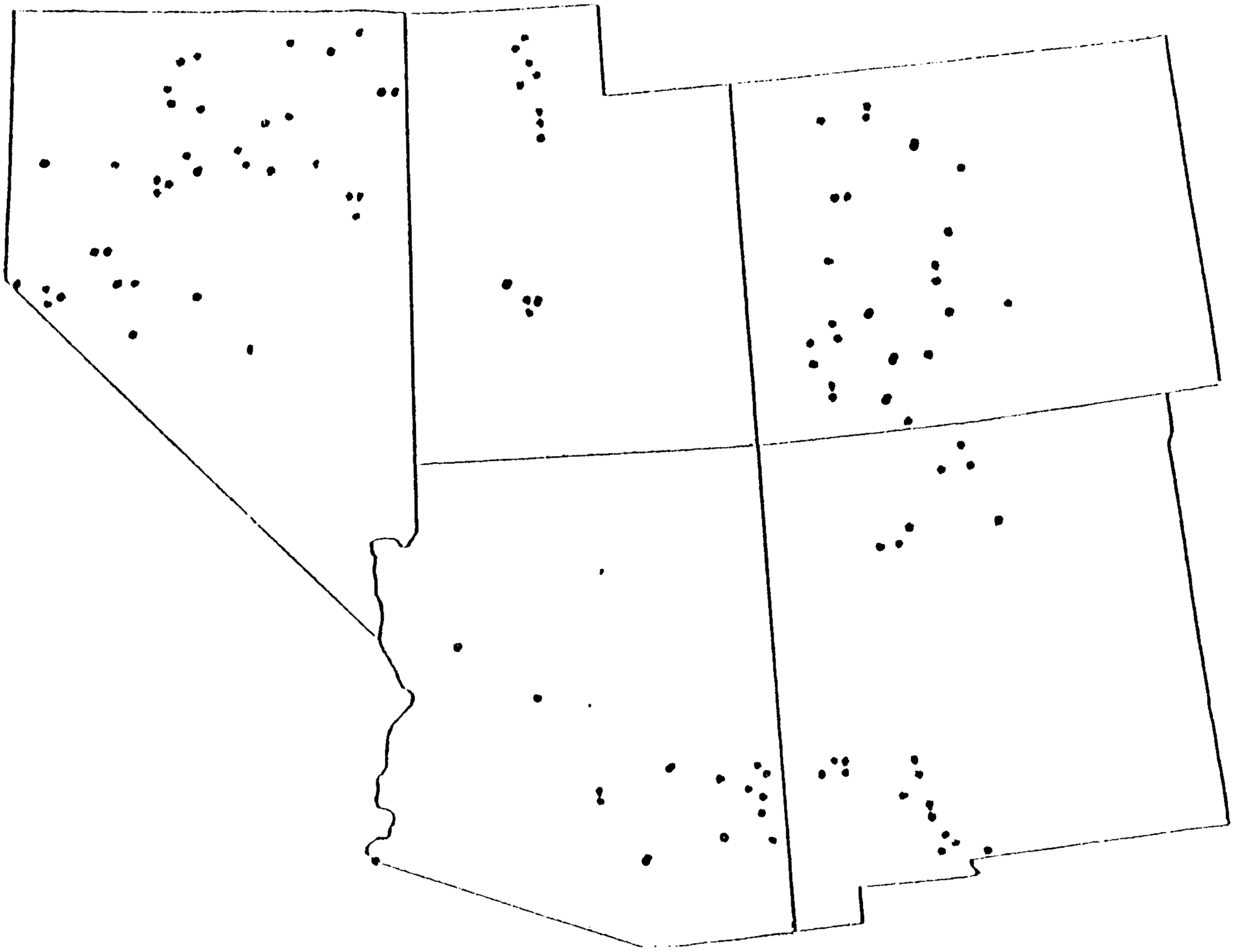

Figure 2 Technologically Feasible Low Temperature Sites in the Southwest.

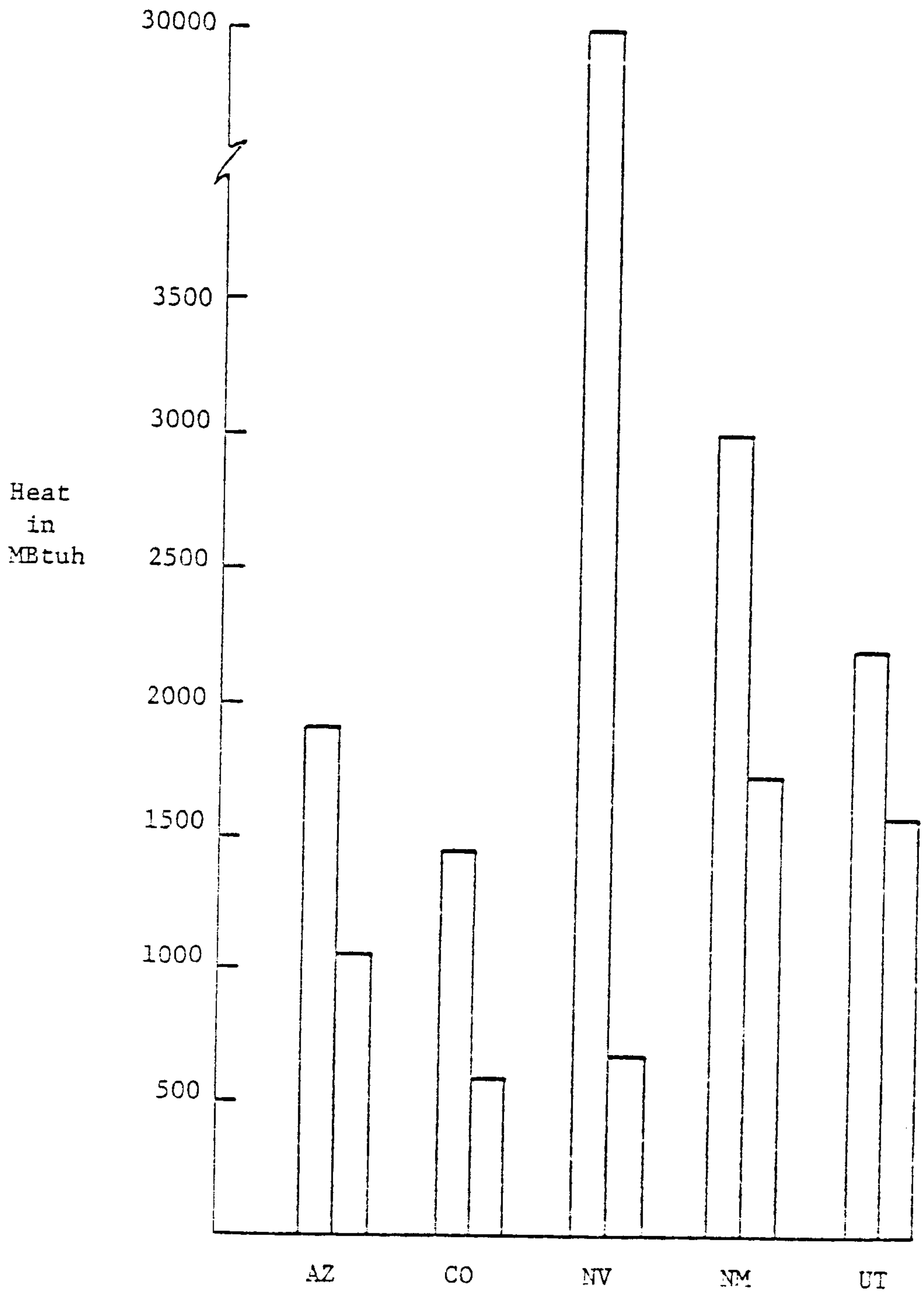

Figure 3 Estimated Energy Potential of Low Temperature Geothermal Energy before and after Technological Screening

Geothermal Internal Rate of Return Algorithm: A Financial Screening Mechanism

Each of the remaining sites will be considered to evaluate its financial potential for space heating. A number of economic considerations which have not yet been introduced will contribute to this judgement. The vehicle to be employed for conducting the economic screening will be described below.

In order to evaluate the economic potential of geothermal energy investment, a discounted cash flow investment model has been developed.

This model is the Geothermal Internal Rate of Return Algorithm (GIRORA). GIRORA is a simple but powerful simulation model which estimates the financial return on investment in low temperature hydrothermal geothermal resources for district space heating. The two sector model simulates: (1) the exploration for and development of a geothermal anomaly by a geothermal producer, and (2) the purchase of geothermal fluid by a district heating unit. The primary output of the model is a calculated internal rate of return on investment earned by the geothermal producer.

This estimate of profitability is analytically useful for a number of reasons. First, of course, the estimated return on investment provides a general measure of market profitability. As technologically feasible geothermal resources are more or less profitable, they are more or less likely to be developed for space heating.(3) Second, if an internal rate of return can be calculated for each geothermal site, then an ordinal ranking of resource areas may be compiled on the basis of estimated profitability. Assuming, ceteris paribus, that the most profitable sites will be developed first, this ranking will provide a unique ordering of geothermal anomalies to be brought "on line." Such information is already in demand to facilitate planning and development efforts.

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(3) Under certain circumstances, the internal rate of return on investment may be deficient as a measure of relative profitability. These circumstances do n however, exist here. For more on this topic, See [2].

The calculation of a site-specific internal rate of return is invaluable for yet another reason. By altering the values of selected variables and parameters within the model, the sensitivity of the rate of return to a number of pertinent factors may be determined. In particular, those factors which heavily influence the return on investment and which are also susceptible to policy manipulation are of acute concern.

A detailed discussion of the GIRORA model is presented in Appendix B. The analytical methodology employed in the calculation of the rate of return on investment, R, and the modeling assumptions which are employed in its calculations are clearly explained. In the following section, therefore only the results of the GIRORA modeling are presented.

Modeling Results

Simulation experiments with GIRORA were designed to evaluate the economic potential of the technologically feasible resource base. Three exercises which yielded a number of interesting and highly informative results were undertaken. First, a baseline scenario was proposed, and the resulting internal rate of return was estimated. This might be considered the case of a hypothetical geothermal developer working on a hypothetical geothermal resource site. From a methodological perspective, the baseline scenario provides a starting point for the subsequent analyses. The second exercise consisted of conducting sensitivity analysis. Changes in selected features of the baseline model were proposed, and the resulting impacts upon the internal rate of return were measured. Finally, several market scenarios were proposed and the rates of return were forecasted. An "Optimistic" and a "Pessimistic" scenario were specified based upon selected values of key determinants of R. The purpose of this exercise was to define, insofar as possible, practical limits to the bounds of potential geothermal resource development.

The Baseline Case

The baseline case depicts a geothermal resource being harnessed to provide space heating. Table 4 summarizes the values specified for all manual inputs and major choice and parametric model variables.

A geothermal resource with a temperature of 100°C is assumed to be the candidate resource. It is located five miles from a population center of 5,000 persons for whom space heating is to be provided. The load factor of the unit is assumed to be 0.6 and the price of natural gas with which geothermal energy must compete is $\$3.00/10^6$ BTU. As for the geothermal producer, an investment tax credit rate of 0.12 is assumed; a royalty rate of 0.15 is assumed; the depletion allowance is zero; and the cost of debt capital is 8.5 percent. Finally, a debt equity ratio of 0.7/0.3 is assumed.

The estimated rate of return for this baseline case is 11.0%. Under the conditions specified, therefore, the prospects for space heating appear to be encouraging. Accordingly, the results of the sensitivity analysis become increasingly important, since they will reveal which factors might prove most influential in altering the internal rate of return on investment.

The Sensitivity Analysis

The values of the physical, geophysical and policy factors specified in Table 4 are variable in this model. Each of these factors exerts impacts upon the rate of return which are, for the most part, clearly defined but quantitatively unspecified. For the sake of convenience, these factors have been grouped into several classes. The first class includes the geophysical factors, and the second class includes policy variables and parameters. The role of the geophysical factors in influencing R will be examined first.

Consider the ramifications of variations in resource temperature upon the estimated rate of return. In this analysis, the temperature span considered

TABLE 4

The Baseline Case Values

Parameter or Variable	Base Case Value
Temperature	100°C
Distance	5 miles
Population	5,000
Load Factor	0.6
Price of Natural Gas ($\$/10^6$BTU)	$3.00
Investment Tax Credit Rate	0.12
Royalty Rate	0.15
Depletion Allowance	0.0
Producer Bond Rate	0.085
Equity Capital	0.3
Internal Rate of Return (R)	11.0%

ranges from 80° to 150°C. The differing values of R at each temperature are illustrated in Figure 4.

