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GRITS: A Computer Program for the Economic Evaluation of Direct-use Applications of Geothermal Energy

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ABSTRACT

The Geothermal Resource Interactive Temporal Simulation (GRITS) model calculates the cost and revenue streams for each year in the lifetime of a project that utilizes low to moderate temperature geothermal resources. With these two estimates, the net present value of the project can be determined for each year. The GRITS model allows preliminary economic evaluations of direct-use applications of geothermal energy under a wide range of resource, demand, and financial conditions, some of which change over the lifetime of the project.

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PREFACE

In order to determine if enough technically and economically viable markets exist for low to moderate temperature (up to 250°F) geothermal resources to warrant further exploration and development of potential geothermal resources in the Atlantic Coastal Plain, a Geothermal Energy Market Study (GEMS) has been performed by the Applied Physics Laboratory (APL) and the Center for Metropolitan Planning and Research (Metro Center) of The Johns Hopkins University. The work has been sponsored by the Department of Energy/ Division of Geothermal Energy (DOE/DGE).

The specific objectives of GEMS are to

1. Identify existing markets for thermal energy at temperatures less than 250°F,

2. Determine the technical feasibility of meeting these energy requirements with the expected geothermal resources,

3. Estimate the costs of satisfying these markets with geothermal energy, and

4. Estimate the extent to which geothermal energy can penetrate these markets.

To date, efforts to meet these objectives have been undertaken for the following four Atlantic Coastal Plain resource areas: southeastern New Jersey, the Delmarva Peninsula, the Norfolk area of Virginia, and eastern North Carolina.

In order to meet the first objective, a detailed energy market survey was made in the four areas of interest. Various data gathering techniques were used to determine the current thermal energy demands in each of four sectors, namely, residential and commercial, military, agricultural, and industrial. A computational approach developed at the Brookhaven National Laboratory was used with Bureau of the Census population data for tracts and minor civil divisions to estimate demands for residential and commercial space and water heating. Military energy consumption data were obtained directly from the Department of Defense. Agricultural energy demands were computed from data obtained from the U.S. Department of Agriculture and the Bureau of the Census. In the industrial sector, as data in the required form are not available from government sources and computational techniques are very unsatisfactory, an extensive effort was made to gather these data directly from over 600 industries in the four areas. Since there has been no comparable survey made, the results gathered here are of unparalleled accuracy. Furthermore, such results are useful for a variety of alternate energy fields such as solar energy and conservation efforts in waste heat recovery, as well as geothermal energy. The results of this market definition phase have been reported in GEMS-002 (Ref. 1). The efforts to meet the second objective cited above will be described in future topical reports on specific applications.

As a part of the third objective, interactive computer programs have been developed to estimate average and marginal costs of delivered geothermal energy for specific resource, market, and economic conditions. The Geothermal Resource Economic Evaluation System (GREES) has been developed to calculate average and marginal costs of geothermal energy to residential users through a geothermal community heating system and to industrial users that are colocated with geothermal resources. The model has undergone further refinements, and a much improved Geothermal Resource Interactive Temporal Simulation (GRITS) model has been developed to account for changing resource and demand conditions over the lifetime of a geothermal project. GRITS calculates both the revenue and the cost streams for each year of the project; from these it gives the net present value for analysis of the system's economic viability. GRITS is described in detail in this report.

The fourth objective is by far the most difficult to meet. The efforts to date have included the development of a model, described in GEMS-006 (Ref. 2), to estimate the rate of market penetration into the residential sector. Currently, this model is being used to examine various incentives that may increase residential hookups to district heating systems. These results will also be published in the near future.

The results of the Geothermal Energy Market Study are being published in a series of reports that reflect the objectives of the study. The series includes

GEMS-001 Executive Summary (to be published)

GEMS-002 Definition of Markets for Geothermal Energy in Northern Atlantic Coastal Plain (May 1980)

GEMS-003 Economic Evaluation Model for Direct Uses of Moderate Temperature (up to 250°F) Geothermal Resources in the Northern Atlantic Coastal Plain (June 1979)

GEMS-004 Geothermal Energy Costs on the Northern Atlantic Coastal Plain (to be published in 1980)

GEMS-005 A Review of Recent Energy Price Projections for Traditional Space Heating Fuel 1985-2000 (March 1979)

GEMS-006 Geothermal Energy Market Penetration: Development of a Model for the Residential Sector (September 1979)

GEMS-007 A Review of Recent Energy Price Projections for Traditional Space and Process Heating Fuels in the Post 1985 Period (April 1980; supersedes GEMS-005)

GEMS-008 GRITS: A Computer Program for the Economic Evaluation of Direct-Use Applications of Geothermal Energy (this report; supersedes GEMS-003)

Further reports may be added to the series as the GEMS efforts continue.

1. OVERVIEW

INTRODUCTION

The GRITS computer model calculates the supply costs for each year of a project directly utilizing the heat of low to moderate temperature geothermal resources. With the model, a user may make preliminary economic evaluations of community heating systems or process heating applications. In addition to computing the annual energy production and costs, the model produces several summary economic accounting measures. The two principal measures are (a) the discounted average cost, i.e., the price that equates the discounted cost and revenue streams, and (b) the net present value, i.e., the sum of the discounted cost and revenue streams. When the user specifies a selling price for the energy produced that differs from the discounted average cost of producing the energy, the net present value differs from zero. The discounted average cost indicates the value of the goods and services required to bring a unit of energy to a customer. The net present value takes into account projected market conditions through the specified selling price (or price trend) for the energy produced and indicates the potential attractiveness of the investment to developers and financiers. Other summary financial measures are also provided.

The user of the model defines a project by specifying values for a wide range of resource conditions (e.g., number of production and reinjection wells, well depth, water temperature, pumping requirements, maximum flow rate), demand conditions (e.g., user type, local weather conditions, rate of market penetration), and financial conditions (e.g., interest rate, inflation rate, project lifetime, cost of purchased energy). The large number of options provides considerable flexibility to study specific situations. To facilitate operation of the program, conditions that the user does not specify for a given run are assigned the values from the previous run. At the outset all conditions are assigned their base case or default[1] values.

The user may specify parameters for many options as time-dependent functions (e.g., declining flow rates over time, rising costs for purchased energy over time). In the discussions in the following subsections, an asterisk (*) indicates that the user may specify the parameter value, while a double asterisk (**) indicates that the user may specify the value as a time-dependent function.

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[1]A default value is a built-in value that has been established but that may be overridden when more pertinent values become available.

GRITS is designed to provide flexibility while keeping its operation simple and inexpensive. Once he has set up a "base case scenario" or if he uses the model's existing "default scenario," the user may specify a large number of parameter values and obtain his desired analysis by changing only those values of interest. The results of model runs may be displayed on an interactive terminal, and, if desired, the detailed outputs may be directed to a line printer. GRITS currently is programmed in English units; a metric version is under consideration.

Any simulation model, even the most complex, is necessarily a highly "stylized" representation of actual conditions. While considerable effort has been devoted to specifically modeling important engineering relationships, the results provided by GRITS are influenced by simplifying assumptions. GRITS is not intended to be an economic engineering model, i.e., one whose principal purpose is to determine the minimum cost engineering solution for a particular application. Engineering relationships in GRITS are modeled with sufficient accuracy to provide insights important for economic decisions. The primary purpose of GRITS is to model the impacts of changes in specific resource and economic parameter values on the economic accounting. In this respect, GRITS fills a gap between the engineering-oriented modeling of geothermal resources and economic modeling based on only the most general engineering relationships.

GRITS permits the incorporation of as much important technical design and operating information as possible, while minimizing the cost of running the program. Although it uses relatively detailed engineering formulas to determine the size and operational characteristics of major capital components, GRITS does not include elaborate internal optimization routines for designing subsections of the utilization system. For example, submersible pumps are sized and priced on the basis of user-specified flow rates and lift requirements. In contrast, the optimization of pipe sizes and insulation thickness for specific subsections of a community heating system is assumed to be reflected in the user-specified costs per mile of installed distribution pipe. The pumps are optimized because their sizes and costs will vary greatly depending on local reservoir conditions. It is important that the cost estimates reflect these local conditions. In contrast, for all but the smallest distribution systems, the average cost per mile of the system will fall within a more narrow range and hence for preliminary evaluations can be estimated in a generally applicable manner. GRITS includes enough engineering simulation to allow the user to track the impact on the cost and revenue streams of changes in reservoir characteristics or the type of end-use. However, since the model is designed to provide preliminary economic assessments, detailed calculations that are appropriate only for much more comprehensive evaluations are simplified in the model.

GEOTHERMAL ENERGY DELIVERY SYSTEM

The general configuration of the geothermal energy delivery system that is modeled by GRITS is shown in Fig. 1. The system consists of two loops. The first is the primary production loop wherein hot geothermal fluids are pumped to the surface by a submersible downhole pump in the production well. At the surface, the geothermal fluids may be temporarily stored in insulated storage tanks, or accumulators, that either permit some load-leveling under peak load conditions or increase the pump cycle times under less than full capacity loads. A circulating pump at the surface moves the geothermal fluids from the accumulator to the heat exchanger, where thermal energy is transferred to the secondary loop. The cooled geothermal fluids leaving the heat exchanger are then reinjected, either into the original aquifer or into some shallower aquifer that is compatible with the cooled geothermal fluid.

The water in the secondary loop is chemically treated to control corrosion in the pipes. It is heated to a higher temperature in the heat exchanger and piped through a two-pipe distribution network to some combination of residential, commercial, or industrial users. Each customer extracts the heat he requires and returns the cooled circulating water through a return network of pipes to the wellhead for reheating.

If the geothermal resource is not hot enough to provide circulating water at the desired temperature for its users, or if the heat demand exceeds the thermal output capability of the well, a fossil-fuel boiler topping system[1] may be used to provide extra heat.

A number of variations to this system can be envisioned. For example, if the quality of the geothermal fluids is good enough so that surface disposal is practical, the reinjection well can be eliminated or the geothermal fluid might be used directly in a single-loop system. Another possibility might include a water-to-water heat pump to transfer the thermal energy from the geothermal

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[1]Topping systems as used here signify boiler systems that are used to increase circulating water temperatures because resource temperatures are too low. As such they are in constant or nearly constant use. Peaking systems mean boiler systems that are used only to supply supplemental heat under peak load conditions. This is done normally by increasing circulating water temperatures; the implication is that resource temperatures are sufficient to meet base load conditions.

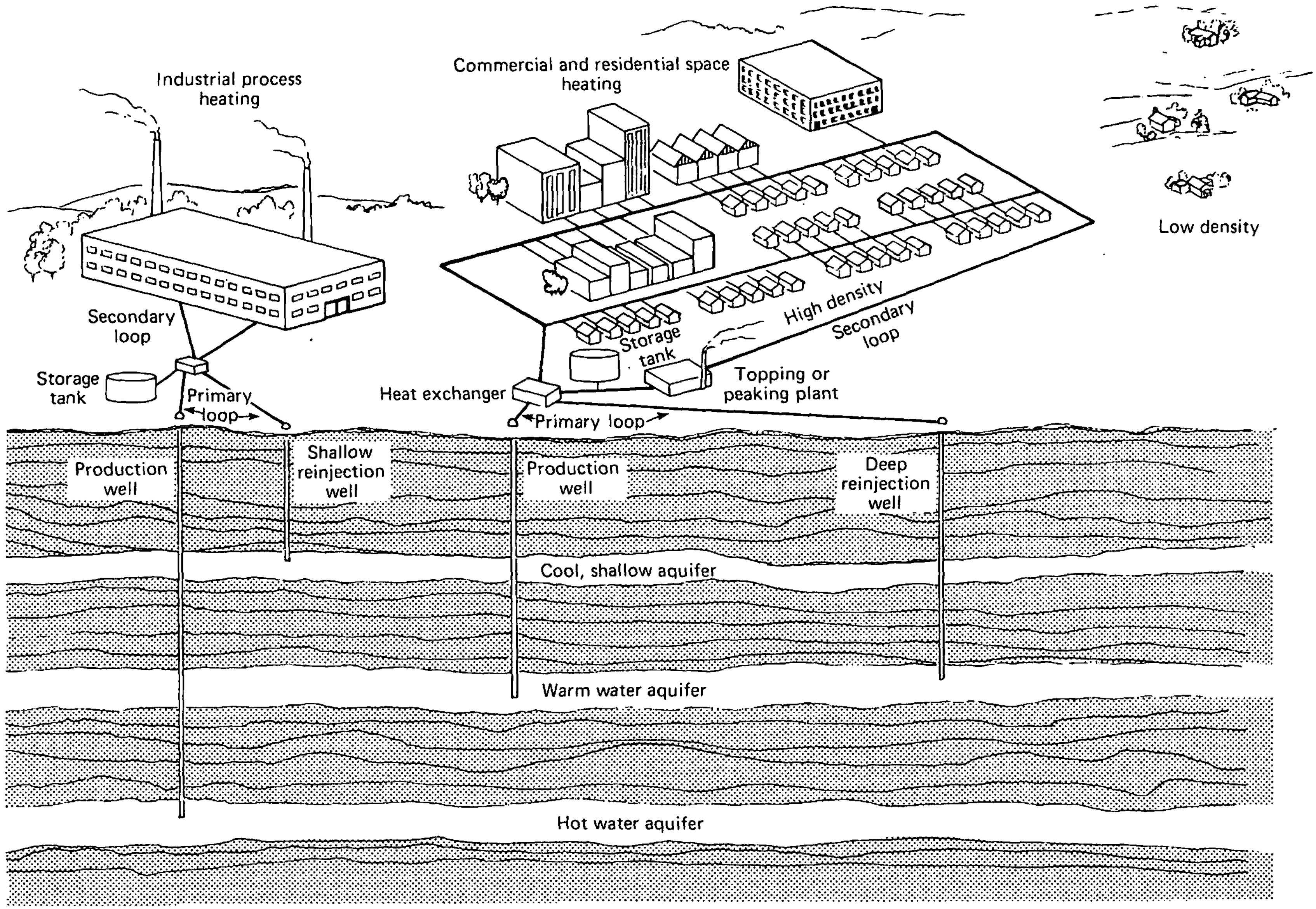

Fig. 1 Direct applications of moderate temperature geothermal energy.

fluid to the circulating water and to elevate the temperature of the circulating water above that of the resource. Still another variation might use fresh, potable water in an open secondary loop, where the customers use or dispose of the water.

Figure 1 represents a conservative system design since it is assumed that the geothermal waters are too brackish or mineralized for either direct use or surface disposal and therefore require a heat exchanger, a secondary loop, and a reinjection well. The secondary loop is assumed to be closed, which entails a two-pipe distribution network. Experience by others (Ref. 3) has shown that the topping system, which is simply a fossil-fuel-fired boiler, is for several reasons a cost-saving addition to the system. First, if the geothermal resource provides only the base load to the system, fewer wells are required and the cost savings easily exceed the cost of the boilers. Most peaking systems begin operating when the ambient temperature falls below a selected design temperature. Under periods of peak loading, the peaking system supplies the extra heat by elevating the circulating water temperature while maintaining constant flow. This allows a smaller size distribution system at additional savings. Finally, by serving the base load only, one geothermal well can be used for a longer time each heating season, which provides more energy for the same capital investment. Therefore, the hybrid system can serve more users at a lower cost than either a geothermal or fossil fuel system alone. One final advantage of a hybrid system is the ability of the peaking system to serve as a temporary backup system should problems occur in the operation of the well.

In order to specify the base load supplied by the geothermal well, the best mix of geothermal energy and topping system energy must be determined. This is done by varying the design temperature of the system and observing the change in the average cost of delivered energy. The design temperature is the lowest ambient temperature for which the geothermal well can supply 100% of the system's thermal needs. As ambient temperatures fall below the design temperature, the peaking system is used to supply the extra thermal energy requirements.

To meet the varying demands on the system, the production rate from the wells will vary, as will the drawdown, i.e., the level at which the water level stabilizes at full production. Based on the results of the well at Crisfield, Md. (Refs. 4, 5, and 6), maximum flow rates from a typical production well are not expected to be much more than 200 gal/min. Therefore, the model will design a system around a well that produces 200 gal/min, unless the user exercises his option to change this default value.

In order to obtain economic flow rates of up to 200 gal/min or more, a submersible pump probably will be required. As water is pumped from the well, the water level will fall until an equilibrium between aquifer productivity and pumping rate is achieved (drawdown). For ease of modeling, the difference between the equilibrium water level and the surface is expressed as a percentage of the depth of the well. Initial estimates for deeper aquifers in the Delmarva Peninsula indicate that drawdowns of up to 15% may be experienced for production rates on the order of 200 gal/min. The type of well completion (i.e., perforated casing versus screening and gravel packing) can significantly influence well drawdown, which in turn seriously affects the costs of delivering geothermal energy. Since the screening and gravel packing method is expected to provide better flow into the well, its use is assumed to reduce drawdown where this may pose a serious problem.

A plate-type, stainless steel wellhead heat exchanger has been assumed, which is corrosion resistant and easily disassembled for maintenance. It is also assumed that it operates in a counterflow manner with a logarithmic-mean temperature difference across the heat exchanger of 5°F. This implies that circulating water is heated to within 5°F of the wellhead resource temperature, a stringent requirement that has been set to maximize the thermal output of the well and maintain reasonable costs.

Other system assumptions will become evident in the discussions that follow. Specific relations between parameters and specific assumptions used with the model are explained in Section 3. The system design for the cost estimates generated by GRITS is fairly complex; however, it is felt that the overall configuration may be the most probable that will be encountered. Because of the system's complexities, the cost estimates of energy delivered by the system under default conditions are likely to be on the conservative side, but the flexibility of the GRITS model allows the specified parameters to be varied to reflect more optimistic as well as more conservative resource and operating conditions. Even with such a complex system design, geothermal energy can be cost competitive with conventional fuels for a wide variety of conditions, especially for industrial users.

EVALUATION PERIOD

The project evaluation period*, or financial lifetime of the project, includes a resource assessment phase (for exploration, testing, licensing, etc.) followed by a utilization phase (well drilling, installation of transmission and distribution system,

*As stated earlier, a single asterisk indicates that the user may specify the parameter value, while a double asterisk indicates that the user may specify the value as a time-dependent function.

acquisition of customers, well operation, and sales of energy). The assessment phase is specified by its duration* and annual cost*. The utilization phase is specified by duration (project evaluation period less length of assessment phase) and a large number of resource, demand, and financial conditions. If the assessment phase is given a zero time period, the evaluation period and utilization phase coincide. It is important to note that, even if the user limits the number of years reported in detail by GRITS, the period over which the project simulation is performed is defined by the full project evaluation period.

During the initial year of the utilization phase, costs are incurred for well drilling, purchase and installation of wellhead equipment, and the transmission pipeline. For community heating applications, the distribution system may be installed at any starting time* and completed over any period** so long as it is installed at a rate that equals or exceeds the rate of market penetration**. Capital components are replaced in the year following the end of their expected useful life*. Typically, pumps and the central heat exchanger are replaced over the course of the utilization phase, while other components have a life exceeding this period.

