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User Manual for Geocity: A Computer Model for Geothermal District Heating Cost Analysis

H. D. Huber
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October 1978

Prepared for the U.S. Department of Energy
under Contract EY-76-C-06-1830

Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute

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ABSTRACT

A computer model called GEOCITY has been developed by Battelle, at the Pacific Northwest Laboratory, to systematically calculate the potential cost of district heating using hydrothermal geothermal resources. GEOCITY combines climate, demographic factors, and heat demand of the city, resource conditions, well drilling costs, design of the distribution system, tax rates, and financial factors into one systematic model. The GEOCITY program provides the flexibility to individually or collectively evaluate the impact of different economic and technical parameters, assumptions, and uncertainties on the cost of providing district heat from a geothermal resource. Both the geothermal reservoir and distribution system are simulated to model the complete district heating system.

GEOCITY consists of two major parts: the geothermal reservoir submodel and the distribution submodel. The reservoir submodel calculates the unit cost of energy by simulating the exploration, development, and operation of a geothermal reservoir and the transmission of this energy to a distribution center. The distribution submodel calculates the unit cost of heat by simulating the design and operation of a district heating distribution system.

GEOCITY calculates the unit cost of energy and the unit cost of heat for the district heating system based on the principle that the present worth of the revenues will be equal to the present worth of the expenses including investment return over the economic life of the distribution system.

CONTENTS

FIGURES

TABLES

USER MANUAL FOR GEOCITY: A COMPUTER MODEL FOR GEOTHERMAL DISTRICT HEATING COST ANALYSIS

INTRODUCTION

In a research program sponsored by the United States Energy Research and Development Administration,[a] the Pacific Northwest Laboratory (PNL)[b] developed a computer simulation model for geothermal district heating cost analysis called GEOCITY. The GEOCITY program simulates the entire production, distribution, and waste disposal process for geothermal district heating systems, but does not include the cost of radiators, convectors, or other in-house heating systems. GEOCITY calculates the cost of district heating based on the climate, population, and heat demand of the city, geothermal resource characteristics and distance from the distribution center, well drilling costs, design of the distribution system, and financial and tax conditions.

GEOCITY is composed of two principal parts: the geothermal reservoir submodel and the distribution system submodel. The reservoir submodel calculates the cost of energy by simulating the exploration, development and operation of a hydrothermal reservoir from the beginning of exploration through the economic life of the distribution system. The reservoir submodel also simulates the transmission of the geothermal water through a fluid transmission system to the distribution center and the disposal of the used water from the distribution system. GEOCITY calculates the unit cost of energy based on the principle that the present worth of the revenues will be equal to the present worth of the expenses including investment return over the economic life of the distribution system. The present worth factor is determined by the capital structure and rates on invested capital for the reservoir.

(a) The Energy Research and Development Administration was assimilated into the U.S. Department of Energy on June 1, 1977.

(b) Pacific Northwest Laboratory is operated for the Department of Energy by Battelle Memorial Institute.

The distribution submodel calculates the cost of heat by simulating the design and the operation of the district heating distribution system. The distribution submodel can simulate many designs for hot water heating systems. These distribution designs include an optional heat exchanger at the inlet to the distribution center and various material and configuration options for pipes, conduits, and insulation. Using discounted cash flow analysis, GEOCITY calculates the unit cost of heat from the distribution system by equating the present worth of the revenues to the present worth of the expenses including investment return over the economic life of the distribution system. The present worth factor is determined by the capital structure and rates of return on invested capital for the distribution system.

GEOCITY can simulate nearly any financial and tax structure through varying the rates of return on equity and debt, the debt-equity ratios, and tax rates. Both private enterprise and municipal utility systems can be simulated. The reservoir submodel and the distribution submodel may have the same or differing financial structures and costs of capital.

GEOCITY is programmed in FORTRAN IV and is operational on the Control Data Cyber 73 computer with Scope 3.4.4 operating system. The source code of GEOCITY and the 1967 ASME Steam Tables[1,2] used to calculate thermodynamic and physical properties of water are available from the Argonne Code Center on one reel of magnetic tape. The tape recording mode is optional: 7-track, 556 BPI, even parity, and BCD code; or 9-track, 800 BPI, odd parity, and EBCDIC code.

In addition to this user manual, two earlier publications[3,4] have described theoretical concepts and applications of the GEOCITY code to simulating geothermal district heating systems. To aid potential users of the code, a sample case simulating a simplified version of the district heating system for Akureyri, Iceland, is illustrated in this user manual.

2. DESCRIPTION OF PROGRAM

2.1 GENERAL PROGRAM DESIGN

GEOCITY is designed in modular fashion, with 65 technical and economic subroutines. In addition to the standard FORTRAN library functions, 63 subroutines comprising the 1967 ASME Steam Tables are used to calculate thermodynamic and physical properties of water, including pressure, temperature, enthalpy, specific volume, density, viscosity and fluid quality. GEOCITY and the steam tables contain approximately 8000 and 4000 FORTRAN statements respectively. The entire program requires approximately 54,000 decimal words of computer memory for execution.

The block diagram in Figure 1 shows an overview of the economic model used in GEOCITY to represent a geothermal district heating system. Figure 2 shows the computational flow through the major submodels of GEOCITY. Figure 3 shows the detailed, logical layout of the subroutines in each major submodel and serves as the basis for the operational description of the major sequence of calculations in GEOCITY.

The major submodels and their associated subroutines in GEOCITY are discussed in Sections 2.2 through 2.8 in the order of their execution in the computer code. The code user may find referring to Figure 3 helpful in reading the following descriptions of the submodels and their subroutines. The submodels are as follows:

- Executive Program and Data Input
- Control Routine for Distribution System and Fluid Transmission
- Fluid Transmission and Disposal (Injection)
- Heat Exchanger
- Distribution System
- Reservoir Economics
- Distribution Economics

The steam table functions are called from many subroutines in GEOCITY, but are not shown in Figure 3 for the sake of brevity. These functions are summarized in Section 2.9 following the descriptions of the submodels and their subroutines.