The changes in resource temperature clearly exert only minimal impacts upon R. If all other parameters and variables considered are maintained at their base case values, the rate of return is 11 percent at 80°C, and it rises to just over 12.5 percent at a temperature of 150°C. Such a finding, that lower temperature resources generate nearly as high a return as the hotter resources is encouraging given the abundance of relatively lower temperature anomalies in the Southwest.

Consider next the importance of the distance to the market as a determinant of the internal rate of return. Given the potentially large size of the transmission expense, changes in distance can be expected to exert substantial impacts upon R. Figure 5 depicts the effects of differences in distance between 0 and 25 miles when all other base case values are held constant. In order to maximize the information provided, the estimated rate of return is plotted against the resource temperature. In this manner, the interactive impacts of changes in distance and temperature become evident.

The distance over which geothermal fluid must be transported strongly influences R values for a given resource site. For example, at distances of 5, 15, and 25 miles, the rate of return falls from 12.75 to 10.0 to -0.25 percent at 120°C. In the case of a user who is located on site (distance = 0), an estimated 21.5 percent return would be earned. For space heating purposes, therefore, the distance between the resource and the user is of major importance in determining the financial return on investment in geothermal energy development.

The third geophysical parameter in which we are interested is the population of the district heating unit. Variations in population will alter both revenues earned and investment costs sustained. To clarify the net impacts upon R, population sizes of 1000, 2000, 3000, 4000, 5000, 10,000, 15,000, and 25,000

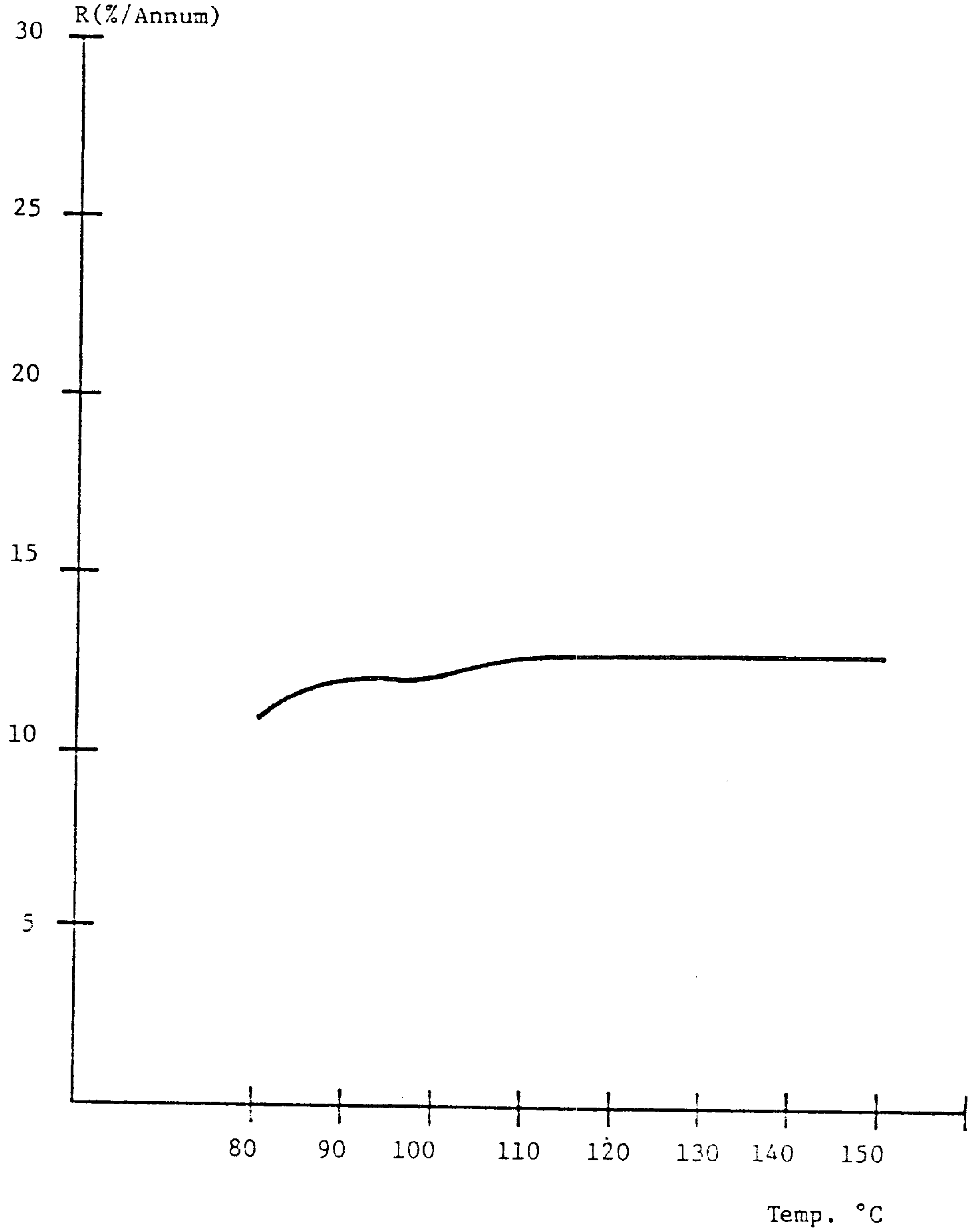

Figure 4. Sensitivity of R to Changes in temperature.

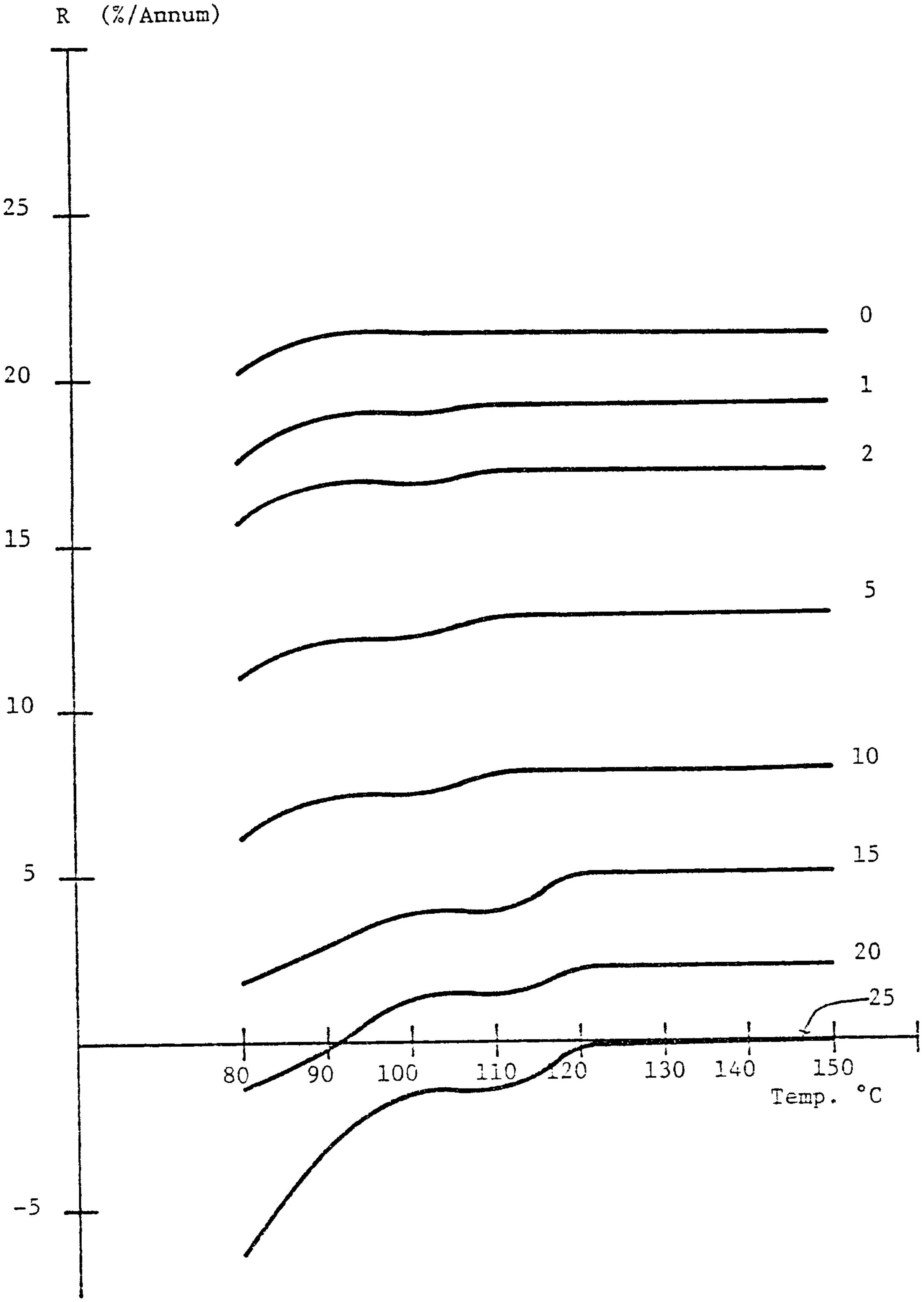

Figure 5 Sensitivity of R to Changes in Distance (in miles)

have been proposed. Figure 6 summarizes the results for various temperatures between 80° and 150°C.

The results are highly informative. Changes in the rate of return are directly related to changes in population at all temperatures. For example, at 120°C, the return on investment rises from 0.75 percent to a healthy 18.5 percent as the population increases from 1000 to 25,000. These findings indicate that sizeable financial incentives exist for investment in space heating for relatively larger versus smaller communities.

The analysis above of the roles of the physical and geophysical resource characteristics in determining the return on investment in geothermal energy provided clear results: for anomalies with temperatures between 80° and 150°C, those which are closer to the largest populations offer the greatest financial incentive. Among the other factors in the model which are of concern are a class of parameters and variables which are, in some sense, policy tools. Some of these have been traditionally employed for stimulating natural resource development. Six policy tools are considered here. These include the royalty rate, the bond rate of the producer, the price of home heating fuels with which geothermal energy must compete, the depleting allowance, the investment tax credit rate, and the system load factor. The role of each of these in determining R is considered below.

The influence of the royalty rate in determing R is ascertained by altering its value from 0.10 to 0.20. Figure 7 presents the results of these calculations. Changes in royalty rates appear to exert quite modest impacts upon R. A reduction of royalty rates from 0.20 to 0.10 raises the rate of return from 12 percent to 13.75 percent. In and of itself, therefore, changes in the royalty rate do not appear to be of major importance in influencing the rate of return.