PROCESS HEATING ROUTINE

The user may select either a process heating routine (industrial) or a community heating routine (residential/commercial). The process heating routine calculates the cost of producing energy and delivering it from the wellhead to the plant gate, via the transmission line. The amount of heat delivered depends on the maximum thermal output of the well (based in turn on resource temperature**, reinjection temperature*, and flow rate**) and the industrial utilization factor* (i.e., the proportion of heat available from around-the-clock full pumping of the well that is utilized by the process heat user). The capital cost of obtaining geothermal heat depends primarily on the well cost (a function of depth*), the length of the transmission* and distribution* lines, and the interest charges*. Variable costs depend primarily on drawdown** and the cost of electricity** to operate the pumps. (A zero drawdown results in no cost for pumping energy or for wellhead pumps.)

COMMUNITY HEATING SYSTEM

The residential/commercial routine simulates the system that supplies dwelling units and commercial buildings through a community heating system. Housing type*, the number* and size* of commercial buildings and their heat load*, and the average hourly temperature data* determine space heating demands. Estimated sanitary hot water demands for both homes and commercial buildings are added to the space heating demand. The geothermal well supplies space heating requirements for outside temperatures at or above the design temperature* and all sanitary hot water. For temperatures below the design temperature, a fossil fuel peaking system raises the water temperature in the distribution network to meet additional requirements.

Energy from the wellhead is sent through the transmission line* to the distribution system and then to individual buildings on the system. The number of buildings served by a well depends on the maximum hourly thermal output of the well and the space and hot water requirements at the design temperature. The commercial heating demand is determined by the product of the total floor space* being served and the heating load per unit of floor space*, which is a function of the outside temperature. This demand at the design temperature is subtracted from the maximum hourly thermal output of the well, which leaves the amount available for residential heating. The remainder is divided by the space and hot water demand for the typical housing unit* (a single unit or a composite of several types) at the design temperature to determine the number of dwelling units served by the well. In addition to supplying all additional heating requirements at outside temperatures below the design temperature, the peaking system serves as a backup system which makes up energy deficiencies due to declining thermal output from the well.

The length of the distribution system needed to serve the commercial and residential area depends on several factors: the length of the commercial portion of the system*, data internal to the program on the density of each housing type, and the residential market saturation* (i.e., the proportion of all housing units within the market service area that ultimately join the system).

The user specifies the pace at which the distribution system is installed** (e.g., half the initial year and the remainder over the next two years). The installation should exceed or at least match the rate of market penetration**. A "rapid" market penetration could reflect mandatory participation, placement of the system in an area of new housing construction or commercial development, or special incentives to join. On the other hand, a community heating system that is just competitive with other fuels and relies on voluntary participation may experience a much slower penetration of its potential market service area.

The annual amount of energy required by system customers depends on the number of buildings and the heat load of each. Engineering relationships determine hourly space heating requirements as a function of outside temperature. The demand at a given temperature is multiplied by the average number of hours in a year which are at that temperature (see page 33). These demands are summed to determine the annual space heating demand. Sanitary hot water demand is determined on the basis of the commercial floor space and the number of households. Space heating and sanitary demands are then summed to determine total annual energy sales to system customers. All space heating demand for temperatures at or above the design temperature and all sanitary hot water demand are used to calculate the volume of water drawn annually from each well. The remaining requirements are used to determine the size of the peaking system boilers and the amount of peaking fuel required each year.

TREATMENT OF INFLATION

Prices in GRITS may be specified in real (constant) dollar terms or in nominal terms. In real dollar calculations, the effects of the overall rate of price inflation in the economy have been eliminated, i.e., only differential price changes are considered. Economists generally prefer real dollar calculations because they can be readily interpreted with respect to the current opportunity costs of a given outlay, e.g., the amount of goods and services that can be purchased for the same price as a unit of energy. However, because nominal costs may be useful for some financial analyses, this approach is also available (OPTION 25).

The user should understand that the price trends for peaking fuel and electricity are input to the model independently of the specified rate of inflation. The user should be sure that these trends are consistent with the real versus nominal dollar choice and, in the case of nominal dollars, with the specified rate of inflation. For example, if real costs are used and the price trend for electricity is input at 1.5%, the user is assuming that the price of electricity is rising 1.5% faster than the general rate of inflation. If nominal costs are used and the specified rate of inflation is 10%, the same price escalation for electricity must be represented by an input value of an 11.65% rate of increase.

Real Dollar Values

While this approach facilitates the economic analysis, the standard loan repayment schedule requires special consideration. Typically, loan repayments are fixed in nominal monetary values for the entire repayment period. As inflation erodes the purchasing power of money, the real value of debt service payments decreases. If all other prices are rising at the general rate of inflation*, then the opportunity cost (i.e., what the debt service payment could buy in the form of other goods and services) of the fixed nominal payment decreases over time. The real value of the fixed payment due in year "t" equals

$$[\text{Nominal payment} \div (1 + \text{rate of inflation})^t] .$$

Loans indexed to inflation may be modeled through the use of a zero rate of inflation and of a real interest rate, e.g., 2 or 3% for low- or non-risk loans.

Nominal Dollar Values

For nominal values all costs, except electricity, peaking fuel, and the selling price of the geothermal energy, are assumed to rise at the specified rate of inflation.[1] Thus, if one project includes a four-year resource assessment period and a rate of inflation of 10%, the price for each capital component is 1.46 times that for a project that has no assessment phase and bought its capital components when the four-year assessment phase was just beginning for the first project. If a piece of equipment is replaced during the project, the replacement cost is assumed to have risen at the rate of inflation. In contrast to the real dollar approach, where debt service payments are actually devalued over time, debt service remains fixed in the nominal approach.

DISCOUNT RATE

Even if costs and revenues for different years have been reduced to the same real price equivalents, it is still important to consider the time preference for project returns. Typically, early revenues are preferred to later revenues, while later costs are preferred to costs incurred early in the project evaluation period. Several reasons support such preferences. If the income is available for productive investment, a dollar of revenue earned early in the project may be invested to provide a larger return later in the period. If a cost may be deferred to some later date, the money to meet that cost may be invested in the interim to provide a greater overall return. If income is needed for consumption, an early return means that the project's financiers must wait a shorter time for that consumption. It can be argued that, from society's point of view, the principal return from a geothermal project is the energy produced. Since such energy is very expensive to store, society prefers that it be produced annually as needed. Yet, if reliability of the geothermal resource becomes less certain as the period of exploitation lengthens, the later portion of the projected cost and revenue stream is less certain than the earlier. Less certain returns are generally valued at a lower level than more certain returns.

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[1]Of course, in the real dollar approach, all prices except energy costs are also assumed (implicitly) to rise at the rate of inflation. This assumption is not shown directly in the model output, since only differential price inflation is of interest.

The distribution of projected returns through time affects their value for many reasons, including forgone investment opportunities, the need to wait longer for consumption, and the greater risk that later projected returns may not be realized. The usual method of treating this change is to reduce the value of later returns through a discount factor. Standard economic practice is to use a single rate of discount compounded annually. For example, if the discount rate is 2%, the projected return of a dollar in 10 years is valued at $0.82. The user of the model may select the appropriate discount rate* (including a zero rate if desired) to reflect time preference, opportunity cost, risk, or a combination of these.

INTERPRETING MODEL OUTPUTS

The treatment of debt service payments, the interrelationship between drawdown and market penetration, and the mid-period replacement of some pieces of capital equipment influence the cost trend in important ways. The user unfamiliar with the model's structure may find certain aspects of the cost trend seemingly counterintuitive. The real level of debt service payments declines over time as inflation erodes the buying power of the annual outlays to repay capital equipment loans. Variable costs will rise as utilization increases. Even at constant utilization, the cost of purchased energy (electricity to drive the downhole pumps and fossil fuel for peaking boilers) will typically rise over the life of the project. Thus, total cost (fixed plus variable) may continue to rise but will likely level off and then decline before the end of the evaluation period.

The particular level of drawdown specified by the user results from operating the well under conditions of "project maturity," i.e., maximum utilization. In the residential/commercial analysis, annual utilization levels will typically start at relatively low levels and require a year or more to reach the maximum level. During the years preceding project maturity, the actual level of drawdown is assumed to be proportionate to the degree of maturity attained to that point. For example, if the system will ultimately serve 20 commercial buildings and 1,000 housing units and will experience a 20% drawdown when this level of demand is first served, the average drawdown in an earlier year when only 10 commercial buildings and 500 units are on the system is assumed to be 10%.

While the typical evaluation period (financial project life) lasts 20 to 30 years, the expected life of some fixed plant components may be considerably shorter (e.g., 10 years for the central heat exchanger and downhole pumps). Such components are replaced in the year following the end of their expected useful lifetime.

The model assumes that the nominal price of these components has been rising at the rate of inflation since the start of the utilization phase. Thus, the real cost remains unchanged. For equipment with a 10-year life, the real value of the debt service payments declines steadily over this period and then jumps in the eleventh year (replacement year) before beginning to decline again.

OPERATING GRITS

The GRITS program may be accessed by telephone using interactive terminals through the DEC-10 computer facility at the Homewood Campus of The Johns Hopkins University in Baltimore. After the user enters the system and accesses the program by typing RUN GRITS, a brief introduction is printed. To obtain a list of parameters and their corresponding option numbers, the user types HELP. The program will then ask which parameter the user wishes to change by printing out OPTION? The user types in the option number associated with the parameter of interest and presses the return key. The program will specify the unit of value to be used (e.g., degrees Fahrenheit, cost per mile) and wait for input. For some parameters where a limited range of values is accepted by the program, if the user types in an unacceptable value, the program will indicate the acceptable bounds and again request input data.

OPTIONS 1 through 10 are operational commands to display current parameter values, output program results to a line printer, specify the type of application (industrial or residential/commercial), execute and exit the program, and perform other program specifications. OPTIONS 11 through 51 allow the user to input specific parameter values for resource characteristics (e.g., wellhead temperature), demand conditions (e.g., rate of market penetration), and financial conditions (e.g., interest rate). To change a parameter value from its base case or default value, the user presses the return key and the program responds by again typing OPTION? After all desired changes have been made, the user may check the current set of values before executing the program by calling OPTION 1. To obtain printouts of model runs, the user calls OPTION 2 and specifies a file name, composed of six letters followed by a period and three additional letters. Once specified, the file remains open and records results until closed. If a file name is not specified for OPTION 2, no line printer record of that run will be made. (The user should note that creation of a file adds to the costs of operating the program. If a file is desired for some but not all runs, the user should close the file by again calling OPTION 2 for the next run and not specifying a file name, i.e., merely pressing RETURN.) OPTION 3 may be used to save a particular scenario for later use.

OPTION 7 executes the program. Final results are displayed on the user's terminal. After it is run, the program indicates its readiness to accept another set of values for the next run by printing OPTION? The user should note that the values input from the previous run are still in effect. They may be changed individually or the user may return to the original set of base case values by calling OPTION 3. After all runs have been made, the user exits the program by calling OPTION 9. Once program execution ends, the user may request that his files be directed to the line printer.

This overview has presented some areas of the model in relatively little detail. Section 2 provides additional information on how specific resource and economic conditions are modeled in GRITS. Section 3 describes the more important engineering formulas and technical relationships internal to the model. Appendix A lists all the options currently available in GRITS.

2. MODELING RESOURCE, DEMAND, AND FINANCIAL CONDITIONS

Figures 2, 3, and 4 illustrate the basic structure of the GRITS model's annual energy production and cost calculations. The utilization phase of the project evaluation period is essentially a series of such calculations. The resource, demand, and financial conditions that the user may specify are illustrated for the residental/commercial scenario in Table 1 and for the industrial scenario in Table 2.

MODELING RESOURCE CONDITIONS

Production and Reinjection Wells

GRITS may be used to model single or multiple well systems with subsurface or surface disposal of spent geothermal fluids. The number of production and reinjection wells is specified through OPTIONS 42 and 43, respectively. The cost of each type of well (exclusive of pumps) is a function of depth. Default values currently in the model are: one production and one reinjection well each 5,000 feet deep and an unmodified well cost function, i.e., a cost coefficient of 1. The cost function coefficient may be modified by the user by OPTION 16 (see p. 45).

Extraction and Reinjection Pumping Energy Requirements

Production well pumping energy requirements are functions of the volume of water extracted and the distance it must be lifted to the surface. Reinjection energy is assumed to equal up-well pumping with a proportional adjustment for reinjection to a different depth; in other words, the requirement is multiplied by the ratio of the reinjection well depth to that of the production well.

Demand conditions, water temperature drop across the wellhead heat exchanger, and the maximum flow rate determine the volume of water extracted. Required lift is input through OPTION 26, "drawdown." This level, measured as a fraction of production well depth, is the average level to which the water in the well falls as a result of exploitation of the reservoir. Artesian pressure, which typically provides some flow at the surface without pumping, may be sufficient in certain cases to meet demand. In this case, pumping is not required; a zero value for drawdown would reflect this condition.

For many situations, flow rates and the amount of pumping energy required are economic trade-offs. The nature of this interrelationship depends on the characteristics of the reservoir under

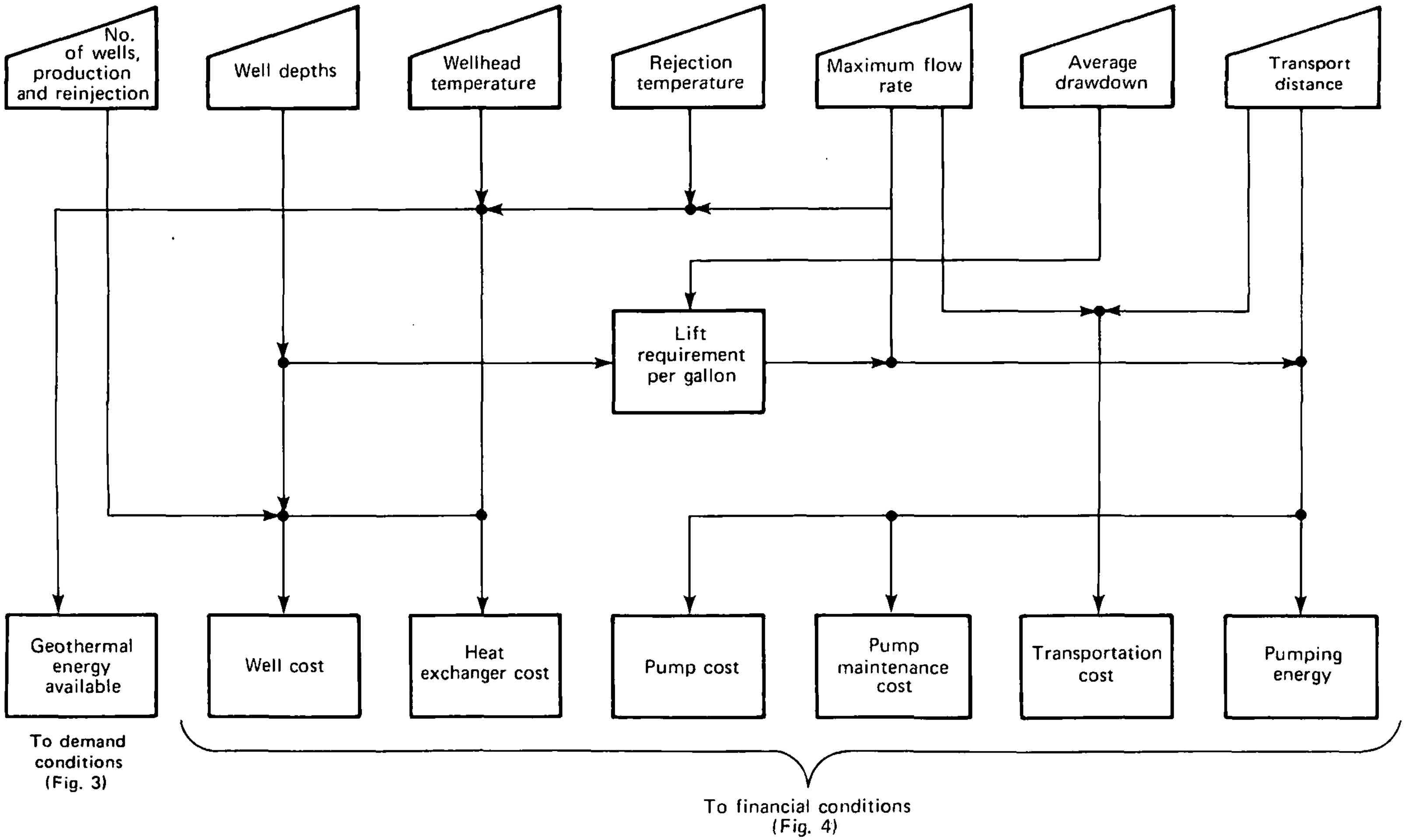

Fig. 2 Schematic structure of GRITS: resource conditions.

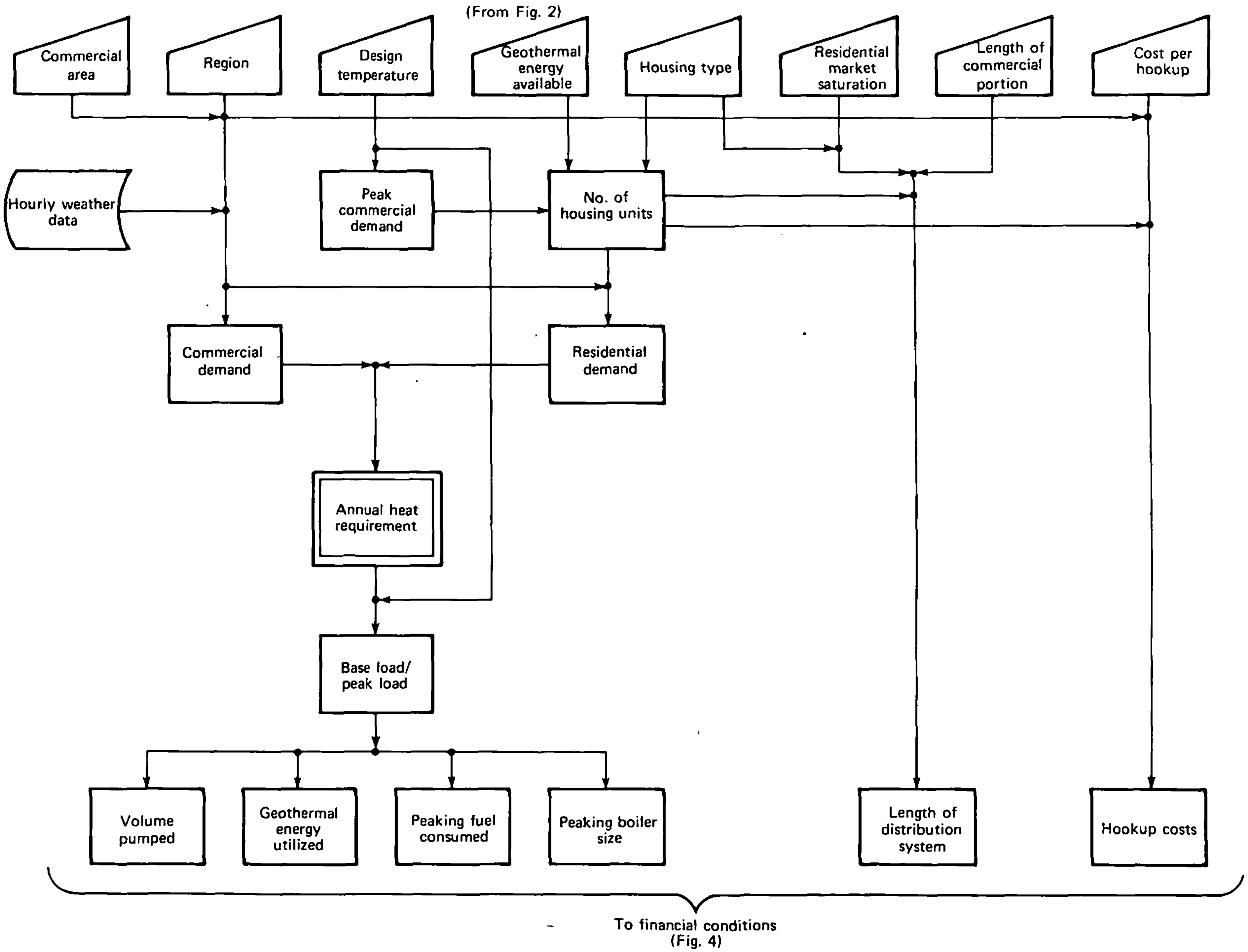

Fig. 3 Schematic structure of GRITS: demand conditions.