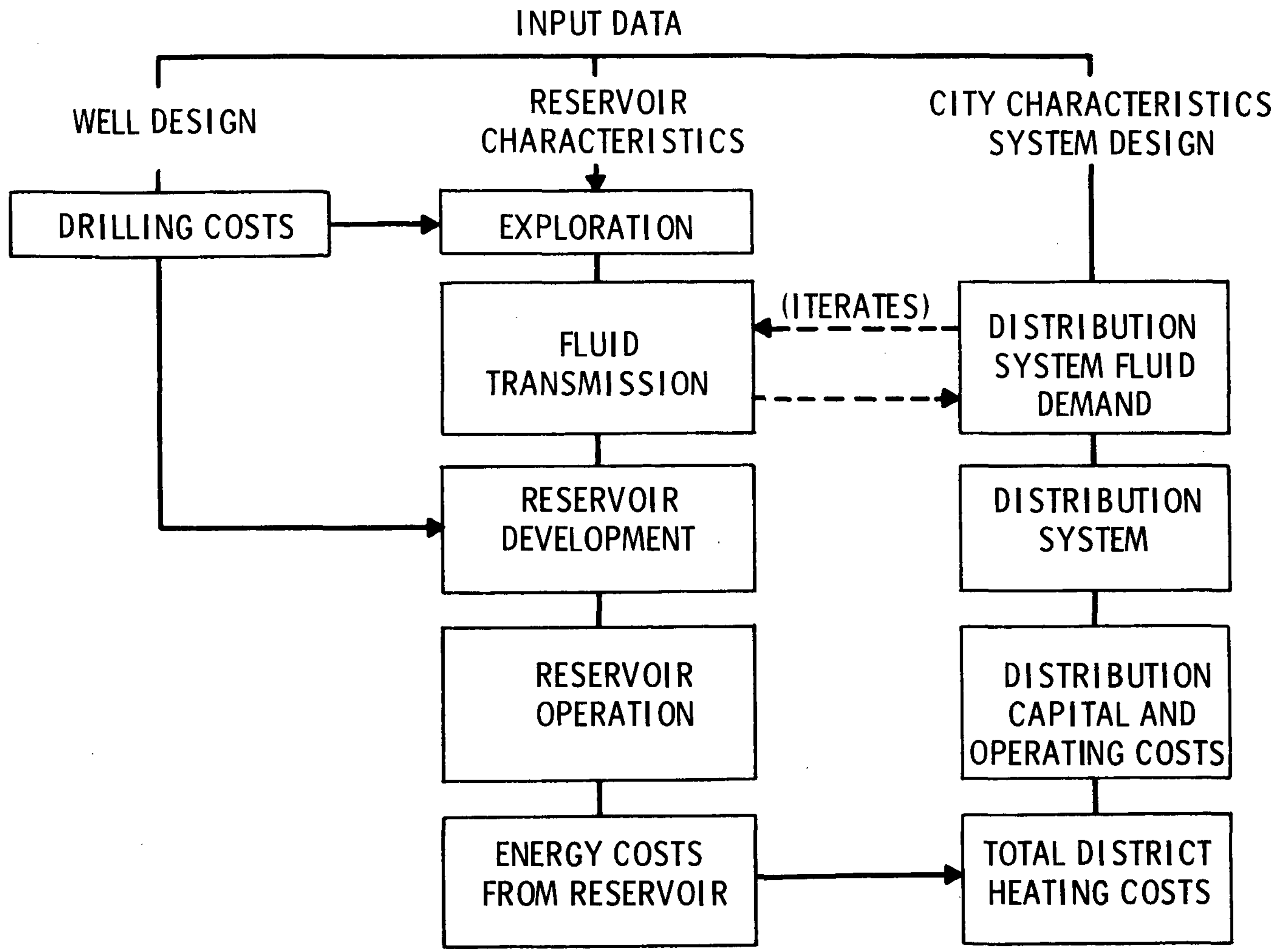


FIGURE 1. Economic Model for Geothermal District Heating Systems

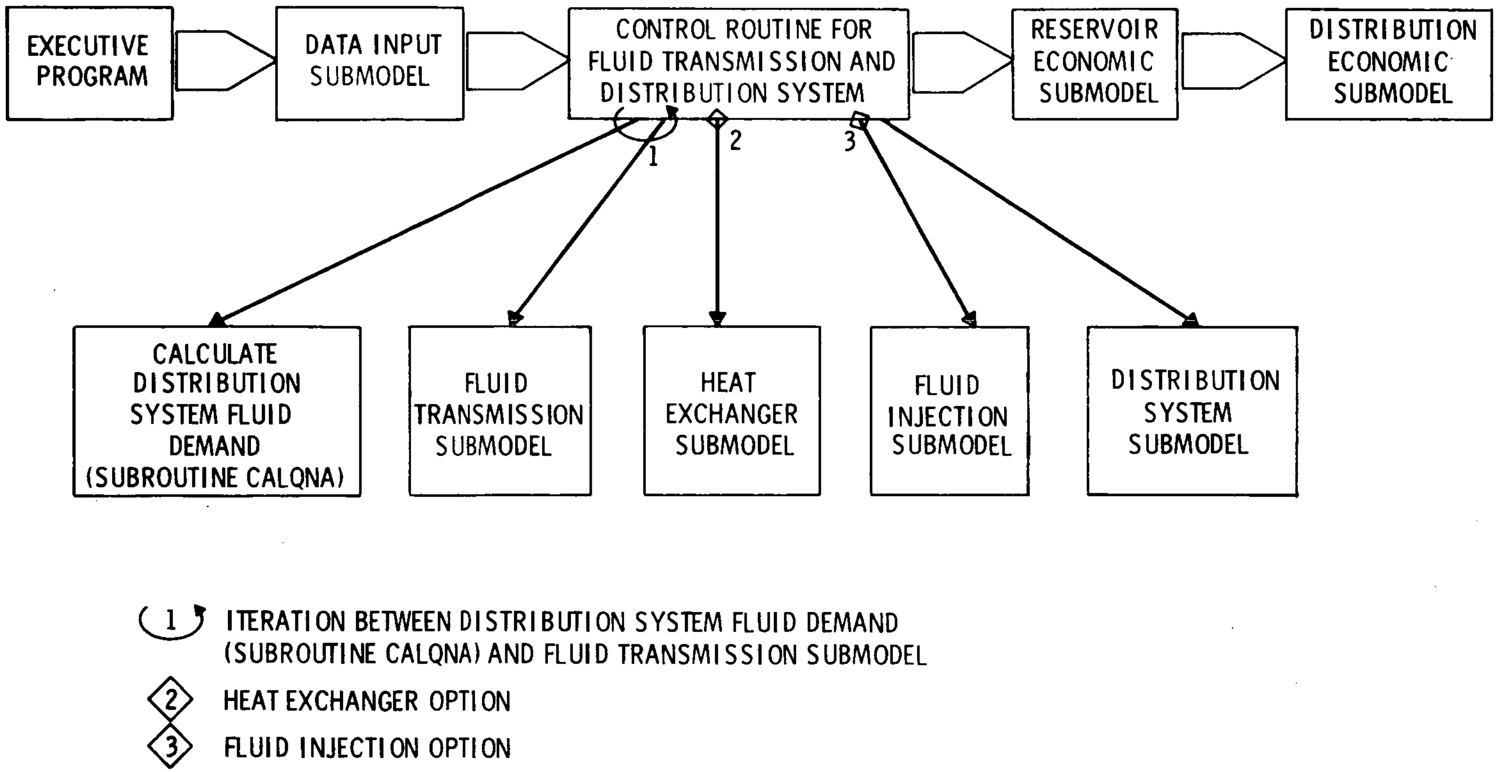


FIGURE 2. Computational Flow Through the Major Submodels of GEOCITY

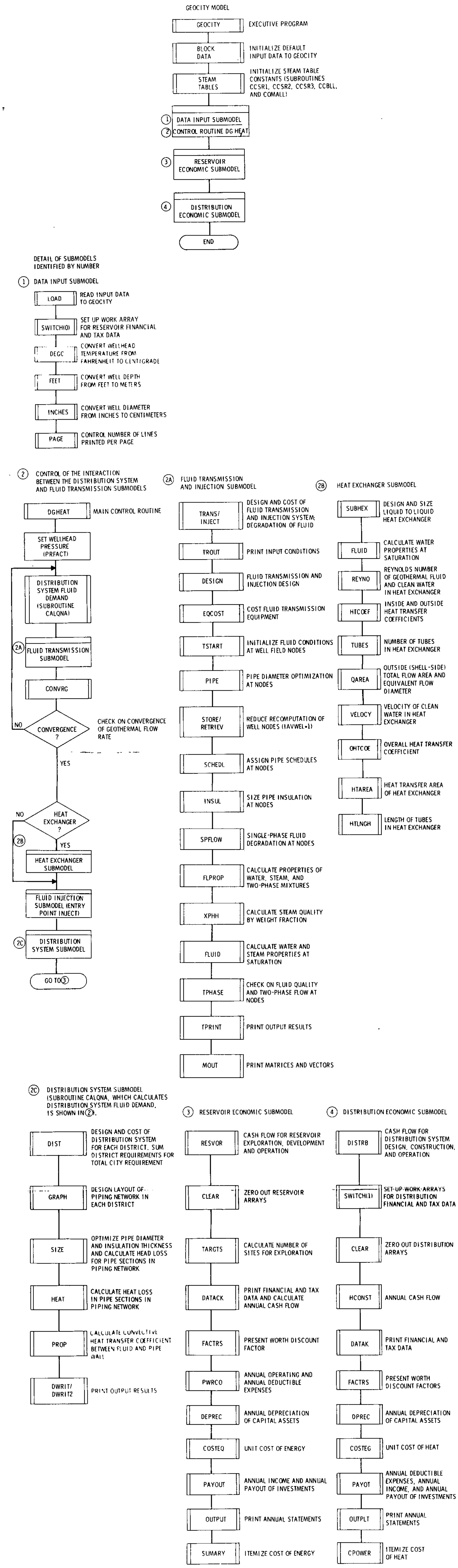


FIGURE 3. Flowchart for GEOCITY

2.2 EXECUTIVE PROGRAM AND DATA INPUT SUBMODEL

The executive program GEOCITY controls the sequence of processing by the major submodels to simulate the technical and economic components of the geothermal district heating model. This includes the data input; fluid transmission and disposal; distribution system for the city; cash flow for the reservoir exploration, development, and operation; and cash flow for the distribution system design, construction, and operation. GEOCITY calls the data input submodel simulated by subroutine LOAD and its associated subroutines to set up the initialization and read the technical and economic input data. This includes the reservoir characteristics, wellhead conditions of the geothermal fluid, well field layout, fluid transmission and disposal parameters, drilling costs, distribution system design for the city, and financial and tax data for the reservoir and distribution system. Each subroutine associated with the executive program and with the data input submodel is described in the order of its execution in the program (Figure 3).

GEOCITY	Controls the sequence of calculations by the major submodels.
BLOCK DATA	Initializes representative values for the input data when the program is loaded into computer memory.
CCSR1, CCSR2 CCSR3, CCBLL, and COMALL	Initialize steam constants required in calculations by the steam table functions.
LOAD	Reads the input data using NAMELIST to override the default values initialized in BLOCK DATA; sets up initial values for the GEOCITY variables; and prints the input data defining reservoir characteristics and well properties. Subroutine LOAD also calls subroutine DGHEAT to execute the distribution system fluid demand, fluid transmission, heat exchanger (optional), fluid disposal (optional), and distribution system submodels.
SWITCH(0)	Stores the first 35 values of the DINPUT array defining input reservoir financial and tax data into an internal work array, D(N), N = 1,...,35. SWITCH(1) stores the

SWITCH(0) (Contd)	second set of 35 values of the DINPUT array, DINPUT(N), N = 36,...,70, defining input distribution system financial and tax data into the same work array, D(N), N = 1,...,35. The common work array has similar definitions for the reservoir and distribution system, although the individual elements transferred from the first and second set of 35 values in the DINPUT array can have different numerical values.
DEGC	Returns Centigrade temperature expressed as a positive number when Fahrenheit temperature is input as a negative number. Centigrade temperature input as a positive number is returned unchanged. The input parameter which can use this option is the wellhead temperature PWTEMP.
FEET	Returns meters expressed as a positive number when feet are input as a negative number. Meters input as a positive number are returned unchanged. The input parameter which can use this option is the well depth STRATA (2,1).
INCHES	Returns centimeters expressed as a positive number when inches are input as a negative number. Centimeters input as a positive number are returned unchanged. The input parameter which can use this option is the well diameter DIA.
PAGE	Controls the number of lines printed per page, prints an input title at the top of the page, and numbers pages when called from various subroutines.

2.3 CONTROL ROUTINE (SUBROUTINE DGHEAT) FOR DISTRIBUTION SYSTEM AND FLUID TRANSMISSION SUBMODELS

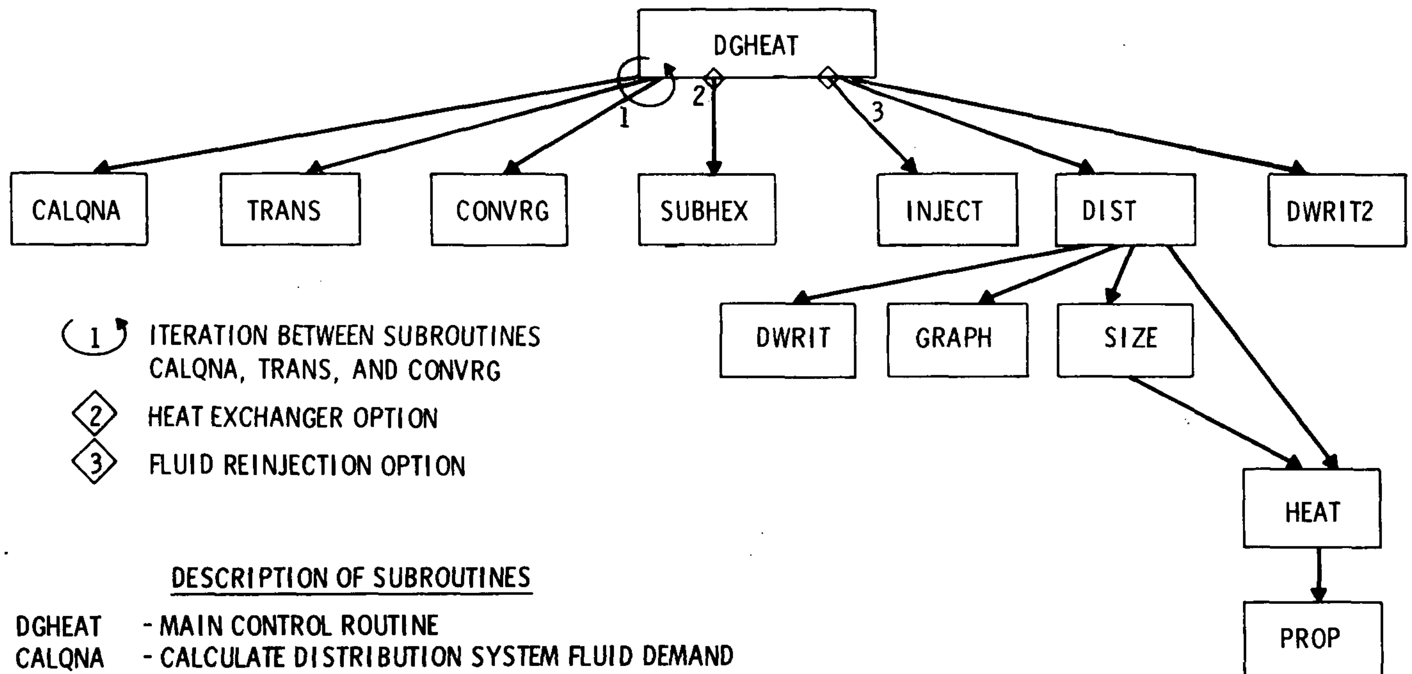
Subroutine LOAD calls subroutine DGHEAT to set the wellhead fluid pressure and to control the interaction between the distribution system submodel and the fluid transmission submodel. Subroutine DGHEAT sets the wellhead fluid pressure at or above saturation by multiplying the saturation pressure corresponding to the input wellhead temperature PWTEMP by the pressurization factor PRFACT ($\geq$ 1.), specified by the user in the input data.

The fluid pressure is thereafter continuously maintained at or above saturation (compressed liquid state) to prevent flashing and two-phase flow in the fluid transmission lines through the use of booster pumps simulated in the fluid transmission submodel (subroutine TRANS).

The block diagram in Figure 4 shows the design structure and time-order sequence of execution of the subroutines called by DGHEAT. For the purpose of simplifying the diagram, only subroutine DIST is expanded below the first level of detail in Figure 4 to show the subroutines it calls in simulating the distribution system submodel.

Subroutine DGHEAT initiates and controls the interaction between the distribution system demand subroutine CALQNA and fluid transmission submodel. Subroutine DGHEAT calls subroutine CALQNA to initially calculate the distribution system's geothermal fluid flow requirements from the reservoir using wellhead conditions. Based upon total flow requirements, the fluid transmission submodel simulated by subroutine TRANS and its associated subroutines is called to calculate the number of required wells, well field layout, pipe lengths and diameters, pumping requirements, costs of the transmission piping system pumps, and associated equipment, and temperature and enthalpy drop (fluid degradation) between the reservoir and distribution center. Subroutine DGHEAT controls the iteration between the distribution system demand subroutine CALQNA, which calculates the increased geothermal fluid flow rate required for the distribution system under the degraded fluid conditions, and the fluid transmission submodel, which provides the increased flow requirements by adding wells and determining the new temperature and enthalpy drop.

Subroutine DGHEAT calls subroutine CONVRG to test the iteration between the distribution system demand subroutine and fluid transmission submodel for convergence of geothermal flow rate. Subroutine CONVRG compares the total geothermal flow requirements computed for the distribution system, based upon the degraded temperature and enthalpy delivered by the fluid transmission submodel in the current iteration, with the total flow requirement calculated in the previous iteration. The convergence criterion requires that the new flow requirement computed for the distribution system



<u>DESCRIPTION OF SUBROUTINES</u>

DGHEAT	- MAIN CONTROL ROUTINE
CALQNA	- CALCULATE DISTRIBUTION SYSTEM FLUID DEMAND
TRANS	- FLUID TRANSMISSION
CONVRG	- FLUID CONVERGENCE TEST
SUBHEX	- HEAT EXCHANGER (OPTIONAL)
INJECT	- FLUID REINJECTION (OPTIONAL)
DIST	- DISTRIBUTION SYSTEM
DWRIT	- DISTRIBUTION SYSTEM PRINTOUT
GRAPH	- DISTRIBUTION PIPING LAYOUT
SIZE	- DISTRIBUTION PIPE AND INSULATION SIZE
HEAT	- DISTRIBUTION PIPING HEAT LOSS
PROP	- CONVECTIVE HEAT-TRANSFER COEFFICIENT
DWRIT2	- DISTRIBUTION SYSTEM PRINTOUT

FIGURE 4. Time-Order Sequence of Subroutines Called by Subroutine DGHEAT

differ by less than 2% from the flow requirement computed in the previous iteration. After satisfying the convergence criterion, the distribution system demand subroutine and fluid transmission submodel are executed one more time at the control of subroutine DGHEAT. This provides flexibility to satisfy the input options of printing the final iteration only or printing the entire interation history. Failure to converge within a maximum limit of 10 iterations results in an abnormal termination and printout of an appropriate error message.

After convergence, subroutine DGHEAT checks the heat exchanger option and calls the heat exchanger submodel if this option is simulated. This option is provided in case the temperature of the geothermal fluid needs to be reduced or the fluid's chemical composition makes it undesirable for direct use in the district heating distribution system. Heat is transferred from the geothermal fluid in the reservoir to circulating clean water for use in the district heating distribution system.

