UPDATE AND ASSESSMENT OF GEOTHERMAL ECONOMIC MODELS, GEOTHERMAL FLUID FLOW AND HEAT DISTRIBUTION MODELS, AND GEOTHERMAL DATA BASES

May, 1985

Prepared for:

U.S. Department of Energy
Assistant Secretary Conservation and Renewable Energy

Geothermal and Hydropower Technologies Division

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Prepared by:

Meridian Corporation
5113 Leesburg Pike, Suite 700
Falls Church, Virginia 22041

Edited By: D. Kenkeremath

ABSTRACT

Numerical simulation models and data bases that were developed for DOE as part of a number of geothermal programs have been assessed with respect to their overall stage of development and usefulness. This report combines three separate studies that focus attention upon: 1) economic models related to geothermal energy; 2) physical geothermal system models pertaining to thermal energy and the fluid medium; and 3) geothermal energy data bases.

Computerized numerical models pertaining to the economics of extracting and utilizing geothermal energy have been summarized and catalogued with respect to their availability, utility and function. The 19 models that are discussed in detail were developed for use by geothermal operators, public utilities, and lending institutions who require a means to estimate the value of a given resource, total project costs, and the sensitivity of these values to specific variables. A number of the models are capable of economically assessing engineering aspects of geothermal projects.

Computerized simulations of heat distribution and fluid flow have been assessed and are presented for ten models. Five of the models are identified as wellbore simulators and five are described as reservoir simulators. Each model is described in terms of its operational characteristics, input, output, and other pertinent attributes.

Geothermal energy data bases are reviewed with respect to their current usefulness and availability. Summaries of eight data bases are provided in catalogue format, and an overall comparison of the elements of each data base is included.

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1.0 GENERAL STATEMENT

In September 1974, the President signed into law Public Law 93-410. The "Geothermal Energy Research and Demonstration Act of 1974" was an act that established a geothermal management program on a federal level to provide for continuing research and development of geothermal resources in the United States. During the following years, the U.S. Department of Energy (DOE) and its predecessor agency sponsored many research and development projects that would increase the quantity of technical data and improve methodologies to assess and develop geothermal energy resources in the United States. A substantial effort was directed towards developing analytical methods and data to assist the geothermal industry. This included computerized models of physical processes in geothermal energy extraction and conversion, as well as computerized economic models. A separate emphasis was also placed upon collecting basic data necessary for the ultimate commercialization of geothermal energy.

The purpose of this report is to serve as a catalogue and to assess the many models and data bases that have been developed with DOE funding. It is hoped that the information presented here will provide interested persons and organizations with knowledge of the location, availability, and application of pertinent geothermal models and data bases.

DOE program participants have included private contractors, national labs, and universities whose work has collectively resulted in the development of the many models and data bases presented herein.

The following report is separated into three chapters that describe the usefulness, availability and applicability of: (1) economic models; (2) heat distribution and fluid flow models; and (3) data bases related to geothermal energy development.

Section 2 presents a general discussion of the characteristics of economic models for geothermal energy utilization, compares the models in a tabular

fashion, and provides a detailed summary of input/output parameters, availability, references, key words, etc., for 19 models.

Section 3 provides a comparison and catalogue of computer models of geothermal heat and fluid flow. Models assessed were limited to wellbore and reservoir models that deal with the simulation of fluid and/or thermal flux through geothermal systems.

Section 4 presents a catalogue and comparison of DOE sponsored geothermal related data bases. The data bases are described with regard to their content, current availability, general purpose, and other pertinent factors.

2.0 ASSESSMENT OF GEOTHERMAL ECONOMIC RELATED MODELS

by James V. Satrape

2.1 Introduction

Throughout the late 1970's and early 1980's, the U.S. Department of Energy sponsored a number of analytical studies with the goals of quantifying, in one sense or another, the costs associated with exploiting geothermal energy resources. Many computer models were developed to perform these calculations. In some cases, the codes were written to assist in the analysis pertaining to a specific study; in other cases, the computer programs themselves were the end result of the research effort.

Outside the small group of people who were involved with the development of the individual models, and in a few instances the users, the capabilities of the models and where they can be obtained is no longer well known. In some cases they may be sitting on shelves waiting to be used. In others, the work had been terminated by funding cutbacks before the computer programs could be documented for the average user.

The purpose of this study is to assess the current status of geothermal energy cost analysis software. This paper provides a general discussion of the applicability and characteristics of the models, followed by a brief abstract for each model. Since the programs described here were funded by the federal government, they are (in theory) available to the public.

In general, a computer model is written with a specific application in mind. In the case of geothermal economic models, this application might be calculations of cost optimization, year by year cash flow simulation, or market penetration studies. Each of these general applications entails a separate methodology in its assumptions and calculations and is targeted to a specific user group.

Parallel to the intended application of the model is the sector of the geothermal community having need for the program. Engineers and A&E firms can

use engineering design and optimization programs to verify their calculations or to visualize the impacts of certain changes on overall cost or efficiency. Developers and utilities need measures of value and total cost for a given project, with some indication of the sensitivity to certain parameters or the amount of risk involved. Financial institutions, insurance companies, and government loan guarantee officers require a cash flow profile as well as some measure of sensitivity in order to make their decisions. Department of Energy program managers need to know the critical areas of research which, if properly funded, will provide the maximum benefit in improving the economics of geothermal energy. Other state, federal and local public officials may have a desire to define localities where there is a potential for the development of a geothermal resource.

Individual models are also written to address particular engineering aspects of geothermal development. They may consider for example, well costs, fluid distribution systems, either direct use or electric production, or any subsets and combinations of these.

2.2 General Discussion of the Models

The general characteristics of the models are described in Tables 1 through 3. Table 1 provides the model name and commonly used mnemonic (e.g. BTHERM), where and when the model was developed, and an indication of the current availability of the model. Table 2 lists the type of geothermal resource evaluated by the model, the types of energy end uses analyzed, and the type of financial analysis or policy analysis for which the model was developed. Table 3 describes the major technical approaches and necessary parameter inputs used in each model.

The remaining text in this section defines and describes the major column headings in the tables. In noteworthy cases, major differences and similarities among the models are highlighted.

2.1.1 Availability

Table 1 lists the models described in this paper, their institution, and year of origin.

The last column in Table 1 describes the availability of each model. Ease of access to the model code and documentation is a very important consideration for anyone planning to use these models.

The availability of the various models is given on a scale of 0 to 5, as follows:

- 0: Unavailable.
- 1: Model has limited availability (DOE or contractors) because of proprietary nature.
- 2: Computer code is available, but without sufficient documentation or assistance. It would require considerable work to implement the program.
- 3: Program listing is available, with documentation. The user may have to enter the program by hand.
- 4: Similar to 3, plus the fact that assistance may be available from one or more of the authors, or the developers of the model may be contracted to perform a given study.
- 5: Program, (tape or cards), listing, and documentation are available "off the shelf." Documentation is adequate to allow fairly rapid startup for a new user.

2.2.2 Applications

Table 2 describes each model with respect to the physical and financial situations which the model was designed to analyze or describe. The main differences among the models lie in their coverage of different types of geothermal resources, energy end use systems, and financial analysis.

Geothermal Resource

Models are included in this study for hydrothermal, hot dry rock, and geopressured resources. The majority of them, as seen in Table 2, are written to evaluate hydrothermal resources. Both high and moderate temperature geothermal reservoirs are represented.

<u>Model Name</u>	<u>Where Developed</u>	<u>Year</u>	<u>Availability*</u>
BTHERM (District Heating Cost)	New Mexico Energy Institute	1980	?
DHM: District Heating Model	Brookhaven National Laboratory	1980	3
GCFM: Geothermal Loan Guaranty Cash Flow Model	MITRE Corporation	1982	5
GEEF: Geothermal Engineering and Economic Feasibility Model	Engineering and Economics Research	1981	2
GELCOM: Geothermal Levelized Busbar Cost Model	MITRE Corporation	1978	2
GEOCITY: Geothermal District Heating Cost Analysis	Battelle-Pacific Northwest Laboratories	1978 1982	5 4
GEOCOM: Geothermal Completion Technology Life-Cycle Cost Model	The BDM Corporation	1982	4
GEOCOST: Geothermal Cost Analysis - Steam Cycle Version	Battelle-Pacific Northwest Laboratories	1975 1981	5 2
GEOCOST-BC: Geothermal Cost Analysis - Binary Cycle Version	Battelle-Pacific Northwest Laboratories	1976 1981	5 2
GEOTHM: Geothermal Thermodynamic and Cost Optimization Model	Lawrence Berkeley Laboratory	1977	?
GEOTHM: (Process Heat Design)	Massachusetts Institute of Technology	1980	3
GPCM: Geothermal Probabilistic Cost Model	Jet Propulsion Laboratory	1981	?
GPPROG: (Geopressured)	Louisiana State University	1979	?
GRITS: Geothermal Resource Interactive Temporal Simulation	John's Hopkins University/ Applied Physics Laboratory	1982	4
HDR3 (Hot Dry Rock District Heating)	Los Alamos National Laboratory	1982	3
TCN: Geothermal Investment and Policy Analysis	Technecon Analytic Research	1981	3
Texas Geopressured Resource Evaluation	University of Texas at Austin	1979	?
VENVAL: (Venture Analysis)	Dupont de Nemours, Inc.	1980	1
WELCST: Geothermal Well Cost Model	Mitre Corporation	1979	3

* For explanation, see text, page 5.

Table 1: List of Economic Models

<u>Model</u>	<u>Geothermal Resource</u>	<u>End Use</u>	<u>Type of Analysis</u>
BTHERM	Hydrothermal	District Heating, Process Heat, Space Heating	Cost/Benefit
DHM	Hydrothermal	District Heating	Cost/Benefit, Market Penetration
GCFM	Hydrothermal	Electricity Production	Cost/Benefit, Risk Assessment
GEEF	Hydrothermal	Process Heat	Cost/Benefit
GELCOM	Hydrothermal	Electricity Production	Cost/Benefit
GEOCITY	Hydrothermal	District Heating/Cooling	Cost/Benefit, Design
GEOCOM	Hydrothermal	None	Cost/Benefit, R&D Planning
GEOCOST	Hydrothermal	Electricity Production	Cost/Benefit, Design
GEOCOST-BC	Hydrothermal	Electricity Production	Cost/Benefit, Design
GEOTHM (LBL)	Hydrothermal	Electricity Production	Design
GEOTHM (MIT)	Hydrothermal	Process Heat	Cost/Benefit, Design
GPCM	Hydrothermal	None	Cost/Benefit, Risk Assessment
GPProg	Geopressured	Methane Production	Cost/Benefit, Risk Assessment, Market Penetration
GRITS	Hydrothermal	District Heating, Process Heat, Space Heating	Cost/Benefit
HDR3	Hot Dry Rock	Space Heating	Cost/Benefit
TCN	Hydrothermal	Electricity Production	Risk Assessment, Market Penetration
Univ. of TX	Geopressured	Methane Production	Cost/Benefit, Market Penetration
VENVAL	N/A	N/A	Cost/Benefit, Risk Assessment
WELCST	Hydrothermal	None	Cost/Benefit, R&D Planning

Table 2: Economic Model Descriptions

End Use

The end use of the model is defined here as the primary energy output considered by each. This includes district heating (geothermal space and hot water heating for cities, towns, or subdivisions), space heat (small scale applications of geothermal heating), process heat (industrial use), and electricity production. Those models indicating no end use do not consider energy conversion but focus on either drilling costs or field development.

Type of Analysis

This information summarizes the most valuable applications for each program.

A cost-benefit study may be used to perform a numerical evaluation of the possible profitability of a given investment. This is applicable to feasibility studies and could be used by developers, utilities, private firms, local governments, or anyone considering investment in a geothermal project.

An assessment of risk can be determined from those models which incorporate probability distribution functions or from those which permit the performance of sensitivity analysis on key unknowns. This risk assessment is valuable to any investor, but would be of greatest interest to utilities, loan institutions, insurance companies, and those involved in loan guarantee programs.

The computer programs which can perform system design based on engineering relationships are useful for initial design studies and preliminary cost estimates. They can conceivably save much time in calculations when numerous designs are to be examined in a quick assessment of alternatives. They do not obviate the need for detailed analysis of the final designs.

Market penetration studies incorporate resource and geographical data bases to predict locations where geothermal energy development may be feasible. These studies could be used by government planners (at local, state, or federal levels) or by developers and firms in search of possible markets. The TCN model places emphasis on a different aspect of market penetration. Based on

extensive surveys of developers and utility decision-makers, it determines the likelihood of investment in a given project defined by a probabilistic financial summary.

The R&D planning models are primarily very detailed cost models which allow variations in individual parameters to gauge the overall effects which technological improvements may have on the economic picture for geothermal development. These models are primarily targeted for DOE program managers or industry R&D planners in order to maximize the value of research funding.

2.2.3 Internal Features

Table 3 compares many of the major internal features of the models. For example, what one model requires as input another might calculate from different physical parameters. This is indicated where appropriate. The various major factors incorporated into each model are also listed.

Reservoir Modeling

The majority of the models (indicated by a "YES" in the second column of Table 3) model the geothermal reservoir as an infinite, homogenous system, at a given temperature and depth, which is capable of sustaining a given flow rate per well. The HDR3 model contains a factor for reservoir temperature decay, and three of the hydrothermal models (GRITS, GEOCOM, and GPCM) contain options for modeling reservoir flow rate degradation. The geopressured models both consider a finite, methane saturated horizon and include defining such parameters as area, thickness, porosity, etc.

In analyzing potential hydrothermal resources, it is probably unnecessary to consider reservoir decline in a preliminary feasibility study. However, it is valuable in the performance of sensitivity analyses which may help to quantify the economic risk involved in a given project.

A number of the models include, in the computer program files, data bases

MODEL	RESERVOIR MODELING	WELL COSTING	FIELD DEVELOPMENT AND PRODUCTION	ENERGY CONVERSION	FINANCIAL ANALYSIS	OUTPUT	MISCELLANEOUS
BTHERM	Yes	Input	Exploration, success ratio, injection, system expansion	Calculates heats demand, System costing, system expansion retrofit, O&M	Life-cycle costing taxes, debt, escalation	Total cost Levelized energy cost	
DHM	Yes, Resource data base	f (depth, hardness)	#wells based on need	Optional supplementary heating, retrofit, O&M, phased construction. Calculates heat demand. optimization	Life-cycle costing taxes	Levelized energy cost	Census and county data bases
GCFM	Yes	f (depth hardness)	Success ratio, injection, downhole pumps, well life, costs based on GELCOM	Dry or flashed steam binary, costing based on GEOCOST, O&M, capital replacement	Life-cycle costing, taxes, debt, escalation	Levelized energy cost, Cash flow	Sensitivity analysis
GEEF	Yes	f (depth hardness)	Exploration, well life	Direct use. User defines heat requirements. Optional supplementary heat. Sizes and costs system. O&M, capital replacement.	Life-cycle costing, taxes, escalation, debt	Levelized energy cost, NPV, Cash flow Payback period	
GELCOM	Yes, Resource data base	f (depth hardness)	Injection, brine treatment, well life	Flashed steam, binary. Plant size fixed: 50MW	Life-cycle costing, taxes, debt, escalation	Levelized busbar cost	
GEOCITY	Yes	f (depth hardness temperature, well design)	Exploration, success ratio, injection, well life, downhole pumps	Direct use. Designs distribution system. Calculates demand. O&M, capital replacement, optimization optional supplementary heat.	Life-cycle costing, taxes, debt, escalation	Levelized energy cost (producer and distributor)	Steam tables
GEOCOM	Yes Reservoir decline, Resource data base	Cost data base. Life time O&M d modeling including workovers.	Single well (injection or production) downhole pumps, brine treatment	N/A	Life-cycle costing	NPV	
GEOCOST	Yes	f (depth hardness, temperature, well design)	Exploration, success ratio, injection, well life, downhole pumps	Dry or flashed steam. Component sizing and costing. O&M, capital replacements.	Life-cycle costing, taxes, debt, escalation	Levelized energy cost (producer and utility)	Steam tables
GEOCOST-BC	Yes	f (depth hardness, temperature, well design)	Exploration, success ratio, injection, well life, downhole pumps	Binary. Component sizing and costing. O&M, capital replacements.	Life-cycle costing, taxes, debt, escalation	Levelized energy cost (producer and utility)	Steam tables
GEOTRM (LBL)	Yes	Input	Injection, downhole pumps	Flashed steam, binary. System design optimized for user selected objective function. Costs based on EPRI study of Heber.	N/A	One time cost	

Table 3: Summary of Key Economic Descriptors

MODEL	RESERVOIR MODELING	WELL COSTING	FIELD DEVELOPMENT AND PRODUCTION	ENERGY CONVERSION	FINANCIAL ANALYSIS	OUTPUT	MISCELLANEOUS
GEOTHM (MIT)	Yes	Input	Success ratio, well replacement	Direct use, optional supplementary heat, multiple end uses --distribution optimized. Costing of components. O&M	Life-cycle costing, taxes, escalation, debt	NPV, IRR, Payback period	
GPCM	Yes, Reservoir decline	Input	Exploration, injection, well life, pdf's	Not included. User may define relationships to model conversion.	Life-cycle costing, taxes, debt, escalation	NPV Levelized energy cost	Probabilistic. User may define other relationships.
GPPROG	Yes, Finite aquifer	Cost data base	1 production, 2 injection wells, O&M	Water-methane separator, O&M	Life-cycle costing, taxes, escalation	NPV, IRR, Optional optimization	Study period 1985-2004. Probabilistic.
GRITS	Yes, Drawdown modeled, Optional reservoir decline	f (depth)	Exploration, single or multiple wells, downhole pumps, injection	Direct use, optional supplementary heating, O&M, capital costing and replacements. Calculates demand. O&M	Life-cycle costing, taxes, escalation, debt	NPV, Payback period, Levelized energy cost	Optional Monte Carlo simulation
HDR3	Yes, Temperature decline	Options: f (depth hardness) or cost data base	Single production and injection system. Optimized (NPV) redrilling program.	Defined by heat requirements, no costing	Life-cycle costing, escalation	NPV	Sensitivity analysis
TCN	Yes, Size of reservoir may be defined as a constant or a pdf.	f (depth hardness) pdf	Exploration, well life, success ratio, pdf	Flashed steam, binary, costs = f (temperature, salinity), pdf	Life-cycle costing, escalation, debt, taxes	NPV, Availability, Levelized busbar cost, Probability of investment	Probabilistic, Combination of several separate models, Detailed forecasting analysis.
UNIV. OF TEXAS	Yes, Finite aquifer	Input	Calculates development scenario for a given reservoir. Injection, success ratio, O&M	Costs input	Life-cycle costing, taxes, escalation	NPV	
VENVAL	N/A	Input	User inputs complete cost schedule.	User inputs complete cost schedule.	Life-cycle costing, debt, taxes much flexibility for userdefined parameters	NPV, IRR, Levelized energy cost, etc.	Probabilistic
WELCST	N/A	Detailed calculation of drilling and completion costs. User may vary specific costs and efficiencies	N/A	N/A	N/A	One time cost	

Table 3: Summary of Key Economic Descriptors (continued)

of information for certain basic reservoir parameters of Known Geothermal Resource Areas (KGRA's), such as temperature, depth, rock hardness, and brine composition.

Well costing

Almost all of the models listed include well costs. For some studies, the cost of drilling a well must be input by the user from actual or best guess estimates. A number of the models use various simplified costing equations where, based on known data, the well cost is defined in terms of depth and rock hardness. WELCST is a detailed drilling cost model which accounts for all of the major activities in the drilling process -- its primary goal is to project the effect of improvements in specific technologies to the overall cost of drilling a well. HDR3 has the option of using either a costing equation or a subprogram which outputs the cost of a well based on the results of a rigorous feasibility study. The GPPROG model uses a simpler algorithm, where costs are based on the results of a separate study. The GEOCOM model computes initial drilling costs from a data base assembled from actual wells in six KGRA's. It also considers the lifetime operation and maintenance costs of the well. It allows the scheduling of workovers (such as stimulation, descaling, reperforating, etc.) which improve well performance. The costs and effectiveness of these procedures can be varied to simulate the impact of technological improvements on life cycle well costs.

The well-cost equations used in the various models vary greatly and can yield quite different cost estimates using the same input parameters. This has been demonstrated in a study of the various geothermal district heating cost models (Reistad, 1983). As a rule, regardless of the costing methodology employed, the user has the option of overriding those costs if actual estimates are known.

Field Development and Production

This column lists the important parameters considered by each model pertaining to the geothermal field. The important factors as listed in Table 3 are discussed below.

(1) Modeling of the exploration phase of field development is often defined in terms of the cost and duration of this phase. Some models have the option of defining this in terms of a probability distribution function.

(2) The success ratio accounts for the costs incurred in drilling dry wells (non-producers). This is usually expressed as a fixed percent, with a given cost per dry well, thereby increasing the cost per well in proportion to the success ratio.

(3) If well life is considered, costs are also included for drilling replacement wells as the need arises.