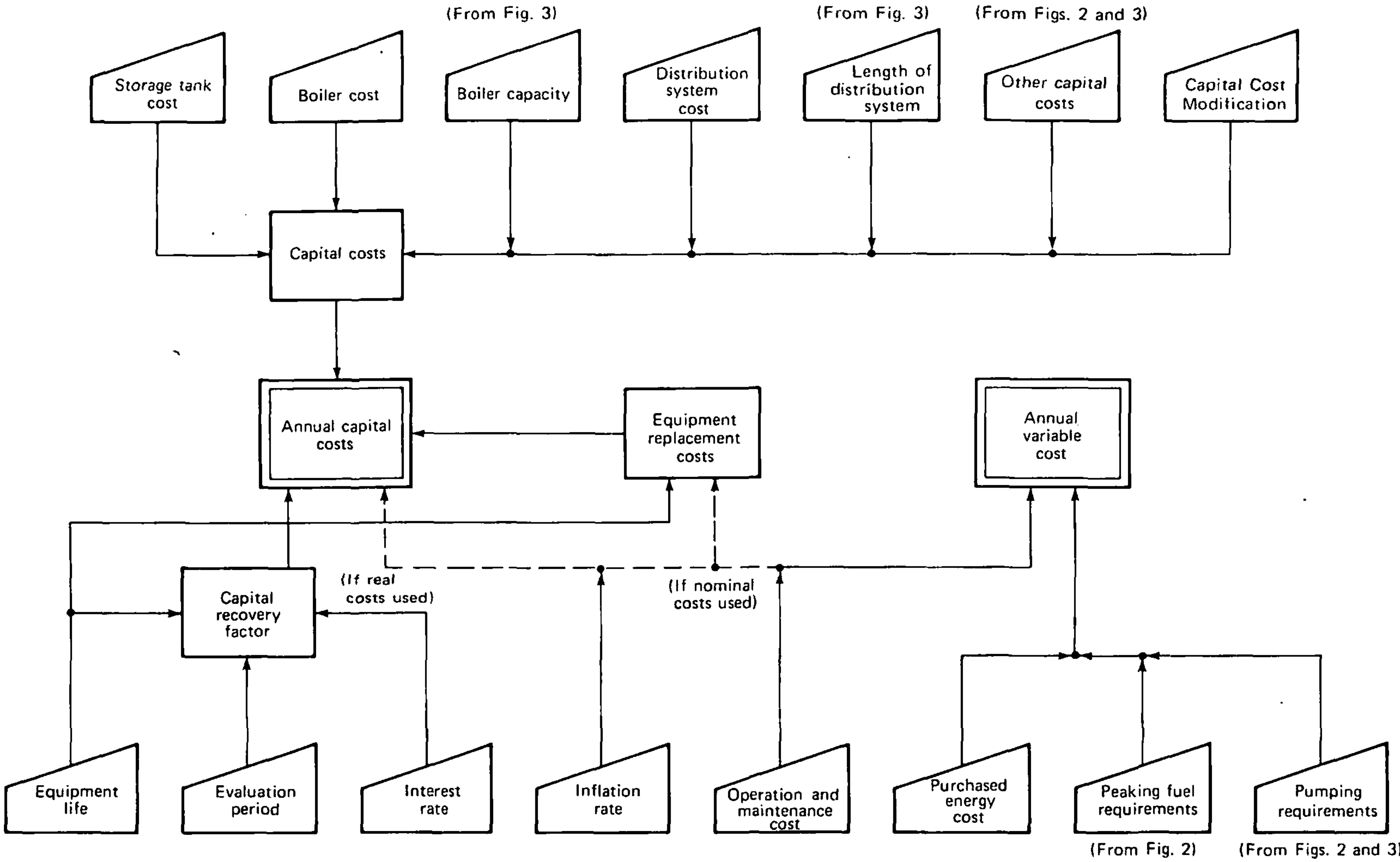

Fig. 4 Schematic structure of GRITS: financial conditions.

Table 1

Default parameters for the residential/commercial scenario of GRITS

```
       (BASE PERIOD FOR COSTS IS SPRING, 1980     )

       RESIDENTIAL-COMMERCIAL SCENARIO PARAMETERS

PROGRAM OPERATING CONDITIONS
----------------------------
#  2   OUTPUT FILE NAME:
#  4   TITLE OF SCENARIO:  (DISPLAYED ABOVE, IF ANY)
#  5   RESIDENTIAL-COMMERCIAL SERVICE CHOSEN.
#  8   DATA FILES WILL NOT BE GENERATED.

RESOURCE CONDITION PARAMETERS
-----------------------------
# 42   NUMBER OF PRODUCTION WELLS:                  1
# 12   DEPTH OF UPWELL (FEET):                   5000.
# 11   WELLHEAD WATER TEMP.(DEG. FAHR.)
          LINEAR FUNCTION USED WITH:
          1-INITIAL WATER TEMP.=    150.0
          2-ANNUAL DROP IN TEMP.=     0.0
# 21   REJECT TEMPERATURE (DEG.FAHR.):           85.0
# 23   DEPTH OF REINJECTION WELL (FEET):        5000.
# 43   NUMBER OF REINJECTION WELLS:                 1
# 25   DRAWDOWN OF UPWELL (PERCENT)
          LINEAR FUNCTION USED WITH:
          INITIAL DRAWDOWN= 15.00
          ANNUAL CHANGE=     0.00
# 32   FLOW FROM WELL (GPM)
          LINEAR FUNCTION USED WITH:
          INITIAL FLOW=        200.00
          ANNUAL CHANGE=         0.00
# 33   TRANSPORT DISTANCE (MILES)  :             0.25

RESIDENTIAL-COMMERCIAL DEMAND CONDITION PARAMETERS
--------------------------------------------------
# 10   AREA UNDER CONSIDERATION:      SALISBURY,MD
# 14   SYSTEM DESIGN TEMP.(DEG. FAHR.):           30
# 28   MIN. AMBIENT TEMPERATURE (DEG.FAHR.):     -5.
# 35   FRACTION OF DISTRIBUTION SYSTEM INSTALLED:
          IN YEAR  0 = 50.000%
          IN YEAR  1 = 12.500%
          IN YEAR  2 = 12.500%
          IN YEAR  3 = 12.500%
          IN YEAR  4 = 12.500%

(RESIDENTIAL-SPECIFIC)
# 13   PERCENTAGES OF HOUSING TYPES ON SYSTEM:
        HOUSING TYPE                      (%)
          1-SINGLE FAMILY SUBURBAN:      0.000
          2-SINGLE FAMILY DENSE:        20.000
          3-TOWNHOUSE:                  40.000
          4-GARDEN APTS.:               40.000
          5-HIGH RISE:                   0.000
# 34   MARKET SATURATION (%):                    70.00
# 19   PERCENTAGE OF ULTIMATE NUMBER OF HOUSEHOLDS
          LINEAR FUNCTION USED WITH:
          1-INITIAL PERCENTAGE=  15.00
          2-ANNUAL CHANGE     =   8.00
# 18   COST PER HOOKUP:                 $       267.
```

Table 1 (cont'd)

Default parameters for the residential/commercial scenario of GRITS

```
(COMMERCIAL-SPECIFIC)
# 45   NUMBER OF TYPES OF COMMERCIAL BUILDINGS:   2
# 46   AVERAGE FLOOR SPACE FOR COMMERCIAL BUILDINGS OF
          TYPE  1 :      4.000 THOUSAND SQ. FT.
          TYPE  2 :     10.000 THOUSAND SQ. FT.
# 47   AVERAGE HEAT DEMAND FOR
       BUILDINGS     SPACE HEAT        HOT WATER HEAT
          OF      (BTU/SQFT/DEG/DAY)  (BTU/SQFT/DAY)
        TYPE  1:         9.0               0.0
        TYPE  2:         9.0               0.0
# 48   NUMBER OF COMMERCIAL BUILDINGS OF
          TYPE  1 :    5
          TYPE  2 :    2
# 51   RATE OF COMMERCIAL MARKET PENETRATION
          LOGISTIC FUNCTION USED WITH:
          1-INITIAL PERCENTAGE=  50.00
          2-YEAR WHEN 100% OF DEMAND IS ON SYSTEM=   2
# 50   LENGTH OF COMMERCIAL DISTRIBUTION SYSTEM:    0.20 MILES
# 49   AVERAGE COST PER HOOKUP FOR A COMMERCIAL BUILDING: $   500.

FINANCIAL CONDITION PARAMETERS
------------------------------
# 40   ECONOMIC ACCOUNTING METHOD: 3-NPV & DISC AVG COST
# 36   SYSTEM SELLING PRICE ($/MIL. BTU):
          GEOTHERMAL SELLING PRICE IS A MULTIPLE OF:
          ELECTRICITY PRICE, FACTOR=          0.70
# 33   STUDY PERIOD: 20 YEARS; INTERVALS OF  5 YRS
# 41   RESOURCE ASSESSMENT PERIOD (YEARS):  0
       ANNUAL RESOURCE ASSESSMENT COST: $        0. THOUSAND
# 16   WELL COST ADJUSTMENT FACTOR:           1.000
       ADJ. TOT. COST OF WELLS($THOUS.):  329.159
# 17   HEAT EXCH. COST ADJUSTMENT FACTOR:   1.000
       ADJ TOT COST OF HEAT EXCHS($THOU):  34.511
# 24   STORAGE TANK CAPACITY:    2.0 HOURS OF FLOW
# 15   CAPITAL EQUIPMENT      LIFETIME IN YEARS:
         WELLS                30.(OR PROJECT LIFE)
         PIPING SYSTEM        30.(OR PROJECT LIFE)
         HEAT EXCHANGER       10.(OR PROJECT LIFE)
         IN-WELL PUMPS        10.(OR PROJECT LIFE)
         HOOKUPS              30.(OR PROJECT LIFE)
         PEAKING BOILER       30.(OR PROJECT LIFE)
         STORAGE TANK         30.(OR PROJECT LIFE)
# 37   DISCOUNT RATE (PERCENT):                2.00
# 27   INTEREST RATE (PERCENT):               12.00
# 25   COST CALCULATIONS ARE IN REAL DOLLARS
       INFLATION RATE (PERCENT):               8.00
# 39   TAXES:
# 20   COST OF ELECTRICITY (CTS/KWH)
          COMPOUNDING FUNCTION USED WITH:
          1-INITIAL ELEC. PRICE=    5.50
          2-PERCENT ANNUAL CHANGE=  1.50
# 29   FOSSIL FUEL COST ($/MIL. BTU)
          COMPOUNDING FUNCTION USED WITH:
          INITIAL FOSS. FUEL PRICE=   5.000
          PERCENT ANNUAL CHANGE=     3.500
# 44   OPER. & MAINT. COST (% OF CAPITAL):   1.00%
# 30   BOILER COST($/100K BTU/HR):        1500.00
# 22   PIPE COST ($THOUSAND/MILE):        250.000
```

Table 2

Default parameters for the industrial scenario of GRITS

```
     (BASE PERIOD FOR COSTS IS SPRING, 1980    )

          INDUSTRIAL SCENARIO PARAMETERS

PROGRAM OPERATING CONDITIONS
----------------------------
#  2   OUTPUT FILE NAME:
#  4   TITLE OF SCENARIO:  (DISPLAYED ABOVE, IF ANY)
#  5   INDUSTRIAL SERVICE CHOSEN.
#  8   DATA FILES WILL NOT BE GENERATED.

RESOURCE CONDITION PARAMETERS
-----------------------------
# 42   NUMBER OF PRODUCTION WELLS:                 1
# 12   DEPTH OF UPWELL (FEET):                 5000.
# 11   WELLHEAD WATER TEMP.(DEG. FAHR.)
          LINEAR FUNCTION USED WITH:
          1-INITIAL WATER TEMP.=    150.0
          2-ANNUAL DROP IN TEMP.=     0.0
# 21   REJECT TEMPERATURE (DEG.FAHR.):          85.0
# 23   DEPTH OF REINJECTION WELL (FEET):       5000.
# 43   NUMBER OF REINJECTION WELLS:                1
# 26   DRAWDOWN OF UPWELL (PERCENT)
          LINEAR FUNCTION USED WITH:
          INITIAL DRAWDOWN= 15.00
          ANNUAL CHANGE=     0.00
# 32   FLOW FROM WELL (GPM)
          LINEAR FUNCTION USED WITH:
          INITIAL FLOW=         200.00
          ANNUAL CHANGE=          0.00
# 38   TRANSPORT DISTANCE (MILES)  :            0.25

INDUSTRIAL DEMAND CONDITION PARAMETER
-------------------------------------
# 31   INDUSTRIAL UTILIZATION FACTOR (%):   25.00

FINANCIAL CONDITION PARAMETERS
------------------------------
# 40   ECONOMIC ACCOUNTING METHOD: 3-NPV & DISC AVG COST
# 36   SYSTEM SELLING PRICE ($/MIL. BTU):
          GEOTHERMAL SELLING PRICE IS A MULTIPLE OF:
          ELECTRICITY PRICE, FACTOR=            0.70
# 33   STUDY PERIOD: 20 YEARS; INTERVALS OF  5 YRS
# 41   RESOURCE ASSESSMENT PERIOD (YEARS):  0
       ANNUAL RESOURCE ASSESSMENT COST: $         0. THOUSAND
# 16   WELL COST ADJUSTMENT FACTOR:            1.000
       ADJ. TOT. COST OF WELLS($THOUS.):  329.159
# 17   HEAT EXCH. COST ADJUSTMENT FACTOR:      1.000
       ADJ TOT COST OF HEAT EXCHS($THOU):  34.511
# 24   STORAGE TANK CAPACITY:   2.0 HOURS OF FLOW
# 15   CAPITAL EQUIPMENT     LIFETIME IN YEARS:
         WELLS               30.(OR PROJECT LIFE)
         PIPING SYSTEM       30.(OR PROJECT LIFE)
         HEAT EXCHANGER      10.(OR PROJECT LIFE)
         IN-WELL PUMPS       10.(OR PROJECT LIFE)
         STORAGE TANK        30.(OR PROJECT LIFE)
# 37   DISCOUNT RATE (PERCENT):                 2.00
# 27   INTEREST RATE (PERCENT):                12.00
# 25   COST CALCULATIONS ARE IN REAL DOLLARS
       INFLATION RATE (PERCENT):                8.00
# 39   TAXES:
# 20   COST OF ELECTRICITY (CTS/KWH)
          COMPOUNDING FUNCTION USED WITH:
          1-INITIAL ELEC. PRICE=    5.50
          2-PERCENT ANNUAL CHANGE=  1.50
# 44   OPER. & MAINT. COST (% OF CAPITAL):     1.00%
```

study. OPTION 32 inputs maximum flow attainable from an average well. Both flow and drawdown may be specified as time-dependent functions; for example, drawdown may increase over time even with a constant flow rate because of reduced pressure within the aquifer. To keep GRITS generally applicable, the model accepts any combination of values for OPTIONS 26 and 32. The user may conduct sensitivity analyses regarding the economic nature of the trade-off by hypothesizing varying relationships between the flow and drawdown and determining the point on each function that results in the lowest cost for the energy produced.

Both the size of submersible pumps for the production well and the size of surface pumps for the reinjection well are determined as a function of the flow and drawdown. The life of these pumps is specified through OPTION 15. Original cost and annual maintenance are a function of size (see pages 45 through 48). The cost of each kilowatt hour of electricity to operate the pumps is specified through OPTION 20. The number of hours the pumps operate during a year depends on the volume of water extracted from a well, which in turn depends upon the utilization level (see page 48).

Thermal Output of the Well

The maximum net hourly output of energy delivered to the transmission line from the wellhead heat exchanger depends on the wellhead resource temperature (OPTION 11), the reject temperature (OPTION 21), and the maximum flow rate (OPTION 32). Utilization of this energy depends on demand conditions (see page 44).

Central Heat Exchanger

A 5°F temperature drop across the wellhead heat exchanger is assumed. Cost estimates internal to the model assume a plate type construction with an expected life of 10 years (see page 49). Other types and special materials may be simulated by modifying the heat exchanger cost function coefficient (OPTION 17) and appropriate changes in expected equipment lifetime (OPTION 15). A zero value for OPTION 17 may be used to simulate an application in which the geothermal fluids are sent directly through the transport and distribution pipes.

Storage Tank

In order to minimize drawdown and therefore pumping energy, it is advantageous to pump longer periods of time at slower rates to reduce wear on the pumps. Thus, a storage tank near the wellhead heat exchanger may be desirable. The user indicates the capacity of this tank as the number of hours of storage at maximum flow from the well (OPTION 24). The cost of the tank is a function of capacity (see page 50). The default value is two hours of storage; a zero value for OPTION 24 eliminates the tank cost.

Transmission Line

The length of the transmission line from the wellhead to the industrial user or district distribution system is specified through OPTION 38. The cost per mile of this line depends on the number of wells and the maximum flow per well. Transmission pump costs and pumping energy requirements depend on the total flow and the length of the transmission pipe. The closed loop system from wellhead to distribution point and back to the wellhead is assumed to eliminate the effect of modest changes in elevation over the transmission distance.

MODELING DEMAND CONDITIONS

Utilization Level of the Resource

On the basis of wellhead temperature, reject temperature, and maximum flow rate, each geothermal well is capable of providing a calculated amount of energy per hour. Since demand is based upon variable conditions (such as the industrial production cycle, weather conditions, or the extent of market penetration), the volume of water extracted from the well will often be less than the maximum and at times will drop to zero. Utilization refers to that fraction of the total annual amount of energy available from a well operating at capacity around the clock that the user requires.

The annual utilization factor for the industrial routine in GRITS is specified through OPTION 31. For the residential/commercial routine, the utilization level is a calculated value based on the number and types of buildings on the community heating system (OPTIONS 13 and 45 through 48), the temperature data for the region (OPTION 10), and the design temperature (OPTION 14), which determine the relative size of the geothermal base load and the fossil fuel peaking load.

Community Heating Systems

Areas Being Served. GRITS may be used to simulate a geothermal-supplied community heating system in any area for which the hourly temperature data are available.[1] Use of the hourly data

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[1]At this time, hourly temperature data for three cities on the Atlantic Coastal Plain are in the model; it can accept such data for any other region. The Metro Center/APL have data available for most major cities in the United States.

rather than the degree day information frequently used in other models lets the user optimize the relative size of the peaking system (see below).