Subroutine DGHEAT next checks the fluid reinjection option and calls the fluid injection submodel if this option is simulated. The fluid injection submodel, beginning with the entry point INJECT in subroutine TRANS, calculates the number of injection wells, injection well field layout, injection pipe diameters and lengths, and costs of the injection piping system and associated equipment. The fluid is reinjected from either the district heating distribution system or the heat exchanger at the end of the fluid transmission line if the heat exchanger option is simulated. If the fluid reinjection option is not simulated, the fluid is assumed to be disposed into a sewer system or river.

Finally, the subroutine DGHEAT calls the distribution system submodel to simulate the design, construction, and operation of the district heating distribution system for the city. The computational flow in the program then returns to subroutine LOAD and the executive program GEOCITY to simulate the reservoir economic submodel and distribution economic submodel.

2.4 FLUID TRANSMISSION AND DISPOSAL (INJECTION) SUBMODEL

Based upon the total flow requirements calculated by the distribution system demand subroutine CALQNA, subroutine TRANS calls the subroutines described below to simulate the fluid transmission submodel. The fluid transmission submodel calculates the following quantities: number of producing wells required, the well field layout, pipeline lengths, optimum pipeline diameters, pipe schedules, pipe insulation, pumping requirements, fluid degradation during conduction from the wellhead to the distribution center, and cost of the pipes, insulation, pumps, valves, and associated equipment. The degradation of the geothermal fluid (temperature, pressure, enthalpy, viscosity, and density) is modeled on a nodal basis during conduction in a compressed liquid state.

Subroutine INJECT, coded as an entry point in subroutine TRANS, performs analogous functions for fluid injection (disposal) by simulating the conduction of the fluid effluent from the city distribution system or the heat exchanger to the injection well field. It calculates the number of injection wells required, injection well field layout, effluent pipeline lengths and diameters, and cost of the injection piping system and associated equipment. In contrast to the fluid transmission submodel, which calculates fluid degradation on a nodal basis, the more simplified fluid injection submodel does not calculate effluent fluid degradation. Instead, the effluent pipeline diameters are sized on a nodal basis as a function of the mass flow rate exiting each node, holding constant the temperature, pressure, viscosity and density of the effluent in effect at the outlet from the city distribution system or the heat exchanger.

TROUT — Prints the input conditions for the fluid transmission and injection submodel.

DESIGN — Calculates the number of producing, nonproducing, and injection wells based on the total geothermal fluid flow rate required by the distribution system and several input conditions, which include: mass flow rate of individual producing wells, ratio of nonproducing to producing wells drilled, and ratio of injection well to producing well flow

DESIGN (Contd) rate. The wells are located at the vertices of equilateral triangles (nodes in a triangular lattice) as shown in Figure 5, with pipe runs parallel to the horizontal X-axis. The fluid transmission system has a manifold pipeline for transmitting the geothermal fluid from all rows of wells to the distribution center. Subroutine DESIGN calculates an effective average acreage (WACRE) per producing well based upon the input well spacing (WELSPC) in acres and the fraction (FRCNPW) of nonproducing (dry) wells according to the following equation:

WACRE = WELSPC * (1.+FRCNPW)

The area (WACRE) encompassed by each producing well (Figure 5) is equal to the area of two equilateral triangles.

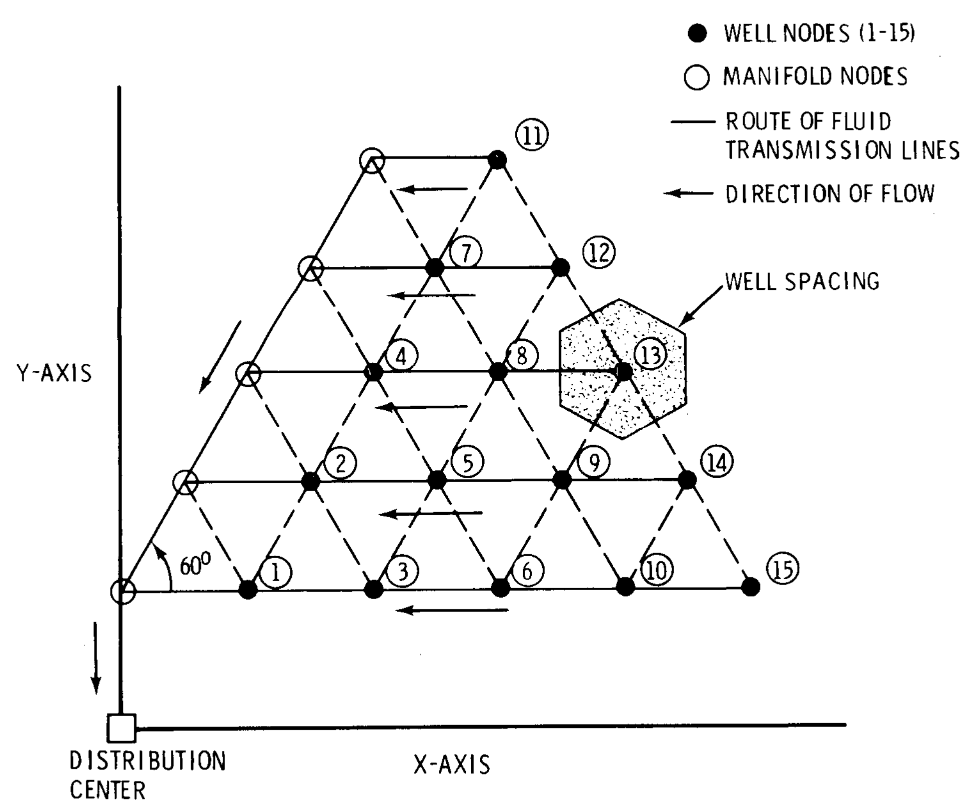


FIGURE 5. Well Layout Design and Routing of Fluid Transmission Lines

DESIGN (Contd) Subroutine DESIGN calculates the pipe length between producing wells based on the equation for the area of an equilateral triangle as follows:

$$\text{Pipe length (m)} = (0.3048006 \text{ m/ft})(5280 \text{ ft/mile})*$$

$$\sqrt{\frac{\text{WACRE (acres)}}{(0.86603)(640 \text{ acres/sq mile})}}$$

EQCOST Calculates the cost of valves, instrumentation, and solids separators for the fluid transmission submodel.

TSTART Initializes the thermodynamic and physical conditions of the geothermal fluid at the two types of nodes in the triangular lattice defining the well field layout. These types are 1) wellhead nodes, and 2) pipe junctions or manifold nodes collecting the fluid from the parallel rows of pipes into one large pipe leading to the distribution center. The following fluid conditions are initialized on a nodal basis for a compressed liquid state: temperature, pressure and flow rate (input variables); enthalpy (computed as a function of the input temperature and pressure); and density and viscosity (computed from the preceding conditions). All wellhead nodes in the field are initialized with the same average conditions. The simulation of variable wellhead conditions requires code modifications. The initial conditions at the nodes are used as the starting point for computing the fluid degradation on a nodal basis during conduction from the well field nodes to the distribution center.

PIPE Calculates the optimum pipe diameter exiting each node. The calculation is based on the fluid mass flow rate, fluid density and viscosity, and economic trade-offs between the components comprising the cost function for the fluid

PIPE (Contd) transmission system: capital cost of the pipe, annual value of energy lost due to friction in the pipeline, and capital cost of pumps and drive motors for pumping the fluid to the distribution center. The cost function for the fluid transmission system is minimized on a nodal basis with respect to internal pipe diameter D by setting its derivative with respect to D to zero. An iterative solution based upon the Newton-Raphson algorithm is obtained for optimum pipe diameter on a nodal basis from the resultant equation.

The pipe equations include a parameter EVALUE(1) which can be adjusted by the program user in the input data to change all pipe diameters in the pipeline network. This option permits the user to avoid unacceptable fluid quality resulting from excessive pressure degradation or two-phase flow.

STORE/RETRIEV Saves and retrieves information associated with the pipeline and thermodynamic condition of the fluid computed in simulating fluid conduction and degradation from well nodes (non-manifold nodes) to adjacent nodes. Calculations are required only once for each set of well nodes in the well layout with the same number of active wells upstream of the nodes, providing all wells have the same average conditions.[(a)] The subsequent retrieval of this information in lieu of recomputation can reduce the execution time for simulating the fluid transmission submodel almost 50% for large well fields. This option is selected by setting the input parameter IAVWEL = 1.

SCHEDL Assigns pipe schedules on a nodal basis by selecting the smallest pipe schedule from a range of 10 to 40 that can withstand the maximum fluid pressure exiting each node.

(a) See description of sample case output.

SCHEDL (Contd)	The maximum pressure each schedule can accommodate is a function of the fluid temperature and ranges from about 350 psia for schedule 10 up to 1000 psia for schedule 40, with temperature ranges from 50°C to 300°C. The pipe schedule and diameter are used in subroutine TRANS to calculate the cost of piping and installation.
INSUL	Sizes pipe insulation on a nodal basis as a function of the fluid temperature, nominal outer pipe diameter, insulation thickness availability, and cost, using one or more types of insulation. The cost of insulation is calculated based on the thickness of each type of insulation used.
SPFLOW	Calculates the enthalpy and temperature degradation of the geothermal fluid during single-phase flow in the pipeline between nodes. Fluid degradation is calculated in one stepsize equal to the distance between nodes. Calculation with smaller stepsize increments, such as 50 ft, in the conduction of water showed no significant difference in the degradation. The enthalpy drop is calculated as a function of nominal outer pipe diameter, fluid temperature, insulation thickness and mass flow rate. The fluid pressure is continuously maintained at or above saturation (compressed liquid state) to prevent two-phase flow in the fluid transmission lines through the use of booster pumps simulated in the fluid transmission submodel (subroutine TRANS). The temperature is obtained from the pressure and enthalpy by using the steam table function TPHL for a compressed liquid.
FLPROP	Identifies the fluid state in the transmission pipeline as compressed liquid, saturated liquid, two-phase mixture, saturated vapor or superheated steam. Subroutine TRANS calls FLPROP on a node-by-node basis. The fluid state is identified based upon the pressure and enthalpy by interrogating subroutine XPHH and the ASME Steam Table

FLPROP (Contd)	functions. After identification of the fluid state at a particular node, subroutine FLPROP calls the appropriate steam table function to compute the specific volume, density, viscosity, temperature, or entropy as requested by subroutine TRANS.
XPHH	Calculates the fluid quality by weight fraction as a function of pressure and enthalpy. It returns 0 for saturated and compressed liquid, 1 for saturated vapor and superheated steam, and values in between for two-phase mixtures of steam and water at saturation.
TPHASE	Tests whether the fluid quality in the pipeline has become unacceptable due to two-phase flow, which is not allowed in the conduction of water to the distribution center.
TPRINT	Prints the results calculated by the fluid transmission submodel for the transmission line from the well field to the distribution center. Results can be printed for the entire distribution system demand and fluid transmission iteration history discussed in Section 2.3, or only for the final iteration satisfying the convergence criterion. In the final iteration, results calculated by the fluid injection (disposal) submodel are also printed. The input parameter LL6 controls the printout for the distribution system demand and fluid transmission iteration: LL6 = 0 suppresses all printout, LL6 = 1 prints the last iteration only, and LL6 = 2 prints the full iteration history.
MOUT	Prints the arrays calculated in the fluid transmission and disposal submodel as matrices or vectors with accompanying titles.

2.5 HEAT EXCHANGER SUBMODEL

An option for a liquid heat exchanger is provided in GEOCITY in case the temperature of the geothermal fluid needs to be reduced or the fluid's chemical composition makes it undesirable for direct use in the distribution system. Heat is transferred from the geothermal fluid in the reservoir to circulating clean water for use in the distribution system. The heat exchanger option HTEXOP and input parameters are defined in the NAMELIST input data by the user and are described in Section 3.4.4.3. The heat exchanger is assumed to be located at the end of the transmission line from the geothermal reservoir (inlet to the distribution center), but owned by the district heating distribution system operator. Thus, the capital and operating costs of the heat exchanger are factored into the distribution economic submodel. The equations for these costs are given in Appendix B. The design characteristics and size of the heat exchanger are determined in subroutine SUBHEX and its associated subroutines described below.

SUBHEX — Calculates the basic design characteristics and size of a liquid-to-liquid heat exchanger based upon a counterflow, single-pass, shell-and-tube unit constructed of carbon steel with an equilateral triangular tube configuration.

The input conditions to subroutine SUBHEX are:

a) Geothermal fluid and clean water flow rates, lb/hr
b) Geothermal fluid temperatures at the heat exchanger inlet and outlet, ^{o}F
c) Clean water temperatures (^{o}F) and enthalpies (Btu/lb)at the heat exchanger inlet and outlet
d) Inside and outside fouling factors, hr-ft^{2}-^{o}F/Btu
e) Inside and outside tube diameters, ft
f) Geothermal fluid velocity in the heat exchanger tubes, ft/hr.