(4) Other factors, i.e. injection, downhole pumps, brine treatment, and operation and maintenance (O&M), are self-descriptive. Those parameters considered by the individual models are so indicated.

Energy Conversion

The end uses considered by the various models are district heating and cooling, small scale space heating, process heat, methane production (from geopressured resources), and electric generation (dry steam, flashed, and binary cycles). These are shown where indicated in Table 2. Table 3 elaborates on the key factors relating to energy conversion included in each model.

A number of the models (GEOCOST, GEOCITY, etc.) use costing equations which are based on component sizes - these sizes are determined from thermodynamic relationships. A few of the models (both GEOTHM models, DHM, GEOCITY) perform some engineering design optimization. Operation and maintenance charges are usually included - some programs compute them as a function of brine salinity. In three models (BTHERM, GELCOM, and GEOTHM [LBL]), the system costs are based

on costs of existing systems.

Most of the direct use models include the option of a clean water system with an intermediate heat exchanger. BTHERM, DHM, GEOCITY, and GRITS calculate heat demand based on such parameters as population and climate. Other models simply define the end use in terms of a required temperature drop and total heat flow.

Financial Analysis

The models which include financial analysis generally use one or more of the large number of methods which fall under the general classification of "engineering economics." As indicated in Table 3, those which perform life-cycle costing use some form of discount rate to account for the time value of money. Among the other parameters incorporated into the various models are taxes (federal, state, property), insurance, various debt structuring (loans, common or preferred stock, bonds), and inflation. All models which account for taxes also include tax benefits such as credits and depreciation. The models so indicated consider price escalation - the increase in real costs of capital replacements, fuel, or other expenses. It is possible that price escalation may be included in some others, but it is not apparent in the available documentation.

Output

The outputs of the programs listed in Table 3 include:

(1) One time cost: The initial cost of a given system, not considering lifetime factors. This is also known as first year cost.

(2) Net Present Value (NPV): The sum of the total value of all cash flows (expenses and profits) over the life of the project, discounted to the start-up or other base-year date.

(3) Payback Period: For a given cash flow and set of financial conditions, this is the amount of time required from the initial investment for the net

present value to reach zero (breakeven point).

(4) Internal Rate of Return (IRR): This is the overall discount rate which yields a net present value of zero over the lifetime of the project.

(5) Levelized Energy Cost: This is the selling cost of energy which results in a NPV of zero over the system life, for an assumed discount rate. This is useful in comparison with alternative energy sources.

Miscellaneous

This column of Table 3 lists some unique characteristics of specific models. One of the more important of these is the use of probability distribution functions (pdf's) to define certain parameters. When this is incorporated into the model's input, the output of the program will also be in the form of a pdf. This is more valuable than a single point estimate, as it provides some measure of characterizing the risk in a given project, in the form of ranges of costs, prices, or rates-of-return.

Another unique output is that of the Technecon model which predicts the likelihood of a field developer and/or a utility investing in a particular project given information about possible cash flows, risks involved, etc. The equations for this prediction are the results of extensive surveys of industry and utility decision makers. This program also optimizes the selling price from developer to utility to maximize the likelihood of both investments. This particular analysis is very useful in forecasting future geothermal development. It is also of great interest because the financial theory behind it has been well documented (Blair et al., 1982).

Other special characteristics of the programs are detailed in the following individual abstracts.

2.3 Model Descriptions

The following subsections provide a synthesis of each of the identified economic models. Each model is described under a standard format for comparison.

2.3.1 BTHERM

DEVELOPED BY: New Mexico Energy Institute
New Mexico State University
Las Cruces, NM

AUTHORS: Roy A. Cunniff, Gary Glazner, Mark Houldsworth

DATES: User's Manual published May 1980

PURPOSE: The BTHERM Model provides an overview of the economic factors involved in a geothermal direct use project, either district heating or process heat applications.

ENERGY

EXTRACTION: The user inputs the time required for exploration and field development. The reservoir is characterized by depth and temperature. Inputs include required flow, well cost for production and injection wells, the drilling success ratio, and the well spacing. Well life is assumed to be equal to project life. New production wells are drilled as the system expands and additional capacity is required.

ENERGY

CONVERSION: This simulation is applicable to district heating (city or subdivision), industrial process heating, small scale commercial projects, and domestic hot water. In district heating, districts (approximately 3,000 people) are quantified in terms of population density and commercial to residential ratios. Additional development is modeled by selecting lag time for the bringing of new districts on line. The heat demand is determined from heating degree days and the design temperature. The cost equations are based on studies of Icelandic data. In the modeling of a commercial complex, the peak heat demand is the critical factor. Process heating is also characterized by the heat demand--the temperature requirements are not a factor.

All applications include the possibilities of retrofit and expansion. Operating costs are a fixed percentage of capital costs.

FINANCIAL

PARAMETERS: The program can be used to simulate either a public utility or a private developer project. Output includes total costs and a levelized cost for heat supplied. Costs for resource investigation, system design, and land leasing are included. The user inputs the percent of capital to be financed and the interest rate. State, federal, and property taxes are considered, as well as tax credits, depreciation, and depletion allowances. Conventional energy costs are subject to escalation. The discount rate used is the total interest rate specified. All default costs are in 1980 dollars.

COMPUTER

CODE: The program is interactive. There is also the possibility of using multi-valued parameters whereby multiple runs will be made.

AVAILABILITY: Unknown.

REFERENCES:

Cunniff, R. A.; Glazner, G.; Houldsworth, M.; Geothermal Energy For Residential, Commercial, Industrial Uses. A Computer Simulation Model, B THERM. NMEI 30-5, December 1979.

Cunniff, R. A. et. al. User's Guide to B THERM NMEI 30-22, May 1980.

Glazner, G.; "Modelling Geothermal District Heating Systems," Geothermal Resources Council, Transactions Vol. 5, October 1981, pp. 639-641.

Houldsworth, M.; "An Optimum Fuel Mix Model For Geothermal District Space Heating Systems,," Geothermal Resources Council, Transactions Vol. 5, October 1981, pp.

See also: Reistad (1983), EER (1982)

KEY WORDS: District Heating, Process Heat, Space Heating, Field Development, Life Cycle Costs.

2.3.2 DHM: District Heating Model

DEVELOPED BY: Brookhaven National Laboratory
Upton, L.I., NY 11973

AUTHORS: Ann Reisman, J. Karkheck

DATES: Published late 1980, active through 1981

PURPOSE: The program is written to provide a means of assessing the economic feasibility of geothermal district heating for any community in the United States.

ENERGY

EXTRACTION: The program accesses a data base with information of the geothermal resources of 13 western states. The input to the program, either from the data base or user input, includes depth, temperature gradients, porosity, rock hardness, and chemical composition of brine. Based upon the heat requirements and local geothermal resource, the program determines the required number of wells and calculates the associated cost.

ENERGY

CONVERSION: The program considers district heating (space and domestic hot water) by geothermal fluid, with the possibility of oil or gas for supplementary and peak heating. It optimizes, by cost, the percentages of geothermal and conventional backup capacity. In determining the district heat requirements, the program accesses a Census Data Base (1970) and a County Data Base. These supply inputs, for the chosen location, on costing factors, weather, heat requirements, area, fuel costs, and the categorization of the area to be heated (i.e., residential, commercial, etc.; there is a total of 12 categories). Based upon flow requirements, piping costs, etc., the program optimizes the cost of the district heating system. There is also the possibility of using a retrofit system. Operating costs are included.

FINANCIAL

PARAMETERS: The program calculates the levelized cost of heat from the district heating system. The user inputs the discount rate. Taxes and investment tax credits are included, and there is the option for time-phasing the construction and capital expenditures. Public or private ownership may be selected.

COMPUTER

CODE: The program is in FORTRAN and is designed to be interactive. At present, there is no documentation available.

AVAILABILITY: Funding of this project was terminated before the documentation and user's manual could be developed. The code itself can be obtained from Brookhaven, but would require considerable assistance from the authors to operate in its present state.

REFERENCES:

- Reisman, A.; Karkheck, J.; District Heating Model, An Overview, BNL-28251, October, 1980.
- Reisman, A.; A Generic Model for District Heating and Geothermal Application, BNL-28892, November 1980.
- Reisman, A.; A Geothermal-District-Heating Assessment Model for Decision Making, BNL-30442, November 1981.
- Reisman, A.; Peterson; The Economic Feasibility of Geothermal District Heating, A Case Study, BNL-30670, December 1981.
- See also: Reistad (1983), EER (1982)

KEY WORDS: District Heating, Western Resources, Resource Data Base, Life-Cycle Costing.

2.3.3 GCFM: Geothermal Loan Guaranty Cash Flow Model

DEVELOPED BY: METREK Division
The MITRE Corporation
McLean, VA

AUTHORS: Mark Keimig, Joseph Rosenberg, Daniel Entingh, Coleman Blake

DATES: Published November 1980. Revisions published through February 1982

PURPOSE: The model estimates project costs and cash flows for geothermal producers and electric plants throughout the construction and operation phases. It was written for the purpose of assisting in the analysis of DOE Geothermal Loan Guaranty applications.

ENERGY

EXTRACTION: The field program module calculates the year by year costs associated with developing and operating the geothermal field. The reservoir is characterized by its depth, wellhead temperatures, pressures, and brine composition. It is modeled as an infinite system with constant parameters over the lifetime. Drilling costs are a function of depth and rock hardness or can be input by the user. There are costs for production and injection wells. A success ratio for drilling is also input. The user defines the flow rate per well, and the program calculates if downhole pumps are necessary. Well life is input to determine the schedule of replacement well drilling. Ten different field designs can be stored in the computer memory while running the program to perform comparisons and sensitivity analyses. Default values are included in the program, based on a detailed industry survey, to allow performance of preliminary calculations with minimal information. The costing equations are based on MITRE's GELCOM Model, updated to 1979.

ENERGY

CONVERSION: The power plant program module can be used to study dry steam, single or dual flash, and binary systems. Costing equations are based upon the GEOCOST Model (Battelle-PNL). User controlled variables include turbine/generator efficiencies, outlet temperature, coolant temperature, pump types, etc. The model calculates brine flow requirements which are then input to the field program module. Plant life is 50 years. As with the field module, up to 10 plant types can be stored as data sets to perform sensitivity analyses. Default values used in preliminary studies can be replaced in the analysis as data becomes available. Life cycle costs such as operation and maintenance, capital asset replacement, and salvage value are considered.

FINANCIAL

PARAMETERS: The financial program module has as input the initial and year by year costs from the other modules and outputs a year by year cash flow and a levelized busbar cost. Initial debt is structured to provide as much leverage as possible, loan life and a sinking fund are designated by the user. State, federal and property taxes are included, as well as tax credits, tax benefits, depreciation, deple-

tion allowances, etc. Electricity prices, geothermal fluid prices, and capital costs are subject to escalation and inflation. There is the possibility to store up to 15 financial data sets. The model can consider either producers or utilities in a given run, but not in combination. All values are in 1979 dollars, but cost indexes exist in the equations to update the values.

COMPUTER

CODE: The program is written in FORTRAN IV under a VM/CMS operating system. It is highly user interactive. The program has been installed on the IBM 370 and Hewlett-Packard 3000 Series 3 systems.

AVAILABILITY: The program, Version 5.0, is available from the National Engineering Software Center at Argonne, with Revisions through February 1982. The code is available for IBM 370 or 303x series systems. The DOE Geothermal Loan Guaranty Program, DOE San Francisco Operations Office, has the HP-3000 version.

REFERENCES:

Keimig, M.A., Rosenberg, J.I.; Entingh, D.J. Geothermal Loan Guaranty Cash Flow Model - Description and User's Manual, MTR-80W160, November, 1980.

See also: EER (1982), Ziman (1983)

KEY WORDS: Electric Power Plant, Steam Cycle, Binary Cycle, Field Development, Life-Cycle Costs.

2.3.4 GEEF: Geothermal Engineering and Economic Feasibility Model

DEVELOPED BY: Engineering and Economics Research, Inc.
Falls Church, VA 22043

AUTHORS:

DATES: Published May 1981

PURPOSE: The program is designed to perform preliminary economic feasibility assessments of using geothermal energy in direct process heat applications, in comparison with other available energy sources.

ENERGY

EXTRACTION: The resource is characterized by the wellhead temperature, depth (production and injection wells), brine salinity, well flow rate, and rock hardness. There is a fixed cost for field exploration, which the user may set. Field development is performed over a period of 3 years, well costs are a function of depth and rock hardness. Well life is considered in the costs of replacement wells over the system life.

ENERGY

CONVERSION: The model is written to consider direct process heating applications with geothermal energy. The user specifies parameters such as process temperature, allowable temperature drop, peak load, utilization factors, and length of the distribution system. There are options for single or binary systems, supplementary heat for augmentation, and two stage processes (for high and low temperatures). The program determines the required geothermal fluid, number of wells, heat exchanger sizes, and associated costs. Operation and maintenance charges are included, as well as capital replacement costs for heat exchangers. The program has default values for costs, but it is possible for the user to override if data is known.

FINANCIAL

PARAMETERS: The program calculates year by year cash flows, net present value (given the price of energy sold), discounted payback, and levelized energy cost. The user can specify fuel and plant costs for an alternative system and comparison data will be generated. There are options for financing: debt fraction can be varied, common stock and preferred stock are considered. Federal, state, and property taxes are included along with investment tax credits, depletion allowances, depreciation, and accounting for tangible and intangible costs. Insurance and royalty payments are also included. Year by year costs are calculated taking into consideration inflation and price escalation in the costs of capital replacements, fuel, and operation and maintenance. All default values are in 1980 dollars.

COMPUTER

CODE: The program is written in FORTRAN IV for an IBM 370 system. There is no internal documentation. It is not interactive.

AVAILABILITY: The computer listing is included in Reference 1. This publication is available from the NTIS as order number DE83007301.

REFERENCES:

Engineering and Economics Research, Inc. GEEF: A Geothermal Engineering and Economic Feasibility Model, Description and User's Manual.
DOE/ID/12174-T1, September 1982.

KEY WORDS: Process Heat, Field Development, Life-Cycle Costing.

2.3.5 GELCOM: Geothermal Levelized Busbar Cost Model

DEVELOPED BY: METREK Division, MITRE Corporation
McLean, VA

AUTHORS: J.N. Gupta; J.G. Leigh

DATES: Published January 1978

PURPOSE: The model can be used to project the costs of electricity generated from a liquid-dominated geothermal resource for either the field operator or the electric utility.

ENERGY

EXTRACTION: The model considers liquid dominated systems at temperatures greater than 150° C. The reservoir is considered to be infinite in that it will not decline in productivity or limit production. It is characterized by temperature, depth, rock hardness, and brine salinity; a data file is included for 26 KGRA's containing this information. Well costs are determined as a function of depth and rock hardness. Costs for production wells, injection wells, and brine treatment are calculated but scheduling can be input by the user if known. Well life is input to determine costs and scheduling of replacement wells.

ENERGY

CONVERSION: The program considers the costs of constructing and operating electric power plants. All plants are assumed to be 50MWe, the user selects the number of plants and when they will come on line. Both flashed steam and binary power cycles are considered. The program contains 12 generic plant designs for temperature, salinity, and conversion cycle and plant costs are calculated by interpolating between these known designs. Operation and maintenance is a fixed percentage of capital cost. The user inputs plant life.

FINANCIAL

PARAMETERS: The program calculates the levelized busbar cost of produced electricity. For life-cycle costs, inflation and price escalation are included. The debt fraction is input with the associated interest rates and the discount rate. Taxes, tax credits, depreciation, royalty payments and insurance are included. Costs are calculated in 1977 dollars.

COMPUTER CODE

The program is written in FORTRAN IV on an IBM 370 system. It is designed to be interactive from a remote terminal. Sensitivity analysis will be performed as required on critical parameters such as temperature, capacity factor, drilling costs, tax credits, etc.

AVAILABILITY: The computer code, with data files, is included in Reference 1.

REFERENCES:

Gupta, J.N.; J.G.; GELCOM: A Geothermal Levelized Busbar Cost Model,
M78-17, January, 1978.

See also: EER (1982)

KEY WORDS: Electric Power Plants, Steam Cycle, Binary Cycle, Field
Development, Resource Data Base, Life-Cycle Costing.

2.3.6 GEOCITY

DEVELOPED BY: Battelle, Pacific Northwest Laboratory
Richland, WA 99352

AUTHORS: Harlan Huber, Clarence Bloomster, Linda Fassbender

DATES: Original version published October, 1978. Updated version, September 1982.

PURPOSE: GEOCITY is a large-scale simulation model which combines both engineering and economics to systematically calculate the cost of geothermal district heating systems for space heating and cooling.

**ENERGY
EXTRACTION:** The exploration, development, and operation of the geothermal field are simulated in the reservoir model. Costs for field exploration are determined in a seven step process, each step of which is characterized by input costs, time, and success ratios. Alternatively, the user can input these costs directly. The reservoir itself is modeled as a constant (over time), infinite system. In the development stage, the user can specify the well design, whereby costs are calculated from default values (function of depth, diameter, bottom-hole-temperature, percent of well cased, rock hardness) or the costs per well can be input directly. The ratio of producers to dry wells is considered. Based upon wellhead characteristics (temperature pressure, flow rate, geothermal fluid) and fluid requirements, the transmission system is sized and priced. Downhole pumps are used if needed. All calculated costs can be overridden with input data. Costs for injection wells are included. Costs for interim capital replacements and operation and maintenance are a function of capital costs and fluid chemistry. Well life is input directly. Fluid characteristics are determined from ASME Steam Tables, incorporated into the computer code.

**ENERGY
CONVERSION:** The GEOCITY Computer Program considers domestic hot water heating, space heating, and space cooling*. The demand is calculated based upon climate (degree days, design temperatures), population, and area. A city is divided into districts, each of which is characterized as one of six standards types (high density, single family; high-rise apartments; etc.) with an associated demand profile. Other types may be specified by the user. The program designs the distribution system and calculates fluid requirements to meet the needs. It also determines pipe sizes and materials, insulation, and physical layout. Pipe sizes and insulation are optimized on a minimum cost basis, with regard to heat losses. Optionally, a binary system with heat exchanger may be chosen, or the capability of wellhead fluid mixing*. Operation and

* Asterisk indicates options which are only available in 1982 version.

maintenance, electrical pumping, and supplemental heating costs are included. The distribution model is derived in part from SOLTES, a solar energy district heating design code written at Sandia National Laboratories.

FINANCIAL

PARAMETERS: For both the producer and distributor, the model calculates the levelized cost of energy. The reservoir model cost output is input to the distribution economics model. There are options for debt or equity financing, and the discount rate is calculated from the corresponding interest rates. State, federal and property taxes are included as well as tax credits and depreciation. Tangible and intangible costs are differentiated for tax purposes. Insurance and royalty payments are included. Either a private enterprise or a public utility is selected by the user for consideration. Escalation* of capital replacement and fuel costs is available. Maximum project life is 50 years. Costs are in 1980 dollars.* Indexes are available to escalate base-year costs to the desired year.

COMPUTER

CODE: The program is written in Fortran IV and is not interactive. Code for the ASME Steam Tables is included for thermodynamic calculations.

AVAILABILITY: The 1978 version (described here) is available from the National Energy Software Center, Argonne, IL, in source deck or magnetic tape for CDC6600 and CYBER74 computers. The user's manual is available either through NESC or NTIS. An updated version of the code (circa approximately 1982) has been completed at PNL but not released. The updated user's manual is available from NTIS.

REFERENCES:

McDonald, C.L.; Bloomster, C.H.; Schulte, S.C. GEOCITY: A Computer Code for Calculating Costs of District Heating Using Geothermal Resources. BNWL-2208, February, 1977.

McDonald, C.L.; Bloomster, C.H. The GEOCITY Model: Description and Application. BNWL-SA-6343, June, 1977.

Huber, H.D.; McDonald, C.L.; Bloomster, Schulte, S.C. User Manual for GEOCITY: A Computer Model For District Heating Cost Analysis. PNL-2742, October 1978.

Huber, H.D., Fassbender, L.L.; Bloomster, C.H. User Manual For GEOCITY: A Computer Model For Geothermal District Heating Cost Analysis. PNL-4422, September 1982.

*Asterisk indicates options available in 1982 version only.

Fassbender, L.L.; Bloomster, C.H.; The Economics of Power Plant District and Process Heating in Richland, Washington. PNL-3719, April 1981.

See also: EER (1982), Reistad (1983), Ziman (1983).

KEY WORDS: District Heating, District Cooling, Engineering Design,
Field Development, Life-Cycle Costs.

2.3.7 GEOCOM

DEVELOPED BY: The BDM Corporation
Albuquerque, NM 87106

AUTHORS: E. R. Anderson; W. C. Hoessel, A. J. Mansure,

DATES: Published July 1982

PURPOSE: The GEOCOM model is designed to evaluate the cost effectiveness of various technologies in well completion, production, and maintenance. Emphasis is placed upon the lifetime cost and performance of a geothermal well.