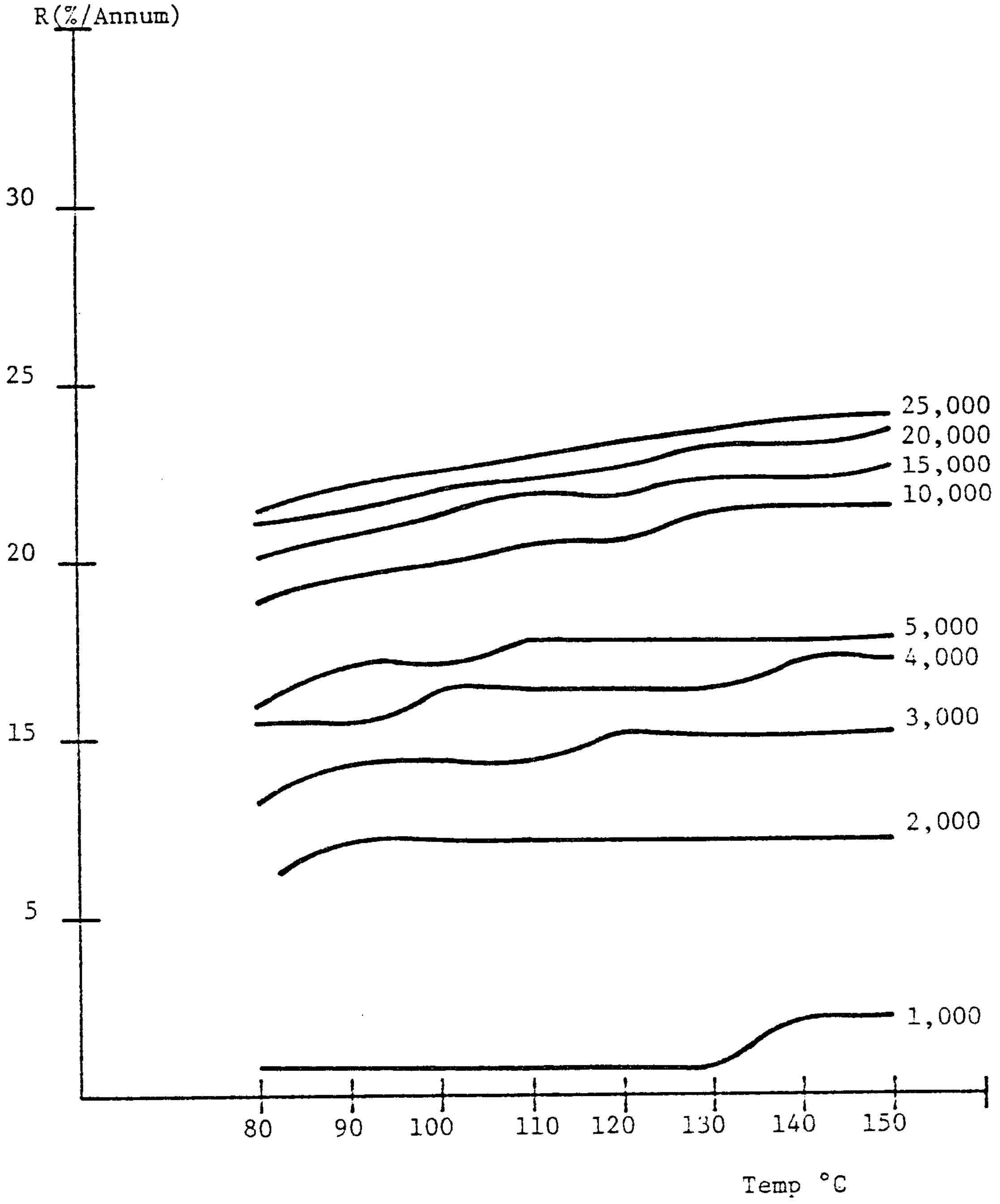

Figure 6. Sensitivity of R to Changes in Population

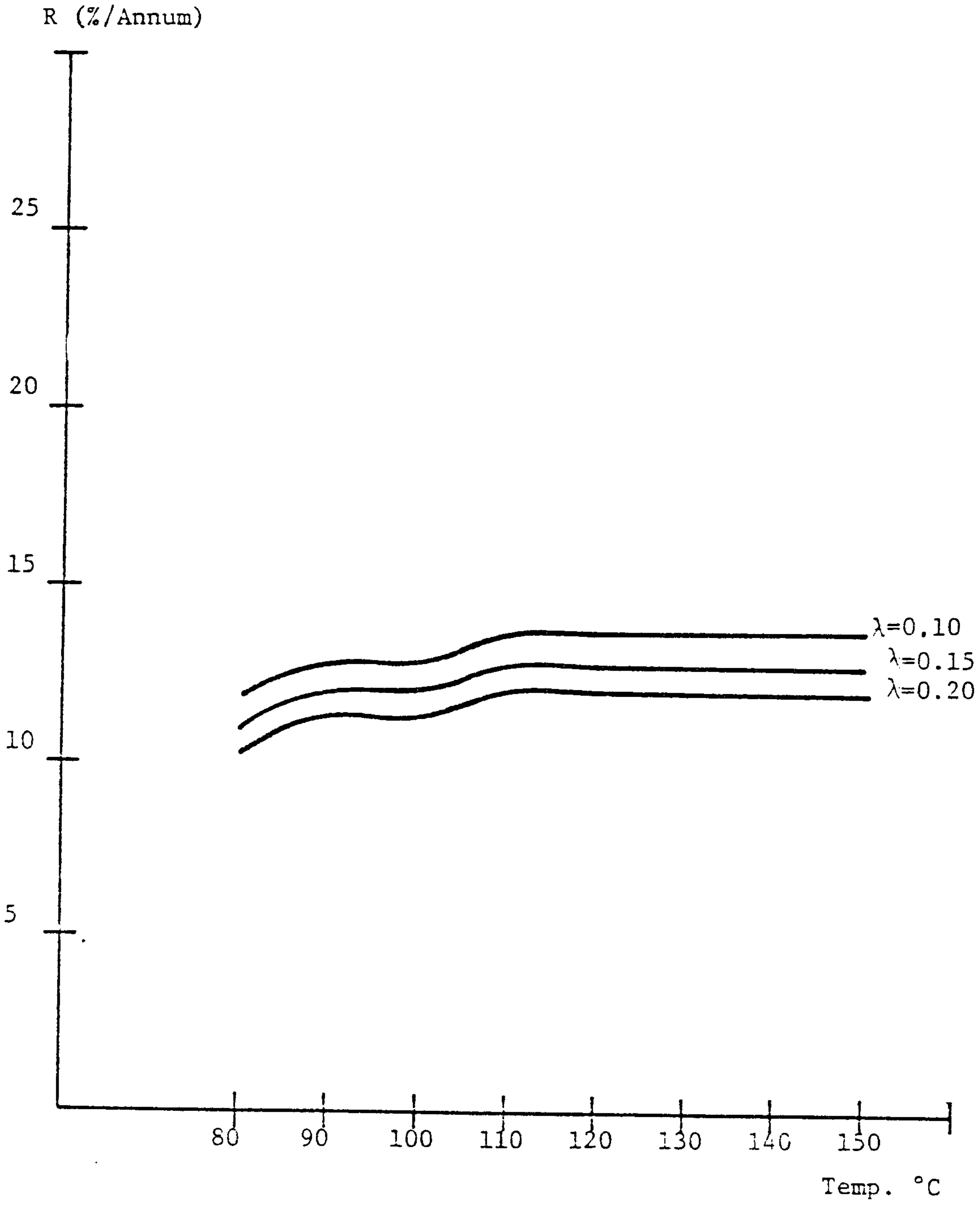

Figure 7 Sensitivity of R to Changes in Royalty Rates

Consider next the results of alterations in the bond rate of the producer in revising the internal rate of return. Government loan guarantee programs are frequently considered as a means for insuring a supply of venture capital at a minimum cost. In this manner, reductions in interest charges from such programs reduce the cost of financial capital, thereby raising the internal rate of return.

Figure 8 reveals that relatively large changes in the bond rate generate relatively small absolute variations in the rate of return. For example, at 120°C, reducing the bond rate from 8.5 percent to 6.5 percent raises the return from 12.75 to 13.75 percent. Furthermore, the leverage which financial capital rates exert upon R is limited at all temperatures between 80° and 150° C. Clearly, reductions in the bond rate do enhance the attractiveness of geothermal investment, in the expected manner, but these effects are of relatively minor importance.

A third policy variable is the price of natural gas. This is the space heating fuel with which geothermal energy must compete throughout much of the Southwest. As natural gas prices rise, the potential revenue recoverable from geothermal energy will rise as well. Accordingly, dollar increments in gas prices from \$3.00 to \$8.00/10^6 BTU have been proposed.

Figure 9 reveals that increases in the price of competing fuel bear heavily upon the rate of return to geothermal investment. At 120°C, an increase in natural gas prices from \$3.00 to \$6.00 raises the rate of return from 13 percent to 24.5 percent. On average, each one dollar rise in price generates an increase in R of four percentage points. Deregulation of energy prices in the U. S. would clearly provide strong impetus to geothermal energy development.

The depletion allowance is yet another potential policy option which may influence the return to geothermal energy development. The depletion allowance was assumed zero in the base case, and its value was raised to 0.11 and 0.22 in the sensitivity analysis. The results, illustrated in Figure 10, are similar to