The basic characteristics calculated for the heat exchanger are:

a) Inside and outside heat transfer coefficients, Btu/hr-ft^{2}-^{o}F
b) Overall heat transfer coefficient, Btu/hr-ft^{2}-^{o}F
c) Number of heat exchanger tubes
d) Total flow area (ft^{2}) and equivalent flow diameter (ft) for the shell side

e) Heat exchanger area, ft^2

f) Heat exchanger length, ft.

The characteristics of the heat exchanger are calculated in steps described below, first for the tube-side or geothermal fluid and then for the shell-side or clean water.

1) The average of the inlet and exit temperatures is calculated for the geothermal fluid and clean water respectively for use in computation of physical properties.

2) The thermal conductivity, density, and viscosity of the geothermal fluid are calculated at the average geothermal temperature in Step 1 using function FLUID.

3) The Reynolds number of the geothermal fluid is calculated in function REYNO. The Prandtl number is calculated in subroutine SUBHEX based on the specific heat c_p, viscosity μ, and thermal conductivity k of the geothermal fluid:

$$Pr = \frac{c_p * \mu}{k}$$

4) The inside or tube-side heat transfer coefficient is determined in function HTCOEF.

5) The number of tubes required for the geothermal fluid is calculated in function TUBES.

6) The total flow area and equivalent flow diameter for the shell side are determined in subroutine QAREA.

7) The specific heat, thermal conductivity, density, and viscosity of the clean water are calculated at the average clean water temperature in Step 1 using function FLUID.

SUBHEX (Contd)

8) The velocity of the geothermal fluid in the tubes is set in the input data. The velocity of the clean water in the heat exchanger shell is calculated in function VELOCY.

9) The Reynolds number of the clean water is calculated in function REYNO. The Prandtl number is calculated in subroutine SUBHEX based on the specific heat, viscosity, and thermal conductivity of the clean water.

10) The outside or shell-side heat transfer coefficient is determined in subroutine HTCOEF.

11) The inside and outside heat transfer coefficients are combined with the thermal conductivity of the tube wall and the fouling factors to determine the overall heat transfer coefficient in fuction OHTCOE.

12) Knowing the amount of overall heat transfer desired, the heat transfer area and heat transfer length are calculated in functions HTAREA and HTLNGH respectively.

The subroutines called by subroutine SUBHEX to calculate the basic characteristics of the heat exchanger are described below. Function FLUID, which is the first routine called by subroutine SUBHEX, is also called from many of the other subroutines in Figure 3 to calculate physical properties of water.

FLUID

Correlates physical properties of 10 different fluids to temperature at saturation. In GEOCITY, function FLUID is called only to calculate physical properties of water.

Each physical property for a particular fluid is expressed as a polynomial function of temperature in the elementary form:

$$\text{Property value} = K_0 + K_1T + K_2T^2 + K_3T^3 \text{ for } T_x < T < T_y$$

FLUID (Contd)

These expressions were correlated to available data in the temperature range T_x to T_y. The data were acquired through a search of numerous reference texts and publications.[2,5-7]

Within the specified temperature range, there is good agreement between the actual and predicted values. A warning message is printed if the input temperature requires extrapolating the polynomials beyond the temperature range T_x to T_y specified in function FLUID for a given equation.

The polynomial functions are used to predict the following physical properties as a function of temperature at saturation: specific heat, thermal conductivity, density, viscosity, heat of vaporization, and surface tension. Critical pressure, critical temperature, and molecular weight are included as constants. When a physical property is desired, the following statement is made:

Property Value = FLUID (I,J,T)

where T = temperature at which the property is required, ^{o}F

I = 1,13 - <u>Property Index</u>

1 - specific heat (liquid)(Btu/lb/^{o}F)
2 - thermal conductivity (liquid)(Btu/hr/ft/^{o}F)
3 - density (liquid)(lb/ft^3)
4 - viscosity (liquid)(lb_m/ft/hr)
5 - specific heat (gas)(Btu/lb/^{o}F)
6 - thermal conductivity (gas)(Btu/hr/ft/^{o}F)
7 - density (gas)(lb/ft^3)
8 - viscosity (gas)(lb_m/ft/hr)
9 - heat of vaporization (Btu/lb)
10 - critical pressure (psia)

FLUID (Contd)

11 - critical temperature (^{o}F)

12 - surface tension (lb_f/ft)

13 - molecular weight (lb/lb_{mole})

J = 1,10 - Fluid Index

1 - water (only fluid used in GEOCITY)

2 - isobutane

3 - n-butane

4 - R-11

5 - R-12

6 - R-21

7 - R-22

8 - R-113

9 - R-114

10 - ammonia

REYNO

Calculates the Reynolds number based upon the fluid density ρ, viscosity μ, velocity V, and flow diameter D:

$$Re = \frac{\rho DV}{\mu}$$

HTCOEF

Calculates inside and outside heat transfer coefficients based on the Dittus-Boelter equation for fully developed turbulent flow in smooth tubes. Subroutine HTCOEF is called by subroutine SUBHEX to calculate the inside heat transfer coefficients for the geothermal fluid and the outside heat transfer coefficients for the clean water in the heat exchanger. The Dittus-Boelter equation is summarized below:

$$h_{conv} = 0.023\ Re_d^{0.8}\ Pr^x\ \frac{K}{d}$$

HTCOEF (Contd) where:

h_{conv} = convective heat transfer coefficient, $Btu/hr\text{-}ft^2\text{-}^oF$

d = tube diameter, ft

K = thermal conductivity, $Btu/hr\text{-}ft\text{-}^oF$

Pr = Prandtl number

Re_d = Reynolds number based on tube diameter

x = 0.4 when fluid is being heated,
0.3 when fluid is being cooled.

TUBES

Determines the number N of tubes required in the heat exchanger based on the geothermal fluid mass flow rate Q, velocity V, density ρ, and flow diameter D. Fractional values of N are increased to the next largest integer. The basic relationship is:

$$N = \frac{(Q/\rho)}{V * \frac{\pi D^2}{4}}$$

where:

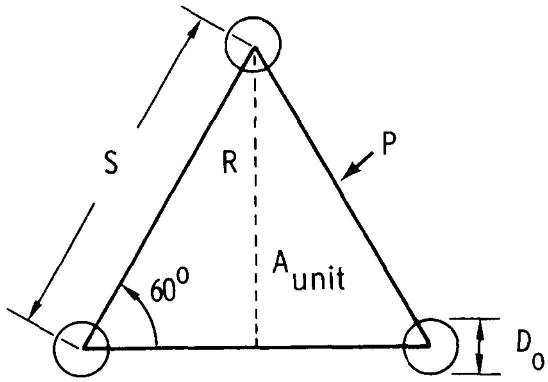
(Q/ρ) is the total required volumetric flow rate of geothermal fluid,

$\frac{\pi D^2}{4}$ is the cross-sectional flow area per tube,

$V * \frac{\pi D^2}{4}$ is the volumetric flow rate per tube.

QAREA

Calculates the total cross-sectional flow area A and equivalent flow diameter D_e for the shell-side or clean water side in the heat exchanger. An equilateral triangular pitch is assumed for the tube configuration, as shown below.



S - TUBE SPACING, ft

D_0 - TUBE OUTER DIAMETER, ft

P - WETTED PERIMETER, ft

A_{unit} - UNIT FLOW AREA, ft

The tube spacing S is assumed to be 1.75 times the tube outer diameter D_0. Based on the area for a equilateral triangle, the unit flow area for the clean water is calculated by the following equation.

$$A_{unit} = \frac{SR}{2} - \frac{3}{6} * \frac{\pi D^2}{4}$$

where:

$$R = S * \sin 60^0$$

$\frac{SR}{2}$ = area of the equilateral triangle

$\frac{3}{6} * \frac{\pi D^2}{4}$ = area of the 3 pie shapes in the 3 tubes which are not included in the flow area for the clean water.

The total cross-sectional flow area A is calculated as the number of tubes times the unit flow area A_{unit}. The equivalent flow diameter D_e for the shell-side is calculated as:

$$D_e = \frac{4 * A_{unit}}{\text{wetted perimeter}}$$

The wetted perimeter P is calculated as:

$$P = 3(S-D_o) + \frac{3\pi D_o}{6}$$

VELOCY

Calculates the fluid velocity V as a function of the mass flow rate Q, fluid density ρ, and total cross-sectional flow area A as follows:

$$V = \frac{(Q/\rho)}{A}$$

where:

(Q/ρ) is the volumetric flow rate.

OHTCOE

Combines the inside and outside heat transfer coefficients with the thermal resistance of the heat exchanger tube walls and the fouling factors. This yields an overall heat transfer coefficient on the basis of the following equation:

$$U = \frac{1}{\frac{A_o}{A_i} * \frac{1}{h_i} + \frac{A_o \ln (r_o/r_i)}{2\pi KL} + \frac{1}{h_o} + f_i + f_o}$$

where:

U = overall heat transfer coefficient, Btu/hr-ft^2-^{o}F

A_o = outside tube surface area, ft^2

A_i = inside tube surface area, ft^2

h_i = inside heat transfer coefficient, Btu/hr-ft^2-^{o}F

h_o = outside heat transfer coefficient, Btu/hr-ft^2-^{o}F

r_i = inside tube radius, ft

r_o = outside tube radius, ft

K = thermal conductivity for the tube wall, Btu/hr-ft-^{o}F

L = tube length, ft

f_i = inside fouling factor, hr-ft^2-^{o}F/Btu

f_o = outside fouling factor, hr-ft^2-^{o}F/Btu

The fouling factors reduce the overall heat transfer coefficient to allow for the accumulation of corrosion deposits on the heat transfer surfaces.

HTAREA

Calculates the heat transfer area A for the heat exchanger. The calculation is based on the clean water flow rate Q; enthalpies of the clean water at the inlet and outlet, H_1 and H_2; overall heat transfer coefficient U; and the logarithmic mean temperature difference LMTD in the following equation.

$$A = \frac{Q * (H_1 - H_2)}{U * (LMTD)}$$

The logarithmic mean temperature difference between the geothermal fluid and clean water is based on the temperature difference at the two ends of the heat exchanger.

$$LMTD = \frac{\Delta T_{in} - \Delta T_{out}}{\ln (\Delta T_{in} / \Delta T_{out})}$$

where:

ΔT_{in} = temperature difference (^{o}F) between the geothermal fluid and clean water at the clean water inlet to the heat exchanger.

ΔT_{out} = temperature difference (^{o}F) between the geothermal fluid and clean water at the clean water outlet from the heat exchanger.

HTLNGH — Calculates the tube length L in the heat exchanger. The calculation is based on the heat tranfer area A, tube outer diameter D_o, and number N of tubes in the heat exchanger.

$$L = \frac{A}{\pi D_o N}$$

2.6 DISTRIBUTION SYSTEM SUBMODEL

The distribution system submodel simulates the design and calculates the capital costs, operating costs, and maintenance costs of the district heating distribution system for a city. The input data to the distribution system submodel is described in Section 3.4 and consists of the city characteristics, characteristics of districts comprising the city, design options for the distribution piping, insulation, and casing, and special options and adjustment factors for the distribution system.

The city is defined by its distance from the geothermal reservoir, climatic characteristics, and the number of districts within the city. The distance from the reservoir to the city is used in designing the fluid transmission line and calculating the fluid temperature and enthalpy entering the distribution center. The climatic parameters are used in determining the distribution of the heat demand, peak heat demand, average heat demand, the load factor, and supplemental heat requirements.

The city is described by disaggregating it into districts. Districts are the basic element of the distribution system submodel. Each district is a contiguous area consisting of buildings of relatively similar heat demand and uniform density. Most of the details needed for design of the distribution piping system are derived from the definitions of the districts. Fluid requirements are computed, and the piping networks are designed for each district. Material requirements, capital costs, operating costs, and maintenance costs are also calculated for each district and totaled for the city.

Districts are defined by two types of input parameters, district type and district definition parameters. District type parameters define the demand density, and the district definition parameters define the size and location of the districts. A comprehensive list of these parameters is given in Section 3.4.2. The primary parameters used to define each district are the district type, the density of buildings, peak space heating demand, hot water demand, the area of the district, and two parameters (length and width) describing a rectangular grid used to approximate the shape of the district.

Five district types, representing typical residential areas, are identified and defined in Section 3.4.2. These district types are described in Table 8. Most residential areas in the United States can be described by one of these district types. Variations of the district types in Table 8 or additional district types can also be defined through the district type parameters in the NAMELIST input data.

The distribution system submodel is decomposed into its component subroutines in Figure 4 and consists of subroutine CALQNA, subroutine DIST, and its associated subroutines: GRAPH, SIZE, HEAT, PROP, and DWRIT.

As previously noted in Section 2.3, the total geothermal fluid flow is established in the iteration between the distribution demand subroutine CALQNA and the fluid transmission submodel. Subroutine CALQNA calculates the total geothermal fluid requirements to meet the heat demands (space heating and hot water) of the city based on the area, building density, space heating demand, hot water demand, specified temperature drop in the geothermal fluid, and the climatic data for all districts in the city. The total city requirement is the sum of the district requirements.