ENERGY

EXTRACTION: The characteristics of six KGRA's are included in the program's data base (Brawley, Heber, Geysers, Baca, Roosevelt Hot Springs, and East Mesa). These parameters are depth, completion interval, well head temperature, average well life, initial well flow, dissolved solids, steam fraction, and exponential reservoir decline rate. For each KGRA, the well design and initial cost is based upon the data base assembled in Reference 3.

The emphasis of the simulation is on the operations phase of the well life. Operation and maintenance costs are a percentage of capital costs. Pumping and chemical treatment costs are calculated from the amount of fluid produced. There are 12 workover types included in the program; the user selects up to 3 and sets the frequency at which they will be performed. The resulting improvement of well flow as a result of the given workover is also included. All calculations in the program are for a single well.

ENERGY

CONVERSION: Costs for conversion or distribution are not considered. The user specifies what the end use is to be (electric, direct heat, total energy, injection well) and the program, based on simple equations and ideal efficiencies, calculates the value of the fluid extracted. In the case of injection wells, the output is the cost in \$/gallon injected.

FINANCIAL

PARAMETERS: The output of the program is life-cycle cost/life-cycle benefit. The inflation and discount rates are input to determine net present value of all costs.

COMPUTER

CODE: The computer program is written in FORTRAN (1966 version).

AVAILABILITY: A list of the computer code is included in Reference 1. The program is presently installed on the Sandia National Laboratories' NOS computer.

REFERENCES:

Anderson, E. R., et. al. Geothermal Completion Technology Life-Cycle Cost Model (GEOCOM), SAND 82-7006, July 1982.

Brown, G. L. Geothermal Wells - The Cost Benefit of Fracture Stimulation Estimated by the GEOCOM Code, SAND 83-7440, September 1983.

Carson, C. C.; Lin, Y. T.; Livesay, B. J. Representative Well Models for Eight Geothermal Resource Areas, SAND 81-2202, February 1983.

KEY WORDS: Field Development, Drilling Costs, Life-Cycle Costs.

2.3.8 GEOCOST: Geothermal Cost Analysis, Steam Cycle Version

DEVELOPED BY: Battelle, Pacific Northwest Laboratories
Richland, Washington 99352

AUTHORS: Harlan Huber, Clarence Bloomster, Linda Fassbender.

DATES: User's manual published March, 1976. Code updated through approximately 1984 but not published.

PURPOSE: The GEOCOST program simulates the over-all design, including major components, of a geothermal steam electric power plant. Components are sized based upon thermodynamic relationships and costs are calculated as a function of size.

ENERGY

EXTRACTION: The exploration, development, and operation of the geothermal field are simulated in the reservoir model. Costs for field exploration are determined in a seven step process, each step of which is characterized by input costs, time, and success ratios. Alternatively, the user can input these costs directly. In the development stage, the user can specify the well design, whereby costs are calculated from default values (function of depth, diameter, bottom-hole-temperature, percent of well cased, rock hardness) or the total cost per well can be input directly. The ratio of producers to dry wells is considered. Based upon wellhead characteristics (temperature, pressure, flow rate, geothermal fluid) and fluid requirements, the transmission system is sized and priced. These can be overridden with input data. Costs for injection wells are included. Costs for interim capital replacements and operation and maintenance are a function of capital costs and fluid chemistry. Well life is input directly by the user. Fluid characteristics are determined from ASME Steam Tables, incorporated into the computer code.

ENERGY

CONVERSION: This version of GEOCOST considers steam powered electric generation. Based upon the specified power plant design, capacity, and geothermal fluid characteristics, the program calculates plant size, cost, and fluid requirements. There are options for particulate removal and multi-stage flashing. Operation and maintenance costs as well as those for replacement of components are based on initial capital cost and fluid chemistry. Construction time for the geothermal power plant is considered.

FINANCIAL

PARAMETERS: For both the geothermal field and the power plant, the program calculates the levelized cost of energy. The reservoir model cost outputs are input to the power plant model. There are options for debt or equity financing and the discount rate is calculated from these interest rates. State, federal, and property taxes are included as well as tax credits and depreciation. Tangible and intangible costs are differentiated. Insurance and

royalty payments are also included. Maximum total project life is 50 years. Costs are in 1974 dollars. Indexes are available to escalate base-year costs to the desired year.

COMPUTER

CODE: The program is written in Fortran IV and is not interactive. Code for the ASME Steam Tables is included for thermodynamic calculations.

AVAILABILITY: The 1975 version (described here) is available from the National Energy Software Center, Argonne, IL, in source deck or on magnetic tape for CDC 6600 and CYBER74 computers. The user's manual is available either through NESC or NTIS. An updated version (circa approximately 1984) of the code has been worked on at PNL but has not been released.

REFERENCES:

Bloomster, C.H., et al; GEOCOST: A Computer Program for Geothermal Cost Analysis, BNWL-1888, February, 1975.

Bloomster, C.H.; "An Economic Model for Geothermal Cost Analysis," Proceedings, 2nd United Nations Symposium on the Development and Use of Geothermal Resources, May 1975, pp. 2273-2282.

Huber, H.D.; Bloomster, C.H.; Walter, R.A.; User's Manual for GEOCOST: A Computer Model for Geothermal Cost Analysis, Volume 1, Steam Cycle Version, BNWL - 1942-V1. November 1975.

Cohn, P.; Bloomster, C.H.; Capital Cost Models for Geothermal Power Plants, BNWL-1990. July, 1976.

Schulte, S.C.; Capital Cost Models for Geothermal Power Plants and Fluid Transmission Systems, PNL-2307. September 1977.

See also: EER (1982), Ziman (1983)

KEY WORDS: Electric Power Plants, Steam Cycle, Engineering Design, Field Development, Life-Cycle Costing.

2.3.9 GEOCOST-BC: Geothermal Cost Analysis, Binary Cycle Version

DEVELOPED BY: Battelle, Pacific Northwest Laboratories
Richland, WA 99352

AUTHORS: Harlan Huber, Clarence Bloomster, Linda Fassbender.

DATES: User's manual published March, 1976. Program updated through approximately 1984 but not released. Updated user's manual has not been written.

PURPOSE: The program simulates the over-all design, including all major components, of a geothermal binary electric power plant. Components are sized based upon thermodynamic relationships and costs are calculated as a function of size.

ENERGY

EXTRACTION: The exploration, development, and operation of the geothermal field are simulated in the reservoir model. Costs for field exploration are determined in a seven step process, each step of which is characterized by input costs, time, and success ratios. Alternatively, the user can input these costs directly. In the development stage, the user can specify the well design, whereby costs are calculated from default values (function of depth, diameter, bottom-hole temperature, percent of well cased, rock hardness) or the costs per well can be input directly. The ratio of producers to dry wells is considered. Based upon well-head characterization (temperature, pressure, flow rate, geothermal fluid) and fluid requirements, the transmission system is sized and priced. These inputs can be overridden with user-defined data. Costs for injection wells are included. Costs for interim capital replacements and operation and maintenance are a function of capital costs and fluid chemistry. Well life is input directly. Fluid characteristics are determined from ASME Steam Tables, incorporated into the computer code.

ENERGY

CONVERSION: This version of GEOCOST considers geothermal electric power generation using the binary cycle. One of 10 available working fluids is selected, and dependent upon the characteristics, either subcritical or supercritical Rankine Cycles are selected by the program (although the user may override). Power plant life, load factor, capacity, and design are input. The program calculates component sizes (and costs), fluid requirements, and parasitic power loads. Operation and maintenance costs, as well as those for replacement of components, are based upon plant size, capital costs, and fluid chemistry.

FINANCIAL

PARAMETERS: For both the geothermal field and the power plant, the program calculates the levelized cost of energy. The reservoir model cost output is input to the power plant model. There are options for debt or equity financing and the discount rate is calculated from these interest rates. State, federal, and property taxes

are included as well as tax credits and depreciation. Tangible and intangible costs are differentiated. Insurance and royalty payments are also included. Maximum total project life is 50 years. Costs are in 1974 dollars. Indexes are available to escalate base-year costs to the desired year.

COMPUTER

CODE: The program is written in Fortran IV and is not interactive. Code for the ASME Steam Tables is included for thermodynamic calculations.

AVAILABILITY: The 1976 version (described here) is available from the National Energy Software Center, Argonne, IL, in source deck or magnetic tape for CDC660 and CYBER74 computers. The user's manual is available either through NESC or NTIS. An updated version of the code (circa approximately 1984) has been written at PNL but has not been released.

REFERENCES:

Bloomster, C.H., et al; GEOCOST: A Computer Program for Geothermal Cost Analysis, BNWL-1888, February, 1975.

Bloomster, C.H.; "An Economic Model for Geothermal Cost Analysis," Proceedings, 2nd United Nations Symposium on the Development and Use of Geothermal Resources, San Francisco, CA, May 1975, pp. 2273-2282.

Huber, H.D.; Walter, R.A.; Bloomster, C.H.; Users Manual for GEOCOST: A Computer Model for Geothermal Cost Analysis, Volume 2, Binary Cycle Version, BNWL - 1942-V2. March 1976.

Cohn, P.; Bloomster, C.H.; Capital Cost Models for Geothermal Power Plants, BNWL-1990. July, 1976.

Walter, R.A.; Modeling and Optimization of Geothermal Power Plants Using the Binary Fluid Cycle, BNWL-2112. September 1976.

Schulte, S.C.; Capital Cost Models for Geothermal Power Plants and Fluid Transmission Systems, PNL-2307. September 1977.

See also: EER (1982), Ziman (1983)

KEY WORDS: Electric Power Plants, Binary Cycle, Engineering Design, Field Development, Life-Cycle Costing.

2.3.10 GEOTHM

DEVELOPED BY: Lawrence Berkeley Laboratory
Berkeley, CA 94720

AUTHORS: M. A. Green; H. S. Pines; W. L. Pope; J. D. Williams; R. N. Healey;
L. F. Silvester

DATES: User's manual published July 1977

PURPOSE: The program allows the optimization of the design of a geothermal electric power plant to minimize a user selected objective function (such as busbar cost, capital cost, losses, etc.).

**ENERGY
EXTRACTION:** The reservoir is modeled as a uniform, semi-infinite system with no decline as a function of time. The user specifies reservoir temperature, depth, and drawdown. Well costs are input directly, production, injection, and spare wells are included. The field may be free flowing or utilize downhole pumps.

**ENERGY
CONVERSION:** The model is able to consider single or dual stage flash, binary, or flash/binary hybrid systems. The program performs thermodynamic modeling using the equations of state and the energy equation. Six parameters are considered (turbine inlet temperature and pressure, condensing pressure, pinch point temperatures for primary heat exchanger and condenser, and cooling tower temperature). Efficiencies of generators, motors, and pumps are input. The user selects permissible ranges for the variable parameters as well as which of them may be altered in the optimization routines. Costs of the system are based upon the sizes of components (specified by the thermodynamics) and are calculated by normalizing the EPRI cost estimates of the Heber Power Plant.

The main feature of the program is the optimization capability, whereby user selected parameters are varied to optimize the user defined objective function.

**FINANCIAL
PARAMETERS:** There are no formal costing routines or financial calculations performed.

**COMPUTER
CODE:** The program is written in FORTRAN, and installed on a CDC 7600 computer.

AVAILABILITY: Unknown.

REFERENCES:

Green, M. A., et. al. GEOTHM - Part 1, A User's Manual for GEOTHM (Computer Design and Simulation of Geothermal Energy Cycles) LBL publication-202, July 1977.

REFERENCES:

Green, M. A.; Pines, H. S.; Pope, W. L.; Williams, J. D. Thermodynamic and Cost Optimization Using Program GEOTHM, LBL-6303, April 1977.

Pines, H. S.; Green, M. A. Use of GEOTHM to Design and Optimize Geothermal Power Cycles, LBL-4454, June 1976.

Pope, W. L. et. al. "Conceptual Design Optimization," Sourcebook on the Production of Electricity from Geothermal Energy, DOE/RA/4051-1, March 1980, pp. 729-772.

KEY WORDS: Electric Power Production, Steam Cycle, Binary Cycle, Engineering Design, Optimization.

2.3.11 GEOTHM

DEVELOPED BY: Massachusetts Institute of Technology
Department of Mechanical Engineering
Cambridge, MA 02139

AUTHOR: Michael B. Packer

DATES: Published May, 1980

PURPOSE: The goal of this model is to serve as an aid in the evaluation of the technical and economic feasibility of process heat applications using geothermal energy.

ENERGY

EXTRACTION: The program uses a simplified method to calculate the cost of developing a geothermal field. Costs for exploration and resource assessment are not considered. Inputs to the program include well head temperatures, pressures, flow rates, the number of wells to be drilled, and the percentage of dry wells. The costs for field development are based on the number of wells drilled, times a cost per well (user-input). Other costs considered are that for the fluid transmission system, the acquisition of land, and general miscellaneous. To account for the degradation of the geothermal wells over time the user inputs the number of new wells to be drilled each year.

ENERGY

CONVERSION: The program is designed for process heat applications only. It can consider a user defined set of processes, each having a given temperature input and output and total heat requirement. The program will optimize the arrangement of the fluid distribution system (based on cost) to serve all required end uses. Costs for the various components (piping, heat exchangers, etc.) have default values in the program. The user has the option of not using the program's optimization routines and directly inputting the end uses and costs. The program can handle liquid, steam, or biphasic flow as well as using a binary system if selected by the user. There is also the option of supplementary heating of the fluid if the temperatures are inadequate. For the system operation, the electric requirements of pumps, etc. are calculated. Maintenance costs are determined as a constant percentage of initial investment.

FINANCIAL

PARAMETERS: The program calculates initial investment and annual costs and determines 1) the net present value of the system; 2) the discounted payback period; and 3) the internal rate-of-return. Costs are divided into tangible and intangible costs for tax and depreciation purposes. Financing can be done with various debt/equity ratios and through loans, bonds, or other. Investment and energy tax credits are considered. Costs for supplementary fuels and the value of energy sold are given by the user. Continuous costs include insurance, property tax, and royalty payments. All calcula-

tions include inflation and price escalation (input by user). The program uses 1978 dollars.

COMPUTER

CODE:

The program is written in FORTRAN, is internally documented, and is not interactive. There is the option to perform multiple runs with different data to do sensitivity analyses.

AVAILABILITY:

The computer code is included in Reference 1. This publication is available in microfiche form or photocopied from NTIS or the MIT library.

REFERENCES:

Packer, Michael B. A Method for Evaluating the Potential of Geothermal Energy in Industrial Process Applications, DOE/ET/28508-04. May 1980.

KEY WORDS:

Process Heating, Optimization, Engineering Design, Life-Cycle Costs, Field Development

2.3.12 GPCM: Geothermal Probabilistic Cost Model

DEVELOPED BY: Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA

AUTHORS: Tom K. Lee, Lowell Orren, G. Michael Ziman, Sue Campbell Jones

DATES: Published August 1981

PURPOSE: The GPCM model determines the probability distribution function of the cost of developing a geothermal field, in terms of the distribution function of the input variables. It does not model end use systems.

ENERGY

EXTRACTION: The user divides the project life into various stages (for example: resource definition, permitting, reservoir development, and operation). The length and costs associated with each stage are input as constants or as pdf's. The user must construct a base case scenario including the number of production and injection wells, flow rate, well life, depth, temperature, and associated costs. The program has the capability to include any additional physical relationships which the user would input. These could include reservoir modeling, flow modeling, etc. If reservoir or well productivity decline is included, a redrilling program is automatically designed to maintain the required heat flow from the wells.

Any physical, economic, or time parameters may be assigned a discrete probability distribution function. Bivariate distributions are also possible. Using a decision tree approach, the model calculates the probability and cost of all possible outcomes.

ENERGY

CONVERSION: In the model itself, the values of total fluid production and plant energy requirements are input to size the production field. The user has the option of modeling the end use system by entering the necessary physical and costing equation subroutines into the program.

FINANCIAL

PARAMETERS: The GPCM calculates life-cycle cost for a project as well as levelized cost of production. The output is a probability distribution for profit, cost, and required capital expenses. Expenditures may be financed at selected debt/equity ratios either with common stock, preferred stock, or loans. Taxes, credits, depreciation, depletion allowances, and royalty payments are included. Other inputs are the price and value of energy, escalation, inflation, and the discount rate to be used. All calculations are based on 1980 dollars.

COMPUTER

CODE: The computer program is written in FORTRAN. The program itself could be applied to any situation as long as the user provided the necessary engineering and economic relationships.

AVAILABILITY: Unknown.

REFERENCES:

Orren, L. H., et. al. Geothermal Probabalistic Cost Study, NASA-CR-168757
August 1981.

See also: EER (1982), Ziman (1983)

KEY WORDS: Field Development, Life-Cycle Cost, Stochastic Analysis.

2.3.13 GPPROG

DEVELOPED BY: Louisiana State University
Baton Rouge, LA 70804

AUTHORS: Fred Wrighton, Adrain Johnson, Jr.

DATES: 1979

PURPOSE: This program was written to provide a comprehensive set of economic data to allow analysis of the commercial potential of geopressured-geothermal prospects in Louisiana.

ENERGY

EXTRACTION: The geopressured reservoir is modeled as a bounded, circular aquifer. The user inputs area, thickness, depth, porosity, permeability, and compressibility. It is assumed to be saturated with methane at the given thermodynamic state.

Costs are considered for a single production well and two injection wells. Drilling costs are based on estimates prepared by Dow Chemical (Reference 1). Operation and maintenance charges for the well and electricity for reinjection pumps are included.

ENERGY

CONVERSION: The plant described in this simulation is a water-methane separator which will then deliver the methane to a gas company. Plant costs are determined from Reference 1. Operation and maintenance costs are included.

FINANCIAL

PARAMETERS: The program calculates net present value and internal rate of return over the life of the project. The study period is assumed to be 1985 to 2004. Federal and state taxes are included, as well as tax credits, depreciation, and depletion allowances. The user inputs the discount rate to be used.

Alternatively, the model contains optimization routines which solve for the minimum value of an economic or physical parameter which will result in an NPV of zero. These parameter options are methane price, tax rate, solubility, and reservoir area. This optimization can be either deterministic or based upon a Monte Carlo simulation.

All cost data are based upon pre-1979 estimates, and inflated to 1985 projected dollars.

COMPUTER

CODE: The program is written in FORTRAN and consists of a main program and 28 subroutines and functions.

AVAILABILITY: Unknown.

REFERENCES:

Dow Chemical Company, "A Study of a Phase 'O' Plan for the Production of Electrical Power from U.S. Gulf Coast Geopressured Geothermal Waters," Proceedings: Second Geopressured Geothermal Energy Conference Volume IV, February 1976, Appendix B.

Johnson, A. E.; et. al. Operations Research and Systems Analysis of Geopressured-Geothermal Energy in Louisiana, DOE/ET/27085-1, Final Report June 1, 1978 - August 31, 1979.

Wrighton, F.M.; Johnson, A.E., "A Description of the Technoeconomical Model Used to Analyze the Development Potential of Louisiana Geopressured Energy Prospects," Proceedings of the Fourth U.S. Gulf Coast Geopressured Geothermal Energy Conference, Volume 3, 1979, pp. 1484-1498.

Ray, T.G.; Johnson, A.E., "Sensitivity of the Economics of a Geopressured Energy Prospect to Variation in Geologic Parameters", Proceedings of the Fourth U.S. Gulf Coast Geopressured Geothermal Energy Conference, Volume 3, 1979, pp. 1499-1509.

KEY WORDS: Geopressured Resources, Life-cycle Costs, Field Development Louisiana.

2.3.14 GRITS: Geothermal Resource Interactive Temporal Simulation

DEVELOPED BY: Johns Hopkins University
Center for Metropolitan Planning and Research
Baltimore, MD 21218

Johns Hopkins University/Applied Physics Laboratory
Laurel, MD 20707

AUTHORS: Richard Weissbrod, William Barron, Kwang Yu, Peter Kroll,
Fletcher Paddison, William J. Toth

DATES: Version 9 user manual published April, 1982.

PURPOSE: The program is designed to allow the performance of preliminary economic evaluations of direct use geothermal energy applications. This enables the user to compare various designs and tradeoffs in performing various feasibility analyses.

ENERGY

EXTRACTION: The model was designed as part of a study of geothermal energy development in the Eastern United States and hence considers primarily low and moderate temperature resources. The user inputs the resource characteristics - resource temperature, flow rate, drawdown (these can be input as functions of time). The reservoir itself can be optionally modeled in terms of the pumping cycle, heat storage, transmissivity, and well radius to determine pumping energy and drawdown. The field can be designed for a single or multiple well system, with or without reinjection. Well costs are a function of depth. Downhole pumps are sized and costed, in terms of required flow rate and drawdown. Included is a resource assessment phase for which the user selects the cost and duration. During the utilization phase, the wells are considered to be drilled during the first year. The option exists of modeling in either a resource limited or demand limited mode.

ENERGY

CONVERSION: The model is capable of analyzing both district heat and process applications, in either a single system or binary mode. There are options for a fossil fuel boiler as a topping system and a storage tank for load leveling. The user inputs the transmission system and cost, the number of houses, buildings, or required process loads. For heating applications, the demand is determined by hourly temperature data (available for 134 cities, or input by user). The capital costs are calculated based on sizes and designs of the items. Lifetimes of capital components are input. In the case of district heating, the rate of system construction can be varied. Operation and maintenance costs are a percentage of capital costs. Maximum project life is 30 years.