Geothermal Base/Fossil Fuel Peaking Loads. When the level of demand depends primarily on outside temperature, it is highly inefficient to restrict the size of the system so that each customer's peak demand can be served by the geothermal well alone. If the system is expanded so that well capacity is reached at some warmer temperature (e.g., 35°F), utilization increases and the fixed costs are spread out over a large number of customers. The outside temperature at which the geothermal well reaches capacity is the design temperature (OPTION 14) of the system.

A peaking system serves incremental demand as the outside temperature falls below the design temperature. While individual customers may provide their own peaking plants, it appears to be better economically to provide this capacity by the community heating system. Among the factors favoring this approach are higher utilization of the distribution system and lower fuel costs to the system compared to those to individual operators (for example, bulk purchases or the possible use of coal in place of oil). OPTION 29 inputs the cost of peaking fuel in dollars per million Btu's. This value may be input as a constant or a price trend. The amount of fuel required is a calculated value based on the size of the system, the temperature data, and the design temperature. The cost of the peaking boilers per 100,000 Btu's per hour of capacity is input through OPTION 30. Peaking capacity is based on the minimum ambient temperature (OPTION 28), which typically would be somewhat below the coldest average temperature to provide a margin of safety. OPTION 28 may also be used to enlarge the boiler capacity sufficiently to provide as much backup (emergency) power as desired.

The user may optimize the design temperature by varying this parameter until the lowest average cost for each unit of energy is found. The principal determinants of this optimum are the pumping energy requirements for the geothermal heat and the cost of the peaking fuel. A larger peaking system may also be viewed as reducing the risk of system failure if the well should temporarily shut down.

Distribution System. The length of the distribution system for a commercial area is a user-specified input (OPTION 50). The length for the residential/commercial area is a calculated value based on the housing type and the market saturation level (i.e., the fraction in a given area of all housing units that ultimately join the system). The cost for each mile of the installed distribution system is input through OPTION 22. This cost is assumed to reflect prior optimization of pipe sizes and insulation thicknesses. GRITS uses a default value of $250,000 per mile for the cost of the installed distribution system.

The rate at which the distribution system is installed is specified through OPTION 35 as the fraction of the total installed each year. Although this rate is independent of the rate of market penetration, it should exceed or at least equal the combined rate of market penetration for the commercial and residential portions of the system.

Commercial Area. The user models the size and makeup of the commercial area by specifying how many building sizes are being served (OPTION 45), the average floor space for each size (OPTION 46), and the number of buildings of each size (OPTION 48). The heating requirements of the commercial floor space in Btu's per square foot per degree day and the sanitary hot water requirements in Btu's per square foot per day are input through OPTION 47.

The hookup cost for each commercial building, specified by OPTION 49, includes the costs of laying the service pipe from the distribution system to the building and the cost of the energy meter to monitor consumption.

Residential Area. In order to determine the number of housing units of a given type or mixture of types that may be served by the combined residential/commercial system, commercial demand at the design temperature is subtracted from the energy available from each geothermal well at maximum flow.

GRITS includes five housing types[1]: single-family suburban, single-family dense, townhouses, garden apartments, and high-rise apartments. The user may mix these five types in any combination, using OPTION 13. Heating requirements per housing unit for each type[2] relative to that for the single-family types are: 65% for townhouses, 35% for garden apartments, and 29% for high-rise apartments.

Selection of the housing type also determines the density of the units and hence the length of the distribution system. The following densities[1] are assumed for each 400 by 200 ft block (street center to street center) in a grid system: single-family suburban, 7 units; single-family dense, 13 units; townhouses, 32 units; garden apartments, 50 units; and high-rise apartments, 120 units.

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[1]These are modeled generally after those in GEOCITY (Ref. 7).
[2]These are modeled generally on data supplied by the Brookhaven National Laboratory (Ref. 8).

Hookup costs per housing unit, specified through OPTION 18, reflect the laying of pipe from the street center to the housing unit and the energy meter. The costs will generally be much lower on a per unit basis for apartments, which can share the service pipes, the meters, or both.

Market Saturation. To reflect conditions under which not all housing units in a given area join a community heating system, a market saturation level (OPTION 34) of less than 100% is used. As market saturation declines, the length of the distribution system required to serve the units that do join the system increases.

The market saturation level reflects the relative competitive position of the community heating system and the conversion costs for each type of housing unit. Some units (those with forced air or hot-water radiator heat) may have modest conversion costs, while others (those with electric baseboard heating) may face very high conversion costs.

Rate of Market Penetration. As noted above, the model first calculates the number of housing units to be served and then defines a service area on the assumption that a specific proportion of the units in this area will not join the system. Thus, the "market" for geothermal heat is defined on the basis of the desired number of customers and the density of units expected to join the system. The "rate of market penetration" refers, then, to the pace at which the predetermined number of customers, distributed over an area of specified size, joins the system. The distribution of joining over time depends on the user-specified functional form. It is important to remember that, when this form is not linear, a "rate" of penetration refers to specific values for the parameters in the function and not to the rate of any single year.

OPTIONS 19 and 51 input the rates of residential and commercial market penetration. The user first selects the appropriate function, (e.g., linear or log). Depending on the function selected, the program requests inputs specifying initial values, annual increments, or year of near-complete penetration. For example, if the user selects a linear function, the program requests the following inputs: initial percentage of housing or commercial units on the system and annual increase as a percentage of the final number of units on the system.

Utilization of the resource will rise as the system penetrates its market more completely each year. After the system reaches maturity (i.e., 100% market penetration for both residential and commercial areas), utilization becomes constant.

Since drawdown is related to flow and hence to utilization of the well, the drawdown specified in OPTION 26 is assumed to occur only when drawdown approaches the level specified at the same rate as the system approaches maturity, i.e., the rate of market penetration.

Industrial Process Heating System

Unlike the community heating system, the market for industrial process heat is not characterized by the distribution of many small users over a large area. Since only a few (or even one) major users represent sufficient demand for a geothermal resource, the industrial routine does not need to consider the market factors included in the community heating system analysis nor a variable demand dependent on ambient temperature. The system transports the energy from the wellhead to the user's plant gate, and the proportion of the well output indicated by the utilization factor is used by the process heat user. Table 2 shows the resource demand and financial conditions that the user may specify for industrial applications.

MODELING FINANCIAL CONDITIONS

Economic Accounting Measures

The two principal summary measures provided by GRITS are the discounted average cost per million Btu's and the net present value of the system at the end of the project evaluation period (project lifetime). The program also calculates the year in which break-even occurs, the total capital cost for the system, and other measures.

The discounted average cost is a useful measure because with only minor adjustments it may be compared directly with the cost of other space heating fuels. The net present value is useful as an indicator of the growth potential for the investment in the geothermal system. OPTION 40 allows the user to select one or both of these measures.

The discounted average cost includes both geothermal and peaking energy outputs and cost for the entire production and utilization system. To permit evaluation of strictly geothermal-related costs and outputs, the discounted average wellhead costs per million geothermal Btu's are also output.

The total capital costs are simply the sum of the unamortized outlays for initial system components, exclusive of replacement costs. Typically, a very high proportion of these costs is incurred in the first year of the utilization phase; hence the capital costs are referred to here as "initial capital costs." This measure is a useful indicator of the size of the initial investment required to utilize the geothermal energy.

Calculation of the net present value requires an assumed selling price for the geothermal developer's energy output. Selling price is input through OPTION 36. Currently, the default price is pegged to 70% of that assumed for electricity (OPTION 20).

Evaluation Period or Lifetime of Project

The evaluation period, or project lifetime, is composed of a resource assessment phase and a utilization phase. The assessment phase is modeled in a very general manner as a total annual assessment cost occurring over a specified period (OPTION 41) before utilization of the resource. This period reflects exploration and testing costs, as well as licensing, permit acquisition, and other requirements. The utilization phase is calculated as the time remaining in the evaluation period (OPTION 33) after the assessment phase. The current default value for the evaluation period is 20 years with no assessment phase. If the user desires the results from only a subset of years in the evaluation period, this request is made during execution of the scenario (OPTION 7), not by changing the length of the evaluation period.

Annual Capital Costs

The nominal annualized cost of capital loans borrowed at an interest rate of "i" and repaid over a period of "T" years is determined by multiplying the amount borrowed by the capital recovery factor (CRF):

$$\text{Amount borrowed} \times \{i \div [(1 + i)^T - 1] + i\} .$$

The CRF is calculated separately for each major component of the fixed plant on the basis of its expected life or the end of the project utilization period, whichever is shorter. At the end of the project evaluation period all debt has been repaid. OPTION 15 allows the user to specify the expected useful life of each major piece of capital equipment. OPTION 27 inputs the interest rate.

When costs are calculated in real dollars (OPTION 25), the model "deflates" the value of the annual debt service payment by the rate of inflation. Thus for inflation rate "r," the model values the annual debt service payments in year "t" as,

$$\frac{\text{Amount borrowed} \times \{i \div [(1 + i)^T - 1] + i\}}{(1 + r)^t} .$$

For example, a well costing \$400,000 financed at 12% interest over 20 years had a nominal annual cost of about \$53,500. In the initial year (Year 0) of the utilization phase, the real value and nominal value coincide. If inflation has progressed at an annual rate of 8% since the start of the utilization phase, the real value of the annual well cost in Year 4 is about $39,000.

Debt Financing

Currently, GRITS assumes that all capital costs are financed through debt and that all operating costs are financed through revenues. This restriction makes the financial simulation less realistic, but introduces only relatively minor distortions in preliminary analyses. Whether they are holders of debt (e.g., bonds) or equity (e.g., common stock), investors will require similar levels of return for investments with a given level of perceived risk. Of course, investors will differ in their willingness to accept risk, in their preference for the timing of the stream of returns, and in the tax liability of different types of returns (such as dividends or interest payments versus capital gains). Such considerations will be important for more comprehensive assessments suitable to a later stage in the evaluation process. However, preliminary assessments that are concerned with more general issues affecting project viability are only minimally affected.

Taxes

A routine to calculate taxes is under development but is not yet implemented in GRITS. As for the method of financing, tax considerations will have a relatively minor impact on the outcome of preliminary economic assessments. Other factors such as long-term resource reliability or the cost of competing fuels are likely to be more uncertain and thus more crucial in the early stages of resource evaluation.

Interest Rate/Inflation Rate

The interest rate is composed of three basic elements: a rate of return reflecting time preference, a rate reflecting investment risk assessment, and the expected rate of inflation. A 15% interest rate may be composed of a 2% time preference (an annual 2% return for a risk-free investment in addition to compensation for inflation over the year), a 3% risk assessment (a 3% return each year as compensation for the possibility that the loan will not be repaid as expected), and a roughly 9½% expected rate of inflation over each year of the loan repayment period — thus yielding an interest rate of (1.02) (1.03) (1.095) = 15%.

The interest rate is input through OPTION 27 and the rate of expected inflation through OPTION 25. Default values for these rates are 12% and 8%, respectively. The base case assumes a low risk investment, or one in which the tax benefits (e.g., municipal bonds) permit the investor to use a lower before-tax real return for time preference and risk premiums.

The use of a loan indexed to inflation may be simulated through a zero rate of inflation and an inflation-free interest rate.

Discount Rate

Returns that come later in a project evaluation period are generally valued less than those that come earlier (see page 21). The most common approach to discounting a stream of returns is to apply a single discounting factor that increases in a multiplicative manner over time, i.e., $(1 + r)^t$, where r is the discount rate and t is the number of years in the future when the return is expected.

At a 2% discount rate, a return of $1.00 will be valued at $0.98 the next year, $0.82 in 10 years, and $0.45 in 40 years. At a 6% discount rate, these returns would be $0.94, $0.56, and $0.10. The discount rate used in GRITS should reflect a real rate, that is, the effects of the general rate should not be considered. Discount rates may also include risk premiums.

Risk Assessment

Considerable uncertainty exists in regard to the long-term reliability of specific geothermal reservoirs. Wells, wellhead equipment, the transmission system, and the distribution system represent large fixed investments that must be incurred even if the resource fails to meet expectations or if demand levels fall short of projections. Thus, potential investors may view geothermal utilization systems as involving considerable amounts of risk. The user may model the level of risk assessment by adding a "risk component" to the interest rate or the discount rate. For example, the interest rate might be raised from 12% to 18% or the discount rate from 2% to 8%. Another approach is to shorten the project evaluation period (financial lifetime). Each of these changes will, of course, raise average cost and lower net present value. This approach reflects the fact that the level of risk assessed by potential private investors is a cost that the geothermal utility can possibly be forced to bear.

Cost of Major Capital Items

GRITS includes internal cost formulas for major system components. The actual cost is calculated on the basis of user-specified values for size and design of each component. To allow greater flexibility, cost formulas for several major components may be scaled up or down to suit local conditions.

Heat exchanger costs are calculated on the basis of the temperature drop (Δt) across the heat exchanger. To simulate the use of special materials, designs, or even the absence of a central heat exchanger, the user may modify the cost of this component by a coefficient input through OPTION 17 (default value = 1.00). If the use of a different material (say, specially coated alloys) is simulated, the user may wish to change the expected life of the heat exchanger in OPTION 15.

GRITS calculates well costs as a function of depth. To account for different soil conditions or other factors affecting well drilling and completion costs, the user may input a value different from 1.00 in OPTION 16 to scale the cost estimate to the desired degree.

The cost of an average mile of an installed dual-pipe distribution system is input through OPTION 22. The estimate is a composite one for a portion of the distribution main and the secondary lines feeding from it. For most types of community heating systems, an average cost per mile is a very convenient and useful first approximation of the actual costs that would be found in a detailed calculation of pipe sizes for subsections of the system, optimal insulation thicknesses, and trenching costs. The default value in GRITS is $250,000 per mile.

The storage tank cost is a function of capacity, which in turn is a function of the maximum flow rate (OPTION 32) and the storage time at maximum flow (OPTION 24).

The cost of each 100,000 Btu's per hour of capacity for the peaking boilers is input through OPTION 30. Total boiler Btu capacity is a calculated value based on the difference in demand at the design temperature (OPTION 14) and at the minimum ambient temperature down to which the system can supply all heating requirements (OPTION 28). If the thermal output potential of the well declines as a result of values used for resource temperature or maximum flow, the capacity of the peaking system automatically expands to make up the difference.

Expected economic lifetimes for major capital components are input through OPTION 15. If a component such as the pumps has an expected lifetime less than the project lifetime (evaluation period), it is replaced in the year following the end of its expected lifetime. Equipment costs are amortized over the expected lifetime of the component or over the remaining years of the project evaluation period, whichever is shorter.

Operation and Maintenance Costs

Operation and maintenance costs are calculated annually as a percentage of the capital investment in the project. The default value of 1% may be changed through OPTION 44.

Cost of Purchased Energy

The user specifies the costs of peaking energy and electricity to operate the pumps through OPTIONS 29 and 20, respectively. The default value for peaking oil costs is $6.00 per million Btu's, rising in real terms (i.e., after allowing for inflation) at a compound rate of 3½% annually. The default price trend for electricity is $0.055 per kilowatt hour, rising at a compound rate of 1.5% annually.

3. TECHNICAL RELATIONSHIPS INTERNAL TO THE MODEL

ECONOMIC CALCULATIONS

The basic annual real cost equation is

$$Cost_t = [\sum_k (CRF_k \times K_k) \div (1 + f)^{t-t_c}] + VC_t ,$$

where:

CRF_k = capital recovery factor for an interest rate r and a repayment period equal to the expected life of capital component k or the length of the utilization phase of the project evaluation period (life of the project), whichever is shorter;

K_k = total cost of capital component k, i.e., production and reinjection wells, downhole and surface pumps, central heat exchanger, storage tank, transmission line, distribution system and hookup equipment (connecting pipe and meter), and peaking equipment;

$(1 + f)^{t-t_c}$ = deflation factor for debt service charges for inflation rate f. t is the year being evaluated. If the piece of equipment is purchased in any year other than t = 0, it is deflated by a proportionately smaller amount since its nominal cost is presumed to have been rising at the rate of inflation in the years between the beginning of the utilization phase (t = 0) and the year the cost was incurred ($t = t_c$). If ($t - t_c$) is negative, the cost is not calculated. If nominal dollars are used, f = 0;

VC_t = variable cost in year t, i.e., pumping energy, peaking fuel, and operation and maintenance costs.

If the terms are in nominal dollars, the equation is

$$Cost_t = [\sum_k (CRF_k \times K_k)] + EC_t + O\&M_t ,$$

where: EC_t = energy costs in year t (user-specified price trend should account for inflation), and

$O\&M_t$ = fixed annual operation and maintenance costs, multiplied by $(1 + f)^t$ in year t.

Heat output at the wells in year t is calculated as

$$O_t = U_t \times \text{maximum output}_t ,$$

where: O_t = the actual amount of geothermal energy consumed by the process heat user or the community heating system in year t (in Btu's);

U_t = the utilization factor in year t. For the industrial routine, this is an input value; for the residential/commercial routine, it is a calculated value based on the design temperature, housing type, level of market penetration, and temperature data; and

Maximum output$_t$ = the number of Btu's per year that would be delivered net to the transmission line based on that year's temperature and flow if the system operated at 100% utilization.

Revenue in year t is calculated as

$$R_t = P_t \times (O_t + FE_t) ,$$

where: P_t = selling price of the system's energy output in year t, and

FE_t = energy supplied by the peaking system (fossil fuel) in year t.

The discounted average cost (DAC) is calculated as

$$DAC = \frac{\sum_{t=0}^{T} \frac{\text{Cost}_t}{(1 + d)^t}}{\sum_{t=0}^{T} \frac{(O_t + FE_t)}{(1 + d)^t}} ,$$

where: d = the discount factor.

Net present value (NPV) is calculated as

$$NPV = \sum_{t=0}^{T} \left[\frac{P_t \times (O_t + FE_t)}{(1 + d)^t} - \frac{Cost_t}{(1 + d)^t} \right] .$$

The break-even point is defined as the year in which the net present value first reaches or exceeds 0.

WELL COSTS

The costs of drilling, casing, and cementing either a production well or a reinjection well increase rapidly with increasing depth. Thus, to allow for accurate well costs, an analytical expression was obtained from a polynomial fit of average costs of drilling oil wells up to 10,000 feet deep in the United States (Ref. 9). The expression for cost thus obtained is given by

$$W_i = dx^4 + cx^3 + bx^2 + ax$$

where: $d = -4.17 \times 10^{-11}$,

$c = +1.00 \times 10^{-6}$,

$b = -3.83 \times 10^{-3}$, and

$a = +28.0$.

Efforts are currently under way to obtain better expressions for water well drilling and completion costs, but results are still inconclusive. Until better data are available, use of the above expression is indicated. The user may modify the expression by a coefficient different from one in OPTION 16.

SUBMERSIBLE PUMP

Pump sizes and costs vary dramatically with the depth from which geothermal waters must be pumped (Ref. 10). Since well depths, flow rates, and drawdown percentages are user-specified variables, the pump size and cost must be calculated in the model for each new set of well parameters. In order to size accurately the required pump and to provide accurate cost estimates, expressions for pump size, capital costs, maintenance costs, and operating costs have been developed with information supplied by J. F. Boutwell of Centrilift, Inc. (Ref. 11).