Subroutine DIST calls the associated subroutines shown in Figure 4 to determine the design and cost of the distribution system. Subroutine GRAPH is called to design the piping network for each district in the city based on the area, building density, heat demand, climatic data, and a rectangular grid used to approximate the shape of the district. Heat demand data and climatic data are used to determine the fluid requirements of each building. Proceeding down the piping network, the fluid requirements are used in subroutine SIZE as a basis for selecting the economic pipe size and insulation thickness and calculating head losses for each segment of the piping network. Heat losses are determined for each segment of the piping network by subroutines HEAT and PROP.

Material requirements for the distribution system are calculated in subroutines DIST and SIZE. Capital costs, operating costs, and maintenance costs for the piping network, pumps, meters, and control equipment are derived based on the distribution system design options in subroutine DIST and the capital and operating cost models described in Appendix B. The output results summarizing the material requirements and costs of the distribution system are printed by subroutines DIST, DWRIT, and DWRIT2 (an entry point in subroutine DWRIT).

Each subroutine of the distribution system submodel is described below in the order of execution illustrated in Figure 4. Numerous comment cards are also provided in the FORTRAN code for these subroutines to facilitate understanding of the logic in the distribution system submodel.

CALQNA — Calculates the distribution system's annual average heat demand and peak heat demand in MBtu/hr, the system load factor, and distribution system's fluid flow requirements with and without future growth in lb/hr. The degree-day method of evaluating heat demand for space heating is

CALQNA (Contd) used. The following equation is used to calculate the annual average heat demand AD (MBtu/hr) for space heating and hot water heating:

$$\sum_{\text{No. of Districts}} \left\{ \begin{array}{l} \text{Density (bldg/sq. mile) * Area (sq. mile)*} \\ \text{Peak Heat Demand at Design Temperature} \\ \text{(MBtu/bldg} \cdot \text{hr) * Number of Heating Degree} \\ \text{Days (}^{o}\text{F} \cdot \text{days/yr)/[365 (days/yr) * (65 -} \\ \text{Design Outdoor Temperature)}^{o}\text{F]} \\ \qquad + \\ \text{Daily Hot Water Demand (gal/bldg} \cdot \text{day) *} \\ \\ \quad 3.631\text{E-5} \ \dfrac{\text{MBtu/hr}}{\text{gal/day}} \end{array} \right\}$$

The conversion factor of 3.631E-5 is based on heating water from 50^{o}F to 140^{o}F[(a)] and the daily hot water demand (gal/bldg · day) as follows:

Heat Demand for Hot Water Heating (MBtu/bldg • hr) = [Daily Hot Water Demand (gal/bldg • day) * .1337 (ft^3/gal)* 61.37 (lb/ft^3)* 1 Btu/(^{o}F•lb) * (140-50)^{o}F * 1.E-6 MBtu/Btu]/24 (hr/day)

(a) This discussion pertains to the default values of cold and hot water temperature for sanitary hot water heating in the city. The cold and hot water temperatures and conversion factors used in calculations for sanitary hot water heating in the city are generalized in the code to handle the values specified by the user in the NAMELIST input data. See Section 3.4.1 for definition of the cold water temperature (TWATC) and hot water temperature (TWATH) in the input data.

CALQNA (Contd) This yields the equation:

Heat Demand for Hot Water Heating (MBtu/bldg • hr) =

Daily Hot Water Demand (gal/bldg • day) *

$$3.0769E\text{-}5 \left(\frac{\text{MBtu/hr}}{\text{gal/day}}\right)$$

Assuming an 18% heat loss from the hot water storage heater, the equation becomes:

Heat Demand for Hot Water Heating (MBtu/bldg • hr) =
Daily Hot Water Demand (gal/bldg • day) * 3.0769E-5 * 1.18, i.e.,

$$\text{Daily Hot Water Demand (gal/bldg} \cdot \text{day)} * 3.631E\text{-}5 \left(\frac{\text{MBtu/hr}}{\text{gal/day}}\right)$$

The following equation is used to calculate the annual peak heat demand PD (MBtu/hr) for space heating and hot water heating:

$$\sum_{\text{No. of Districts}} \text{Density (bldg/sq. mile)} * \text{Diversity Factor} * \text{Area (sq. mile)} * \left\{\text{Peak Heat Demand at Design Temperature (MBtu/bldg} \cdot \text{hr)} + \text{Peak Hot Water Demand (MBtu/bldg} \cdot \text{hr)}\right\}.$$

The calculation of the peak hot water demand (MBtu/bldg · hr) is as follows:

$$\text{Daily Hot Water Demand (gal/bldg} \cdot \text{day)} * 738.47E\text{-}6 \left(\frac{\text{MBtu/day}}{\text{gal/day}}\right)$$

* (1/7), where the assumption is that the peak hot water demand in 1 hr represents about 1/7 that of the average daily demand in 24 hrs.

The system load factor PF is calculated as follows:

PF = Annual Average Heat Demand (AD)/
Annual Peak Heat Demand (PD)

CALQNA (Contd)

Subroutine CALQNA factors into account the optional heat exchanger at the end of the transmission line (inlet to the distribution center) in calculating the peak flow rate required to meet the peak space heating demand at design temperature and peak hot water demand of the distribution system. Two flow rates are calculated.

First, the required peak fluid flow rate QNA (lb/hr) inside the distribution system, when allowing for future growth in heat demand, is calculated as follows:

$$\sum_{\text{No. of Districts}} \{\text{Peak Heat Demand at Design Temperature (MBtu/bldg} \cdot \text{hr) + Peak Hot Water Demand (MBtu/bldg} \cdot \text{hr)}\} *$$

1.E6 Btu/MBtu * Density (bldg./sq. mile) * Diversity Factor * Area (sq. mile) * (1. + Fractional Heat Demand Growth Rate Over the Number of Growth Years)/{Temperature Drop of the Fluid Inside the Distribution System (^{o}F) * Specific Heat of the Fluid Inside the Distribution System * 0.95}.

Without a heat exchanger, the fluid temperature drop inside the distribution system is calculated as the geothermal fluid temperature at the inlet to the distribution center minus the geothermal fluid temperature at the outlet of the distribution system. With a heat exchanger at the end of the transmission line, the fluid temperature drop inside the distribution system is calculated as the clean water temperature out of the heat exchanger [TWATOT (^{o}F) in the input data] minus the clean water temperature out of the distribution system. The fluid flow rate inside the distribution system is also calculated in subroutine DIST.

The factor 0.95 is used to allow for heat losses between the reservoir wellhead and individual user.

CALQNA (Contd) The above equation for the peak fluid flow rate QNA inside the distribution system is derived from the following heat transfer equation:

Required Heat at Peak Demand (Btu/hr) * (1. + Growth Fraction) = Temperature Drop (^{o}F) * Specific Heat $\left(\frac{\text{Btu}}{\text{lb.}^{o}\text{F}}\right)$ * 0.95 * QNA (lb/hr)

The peak fluid flow rate QNA is used to size the distribution pipeline system, allowing for future growth in heat demand.

Second, the required peak geothermal flow rate QNANG (lb/hr) from the geothermal wells to meet current heat demands (without regard for future growth in heat demand) is calculated. The peak geothermal flow rate QNANG is used to calculate the required number of producing wells and size the transmission pipes based on current demand. The assumption is that the reservoir capacity can be expanded to meet future heat demand by drilling more wells. The equation used to calculate the peak geothermal flow rate QNANG (lb/hr) is as follows:

$$\sum_{\text{No. of Districts}} \{\text{Peak Heat Demand at Design Temperature (MBtu/bldg} \cdot \text{hr)} + \text{Peak Hot Water Demand (MBtu/bldg} \cdot \text{hr)}\} * \text{1.E6 (Btu/MBtu)} * \text{Density (bldg/sq. mile)} * \text{Diversity Factor} * \text{Area (sq. mile)} / \{\text{Temperature Drop of the Geothermal Fluid } (^{o}\text{F}) * \text{Specific Heat of the Geothermal Fluid} * 0.95\}.$$

CALQNA (Contd) Without a heat exchanger, the temperature drop of the geothermal fluid is calculated as the inlet temperature to the distribution center minus the outlet temperature from the distribution system. With a heat exchanger at the end of the transmission line, the temperature drop of the geothermal fluid is defined as the temperature drop across the heat exchanger, which is defined as HXDELT(^{o}F) in the input data.

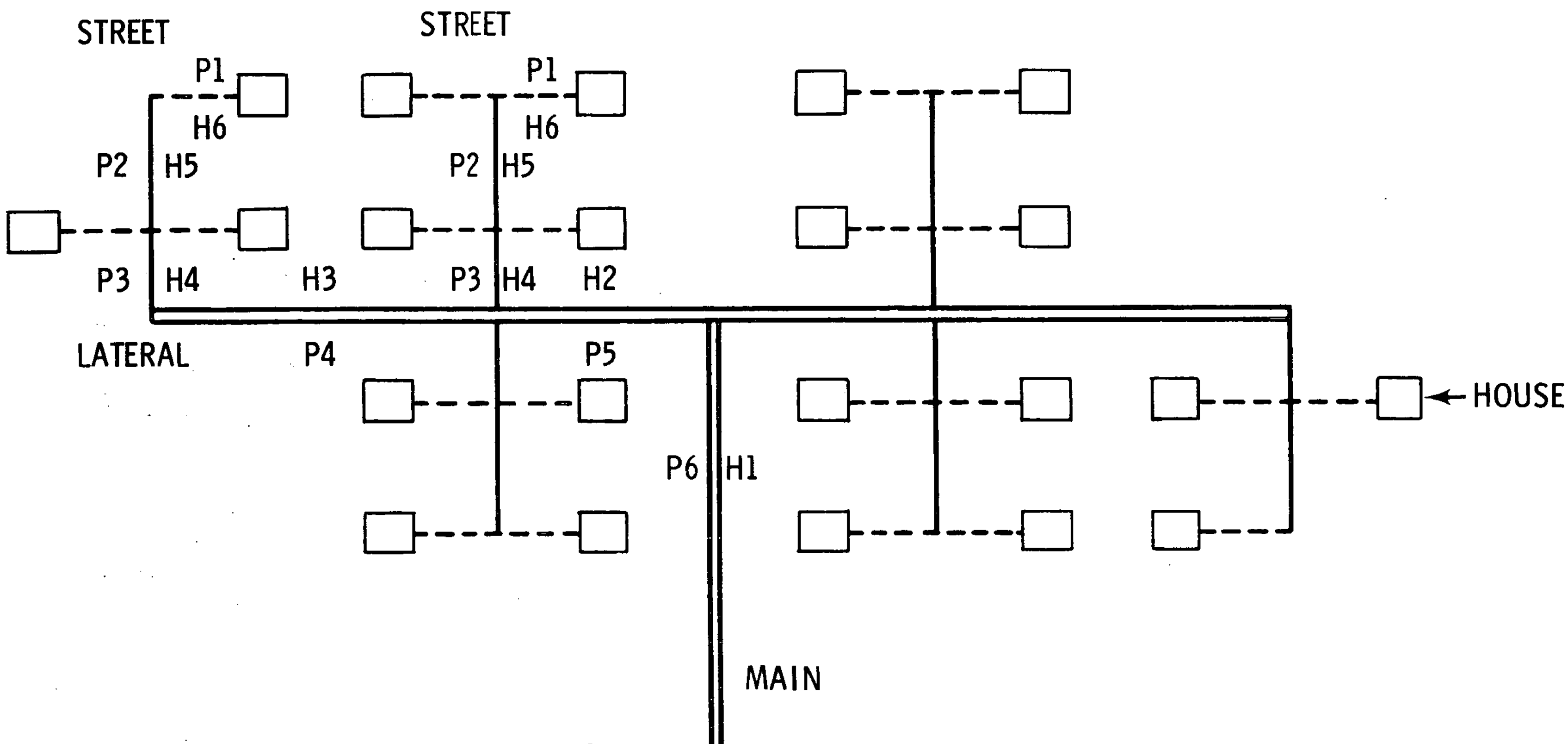
Both peak flow rates QNA and QNANG are increased to factor into consideration the fraction WLEAK of fluid lost due to leakage in the transmission and distribution system:

QNA = QNA * (1. + WLEAK)
QNANG = QNANG * (1. + WLEAK)

The variable WLEAK is specified by the program user in the input data.

DIST Calls the subroutines comprising the distribution system submodel in Figure 4 to simulate the design, capital costs, operating costs, and maintenance costs of the district heating distribution system. The design, material requirements, and costs of the distribution system are calculated separately in steps 1-11 below for each district in the city and then totaled over all districts for the city.

1) The network of pipes from buildings to streets, down streets connecting buildings, across the lateral connecting with the midpoint of the streets, and up the main connecting with the midpoint of the lateral is designed for each district using subroutine GRAPH. An example layout of a piping network is illustrated in Figure 6. The piping network is symmetrical about the main and lateral pipes as described in the description of subroutine GRAPH.