FINANCIAL

PARAMETERS: The program either calculates levelized cost of Btu's, or the net present value of the system and discounted payback period, if the selling price of geothermal energy is known. The debt structure and interest rates are inputs, as is the discount rate. For comparison purposes as well as in determining yearly expenses, the user defines price trends for the costs of fuel and electricity. Taxes are not considered. Constant or current dollars may be used.

COMPUTER

CODE: The program is interactive and allows the creation of a base case from which parameters may be varied for sensitivity studies. GRITS, Version 9 incorporates a number of earlier models developed in connection with the same study, including DSM, GREES, and BIGMAC. The program is written in FORTRAN.

AVAILABILITY: The program is available as a listing or on tape from JHU/APL. Versions of the code have been written for IBM, DEC, and VAX systems. The latest edition of the user's guide is available through NTIS (order number PV 82246026).

REFERENCES:

- Weissbrod, R.; Barron, W.; Kroll, P.; Toth, W.; Economic Evaluation Model for Direct Use of Moderate Temperature (up to 250°F) Geothermal Resources in the Northern Atlantic Coastal Plain, JHU/APL, QM-79-124, June 1979.
- Kroll, P.; Barron, W.; Toth, W. The Demand Specified Model for Direct Applications of Geothermal Energy; A User's Guide, JHU/APL, QM-80-131, December, 1980.
- Kroll, P.; Barron, W.; Yu, K.; Toth, W. BIGMAC: Basic Interactive Geothermal Model with Aquifer Characterization, a User's Guide, JHU/APL, QM-81-089, October, 1981.
- Kroll, P.; Kane, S.M. GRITS (Version 9): Model Description and User's Guide, JHU/APL, QM-81-112, October, 1981.
- Kane, S. M.; Kroll, P.; Nilo, B. Sensitivity Analysis - Cost of Geothermal Energy, JHU/APL, QM-82-004, December 1982.
- Kane, S. M.; Barron, W.F.; Paddison, F.C.; Kroll, P.; GRITS - A Computer Program For Economic Evaluation of Geothermal Energy," ASHRAE Transactions, Volume 88, Part 1, 1982. pp. 1323-1336.
- See also: EER (1982), Reistad (1983).

KEY WORDS: District Heating, Process Heat, Field Development, Life-Cycle Costs, Eastern U.S., Moderate Temperature Resources.

2.3.15 HDR3

DEVELOPED BY: Los Alamos National Laboratory
Los Alamos, NM 87545

AUTHOR: Connie J. Arundale

DATES: Published October 1982

PURPOSE: This program is used to estimate the total reservoir costs of a geothermal space heating system using hot dry rock geothermal resources.

ENERGY

EXTRACTION: This program considers the costs associated with developing and maintaining a hot dry rock geothermal reservoir. Inputs include the geothermal gradient and the number of fractures. Dependent upon heat requirements, the model determines the most economic depth to be drilled. Temperature decline of the reservoir is calculated and the program has the option of ameliorating it by either (1) redrilling a new well to the same depth; (2) redrilling to deeper depths; or (3) using conventional energy for supplementary heating. Of these three, the one with the lowest net present value is chosen by the program.

There are two options for calculating drilling costs. The program incorporates a function, based on the GEOCOST equations, whereby well cost is a function of depth and rock hardness. The second alternative uses a subprogram, (RGICOST), where costs are based on a study by Republic Geothermal and calculated as a function of depth and other technical and geographical factors.

ENERGY

CONVERSION: The HDR3 program considers space heating applications. The user inputs the temperature drop through the system, the required heat flow, and the design temperature. These are used to calculate requirements from the reservoir. There are no calculations for designing or costing the distribution system.

FINANCIAL

PARAMETERS: The program loops on discount rate, fuel price escalation, and drilling cost escalation and determines the present value of the system and a cost-benefit ratio comparing it to the avoided cost of using conventional fuels. The output is given for each set of varied parameters.

COMPUTER

CODE: The program is written in FORTRAN. It is not interactive.

AVAILABILITY: The computer code for HDR3, as well as that for the auxiliary program RGICOST are included in the user's manual. This publication is available through NTIS.

REFERENCES:

Arundale, C. J.; User's Manual for HDR3 Computer Code, LA-9560-M,
October 1982.

Republic Geothermal, Inc. Industrial Assessment of Drilling, Completion,
and Workover Costs of the Well and Fracture Subsystems of
Hot Dry Rock Geothermal Systems, prepared for Los Alamos
National Laboratory, 17 March 1979.

KEY WORDS: District Heating, Hot Dry Rock Resource, Drilling Costs,
Life-Cycle Costs.

2.3.16 TCN

DEVELOPED BY: Technecon Analytic Research, Inc.
Philadelphia, PA

AUTHORS: Thomas Cassel, Chris Amundsen, Robert Edelstein

DATES: Reservoir Development program published October 1979.
Utility Investment module added May 1981. Hydrothermal
Exploration and Discovery Model published 1982. Models
updated during 1983.

PURPOSE: The Technecon simulation provides a means for making
probabilistic estimates of the commercial potential of
the development of geothermal power in the United States.

ENERGY

EXTRACTION: For predicting geothermal energy potential, a hydrothermal ex-
ploration, discovery, and resource quality model has been devel-
oped to project the number of future resource discoveries. The
model is capable of forecasting the yearly rate of exploration
activity, the number of discoveries which can be anticipated, and
the likely quality of these resources. Incorporated in the
analysis are such factors as resource depletion, economic and in-
vestment climate, and historical trends in discovered resource
quality. The modeling techniques are for the first time applied
to the geothermal industry, although they have been extensively
used in recent oil and gas industry evaluations. The model com-
ponents are estimated from historic data, and accurately replicate
past hydrothermal exploration, discovery, and resource quality
trends. For a specific development, the geothermal resource
is characterized in terms of temperature, depth, geology
(sedimentary or igneous), reservoir size, and well life.
Costs for early exploration, land acquisition, and preliminary
studies are included as sunk costs. Well cost is a function
of geology and depth. Redrilling of wells is included in the
life of the project. Certain parameters may be described
stochastically, specifically: resource temperature, well flow
rate, well cost, and the frequency of dry wells.

ENERGY

CONVERSION: The model considers electric power plants using either the
flashed steam or binary cycles. Plant costs are based on
relatively simple algorithms as a function of temperature and
salinity. Other factors included are operation and maintenance,
fuel costs, piping systems, and plant efficiency. A probability
distribution function may be input to describe piping costs,
plant cost, and plant availability.

FINANCIAL

PARAMETERS: The financial analysis calculates probabilistic descriptions
of levelized busbar cost, plant availability, net output,
rate-of-return, net present value, and investment at risk.
Factors considered include debt structure (loans, common

stock, preferred stock), taxes, tax credits, royalties, and insurance. With the resultant probability distribution functions, the model outputs the likelihood of both developer and utility investment in the project. This determination is based on extensive surveying of industry personnel and characterization of their attitudes. The methodology analytically compares time-wise geothermal investment opportunities to other investment opportunities available to resource developers and electric utilities. The program optimizes the selling cost of geothermal fluid to maximize the probability of both producer and utility investment.

COMPUTER

CODE:

The TCN simulation is actually a series of separate but inter-related models. It is written in APL and can be run on virtually any computer with an APL compiler.

AVAILABILITY:

The computer code is available from Technecon. No user manuals or formal documentation have been published.

REFERENCES:

Cassel, T. A. V.; Edelstein, R. H.; Blair, P. D.; Amundsen, C. B. Geothermal Investment and Policy Analysis with Evaluation of California and Utah Resource Areas, DOE/RA/4713-1, October 1979.

Cassel, T. A. V.; Amundsen, C. B.; Edelstein, R. H.; Blair, P. D. Geothermal Well Field and Power Plant Investment Decision Analysis, DOE/ET/27242-T1, May 1981.

Cassel, T.A.V. et al; National Forecast For Geothermal Resource Exploration and Development, DOE/ET/27242-T2, March 1982.

Blair, P.D.; Cassel, T.A.V.; Edelstein, R.H.; Geothermal Energy: Investment Decisions and Commercial Development, John Wiley & Sons, Inc., 1982.

Amundsen, C.B.; Cassel, T.A.V.; Kathan, D.W.; Federal Geothermal Royalty Income Derived From the Benefits of Government Sponsored R&D, DOE/SF/11727-T1, January 1984.

See also: EER (1982)

KEY WORDS:

Field Development, Electric Power Plants, Life-Cycle Costing, Market Penetration, Stochastic Analysis.

2.3.17 Texas Geopressured Resource Evaluation

DEVELOPED BY: Center for Energy Studies
The University of Texas at Austin
Austin, TX

AUTHORS: John Cornwall, William Lesso, C. Dale Zinn

DATES: 1979

PURPOSE: To provide a means of evaluating alternative scenarios for developing the Texas geopressured resources under known or best estimate conditions.

ENERGY

EXTRACTION: This model takes the given reservoir characteristics of a region (thickness, permeability, temperature, pressure, porosity, etc.), incorporates depletion (constant percentage per year) and evaluates a lifetime flow profile for a single well. If this flow meets minimum requirements for acceptability, the simulation then calculates a development scenario for the particular region. Based upon the maximum number of sites to be drilled, reservoir size, available rigs, etc., the model computes a timetable for drilling the wells. A drilling success ratio is included, and reinjection wells will be drilled if required. The cost per well drilled (for production or injection) is input by the user. Field operating costs are included.

ENERGY

CONVERSION: The user inputs the cost of the fuel plant and power plant directly, as well as the percentage of operating costs.

FINANCIAL

PARAMETERS: The program outputs the net present value of developing the geopressured field. Inputs included are the discount rate, the selling price of methane, and the escalation factor. Taxes, depreciation, depletion allowances, and royalties are included.

COMPUTER

CODE: Interactive. This simulation is a combination of three separate models; a reservoir model which assesses the potential of a given fairway; a development model which incorporates "hit" probabilities; and an economic analysis model.

AVAILABILITY: Unknown.

REFERENCES:

Zinn, C.D.; Operations Research and Systems Analysis of Geothermal/Geopressured Resources in Texas, Center For Energy Studies, University of Texas at Austin, December 1977.

Zinn, C.D.; Systems Analysis of the Texas Gulf Coast Geopressured Resources, Texas Energy Advisory Council, July 1979.

Cornwall, J. B.; Lesso, W. G.; Zinn, C. D. "The Resource Assessment, Scheduling, and Economics of Developing the Geopressured-Geothermal Resource in Texas," Proceedings: 4th U.S. Geopressured Geothermal Energy Conference, October 1979, pp. 1545-1575.

KEY WORDS: Geopressured Resource, Field Development, Life-Cycle Costs, Texas.

2.3.18 VENVAL

DEVELOPED BY: Dupont de Nemours, Inc.
Wilmington, DE

AUTHORS: Jack Whelan, J. B. Muddiman

DATES: Published July 1980

PURPOSE: VENVAL is a venture analysis model developed by Du Pont, Inc. It is a financial cash flow tool developed to aid in the evaluation of proposed business investments. The model is quite flexible and can be applied to a rather diverse range of ventures.

ENERGY

EXTRACTION: VENVAL does not contain physical and engineering equations and costing routines. The user inputs the costs associated with each account and their scheduling.

ENERGY

CONVERSION: See above.

FINANCIAL

PARAMETERS: In order to perform a VENVAL evaluation, a complete set of cost accounts, together with a schedule of their occurrence, and a complete set of financial parameters applicable to the particular venture must be available. Almost any number of cost accounts in a number of various categories can be considered. A variety of depreciation schemes and borrowing arrangements can be implemented, and a number of different economic figures of merit for the project being evaluated can be generated, including internal rate of return and net present value. VENVAL provides an accounting structure with an almost endless number of possibilities for the flow of accounts. At the user's discretion, specific relationships and options can be employed through the use of input coefficients. The program can project interrelated values of installed capacity, production, sales revenue, operating costs, depreciation, investment, debt, earnings, taxes, depletion, return on investment, and other cash flow measures. It can also compute related public sector and other external costs and revenues. Each case computed may have up to 50 years of venture life. The user has a choice of several hundred equations for the above computations. Each calculation may use any equation any number of times and values can be automatically escalated from year to year. It is also possible to perform risk analyses. Cases may be run using Monte Carlo techniques to produce statistics on selected economic parameters if the appropriate inputs have been entered in the form of probability distributions.

COMPUTER

CODE: Proprietary.

AVAILABILITY: VENVAL is a proprietary model developed by DuPont.

REFERENCES:

Whelan, J.; Muddiman, J. B. Synfuels Program Analysis, Volume II: VENVAL User's Manual, DOE/RA/00001-T5, Volume 2, July 1980.

Ziman, Michael G.; Rosenberg, L. S. "A Comparison of Economic Evaluation Models as Applied to Geothermal Energy," Energy (Oxford); 8: No. 10 pp. 797-811 (October 1983).

See also: EER (1982)

KEY WORDS: Life-Cycle Costing, Stochastic Analysis.

2.3.19 WELCST

DEVELOPED BY: METREK Division
The Mitre Corporation
McLean, VA

AUTHORS: Daniel Entingh, Al Lopez

DATES: Published February 1979

PURPOSE: This program provides a vehicle to calculate the cost of drilling geothermal wells and to estimate the potential benefits of technology improvements on total cost.

ENERGY

EXTRACTION: The model does not simulate a geothermal reservoir, it is limited to calculating the cost of drilling and completing a geothermal well. Activities considered are: site preparation, rig up, rig down, drilling, tripping pipe, running casing, cementing, logging, and spent fluid disposal. The user selects from 10 typical drilling/casing designs, or can enter a new design. Downhole motors, surface equipment, production well head, and drill bit characteristics are incorporated into the program. The frequency and costs of major drilling accidents are included in the total well costs. Depth, temperature, and rock hardness are the physical parameters considered. The costs are determined for each activity, service, equipment, and purchase based on literature reviews and surveys of drilling personnel. The resultant output is the cost of drilling a single well.

ENERGY

CONVERSION: This is not considered in this model.

FINANCIAL

PARAMETERS: The output of the program is a one-time cost for drilling a given well

COMPUTER

CODE: The program is written in FORTRAN. It is not interactive. The user has the option of altering 86 engineering and cost parameters to study the economic impacts of new technology.

AVAILABILITY: The computer code is included in Reference 1.

REFERENCES:

Entingh, D.J.; Lopez, A. WELCST: Engineering Cost Model of Geothermal Wells, DOE/ET/28505-T1, February 1979.

KEY WORDS: Well costs. R&D benefits.

2.4 Other Models

The following is a list of models which have been identified, but were determined to be outside the goals of this assessment.

- 1) BIGMAC: This model was developed by JHU/APL and has been incorporated into GRITS, version 9.
- 2) DSM: Developed by JHU/APL. It was incorporated into BIGMAC.
- 3) GEOBEN: This was a software program, developed by Mitre Corporation, which took the output of WELCST and GELCOM, and projected the results of these programs in terms of the DOE Geothermal Program's 20 year development scenario (1979-1999). It was never actually formulated and documented as an independent computer model.
- 4) GEODRL: This model, developed by the BDM Corporation, forecasts geothermal well drilling activity to the year 2000. The computations are based on historical drilling data and known reservoir parameters. The economic influences or impacts are not considered.
- 5) GEOWELL: This model was developed by Los Alamos in the early 1970's under sponsorship of the NSF. It was a very detailed drilling cost model specifically designed for the Subterrene drilling system. Because of its limited applicability and age, it has been omitted from detailed description.
- 6) GREES: An economic model written at JHU/APL, it has been incorporated into GRITS.
- 7) GTCOST: This was a preliminary model written at JHU/APL. It was incorporated into GREES.

2.5 Summary

There is a substantial range of applications of the existing geothermal economic models which have been developed. These models are potentially powerful tools for work involving design, feasibility studies, project costing, or R&D planning. The major drawbacks associated with the various models are:

(1) The costing equations and default values are dated to the time of model development. This can be overruled if the user has access to actual cost estimates for the project being considered.

(2) Only four of the models (GEOCOST, GEOCOST-BC, GEOCITY, GCFM) are available through software distribution centers. The user interested in any of the other modes would be required to put forth substantial effort to obtain and

activate the models.

2.6 General References

The references associated with each individual model are listed separately under the specific headings in the model abstracts. The following is a list of publications of studies which have performed comparative analyses of different models.

El-Sawy, A.H.; Leigh, J.G; Trehan, R.K.; A Comparative Analysis of Energy Costing Methodologies, MITRE Corporation, Technical Report MTR-7689, February 1979.

Engineering and Economics Research, Integrationo of Hydrothermal Energy Economics Related Quantitative Studies, October, 1982.

Ziman, M.G.; Rosenberg, L.S.; "A Comparison of Economic Evaluation Models as Applied to Geothermal Energy," Energy (Oxford); 8: No. 10, pp. 797-811, (1983).

Reistad, G.M.; Lawrence, T.; Geothermal District Heating Models: A Review of Comaptibility and Validity, Oregon State University, January 1983.

3.0 ASSESSMENT OF COMPUTER MODELS OF GEOTHERMAL HEAT AND FLUID FLOW by Richard McKenna

3.1 Introduction

Over the past decade, the level of interest in geothermal energy development has steadily increased, and this is reflected in increased levels of federal and private sector activities in geothermal energy research, development and production. One area which has seen considerable effort is the development of computerized models of geothermal processes and systems, and it is this topic with which this report is concerned. In recent years, the Department of Energy has sponsored the development of many such models. This document was prepared for the purpose of cataloguing these models and serving as a ready reference of basic information on model operation, inputs, outputs and availability. In the event that future modeling activities may be undertaken, this information will provide a useful reference to past efforts. In addition, the catalogue should serve to inform potential users of the variety of geothermal models available, what the models do, how they do it, and how specific models can be obtained for use.

The number of geothermal models extant is quite large and, consequently, several restrictions were applied in order to narrow the scope of the cataloguing effort. Of primary interest are those models produced under DOE sponsorship and developed specifically for simulating physical systems and processes directly associated with geothermal energy development. Models developed by other public agencies (such as the U.S. Geological Survey) are thus excluded, as are privately developed models. Also excluded are models which, although applicable to geothermal systems, were not developed specifically for geothermal energy purposes. Examples of these are the subsurface heat and fluid flow models, sponsored by the DOE Office of Waste Isolation, for application to the study of radionuclide transport related to subsurface disposal of nuclear wastes.

The term "model" can be applied to a variety of techniques or methodologies employed to visualize, describe, simulate or quantify the unseen characteristics of, or processes and interactions within, a subsurface geothermal system. The models discussed herein are limited to computerized numerical models which, through the solution of a set of mathematical equations which describe the physical processes and interactions occurring in the system, produce a simulated sequence of these processes and interactions over time (e.g., fluid flow and heat flux) which closely resembles the actual activity of the physical system. Not included in this report are empirical or curve fitting techniques, conceptual models or analytical solutions to equations describing physical processes, or analog or physical models of geothermal systems.

In the course of the information search conducted for this report, many models were identified which fall into the excluded categories noted above. The Annotated Bibliography at the end of this report lists the appropriate literature citations and indicates the reason for exclusion. Additionally, several documents were identified which provide useful comparative discussions of a number of simulation models - including some of the DOE-sponsored models contained herein, as well as models produced by other public agencies, proprietary privately developed models, curvefitting and empirical models, etc. These publications are listed in the References section.

3.2 Comparative Discussion

Models of physical geothermal systems can be broadly classified into four types. Reservoir definition models are used in geothermal prospecting and exploration. These take input from geothermal surveys, such as magnetotelluric or electrical resistivity data, and provide the prospector with an interpretation of the extent and character of subsurface reservoirs and formations. Geochemistry models rely on input describing subsurface chemical

and physical characteristics to simulate the chemical interactions occurring between geothermal fluids and the surrounding soil or rock matrix. Wellbore and reservoir models are generally concerned with the simulation of fluid and/or thermal fluxes through the wellbore or within the reservoir.

A review of the models in all four categories is beyond the scope of the current report, and only the latter two categories are examined here. In fact, these two types of models are sufficiently similar to one another, and sufficiently dissimilar to the geochemistry and reservoir definition models, to warrant their separate treatment. Both the wellbore and reservoir models involve the simulation of thermal and/or fluid flows. Frequently, a wellbore model will have some capability of simulating reservoir flow to the wellbore and, similarly, a reservoir model may be capable of simulating flow up a wellbore. Reservoir definition and geochemistry models, on the other hand, are designed for entirely different applications, have different input requirements and produce a different form of output information. For these reasons, reservoir definition and geochemistry models are not examined here, though these may be the focus of a future cataloguing effort.

3.2.1 Wellbore Models

Five models are identified for simulating conditions within a wellbore drilled into a geothermal resource and these are identified, along with pertinent characteristics, in Tables 1 and 2. Generally, the wellbore itself is modeled at a constant diameter over its entire depth, although GEOTEMP2 and DEGEOWEL can provide for variable well diameters at specified depths. All of the models are capable of providing wellbore thermal profiles, and the three models which have provisions for simulating interactions between the wellbore and the surrounding geologic matrix (GEOTEMP2, IFDM and WELBORE) will also provide temperature profiles at radial positions around the wellbore.