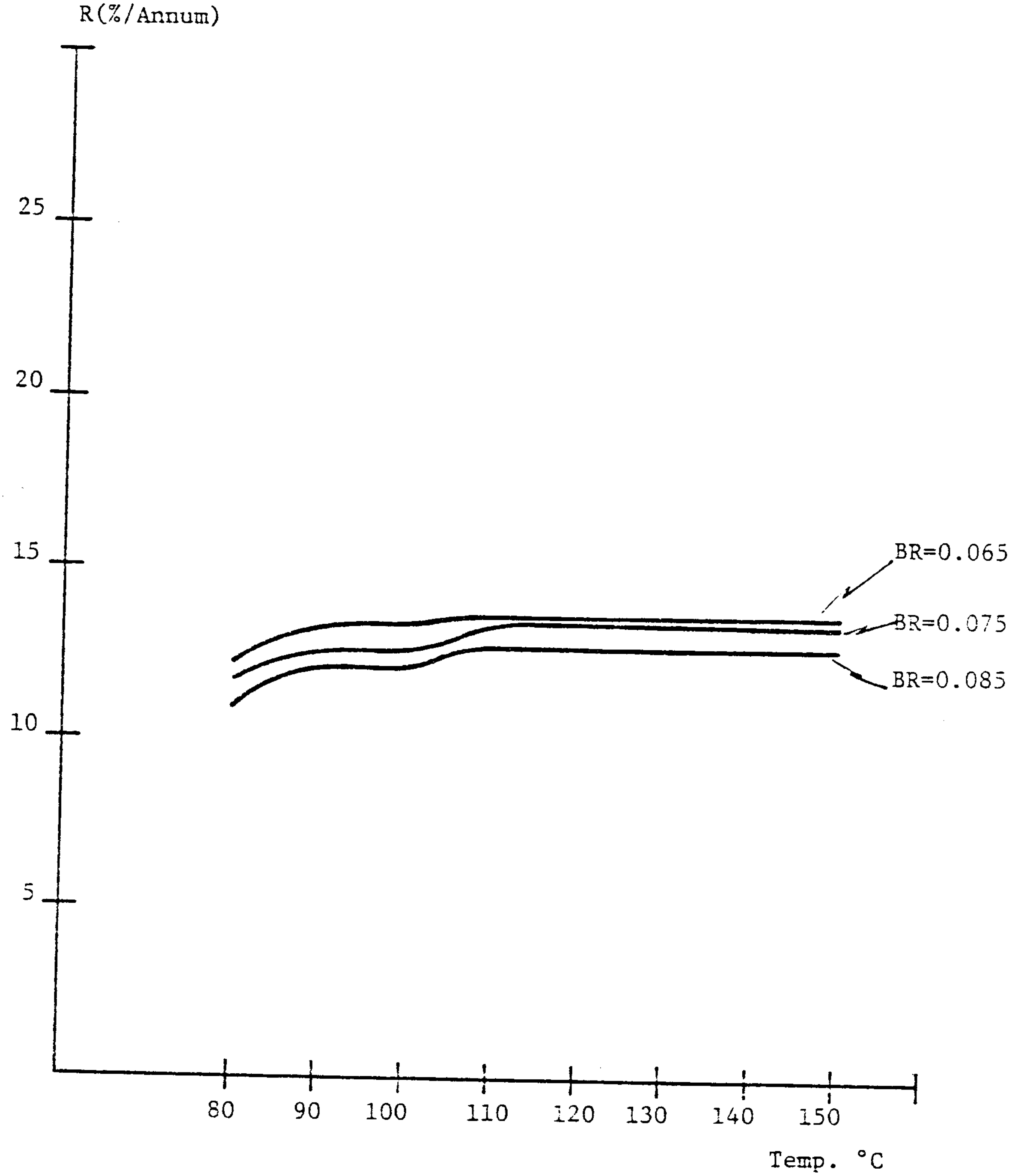

Figure 8. Sensitivity of R to Changes in Bond Rate

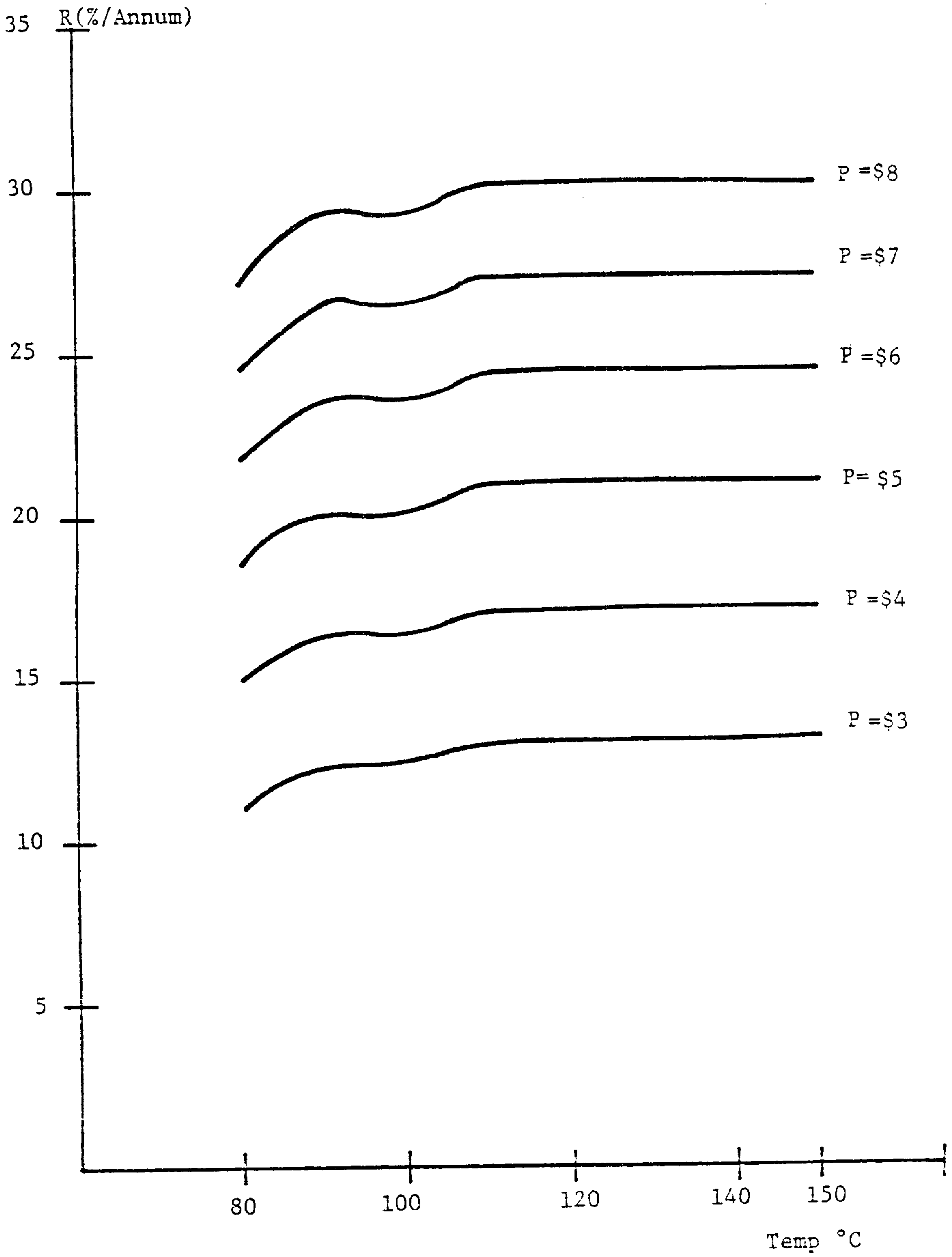

Figure 9. Sensitivity of R to Changes in Energy Prices

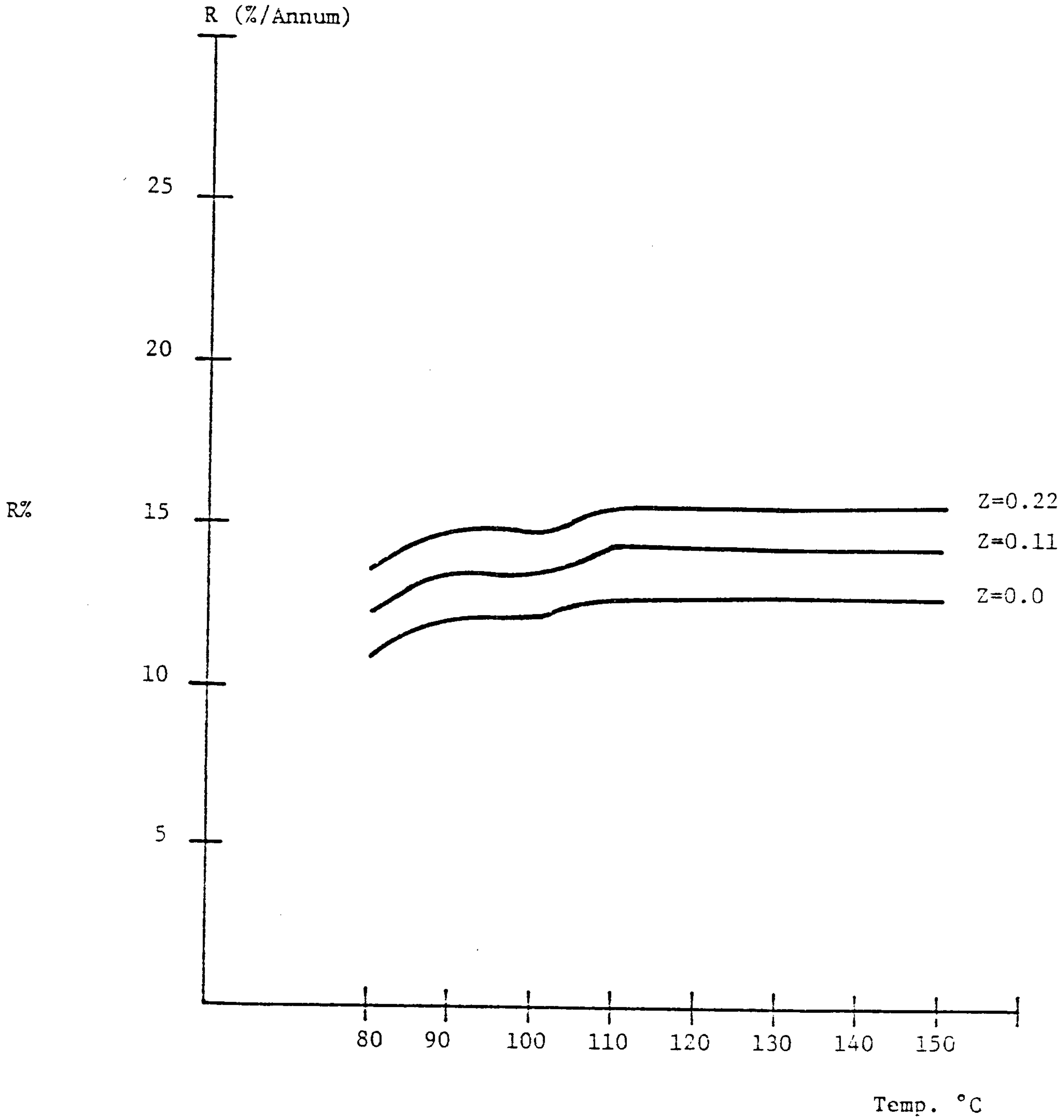

Figure 10. Sensitivity of R to Changes in Depletion Allowances

those for the royalty and bond rates. Although the direction of the changes in R are as expected, the magnitude of the absolute change is limited. Increasing the depletion rate from 0 to 0.22 raises the rate of return roughly 2.5 percentage points at all temperatures. By itself, therefore, the depletion allowance offers relatively limited policy potential as a means of improving the profitability of geothermal energy investment.

A final traditional policy variable which is considered is the investment tax credit rate. A range of investment tax rates has been specified between 0.04 and 0.20. Figure 11 verifies that this is also a relatively insignificant factor in affecting the absolute value of R. Raising the tax credit rate from 0.04 to 0.20 only increases R by 1.5 percentage points, from 12.25 to 13.75 percent. As in the case of the royalty rate, bond rate and depletion allowances, the tax credit alone is also of little consequence in determining the profitability of low temperature resources.

A parameter in the model which might be loosely considered a policy option is the load factor. The load factor is a measure of the efficiency of utilization of the entire physical plant. For a space heating system of a given capacity, the greater or lesser the load factor, the greater or lesser will be the revenues earned; and the greater or lesser the revenues earned for a given investment outlay, the more or less profitable the investment will be. Although the load factor has not been a traditional policy tool, increases in system load factors are subject to policy manipulation.

Figure 12 illustrates the impacts of variations in the user load factor. at 120°C, the rate of return for load factors of 0.5, 0.6, 0.7, and 0.8 are 10.5 percent, 12.75 percent, 15 percent, and 17.25 percent, respectively. Thus, raising the load factor by 40 percent rates R by roughly 70 percent, a highly favorable trade-off. Insofar as the load factor potential may vary from