P1-P6 ORDER OF SIZING PIPE SECTIONS IN THE SUPPLY PIPES

H1-H6 ORDER OF CALCULATING HEAT LOSS IN THE SUPPLY PIPES

FIGURE 6. Layout for a District With 22 Buildings; The Piping Network is Symmetrical about the Main and the Lateral

DIST (Contd)

2) The required peak geothermal flow rate per building is calculated based on the peak space heating demand and peak hot water demand specified in the input data for this district type and the specified temperature drop of the geothermal fluid. Based on the peak geothermal flow rate, the pipe size and insulation thickness are optimized and the head loss is calculated for pipe sections in the supply pipes beginning from the building to the street, down streets, across the lateral, and up the main using subroutine SIZE. Due to the symmetry in the piping network, only a few pipe sections need to be considered to size the whole network for the district. The size of the return pipes is set equal to the size of the supply pipes.

3) The heat losses in the sections of the supply pipes starting with the main, across the lateral, up the street, and from the street to the building are calculated using subroutine HEAT.

4) The heat losses in the sections of the return pipes starting from building to street, down the street, across the lateral, and up the main are calculated using subroutine HEAT.

5) The output illustrated by the sample output on p. E-9 is printed. This summarizes the flow rate, heat loss, supply and return temperatures, head loss, nominal outer pipe diameter, and insulation thickness in the sections of pipe from building to street, down a street, across the lateral, and up the main. Because of the symmetry of the piping network, it is necessary to print only the pipe sections from one building to the street, pipe sections connecting pairs of buildings down a half-street (either above or below

DIST (Contd)

the lateral), and pipe sections connecting streets across a half-lateral (either to the right or left of the main).

6) The total head loss and heat loss in the piping network are calculated for the district. Based on the total head loss, the required pumping capacity and capital costs of the pumps are calculated.

7) The material requirements and capital costs of the piping network are calculated based on the material and configuration options specified for pipes, insulation, and casing and the capital cost models described in Appendix B. The length of pipe, number of fittings, valves, and expansion loops, and the capital costs of pipes, fittings, valves, insulation casing, expansion loops, and trenches are tabulated by up to 17 categories of nominal outer pipe diameter sizes that can be used throughout the piping network. These costs are then summed over all pipe sizes and combined with the cost of meters, pumps, and retrofitting of buildings to handle geothermal heating to obtain total capital costs for the district piping system.

8) The output illustrated by the sample output on page E-10 is printed. This summarizes the material requirements and capital costs calculated in step 7 by up to 17 categories of nominal outer pipe diameter sizes and also summarizes the total capital costs for the district piping system.

9) The annual average heat demand (space heating and hot water) in MBtu/yr is calculated for the district based on the peak heat demand, climate, density, area, and peak hot water demand. The peak hot water demand is assumed to be 1/7 of the daily hot water demand,

DIST (Contd)

occurring at the same time as the hourly peak heat demand. The annual peak heat demand (space heating and hot water) in MBtu/hr is calculated for the district based on the peak heat demand, peak hot water demand, density, area, and diversity factor. The diversity factor defined in Section 3.4.2 is used to reduce the size of laterals and mains supplying a district by considering that the peak load for all buildings in a district will not occur simultaneously. The annual average heat demand and annual peak heat demand are also summed over all districts in the city.

10) The return temperature for each district is weighted by the mass flow rate for each district to calculate an average reinjection temperature from the city distribution system.

11) The peak supplemental heat requirements (MBtu/hr) are calculated for each district based on the peak heat demand, climate, density, and area of the district.

12) The output illustrated by the sample output on page E-25 is printed. This summarizes the flow rate, heat loss, supply and return temperatures, head loss, nominal outer pipe diameter, and insulation thickness for the mains to the districts.

13) The design parameters and capital cost of the heat exchanger are printed if the option to use a heat exchanger at the interface between the transmission line from the reservoir and distribution main is simulated.

14) The output illustrated by the sample output on page E-26 is printed. This summarizes the total material requirements and capital costs for the entire city

DIST (Contd) distribution system by up to 17 categories of nominal outer pipe diameters. The total capital costs summed over all pipe sizes and the total operating expenses are also printed for the entire city distribution system.

15) The total supplemental heat requirements (MBtu/yr) are calculated for the city based on the annual average heat demand calculated in step 9 for the city and the climate. The cost of providing the total supplemental heat requirements is also calculated.

GRAPH Designs the layout of the piping network for the distribution system in each district based upon the area, density, length, and width which the user can approximate from a map of the district. Subroutine GRAPH calculates the number of buildings in a given district (area * density) and places them on a rectangular grid such that the ratio of rows to columns is equal to the ratio of width to length of the district. The rectangular grid defaults to a square with length and width equal to 1 mile if these two parameters are not defined in the NAMELIST input data.

An example layout designed by subroutine GRAPH for a district with 22 buildings and with ratio of length to width equal to 2 is shown in Figure 6. Pairs of columns of houses are assigned by subroutine GRAPH to streets. A lateral pipe, located at the midpoint of the streets, connects all of the street pipes. A main pipe connects with the midpoint of the lateral. If a street cannot be completely filled out with buildings, these remaining buildings are placed on 2 short streets, one at each end of the lateral, so that the resultings network is symmetrical both about the lateral and main.

SIZE Optimizes the pipe diameter (meters) and insulation thickness (meters) and calculates the pressure drop (meters of

SIZE (Contd) H_2O) for each section of pipe in the distribution piping network. Since all pipes from building to street are identical in a given district, and since the piping network is symmetrical about the main and lateral pipes, only a few pipe sections need to be considered to size the whole network in a given district. The optimal pipe diameter for each pipe section is determined by searching a set of feasible pipe sizes to find the size that will minimize the sum of the annualized capital cost of pipe, insulation, casing, valves, fittings, expansion loops, trenches, and pumps and the annual costs of heat loss and pumping power costs. The optimal insulation thickness is determined by minimizing the sum of the annualized capital cost of insulating the pipes, valves, fittings, and expansion loops, annualized costs of casing and trenching, and annual value of lost heat.

The material and configuration options for pipes, insulation, and casings used in subroutine SIZE are specified in the input described in Section 3.4.3. These design options include: single pipe systems; various two-pipe systems; use of steel or fiberglass reinforced plastic pipes; use of calcium silicate or polyurethane foam insulation; and use of steel, plastic (PVC), or field-constructed concrete casings. Material requirements including pipe, insulation, casing, valves, fittings, expansion loops, and trenches are accumulated by size at each section in the distribution piping network. The capital cost models used in subroutine SIZE are based on the design options specified in the input data and are described in Appendix B.

HEAT Calculates the radial heat loss (joules/sec • meters) through a composite series of walls (pipe, insulation, annular air space and ground) due to convection and

HEAT (Contd) — conduction for fluid flow in a cylindrical pipe buried below the ground. Subroutine HEAT is called by both subroutines SIZE and DIST.

DWRIT (entry point DWRIT 2) — Prints the output entitled "Definition of Districts" with results in both English and metric units and the output entitled "District Populations" illustrated in the sample output on pages E-7 and E-8. This output consists principally of the input data defining the districts and district types in the distribution system described in Section 3.4.2. Subroutine DWRIT (entry point DWRIT 2) also prints the output entitled "Distribution System Description" with results in both English and metric units. This output summarizes the calculated heat demands, brine temperatures, brine flow rates, and costs by district for the distribution system. The output is illustrated in the sample output on page E-27.

PROP — Calculates the convective heat-transfer coefficient for fluid flow in a cylindrical pipe based on the Dittus-Boelter equation as follows:

$$h_{conv} = \frac{.0225 * K * Re^{0.8} * Pr^{0.4}}{D}$$

where:

h_{conv} = convective heat-transfer coefficient, joules/sec • meter^2 • ^oK

K = thermal conductivity of the fluid, joules/sec • meter^2 • ^oK/meter

Re = Reynolds number

Pr = Prandtl number

D = inside pipe diameter, meters

PROP (Contd) Subroutine PROP is called by subroutine HEAT in order to calculate the portion of radial heat loss due to convection for fluid flow in a cylindrical pipe.

2.7 RESERVOIR ECONOMIC SUBMODEL

After the required total geothermal fluid flow is established, GEOCITY calls the reservoir economic submodel simulated by subroutine RESVOR and its associated subroutines. This submodel determines the cash flow associated with the exploration, development, and operation of the reservoir from the beginning of exploration through the economic life of the distribution system. The exploration process identifies and evaluates potential reservoir sites by a series of discrete steps, which can occur either sequentially in time or with some specified time overlap. Each step has a task description, time period, associated cost, and success ratio (finding rate). The major steps are: 1) identification of target sites, 2) preliminary reconnaissance, 3) detailed reconnaissance, 4) identification of drillable sites, 5) exploratory drilling, 6) development of the reservoir and fluid transmission and disposal system, and 7) operation of that system. Both capitalized and expensed costs are determined for each of the steps in the reservoir exploration. The total exploration cost calculated for the reservoir thermal capacity specified in the input data is prorated to provide the energy supply for the calculated distribution system heat demand in calculating the cost of energy to the distribution system.

Reservoir development and operation expenses are based upon the number of producing, nonproducing, and injection wells and the fluid transmission and disposal system established in the distribution system demand and fluid transmission iteration. Reservoir development costs include: drilling costs based upon the required number of wells and the drilling costs input for individual producing, nonproducing, and injection wells; capital cost of the fluid transmission system calculated in subroutine TRANS; and capital cost of the fluid disposal system calculated in subroutine INJECT. The cost of drilling producing wells is subdivided into both tangible and intangible drilling costs because tax regulations may treat these costs differently.

Costed reservoir operation tasks include: replacement well drilling, subdivided into tangible and intangible costs; nonproducing well drilling associated with replacement wells; well abandonment and maintenance; overhead and management; well redrilling due to scale buildup; and fluid transmission and disposal maintenance. Both reservoir development and operation costs are computed on the basis of the calculated distribution system size.

Using discounted cash flow analysis, the unit cost of energy from the reservoir is calculated by equating the present worth of the revenues and expenses from the beginning of reservoir exploration through the economic life of the distribution system. Descriptions follow of the subroutines associated with subroutine RESVOR and the reservoir economic submodel.

CLEAR	Clears consecutive locations in memory for initializing arrays in various subroutines to zero.
TARGTS	Calculates the number of prospective geothermal sites to explore in each of the successive discrete steps comprising the reservoir exploration process, based upon the success ratios (finding rates) input for each step. The successive reduction in the number of sites to explore at each step culminates in a single producible site at the last step, completing the exploration process.
DATACK	Prints the financial and tax input data for the reservoir and both calculates and prints the reservoir's annual cash flow statement from exploration through the economic life of the distribution system. This statement includes each year of exploration, development, and operation of the reservoir, the distribution system load factor or fraction of annual time the distribution system is operating at full capacity, and the cash flows computed on an annual basis for the following items: identifying geothermal target sites, remaining reservoir exploration beginning with preliminary reconnaissance, reservoir development, reservoir operation, property taxes and insurance, interim

DATACK (Contd)	capital replacements for the fluid transmission and disposal system, and the sum of these costs.
FACTRS	Calculates the present worth discount factor based on the cost of capital from both debt (bond) and equity (stock) financing, using the effective bond interest rate after taxes. All expenses and revenues are assumed to be incurred at midyear. If year-end discounting is desired, the variable TIMD appearing in subroutine FACTRS should be reset from 0.5 to 1.0 in the BLOCK DATA subroutine. Subroutine FACTRS is called by both the reservoir and distribution economic subroutines as shown in Figure 3.
PWRCO	Calculates the annual reservoir operating expenses from exploration through the economic life of the distribution system. Subroutine PWRCO also calls subroutine DEPREC to calculate well depreciation and reservoir depletion and depreciation. These are printed by subroutine OUTPUT in the statement of annual deductible expenses.
DEPREC	Calculates the annual depreciation of the reservoir capital assets, including interim capital replacements. The input parameter LL2 selects one of two available options: the straight line method (LL2 = 1) or the sum-of-years-digits method (LL2 = 2).
COSTEQ	Calculates the unit cost of energy from the reservoir by setting the present worth of the revenues equal to the present worth of the expenses from the beginning of reservoir exploration through the economic life of the distribution system.

Unit cost of energy (cents/MBtu) = (present worth of the expenses - present worth of tax credits)/ [(present worth of energy supplied) * (1 - state gross revenue tax rate) * (1 - combined federal and state income tax rate)]

COSTEQ (Contd) The present worth of energy supplied takes into account the distribution system load factor.

PAYOUT Calculates the annual income statement and annual payout of investments for the reservoir. This includes the total energy sales (gross revenues), state and federal income taxes, revenue taxes, royalty payments, and the changes in capitalization: outstanding bonds, bonds repaid, unrecovered equity, equity recovered, bond interest, and earnings on unrecovered equity.