Fluid flow through the wellbore can be simulated, to a greater or lesser

Table 4: General Physical Model Information

<u>Model Name</u>	<u>Where Developed</u>	<u>Year Released</u>	<u>Availability*</u>	<u>Quality of Documentation</u>
<u>Wellbore Models</u>				
GEOTEMP2	Enertech Engineering & Research	1982	3	Good
IFDM	Petroleum Training & Technical Service, Republic Geothermal Inc.	1980	2	Fair
GEOFLO	Brown University	1981	1	Fair
WELBORE	Lawrence Berkeley Laboratory	1980	3	Good
DEGEOWEL	Denver Research Institute, Coury & Associates	1982	1	Poor
<u>Reservoir Models</u>				
TERZAGI	Lawrence Berkeley Laboratory	1980	3	Good
VARFLOW	Lawrence Berkeley Laboratory	1982	1	Good
ANALYZE	Lawrence Berkeley Laboratory	1980	3	Good
SHAFT79	Lawrence Berkeley Laboratory	1980	3	Good
CCC	Lawrence Berkeley Laboratory	1980	3	Good

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- * 1 = Available only as a printed program listing
 2 = Obtainable on magnetic tape
 3 = Magnetic tape and full documentation available from the National Energy Software Center

Table 5: Physical Model Characteristics (Continued)

<u>Model Name</u>	<u>Model Type</u>	<u>Dimensions</u>	<u>Phases</u>	<u>Flow and Reservoir Characteristics*</u>	<u>Wellbore- Reservoir Interactions?</u>	<u>Output</u>
<u>Reservoir Models</u>						
TERZAGI	Reservoir fluid flow	1, 2, 3	1	SS/NS, IT, H/NH, I/N, S/US	No	Fluid potential at selected nodes, pressure head and fluxes
VARFLOW	Reservoir pressure response	1	1	IT, H, I/N, S	Yes	Pressure response in vicinity of well
ANALYZE	Reservoir pressure response	1	1	IT, H, I, S	Yes	Pressure response, reservoir parameters S and T
SHAFT79	Reservoir heat and fluid flow	1, 2, 3	2	NI, NS, NH, I	No	Fluid conditions and fluxes at user-defined interfaces
CCC	Reservoir consolidation; heat and fluid flow	1, 2, 3	1	SS/NS, IT/NI, H/NH, I/N, S	No	Pressure, temp and consolidation at each node

-
- * SS/NS = Steady state/non-steady state
 IT/NI = Isothermal/non-isothermal
 H/NH = Homogeneous/non-homogeneous
 I/N = Isotropic/non-isotropic

Table 5: Physical Model Characteristics

<u>Model Name</u>	<u>Model Type</u>	<u>Dimensions</u>	<u>Phases</u>	<u>Flow and Reservoir Characteristics*</u>	<u>Wellbore- Reservoir Interactions?</u>	<u>Output</u>
<u>Wellbore Models</u>						
GEOTEMP2	Wellbore thermal	1, (2)**	1, 2	NI, NS	Yes	Wellbore and radial temp profiles
IFDM	Fracture generation; wellbore and fracture thermal	1, (2)**	1	NI	Yes	Wellbore temp profiles, fracture parameters, fracture temp curves
GEOFLO	Wellbore thermal and fluid flow	1	2	NI, SS	No	Wellbore temp and pressure profiles, flow characteristics
WELBORE	Wellbore thermal and fluid flow	1, (2)**	1, 2	NI, SS/NS	Yes	Wellbore and radial temp profiles, flow characteristics
DEGEOWEL	Wellbore thermal and fluid flow	1	1, 2	NI, SS	No	Wellbore temp and pressure profiles, flow characteristics

* SS/NS = Steady state/non-steady state
 IT/NI = Isothermal/non-isothermal
 H/NH = Homogeneous/non-homogeneous
 I/N = Isotropic/non-isotropic
 S/US = Saturated/unsaturated

*** Although fluid flow is modeled in one dimension, temperature profiles are available, for the surrounding formation, at radial positions around the well.

extent, by all of these models. Only WELBORE, however, has been directly coupled to a reservoir flow model to allow a complete simulation of geothermal production fluid flow rates and properties through the reservoir, through the wellbore and to the wellhead. Fluid flow simulation in the other models (fracture fluids in IFDM, geothermal production fluids in DEGEOWEL and GEOFLO, and drilling fluids and/or production/injection fluids in GEOTEMP2) generally requires that flow rates through the well be input by the model user. With flow rates thus known, output consists of fluid properties such as pressure, quality, flow structure, density and viscosity. Two-phase fluid flow can be handled by all models except IFDM. Since all of these models include the ability to produce wellbore temperature profiles, in-well conditions are naturally modeled as being non-isothermal. Only GEOTEMP2 and WELBORE are capable of modeling the non-steady state flow case; all the others are restricted to steady state simulation.

As is evident from the above discussion, these five models are at once both similar and dissimilar; while sharing many characteristics, each has its own attributes and may be best suited to particular simulation problems. The IFDM model was specifically intended for use in the design of fracture stimulation treatments for geothermal reservoirs. By modeling the temperature of the fracture fluid, its temperature-dependent physical properties can be calculated and used to generate a more realistic fracture design. As noted earlier, the WELBORE model is unusual (and, perhaps, all the more useful) in the fact that it is directly linked to a reservoir flow model and can thus be used to simulate an entire geothermal production system. DEGEOWEL has the ability to model the effects of dissolved solids and gases on fluid flow rates and properties; it is the only one of these models with this feature. GEOTEMP2 is perhaps the most versatile of the wellbore thermal simulators insofar as it is reportedly capable of handling multiple fluids in the wellbore, air, nitrogen or mist drilling,

and many other complexities. It is therefore important that careful consideration be given to the technical problem to be addressed when selecting a simulation model, in order to achieve a match between user needs and model capabilities.

Each of the five wellbore simulation models discussed here is individually summarized in greater detail in the Model Summaries section of this report. Included in the summaries is a list of references from which additional published information on each model can be obtained, an indication of where the model can be found and how it may be acquired, and an information contact who can provide additional details of the models' operation and potential uses.

3.2.2 Reservoir Models

Five additional models are identified in Tables 1 and 2 as being reservoir heat and fluid flow models. Lawrence Berkeley Laboratory (LBL) has been the focal point for DOE-sponsored research into geothermal reservoir flow simulation, and all of these models were developed either by LBL scientists or through subcontracts let by the Laboratory.

Only two of these models, SHAFT79 and CCC, have the capability to simulate both heat and fluid fluxes through a geothermal reservoir. These models operate by solving coupled mass- and energy-balance equations using integrated finite difference techniques. Both of these codes treat the reservoir three-dimensionally, but neither one provides a direct linkage to a geothermal production well. While the CCC model is restricted to single-phase fluid flow, SHAFT79 is capable of two-phase fluid modeling. In fact, SHAFT79 is the only one of the five reservoir models with this ability. Both models provide, as output, fluid and thermal fluxes at user-specified interfaces within the reservoir. CCC, however, has the additional capability of modeling the one-dimensional consolidation of a reservoir subjected to geothermal fluid production.

Of the remaining models, only TERZAGI models fluid flows through a three-dimensional reservoir. The fluid is modeled as isothermal, however, so thermal fluxes cannot be simulated. TERZAGI is a very general model in the sense that reservoir properties may be homogenous or non-homogeneous, isotropic or non-isotropic; the reservoir may be saturated or unsaturated (using an associated program, TRUST, from which TERZAGI is derived), and the fluid flow regime may be steady state or non-steady state. Although wellbore storage effects can be included as part of the reservoir flow simulation, TERZAGI does not include a wellbore flow simulation component.

VARFLOW and ANALYZE, the remaining two programs, are somewhat different in nature from the other programs discussed here. These are identified in Table 2 as having the capability of linking reservoir and wellbore fluid flow interactions. Both programs take input in the form of flow histories from a number of production and/or injection wells. VARFLOW also requires input values of the reservoir parameters of storativity and transmissivity. Using these data, VARFLOW simulates the reservoir response to geothermal production/injection and calculates the resulting pressure distributions in the vicinity of each specified well. ANALYZE takes a somewhat opposite approach. It, too, requires production/injection flow histories and has the additional input requirement of observed drawdown (pressure response) at a number of observation wells. Then, using estimated values of reservoir storativity and transmissivity, the model produces a set of simulated pressure responses. This simulation process is repeated in an iterative fashion, with the model constantly revising the storativity and transmissivity parameters, until a good match is obtained between the observed and simulated pressure responses. The model then returns the reservoir parameters which produced this match.

As with the wellbore models discussed in the previous section, considerable variety in structure and purpose is seen in the reservoir models dis-

cussed here. Again, the need for careful consideration of the needs at hand should be emphasized when selecting a model for problem simulation. It should also be noted that simulation models are often developed for very specific applications and, often, with very site-specific data. For this reason, some models may not be general enough for easy transferral and application to other problems or sites.

A more detailed discussion of model operations, input requirements and output data, model availability and sources of additional information is presented for each of these simulators in the Model Summaries section of this report.

3.3 Model Descriptions

The following subsections provide a synthesis of each of the assessed wellbore and reservoir models. Each model description is presented in a standard format for comparison. Parameters addressed in the description include general information about the model's developer(s), an overall description of the model, input/output parameters, computer code description, a statement on availability, and a reference list.

3.3.1 GEOTEMP2

MODEL TYPE: Wellbore thermal simulator

DEVELOPED BY: Enertech Engineering and Research Co.
2600 S.W. Freeway, Suite 300
Houston, TX 77098

CONTRACT: Sandia Laboratories contract 46-5670, for the U.S. Department of Energy under contract DE-AC04-76DP00789

AUTHOR(S): Robert F. Mitchell

INFORMATION

CONTACT: Leonard Duda
Sandia National Laboratory
Albuquerque, NM 87185

MODEL

DESCRIPTION: The major technical features and capabilities of GEOTEMP2 include the following:

1. The flowing stream energy balance is fully transient, that is, temperature predictions are accurate for short time intervals. The thermal analysis is not "steady state."
2. The thermal properties of the wellbore are fully described, including the steel, cement, and fluids in real well completions. The program is sufficiently general to describe most wells.
3. The temperature calculations in the wellbore and the surrounding formation are directly coupled.
4. The code has been designed with enough flexibility so that the complete life of a well from drilling to production, shut-ins for workovers, injection, etc. can be simulated in one computer run.
5. Several different wellbore fluids can be specified, such as drilling muds, packer fluids, cements, and production fluids. Further, more than one fluid may be in the wellbore at the same time, and the displacement of one fluid by another is automatically determined.
6. Two-phase steam production and injection can be simulated with GEOTEMP2. Flowing stream properties and flow types (e.g. slug flow) are determined as well as flow temperatures.

GEOTEMP2 is a wellbore thermal simulator designed for geothermal well drilling and production problems. It is an extensively modified version of a previous model called GEOTEMP (Reference 4). Principal improvements incorporated into GEOTEMP2 include the ability to consider: variable tubing flow areas; multiple fluids in the wellbore; deviated wellbore; air or nitrogen drilling; mist drilling; and two-phase steam production/injection.

7. Air, nitrogen, and mist drilling can be simulated. GEOTEMP2 can switch between air and mud drilling at any time desired.

A major part of the GEOTEMP2 wellbore thermal simulator is the gas drilling/mist drilling capability. Previously, one of the few models available for gas drilling applications was that developed by R. R. Angel in the 1950's. The GEOTEMP2 gas drilling simulator goes far beyond previously available analyses by including a balance of aerodynamic drag and buoyancy forces on the cuttings, a fully described bottom hole assembly, and the effects of mist addition and water influx.

The other major component of GEOTEMP2 is the two-phase steam injection and production model. The empirical flow correlations used to develop the flow model were based on the Orkiszewski vertical two-phase flow equations. These correlations are based on field data from over 200 wells and have been further verified by other measurements. The accuracy of the model is considered to be better than 10%. The steam thermodynamic correlations use the equations of state published by Keenan and Keyes in their current edition of steam tables.

Sandia National Laboratory (SNL) reports that GEOTEMP2 has recently been undergoing considerable revision to correct computational deficiencies and other problems with the program code. SNL does not recommend use of the model in its current state and also advises that program documentation given in References 2 and 3 is now obsolete. Revisions and corrections have recently been completed at SNL and the revised model will be available through the National Energy Software Center late in 1984.

INPUT DATA: The data required to fully describe a GEOTEMP2 problem include the following: tubing and casing interval depths and diameters; wellbore total depth, true vertical depth, depth of deviation, and maximum hole diameter; surface, bottom hole and intermediate depth temperatures; drilling fluid densities, plastic viscosities, and yield points.

OUTPUT DATA: The output from GEOTEMP2 is a temperature profile (temperature vs. depth) of the production/injection fluid in the wellbore at user-specified times and flow rates. Temperature profiles are also given for five radial positions: the tubing and annulus temperatures, the first two formation temperatures, and the undisturbed temperature. All temperatures are given at depth increments of 200 feet.

**COMPUTER
CODE:**

GEOTEMP2 has been written in FORTRAN IV. Efforts have been made to keep the programming as conventional as possible so that GEOTEMP2 will run without modification on most computers. GEOTEMP2 was developed on a Prime 550 mini-computer, and clearly should run on most mainframe computers. Smaller 16 bit mini and micro computers probably will not be suitable because of the pro-

gram's size.

AVAILABILITY: The revised version of GEOTEMP2 and appropriate documentation will be available from the National Energy Software Center late in 1984. Further details can be obtained from the Information Contact identified above.

SELECTED REFERENCES:

1. Mitchell, R. F., 1982. Advanced Wellbore Thermal Simulator GEOTEMP2 Research Report. Sandia National Laboratories, report SAND 82-7003/1. Prepared under Sandia contract 46-5760 for the U.S. Department of Energy under contract DE-AC04-76DP00789, 79p.
2. Mitchell, R. F., 1982. Advanced Wellbore Thermal Simulator GEOTEMP2 User Manual. Sandia National Laboratories, report SAND 82-7003/2. Prepared under Sandia contract 46-5760 for the U.S. Department of Energy under contract DE-AC04-76DP00789, 92p.
3. Mitchell, R. F., 1982. Advanced Wellbore Thermal Simulator GEOTEMP2 Appendix: Computer Program Listing. Sandia National Laboratories, report SAND 82-7003/Appendix. Prepared under Sandia contract 46-5760 for the U.S. Department of Energy under contract DE-AC04-76DP00789, 98p.
4. Wooley, G. R., 1978. Wellbore and Soil Thermal Simulation for Geothermal Wells - Development of a Computer Model and Acquisition of Field Temperature Data. Sandia National Laboratories report prepared under contract 13-0212.

3.3.2 Interactive Fracture Design Model

MODEL TYPE: Fracture stimulation treatment design model

DEVELOPED BY: Petroleum Training and Technical Services
Norman, OK
and
Republic Geothermal, Inc.
11823 E. Slauson Avenue, Suite 1
Santa Fe Springs, CA 90670

CONTRACT: U.S. Department of Energy contract DE-AC32-79AL10563

AUTHOR(S): Unidentified

INFORMATION

CONTACT: Charles Morris Schlamberger

MODEL

DESCRIPTION: The Interactive Fracture Design Model (IFDM) can be used to design a fracture stimulation treatment for geothermal reservoirs. Because of the high temperature associated with geothermal reservoirs, standard isothermal calculations of fracture geometry inadequately describe fracturing in these reservoirs. The IFDM, however, calculates the temperature of the fracture fluid as a function of time and distance in the fracture. This information is used to determine the temperature dependent properties of the fracture fluid, and these fluid properties are utilized to calculate the fracture geometry as a function of time. The model thus allows for more realistic evaluation of various design parameters than could be obtained from isothermal estimations.

The IDFM consists of three distinct yet integrated subprograms: (1) A wellbore thermal simulator which computes the temperature profile within the wellbore. An existing program (WELTEM) developed by Romero-Juarez (Reference 4) is used to calculate the temperature profile within the flowing stream and to allow the determination of sand-face viscosity of the fracture fluid--which is important for realistic fracture design. (2) A fracture generation model which calculates the fracture parameters (width, length, volume) based on user-supplied design input and the input received from the wellbore model. (3) A fracture fluid heat transfer program which determines the viscosity of the fluid in the fracture by modeling its temperature over time. Two options are available here. The Sinclair temperature model (Reference 2) can be used to simulate a constant "leak-off rate," or thermal flux, with time and distance; or the Whitsitt-Dysart model (Reference 3) can be used for the variable leak-off rate case. Both options will consider both conduction and convection heat losses.

INPUT DATA: A great deal of physical data is required to describe the reservoir (temperature, pressure, geothermal gradient), the wellbore

(surface and bottom hole temperatures, depth, tubing and casing diameters), the fracture fluid (type, injection rate, viscosity, specific heat, volumetric heat capacity, thermal conductivity, initial temperature), and the surrounding formation (rock shear modulus, fracture height, volumetric heat capacity, thermal conductivity, porosity, permeability, rock density).

OUTPUT DATA: The wellbore thermal simulator subprogram gives, as output, time dependent temperature profiles in the wellbore. The fracture generation program gives the fracture parameters--width, length, volume and efficiency--as well as fracture fluid temperature as a function of time. The fracture fluid heat transfer program produces families of curves (time dependent) for fracture fluid temperature and viscosity as a function of distance in the fracture.

**COMPUTER
CODE:**

The Interactive Fracture Design Model is written in FORTRAN IV and can be run either interactively or batch. For interactive execution, a CRT terminal with plotting capabilities is required. For batch runs, the plotted output can be spooled to a CALCOMP or similar plotting device. The load module requires 128 K storage to execute.

AVAILABILITY: The complete FORTRAN code listing is available as Appendix C in Reference 1 below. Limited copies of the program on magnetic tape may be obtained from Republic Geothermal. Further details are available from the information contact identified above.

SELECTED REFERENCES:

1. Petroleum Training and Technical Services, 1980. Interactive Fracture Design Model. Prepared by PTTS, Republic Geothermal, Inc., Sante Fe Springs, CA, for the U.S. Department of Energy under contract DE-AC32-79AL10563. Publication DOE/AL/10563-T4, 87p.
2. Sinclair, A. R., 1971. Heat Transfer Effects in Deep Well Fracturing. Journal of Petroleum Technology, December 1971, p. 1484-1492.
3. Whitsitt, N. F., and G. R. Dysart, 1970. The Effect of Temperature on Stimulation Design. Journal of Petroleum Technology, April 1970, p. 493-502.
4. Romero-Juarez, A., 1979. A Simplified Method for Calculating Temperature Changes in Deep Wells. Journal of Petroleum Technology, June 1979, p. 763-768.

3.3.3 GEOFLO

MODEL TYPE: Wellbore thermodynamics model

DEVELOPED BY: Division of Engineering
Brown University
Providence, R.I.

CONTRACT: U.S. Department of Energy contract DE-AC02-79ET27225,
LASL 4-X60-6306P-1

AUTHOR(S): Z. Bilicki, J. Kestin, E.E. Michaelides

INFORMATION
CONTACT: Z. Bilicki (Brown University)

MODEL

DESCRIPTION: GEOFLO provides a simulation of the thermodynamic properties of steady, one-dimensional, two-phase flow in a wellbore. The most essential characteristic of the model is its ability to adjust the void fraction in the flowing stream according to the flow pattern, and to keep track of the changes in the structure of the flow through the wellbore. The model can thus be used to calculate the thermodynamic properties of any two-phase vertical flow.

Further assumptions which govern the modeling of the flowing stream include: (1) the liquid and vapor phases are in thermodynamic equilibrium; (2) when flow becomes two-phase, above the flashing point, the sequence of flow structures is limited to bubbly flow ---> slug flow ---> froth flow ---> annular-mist flow; (3) each transition is described by a characteristic criterion, determined internally by the model, and the void fraction of each flow structure is described by a characteristic correlation, also determined internally by the model; and (4) the void fraction varies along the wellbore as a smooth function of depth, so there is no jump in void fraction at a flow structure boundary.

INPUT DATA: Input data to GEOFLO includes the well flow rate, bottom hole temperature and static pressure, and the depth and diameter of the well. A drawdown factor and the molality of the brine solution must also be provided.

OUTPUT DATA: GEOFLO calculates the temperature and pressure gradients along the wellbore. The depths of phase and flow structure transitions are determined and, for these depths, GEOFLO prints the temperature, pressure, quality and void fraction of the flowing stream. At the wellhead, GEOFLO also gives the temperature, pressure, quality and void fraction, along with the ratio of pressure drop and the mass flow rates for both the liquid and vapor phases.

COMPUTER

CODE: GEOFLO has been written in both Hewlett-Packard BASIC and
FORTRAN IV.

AVAILABILITY: Both the H-P BASIC and FORTRAN program listings are provided as
Appendix A of Reference 1 below.