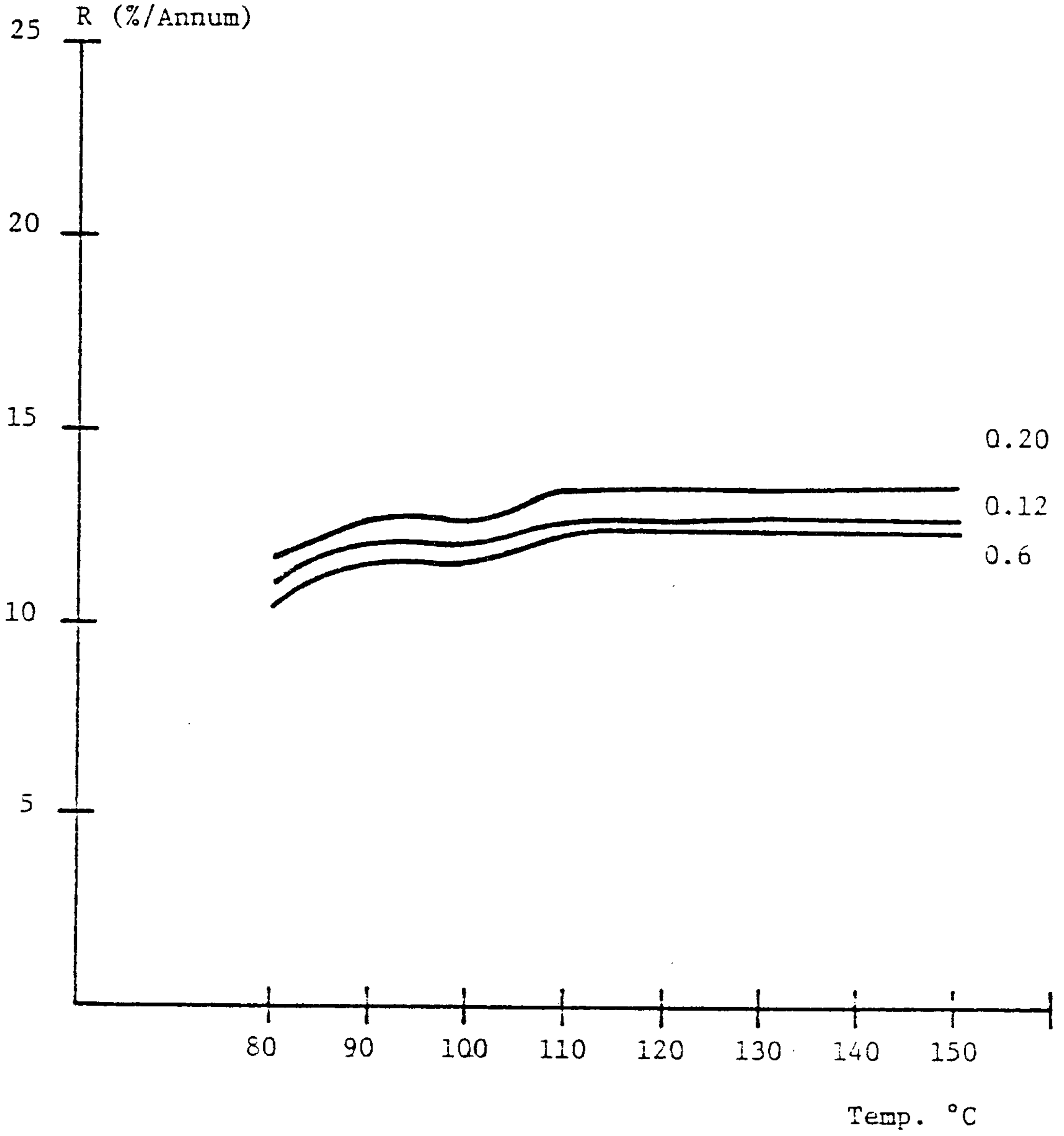

Figure 11. Sensitivity of R to Changes in Investment Credits

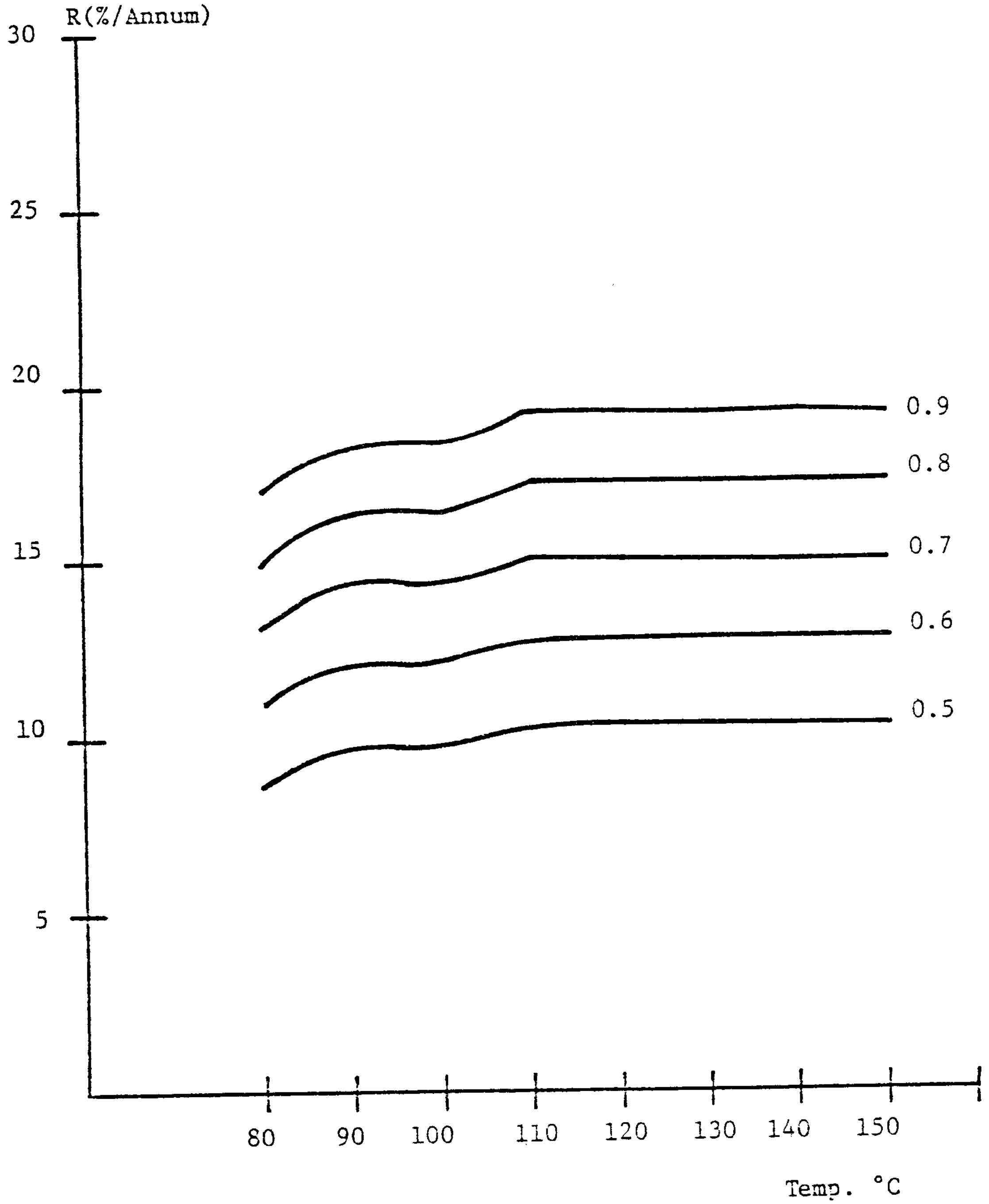

Figure 12. Sensitivity of R to Changes in Load Factor

community to community, these findings suggest that the fullest appreciation should be granted the load factor.

The Scenario Forecasts

In the sensitivity analysis above, the impacts of altering a single variable or parameter value were calculated. A mere meaningful analysis could be provided if a number of properties of the base case scenario could be varied simultaneously. This exercise would provide valuable information on two counts. First, it would elucidate the interactive impacts upon R of several variables or parameters; and second, if the complete set of policy factors are altered simultaneously, the results would infer the full potential of public policy in influencing the profitability of investment in geothermal energy.

Accordingly, a Pessimistic and an Optimistic forecasting scenario were prepared. Each scenario consisted of a designated set of policy variable values, with all other values assuming their base case magnitudes. The Pessimistic scenario posited an energy market in which policy conditions are relatively hostile to geothermal energy development. In return the Optimistic scenario pictured an environment which is relatively receptive to geothermal development. The differences in the return on investment between each case provide a measure of the potential of public policy for influencing geothermal energy development.

The scenario values specified for the six policy variables are presented in Table 5. The estimated internal rates of return between the scenarios differ dramatically at all temperatures as seen in Figure 13. In the Pessimistic setting, with circumstances generally hostile to development, R is 9.5 percent at 120°. At the same temperature in the Optimistic scenario, R is a healthy 50 percent. Quite evidently, the combined efforts of all of the policy variables considered in Table 5 are sufficient to generate a large range of possible return on investment. This finding suggests that a carefully orchestrated mix of policies is capable of inducing space heating applications of geothermal energy as a much broader basis than would otherwise occur.

TABLE 5

Optimistic and Pessimistic Scenarios

Parameter or Variable	Pessimistic	Optimistic
Load Factor	0.5	0.9
Price ($/$10^6$ BTU)	$3.00	$8.00
Royalty Rate	0.2	0.1
Tax Credit	0.0	0.2
Bond Rate	0.085	0.065
Depletion Allowance	0.0	0.22

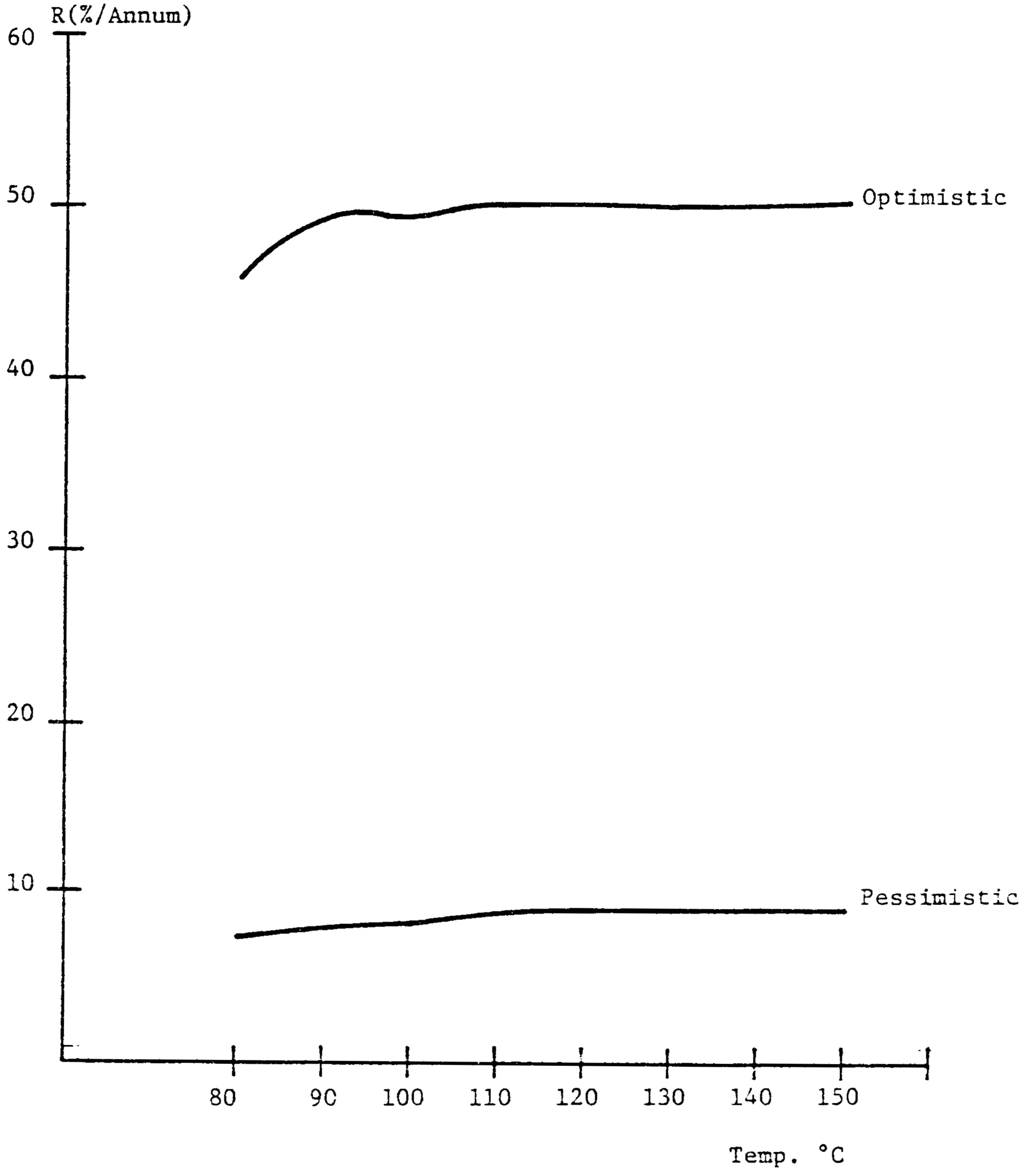

Figure 13. Estimated R for Optimistic and Pessimistic Scenarios

A Financial Screening of the Regional Low Temperature Resource Endowment

The modeling analysis alone calculates the expected profitability of a hypothetical low temperature geothermal resource which has been harnessed for district space heating. The findings (i) present a ballpark estimate of expected profitability under specified conditions; (ii) identify the relevance or irrelevance of numerous factors as determinants of profitability; and (iii) evaluates the effectiveness of public policy in altering profitability. All of these findings are relevant, however, only for a hypothetical resource.

The final task for estimating the space heating supply potential of low temperature geothermal resources in the Southwest consists of estimating the financial promise of each anomaly. In effect, this exercise constitutes a second screening on the basis of economic rather than technical criteria, and those resources which passed the initial technological screening are of greatest concern. Ceteris Paribus, geothermal resources will or will not be developed as they earn or fail to earn a minimum return on investment, and GIRORA effectively differentiates the former from the latter.

For each of the technologically feasible sites in Table 3, a unique internal rate of return is estimated. The return is calculated on the basis of the resource temperature, the distance to market, and the market population. In turn, the estimated returns will be compared with a minimum acceptable rate of return, designated as 12 percent. This is the return frequently allowed nonprofit, publicly regulated enterprises, and it is considered as the minimum acceptable figure for a privately financed business.

The geothermal resources which are expected to earn an internal rate of return greater than 12 percent are designated with double asterisk (**) in Column 3 (Comments) of Appendix A. Figure 14 identifies each site according to its location within the region. The number is relatively small: of the

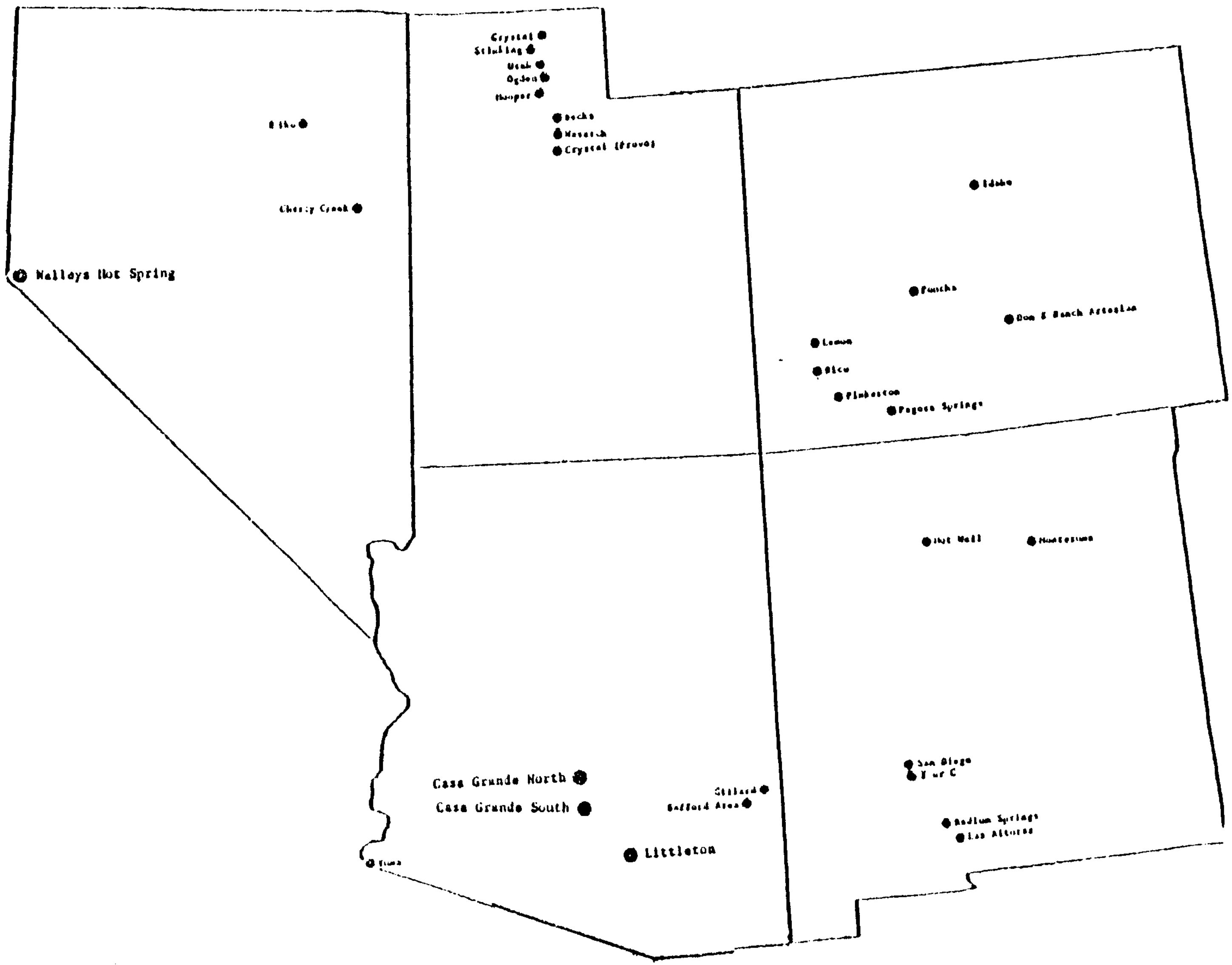

Figure 14. Economically Feasible Low Temperature Sites in the Southwestern Region

eighty-eight candidate sites, only 30 (34 percent) will earn at least 12 percent. Alternatively, in view of MBtuh, of the original 5602 only 2071 (37 percent) successfully pass the economic screening. Thus, roughly one third of the geothermal resource base which survived the technological screening will generate a minimum acceptable return in investment.