OUTPUT Prints the statements of annual deductible expenses, income, and payout of investments for the reservoir from the beginning of reservoir exploration through the economic life of the distribution system. The statement of annual deductible expenses lists the items: year, present worth factor for that year, reservoir operating expenses, bond interest, well depreciation, reservoir depletion and depreciation, total deductible operating expenses, and state income taxes. The statement of annual income lists the items: year, trillion Btu of energy supplied, energy sales, revenue taxes, royalty payments, total tax deductible expenses, taxable income (federal), and federal income tax. The statement of payout of investments lists the items: year, net cash flow, outstanding bonds, equity capital not recovered, bond interest, earnings on unrecovered equity, bonds repaid, and recovery of equity.

SUMARY Calculates and prints the breakdown of the unit cost of energy from the reservoir in cents/MBtu and equivalent annual costs in millions of dollars. These are itemized as follows: identification and exploration, development, operating costs, revenue taxes, state income taxes, royalty payments, federal income taxes and bond interest. In another set of calculations, the taxes, royalty payments, SUMARY (Contd) and bond interest are reallocated to the direct cost components for the reservoir: identification and exploration, development, and operating costs. The rate of return on investment is included in the distributed energy cost for each component. The deductible nature of the bond interest causes this expense to be partially included in the rate of return (the part which is included in the present worth factor) and the remainder to be accounted for separately.

2.8 DISTRIBUTION ECONOMIC SUBMODEL

The reservoir revenue is a cost to the distribution system. GEOCITY calls the distribution economic submodel, simulated by subroutine DISTRB and its associated subroutines. This submodel combines the energy cost from the reservoir with the distribution capital and operating costs and generates the cash flow associated with the design, construction, and operation of the distribution system throughout its useful life. The required revenue and unit cost of heat are determined by using discounted cash flow analysis, and equating the present worth of the revenues and expenses over the economic life of the distribution system. Descriptions of the subroutines associated with subroutine DISTRB and the distribution economic submodel follow.

HCONST Calculates the following costs appearing in the annual cash flow statement for the distribution system: capital costs, operating costs, interim capital replacements, property taxes and insurance, the sum of all these costs with the energy cost from the reservoir, and investment tax credits. The total capital cost of the distribution system for the construction period (NYC years, specified in the input data) is calculated in subroutine DIST according to the component capital cost models in Appendix B. This cost includes the following items: pipe, insulation, casing, fittings, expansion loops, trenches, valves, meters, pumps, metering and control equipment, buildings and land use, building retrofit (optional), heat exchanger (optional), HCONST (Contd) and engineering and administration. Subroutine HCONST apportions the capital cost by year over the number of years (NYC) input for distribution system construction. The apportionment is based on the following function.

$$C(t) = \frac{100}{\left[1 + e^{k(a-t)}\right]}$$

where:

- C(t) is the cumulative percent expenditure at time t.
- k is a constant, 0.0847.
- a is the 50% expenditure point in time, currently set to the 60% point in the construction schedule.
- t is the time in years from beginning of construction.

If the option to allow growth in heating demand is specified in the input data (NYGRO > 0), additional annual capital costs beyond the construction period are calculated in subroutine HCONST. Additional capital costs during each year after the first year of operation are calculated by applying a compound growth curve to the total street and house pipe capital costs incurred during the construction period. Only additional street and house pipe capital costs are calculated beyond the construction period because the distribution system model designs the main and lateral pipes with sufficient capacity to meet the specified future growth.

Annual operating costs are calculated in subroutine DIST according to the operating cost models in Appendix B. This includes the following items: personnel costs for operating the distribution system and for administrative

HCONST (Contd) functions; routine repair and maintenance of the distribution system; pump operating costs; meter readers; supplemental heating costs; and operation of a heat exchanger (optional).

If the growth option is specified, subroutine HCONST increases the annual operating costs after the first year of operation during each year of growth. The proportion of operating costs attributed to the expansion of street and house pipes is increased annually during the growth period according to a compound growth curve. The computed increment in the operating cost in year N from the first year of operation is added to the first-year operating cost to obtain the operating cost in year N during the period of growth.

Interim capital replacements are calculated as a fraction of construction period capital costs.

> Interim capital replacements ($) = [input fraction DINPUT(53), with default value 0.0035] * (construction period capital cost)

Property taxes and insurance are calculated annually as a fraction of total capital costs (construction period capital costs plus all interim capital replacements) up to the year of interest in the calculation.

> Property tax ($) = [input fraction DINPUT(52), with default values 0.0250] * (total capital cost up to the year of interest in the calculation)

> Property insurance ($) = [input fraction DINPUT(54), with default value 0.0012] * (total capital cost up to the year of interest in the calculation)

HCONST (Contd) Investment tax credits in the first year of operation are calculated as a fraction of construction period capital cost and interim capital replacements during the first year of operation.

Investment tax credit ($) = [0.01 * input percentage PIVTCP, with default value 0] * (construction period capital cost and interim capital replacements in the first year of operation)

Investment tax credits in subsequent years of operation are calculated as a fraction of the interim capital replacements.

> Investment tax credit ($) = [0.01 * input percentage PIVTCP, with default value 0] * (interim capital replacements in the year of interest)

Subroutine HCONST also calculates the annual net production of useable heat (after allowance for heat losses in the distribution system piping) in units of Btu/yr and MBtu/yr. If the growth option is specified, the annual net production of useable heat is increased after the first year of operation according to a compound growth curve.

DATAK Prints the financial and tax input data for the distribution system.

DPREC Calculates the annual depreciation of the distribution system capital assets, including interim capital replacements. The input parameter LL2 selects one of two available options: the straight line method (LL2 = 1) or the sum-of-years-digits method (LL2 = 2).

COSTEG Calculates the unit cost of heat from the distribution system by setting the present worth of the revenues equal to the present worth of the expenses throughout the economic life of the distribution system.

COSTEG (Contd) Unit cost of heat (cents/MBtu) = (present worth of expenses - present worth of tax credits)/[(present worth of heat production) * (1 - state gross revenue tax rate) * (1 - combined federal and state income tax rate)].

The present worth of heat production takes into account the distribution system load factor.

PAYOT Calculates the distribution system's annual income statement and annual payout of investments. This includes the total heat sales (gross revenues), total tax deductible expenses, taxable income (federal), state and federal income taxes, revenue taxes, and the changes in capitalization: outstanding bonds, bonds repaid, unrecovered equity, equity recovered, bond interest, and earnings on unrecovered equity.

OUTPLT Prints the statements of annual cash flow, tax deductible expenses, income and payout of investments from the beginning of distribution system construction through its economic life. The statement of annual cash flow lists the items: year, distribution system load factor, capital costs, energy costs from the reservoir, distribution operating costs, interim capital replacements, property taxes and insurance, and the sum of these costs. The statement of annual tax deductible expenses lists the items: year, present worth factor for that year, operating expenses, bond interest, depreciation, total deductible operating expenses, and state income taxes. The statement of annual income lists the items: year, trillion Btus of heat produced, heat sales, revenue taxes, total tax deductible expenses, taxable income (federal), and federal income tax. The statement of payout of investments lists the items: year, net cash flow, outstanding bonds, equity

OUTPLT (Contd)	capital not recovered, bond interest, earnings on unrecovered equity, bonds repaid, and recovery of equity.
CPOWER	Calculates and prints the breakdown of the unit cost of heat from the distribution system in cents/MBtu and equivalent annual costs in millions of dollars. These are itemized as follows: distribution system capital costs, interim capital replacements, energy supply from the reservoir, operating expenses, property taxes and insurance, revenue taxes, state income taxes, federal income taxes, and bond interest. The difference between the unit cost for energy supply at the distribution system and the unit cost of energy from the reservoir calculated in subroutine COSTEQ is caused by heat losses in the distribution system piping. In another set of calculations, the taxes and bond interest are reallocated to the direct cost components for the distribution system: capital costs, interim capital replacements, energy supply, operating expenses, and property taxes and insurance.

2.9 STEAM TABLE FUNCTIONS

Tables 1 and 2 give the 1967 ASME Steam Table functions used to calculate thermodynamic and physical properties of water and steam, their arguments, and the temperature-pressure subregions in which they are applicable. The subregions are illustrated relative to the saturation line on the temperature-pressure diagram in Figure 7. Subregion 6 is the area just above and below the saturation line. When calculations of properties are needed near the critical point in subregion 5, the accuracy of the functions used should be checked against the individual requirements since the properties vary rapidly in this area. Definitions for the symbols used in Tables 1 and 2 follow.

p - Pressure, psia
t - Temperature, °F
h - Specific Enthalpy, Btu/lb
s - Specific Entropy, Btu/lb-°F

v - Specific Volume, ft^3/lb

x - Quality by weight fraction, %/100

μ - Viscosity, lb/ft-sec

k - Thermal conductivity, Btu/hr-ft-°F

Pr - Prandtl number

Vc - Critical velocity, ft/sec

Fc - Critical flow, $lb/hr\text{-}in^2$

γ - Isentropic exponent (pv^{γ} = Constant)

°s - Degrees superheat

Many of the functions are interdependent. Consequently, if the use of a function is desired the majority of the steam table functions must be loaded into computer memory.

GEOCITY initially calls the following subroutines in the steam tables to initialize steam table constants appearing in labeled common: CCSR1, CCSR2, CCSR3, CCBLL, and COMALL.

TABLE 1. ASME Steam Table Single Valued Functions

State Unknown
(either wet (two-phase) or superheated)

FORTRAN Code Name	Function	Subregion
HPS	h = f(p,s)	2, 3, 4
SPH	s = f(p,h)	2, 3
VPH	v = f(p,h)	2, 3
VPS	v = f(p,s)	2, 3, 4
TPH	t = f(p,h)	2, 3, 4
TPS	t = f(p,s)	2, 3, 4
THS	t = f(h,s)	2, 3, 4, 6
PHS	p = f(h,s)	2, 3, 4, 6
XPH	x = f(p,h)	
XPS	x = f(p,s)	

Saturation Line and Wet Steam

FORTRAN Code Name	Function	Subregion
HPSW	h = f(p,s)	6
SPHW	s = f(p,h)	6
VPHW	v = f(p,h)	6
VPSW	v = f(p,s)	6
TSL/TSATP	t = f(p)	Sat. Line
PHSW	p = f(h,s)	6
PSL/PSATT	p = f(t)	Sat. Line

Superheated Steam

HPSD	h = f(p,s)	2, 3, 4
HPTD	h = f(p,t)	2, 3, 4
SPHD	s = f(p,h)	2, 3, 4
SPTD	s = f(p,t)	2, 3, 4
VPHD	v = f(p,h)	2, 3, 4
VPSD	v = f(p,s)	2, 3, 4
VPTD	v = f(p,t)	2, 3, 4
TSUPH/TPHD	t = f(p,h)	2
TSUPS/TPSD	t = f(p,s)	2, 3, 4
THSD	t = f(h,s)	2, 3, 4
PHSD	p = f(h,s)	2, 3, 4
VISV	μ = f(p,t)	2, 3, 4
CONDV	k = f(p,t)	2, 3, 4
PRSTM	Pr = f(p,t)	2, 3, 4

Compressed Liquid

HPTL	h = f(p,t)	1, 3, 4
SPTL	s = f(p,t)	1, 3, 4
VPTL/VCL	v = f(p,t)	1, 3, 4
TPHL	t = f(p,h)	1, 4
TPSL	t = f(p,s)	1, 4
VISL	μ = f(p,t)	1, 2, 3, 4
CONDL	k = f(p,t)	1
PRLIQ	Pr = f(p,t)	1

Saturated Vapor

HGP	h = f(p)	Sat. Line
HGT	h = f(t)	Sat. Line
SGP	s = f(p)	Sat. Line
SGT	s = f(t)	Sat. Line
VGP	v = f(p)	Sat. Line
VGT	v = f(t)	Sat. Line
PSV	p = f(s)	Sat. Line

Saturated Liquid

TSLH	t = f(h)	Sat. Line
HFP	h = f(p)	Sat. Line
HFT/HSL	h = f(t)	Sat. Line
SFP	s = f(p)	Sat. Line
SFT/SSL	s = f(t)	Sat. Line
VFP	v = f(p)	Sat. Line
VFT/VSL	v = f(t)	Sat. Line

Some subroutines have been given two names separated by a / mark. When calling these subroutines, the names can be used interchangeably.