SELECTED REFERENCES:

1. Bilicki, Z., J. Kestin and E.E. Michaelides, 1981. Flow in Geothermal Wells: Part III, Calculation Model for Self-Flowing Well. Division of Engineering, Brown University, report GEOFLO/5. Prepared for the U.S. Department of Energy under contract DE-AC02-79ET27225, LASL 4-X60-6306P-1. Publication DOE/ET/27225-8. 83p.

3.3.4 WELBORE

MODEL TYPE: Wellbore fluid and heat flow model

DEVELOPED BY: Earth Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

CONTRACT: U.S. Department of Energy contract W-7405-ENG-48

AUTHOR(S): Constance W. Miller

INFORMATION

CONTACT: Constance W. Miller
Berkeley Group, Inc.
2000 Center Street, Suite 302
Berkeley, CA 94704

MODEL

DESCRIPTION: WELBORE is a computer code for simulating transient, one-dimensional two-phase or single-phase non-isothermal fluid flow in a wellbore. The program uses a partially implicit method to solve the finite difference approximation of the Navier-Stokes equations of mass, momentum, and energy conservation. Terms that would impose a severe time restriction, such as the compressibility terms, are evaluated implicitly while other terms are expressed in an explicit manner. The convection effects are represented with a conserving upwind finite difference. Both the slip between the phases (when the flow is two-phase) and the frictional losses are given as empirical correlations. The primary thermodynamic variables used in solving the equations are the pressure and specific energy. An equation of state subroutine provides the density, quality, and temperature. The heat loss out of the wellbore is calculated by solving a radial diffusion equation for the temperature changes outside the bore. The calculation is done at each node point in the wellbore. The code has been coupled with a single phase radial flow reservoir model, and a version of the wellbore code coupled with a two-phase reservoir model was also developed (Reference 2).

The important difference between this program and other reported wellbore models is that a steady state is not assumed, i.e., the mass into the well does not necessarily equal the mass out of it. Nevertheless, a steady state solution can be obtained. The transient wellbore model, with or without the reservoir model, is useful in understanding well test results. The response of the fluid in the well can be eliminated in the analysis of well test data, i.e., given the wellhead flow rate or well head pressure and the downhole pressure, the sandface flow rate can be calculated. By knowing the actual reservoir flow, reservoir properties can be determined by using a variable well test analysis technique to reduce the transient pressure data. Also, one can solve for the flow in the bore during a complete shut-in to

determine the effects of phase redistribution, which is not possible with a steady state model.

The heat loss out of the wellbore is a function of time. For each nodal point defined in the well, the temperature change in the surrounding rock is calculated by solving a finite difference approximation of the radial conduction equation, using a constant linear thermal gradient which is provided as input. The temperature in the rock is solved as a function of depth and radial position.

The single phase reservoir model provided with the program solves a finite difference approximation of the radial pressure diffusion equation using a variable grid as in the rock temperature calculation. The linking between the reservoir calculations and the wellbore calculation is done explicitly. The flow changes in the wellbore are calculated implicitly using the calculated value of the sandface reservoir pressure. Then the reservoir pressure is recalculated using the new value of the downhole pressure in the well, but the old value of the reservoir pressure. The exact mass flowrate that entered the wellbore leaves the reservoir in that time step calculation.

INPUT DATA: The initial conditions needed to start a problem with WELBORE are the downhole pressure, the specific energy flowing in from the reservoir and the mass flow rate out of the well. This is sufficient to give a steady state solution. For a transient calculation, either the bottom hole pressure as a function of time must be known or the reservoir model can be used, keeping the pressure far from the well constant. In either case, it is necessary to provide the pressure, mass flow rate, or volume flow rate, as a function of time, at the wellhead. Other input parameters include the radius and length of the wellbore, the thermal conductivity and diffusivity of the surrounding rock, and the maximum and minimum temperatures of the geothermal gradient. If the reservoir model option is executed, the permeability, porosity, compressibility and thickness of the reservoir must be provided, along with the viscosity of the reservoir fluid.

OUTPUT DATA: The change in downhole and wellhead pressure is given for every other time step of the simulation. At user-specified time increments, the fluid properties in the wellbore are printed as a function of depth. These include pressure, energy, density, velocity and equilibrium density. In the case of two-phase flow, the steam and liquid velocities and the quality in place are also provided--again as a function of depth. At the same user-specified times, the temperature profile in and around the bore, as well as the reservoir pressure around the bore, are given as functions of both depth and radial position.

COMPUTER

CODE: WELBORE is written in FORTRAN IV and was developed on a CDC 7600. It has also been run on the CYBER 175. 55,000 octal words of storage are required for execution.

AVAILABILITY: The WELBORE program including the single-phase radial flow reservoir model is available, along with associated documentation, from the National Energy Software Center. The version of WELBORE which includes the two phase reservoir model is obtainable from Lawrence Berkeley Laboratory.

SELECTED REFERENCES:

1. Miller, Constance W., 1980. WELBORE User's Manual. Lawrence Berkeley Laboratory report LBL-10910. Prepared for the U.S. Department of Energy under contract W-7405-ENG-48, 48p.
2. Miller, C. W., S. Benson, M. Sullivan and K. Pruess, 1982. Wellbore Effects on the Analysis of Two Phase Geothermal Well Tests. Society of Petroleum Engineers Journal, June 1982.

3.3.6 VARFLOW

MODEL TYPE: Reservoir pressure-response model

DEVELOPED BY: Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

CONTRACT: U.S. Department of Energy contract DE-AC07-76ID01570

AUTHOR(S): S. M. Benson (LBL)

INFORMATION

CONTACT: S. M. Benson

MODEL

DESCRIPTION: The VARFLOW computer program was developed to calculate the reservoir pressure response (drawdown) to geothermal production/injection. It is particularly useful in those applications where drawdown cannot otherwise be easily calculated: where more than one well is flowing and/or brines are also being injected, or where the flow rate from a well is not held constant. VARFLOW can be used to calculate the anticipated pressure response at up to ten observation wells, due to the flows occurring at up to ten production and/or injection wells.

The idealized reservoir system described under the model is assumed to be of infinite areal extent, or bounded on one side by a linear constant potential or barrier boundary, and completely saturated with a single-phase fluid, the flow of which is described by Darcy's Law. The reservoir is assumed to be horizontal, of a constant thickness, isothermal, homogeneous and bounded above and below by impermeable layers. The reservoir permeability may be isotropic or anisotropic in the horizontal plane.

The flow into or from a fully penetrating well is uniformly distributed over the length of the well. The well is modeled as a line source. However, a skin effect, indicative of wellbore condition can be included in the analysis.

Flow rates from up to ten wells can vary arbitrarily. Flow rates are modeled by superposition of consecutive "production pulses." Within any "production pulse" the flow rate may be constant or vary linearly. With this scheme for modeling flow rates, any variable flow rate history can be represented to the desired accuracy by a series of sequential straight-line segments, each of the appropriate duration and inclination.

INPUT DATA: The physical character of the reservoir is described by providing input values for reservoir transmissivity in the x and y directions, reservoir storativity, and the distance and azimuth (from an

arbitrary origin) to the hydrologic boundary, and the boundary type (i.e., barrier or constant potential). Each of the production, injection and monitoring wells is described by providing its x-y coordinates (from the same arbitrary origin) and the initial pressure at the well prior to the start of pumping. In addition, time-flow rate data pairs must be provided for each well identified as a production or injection well.

OUTPUT DATA: For each well specified in the input data, VARFLOW will print (at user-specified time increments) the pressure response resulting from the indicated time-flow rate regime.

COMPUTER

CODE: VARFLOW is written in FORTRAN.

AVAILABILITY: The complete FORTRAN code is included as Appendix E in Reference 1 below.

SELECTED REFERENCES:

1. EG&G Idaho, Inc., and Lawrence Berkeley Laboratory, 1982. Low-to-Moderate Temperature Hydrothermal Reservoir Engineering Handbook. Geothermal Programs, Idaho Operations Office, Joint Project Report of Lawrence Berkeley Laboratory and the Idaho National Engineering Laboratory, report IDO-10099. Prepared for the U.S. Department of Energy under contract DE-AC07-76ID01570.

3.3.7 TERZAGI

MODEL TYPE: Reservoir fluid flow model

DEVELOPED BY: Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

CONTRACT: U.S. Department of Energy contract W-7405-ENG-48

AUTHOR(S): T. N. Narasimhan

INFORMATION
CONTACT: T. N. Narasimhan (LBL)

MODEL

DESCRIPTION: TERZAGI is an integrated finite-difference computer program which solves for transient and steady-state fluid potentials in one-, two- or three-dimensional, saturated, deformable, confined systems having isothermal flow. It is applicable to artesian aquifers or petroleum reservoirs. The system can be made up of porous or fractured materials and can have complex geometry. The flow region can be heterogeneous, and anisotropy can be handled by orienting surfaces of volume elements normal to principal axes of permeability. Wellbore storage effects can be included as part of the flow region. The material properties such as permeability and matrix compressibility can be functions of pressure. Boundary conditions can be functions of potential or time. The program has been applied to problems related to ground subsidence, flow in fractured rocks, and hydraulic fracturing and has been extensively validated. The program is based on the integrated finite-difference method of Narasimhan and Witherspoon (Reference 2), and uses a mixed explicit-implicit iterative technique for solving the confined system flow problem.

TERZAGI is a saturated-flow version of the more general program TRUST (Transient flow in Unsaturated and Strained porous media) which solves for both saturated and unsaturated flow in porous media (References 3 and 4).

INPUT DATA: Reservoir geometry can be specified in one, two or three dimensions, employing rectangular, cylindrical, axial or spherical symmetry. The volumetric properties of each grid block and the geometric properties of each node connection must be input. Each grid block can be assigned a different material, and the permeability and fluid storage coefficient of each material can either be specified as constants or calculated by the program using user-supplied functions relating these parameters to effective stress, void ratio or coefficient of compressibility. The water density, viscosity and compressibility are all required inputs, as are the volumetric fluid generation rate from sources and sinks, initial pressure head, preconsolidation stress and boundary conditions.

OUTPUT DATA: The value of pressure head and its time derivative at a selected node and the pressure heads and fluxes of all the grid blocks can be output at regular time intervals or cycles. Separate graphic programs can be used to process the output data.

COMPUTER

CODE: The computer code is written in FORTRAN IV. The program was developed on the CDC 7600, but has been adapted to a number of computer systems. 106,000 octal words of memory are required for execution.

AVAILABILITY: The TERZAGI model is available on magnetic tape from the National Energy Software Center. Program listings of the general model, TRUST, can be obtained from Lawrence Berkeley Laboratory.

SELECTED REFERENCES:

1. Narasimhan, T. N., 1980. Program TERZAGI User's Manual. Lawrence Berkeley Laboratory report LBL-10908. Prepared for the U.S. Department of Energy under contract W-7405-ENG-48. 14p.
2. Narasimhan, T. N. and P. A. Witherspoon, 1976. An Integrated Finite Difference Method for Analyzing Fluid Flow in Porous Media. Water Resources Research, 12:1, p.57-64.
3. Narasimhan, T. N. and P. A. Witherspoon, 1977. Numerical Model for Saturated-Unsaturated Flow in Deformable Porous Media, 1. Theory. Water Resources Research, 13:3, p657-667.
4. Narasimhan, T. N., P. A. Witherspoon and A. L. Edwards, 1978. Numerical Model for Saturated-Unsaturated Flow in Porous Media, 2. The Algorithm. Water Resources Research, 14:2, p255-261.

3.3.8 ANALYZE

MODEL TYPE: Analysis of well interference/production

DEVELOPED BY: Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

CONTRACT: Department of Energy contract W-7405-ENG-48

AUTHOR(S): D. McEdwards and S. M. Benson

INFORMATION
CONTACT: S. M. Benson (LBL)

MODEL

DESCRIPTION: ANALYZE is a history matching program designed for the analysis of both interference tests and production tests in single phase, fluid saturated, hydrothermal reservoirs. The model operates to minimize the difference between a set of measured pressure points and a set of calculated pressure points, and then returns reservoir parameters of transmissivity, storativity, and distance to a single linear reservoir boundary. The technique employed allows the simultaneous analysis of pressure from up to twenty observation wells, each influenced by the production (and/or injection) of as many as 20 wells with arbitrarily varying flow rates. An analytic solution calculates pressure responses in an isothermal, isotropic, homogenous, porous media of constant thickness and infinite areal extent. The production well is modeled as a fully penetrating line source. Flow in the reservoir is radial and of uniform flux over the height of the well.

The type of well test data to be analyzed may be placed in two groups: interference test data and production test data. Interference test data comprise pressure records from one or more observation wells (no dual wells) and flow data from one or more production wells (regular production wells and/or dual wells). Production test data comprise pressure attributable to the skin effect. Interference test pressure data are analyzed for global values of transmissivity, storativity, and the presence and type of hydrological boundaries (impermeable or constant potential). Production test pressure data comprise records from one or more dual wells. The skin effect and local transmissivity and storability values are sought for each dual well. The presence of a boundary may be detected in a dual well's pressure record if the duration of the test is sufficiently long.

To handle a variable flow rate, the production rate history is assumed to be adequately represented by a series of straight line segments of appropriate length and inclination. The drawdown caused by the production rate is obtained via a line source solution, and the pressure response of the series of production pulses is obtained by summing the individual responses.

Calculated pressure responses are compared to observed responses and a non-linear least squares matching routine is used to minimize the difference by varying the reservoir parameters for transmissivity, storativity and the distance to a reservoir boundary. This is accomplished by starting from an initial set of parameter values and changing the parameter values in such a fashion as to iteratively reduce the value of the least squares statistic. When an acceptable minimum has been reached, the calculated pressure responses will be nearly equal to the observed responses, and the parameter values that correspond to the minimum are accepted as final results.

INPUT DATA: Required input data for the ANALYZE program include the x-y coordinates of each observation and production well, observed pressure (for each observation well) or flow (for each production well) sequences as a function of time, and initial estimates of reservoir transmissivity and storativity. This core information is sufficient to do a two-parameter (S and T) interference test analysis involving several observation and production wells. For boundary analysis, one must also specify boundary type (barrier or constant potential) and provide initial estimates of boundary azimuth and distance. A skin effect analysis can also be obtained by specifying the production wells of interest and providing initial skin effect values.

OUTPUT DATA: For each observation well and for each data point, ANALYZE provides the time, observed drawdown, calculated drawdown, the difference between the calculated and observed drawdown, the ratio between the calculated and observed drawdown and a log-log plot of observed and calculated drawdowns versus time. The final values of the storativity and transmissivity parameters are also given; as is the value of the least squares statistic at the best minimum.

COMPUTER

CODE: The program was written for use on a CDC 7600 and uses LCM. The program, however, has no unusual memory requirements. It is easily transferable to other computer systems.

AVAILABILITY: The ANALYZE program and documentation are available through the National Energy Software Center.

SELECTED REFERENCES:

1. D. McEdwards and S.M. Benson, 1980. ANALYZE User's Manual. Lawrence Berkeley Laboratory report LBL-10907. Prepared for the U.S. Department of Energy under contract W-7405-ENG-48. 42 p.

.9 SHAFT79

MODEL TYPE: Reservoir fluid and heat flow model

DEVELOPED BY: Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

TRACT: U.S. Department of Energy contract W-7405-ENG-48

PIOR(S): K. Pruess and R. C. Schroeder

INFORMATION

CONTACT: K. Pruess (LBL)

DESCRIPTION

SHAFT79 (Simultaneous Heat And Fluid Transport) is an integrated finite difference program for computing two-phase non-isothermal flow in porous media. The principal application for which SHAFT79 is designed is in geothermal reservoir simulation in one, two or three dimensions. SHAFT79 solves the same equations as an earlier version, called SHAFT78 (References 3 and 4), but uses much more efficient mathematical and numerical methods.

SHAFT79 solves coupled mass- and energy-balance equations under the following assumptions: (1) The physical systems described by SHAFT79 are approximated as systems of porous rock saturated with one-component fluid in liquid and vapor form. (2) Except for porosity, which can vary with pressure and temperature, all other rock properties (density, specific heat, thermal conductivity, absolute permeability) are independent of temperature, pressure, or vapor saturation. (3) Liquid, vapor, and rock matrix are in local thermodynamic equilibrium (i.e., at the same temperature and pressure) at all times. (4) Capillary pressure is neglected. Applications of SHAFT79 to fractured reservoirs are possible, using double or multiple porosity techniques (References 5 and 6).

The equilibrium thermodynamic properties of the fluid filling the void space are described by way of a "fluid table," which gives all required quantities (temperature, pressure, vapor saturation, heat conductivity, liquid and vapor viscosities, densities, specific internal energies) as functions of the two principal dependent variables, which are fluid density and fluid specific internal energy. All thermodynamic information, including all derivatives, is obtained by means of bivariate interpolation from the fluid table. Such a table can be specified for any one-component fluid, and hence SHAFT79 is capable of modeling the flow of any one-component fluid in porous rock. A fluid table which covers most of the equation of state of water substance in the temperature range 5-400°C and the pressure range 0.5-200 bar, is available as part of the SHAFT79 program package.

INPUT DATA: Required inputs to SHAFT79 include data describing the reservoir geometry, boundary conditions (heat and mass flow, pressure and temperature conditions), composition and properties of the reservoir matrix (porosity and permeabilities, rock density, heat conductivity, and specific heat), sinks and sources of mass and heat (generation rates), and initial conditions.

OUTPUT DATA: SHAFT79 produces, as output, a complete specification of the thermodynamic state of the fluid throughout the reservoir, and considerable information relating to instantaneous and cumulative, liquid and vapor, mass and energy, flows and balances across user-defined interfaces within the simulated reservoir.

COMPUTER CODE: SHAFT79 is written in FORTRAN IV and was developed on a CDC 7600. Minor modifications necessary to suit other machines are easily accomplished, however, and the program has been successfully installed on IBM, Burroughs and Cray systems. The program is quite large and requires 725,000 octal words of storage.

AVAILABILITY: The computer program, with associated documentation, is available through the National Energy Software Center.

SELECTED REFERENCES:

1. Pruess, K., and R. C. Schroeder, 1980. SHAFT79 User's Manual. Lawrence Berkeley Laboratory report LBL-10861. Prepared for the U.S. Department of Energy under contract W-7405-ENG-48. 47p.
2. Pruess, K., and R. C. Schroeder, 1979. Geothermal Reservoir Simulation with SHAFT79. Lawrence Berkeley Laboratory report LBL-10066, presented at the Fifth Geothermal Reservoir Workshop, Stanford, CA.
3. Pruess, K., R. C. Schroeder, P. A. Witherspoon, and J. M. Zerzon, 1979. SHAFT78, a Two-Phase Multidimensional Computer Program for Geothermal Reservoir Simulation. Lawrence Berkeley Laboratory Report LBL-8264.
4. Pruess, K., J. M. Zerzan, R. C. Schroeder and P. C. Witherspoon, 1979. Description of the Three-Dimensional Two-Phase Simulator SHAFT78 for Use in Geothermal Reservoir Studies. Paper SPE-7699 presented at the Fifth Symposium on Reservoir Simulation, Denver, CO.
5. Pruess, K., and T.N. Narasimhan, 1982. On Fluid Reserves and the Production of Superheated Steam from Fractured, Vapor-Dominated Geothermal Reservoirs. Journal of Geophysical Research, Vol. 87, no. B11, p. 9329-9339.
6. Pruess, K., 1983. GMINC

3.3.10 CCC

MODEL TYPE: Reservoir flow, temperature and consolidation model

DEVELOPED BY: Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

CONTRACT: U.S. Department of Energy contract W-7405-ENG-48

AUTHOR(S): M. J. Lippmann

INFORMATION

CONTACT: M. J. Lippmann (LBL)

MODEL

DESCRIPTION: The CCC model (Conduction-Convection-Consolidation), numerically solves coupled heat- and mass-flow equations for a liquid saturated medium, and computes one-dimensional consolidation of the simulated system. The model employs the integrated finite difference method in discretizing the saturated medium and formulating the governing equations. The sets of equations are solved by an iterative solution technique in which the flow regime is divided into arbitrarily shaped polyhedrons constructed by drawing perpendicular bisectors to lines connecting nodal points. This permits easy evaluation of the surface integrals of the mass - and energy-flow equations. The deformation of the medium is calculated using the one-dimensional consolidation theory of Terzaghi.

In the development of the mathematical model used in the computer code, the following primary assumptions have been employed: (1) Darcy's law adequately describes fluid movement through fractured and porous media; (2) the rock and the fluid are in thermal equilibrium at any given time; (3) energy changes due to the fluid compressibility, acceleration and viscous dissipation are neglected; and (4) the one-dimensional consolidation theory can adequately describe the vertical deformation of the medium. Assumptions 1 to 3 are generally employed in the numerical modeling of geothermal reservoirs. The chief limitation of the method is that the finite difference gradient approximation is inadequate in evaluating tangential gradients along the interfaces and handling tensorial properties such as the stress fields, which generally rotate with time.