Summary

The objective of this research has been the estimation of the supply potential of low temperature geothermal resources for district space heating in the Southwest. On the basis of several key technological and economic conditions, several geothermal supply scenarios may be prepared. The first of these depicts the gross energy potential (MBtuh) of the low temperature resources located in the Southwest. The second scenario presents the expected energy potential of the technologically usable resources, as defined earlier. The final scenario measures the energy potential of geothermal resources subject to the technological and economic screenings. Each of these scenarios provides an increasingly more realistic appraisal of the true potential of low temperature geothermal energy in the Southwest.

All the scenarios are illustrated in Figure 15 and the findings are summarized in Table 6. These illustrations confirm that roughly five percent of the low temperature resource endowment is the Southwest offer district space heating potential.

TABLE 6

Distribution by State of Low Temperature Geothermal Resources which pass Technological and Economical Screening

State	Number of Resource Sites	Estimated Supply Potential in MBtuh
Arizona	6	364
Colorado	7	234
Nevada	3	186
New Mexico	6	383
Utah	8	904
Total	30	2071

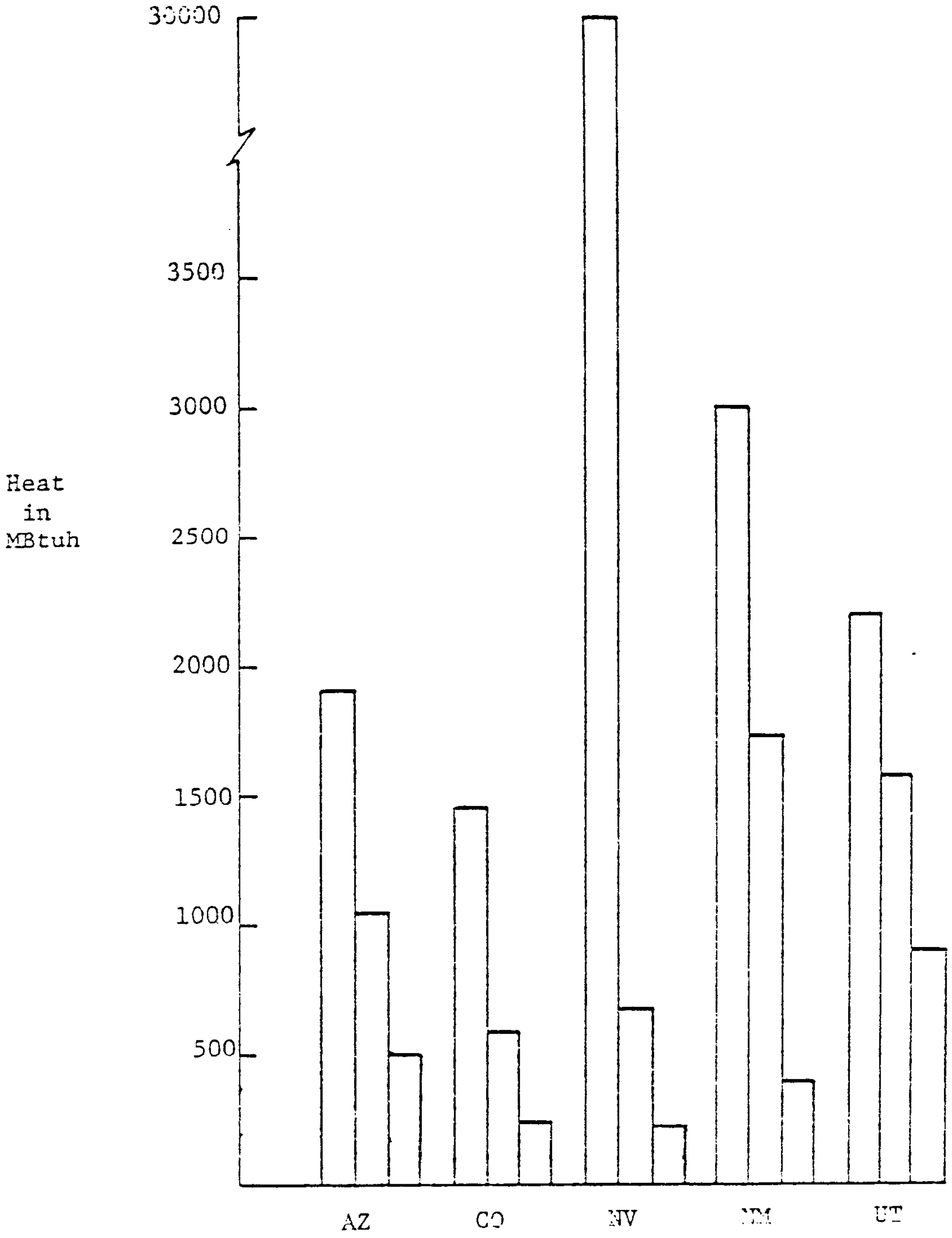

Figure 15. Estimated Energy Potential of Low Temperature Geothermal Energy before and after Technological and Economic Screening

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APPENDIX A

Baseline Inventory of Known Low Temperature Hydrothermal Geothermal Anamolies in the Southwest

State	Resource Site	Temperature C°	Comments
Arizona	Gillard HS	140	**
	Eagle Creek HS	130	*
	Coolidge HS	120	*
	Coffers HS	120	*
	Cat Tank	115	*
	Javelina Peak	110	
	Safford Area	110	**
	Indian HS	105	
	Castle HS	105	*
	Coolidge Area	61	
	Radium Springs	50	
	Hookers HS	53	
	Buckhorn Area	49	
	Agua Caliente	46	
	Artesian HW	44	
	Mt Graham	44	
	Lucats Spa	42	
	Palomas Mts	42	
	Barngan Mtn	39	
	Theba	38	
	Bowie Area	36	
	Mobil Area	35	
	Artesia Area	33	
	Tom Niece Warm Springs	32	

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Elko HS	115	**
	The Hot Springs	110	
	Sodaville Springs	105	*
	Hot Springs Ranch	100	
	Wild Horse HS	100	
	Lower Ranch	100	
	Monte Neva HS	89	
	Carlin	120	
	Walti HS	120	
	Ruby Lake	65	
	Walley's HS	110	**
	Hind's HS	105	*
	Diana's Punch Bowl	59	
	Soldier Meadows HS	115	
	Bog HS	115	
	Washoe Valley	53	
	Goose Creek	43	
	SSE Patsville	41	
	Alkali HS	60	
	Ash Springs	36	
	Benefit Springs	21	
	Big Locke Springs	37	
	Big Springs	28	
	Hardy Creek	23	
	RR Valley-Eagle	38	
	N. Winnemucca Lake	86	
	Carson Lake	81	*
	Brooks Spring	37	

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Arizona	Eloy	27	
	Florence	28	
	Coolidge	42	
	Casa Grande	24	
	Mammoth	32	
	Papago Farms	31	
	Wikieup	22	
	San Simone	134	
	Yuma	138	**
	White Water	64	
	Littleton	147	**
	Wilcox	87	*
	Casa Grande (North)	113	**
	Casa Grande (South)	110	**
	Hyder Valley	49	
	Hoover Dam	40	
Colorado	Juniper	38	
	Craig Warm Water Wel	90	*
	Rout HS	145	*
	Steam Boat Springs	120	*
	Brands Ranch Artesia	42	
	Hot Sulphur Springs	95	*
	Haystack Butte WWW	28	
	El Dorado	26	
	Idaho Springs	120	**
	Doisero Warm Springs	32	

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Colorado	Glenwood Hot Springs	130	*
	South Canyon Hot Springs	105	*
	Penny Avalanche HS	150	
	Colonel Chinn Hot Well	80	*
	Conundrum HS	38	
	Cement Creek WS	26	
	Ranger WS	27	
	Rhodes WS	25	
	Hartsell HS	105	*
	Brown Canyon Thrml A	100	*
	Poncha HS	145	**
	Wellsville Swissvale	40	
	Canon City HS	50	
	Fremont Natatorium	43	
	Florence Artesian WE	42	
	Don K. Ranch Art.	110	**
	Clark Artesian W	40	
	Mineral HS	105	*
	Valley View HS	50	
	Shaws WS	130	*
	Sand Dunes Swimming	160	
	Splashland HW	160	
	Dexter McIntyre	35	
	Dutch Crowly Stinking	70	*
	Eoff Artesian W	50	
	Pagosa Springs	140	**
	Rainbow HS	45	

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Colorado	Wagon Wheel Gap HS	140	*
	Antelope Birdsie	44	
	Cebolla HS	135	*
	Orvis HS	105	*
	Ouray HS	80	*
	Lemon HS	140	**
	Dunton Geysr Paradise	50	
	Rico	140	**
	Pinkerton	100	**
	Tripp & Trimble WS	110	*
	Full N Wider WS	18	
Nevada	Darrough's HS	140	
	Dyke HS	140	
	Howard HS	130	
	Cherry Creek HS	130	**
	Buffalo Valley HS	130	
	Hot Pot Blossom	130	*
	Fly Ranch	130	*
	Mineral HS	130	
	Trego	130	
	Spenser HS	125	
	Hot Springs Point	125	*
	Gonconda	125	
	Klobe HS	130	
	Warm Springs	125	*
	Hyder HS	120	
	South HS	115	*

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

State	Resource Site	Temperature C°	Comments
Nevada	Bruffey's HS	66	
	Whipple Peak	24	
	Cain Springs	23	
	Caliente HS	57	
	Carson-Pinyon Hills	49	
	Alkali Flat	27	
	RR Valley-Panc	71	
	Collar and Elbow Spr	33	
	Crystal Pool	32	
	Crystal Springs	32	
	Delmues Spring	21	
	Point of Rocks Spr	34	
	Emigrant Springs	21	
	Fairbanks Spring	27	
	Fish Springs	23	
	Flag Springs	23	
	Flynn Ranch Springs	25	
	Gambles Hole	43	
	Geyser Ranch Springs	21	
	Geyser Ranch Springs	21	
	Mount Grafton	21	
	Hay Corral Spring	37	
	Sarcobatus Flat-Beat	43	
	Hiko Spring	32	
	Horseshoe Ranch Spr	58	
	Forest Moon Ranch	33	
	Hot Creek Springs	68	
	Hot Hole Elko HOt	33	

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Hot Spring	48	
	Hot Creek Canyon	82	
	Hot Springs	82	
	Bartine HS	41	
	Vivian Siding	37	
	Battle Mountain	55	
	Carlotti Ranch Spr	39	
	Duff Creek	86	
	Hot Springs	53	
	Mulligan Creek	30	
	Tennessee Mountain	40	
	Hot Springs	54	
	Hot Springs	49	
	Huffaker Springs	34	
	Indian Springs	25	
	Izzenhood Ranch Spr	28	
	Jack Rabbit Spr	27	
	John Salvis HS	65	
	Kate Spring	22	
	Ely-Lackawanna HS	35	
	Lawton HS	33	
	Longstreet Spring	27	
	Mac Fairlane's	77	
	Manse Springs	23	
	McCoy Springs	49	
	McGill Spring	29	
	Moon River Spring	33	
	Buck Pass	24	
	Moorman Spring	38	

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Mountain Sprg Mine	43	
	Mud Springs	21	
	Mud Springs	75	
	Noapa	32	
	Panaca Spring	32	
	Pearl Hot Sprgs	37	
	Point of Rock Sprg	28	
	Preston Springs	22	
	Rizzi Ranch HS	41	
	Mt. Stirling	28	
	Shipley HS	41	
	Siri Ranch Spr	30	
	Springs	29	
	Spring	38	
	Spring	33	
	Spring	27	
	Wine Cup Ranch	59	
	Spring Hot	45	
	Spring	26	
	Spring	39	
	Storm Spring	29	
	Sulphur Spring	23	
	Fortynine Lake	22	
	Upper Warm Spring	33	
	Wall Spring	28	
	Warm Springs	32	
	Warm Springs	18	
	Gridley Lake	42	

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Wedell HS	62	
	West Spring	42	
	Williams HS	53	
	Wilson HS	84	*
	Virgin V. Campground	32	
	Middle Lake	28	
	Virgin Valley		NPK
	McGee Mountain	55	
	Little Sage Hen Sprg		NPK
	Jordan Meadow Mts		NPK
	Fivemile Spring	28	
	Bilk Creek Reserv.	57	
	Ninemile Summit Sprg	26	
	Quinn River Crossing	24	
	Beer Creek Peak	21	
	DeLong Sprg	26	
	Quinn River	27	
	Surprise Valley	39	
	Parman	39	
	Connelly Peak	63	
	Cordero Mercury Mine	59	
	Goosey Lake Flat		NPK
	Deep Crk-Sulphur Ck		NPK
	South Fork	90	
	Burns Creek		NPK
	Sand Dunes	70	
	Midas		NPK
	Dry Creek Mtn	47	

NPK: Temperature of the site not precisely known.