The dynamic pressure head that must be supplied by a downhole, submersible pump is given by (Refs. 12 and 13)

$$H(ft) = d_d + F_t + P_d ,$$

where d_d is the head lift, F_t is the frictional head loss in the production tubing, and P_d is the discharge pressure head at the surface. The pump is assumed to be set about 150 ft below the lowest water level in the well under full production, f. The lowest water level is given by the well depth times the percentage of well drawdown. The frictional head losses are assumed to be 25 ft/1,000 ft of lift for nominal production tubings. The discharge pressure at the surface is assumed to be on the order of 50 psi. Any additional pressure that may be needed for surface circulation is assumed to be provided by surface pumps. Converting to pressure (in psi), the pressure head (P_H) required from the downhole pump is given by

$$P_H = 0.480 \text{ (PC) (WD)} - 20.0 ,$$

where PC is the fractional well drawdown and WD is the well depth.

The fluid horsepower required is given by

$$F_{hp} = \frac{P_h f}{1714} ,$$

where f is the production flow rate. In order to produce this power rating, pump inefficiencies must be considered. Pump ratings are given in terms of brake horsepower, which is defined as

$$B_{hp} = \frac{F_{hp}}{\varepsilon} ,$$

where ε is the pump efficiency, which has been assumed to be 0.76 (Ref. 13). Thus, the pump size (in horsepower) required for a particular set of well conditions is given by

$$B_{hp} = [3.68 \times 10^{-4} \text{ (PC) (WD)} - 1.54 \times 10^{-2}] f .$$

Costs of the pumps are then calculated by

$$C_{sp} = 1175 \times B_{hp}^{0.7} \qquad \text{(Ref. 10)}.$$

REINJECTION PUMP (Ref. 10)

In the case where spent geothermal fluids are to be reinjected either into the aquifer from which they were taken or into a shallower aquifer with the same transmissibility, the energy required for reinjection will be the same as that required to bring the fluids to the surface, under the assumptions of an isotropic, homogeneous aquifer matrix, no precipitation of solids to restrict flow into the aquifer, and no direct communication of pressure changes between the production well and the reinjection well (i.e., their separation distance is greater than the combined radii of influence of the two wells). Therefore, total well pumping is given by twice the production pumping energy.

The situation changes somewhat when reinjection occurs in shallower aquifers whose transmissibility is higher. For simplicity, it is assumed that the transmissibility of the reinjection aquifer scales linearly with depth, i.e.,

$$T \propto \frac{1}{D} .$$

Thus, an aquifer at half the depth has twice the transmissibility. In this case, the percentage drawdown is the same in the two wells, and the pumping energy for reinjection (RE) scales linearly with depth and can be expressed as a function of the production energy (PE), i.e.,

$$RE = PE \frac{Dr}{Dp} ,$$

where Dr is the depth of the reinjection well and Dp is the depth of the production well. The model calculates the total pumping energy (TE) as

$$TE = PE \left(1 + \frac{Dr}{Dp}\right) .$$

Reinjection pumps located on the surface are cheaper than submersible pumps. The reinjection pump costs (C_{rp}) are scaled as

$$C_{rp} = \$3.00 \times f + \$40.00 \times B_{hp} \times \frac{Dr}{Dp} ,$$

where f is the flow rate in gal/min, B_{hp} is the brake horsepower currently calculated for the production well submersible pump, and the ratio Dr/Dp scales the size to reflect the smaller sized pump needed.

PUMP MAINTENANCE COST

The operating lifetimes of submersible pumps are extremely variable, but under conditions that might be encountered on the Atlantic Coastal Plain, operating lifetimes may be on the order of two to four years. After these periods, the pump must be pulled and reworked. Centrilift has provided estimates of annual repair costs for its submersible pumps (Ref. 11). An average of these quotations is given by

$$\text{Annual submersible pump maintenance} = \$65 \times B_{hp} \ .$$

Reinjection pumps are more readily accessible and preventive maintenance may be performed more easily and cheaply. Therefore, reinjection pump maintenance costs are given by

$$\text{Annual surface pump maintenance} = 1.5\% \times \text{initial cost} \ .$$

PUMPING ENERGY

Pumping energy (Ref. 14) for the production well is a function of production rate from the well (determined by such characteristics of the aquifer as saturated thickness and permeability) and of heating demand. The characteristics of the aquifer, accounted for through a user-specified well drawdown, are assumed to result from pumping to maintain a flow rate above that which would result from artesian pressure. From the above, the power requirement for a downhole pump is given by

$$kW = 0.746 \ B_{hp} \ .$$

However, motor inefficiency increases power requirements to

$$kW = \frac{0.746B_{hp}}{0.80} = [3.43 \times 10^{-4} \ (PC)(WD) - 1.44 \times 10^{-2}]f \ .$$

If the well were to be operated around the clock for an entire year, the number of kilowatt hours of electricity required is given by annual kWh = [3.006 (PC)(WD) - 125.8] flow. For most applications, especially residential space heating, heat demands do not require year-round well operation. Thus, a utilization factor is required to scale the annual number of kilowatt hours of pumping energy to the specific load.

Heating demand for a housing unit is a function of ambient temperature and the type of unit. For ambient temperatures above the system design temperature, heating requirements for the total number of housing units on the district heating system are calculated as a fraction of the energy that could be supplied by the geothermal well if pumped at maximum flow. To estimate the length of time that the demand should remain at a given level, average hourly weather data for the major city climatically closest to the study area are used.

Although pumping energy is a nonlinear (convex) function of flow rate, the model uses a linear approximation of the fraction of the energy required to maintain that rate compared to the energy for maximum flow. (The linear approximation was purposely used to make the pumping energy estimates more conservative by slightly overstating the pumping energy required at most levels.) The number of hours at each flow rate is then multiplied by this fraction to obtain "full pumping equivalent hours," which are then summed and taken as a fraction of the number of hours in a year.

The model calculates the annual pumping energy as given above; the resulting value is multiplied by the fraction described above to produce an estimate of actual pumping energy required.

RATIO OF EXTRACTED GEOTHERMAL ENERGY TO INPUT PUMPING ENERGY

The expression for the ratio of the extracted geothermal energy to the input electrical pumping energy (the coefficient of performance) is

$$\frac{\varepsilon_G}{\varepsilon_p} = \frac{\text{Geothermal heat extracted}}{\text{Pumping energy}} \equiv COP_{GT}$$

This expression allows direct comparison of the energy efficiency of a geothermal production well to a heat pump.

HEAT EXCHANGER COST

Many applications of moderate temperature geothermal resources will require the use of a water-to-water heat exchanger at the wellhead in order to minimize corrosion and scaling of saline or mineralized waters. For the purposes of this study, plate-type heat exchangers have been considered, since they have a number of attributes such as ease of cleaning and high thermal transfer efficiency that are important in geothermal systems. The cost of any heat exchanger is a function of the logarithmic mean temperature difference, ΔTm, across the heat exchanger and the total heat flow, Q, through it. For stainless steel plate heat exchangers the costs (Refs. 15 and 16) can be expressed as

$$C = \frac{0.285\ Q^{0.84}}{\Delta Tm}$$

where

$$\Delta Tm = \frac{(T_1 - T_3) - (T_2 - T_4)}{\ln \frac{(T_1 - T_3)}{(T_2 - T_4)}} ,$$

and $Q = 498\ f\ (T_1 - T_2)$. The heat flow, Q, is expressed in Btu's per hour, f is the well flow rate, T_1 is the geothermal wellhead temperature, T_2 is the reinjection temperature, T_3 is the supply temperature in the secondary loop, and T_4 is the loop return temperature.

A trade-off must be made between high heat exchanger cost at low values of ΔTm, and high reinjection temperatures for the geothermal waters for large values of ΔTm. Since pumping energy is likely to be one of the largest costs in a geothermal system and since the knee of the cost curve is somewhat pronounced, ΔTm has been set at 5°F. This simplifies the cost equation to

$$C = 0.057\ Q^{0.84}$$

The user specifies the wellhead temperature, T_1, and the reinjection temperature, T_2, which is usually assumed to be 75 or 85°F, and the program calculates the cost. The default values for T_1 and T_2 are 150 and 85°F, respectively.

STORAGE TANK COST

After a survey of several vendors involved in the construction of large storage tanks, an expression for the costs has been developed (Ref. 17):

$$C_{ST} = \$0.0951V + \$8.70V^{\frac{2}{3}} + \$44,600$$

where V is the tank volume in gallons. The expression applies to tanks from 30,000 to 1,000,000 gallons capacity; these tank sizes correspond to storage times for the output from a nominal geothermal well (500 gal/min) of 1 hour to about 1½ days.

DEMAND FOR SPACE HEATING

In a single-family detached home, the hourly demand for space heating may be given by: $(65 - T_0) \times 1200$ (Ref. 18). For other types of residential housing, the space heating may be expressed as some fraction of the above expression (Ref. 8). The hourly demand on the system is $(65 - T_0) \times 1200 \times h_i \times N_i$, for a community containing several housing types, where h_i is the fraction of the single-family space heating demand required by other types of housing units, and N_i is the number of houses of type i that use the system.[1] The heating demands for the given housing types in the model are shown in Table 3.

Table 3

Heating demand by housing type

Housing type	h_i[1]	Approximate size (ft^2)
Single family, suburban	1.0	1600
Single family, dense	1.0	1600
Townhouse or rowhouse	0.65	1000
Garden apartment	0.35	1000
High-rise apartment	0.29	800

[1]The fraction h_i reflects the various sizes of the different housing types as well as the resulting reduced heating load due to shared walls, ceilings, etc. The approximate size is shown for an average unit. The values of h_i were obtained from data that included a large mix of housing stock.

The average number of hours during which the ambient temperature is in a given temperature range, i.e., the time-temperature distribution, is already in the model for three eastern cities. Data for additional cities may be input by the user.

DOMESTIC HOT WATER DEMAND

GRITS assumes that all housing units regardless of type consume 20.1 million Btu's per year (Ref. 19). A peak demand of 2.4 times the average hourly demand is assumed when the system is being sized. Thus for single-family units, at a design temperature of 30°F, the peak geothermal load per unit is

$$[1200\ (65 - 30) + 5500] = 47{,}500 \text{ Btu's/h}$$

BOILER SIZE

The boiler for the peaking system is sized by computing the difference in heating demand at a lowest expected ambient temperature for a given locale and the heating demand at the design temperature (DT) (Ref. 3). The boiler costs include buildings for the boilers and estimates of \$1,500 per 10^5 Btu's/h of capacity.

FOSSIL FUEL REQUIREMENTS

The fossil fuel requirements to supply the peak loads are derived from the hourly weather data. Using the time-temperature distribution, the hourly loads to be supplied by the boiler are determined for each expected ambient temperature below the design temperature. This load is multiplied by the average number of hours in a year during which the ambient temperature is expected to be at that level. To account for boiler inefficiencies, heat requirements are multiplied by 1.33, the reciprocal of the 75% boiler efficiency assumed in the model.

COST OF DISTRIBUTION SYSTEM

The cost of the distribution system is found by multiplying the total length of the system by a user-specified cost per mile of installed insulated dual pipe (for two-way circulation), with a default value of \$250,000. This amount is just above the cost suggested in the Brookhaven National Laboratory study (Ref. 20) and is close to the median value of pipe costs surveyed by John Beebee (Ref. 21).

LENGTH OF DISTRIBUTION SYSTEM

The length of the distribution system is determined by the total number of households to be served by the system and the density and market saturation level of these users. Density levels for various types of houses are taken from GEOCITY (Ref. 7) and converted to a block density based on a grid system of 400 by 200 ft blocks (street center to street center). This results in the densities per block given in Table 4.

Table 4

Housing densities per block

Type of residence	No. of households per block
Single family, suburban	7.3
Single family, dense	12.9
Townhouse or rowhouse	32.1
Garden apartment	50.4
High-rise apartment	119.3

The length of the distribution system is then measured directly, based on the block length. This is the length that would occur under 100% saturation. To account for nonparticipation by some households, the length of the system is multiplied by the reciprocal of a user-specified market saturation level (the default value is 70%).

COST OF TRANSMISSION SYSTEM

The cost of transmission depends on the length of the system and the volume of water transported. Transmission pipe diameter is calculated from the volume and an assumed optimal flow rate. The cost per unit length of transmission pipe of a given diameter is developed from data presented at the Swedish District Heating Workshops (Ref. 22). The cost formula used in the model is

$$\$/\text{mile} = 1 \times 10^6 \, (0.207 + 0.047\, d)$$

where: d = pipe diameter in in. = $0.2350 \sqrt{Q}$ (Ref. 23), and

Q = flow in gal/min.

The cost of the transmission line pump is calculated in the following manner:

$$C_p = n\, C_o$$

where: if $Q \leq 110$ gal/min, then

$$n = (89.232\, Q^{-0.617}\, L)\ ,$$

$$C_o = 196\, Q^{0.352}\ ;$$

or: if $Q > 110$ gal/min, then

$$n = (35.112\, Q^{-0.617}\, L)\ ,$$

$$C_o = 108.8\, Q^{0.661}\ ;$$

where n is rounded up to the nearest integer, Q is the flow in gal/min, and L is the length in miles (Ref. 23).

Pumping energy required to pump for a full year is given by

$$E_p = 34181\, Q^{0.315}\, L\ ,$$

where E_p is the pumping energy in kilowatt hours.

The cost of electricity per kilowatt hour is a user-specified variable.

CAPITAL RECOVERY FACTORS

While pump maintenance costs, pumping energy costs, and fossil fuel requirements may be calculated directly on an annual basis, the remaining cost components must be determined on an annual basis through the use of a CRF that reflects the cost of borrowed funds and the specific life expectancy of individual system components (and thus the assumed amortization period). The interest rate is held constant for all system components under a given model run. Although a developer might choose to amortize all system components over a single period in calculating his financial costs, the actual life expectancy of each component is the more relevant factor in determining economic costs.

The capital recovery factors are determined directly from user-specified or default values. The capital recovery factor reflects the annual payment required to repay a loan at i% interest over n time periods, which is given by

$$CRF = \frac{i}{(1 + i)^n - 1} + i ,$$

where i is expressed as its decimal equivalent.

Table 5 shows the capital recovery factors for a range of interest rates and amortization periods. The amortization periods used in the model are based on life expectancies of each system component in order to be consistent with an economic rather than a financial approach. Wells, the distribution system, and hookups are expected to last about 30 years and the wellhead heat exchanger and in-well pumps about 10 years. These lifetimes are the default values, which may be changed by the user. A financial approach may be simulated by changing the amortization periods and interest rates to reflect the desired financial conditions.

Table 5

Capital recovery by interest rate and time

Interest rate (%)	Repayment period (yr)				
	10	15	20	25	30
8	0.149	0.117	0.102	0.094	0.089
10	0.163	0.131	0.117	0.110	0.106
12	0.177	0.149	0.134	0.127	0.124
14	0.192	0.163	0.151	0.145	0.143
18	0.222	0.196	0.187	0.183	0.181

4. SUMMARY

The GRITS model is a flexible tool for the study of the economics of the direct application of geothermal energy. The large number of options allow examination of a wide range of relationships. Once the user becomes familiar with the model's operation and selects his desired base case parameter values, extensive sensitivity analysis may be conducted easily and inexpensively. The options available to the user of GRITS are given in Appendix A.

Persons interested in using the program should contact the authors through The Johns Hopkins University Applied Physics Laboratory or the Center for Metropolitan Planning and Research. Because it is anticipated that GRITS will be enhanced in the future, enquiries about the enhancements incorporated in the program should also be directed to the authors.

Appendix A

OPTIONS AVAILABLE TO THE USER OF GRITS

Option No.	Parameter
H	TYPES OUT THIS LIST OF POSSIBLE INPUTS
1	TYPES OUT THE CURRENT SCENARIO PARAMETERS
2	NAME OF FILE TO RECEIVE OUTPUT OF GRITS. THE FILE NAME MUST FOLLOW STANDARD DEC-10 CONVENTIONS.
3	RETURN TO THE DEFAULT SCENARIO
4	TYPE IN RUN NAME (up to 80 characters)
5	SELECT WHETHER THE MODEL IS FOR RESIDENTIAL-COMMERCIAL OR INDUSTRIAL SALES (residential-commercial is default)
6	RETYPE RESULTS OF MOST RECENT SCENARIO RUN
7	RUN THE CURRENT SCENARIO
8	GENERATE DATA FILE FOR TABULATION OR LATER PLOT GENERATION
9	END EXECUTION OF GRITS
10	AREA UNDER CONSIDERATION
	1 - ATLANTIC CITY, NJ
	2 - SALISBURY, MD
	3 - NORFOLK, VA
	4 - AREA CHOSEN BY USER (hourly weather data must then be input)
11	WATER TEMPERATURE AT WELLHEAD (°F)
12	AVERAGE DEPTH OF UPWELL (ft)
13	HOUSING TYPE, EITHER
	1 - SINGLE FAMILY SUBURBAN
	2 - SINGLE FAMILY DENSE
	3 - TOWNHOUSES
	4 - GARDEN APARTMENTS
	5 - HIGH-RISE MULTIFAMILY HOUSING
	6 - MIXED HOUSING
14	DESIGN TEMPERATURE OF SYSTEM (°F)
15	CAPITAL EQUIPMENT LIFE FOR:
	0 - ALL EQUIPMENT
	1 - WELLS
	2 - DISTRIBUTION SYSTEM
	3 - HEAT EXCHANGER
	4 - HOOKUP COSTS
	5 - IN-WELL PUMPS
	6 - PEAKING SYSTEM BOILER (fossil fuel)
16	ADJUSTMENT FACTOR FOR COST OF AVERAGE WELL
17	ADJUSTMENT FACTOR FOR COST OF HEAT EXCHANGER
18	COST PER HOOKUP ($)
19	PERCENTAGE OF ULTIMATE NUMBER OF HOUSEHOLDS ON SYSTEM

Option No.	Parameter
20	PRICE OF ELECTRICITY (¢/kWh)
21	REJECT TEMPERATURE (°F)
22	PIPE COSTS FOR DISTRIBUTION SYSTEM (thousands of dollars/mile)
23	DEPTH OF AVERAGE REINJECTION WELL (ft)
24	STORAGE TANK CAPACITY (hours of flow)
25	INFLATION RATE--AVE. ANNUAL RATE FOR LIFE OF PROJECT (%)
26	WELL DRAWDOWN (%)
27	INTEREST RATE (%)
28	MINIMUM AMBIENT TEMPERATURE (°F)
29	FOSSIL FUEL PRICE ($/million Btu)
30	BOILER COST ($/hundred thousand Btu/hour)
31	INDUSTRIAL UTILIZATION FACTOR (%)
32	MAXIMUM FLOW RATE OF WATER FROM AQUIFER (gal/min)
33	LENGTH OF STUDY PERIOD* AND INTERVAL FOR COST CALCULATIONS (years)
34	ULTIMATE DENSITY OF HOUSEHOLDS ON GEOTHERMAL SYSTEM (%)
35	PERCENTAGE OF DISTRIBUTION SYSTEM INSTALLED EACH YEAR
36	SELLING PRICE OF SYSTEM ENERGY ($/million Btu)
37	DISCOUNT RATE--TIME PREFERENCE ONLY (%)
38	TRANSPORT DISTANCE (miles)
39	TAXES
40	ECONOMIC ACCOUNTING METHOD
41	RESOURCE ASSESSMENT PERIOD AND COST
42	NUMBER OF PRODUCTION WELLS
43	NUMBER OF REINJECTION WELLS
44	OPERATION AND MAINTENANCE COSTS (% of capital equipment costs)
45	CHARACTERISTICS OF COMMERCIAL BUILDINGS
46	FLOOR AREA OF COMMERCIAL BUILDING TYPES (ft^2/building)
47	HEAT REQUIREMENTS OF COMMERCIAL BLDG TYPES
	1 - SPACE HEAT (Btu/°F/ft^2/day)
	2 - HOT WATER HEAT (Btu/ft^2/day)
48	NUMBER OF COMMERCIAL BUILDINGS OF EACH TYPE
49	HOOKUP COST FOR COMMERCIAL BUILDINGS ($/hookup)
50	LENGTH OF DISTRIBUTION SYSTEM FOR COMMERCIAL BUILDINGS (miles)
51	RATE OF COMMERCIAL MARKET PENETRATION (%)

*This defines the lifetime of the project. The choice to observe only a selected subset of the series of annual results is made upon execution of the scenario in OPTION 7.