INPUT DATA: The CCC program requires substantial and fairly detailed input data. Included in the data requirements are information related to: reservoir and node geometry; initial conditions in the reservoir and at the nodes; mass flow rates between nodes; and the properties of the reservoir materials, fluid and overburden. The code allows specification of up to twelve different materials. For each material the porosity, permeability, specific storage, thermal conductivity, heat capacity and density of the solid must be specified. These parameters may be constant or may vary

with temperature, and/or effective stress. The porosity and specific storage can vary with the effective stress, the permeability with both temperature and effective stress, and the thermal conductivity and heat capacity with temperatures only. These relations are specified by tables, which are interpolated during each time step.

Input parameters for fluid properties include viscosity, heat capacity, density and compressibility of water. A constant value of the compressibility must be specified; other fluid properties may also be assumed constant. However, the code provides the option of specifying the viscosity and heat capacity as a function of temperature, and density as a function of temperature and pressure. An empirical formula is used for the density function, while the code interpolates input tables for the appropriate value of the viscosity and heat capacity during each time step.

OUTPUT DATA: Output is provided according to specified times or specified time steps. The pressure, temperature and first and second order derivatives are printed for each node, as is the total nodal pore volume reduction (consolidation). The fluid and energy fluxes are given for each node connection. The mass and the energy balance are also included in the output.

COMPUTER

CODE: CCC is written in FORTRAN IV and was developed on the CDC 7600. Execution requires 66,000 octal words of memory.

AVAILABILITY: The code listing and documentation is available from Lawrence Berkeley Laboratory, or may be purchased from the National Energy Software Center.

SELECTED REFERENCES:

1. Mangold, D.C., M.J. Lippmann and G.S. Bodvarsson, 1980. CCC User's Manual. Lawrence Berkeley Laboratory report LBL-10909. Prepared for the U.S. Department of Energy under contract W-7405-ENG-48. 50p.
2. Lippmann, M.J., C.F. Tsang and P.A. Witherspoon, 1977. Analysis of the Response of Geothermal Reservoirs Under Injection and Production Procedures. Society of Petroleum Engineers Paper 6537, presented at the 47th Annual California Meeting, SPE-AIME, Bakersfield, CA.
3. Mangold, D.C., C.F. Tsang, M.J. Lippmann and P.A. Witherspoon, 1979. A Study of Thermal Effects in Well Test Analysis. Lawrence Berkeley Laboratory report LBL-9769. Society of Petroleum Engineers Paper 8232, presented at the 54th Annual Fall Technical Conference, SPEAIME, Las Vegas, NV.

3.4 References

- Dudak, B., R. Galbraith, L. Hansen, D. Sverjensky and O. Weres, 1982. Fluid Sampling and Chemical Modeling of Geopressured Brines Containing Methane, Final Report. Lawrence Berkeley Laboratory report LBL-12832 prepared for the U.S. Department of Energy under contract DE-AC01-76SF00098. 126p.
- Miller, I., W. Dershowitz, K. Jones, L. Myer, K. Roman and M. Schauer, 1980. Detailed Report on Tested Models, Companion Report 2 to Simulation of Geothermal Subsidence (LBL-10571). Lawrence Berkeley Laboratory report LBL-10837 prepared by Golder Associates, Seattle, WA for the U.S. Department of Energy under contract W-7405-ENG-48. 206p.
- Molloy, M.W., 1980. Proceedings: Special Panel on Geothermal Model Intercomparison Study. Sixth Annual Workshop on Geothermal Reservoir Engineering, Stanford, CA, conducted for the U.S. Department of Energy under contract DE-AT03-80SF11459. 120p.
- Pinder, G.F., 1979. State-of-the-Art Review of Geothermal Reservoir Modeling. Lawrence Berkeley Laboratory Report LBL-9093 prepared by Golder Associates, Seattle, WA, for the U.S. Department of Energy under contract W-7405-ENG-48. 144p.
- Wang, J.S.Y., C.F. Tang and R.A. Sterbentz, 1982. The State of the Art of Numerical Modeling of Thermohydrologic Flow in Fractured Rock Masses. Lawrence Berkeley Laboratory Report LBL-10524 prepared for the U.S. Department of Energy under contract DE-AC03-76SF00098. 243p.
- Zais, E.J., 1980. Analysis of Production Decline in Geothermal Reservoirs. Lawrence Berkeley Laboratory Report LBL-11215 prepared by Elliot Zais & Associates, Corvallis, OR, for the U.S. Department of Energy under contract W-7405-ENG-48. 75p.

3.5 Annotated Bibliography

- Achenbach, J.D., Z.P. Bazant, J. Dundurs, L.M. Keer, S. Nemat-Nasser, T. Mura and J. Weertman, 1980. Hot Dry Rock Reservoir Characterization and Modeling, Final Report. Prepared by Northwestern University Technological Institute, Evanston, IL, for the U.S. Department of Energy under contract W-7405-ENG-36. Report no. LA-8343-MS. 160p.

Note: Lab experimentation and analytical solutions.

- Aydelotte, S.R., 1980. Transient Well Testing in Two-Phase Geothermal Reservoirs. Lawrence Berkeley Laboratory Report LBL-10562, prepared by Intercomp Resource Development and Engineering under subcontract 3976812, for the U.S. Department of Energy under contract W-7405-ENG-48. 139p.

Note: Application of proprietary Intercomp simulation models.

- Bodvarsson, G.S., 1982. Mathematical Modeling of the Behavior of Geothermal Systems under Exploitation. Lawrence Berkeley Laboratory report LBL-13937

prepared for the U.S. Department of Energy under contract W-7405-ENG-48. 377p.

Note: Ph.D Thesis, involving modifications to the CCC model (see main report).

Carson, C.C., Y.T. Lin and B.J. Livesay, 1983. Representative Well Models for Eight Geothermal Resource Areas. Sandia National Laboratory Report SAND81-2202 prepared for the U.S. Department of Energy under contract DE-AC04-76DP00789. 132p.

Note: Drilling time and cost studies of "model wells"; no simulation modeling employed.

Dedolph, R.E. and W.T. Parry. A Thermodynamic Model of the Hydrolysis of Microcline in Acid Sulfate Solutions. Prepared by the University of Utah for the U.S. Energy Research and Development Administration under contract EY-76-S-07-1601. 63p.

Note: Older geochemistry code, ERDA-sponsored.

Dittman, G.L. 1977. Wellflow for Geothermal Wells: Description of a Computer Program Including Effects of Brine Composition. Lawrence Livermore Laboratory report UCID-17473 prepared for the U.S. Energy Research and Development Administration under contract W-7405-ENG-48. 49p.

Note: Older code, ERDA-sponsored.

Energy Research and Development Administration, 1974. SIMPAC: A General Purpose Simulation Package for Fluid Flow in Porous Media and Heat Conduction in Solids. Report TID-27323 prepared by the ERDA Morgantown Energy Research Center. 48p.

Note: Older code developed by ERDA.

MacDonald, R.C., K. Sepehrnoori and H. Ohkuma, 1982. Gulf Coast Geopressured-Geothermal Reservoir Simulation: Final Report, Year 4. Prepared by the University of Texas, Austin, Center for Energy Studies, for the U.S. Department of Energy under contract DE-AC08-79ET27112. Report no. DOE/ET/27112-3. 96p.

Note: Does not involve simulation model development.

Michaelides, E.E., 1980. Models for Geothermal Wells. Ph.D. Thesis, Brown University, Providence, RI. Prepared for the U.S. Department of Energy under contract DE-AC02-79ET27225. Report no. DOE/ET/27225-T3. 148p.

Note: Ph.D. Thesis, involving model component development.

Miller, A.B., 1978. Brine-Steam Properties Computer Program for Geothermal Energy Calculations. Lawrence Livermore Laboratory report UCRL-52495 prepared for the U.S. Department of Energy under contract W-7405-ENG-48. 50p.

Note: Thermodynamic properties using equations of state. Not a simulation model itself, but could be used as a subprogram in a simulation model.

Miller, D.G., A.J. Piwinski and R. Yamauchi, 1977. Use of Geochemical Equilibrium Computer Calculations to Estimate Precipitation from Geothermal Brines. Lawrence Livermore Laboratory report UCRL-52197 prepared for the U.S. Energy Research and Development Administration under contract W-7405-ENG-48. 38p.

Note: Older code, ERDA-sponsored.

Riemer, D.H., H.R., Jacobs and R.F. Boehm, n.d. University of Utah Direct Contact Geothermal Power Project Report: A Computer Program for Determining the Thermodynamic Properties of Water. Prepared by the University of Utah for the U.S. Energy Research and Development Administration under contract AER-75-01039. Report no. UTEC-ME-76-171. 73p.

Note: Older code, ERDA-sponsored.

Rogers, L.A., 1980. Computer Simulation of Production from Geopressured-Geothermal Aquifers. Prepared by the Institute of Gas Technology, Chicago, for the U.S. Department of Energy under contract DE-AC08-78ET27098. Report no. DOE/ET/27098-1. 102p.

Note: Uses proprietary Intercomp model.

Schroeder, R.C., 1976. Modeling the Temperature-Dependent Scale Accumulation from Geothermal Brine. Lawrence Livermore Laboratory report UCRL-52145 prepared for the U.S. Energy Research and Development Administration under contract W-7405-ENG-48. 16p.

Note: Older code, ERDA-sponsored.

Sullivan, W.N., 1970. Wellbore Thermal Model. Sandia National Laboratory report SAND-75-0491 prepared for the U.S. Energy Research and Development Administration under contract AT(29-1)-789. 22p.

Note: Older code, ERDA-sponsored.

Weare, J.H., 1981. Geothermal Brine Modeling - Prediction of Mineral Solubilities in Natural Waters: The Na-K-Mg-Ca-H-Cl-SO₄-OH-HCO₃-CO₃-CO₂-H₂O System to High Ionic Strengths at 25°C. Prepared by the Department of Chemistry, University of California, San Diego, for the U.S. Department of Energy under contract DE-AT03-81SF11563. Report no. DOE/SF/11563-T1. 107p.

Note: Not a simulation model.

Weres, O. and R.C. Schroeder, 1978. Documentation for Program OGRE. Lawrence Berkeley Laboratory report LBL-7060 prepared for the U.S. Department of Energy under contract W-7405-ENG-48. 61p.

Note: Grid construction program for coupling to subsurface models, not a simulation model itself.

4.0 ASSESSMENT OF GEOTHERMAL RELATED DATA BASES by Robert E. Blackett

4.1 Summary

Data bases that were developed for, or in connection with DOE sponsored geothermal evaluation programs were reviewed with respect to their applicability and usefulness. Eight data bases were selected for the review based upon their potential widespread appeal and other factors. The data bases considered for this study were:

- 1) GEOTHERM - compiled by the U.S. Geological Survey
- 2) GRAD - Developed by Lawrence Berkeley Laboratory
- 3) GPM - Developed by Mitre Corporation, currently under direction of Meridian Corporation
- 4) OIT Site Data Bases - Compiled by the Oregon Institute of Technology, Geo-Heat Utilitization Center
- 5) UURI Open File Data - Compiled by the University of Utah Research Institute, Earth Science Laboratory
- 6) UURI Sample Library - Compiled by the University of Utah Research Institute, Earth Science Laboratory
- 7) Leasing and Permitting Data Base - Developed by WAPORA, Inc.
- 8) LOGDEX Data Base - Compiled by the University of Texas at Austin.

These data bases were found to be useful for certain aspects regarding geothermal development and utilization. The results of the review are generalized on Table 6, and are outlined in more detail in the Data Base Catalogue.

4.2 Introduction

Since the initiation of U.S. government direct involvement in assessment and evaluation of geothermal energy resources and related technologies by the Department of Energy and predecessor agencies, data have been either generated or compiled in support of the many programs. As a result of the DOE sponsored

geothermal programs, data have been generated from research and resource assessment projects. These data, in addition to already existing information, have been the focus of still other data gathering programs that have addressed the compilation of basic resource and resource utilization related information in the form of physical, chemical, mineralogic, engineering, and institutional parameters.

The purpose of this study was to identify the data bases, and describe their availability, scope, and usefulness. Contained in the report is a catalogue and description of various data bases that have been compiled as a direct result of DOE programs. The catalogue and descriptions were compiled by obtaining program summaries and samples of the data bases from the Department of Energy Technical Information Center (TIC), the National Technical Information Service (NTIS), and the library services at the Department of Energy headquarters. Data base literature searches were performed through the DOE library computer services by using DOE/RECON, the Department's on-line information retrieval system. Abstracts that were obtained from the searches were then reviewed for applicability. Detailed information was then gathered on selected individual data sets.

The data sets reviewed in this report represent those data bases that have been developed for the expressed purpose of providing to users, a framework for geothermal exploration, development, and utilization. It is recognized that other data sets exist, and have localized importance. However, the focus of this study was to identify and compare those data sets that possess detailed resource related information and have broad based coverage.

Each data base summary identifies the data base by title and presents the following information: 1) who compiled it; 2) where the data base or information concerning the data base is physically located 3) who the technical coordinators are or a central contact point of reference; 4) dates that may be relevant to the

compilation of information, or the design of the program; 5) a general discussion of the rationale and purpose for the data base; 6) a description of the data base with regard to the parameters and physical format; 7) selected references to provide more detailed information about the data base; 8) a brief statement as to the current availability of the data base; and 9) a key word list to aid the prospective user in the search for particular data elements.

Table 6 is a matrix that compares the elements contained and relative usefulness of each data base. The name of the data base appears at the top of the matrix and corresponds to the summaries within the attached Data Base Catalogue.

The Department of Energy and its predecessor agencies have maintained the Technical Information Center (TIC) in Oak Ridge, Tennessee as the national center for scientific and technical information. TIC places under bibliographic control, worldwide literature on scientific and technical advances in the energy field. In addition to scientific literature, coverage is extended to DOE programmatic, socioeconomic, environmental, legislative/regulatory, energy analysis, and policy-related areas. Computer retrieval systems are used to access the bibliographic file and obtain abstracts of specified literature. The public can gain access to the Center's Energy Data Base (EDB) through various commercial on-line retrieval systems. Other government agencies, state energy agencies, DOE offices, and contractors can utilize DOE/RECON, the Department's on-line information retrieval system.

4.3 Data Base Comparison

Base by base comparison of the current usefulness of each data base is presented here. Although data files are an important source of backup information, the accessibility and "ease of use" of those files are important considerations. Detailed data base summaries are included in the appendix following the comparison.

	GEOTHERM	GRAD	GPM	OIT SITE DATA BASE REPORTS	UURI/ESL OPEN FILE DATA	UURI/ESL SAMPLE LIBRARY	LEASING AND PERMITTING DATA BASE	LOGDEX
GEOLOGY	NA	NA	NA	<ul style="list-style-type: none"> o Geologic summaries o Site descriptions 	<ul style="list-style-type: none"> o Geologic reports, maps, cross-sections o Lithologic logs o Photogeologic interpretation 	<ul style="list-style-type: none"> o Lithology displays on chip boards o Thin sections 	NA	<ul style="list-style-type: none"> o Subsurface well log information
TEMPERATURE MEASUREMENTS	<ul style="list-style-type: none"> o Well head and springs temps 	<ul style="list-style-type: none"> o Well head temps 	NA	<ul style="list-style-type: none"> o Wellhead, subsurface, and spring temps 	<ul style="list-style-type: none"> o Thermal gradient surveys o Heat flow measurements 	NA	NA	<ul style="list-style-type: none"> o Bottom hole temperatures
FLUID CHEMISTRY	<ul style="list-style-type: none"> o Major, minor, and trace elements o Gas condensate o Stable isotopes 	<ul style="list-style-type: none"> o Total dissolved solids 	NA	<ul style="list-style-type: none"> o Total dissolved solids o Major elements o Geothermometers 	<ul style="list-style-type: none"> o Major, minor, and trace elements o Soil-gas geochemistry 	NA	NA	NA
EXPLORATORY SURVEYS	NA	<ul style="list-style-type: none"> o Listing of exploratory activities 	NA	<ul style="list-style-type: none"> o Summaries of exploratory activities 	<ul style="list-style-type: none"> o Geophysics: seismic, heat flow, gravity, magnetic, and electrical surveys 	NA	NA	NA
DEEP DRILLING	<ul style="list-style-type: none"> o Flow rates 	<ul style="list-style-type: none"> o Location, ownership, dates, pressure, flow rates, footages 	<ul style="list-style-type: none"> o Completion status and trends, footages, number of wells and other drilling statistics 	<ul style="list-style-type: none"> o Flow rates 	<ul style="list-style-type: none"> o Geophysical logs o Down-hole production tests o Lithologic logs 	<ul style="list-style-type: none"> o Cutting samples o Core samples 	NA	<ul style="list-style-type: none"> o Deep drilling electrical nuclear, and mechanical well logs - Texas and Louisiana Gulf Coast
LAND ACQUISITION	NA	<ul style="list-style-type: none"> o Detailed leasing summaries: holder, land description, acreage, age, price and terms 	<ul style="list-style-type: none"> o Summaries of new leasing activities 	<ul style="list-style-type: none"> o Lease holder, acreage 	NA	NA	<ul style="list-style-type: none"> o Time frame for lease application and permit processing 	NA
ENVIRONMENTAL STUDIES	NA	NA	<ul style="list-style-type: none"> o Notices of environmental studies 	<ul style="list-style-type: none"> o Summary of environmental factors: air and water quality, climate, biological 	NA	NA	NA	NA
INSTITUTIONAL/ REGULATORY	NA	NA	NA	<ul style="list-style-type: none"> o History of legal actions o Institutional summaries 	NA	NA	NA	NA
COMMENTS	Most comprehensive compilation of resource temperature and chemical characteristic in the U.S.	Detailed drilling & leasing information base current thru 1982. Limited resource information. Only applicable to KGMAs.	Status monitor for geothermal activities. Infrequent publication.	Contains site-specific environmental, geology and resource data. Reports completed for Alaska, Idaho, Montana, Oregon, Washington, and Wyoming.	Files contain mainly raw, uninterpreted data. Can only be reviewed at four locations, or ordered from UURI/ESL.	Samples are held as both unprepared and prepared cuttings. Use must be arranged with UURI/ESL.	Length of time for leasing and permitting can be estimated. Information is valid thru October, 1979.	Includes digitized well log information and bibliographic citations for geopressured-geothermal resources along Texas/Louisiana Gulf Coast.

Table 6: Generalized Data Base Comparison

REPRODUCED FROM
BEST AVAILABLE COPY

GEO THERM

The GEO THERM data base was compiled by the U.S. Geological Survey and represents the most complete data set relative to an overall geothermal resource assessment of the United States. Data from GEO THERM, which include fluid geochemistry, stable isotopes, gas condensate, temperature, and production rate measurements of over 10,000 thermal wells and springs in the U.S., can be used to augment regional, area, and prospect-sized geothermal evaluations. Data for GEO THERM were input until 1981. The file was released for distribution in 1982. The input period covered the major portion of government sponsored resource assessment and commercialization planning programs and therefore contain the principal set of non-proprietary data elements gathered from government/state cooperative and government/industry cooperative programs.

GRAD

GRAD or "Geothermal Resource Areas Data base" was initiated in 1979 at Lawrence Berkeley Laboratory, as a complement to the National Geothermal Progress Monitor System. GRAD organized data from existing geothermal areas where high quality hydrothermal reservoirs had been identified and characterized through exploration programs. The data base not only includes resource characteristics, but also incorporates financial and institutional factors. The user could interactively enter the GRAD data base through the SPIRES data management system at Stanford University and formulate status reports according to informational needs.

GRAD maintains information pertaining to leasing, exploration, development, powerplant siting, legal, and institutional factors.

The National Geothermal Information Resource (GRID) was a program conducted by Lawrence Berkeley Laboratory and sponsored by the U.S. Department of Energy to provide critically evaluated data and other information for the development and utilization of geothermal energy. GRID consisted of predominantly bibliographic

information for search and retrieval using various descriptors. The project was discontinued in 1979 and succeeded by the GRAD project. Bibliographic citations from GRID covering worldwide literature sources through 1978 are available from NTIS.

The GRAD data base is presently off line with no data entries since late 1982. Due to the changeable character of the non-resource oriented portions of the data entries, a significant amount of updating would be necessary to make current those legal and institutional elements. Resource portions of the data base would not change significantly, but rather would need additions such as data about newly drilled wells, or geophysical surveys.

Geothermal Progress Monitor (GPM)

The GPM was initiated in 1979 as part of the National Geothermal Progress Monitoring System. The original concept was to familiarize DOE program personnel and others with current status and events in the geothermal industry, and to meet reporting requirements. The GPM contains information about geothermal development in the United States in the form of development statistics and current trends in the geothermal industry.

The emphasis of the GPM was initially directed at informing DOE personnel about federally sponsored programs and tracking the geothermal industry "pulse". Recent changes in GPM reporting will shift the emphasis more toward informing industry and other sectors about Department of Energy RD&D activities and information dissemination programs.

UURI/ESL Open File Data

The Industry Coupled Case Studies Program was a cost share cooperative geothermal exploratory program conducted by DOE and various corporations to investigate geothermal resources primarily in northern Nevada. The data generated by the program include the results of geological, geochemical, and geophysical

surveys. The data sets and accompanying reports represent a basic suite of data relative to any geothermal investigation and are available at a number of locations as noted on the summary sheet.