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Hot Lake		NPK
	Willow Creek Reserv		NPK
	Evans Creek		NPK
	Lone Butte	21	
	Jarbidge Mountains	27	
	Jackpot	38	
	San Jacinto Ranch Sp	64	
	Rock Spring Crk	29	
	Wilkins		NPK
	Thousand Springs	96	
	Gonce Creek		NPK
	North Fork		NPK
	Mary's River Rch	50	
	Winter Creek		NPK
	Clover Valley		NPK
	Cobre	77	
	Fly Ranch, N.E.		NPK
	Squaw Valley		NPK
	Cholona		NPK
	Sulphur		NPK
	Sawmill		NPK
	Little Sawmill Canyon	28	
	Gerlach N.E.		NPK
	Southern Eugene Mtns		NPK
	Dun Glen Creek		NPK
	North Fox Range		NPK
	Selenite Peak		NPK
	Buffalo Creek		NPK

NPK: Temperature of the site not precisely known.

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Rye Patch		NPK
	Smoke Creek		NPK
	S. Smoke Crk. Desert	23	
	Sand Pass		NPK
	Gold Mtn	24	
	Colado	68	
	Nugent Sprgs		NPK
	Humboldt River	29	
	Winnemucca	29	
	Kent Sprgs		NPK
	Timber Canyon	24	
	Sheep Crk Range		NPK
	Pine Creek		NPK
	Dry Lake		NPK
	Needle Peak		NPK
	N.Y.Cnyn Kaolin Dep		NPK
	Chillis	39	
	Carico Lake	22	
	Diamond Valley	30	
	Winnemucca Mtn	34	
	Cold Creek		NPK
	Winchett Lake		NPK
	Wood Hills	30	
	Dolly Varden		NPK
	Anaho Island	49	
	Dogskin Mtn		NPK
	Warm Sprs Valley	43	
	North Valley		NPK

NPK: Temperature of the site not precisely known.

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Huxley		NPK
	Carson SNK Alk Flt W		NPK
	Lone Rock		NPK
	Comstock Mine Hmblt		NPK
	Desert Peak		NPK
	Eagle Salt Works		NPK
	Hot Springs Mtns		NPK
	Carson SNK, AF East		NPK
	Spanish Springs		NPK
	Lockwood		NPK
	IXL	24	
	Deep Canyon		NPK
	Moana Sprg-Lawton	48	
	Biddleman Sprg	24	
	Table Mountain		NPK
	Pirouette Mountain		NPK
	Rainbow Mtn		NPK
	S. Stillwater Range		NPK
	Fairfview Valley		NPK
	Crystal Bay	60	
	Comstock Mining Dist.		NPK
	Dayton	35	
	Churchill Valley		NPK
	Hobo-Saratoga Sps	50	
	Carson Hill		NPK
	Eight Mile Flat	81	*
	Four Mile Flat		NPK
	North Sand Sps. Range		NPK

NPK: Temperature of the site not precisely known.

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Bell Flat		NPK
	Eagleville		NPK
	Iron Tank Spring	29	
	Wild Horse		NPK
	Senator		NPK
	Mt. Grant		NPK
	Edwards Crk Valley	24	
	Iowa Canyon Ramches	39	
	Santa Fe Creek	23	
	Shippley Hot Springs	41	
	Northern Clan Alpine		NPK
	Tule Dam Spring	23	
	S. Clan Alpine MC		NPK
	Birchim Creek		NPK
	Clipper Gap Canyon		NPK
	Kingston		NPK
	Wildcat Canyon		NPK
	McLeod's Ranch Sprg		NPK
	Diamond Mtns	24	
	Cuck Creek		NPK
	Becky Peak	28	
	Shellborne Pass	25	
	North Spring Valley	32	
	Pleasant Valley		NPK
	Pancake Summit		NPK
	Steptoe	24	
	Snake Range		NPK
	Bull Creek		NPK

NPK: Temperature of the site not precisely known.

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Buckskin Range	28	
	Mount Wilson		NPK
	Double Spring	21	
	West Gabbs Valley	68	
	Double Spring Flat	21	
	Wellington	67	*
	Wilson HS		NPK
	Dead Horse Wells-Wed	67	
	Aldrich Station	43	
	Hawthorne	26	
	Soda Spring Valley		NPK
	Whiskey Flat	43	
	Rhodes Salt Marsh		NPK
	Huntoon Valley		NPK
	Downeyville	68	
	Kelly's Wells		NPK
	Mosquito Crk Ranch	35	
	Little Fish Lake V.	48	
	Hot Creek Valley	61	
	Rayson Hills		NPK
	Wilson Spring		NPK
	Pinon Peak	26	
	Lunar Crater		NPK
	Tonopah Mining Distr		NPK
	Saulsbury Wash	30	
	Willow Creek	29	
	Duckwater		NPK
	Williams HS		NPK

NPK: Temperature of the site not precisely known.

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Doyles Well		NPK
	Schell Creek Range		NPK
	Granite Peak		NPK
	Coyote Hole Sprg		NPK
	Camp Valley Creek		NPK
	Basalt		NPK
	Emigrant Peak	27	
	Gap Spring		NPK
	Mt. Diablo		NPK
	Fish Lake Falley		NPK
	Valcalda Sprg		NPK
	Southern Clayton V.		NPK
	Reveille Mill	29	
	Dry Valley	25	
	Sand Spring Valley	30	
	Sand Spring Valley W.	28	
	Sand Sp. Valley S.		NPK
	Steves Pass	29	
	Jackass Flats	36	
	Lathrop Wells	28	
	Desert Rock	33	
	Rockvalley	27	
	Scranton Well	29	
	Skeleton	31	
	Frenchman Flat	38	
	Spotted Range	27	
	Muddy Mountains	31	
	Sixmile Spring	28	

NPK: Temperature of the site not precisely known.

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Nevada	Sunrise Mtn	29	
	Boulder Junct. E.	41	
	Black Canyon	63	
	Jean Lake	27	
	Willow Sprg	31	
	Davis Dam	27	
New Mexico	Spence Sp (Jemez)	42	
	Radium Spgs	130	*
	Ojo Caliente	130	*
	Gila HS-Below Bridge	66	*
	Gila HS-Middle Fork	65	*
	Montezuma HS	130	**
	Gila HS-Doc Campbell	66	
	Mamby's HS	125	*
	Turkey Creek	74	*
	Las Alturas	120	*
	Berino-Mesquite	120	
	Mimbres HS	58	
	Ponce de Leon	105	*
	E. San Augustine Plain	35	
	Upper San Francisco HS	37	
	Faywood HS	54	
	T or C	100	**
	Gila HS-Upper Mdle Frk	36	*
	W. Mesa Black Mtn	95	
	Closson	61	
	Playas Valley	28	
	Cliff Area	31	
	Derry WS	100	*
	Tohatchi Area	39	

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
New Mexico	Crown Point	37	
	Guadalupe Sprg	120	*
	Hot Well	100	**
	San Ysidro	100	*
	Crocker	30	
	Freiborn Canyon	30	
	Las Palomas	30	
	Rincon East	50	
	Aleman	110	*
	McKinley West	60	
	Garton Well	34	
	Gallinas Creek	50	
	Carne	30	
	San Diego Mtn	125	**
	Fort Wingate	61	
	San Augustine Plain	35	
	Isleta	33	
	Albuquerque	27	
	Laguna	50	
Utah	Joseph HS	140	*
	Red Hills HS	135	*
	Crystal HS	135	*
	Abraham HS	125	*
	Wasatch HS	120	**
	Monroe (Cooper) HS	120	*
	Ogden HS	110	**
	Stinking Sprg	110	**
	Meadow HS	105	*
	Hooper HS	105	**

* Sites that are technologically feasible

** Sites that are technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Utah	Utah HS	95	**
	Becks HS	90	**
	Crystal HS	90	**
	Wilson HS	61	
	Midway HS	45	
	Saratoga HS	44	
	Uddy HS	43	
	Crater HS	43	
	Laverkin HS	42	
	Veyo HS	42	
	Unnamed HS	42	
	Castilla HS	40	
	Hatton HS	38	
	Radium (Dotson) HS	33	
	Lincoln Point WS	32	
	Split Mountain WS	30	
	Fish Springs	28	
	Gandy	27	
	Morgan WS	27	
	Blue WS	27	
	Warm Spring	27	
	Warm Sprg-Utah Lake	25	
	Johnson WS	25	
	Como HS	25	
	Gransville	24	
	Russels WS	22	
	Richfield WS	22	
	Diamond Fork WS	20	

* Sites that are technologically feasible

** Sites that are both technologically and economically feasible

APPENDIX A (Continued)

State	Resource Site	Temperature C°	Comments
Utah	Goshen WS	20	
	Sterling Sprg	19	
	Big WS	18	
	Utah 7	30	
	Utah 8	30	
	Utah 9	30	

APPENDIX B

A DISTRICT SPACE HEATING MODEL - GIRORA: NONELECTRIC

To find the commercial feasibility of a geothermal resource for district heating, an internal rate of return model is developed, which is labeled as GIRORA-NONELECTRIC.

GIRORA NON-ELECTRIC is a simple but powerful simulation model which evaluates the economic potential of low temperature hydrothermal geothermal resources for district space heating. The model also provides a means for measuring the estimated economic impacts of variations in a number of policy variables and site specific geophysical variables. In composite, these findings present an empirical collage which provides richly productive in evaluating the potential of low temperature geothermal energy.

GIRORA NON-ELECTRIC will be considered in detail below. The primary output of the model is an estimated measure of profitability for a geothermal producer developing a given geothermal resource site. On this basis, an ordinal ranking of low temperature sites in Region 4 can be compiled with respect to expected profitability. Such a ranking provides a best guess listing, *ceteris paribus*, of which sites might be expected to come "on line" and in what order they will be developed.

While a number of analytical models similar to the model described herein are being developed, each of the current generation is dependent upon the original GEOCITY model developed by Bloomster, et. al., at Batelle Pacific Northwest Laboratories[1]. Unfortunately for most analysts interested in broad regional study, GEOCITY may be too elegant. "GEOCITY is an offshoot of the GEOCOST program. . .," a highly technical and extremely detailed

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[1] Bloomster, C. H., Fassbender, L. L. and McDonald, C. L. *Geothermal Energy Potential for District and Process Heating Applications in the U.S. An Economic Analysis*. Battelle Pacific Northwest Laboratories, Richland, Washington, August 1977.

simulation model which describes the development of high temperature resources for generating electricity[2]. As a result, GEOCITY might be more appropriately described as an engineering description of a district heating model than as a financial feasibility model.

For a broader research thrust with which little proprietary data or detailed district heating plans are available, many properties of GEOCITY are redundant. Given the objectives of the present analysis, therefore, a simpler more functional model is necessary. Accordingly, Geothermal Internal Rate of Return Algorithm (GIRORA) has been developed.