** G R I T S **

GEOTHERMAL RESOURCE INTERACTIVE TEMPORAL SIMULATION

VERSION 6A

SAMPLE OUTPUT OF RESIDENTIAL/COMMERCIAL SCENARIO

FORMULATED BY BILL BARRON

WRITTEN BY PETER KROLL

ADDITIONAL PROGRAMMING BY SUSAN MITCHELL

CENTER FOR METROPOLITAN PLANNING & RESEARCH
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BALTIMORE, MARYLAND 21218

APRIL 1980

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GRITS:  GEOTHERMAL RESOURCE INTERACTIVE TEMPORAL SIMULATION                27-May-80                                PAGE   1
CENTER FOR METROPOLITAN PLANNING & RESEARCH, THE JOHNS HOPKINS UNIVERSITY

                                GRITS SAMPLE OUTPUT--RESIDENTIAL-COMMERCIAL APPLICATION

     (BASE PERIOD FOR COSTS IS SPRING, 1980     )

     RESIDENTIAL-COMMERCIAL SCENARIO PARAMETERS

PROGRAM OPERATING CONDITIONS
----------------------------
# 2    OUTPUT FILE NAME:                          GRITS.SMP
# 4    TITLE OF SCENARIO:  (DISPLAYED ABOVE, IF ANY)
# 5    RESIDENTIAL-COMMERCIAL SERVICE CHOSEN.
# 3    DATA FILES WILL NOT BE GENERATED.

RESOURCE CONDITION PARAMETERS
-----------------------------
# 42   NUMBER OF PRODUCTION WELLS:                    1
# 12   DEPTH OF UPWELL (FEET):                    5000.
# 11   WELLHEAD WATER TEMP.(DEG. FAHR.)
          LINEAR FUNCTION USED WITH:
          1-INITIAL WATER TEMP.=    150.0
          2-ANNUAL DROP IN TEMP.=     0.0
# 21   REJECT TEMPERATURE (DEG.FAHR.):             85.0
# 23   DEPTH OF REINJECTION WELL (FEET):          5000.
# 43   NUMBER OF REINJECTION WELLS:                   1
# 26   DRAWDOWN OF UPWELL (PERCENT)
          LINEAR FUNCTION USED WITH:
          INITIAL DRAWDOWN= 15.00
          ANNUAL CHANGE=     0.00
# 32   FLOW FROM WELL (GPM)
          LINEAR FUNCTION USED WITH:
          INITIAL FLOW=        200.00
          ANNUAL CHANGE=         0.00
# 33   TRANSPORT DISTANCE (MILES)  :               0.25

RESIDENTIAL-COMMERCIAL DEMAND CONDITION PARAMETERS
--------------------------------------------------
# 10   AREA UNDER CONSIDERATION:      SALISBURY,MD
# 14   SYSTEM DESIGN TEMP.(DEG. FAHR.):            30
# 28   MIN. AMBIENT TEMPERATURE (DEG.FAHR.):       -5.
# 35   FRACTION OF DISTRIBUTION SYSTEM INSTALLED:
          IN YEAR  0 = 50.000%
          IN YEAR  1 = 12.500%
          IN YEAR  2 = 12.500%
          IN YEAR  3 = 12.500%
          IN YEAR  4 = 12.500%

(RESIDENTIAL-SPECIFIC)
# 13   PERCENTAGES OF HOUSING TYPES ON SYSTEM:
         HOUSING TYPE                  (%)
          1-SINGLE FAMILY SUBURBAN:    0.000
          2-SINGLE FAMILY DENSE:      20.000
          3-TOWNHOUSE:                40.000
          4-GARDEN APTS.:             40.000
          5-HIGH RISE:                 0.000
# 34   MARKET SATURATION (%):                70.00
# 19   PERCENTAGE OF ULTIMATE NUMBER OF HOUSEHOLDS
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          LINEAR FUNCTION USED WITH:
          1-INITIAL PERCENTAGE=  15.00
          2-ANNUAL CHANGE      =   8.00
# 18   COST PER HOOKUP:                    $        267.

(COMMERCIAL-SPECIFIC)
# 45   NUMBER OF TYPES OF COMMERCIAL BUILDINGS:   2
# 46   AVERAGE FLOOR SPACE FOR COMMERCIAL BUILDINGS OF
          TYPE  1 :     4.000 THOUSAND SQ. FT.
          TYPE  2 :    10.000 THOUSAND SQ. FT.
# 47   AVERAGE HEAT DEMAND FOR
       BUILDINGS      SPACE HEAT       HOT WATER HEAT
          OF      (BTU/SQFT/DEG/DAY)  (BTU/SQFT/DAY)
        TYPE  1:          9.0               0.0
        TYPE  2:          9.0               0.0
# 48   NUMBER OF COMMERCIAL BUILDINGS OF
          TYPE  1 :     5
          TYPE  2 :     2
# 51   RATE OF COMMERCIAL MARKET PENETRATION
          LOGISTIC FUNCTION USED WITH:
          1-INITIAL PERCENTAGE=  50.00
          2-YEAR WHEN 100% OF DEMAND IS ON SYSTEM=   2
# 50   LENGTH OF COMMERCIAL DISTRIBUTION SYSTEM:    0.20 MILES
# 49   AVERAGE COST PER HOOKUP FOR A COMMERCIAL BUILDING: $   500.