UURI/ESL Geothermal Sample Library

Data from Geothermal Resource Assessment programs that have been either wholly or partially funded by DOE have been collected, catalogued, and stored at the University of Utah Research Institute, Earth Science Laboratory (UURI/ESL). Cuttings and core samples from the Industry Coupled and State Coupled Cooperative Drilling Programs and the User Coupled Confirmation Drilling Program have been organized at ESL for use by the public and private sector. The samples represent the most complete set of lithologic data gathered for federally funded geothermal exploration programs.

The usefulness of the library is limited by the nature of the samples. The samples usually need to be studied at the ESL sample library in Salt Lake City. For special requests, such as sample preparation and analysis, a time element is involved as it becomes necessary to utilize a curator and the services of the geochemical laboratory and staff at ESL. Accessibility to the samples is only through the sample library. Drill cutting samples are often the most useful data gathered from costly drilling programs.

OIT Site Data Base Reports

The Oregon Institute of Technology (OIT) developed status reports for geothermal development in the states of Alaska, Idaho, Montana, Oregon, Washington, and Wyoming. The reports not only included resource characteristics, but also environmental data that could be used by geothermal developers as an aid to planning and commercialization. State by state institutional analyses are included that address major obstacles to geothermal development.

The site status reports by OIT represent a basic compilation of physical and institutional factors surrounding all geothermal areas in the particular states. The data are several years old and therefore, the institutional portions should be used with a degree of caution as legislative and economic factors change over time.

Geothermal Leasing and Permitting Data Base

A data file on all separate actions taken by the responsible agencies in implementing the Geothermal Steam Act of 1970, developed by WAPORA, Inc., was created to provide a mechanism for monitoring the performance of the Federal non-competitive leasing program. The data base is also capable of providing area- or site-specific leasing information on geothermal prospect areas. The project was initiated to aid in the development of improvements to the Federal geothermal leasing program.

The data base was used to track applications and quantify the timeframes of actions taken by the responsible agencies. The data could be manipulated to provide various table formats and time-lapse distributions of lease applications.

LOGDEX

The LOGDEX data base has been developed by the University of Texas at Austin, Center for Energy Studies (CES) in support of programs sponsored by the U.S. Department of Energy that deal with the assessment of geopressured-geothermal energy resources. The data base consists of digitized well log information for several hundred oil and gas test wells located along the northern Gulf Coast of Texas and Louisiana. A subsidiary data base compiled by the CES is comprised of the Geopressured Geothermal Information System Bibliography (GEOBIB), that includes a bibliography and citation extracts of references dealing with geopressured resource and utilization.

4.4 Data Base Descriptions

The following sections present a description of the individual data bases and include: 1) who compiled the data base; 2) where the data base is currently available; 3) the purpose of the data base; 4) a general description of parameters; and 5) references for further information.

4.4.1 GEO THERM

COMPILED BY: U.S. Department of the Interior, Geological Survey
345 Middlefield Road, M.S. 984
Menlo Park, CA 94025

AVAILABLE
THROUGH: U.S. Department of Commerce
National Technical Information Service (NTIS)
Springfield, VA 22161

TECHNICAL
COORDINATOR(S): James D. Bliss (USGS)

RELEVANT DATES: Date of Release - 1982;

PURPOSE: The purpose of GEO THERM is to gather, organize and provide an information data base pertaining to geothermal well, springs, fumaroles, etc. as they may relate to resource characterization.

DESCRIPTION: The GEO THERM data base contains some 10405 records on magnetic tape. The records give information on resource location, temperature, and fluid geochemistry. Records may contain up to 118 items. Analyses and concentration of condensate, gas and stable isotopes may be present. All numeric fields use the following format: C999 where C = qualification code which is always present. ~~y~~ is blank, and 999 is the numeric field for concentration values. Entries include: L = less than, G = greater than, T = trace (not followed by a number), Q = qualified (other data in qualification field), E = estimated, R = midpoint of range (actual range in qualification field). Analytical values for some 55 elements and compounds may be contained within the record, plus analyses of stable isotopes of oxygen, sulfur, and carbon. Production flow rates are also included.

SELECTED
REFERENCES: Bliss, J.D., and Rapport, A., 1983, GEO THERM: The U.S. Geological Survey Geothermal Information System: Computers and Geosciences, V. 9, no. 1, p. 35-39.

AVAILABILITY: The GEO THERM file is available on magnetic tape through NTIS at a cost of \$140.00, NTIS Order No. is PB 84-107705. A hard copy as either paper or microfiche is available through the USGS.

KEY WORDS: Geothermal springs, geothermal wells, fumaroles, geochemistry, temperature, flow rate, stable isotopes, geotherm.

4.4.2 GRAD

COMPILED BY: University of California, Lawrence Berkeley
Laboratory, Engineering and Technical Services
Division
Berkeley, California 94720

AVAILABLE
THROUGH: Lawrence Berkeley Laboratory or,
National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

TECHNICAL
COORDINATORS: J. Dennis Lawrence (LBL)

RELEVANT DATES: Initiated in 1979 as a complement to the computerized "Project Management System" developed by Mitre Corporation. Project was discontinued in 1982.

PURPOSE: Geothermal Resource Areas Data Base (GRAD) was created as part of the the National Geothermal Progress Monitor System in 1979. The data base is organized around the concept of a geothermal area.

DESCRIPTION: The Geothermal Resource Areas Data Base summarizes the status of exploration and development activities at over 300 resource areas in the United States. GRAD has been organized around the concept of a geothermal resource area, defined as: "An expanse of land associated with a geothermal reservoir that is currently utilized or might be developed in the near future."

Sixteen records have been defined to provide a profile of development activities at each area. Individual facts, (e.g., lease number, well depth, plant name), are grouped together to form the data elements aggregated in each record. The record entry categories are:

1) Area Description	9) Feasibility Studies
2) Permitting	10) Financial Negotiations
3) Leasing	11) Power Plant
4) Geothermal Wells	12) Direct Applications
5) Exploratory Surveys	13) Development Issues
6) Resource Evaluations	14) Laws and Regulations
7) Land Acquisition	15) Names and Addresses
8) Environmental Impact	16) References

The GRAD data base was implemented through the SPIRES data management system at Stanford University. Users could enter the data base directly, and through the interactive feature of the system, formulate and generate status reports according to information needs.

AVAILABILITY: GRAD is currently off-line and is stored on three reels of magnetic tape at Lawrence Berkeley Laboratory. Information has not been added to the database since autumn of 1982.

In order to obtain access to the GRAD file, it would be necessary to bring the file back on-line and access GRAD through the SPIRES system at Stanford University.

SELECTED

REFERENCES:

Yen, Winifred W.S., and Lawrence, Dennis J., 1981, GRAD - A Tool for Program Analysis and Progress Monitoring: Geothermal Resources Council Transactions V. 5, pp. 627-630.

Lawrence, Dennis J., Leung, Keith, and Yen, Winifred, 1981, A User's Guide to the Geothermal Resource Areas Database: Lawrence Berkeley Laboratory Report No. LBL-11492, UC-66a. Prepared for the U.S. Department of Energy under contract No. W-7405-ENG-48., 61 p.

KEY WORDS:

Geothermal - Area, - Exploration, - Development, - Leasing, Institutional Analysis, GRAD

4.4.3 Geothermal Progress Monitor (GPM)

COMPILED BY: Mitre Corporation
McLean, Virginia

AVAILABLE
THROUGH: National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

TECHNICAL
COORDINATOR: Deepak C. Kenkeremath
Meridian Corporation
5113 Leesburg Pike, Suite 700
Falls Church, VA 22041

RELEVANT DATES: Concept of the GPM was initiated in 1975. Rationale for a progress monitoring system was developed in 1979 after evaluation of a number of plans. The system was recommended for implementation by a DOE geothermal commercialization panel in July of 1979. The first report of the GPM was issued in January of 1980.

PURPOSE: The GPM is an information system designed for the Geothermal and Hydropower Technologies Division of the U.S. Department of Energy. The system was developed to identify and quantify trends in the development and use of geothermal energy resources.

DESCRIPTION: The National Geothermal Progress Monitoring System was established by the Department of Energy to support efficient management of federal geothermal programs and to meet reporting requirements. The Geothermal Progress Monitor supplies information about geothermal development in the United States and the world. The information network set up for the GPM consists of DOE program managers at headquarters plus regional offices, state resource assessment teams, industry organizations, national laboratories, and major DOE contractors. Two computerized information systems have been developed as part of the GPM system. These information systems include a Project Management System developed at MITRE Corporation and the Geothermal Resource Area's Data Base (GRAD) developed by Lawrence Berkeley Laboratory. The information reported by the Geothermal Progress Monitoring Systems through the intermittantly published progress report includes: deep drilling and other exploratory activities; summary of leasing; permitting, resource assessments; data releases; legal and institutional developments; direct use projects; and other activities on a state-by-state basis; technology transfer; and electric power development.

SELECTED

REFERENCES: Lopez, A.F., Entingh, D.J., and Neham, E.A., 1980,
The Geothermal Progress Monitor: Geothermal Resources
Council Transactions Vol. 4, pp. 807-810.

AVAILABILITY: Copies of the Geothermal Progress Monitor are available through
the National Technical Information Service. Eight reports had
been published by the end of 1983.

KEY WORDS: Geothermal Energy-information systems; Geothermal Industry-
information systems; Program Management.

4.4.4 UURI/ESL Open File Data

COMPILED BY: Earth Science Laboratory
University of Utah Research Institute
391 Chipeta Way, Suite A
Salt Lake City, Utah 84108

AVAILABLE THROUGH: Earth Science Laboratory

TECHNICAL
COORDINATOR(S): Dennis L. Nielson (UURI/ESL)

RELEVANT DATES: DOE implemented program in 1977 for cost shared exploration throughout the Basin and Range Province. Phase I investigated geothermal areas in southwest Utah. Phase II, beginning in 1978, covered a much broader area throughout northern Nevada. Exploration case histories were developed under 18 cost shared contracts. The program was largely completed by 1981.

PURPOSE: The U.S. Department of Energy's Industry Coupled Case Study program was designed to acquire and disseminate a wide range of exploration data pertaining to geothermal reservoirs in the Basin and Range.

DESCRIPTION: Industry Coupled Program Open File Data consist of results of geochemical, and geophysical surveys as well as both shallow and deep drilling data from some 14 distinct project areas in northern Nevada and southwestern Utah. Included in the Data Set, which are comprised of some 150 separate open file reports, are: Daily Drilling Reports; Mud Logs; Lithologic Logs; Well Summaries; Thermal Gradient Surveys; Directional Surveys; Down-Hole Electrical and Nuclear Surveys; Surface Electrical, Magnetic, and Gravity Surveys; Seismic Survey Data; Water and Soil Geochemical Data; Photogeologic and Field Geologic Studies;

SELECTED
REFERENCES: Fiore, J.N., 1980, Overview and Status of the U.S. Department of Energy's Industry-Coupled Geothermal Reservoir Assessment Program: Geothermal Resources Council Transactions V.4, pp. 201-204.

AVAILABILITY: Open File Reports are available at reproduction costs from the Earth Science Laboratory. All materials are available for Public Viewing at the following locations:

Marriott Library Special Collections
University of Utah
Salt Lake City, Utah

U.S. Geological Survey
Public Inquiries Office
125 S. State, Room 8105
Federal Building
Salt Lake City, Utah

AVAILABILITY

(Continued):

Nevada Bureau of Mines and Geol.
Library, Room 311
Scrugham Engineering Bldg.
University of Nevada
Reno, Nevada

U.S. Geological Survey
Library
National Center,
12201 Sunrise Valley Dr.
Reston, Virginia

KEY WORDS:

Case Studies, Geothermal Resources, Basin and Range, Industry
Coupled Program.

4.4.5 UURI/ESL Geothermal Sample Library

COMPILED BY: Earth Science Laboratory
University of Utah Research Institute
391 Chipeta Way, Suite A
Salt Lake City, Utah 84108

AVAILABLE
THROUGH: Earth Science Laboratory

TECHNICAL
COORDINATORS: P.M. Wright (UURI/ESL)

RELEVANT DATES: Late 1970's through early 1980's.

PURPOSE: The Geothermal Sample Library was organized as a single location for the collection and cataloguing of geothermal well cuttings and core from DOE funded geothermal drilling projects for use by individuals, researchers, and government agencies.

DESCRIPTION: The Library, located in Salt Lake City, contains cuttings and core samples from over 190 wells and temperature gradient test holes located in 25 geothermal areas throughout the western U.S. The project areas are:

California
The Geysers
Coso H.S.

Colorado
Pagosa Springs

Idaho
Madison County
INEL Test Site
Raft River

Nevada
Baltazor
Tuscarora
San Emidio
Humbolt House
Colado

Oregon
North Central Cascades
Ore-Ida

Beowawe
Desert Peak
McCoy
Dixie Valley
Stillwater
Soda Lake

Utah
Hill AFB
Utah Roses
Petrovest
Cove Fort-Sulphurdale
Roosevelt H.S.

SELECTED REFERENCES:

University of Utah Research Institute/Earth Science Lab, 1982,
Catalog of the Geothermal Sample Library: Unpublished inventory
of core and cuttings samples.

AVAILABILITY: Samples are available for inspection and analysis by contacting the Earth Science Lab for arrangements to visit the library.

KEY WORDS: Geothermal wells, cuttings samples, core samples.

4.4.6 Oregon Institute of Technology - Site Data Base Reports

COMPILED BY: Oregon Institute of Technology
Geo-Heat Utilization Center
Klamath Falls, Oregon 97601

AVAILABLE
THROUGH: U.S. Department of Commerce
National Technical Information Service (NTIS)
Springfield, VA. 22161

TECHNICAL
COORDINATOR: Paul J. Lienau (OIT)

RELEVANT DATES: Project was initiated in 1978 in support of DOE's National and Regional Planning and Operations Research. Reporting was completed in 1982.

PURPOSE: To provide the necessary base information to formulate local, state, federal and private development planning affecting geothermal energy resources in Alaska, Idaho, Montana, Oregon, Washington, and Wyoming.

DESCRIPTION: The OIT Geo-Heat Utilization Center has evaluated the geothermal energy resource development potential of Alaska, Idaho, Montana, Oregon, Washington, and Wyoming. The collective goal of these studies has been to summarize, for the region, on a site-specific basis the various factors affecting development including resource data base, geological description, reservoir characteristics, environmental characteristics, lease and development status, institutional factors, economics, population and market, and development potential.

SELECTED REFERENCES:

Bloomquist, R.G., 1979, Geothermal Energy in Washington-Site Data Base and Development Status: OIT Geo-Heat Center Report, prepared in cooperation with Washington Division of Geology and Earth Resources and Washington Energy Office, 192 p.

Brown, Keith E., 1979, Geothermal Energy in Montana-Site Data Base and Development Status: OIT Geo. Heat Center Report, prepared in cooperation with Montana Energy Office, 269 p.

Justus, D., 1979, Geothermal Resources in Oregon-Site Data Base and Development Status: OIT Geo-Heat Center Report, prepared in cooperation with Oregon Energy Office, 438 p.

Markle, D., 1979, Geothermal Energy in Alaska - Site Data Base and Development Status: OIT Geo-Heat Center Report, prepared in cooperation with the State of Alaska, Division of Energy and Power Development, 572 p.

McClain, D., 1979, Geothermal Energy in Idaho - Site Data Base and Development Status: OIT Geo-Heat Center Report, prepared in cooperation with the Idaho Energy Office, 465 p.

AVAILABILITY: The OIT Site Data Base Reports are available as hard copy reports through NTIS upon ordering. Library copies are available on loan from the Geo-Heat Center Library in Klamath Falls, Oregon.

KEY WORDS: Data Base, Geothermal Energy, Site Specific, Environmental, Geology, Resource Characteristics.

4.4.7 Geothermal Leasing and Permitting Data Base

COMPILED BY: WAPORA, Inc.
6900 Wisconsin Avenue
Chevy Chase, MD 20015

AVAILABLE
THROUGH: National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

TECHNICAL
COORDINATOR: Gene V. Beeland
Meridian Corporation
5113 Leesburg Pike
Falls Church, Virginia 22041

RELEVANT
DATES: Collection of information was initiated in 1978 to support the efforts of the Interagency Geothermal Streamlining Task Force, a group organized to develop and recommend remedial changes to geothermal leasing. Results of the initial program were reported to the Task Force and DOE in a report entitled Statistical Characterization of the Federal Geothermal Leasing and Permitting Program. The preliminary report was printed as an appendix to the Task Force report to the Interagency Geothermal Coordinating Council (IGCC) of January 1979.

PURPOSE: The purpose of the data file is to provide a mechanism for monitoring the performance of the noncompetitive leasing program, and to provide area- or site-specific information on geothermal prospect areas. The needs of the Task Force included to: 1) track each application through the various steps in the non-competitive leasing process; 2) quantify the timeframe of each action taken; 3) quantify the length of time for pending applications; and 4) obtain specific insight into Forest Service performance.

DESCRIPTION: The non-competitive data base developed initially has two parts. The first is designed to quantify the timeframes required for processing each application through each step in the leasing system. The second contains information on areas designated by BLM and the Forest Service for application of the environmental assessment requirements of the National Environmental Policy Act of 1969 (NEPA).

The non-competitive data base quantifies: 1) the timeframe required for each action on each application as it moves through the process, and 2) the timeframe from date of application to final disposition. The data can be manipulated to show BLM and Forest Service performance by state, study area, or time period.

Files are divided into 3 sets. The first set includes step-by-step progress of non-competitive lease applications through the leasing process. Data on all applications processed by the BLM and Forest Service are included from the following states.

GROUP I

<u>BLM</u>	<u>USFS</u>
Arizona	Arizona
California	California
Colorado	Colorado
Montana	Montana
Oregon	Nevada
Washington	New Mexico
Wyoming	Oregon
	Washington
	Utah
	Wyoming.

A random selection of 10 percent of lease application data (due to the volume of applicants for the period ending June, 1978) from the following states are also included in the first file.

GROUP II

<u>BLM</u>	<u>USFS</u>
Idaho	Idaho
Nevada	
New Mexico	
Utah	

The second data set includes all actions of the previous offices within all the aforementioned states to June, 1978.

The third data set consists of all information for states contained within Group I to June 1978 and Group II to October 1979.

SELECTED

REFERENCES: Beeland, G.V., Schumann, E., Wieland, M., 1980, Geothermal Leasing and Permitting Data Base - A Tool for Future Planning: U.S. Department of Energy Report DOE/ET/27208-T1, WAPORA, Inc., 50p., Appendices.

AVAILABILITY: The final report, August 22, 1979-December 31, 1980 is available through NTIS.

KEY WORDS: Institutional, Geothermal Leasing, Federal Leasing, Permitting.

4.4.8 LOGDEX

COMPILED BY: University of Texas at Austin
Center for Energy Studies
Austin, Texas 78712
Phone: (512) 471-4946

AVAILABLE
THROUGH: Center for Energy Studies: Digitized Well Log Data
National Technical Information Service: Summary Listing

TECHNICAL
COORDINATOR: Robert Schneider
Center for Energy Studies

RELEVANT
DATES: Compilation of the data base began in 1977 and has continued through the present. Additions will be made through early 1985 and completion is expected in late 1985, when digitized well log data will be available on magnetic tape.

PURPOSE: The LOGDEX data base was developed to serve as a resource base for the many DOE sponsored geopressured geothermal programs along the Texas-Louisiana Gulf Coast. The data base was assembled to complement geoscience research and well log analysis.

DESCRIPTION: LOGDEX is comprised of data from over 350 wells situated in potential geopressured geothermal areas along the northern Gulf Coast. The well logs were obtained from various oil companies and then digitized to numeric information on magnetic tape.

The overall data base includes a summary listing of well information, an index to well information based upon a classification criteria, and the digitized well logs.

The data components provided in the summary listing include:
1) LOGDEX unique identification number; 2) Name of the operator;
3) well name; 4) well location; 5) abstract, track, or block name; 6) API number (if applicable); and 7) log types available.

SELECTED
REFERENCES: Hill, T., and Sepehrnoori, K., 1981, "Summary of LOGDEX Data Base," U.S. Department of Energy Report number DOE/ET/27018-1 Summary, 231 p.

Hill, T., and Sepehrnoori, K., 1981, "Geopressured Geothermal Bibliography - Volume I (Citation Extracts), and Volume II (Geopressure Thesaurus)," U.S. Department of Energy Report number DOE/ET/27018-1 Vols. I and II.

AVAILABILITY: The reports containing the summary listing, index, and bibliographic information as listed above are available through NTIS. The digitized log data base is available only to persons with access to the computer center at the University of Texas at Austin.

Application programs have been developed at the CES which makes use of the digitized data. These application programs range from simply plotting the curves available for a given log to analyzing digitized well logs for generating synthetic seismograms.

Future plans include the continued updating of the data base through early 1985. The CES is currently in the process of making the digitized data base available for purchase to private individuals by late 1985.

KEY WORDS: Geopressured, Geothermal, Well Logs, Bibliography.