From an analytical perspective, GIRORA NON-ELECTRIC is a discounted cash flow model which simulates required investments, revenues, and operating outlays for each year of the investment life of a geothermal anomaly. The model iterates for the internal rate of return which equates the sums of investment costs incurred with net revenues, discounted to the present. In simple terms, the model calculates R (internal rate of return) from

$$\sum_{t=1}^{T} \text{Investments } (1+R)^{-t} = \sum_{t=1}^{T} \text{Net Revenues}_t \ (1+R)^{-t} \qquad \text{(B.1)}$$

T: Each year of the period, t=1,...T

Simulating the life of an investment through T years results in a T-th order polynomial which is solved iteratively by Newton's method of approximation for a unique real root, R. This root is a measure of the expected profitability of an investment. <u>Ceteris Paribus</u>, the greater the present value of all net revenues or the lowest cost of all investments throughout the productive life of a resource, the higher is R, and vice versa.

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[2] Bloomster, C. H., Huber, H. D. and Walter, R. A. <u>User Manual for GEOCOST: A Computer Model for Geothermal Cost Analysis</u>; Vols. 1 & 2, Battelle Pacific Northwest Laboratories, Richland, Washington, 1975-1976.

The heart of the simulation model is an expanded version of equation (B.1).

$$\sum_{t=1}^{T} INV(1+R)^{-t} = \sum_{t=1}^{T} (REV_t - TC_t - TX_t)(1+R)^{-t} \qquad (B.2)$$

INV: Equity Investment by project developers

REV_t: Total revenues in year t.

TC_t: Variable costs in year t.

TX_t: Taxes in year t.

R: Discount rate of internal rate of return.

t: Each year of project, t=1,...T.

The remainder of the model identifies explicitly each element of equation (B.2). Beginning on the left side of the equation and working to the right,

$$INV = (EK)(TNV) \qquad (B.3)$$

EK: Equity portion of capital.

TNV: Total Investment.

Equation (B.3) indicates that the return to <u>risk</u> capital is of primary concern, since the return on debt capital will be specified by a bond rate.

Total investment costs include drilling investment, leasing costs, plant investment, and interest paid during construction. During the early years of a geothermal resource investment, i.e. during the period of resevoir exploration and development and plant construction, investment cost is the sum of all of the four components above. Thereafter, during the actual operation of the space heating system, total investment is the sum of drilling, leasing, and interest expenses. Thus,

$$TNV_t = DNV_t + LNV_t + IDC_t + PLV_t, \; t = EXP + DVP + CON \qquad (B.4a)$$

$$TNV_t = DNV_t + LNV_t + IDC_t, \; t \neq EXP + DVP + CON \qquad (B.4b)$$

DNV_t = Drilling investment costs in year t, $

LNV_t = Leasing investment cost in year t, $

PLV = Plant investment cost for transmission and distribution system, $

IDC_t = Interest during construction in year t, $

EXP = Exploration period in years, input variable

DVP = Development period in years, input variable

CON = Plant construction period in years, input variable

Each of the four components of the capital investment is estimated individually. The first is the drilling investment. Drilling investment is a function of the number of geothermal production and injection wells required, the average depth of production and injection wells, and the cost per unit depth of proudction and injection wells.

$$DNV_t = \left(\frac{NPW_t}{PSS}\right) (ADDP) \quad (CPFP) + \left(\frac{NIW}{ISS}t\right) \quad (ADDI) \quad (CPFI) \qquad (B.5)$$

NPW_t = New production wells to be drilled in year t

PSS = Production well success ratio; input variable,

ADDP = Average depth of production well in feet; input variable,

CPFF = Drilling cost per foot of production well, $, input variable,

NIW_t = New injection wells to be drilled in year t,

ISS = Injection well success ratio; input variable,

ADDI = Average depth of injection well in feet; input variable,

CPFI = Drilling cost per foot of injection well, $, input variable.

The number of production wells required is dependent upon the amount of hot water required to meet the space heating system demand and the flow rate of each production well.

$$RPW = HWLBH/FR \quad (B.6)$$

RPW = Required number of production wells to be drilled,

HWLBH = Hot water required to meet system demand, lbs/hr,

FR = Flow rate of the production well, lbs/hr; input variable.

In return, the amount of hot water that is required to meet the demand of the space heating system is jointly dependent upon the estimated peak heat demand (PHD) of the user and the usable heat (TD) from the available water. In the case of the former, the hot water required is assumed to be 75 percent of the amount necessary to supply peak heat demand, with the remaining 25 percent supplied by conventionally fueled backup units. Thus[3]

$$HWLBH = 0.75\ [PHD/TD] \quad (B.7)$$

When estimating peak heat demand, the user mix or the percent of the population residing in single family dwelling units versus multiple family dwelling units is specified. In addition, the non-residential demand is assumed to be 50 percent of residential demand.

$$PHD = 1.5\ [2.016\ (\Omega) + 0.914\ (1-\Omega)]\ [POP/3]\ [DEGD] \quad (B.8)$$

DEGD = Heating degree days (°F) of the community

POP = Population of the community; input

Ω = User mix ($0.0 < \Omega < 1.0$)

TD = Usable temperature from the available hot water

As the hot water is transported from the resource site to the demand site, there will be a decline in temperature of hot water proportional to the distance. In addition, the usable temperature also depends on the downhole temperature of the hot water at the source.[4]

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[3] E. F. Wehlage, The Basics of Applied Geothermal Engineering, Geothermal Information Services, California, 1976.

[4] E G & G Idaho Inc., The Potential for Utilizing Geothermal Energy in Reconstructed Sugar City, Idaho, TREE-116, January 1977.

$$TD = -75.41 + 0.7142\ (TEMP - DIST) \quad (B.9)$$

TEMP = Downhole temperature of hot water at source, °F; input variable,

DIST = Distance from resource to the population center, miles; input variable.

Neither the temperature nor the flow rate is assumed to decline through time. Accordingly, once the production and injection wells are drilled at the beginning of the project, they are assumed adequate to support the estimated demand throughout the project life.

$$NPW_t = RPW \qquad t=1 \quad (B.10a)$$

$$NPW_t = 0 \qquad t>1 \quad (B.10b)$$

$$NIW_t = NPW_t\ /PIR \quad (B.11)$$

PIR = Necessary production well to injection well ratio; input variable.

The second component of investment expenditures is the leasing investment. Leasing investment is a joint function of the acreage required for production and injection wells and the leasing cost per acre.

$$LNV_t = (DPAC)\ (ACPW)\ (NPW_t) + (DPAC)\ (ACIW)\ (NIW_t) \quad (B.12)$$

DPAC = Leasing cost, \$ per acre; input variable,

ACPW = Required acreage per production well; input variable,

ACIW = Required acreage per injection well; input variable.

The third component of investment cost necessary for the development of a low temperature geothermal resource is the plant investment cost. Plant investment consists of two components. The first is transmission investment, the costs incurred in transporting geothermal hot water from the supply site to the point of demand. The second component is distribution investment, which consists of costs incurred in distributing geothermal water to individual demand units.

$$PLV = TRNV + DINV \qquad (B-13)$$

TRNV = Transmission costs, \$

DINV = Distribution costs, \$

Each of these two investment expenses is individually explained below.

The transmission cost is a dual function of the transmission line pipe diameter (which is itself directly related to the amount of hot water to be transported) and the distance from the geothermal resource to the population center. This cost includes the expense of schedule 10 international pipe, fittings and valves, 2.5" insulation, tin shield, labor and trenching, modified expansion loop and miscellaneous costs associated with transmission pipe installation[5,6] More specifically,

$$TRNV = 7.2474 + 2.699\ (TPD) \times 5280 \times DIST \qquad (B.14)$$

TPD = Transmission line pipe diameter, inches (B.15)

$$TPD = 6.6 + 4.04 \times HWLBH \times 10^{-6}$$

The transmission line pipe diameter is in each case adjusted to the next highest integer.

The distribution investment is a function of the peak heat demand.[6]

$$DINV = 0.75\ (115{,}000 \times PHD/3.413) \qquad (B.16)$$

The final component of investment cost is the interest expense incurred during construction.

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[5] C. L. McDonald and C. H. Bloomster, The Geocity Model: Description and Application, Battelle Pacific Northwest Laboratories, Richland, Washington, June 1977.

[6] S. S. Einarsson, Geothermal Space Heating and Cooling, Second U. N. Symposium on the Development and Use of Geothermal Resources, San Francisco, California, 1975.

$$IDC_t = [BR] [\sum_{j=1}^{t} (DNV_j + LNV_j)] [DK], \quad (B.17a)$$

$t = EXP + DVP,$

$$IDC_t = [BR] [\sum_{j=1}^{t} (DNV_j + LNV_j + PLV_j) [DK], \quad (B.17b)$$

$t = EXP + DVP + CON,$

$$IDC_t = 0, \qquad t > EXP + DVP + CON \quad (B.17c)$$

where

The sum of the present values of all of these four investment costs, including drilling, leasing, plant investment and interest during construction is equated to the sum of the net revenues earned. Net revenue is defined as gross revenue (REV) less variable expenses (TC) and taxes (TX). Taking each of these items in order,

$$REV_t = (AHD)\ (8760)\ P\ (1 + i)^t\ (1 - \lambda) \quad (B.18)$$

AHD = Average heat demand of the population center, in million Btu/hr

P = Price of alternate fuel (natural gas), \$ per million Btu equivalent; input variable,

i = rate of growth of alternate fuel price; input variable,

λ = Royalty rate; input variable

$$AHD = (PHD)\ (LF) \quad (B.19)$$

PHD = Peak heat demand of the population center in million Btu/hr

LF = Load factor; input variable

Gross revenue is directly related to the average heat demand placed upon the system. In theory, the demand for space heating is extremely variable, both as a diurnal and on an annual basis. As mentioned above, the space heating system is assumed to have installed capacity sufficient to fulfill 75 percent of estimated peak heat demand; the remaining demand is assumed to be supplied by an appropriate backup system. Over a period of a year, the space heating system will function at a certain percent of its peak capacity, and this element is defined as the load factor.

Having thus calculated gross revenues, net revenues are gross revenues less operating costs and taxes. Property taxes are assumed proportional to the plant investment. In the case of total cost,

$$TC_t = [OCE_t + (BR)\ (DK) + DEPRD_t] \times [\sum_{j=1}^{t} (TNV_j - IDC_j)],$$

$$t = EXP + DVP \qquad (B.20a)$$

$$TC_t = [OCP_t + (BR)\ (DK) + DEPRD_t] \times [\sum_{j=1}^{t} (TNV_j - IDC_j)]$$

$$+ PTX_t,\ t = EXP + DVP + 1,\ EXP + DVP + 2, \ldots,\ T \qquad (B.20b)$$

OCE_t = Percent of drilling costs which constitutes operating expenses

OCP_t = Percent of drilling and plant costs which constitutes operating expenses

PTX_t = Property taxes during year T

$$PTX_t = [PTXR_t]\ [PLV] \qquad (B.21)$$

$PTXR_t$ = Property tax rate

$$OCE_t = C(1 + \dot{C})^t \qquad (B.22)$$

$$OCP_t = PC\ (1 + \dot{PC})^t \qquad (B.23)$$

C = Base year percentage; input variable,

$\dot{C}$ = Rate of increase of C over time; input variable

PC = Base year percentage; input variable

$\dot{PC}$ = Rate of increase of PC over time; input variable

$DEPRD_t$ = Depreciation for drilling investment in year t

$$DEPRD_t = (D + 1 - t)\ /\ \sum_{j=1}^{D} j \qquad (B.24)$$

D = period of depreciation for drilling and leasing (Input)

Finally, income taxes are computed

$$TX_t = \{TXRT\} \{[REV_t (1 - Z)] - [TC_t - (BR \cdot DK + DEPRD_t) \quad (B.25)$$

$$(\sum_{j=1}^{t} TNV_t - IDC_t)]$$

$$- [Y - (DEPRD_t) \sum_{j=1}^{t} LNV_j) = DNVD_t + DEPRN_t \quad PLV]\}$$

$$- \{[CRRT] [(1 - Y) \{\sum_{j=1}^{t} LNV_j = PLV\}]\}$$

TXRT = Tax rate (Input)

Z = Depletion allowance (Input)

Y = Percentage tangible investment (Input)

$DNVD_t$ = A dollar amount for depreciation of drilling investment in year t

DLPRN = Depreciation for plant investment in year t

CRRT = Investment tax credit rate (Input)

$$DNVD_t = \sum_{j=1}^{t} DNV \cdot DEPRD_{t-j+1} \qquad (B.26)$$

$$DEPRN_t = 0, \qquad t \leq PPY \qquad (B.27a)$$

$$= (N + PPY + 1 - t) / \sum_{j=1}^{N} , \qquad t > PPY \qquad (B.27b)$$

N = Depreciation period for plant; input variable

All of the appropriate terms in equation (B.2) are now known, except for R. Any variables which have not been identified are manual inputs to the simulation model. Equation (B.2) is a polynomial of order T, and it is solved iteratively for a value of R.

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