FINANCIAL CONDITION PARAMETERS
------------------------------
# 40   ECONOMIC ACCOUNTING METHOD: 3-NPV & DISC AVG COST
# 36   SYSTEM SELLING PRICE ($/MIL. BTU):
          GEOTHERMAL SELLING PRICE IS A MULTIPLE OF:
          ELECTRICITY PRICE, FACTOR=           0.70
# 33   STUDY PERIOD: 20 YEARS; INTERVALS OF  5 YRS
# 41   RESOURCE ASSESSMENT PERIOD (YEARS):  0
       ANNUAL RESOURCE ASSESSMENT COST: $        0. THOUSAND
# 16   WELL COST ADJUSTMENT FACTOR:            1.000
       ADJ. TOT. COST OF WELLS($THOUS.):  329.159
# 17   HEAT EXCH. COST ADJUSTMENT FACTOR:   1.000
       ADJ TOT COST OF HEAT EXCHS($THOU):  34.511
# 24   STORAGE TANK CAPACITY:   2.0 HOURS OF FLOW
# 15   CAPITAL EQUIPMENT    LIFETIME IN YEARS:
         WELLS              30.(OR PROJECT LIFE)
         PIPING SYSTEM      30.(OR PROJECT LIFE)
         HEAT EXCHANGER     10.(OR PROJECT LIFE)
         IN-WELL PUMPS      10.(OR PROJECT LIFE)
         HOOKUPS            30.(OR PROJECT LIFE)
         PEAKING BOILER     30.(OR PROJECT LIFE)
         STORAGE TANK       30.(OR PROJECT LIFE)
# 37   DISCOUNT RATE (PERCENT):                 2.00
# 27   INTEREST RATE (PERCENT):                12.00
# 25   COST CALCULATIONS ARE IN REAL DOLLARS
       INFLATION RATE (PERCENT):                8.00
# 39   TAXES:
# 20   COST OF ELECTRICITY (CTS/KWH)
          COMPOUNDING FUNCTION USED WITH:
          1-INITIAL ELEC. PRICE=    5.50
          2-PERCENT ANNUAL CHANGE=  1.50
# 29   FOSSIL FUEL COST ($/MIL. BTU)
          COMPOUNDING FUNCTION USED WITH:
          INITIAL FOSS. FUEL PRICE=   5.000
          PERCENT ANNUAL CHANGE=      3.500
```

44 OPER. & MAINT. COST (% OF CAPITAL): 1.00%
30 BOILER COST($/100K BTU/HR): 1500.00
22 PIPE COST ($THOUSAND/MILE): 250.000

* * COST OF INITIAL CAPITAL EQUIPMENT * *

WELLS:	$	329.159	THOUSAND
DISTRIBUTION SYSTEM:	$	193.000	THOUSAND
HEAT EXCHANGERS:	$	34.511	THOUSAND
PUMPS:	$	28.750	THOUSAND
HOOKUPS:	$	55.543	THOUSAND
PEAKING BOILER:	$	31.443	THOUSAND
TRANSPORT SYSTEM:	$	104.420	THOUSAND
STORAGE TANK:	$	52.239	THOUSAND
* TOTAL *	$	894.065	THOUSAND

GRITS SAMPLE OUTPUT--RESIDENTIAL-COMMERCIAL APPLICATION

RESIDENTIAL-COMMERCIAL SCENARIO IN YEAR 0

OPTION		VALUE
10	AREA UNDER CONSIDERATION:	SALISBURY,MD
11	WELLHEAD WATER TEMP.(DEG. FAHR.):	150.0
12	DEPTH OF UPWELL (FEET):	5000.
13	HOUSING TYPE:	6
14	SYSTEM DESIGN TEMP.(DEG. FAHR.):	30
15	CAPITAL EQUIPMENT LIFETIME IN YEARS:	
	WELLS	30.(OR PROJECT LIFE)
	PIPING SYSTEM	30.(OR PROJECT LIFE)
	HEAT EXCHANGER	10.(OR PROJECT LIFE)
	IN-WELL PUMPS	10.(OR PROJECT LIFE)
	HOOKUPS	30.(OR PROJECT LIFE)
	PEAKING BOILER	30.(OR PROJECT LIFE)
	STORAGE TANK	30.(OR PROJECT LIFE)
16	WELL COST ADJUSTMENT FACTOR:	1.000
17	HEAT EXCH. COST ADJUSTMENT FACTOR:	1.000
18	AVERAGE COST PER HOOKUP: $	257.
19	MKT PENETRATION: 15.0%; HOUSEHOLDS:	29.
20	COST OF ELECTRICITY (CTS/KWH):	5.500
21	REJECT TEMPERATURE (DEG.FAHR.):	85.0
22	PIPE COST ($THOUSAND/MILE):	250.000
23	DEPTH OF REINJECTION WELL (FEET):	5000.
24	STORAGE TANK CAPACITY (GALLONS):	24000.
25	REAL/NOMINAL$:R; INFLATION RATE(%):	8.00
26	DRAWDOWN OF UPWELL (PERCENT):	2.65
27	INTEREST RATE (PERCENT):	12.00
28	MIN. AMBIENT TEMPERATURE (DEG.FAHR.):	-5.
29	FOSSIL FUEL COST ($/MIL. BTU):	6.00
30	BOILER COST($/100K BTU/HR):	1500.00
32	MAXIMUM FLOW RATE (GAL./MINUTE):	200.00
33	STUDY PERIOD: 20 YRS; INTERVALS OF	5 YRS
34	MARKET SATURATION (%):	70.00
35	PCT. OF DISTRIB. SYS. BUILT THIS YEAR:	50.
36	SYSTEM SELLING PRICE ($/MIL. BTU):	11.28
37	DISCOUNT RATE (IN PERCENT):	2.00
38	TRANSPORT DISTANCE (MILES):	0.250
39	TAXES:	
40	ECONOMIC ACCOUNTING METHOD:	NPV & DISC. AVG. COST
41	RESOURCE ASSESSMENT: 0 YRS @ $THOU	0./YR
42	NUMBER OF PRODUCTION WELLS:	1
43	NUMBER OF REINJECTION WELLS:	1
44	OPER. & MAINT. COST (% OF CAPITAL):	1.00%
46	COMM. FLOORSPACE ON LINE(THOU.SQ FT):	20.
49	COST FOR COMMERCIAL HOOKUP: $	500.00
51	MKT PENETRATION: 50.0%; BUILDINGS:	4.

RESULTS OF RESIDENTIAL-COMMERCIAL MODEL FOR YEAR 0

LENGTH OF DISTRIBUTION SYSTEM:	0.40 MILES
TOTAL RESIDENTIAL BTU'S (MILLIONS):	2694.56
TOTAL GEOTHERMAL BTU'S (MILLIONS):	3351.55
TOTAL SYSTEM BTU'S (MILLIONS):	3446.63
COEFFICIENT OF PERFORMANCE:	108.003
PERCENTAGE GEOTHERMAL UTILIZATION:	5.89
PERCENTAGE SERVICE GEOTHERMAL:	97.24
PUMPING ENERGY:	0.009 MILLION KWH
ANNUALIZED COSTS (THOUSANDS OF DOLLARS):	
WELL COSTS:	44.067
DISTRIBUTION SYSTEM COSTS:	13.254
HEAT EXCHANGER COSTS:	6.108
ORIGINAL PUMP COSTS:	5.038
HOOKUP COSTS:	1.279
PUMP OVERHAUL COSTS:	4.005
PUMPING COSTS:	0.500
PEAKING BOILER COSTS:	10.904
FOSSIL FUEL COSTS:	0.759
TRANSPORT COST:	13.930
STORAGE TANK COST:	8.333
OPERATION AND MAINTENANCE COSTS:	8.941
RESOURCE ASSESSMENT COSTS:	0.000
TOTAL ANNUAL WELLHEAD COSTS:	62.741
TOTAL ANNUAL SYSTEM COSTS:	117.217
WELLHEAD COST PER GEO MIL. BTU($):	18.72
SYSTEM COST PER MIL. BTU($):	34.01
REVENUE ($ THOUSANDS):	38.891
NET REVENUE ($ THOUSANDS):	-78.326

*(BASE PERIOD FOR COSTS IS SPRING, 1980)

GRITS SAMPLE OUTPUT--RESIDENTIAL-COMMERCIAL APPLICATION

RESIDENTIAL-COMMERCIAL SCENARIO IN YEAR 5

OPTION		VALUE
10	AREA UNDER CONSIDERATION:	SALISBURY,MD
11	WELLHEAD WATER TEMP.(DEG. FAHR.):	150.0
12	DEPTH OF UPWELL (FEET):	5000.
13	HOUSING TYPE:	6
14	SYSTEM DESIGN TEMP.(DEG. FAHR.):	30
15	CAPITAL EQUIPMENT LIFETIME IN YEARS:	
	WELLS	30.(OR PROJECT LIFE)
	PIPING SYSTEM	30.(OR PROJECT LIFE)
	HEAT EXCHANGER	10.(OR PROJECT LIFE)
	IN-WELL PUMPS	10.(OR PROJECT LIFE)
	HOOKUPS	30.(OR PROJECT LIFE)
	PEAKING BOILER	30.(OR PROJECT LIFE)
	STORAGE TANK	30.(OR PROJECT LIFE)
16	WELL COST ADJUSTMENT FACTOR:	1.000
17	HEAT EXCH. COST ADJUSTMENT FACTOR:	1.000
18	AVERAGE COST PER HOOKUP: $	267.
19	MKT PENETRATION: 55.0%; HOUSEHOLDS:	107.
20	COST OF ELECTRICITY (CTS/KWH):	5.925
21	REJECT TEMPERATURE (DEG.FAHR.):	85.0
22	PIPE COST ($THOUSAND/MILE):	250.000
23	DEPTH OF REINJECTION WELL (FEET):	5000.
24	STORAGE TANK CAPACITY (GALLONS):	24000.
25	REAL/NOMINAL$:R; INFLATION RATE(%):	8.00
26	DRAWDOWN OF UPWELL (PERCENT):	8.77
27	INTEREST RATE (PERCENT):	12.00
28	MIN. AMBIENT TEMPERATURE (DEG.FAHR.):	-5.
29	FOSSIL FUEL COST ($/MIL. BTU):	7.13
30	BOILER COST($/100K BTU/HR):	1500.00
32	MAXIMUM FLOW RATE (GAL./MINUTE):	200.00
33	STUDY PERIOD: 20 YRS; INTERVALS OF	5 YRS
34	MARKET SATURATION (%):	70.00
35	PCT. OF DISTRIB. SYS. BUILT THIS YEAR:	0.
36	SYSTEM SELLING PRICE ($/MIL. BTU):	12.15
37	DISCOUNT RATE (IN PERCENT):	2.00
38	TRANSPORT DISTANCE (MILES):	0.250
39	TAXES:	
40	ECONOMIC ACCOUNTING METHOD: NPV & DISC. AVG. COST	
41	RESOURCE ASSESSMENT: 0 YRS @ $THOU	0./YR
42	NUMBER OF PRODUCTION WELLS:	1
43	NUMBER OF REINJECTION WELLS:	1
44	OPER. & MAINT. COST (% OF CAPITAL):	1.00%
45	COMM. FLOORSPACE ON LINE(THOU.SQ FT):	40.
49	COST FOR COMMERCIAL HOOKUP: $	500.00
51	MKT PENETRATION: 100.0%; BUILDINGS:	7.

RESULTS OF RESIDENTIAL-COMMERCIAL MODEL FOR YEAR 5

LENGTH OF DISTRIBUTION SYSTEM:	0.79 MILES
TOTAL RESIDENTIAL BTU'S (MILLIONS):	9880.05
TOTAL GEOTHERMAL BTU'S (MILLIONS):	11077.24
TOTAL SYSTEM BTU'S (MILLIONS):	11384.20
COEFFICIENT OF PERFORMANCE:	31.950
PERCENTAGE GEOTHERMAL UTILIZATION:	19.45
PERCENTAGE SERVICE GEOTHERMAL:	97.30
PUMPING ENERGY:	0.102 MILLION KWH
ANNUALIZED COSTS:	(THOUSANDS OF DOLLARS):
WELL COSTS:	29.992
DISTRIBUTION SYSTEM COSTS:	20.457
HEAT EXCHANGER COSTS:	4.157
ORIGINAL PUMP COSTS:	3.463
HOOKUP COSTS:	3.591
PUMP OVERHAUL COSTS:	4.005
PUMPING COSTS:	6.019
PEAKING BOILER COSTS:	7.421
FOSSIL FUEL COSTS:	2.909
TRANSPORT COST:	9.514
STORAGE TANK COST:	5.671
OPERATION AND MAINTENANCE COSTS:	8.941
RESOURCE ASSESSMENT COSTS:	0.000
TOTAL ANNUAL WELLHEAD COSTS:	50.459
TOTAL ANNUAL SYSTEM COSTS:	106.148
WELLHEAD COST PER GEO MIL. BTU($):	4.56
SYSTEM COST PER MIL. BTU($):	9.32
REVENUE ($ THOUSANDS):	138.383
NET REVENUE ($ THOUSANDS):	32.235

*(BASE PERIOD FOR COSTS IS SPRING, 1980)

GRITS SAMPLE OUTPUT--RESIDENTIAL-COMMERCIAL APPLICATION

RESIDENTIAL-COMMERCIAL SCENARIO IN YEAR 10

OPTION		VALUE
10	AREA UNDER CONSIDERATION:	SALISBURY,MD
11	WELLHEAD WATER TEMP.(DEG. FAHR.):	150.0
12	DEPTH OF UPWELL (FEET):	5000.
13	HOUSING TYPE:	6
14	SYSTEM DESIGN TEMP.(DEG. FAHR.):	30
15	CAPITAL EQUIPMENT. LIFETIME IN YEARS:	
	WELLS	30.(OR PROJECT LIFE)
	PIPING SYSTEM	30.(OR PROJECT LIFE)
	HEAT EXCHANGER	10.(OR PROJECT LIFE)
	IN-WELL PUMPS	10.(OR PROJECT LIFE)
	HOOKUPS	30.(OR PROJECT LIFE)
	PEAKING BOILER	30.(OR PROJECT LIFE)
	STORAGE TANK	30.(OR PROJECT LIFE)
16	WELL COST ADJUSTMENT FACTOR:	1.000
17	HEAT EXCH. COST ADJUSTMENT FACTOR:	1.000
18	AVERAGE COST PER HOOKUP: $	267.
19	MKT PENETRATION: 95.0%; HOUSEHOLDS:	185.
20	COST OF ELECTRICITY (CTS/KWH):	6.383
21	REJECT TEMPERATURE (DEG.FAHR.):	95.0
22	PIPE COST ($THOUSAND/MILE):	250.000
23	DEPTH OF REINJECTION WELL (FEET):	5000.
24	STORAGE TANK CAPACITY (GALLONS):	24000.
25	REAL/NOMINAL$:R; INFLATION RATE(%):	9.00
26	DRAWDOWN OF UPWELL (PERCENT):	14.31
27	INTEREST RATE (PERCENT):	12.00
28	MIN. AMBIENT TEMPERATURE (DEG.FAHR.):	-5.
29	FOSSIL FUEL COST ($/MIL. BTU):	8.45
30	BOILER COST($/100K BTU/HR):	1500.00
32	MAXIMUM FLOW RATE (GAL./MINUTE):	200.00
33	STUDY PERIOD: 20 YRS; INTERVALS OF	5 YRS
34	MARKET SATURATION (%):	70.00
35	PCT. OF DISTRIB. SYS. BUILT THIS YEAR:	0.
36	SYSTEM SELLING PRICE ($/MIL. BTU):	13.10
37	DISCOUNT RATE (IN PERCENT):	2.00
38	TRANSPORT DISTANCE (MILES):	0.250
39	TAXES:	
40	ECONOMIC ACCOUNTING METHOD: NPV & DISC. AVG. COST	
41	RESOURCE ASSESSMENT: 0 YRS @ $THOU	0./YR
42	NUMBER OF PRODUCTION WELLS:	1
43	NUMBER OF REINJECTION WELLS:	1
44	OPER. & MAINT. COST (% OF CAPITAL):	1.00%
45	COMM. FLOORSPACE ON LINE(THOU.SQ FT):	40.
49	COST FOR COMMERCIAL HOOKUP: $	500.00
51	MKT PENETRATION:100.0%; BUILDINGS:	7.

RESULTS OF RESIDENTIAL-COMMERCIAL MODEL FOR YEAR 10

LENGTH OF DISTRIBUTION SYSTEM:	0.79 MILES
TOTAL RESIDENTIAL BTU'S (MILLIONS):	17065.54
TOTAL GEOTHERMAL BTU'S (MILLIONS):	18075.86
TOTAL SYSTEM BTU'S (MILLIONS):	18569.69
COEFFICIENT OF PERFORMANCE:	19.514
PERCENTAGE GEOTHERMAL UTILIZATION:	31.75
PERCENTAGE SERVICE GEOTHERMAL:	97.34
PUMPING ENERGY:	0.271 MILLION KWH
ANNUALIZED COSTS	(THOUSANDS OF DOLLARS):
WELL COSTS:	20.412
DISTRIBUTION SYSTEM COSTS:	13.929
HEAT EXCHANGER COSTS:	6.103
ORIGINAL PUMP COSTS:	5.088
HOOKUP COSTS:	5.382
PUMP OVERHAUL COSTS:	4.005
PUMPING COSTS:	17.329
PEAKING BOILER COSTS:	5.050
FOSSIL FUEL COSTS:	5.559
TRANSPORT COST:	6.475
STORAGE TANK COST:	3.850
OPERATION AND MAINTENANCE COSTS:	8.941
RESOURCE ASSESSMENT COSTS:	0.000
TOTAL ANNUAL WELLHEAD COSTS:	55.142
TOTAL ANNUAL SYSTEM COSTS:	102.138
WELLHEAD COST PER GEO MIL. BTU($):	3.05
SYSTEM COST PER MIL. BTU($):	5.50
REVENUE ($ THOUSANDS):	243.174
NET REVENUE ($ THOUSANDS):	141.036

*(BASE PERIOD FOR COSTS IS SPRING, 1980)

GRITS SAMPLE OUTPUT--RESIDENTIAL-COMMERCIAL APPLICATION

RESIDENTIAL-COMMERCIAL SCENARIO IN YEAR 15

OPTION		VALUE
10	AREA UNDER CONSIDERATION:	SALISBURY,MD
11	WELLHEAD WATER TEMP.(DEG. FAHR.):	150.0
12	DEPTH OF UPWELL (FEET):	5000.
13	HOUSING TYPE:	6
14	SYSTEM DESIGN TEMP.(DEG. FAHR.):	30
15	CAPITAL EQUIPMENT	LIFETIME IN YEARS:
	WELLS	30.(OR PROJECT LIFE)
	PIPING SYSTEM	30.(OR PROJECT LIFE)
	HEAT EXCHANGER	10.(OR PROJECT LIFE)
	IN-WELL PUMPS	10.(OR PROJECT LIFE)
	HOOKUPS	30.(OR PROJECT LIFE)
	PEAKING BOILER	30.(OR PROJECT LIFE)
	STORAGE TANK	30.(OR PROJECT LIFE)
16	WELL COST ADJUSTMENT FACTOR:	1.000
17	HEAT EXCH. COST ADJUSTMENT FACTOR:	1.000
18	AVERAGE COST PER HOOKUP: $	267.
19	MKT PENETRATION:100.0%; HOUSEHOLDS:	195.
20	COST OF ELECTRICITY (CTS/KWH):	6.875
21	REJECT TEMPERATURE (DEG.FAHR.):	85.0
22	PIPE COST ($THOUSAND/MILE):	250.000
23	DEPTH OF REINJECTION WELL (FEET):	5000.
24	STORAGE TANK CAPACITY (GALLONS):	24000.
25	REAL/NOMINAL$:R; INFLATION RATE(%):	8.00
26	DRAWDOWN OF UPWELL (PERCENT):	15.00
27	INTEREST RATE (PERCENT):	12.00
28	MIN. AMBIENT TEMPERATURE (DEG.FAHR.):	-5.
29	FOSSIL FUEL COST ($/MIL. BTU):	10.05
30	BOILER COST($/100K BTU/HR):	1500.00
32	MAXIMUM FLOW RATE (GAL./MINUTE):	200.00
33	STUDY PERIOD: 20 YRS; INTERVALS OF	5 YRS
34	MARKET SATURATION (%):	70.00
35	PCT. OF DISTRIB. SYS. BUILT THIS YEAR:	0.
36	SYSTEM SELLING PRICE ($/MIL. BTU):	14.11
37	DISCOUNT RATE (IN PERCENT):	2.00
38	TRANSPORT DISTANCE (MILES):	0.250
39	TAXES:	
40	ECONOMIC ACCOUNTING METHOD: NPV & DISC. AVG. COST	
41	RESOURCE ASSESSMENT: 0 YRS @ $THOU	0./YR
42	NUMBER OF PRODUCTION WELLS:	1
43	NUMBER OF REINJECTION WELLS:	1
44	OPER. & MAINT. COST (% OF CAPITAL):	1.00%
45	COMM. FLOORSPACE ON LINE(THOU.SQ FT):	40.
49	COST FOR COMMERCIAL HOOKUP: $	500.00
51	MKT PENETRATION:100.0%; BUILDINGS:	7.

RESULTS OF RESIDENTIAL-COMMERCIAL MODEL FOR YEAR 15

LENGTH OF DISTRIBUTION SYSTEM:	0.79 MILES
TOTAL RESIDENTIAL BTU'S (MILLIONS):	17963.73
TOTAL GEOTHERMAL BTU'S (MILLIONS):	18950.69
TOTAL SYSTEM BTU'S (MILLIONS):	19467.87
COEFFICIENT OF PERFORMANCE:	18.603
PERCENTAGE GEOTHERMAL UTILIZATION:	33.28
PERCENTAGE SERVICE GEOTHERMAL:	97.34
PUMPING ENERGY:	0.298 MILLION KWH
ANNUALIZED COSTS	(THOUSANDS OF DOLLARS):
WELL COSTS:	13.892
DISTRIBUTION SYSTEM COSTS:	9.480
HEAT EXCHANGER COSTS:	4.157
ORIGINAL PUMP COSTS:	3.453
HOOKUP COSTS:	4.022
PUMP OVERHAUL COSTS:	4.005
PUMPING COSTS:	20.524
PEAKING BOILER COSTS:	3.437
FOSSIL FUEL COSTS:	6.914
TRANSPORT COST:	4.407
STORAGE TANK COST:	2.627
OPERATION AND MAINTENANCE COSTS:	8.941
RESOURCE ASSESSMENT COSTS:	0.000
TOTAL ANNUAL WELLHEAD COSTS:	43.360
TOTAL ANNUAL SYSTEM COSTS:	85.869
WELLHEAD COST PER GEO MIL. BTU($):	2.55
SYSTEM COST PER MIL. BTU($):	4.41
REVENUE ($ THOUSANDS):	274.638
NET REVENUE ($ THOUSANDS):	188.769

*(BASE PERIOD FOR COSTS IS SPRING, 1980)

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
LAUREL, MARYLAND

GRITS SAMPLE OUTPUT--RESIDENTIAL-COMMERCIAL APPLICATION

RESIDENTIAL-COMMERCIAL SCENARIO IN YEAR 19

OPTION		VALUE
10	AREA UNDER CONSIDERATION:	SALISBURY,MD
11	WELLHEAD WATER TEMP.(DEG. FAHR.):	150.0
12	DEPTH OF UPWELL (FEET):	5000.
13	HOUSING TYPE:	6
14	SYSTEM DESIGN TEMP.(DEG. FAHR.):	30
15	CAPITAL EQUIPMENT LIFETIME IN YEARS:	
	WELLS	30.(OR PROJECT LIFE)
	PIPING SYSTEM	30.(OR PROJECT LIFE)
	HEAT EXCHANGER	10.(OR PROJECT LIFE)
	IN-WELL PUMPS	10.(OR PROJECT LIFE)
	HOOKUPS	30.(OR PROJECT LIFE)
	PEAKING BOILER	30.(OR PROJECT LIFE)
	STORAGE TANK	30.(OR PROJECT LIFE)
16	WELL COST ADJUSTMENT FACTOR:	1.000
17	HEAT EXCH. COST ADJUSTMENT FACTOR:	1.000
18	AVERAGE COST PER HOOKUP: $	267.
19	MKT PENETRATION:100.0%; HOUSEHOLDS:	195.
20	COST OF ELECTRICITY (CTS/KWH):	7.293
21	REJECT TEMPERATURE (DEG.FAHR.):	85.0
22	PIPE COST ($THOUSAND/MILE):	250.000
23	DEPTH OF REINJECTION WELL (FEET):	5000.
24	STORAGE TANK CAPACITY (GALLONS):	24000.
25	REAL/NOMINAL$:R; INFLATION RATE(%):	8.00
26	DRAWDOWN OF UPWELL (PERCENT):	15.00
27	INTEREST RATE (PERCENT):	12.00
28	MIN. AMBIENT TEMPERATURE (DEG.FAHR.):	-5.
29	FOSSIL FUEL COST ($/MIL. BTU):	11.54
30	BOILER COST($/100K BTU/HR):	1500.00
32	MAXIMUM FLOW RATE (GAL./MINUTE):	200.00
33	STUDY PERIOD: 20 YRS; INTERVALS OF 5 YRS	
34	MARKET SATURATION (%):	70.00
35	PCT. OF DISTRIB. SYS. BUILT THIS YEAR:	0.
36	SYSTEM SELLING PRICE ($/MIL. BTU):	14.97
37	DISCOUNT RATE (IN PERCENT):	2.00
38	TRANSPORT DISTANCE (MILES):	0.250
39	TAXES:	
40	ECONOMIC ACCOUNTING METHOD: NPV & DISC. AVG. COST	
41	RESOURCE ASSESSMENT: 0 YRS @ $THOU	0./YR
42	NUMBER OF PRODUCTION WELLS:	1
43	NUMBER OF REINJECTION WELLS:	1
44	OPER. & MAINT. COST (% OF CAPITAL):	1.00%
46	COMM. FLOORSPACE ON LINE(THOU.SQ FT):	40.
49	COST FOR COMMERCIAL HOOKUP: $	500.00
51	MKT PENETRATION:100.0%; BUILDINGS:	7.

RESULTS OF RESIDENTIAL-COMMERCIAL MODEL FOR YEAR 19

LENGTH OF DISTRIBUTION SYSTEM:	0.79 MILES
TOTAL RESIDENTIAL BTU'S (MILLIONS):	17953.73
TOTAL GEOTHERMAL BTU'S (MILLIONS):	18950.69
TOTAL SYSTEM BTU'S (MILLIONS):	19457.87
COEFFICIENT OF PERFORMANCE:	18.603
PERCENTAGE GEOTHERMAL UTILIZATION:	33.28
PERCENTAGE SERVICE GEOTHERMAL:	97.34
PUMPING ENERGY:	0.293 MILLION KWH
ANNUALIZED COSTS	(THOUSANDS OF DOLLARS):
WELL COSTS:	10.211
DISTRIBUTION SYSTEM COSTS:	6.968
HEAT EXCHANGER COSTS:	3.055
ORIGINAL PUMP COSTS:	2.545
HOOKUP COSTS:	2.955
PUMP OVERHAUL COSTS:	4.005
PUMPING COSTS:	21.784
PEAKING BOILER COSTS:	2.526
FOSSIL FUEL COSTS:	7.934
TRANSPORT COST:	3.239
STORAGE TANK COST:	1.931
OPERATION AND MAINTENANCE COSTS:	8.941
RESOURCE ASSESSMENT COSTS:	0.000
TOTAL ANNUAL WELLHEAD COSTS:	43.989
TOTAL ANNUAL SYSTEM COSTS:	76.095
WELLHEAD COST PER GEO MIL. BTU($):	2.32
SYSTEM COST PER MIL. BTU($):	3.91
REVENUE ($ THOUSANDS):	291.491
NET REVENUE ($ THOUSANDS):	215.395

*(BASE PERIOD FOR COSTS IS SPRING, 1980).

```
*** INITIAL CAPITAL COST:       894.065 THOUSAND DOLLARS      ***
*** NET PRESENT VALUE:         1508.965 THOUSAND DOLLARS      ***
*** DISCOUNTED AVERAGE COST:     7.011 DOLLARS/MILLION BTU ***
*** DISC. AVG WELLHEAD COST:     3.799 DOLLARS/MILLION BTU ***
*** BREAK-EVEN POINT ACHIEVED IN YEAR  8                    ***
```

** G R I T S **

GEOTHERMAL RESOURCE INTERACTIVE TEMPORAL SIMULATION

VERSION 6A

SAMPLE OUTPUT OF INDUSTRIAL SCENARIO

FORMULATED BY BILL BARRON

WRITTEN BY PETER KROLL

ADDITIONAL PROGRAMMING BY SUSAN MITCHELL

CENTER FOR METROPOLITAN PLANNING & RESEARCH
THE JOHNS HOPKINS UNIVERSITY
BALTIMORE, MARYLAND 21218

APRIL 1980

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GRITS:  GEOTHERMAL RESOURCE INTERACTIVE TEMPORAL SIMULATION                 27-May-80                          PAGE    1
CENTER FOR METROPOLITAN PLANNING & RESEARCH, THE JOHNS HOPKINS UNIVERSITY

                                        GRITS SAMPLE OUTPUT--INDUSTRIAL APPLICATION

     (BASE PERIOD FOR COSTS IS SPRING, 1980     )

           INDUSTRIAL SCENARIO PARAMETERS

PROGRAM OPERATING CONDITIONS
----------------------------
#  2   OUTPUT FILE NAME:                    INDUST.GRT
#  4   TITLE OF SCENARIO:  (DISPLAYED ABOVE, IF ANY)
#  5   INDUSTRIAL SERVICE CHOSEN.
#  3   DATA FILES WILL NOT BE GENERATED.

RESOURCE CONDITION PARAMETERS
-----------------------------
# 42   NUMBER OF PRODUCTION WELLS:                 1
# 12   DEPTH OF UPWELL (FEET):                  5000.
# 11   WELLHEAD WATER TEMP.(DEG. FAHR.)
          LINEAR FUNCTION USED WITH:
          1-INITIAL WATER TEMP.=     150.0
          2-ANNUAL DROP IN TEMP.=      0.0
# 21   REJECT TEMPERATURE (DEG.FAHR.):          85.0
# 23   DEPTH OF REINJECTION WELL (FEET):        5000.
# 43   NUMBER OF REINJECTION WELLS:                1
# 25   DRAWDOWN OF UPWELL (PERCENT)
          LINEAR FUNCTION USED WITH:
          INITIAL DRAWDOWN= 15.00
          ANNUAL CHANGE=     0.00
# 32   FLOW FROM WELL (GPM)
          LINEAR FUNCTION USED WITH:
          INITIAL FLOW=        200.00
          ANNUAL CHANGE=         0.00
# 38   TRANSPORT DISTANCE (MILES)  :            0.25

INDUSTRIAL DEMAND CONDITION PARAMETER
-------------------------------------
# 31   INDUSTRIAL UTILIZATION FACTOR (%):    25.00

FINANCIAL CONDITION PARAMETERS
------------------------------
# 40   ECONOMIC ACCOUNTING METHOD: 3-NPV & DISC AVG COST
# 36   SYSTEM SELLING PRICE ($/MIL. BTU):
          GEOTHERMAL SELLING PRICE IS A MULTIPLE OF:
          ELECTRICITY PRICE, FACTOR=          0.70
# 33   STUDY PERIOD: 20 YEARS; INTERVALS OF  5 YRS
# 41   RESOURCE ASSESSMENT PERIOD (YEARS):  0
       ANNUAL RESOURCE ASSESSMENT COST: $        0. THOUSAND
# 16   WELL COST ADJUSTMENT FACTOR:          1.000
       ADJ. TOT. COST OF WELLS($THOUS.):   329.159
# 17   HEAT EXCH. COST ADJUSTMENT FACTOR:    1.000
       ADJ TOT COST OF HEAT EXCHS($THOU):   34.511
# 24   STORAGE TANK CAPACITY:   2.0 HOURS OF FLOW
# 15   CAPITAL EQUIPMENT     LIFETIME IN YEARS:
         WELLS               30.(OR PROJECT LIFE)
         PIPING SYSTEM       30.(OR PROJECT LIFE)
         HEAT EXCHANGER      10.(OR PROJECT LIFE)
```

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          IN-WELL PUMPS          10.(OR PROJECT LIFE)
          STORAGE TANK           30.(OR PROJECT LIFE)
# 37    DISCOUNT RATE (PERCENT):                 2.00
# 27    INTEREST RATE (PERCENT):                12.00
# 25    COST CALCULATIONS ARE IN REAL DOLLARS
        INFLATION RATE (PERCENT):                8.00
# 39    TAXES:
# 20    COST OF ELECTRICITY (CTS/KWH)
           COMPOUNDING FUNCTION USED WITH:
            1-INITIAL ELEC. PRICE=    5.50
            2-PERCENT ANNUAL CHANGE=  1.50
# 44    OPER. & MAINT. COST (% OF CAPITAL):    1.00%

* *  COST OF INITIAL CAPITAL EQUIPMENT  * *
-------------------------------------------
WELLS:                  $     329.159 THOUSAND
HEAT EXCHANGERS:        $      34.511 THOUSAND
PUMPS:                  $      28.750 THOUSAND
TRANSPORT SYSTEM:       $     104.420 THOUSAND
STORAGE TANK:           $      62.239 THOUSAND
-------------------------------------------
* TOTAL *               $     559.079 THOUSAND
```

GRITS SAMPLE OUTPUT--INDUSTRIAL APPLICATION

```
          INDUSTRIAL SCENARIO IN YEAR  0
-----------------------------------------------------------
OPTION                                           VALUE
-----------------------------------------------------------
   10   AREA UNDER CONSIDERATION:          SALISBURY,MD
   11   WELLHEAD WATER TEMP.(DEG. FAHR.):       150.0
   12   DEPTH OF UPWELL (FEET):                  5000.

   15   CAPITAL EQUIPMENT    LIFETIME IN YEARS:
          WELLS               30.(OR PROJECT LIFE)
          PIPING SYSTEM       30.(OR PROJECT LIFE)
          HEAT EXCHANGER      10.(OR PROJECT LIFE)
          IN-WELL PUMPS       10.(OR PROJECT LIFE)
          STORAGE TANK        30.(OR PROJECT LIFE)
   16   WELL COST ADJUSTMENT FACTOR:            1.000
   17   HEAT EXCH. COST ADJUSTMENT FACTOR:      1.000


   20   COST OF ELECTRICITY (CTS/KWH):          5.500
   21   REJECT TEMPERATURE (DEG.FAHR.):          85.0
   23   DEPTH OF REINJECTION WELL (FEET):        5000.
   24   STORAGE TANK CAPACITY (GALLONS):        24000.
   25   REAL/NOMINAL$R;  INFLATION RATE(%):     9.00
   26   DRAWDOWN OF UPWELL (PERCENT):           15.00
   27   INTEREST RATE (PERCENT):                12.00
   31   INDUSTRIAL UTILIZATION FACTOR (%):      25.00
   32   MAXIMUM FLOW RATE (GAL./MINUTE):       200.00
   33   STUDY PERIOD: 20 YRS; INTERVALS OF   5 YRS
   36   SYSTEM SELLING PRICE ($/MIL. BTU):      11.28
   37   DISCOUNT RATE (IN PERCENT):              2.00
   38   TRANSPORT DISTANCE (MILES):             0.250
   39   TAXES:
   40   ECONOMIC ACCOUNTING METHOD: NPV & DISC. AVG. COST
   41   RESOURCE ASSESSMENT: 0 YRS.@ $THOU       0./YR
   42   NUMBER OF PRODUCTION WELLS:                 1
   43   NUMBER OF REINJECTION WELLS:                1
   44   OPER. & MAINT. COST (% OF CAPITAL):     1.00%
```

```
      RESULTS OF INDUSTRIAL MODEL FOR YEAR  0
----------------------------------------------------------

----------------------------------------------------------
TOTAL GEOTHERMAL BTU'S (MILLIONS):       14235.00
PUMPING ENERGY:                      0.224 MILLION KWH
COEFFICIENT OF PERFORMANCE:                18.608
ANNUALIZED COSTS          (THOUSANDS OF DOLLARS):
  WELL COSTS:                          44.057
  HEAT EXCHANGER COSTS:                 6.103
  ORIGINAL PUMP COSTS:                  5.038
  PUMP OVERHAUL COSTS:                  4.005
  ANNUAL PUMPING COSTS:                12.331
  TRANSPORT COSTS:                     13.930
  STORAGE TANK COSTS:                   8.333
  OPERATION AND MAINTENANCE COSTS:      5.591
  RESOURCE ASSESSMENT COSTS:            0.000
  ----------------------------------------------
  TOTAL ANNUAL WELLHEAD COSTS:         74.095
  TOTAL ANNUAL SYSTEM COSTS:           99.502


 WELLHEAD COST PER GEO MIL. BTU($):     5.21
  SYSTEM COST PER MIL. BTU($):          6.99

  REVENUE ($ THOUSANDS):              160.624
  NET REVENUE ($ THOUSANDS):           61.121


 *(BASE PERIOD FOR COSTS IS SPRING, 1980    )
```

*** BREAK-EVEN POINT ACHIEVED IN THIS YEAR ***

GRITS SAMPLE OUTPUT--INDUSTRIAL APPLICATION

INDUSTRIAL SCENARIO IN YEAR 5

OPTION		VALUE
10	AREA UNDER CONSIDERATION:	SALISBURY,MD
11	WELLHEAD WATER TEMP.(DEG. FAHR.):	150.0
12	DEPTH OF UPWELL (FEET):	5000.
15	CAPITAL EQUIPMENT LIFETIME IN YEARS:	
	WELLS	30.(OR PROJECT LIFE)
	PIPING SYSTEM	30.(OR PROJECT LIFE)
	HEAT EXCHANGER	10.(OR PROJECT LIFE)
	IN-WELL PUMPS	10.(OR PROJECT LIFE)
	STORAGE TANK	30.(OR PROJECT LIFE)
16	WELL COST ADJUSTMENT FACTOR:	1.000
17	HEAT EXCH. COST ADJUSTMENT FACTOR:	1.000
20	COST OF ELECTRICITY (CTS/KWH):	5.925
21	REJECT TEMPERATURE (DEG.FAHR.):	85.0
23	DEPTH OF REINJECTION WELL (FEET):	5000.
24	STORAGE TANK CAPACITY (GALLONS):	24000.
25	REAL/NOMINAL$R; INFLATION RATE(%):	8.00
26	DRAWDOWN OF UPWELL (PERCENT):	15.00
27	INTEREST RATE (PERCENT):	12.00
31	INDUSTRIAL UTILIZATION FACTOR (%):	25.00
32	MAXIMUM FLOW RATE (GAL./MINUTE):	200.00
33	STUDY PERIOD: 20 YRS; INTERVALS OF	5 YRS
35	SYSTEM SELLING PRICE ($/MIL. BTU):	12.15
37	DISCOUNT RATE (IN PERCENT):	2.00
38	TRANSPORT DISTANCE (MILES):	0.250
39	TAXES:	
40	ECONOMIC ACCOUNTING METHOD: NPV & DISC. AVG. COST	
41	RESOURCE ASSESSMENT: 0 YRS @ $THOU	0./YR
42	NUMBER OF PRODUCTION WELLS:	1
43	NUMBER OF REINJECTION WELLS:	1
44	OPER. & MAINT. COST (% OF CAPITAL):	1.00%

RESULTS OF INDUSTRIAL MODEL FOR YEAR 5

TOTAL GEOTHERMAL BTU'S (MILLIONS):	14235.00
PUMPING ENERGY:	0.224 MILLION KWH
COEFFICIENT OF PERFORMANCE:	13.603
ANNUALIZED COSTS (THOUSANDS OF DOLLARS):	
WELL COSTS:	29.992
HEAT EXCHANGER COSTS:	4.157
ORIGINAL PUMP COSTS:	3.453
PUMP OVERHAUL COSTS:	4.005
ANNUAL PUMPING COSTS:	13.284
TRANSPORT COSTS:	9.514
STORAGE TANK COSTS:	5.671
OPERATION AND MAINTENANCE COSTS:	5.591
RESOURCE ASSESSMENT COSTS:	0.000
TOTAL ANNUAL WELLHEAD COSTS:	57.585
TOTAL ANNUAL SYSTEM COSTS:	75.676
WELLHEAD COST PER GEO MIL. BTU($):	4.05
SYSTEM COST PER MIL. BTU($):	5.32
REVENUE ($ THOUSANDS):	173.037
NET REVENUE ($ THOUSANDS):	97.361

*(BASE PERIOD FOR COSTS IS SPRING, 1980)

GRITS SAMPLE OUTPUT--INDUSTRIAL APPLICATION

INDUSTRIAL SCENARIO IN YEAR 10

OPTION		VALUE
10	AREA UNDER CONSIDERATION:	SALISBURY,MD
11	WELLHEAD WATER TEMP.(DEG. FAHR.):	150.0
12	DEPTH OF UPWELL (FEET):	5000.
15	CAPITAL EQUIPMENT	LIFETIME IN YEARS:
	WELLS	30.(OR PROJECT LIFE)
	PIPING SYSTEM	30.(OR PROJECT LIFE)
	HEAT EXCHANGER	10.(OR PROJECT LIFE)
	IN-WELL PUMPS	10.(OR PROJECT LIFE)
	STORAGE TANK	30.(OR PROJECT LIFE)
16	WELL COST ADJUSTMENT FACTOR:	1.000
17	HEAT EXCH. COST ADJUSTMENT FACTOR:	1.000
20	COST OF ELECTRICITY (CTS/KWH):	6.333
21	REJECT TEMPERATURE (DEG.FAHR.):	85.0
23	DEPTH OF REINJECTION WELL (FEET):	5000.
24	STORAGE TANK CAPACITY (GALLONS):	24000.
25	REAL/NOMINAL$R; INFLATION RATE(%):	3.00
26	DRAWDOWN OF UPWELL (PERCENT):	15.00
27	INTEREST RATE (PERCENT):	12.00
31	INDUSTRIAL UTILIZATION FACTOR (%):	25.00
32	MAXIMUM FLOW RATE (GAL./MINUTE):	200.00
33	STUDY PERIOD: 20 YRS; INTERVALS OF	5 YRS
35	SYSTEM SELLING PRICE ($/MIL. BTU):	13.10
37	DISCOUNT RATE (IN PERCENT):	2.00
38	TRANSPORT DISTANCE (MILES):	0.250
39	TAXES:	
40	ECONOMIC ACCOUNTING METHOD: NPV & DISC. AVG. COST	
41	RESOURCE ASSESSMENT: 0 YRS @ $THOU	0./YR
42	NUMBER OF PRODUCTION WELLS:	1
43	NUMBER OF REINJECTION WELLS:	1
44	OPER. & MAINT. COST (% OF CAPITAL):	1.00%

RESULTS OF INDUSTRIAL MODEL FOR YEAR 10

TOTAL GEOTHERMAL BTU'S (MILLIONS):	14235.00
PUMPING ENERGY:	0.224 MILLION KWH
COEFFICIENT OF PERFORMANCE:	18.608
ANNUALIZED COSTS	(THOUSANDS OF DOLLARS):
WELL COSTS:	20.412
HEAT EXCHANGER COSTS:	6.108
ORIGINAL PUMP COSTS:	5.083
PUMP OVERHAUL COSTS:	4.005
ANNUAL PUMPING COSTS:	14.311
TRANSPORT COSTS:	6.475
STORAGE TANK COSTS:	3.850
OPERATION AND MAINTENANCE COSTS:	5.591
RESOURCE ASSESSMENT COSTS:	0.000
TOTAL ANNUAL WELLHEAD COSTS:	52.320
TOTAL ANNUAL SYSTEM COSTS:	55.849
WELLHEAD COST PER GEO MIL. BTU($):	3.68
SYSTEM COST PER MIL. BTU($):	4.63
REVENUE ($ THOUSANDS):	186.410
NET REVENUE ($ THOUSANDS):	120.561

*(BASE PERIOD FOR COSTS IS SPRING, 1980)

THE JOHNS HOPKINS UNIVERSITY
APPLIED PHYSICS LABORATORY
LAUREL, MARYLAND

GRITS SAMPLE OUTPUT--INDUSTRIAL APPLICATION

INDUSTRIAL SCENARIO IN YEAR 15

OPTION		VALUE
10	AREA UNDER CONSIDERATION:	SALISBURY,MD
11	WELLHEAD WATER TEMP.(DEG. FAHR.):	150.0
12	DEPTH OF UPWELL (FEET):	5000.
15	CAPITAL EQUIPMENT LIFETIME IN YEARS:	
	WELLS	30.(OR PROJECT LIFE)
	PIPING SYSTEM	30.(OR PROJECT LIFE)
	HEAT EXCHANGER	10.(OR PROJECT LIFE)
	IN-WELL PUMPS	10.(OR PROJECT LIFE)
	STORAGE TANK	30.(OR PROJECT LIFE)
16	WELL COST ADJUSTMENT FACTOR:	1.000
17	HEAT EXCH. COST ADJUSTMENT FACTOR:	1.000
20	COST OF ELECTRICITY (CTS/KWH):	5.875
21	REJECT TEMPERATURE (DEG.FAHR.):	85.0
23	DEPTH OF REINJECTION WELL (FEET):	5000.
24	STORAGE TANK CAPACITY (GALLONS):	24000.
25	REAL/NOMINAL$R; INFLATION RATE(%):	8.00
26	DRAWDOWN OF UPWELL (PERCENT):	15.00
27	INTEREST RATE (PERCENT):	12.00
31	INDUSTRIAL UTILIZATION FACTOR (%):	25.00
32	MAXIMUM FLOW RATE (GAL./MINUTE):	200.00
33	STUDY PERIOD: 20 YRS; INTERVALS OF	5 YRS
35	SYSTEM SELLING PRICE ($/MIL. BTU):	14.11
37	DISCOUNT RATE (IN PERCENT):	2.00
38	TRANSPORT DISTANCE (MILES):	0.250
39	TAXES:	
40	ECONOMIC ACCOUNTING METHOD: NPV & DISC. AVG. COST	
41	RESOURCE ASSESSMENT: 0 YRS @ $THOU	0./YR
42	NUMBER OF PRODUCTION WELLS:	1
43	NUMBER OF REINJECTION WELLS:	1
44	OPER. & MAINT. COST (% OF CAPITAL):	1.00%

RESULTS OF INDUSTRIAL MODEL FOR YEAR 15

TOTAL GEOTHERMAL BTU'S (MILLIONS):	14235.00
PUMPING ENERGY:	0.224 MILLION KWH
COEFFICIENT OF PERFORMANCE:	18.608
ANNUALIZED COSTS (THOUSANDS OF DOLLARS):	
WELL COSTS:	13.892
HEAT EXCHANGER COSTS:	4.157
ORIGINAL PUMP COSTS:	3.453
PUMP OVERHAUL COSTS:	4.005
ANNUAL PUMPING COSTS:	15.417
TRANSPORT COSTS:	4.407
STORAGE TANK COSTS:	2.627
OPERATION AND MAINTENANCE COSTS:	5.591
RESOURCE ASSESSMENT COSTS:	0.000
TOTAL ANNUAL WELLHEAD COSTS:	43.511
TOTAL ANNUAL SYSTEM COSTS:	53.558
WELLHEAD COST PER GEO MIL. BTU($):	3.06
SYSTEM COST PER MIL. BTU($):	3.76
REVENUE ($ THOUSANDS):	200.817
NET REVENUE ($ THOUSANDS):	147.259

*(BASE PERIOD FOR COSTS IS SPRING, 1980)

GRITS SAMPLE OUTPUT--INDUSTRIAL APPLICATION

```
              INDUSTRIAL SCENARIO IN YEAR 19
-----------------------------------------------------
OPTION                                          VALUE
-----------------------------------------------------
  10   AREA UNDER CONSIDERATION:       SALISBURY,MD
  11   WELLHEAD WATER TEMP.(DEG. FAHR.):      150.0
  12   DEPTH OF UPWELL (FEET):                5000.

  15   CAPITAL EQUIPMENT   LIFETIME IN YEARS:
         WELLS             30.(OR PROJECT LIFE)
         PIPING SYSTEM     30.(OR PROJECT LIFE)
         HEAT EXCHANGER    10.(OR PROJECT LIFE)
         IN-WELL PUMPS     10.(OR PROJECT LIFE)
         STORAGE TANK      30.(OR PROJECT LIFE)
  16   WELL COST ADJUSTMENT FACTOR:           1.000
  17   HEAT EXCH. COST ADJUSTMENT FACTOR:     1.000

  20   COST OF ELECTRICITY (CTS/KWH):         7.298
  21   REJECT TEMPERATURE (DEG.FAHR.):         85.0
  23   DEPTH OF REINJECTION WELL (FEET):      5000.
  24   STORAGE TANK CAPACITY (GALLONS):      24000.
  25   REAL/NOMINAL$R; INFLATION RATE(%):     8.00
  26   DRAWDOWN OF UPWELL (PERCENT):          15.00
  27   INTEREST RATE (PERCENT):               12.00
  31   INDUSTRIAL UTILIZATION FACTOR (%):     25.00
  32   MAXIMUM FLOW RATE (GAL./MINUTE):      200.00
  33   STUDY PERIOD: 20 YRS; INTERVALS OF  5 YRS
  35   SYSTEM SELLING PRICE ($/MIL. BTU):    14.97
  37   DISCOUNT RATE (IN PERCENT):             2.00
  38   TRANSPORT DISTANCE (MILES):            0.250
  39   TAXES:
  40   ECONOMIC ACCOUNTING METHOD: NPV & DISC. AVG. COST
  41   RESOURCE ASSESSMENT: 0 YRS @ $THOU      0./YR
  42   NUMBER OF PRODUCTION WELLS:               1
  43   NUMBER OF REINJECTION WELLS:              1
  44   OPER. & MAINT. COST (% OF CAPITAL):    1.00%
```

```
        RESULTS OF INDUSTRIAL MODEL FOR YEAR 19
-----------------------------------------------------
-----------------------------------------------------
TOTAL GEOTHERMAL BTU'S (MILLIONS):      14235.00
PUMPING ENERGY:                    0.224 MILLION KWH
COEFFICIENT OF PERFORMANCE:               18.609
ANNUALIZED COSTS         (THOUSANDS OF DOLLARS):
  WELL COSTS:                            10.211
  HEAT EXCHANGER COSTS:                   3.055
  ORIGINAL PUMP COSTS:                    2.545
  PUMP OVERHAUL COSTS:                    4.005
  ANNUAL PUMPING COSTS:                  16.363
  TRANSPORT COSTS:                        3.239
  STORAGE TANK COSTS:                     1.931
  OPERATION AND MAINTENANCE COSTS:        5.591
  RESOURCE ASSESSMENT COSTS:              0.000
  ---------------------------------------------
  TOTAL ANNUAL WELLHEAD COSTS:           33.843
  TOTAL ANNUAL SYSTEM COSTS:             46.940


 WELLHEAD COST PER GEO MIL. BTU($):       2.73
  SYSTEM COST PER MIL. BTU($):            3.30

  REVENUE ($ THOUSANDS):                213.140
  NET REVENUE ($ THOUSANDS):            155.199


*(BASE PERIOD FOR COSTS IS SPRING, 1980    )
```

```
*** INITIAL CAPITAL COST:       559.079 THOUSAND DOLLARS     ***
*** NET PRESENT VALUE:         1901.712 THOUSAND DOLLARS     ***
*** DISCOUNTED AVERAGE COST:     4.914 DOLLARS/MILLION BTU   ***
*** DISC. AVG WELLHEAD COST:     3.820 DOLLARS/MILLION BTU   ***
*** BREAK-EVEN POINT ACHIEVED IN YEAR  0                     ***
```

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