TABLE 2. ASME Steam Table Multiple Valued Functions

FORTRAN Code Name	Function	State
HSSISS	$h,t,v,x = f(p,s)$	Wet or Superheated Steam
HPSISS	$h,t,v,x = f(p,s)$	Superheated Steam
HSS	$h,s,v = f(p,t)$	Superheated Steam
HSV	$h,t,s,v = f(p)$	Saturated Vapor
HCL	$h,s = f(p,t)$	Compressed Liquid
HSSICL	$h,t = f(p,s)$	Compressed Liquid
SSSISS	$s,t,v,x = f(p,h)$	Wet or Superheated Steam
SPSISS	$s,t,v,x = f(p,h)$	Superheated Steam
SSICL	$s,t = f(p,h)$	Compressed Liquid
CRFLO	$fc,\ {}^{\circ}S = f(p,h)$	Wet or Superheated Steam
CRVEL	$Vc,\ \gamma = f(p,h)$	Wet or Superheated Steam
Isentropic Drop Subroutines		
ZSDT	$h_1,s_1,x_1,v_1,t_2,x_2,v_2,h_2 = f(p_1,p_2,t_1)$	Wet or Superheated Steam
ZSDH	$t_1,s_1,x_1,v_1,t_2,x_2,v_2,h_2 = f(p_1,p_2,h_1)$	Wet or Superheated Steam
ZSRT	$h_1,s_1,t_2,h_2 = f(p_1,p_2,t_1)$	Compressed Liquid
ZSRH	$t_1,s_1,t_2,h_2 = f(p_1,p_2,h_1)$	Compressed Liquid

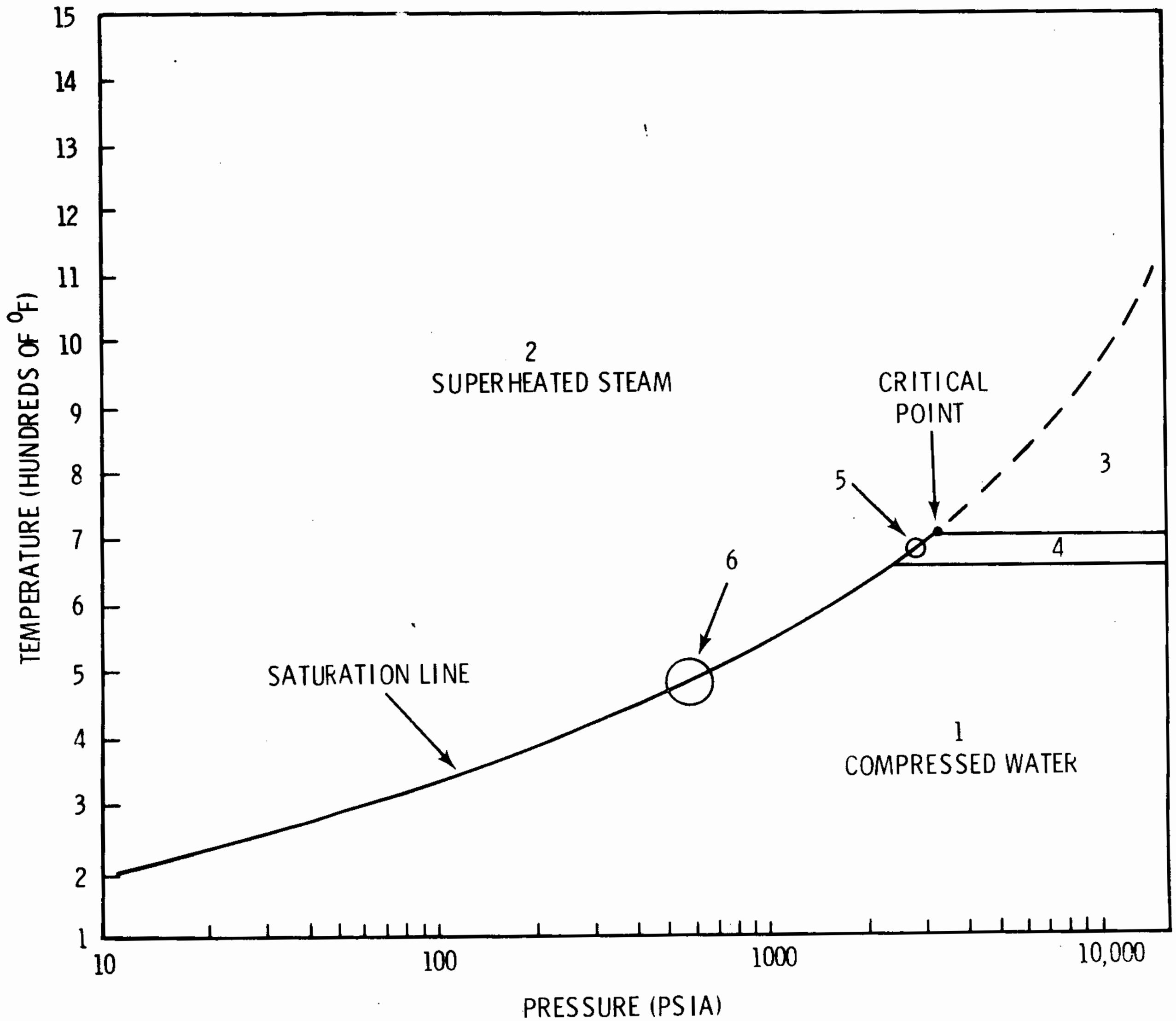


FIGURE 7. Steam Table Subregions as a Function of Temperature and Pressure

3. PREPARATION OF INPUT DATA

3.1 NAMELIST INPUT RULES

The first card required in the input data specifies a Hollerith title of 80 characters or less for identifying the simulation printout. The remaining data cards permit the user to override default values initialized for the input variables in the BLOCK DATA subroutine. These cards are input using the NAMELIST statement, which permits input of numerical values for variables and arrays preceded by the identifying variable or array names. No format specification is used. This section gives a brief description of the NAMELIST rules for the Cyber computer, which are applicable to most other machines with minor variations. The reader may wish to consult the FORTRAN manual available at his/her installation for a more detailed discussion. A sample case illustrating the NAMELIST input is given in the next section. The reader may find it helpful to refer to the sample input during the following discussion. The definitions of the NAMELIST input variables and their default values in GEOCITY are given following the sample input.

The NAMELIST input to GEOCITY is composed of two sets of data: 1) the reservoir and transmission system data and 2) the distribution system data. The reservoir and transmission system data begin in column 2 of the second data card (the first card is the title card mentioned above) with the NAMELIST group name $RESVOR. The distribution system data begin in column 2 of the data card following the reservoir and transmission system data with $DISTRB. Each NAMELIST group name is separated by one or more spaces from its succeeding list of variables, array names, and their numerical values.

Input variables and arrays may be defined in three ways.

- variable = constant
- array name = constant,...,constant,
- array name (integer constant subscript) = constant,...,constant,

Commas separate each definition from succeeding definitions. Constants can be preceded by a repetition number and an asterisk, as for example, array name = 3 * 1.0. This sets the first three locations in the array to the values 1.0. In defining arrays, the number of constants, including repetitions, given for an array name should not exceed the number of elements in the array. The number of elements in the GEOCITY arrays are given accompanying the definition of the input variables and their default values following the sample input case. When data are input using the definition, array name (integer constant subscript) = constant,...,constant, the array elements are defined consecutively beginning with the location given by the integer constant subscript. The number of constants need not equal, but may not exceed, the remaining number of elements in the array.

Integer or real constants are converted to the type of the variable or array. All input variables to GEOCITY beginning with the letters I through N, except the variables IO and KINS, are integer. The variables IO and KINS are declared real (floating point) variables in GEOCITY. All other input variables are real.

The variables, array names, and their numerical values succeeding the NAMELIST group name $RESVOR or $DISTRB are read until another $ is encountered to complete the definition of the input data for the reservoir and transmission system or distribution system respectively. Variables may be in any order. Blanks may be used freely to improve readability except between $ and RESVOR or $ and DISTRB, or within array names and variable names, or within numerical values.

A minimum of three data cards is needed to define the input data for a simulation case. The first column of each card is ignored and should not contain any data. All cards except the last for a NAMELIST group name must end with a constant followed by a comma. The last card for each NAMELIST group name must end with a $ sign.

Consecutive simulation cases can be set up in the input data. Each new simulation case requires the following cards: 1) a title card, 2) a $RESVOR card and, when necessary, continuation cards defining the NAMELIST input variables to be changed from the preceding simulation case for the reservoir and transmission system, and 3) a $DISTRB card and, when necessary, continuation cards defining the NAMELIST input variables to be changed from the preceding simulation case for the distribution system. The last card for each NAMELIST group name must end with a $ sign. The input data for a simulation case may consist of any subset of the NAMELIST input variables. In setting up consecutive simulation cases in the input data, only the input variables with values differing from the preceding simulation case require redefinition. The values of variables and arrays not included in the input data for a particular simulation case remain unchanged from:

- The default values in BLOCK DATA for the first simulation case.
- The values from the preceding simulation case for cases after the first case.

If no values are to be changed from the default values in BLOCK DATA in the first simulation case, the input data consists of: 1) a title card, 2) a card with $RESVOR $ beginning in column two, and 3) a card with $DISTRB $ beginning in column two.

3.2 INPUT INSTRUCTIONS AND SAMPLE CASE INPUT

The data input to GEOCITY consists of the following three types of cards:

- A title card of 80 characters or less to identify the simulation printout.
- Data cards defining values for the reservoir and transmission system input variables beginning in column two with $RESVOR according to NAMELIST input rules.
- Data cards defining values for the distribution system input variables beginning in column two with $DISTRB according to NAMELIST input rules.

The following steps are suggested for preparing the data input:

Step 1. Review the NAMELIST input rules summarized in the preceding section.

Step 2. Prepare a title card of 80 characters or less.

Step 3. Prepare cards defining the technical and economic input variables for the reservoir and transmission system following the NAMELIST input rules.

Step 4. Prepare cards defining the technical and economic input variables for the distribution system following the NAMELIST input rules.

All input variables and their default values are defined in the next section. Those input variables not included in the list of variables in the data cards for a given case are left set to the default values. To aid the user, an overview of the key technical and economic input variables and their default values is summarized in Table 3.

To illustrate the input instructions, a sample case input is shown below for simulating a simplified version of the district heating system for Akureyri, Iceland. The distribution system is supplied with hot water from wells distributed throughout a hydrothermal reservoir through transmission pipelines. The city is divided into 8 districts, classified according to two district types: residential or industrial. The layout of the districts used in the Akureyri simulation is shown in Figure 8. The size and relative location and heat demand density of the districts based on data obtained on Akureyri are shown in Table 4.

A network of branching mains, shown in Figure 8, is used to transport the hot water from the distribution center to the districts. The districts served by the mains are defined by the matrix DNET (District no., Main no.), shown in Table 4 and summarized below:

Main	Districts Served by Main
1	1,2,3,4,5,6,7
2	3,4
3	5
4	8

TABLE 3. Key Technical and Economic Input Variables and Default Values

Input Variables	FORTRAN Name	Default Value
Reservoir Characteristics and Well Properties		
Well Flow Rate	FLORAT	400,000 lb/hr
Wellhead Temperature	PWTEMP	100°C
Well Life	AVGWL	10 yr
Well Spacing	WELSPC	20 acres
Wellhead Pressurization Factor (≥1.)	PRFACT	2.
Reservoir Financial and Tax Data		
Fraction of Initial Investment in Bonds	DINPUT (4)	0.42
Bond Interest Rate	DINPUT (5)	0.08
Equity Earning Rate After Taxes	DINPUT (6)	0.15
Federal Income Tax Rate	DINPUT (7)	0.48
State Income Tax Rate	DINPUT (15)	0.07
Property Tax Rate	DINPUT (17)	0.025
Distribution System Operating Life	DINPUT (26)	30 yr
Royalty Payment	DINPUT (27)	10%
Individual Well Drilling Costs		
Producing Well	DCPW	$400,000.
Nonproducing Well	DCNPW	$300,000.
Injection Well or Exploratory Well	DCINJW	$350,000.
Distribution Financial and Tax Data		
Fraction of Initial Investment in Bonds	DINPUT (39)	0.59
Bond Interest Rate	DINPUT (40)	0.08
Equity Earning Rate After Taxes	DINPUT (41)	0.12
Federal Income Tax Rate	DINPUT (42)	0.48
State Income Tax Rate	DINPUT (50)	0.07
Property Tax Rate	DINPUT (52)	0.025
Distribution System Operating Life	DINPUT (61)	30 yr
Distribution System Characteristics		
Length of Transmission Line	DRES	10 miles
Total Annual Degree Days	ADGDAY	6500°F days
Degree Days at Design Temperature	DDGDAY	6000°F days
Minimum Outdoor Temperature	TMIN	-5°F
Design Outdoor Temperature	TDES	0°F
Number of Districts in the City	NDTR	1
Type N of District for District Number M	IDTR (M)	1 (suburban)
Density of Buildings in District Type N	DENSE (N)	Table 8
Peak Heat Demand per Building in District Type N	HQ (N)	Table 8
Daily Hot Water Demand per Building in District Type N	HW (N)	Table 8
Temperature of Return Water in District Type N	TREJ (N)	Table 8
Diversity Factor in District Type N	DIVF (N)	Table 8
Area of District Number M	AREA (M)	1 sq. mile
Width of District Number M	WIDTH (M)	1 mile
Length of District Number M	XLNGTH (M)	1 mile
Length of Main to District Number M	DDTR (M)	1 mile
Pipe Option for Distribution System	PO	1 (insulated supply, uninsulated return)
Pipe Material Option	PMO	1 (carbon steel)
Insulation Option	IO	1 (calcium siliate)
Casing Option	CO	1 (prefabricated steel)
Branching Mains Option	DNET (district no. M, main no. MM)	All 0s

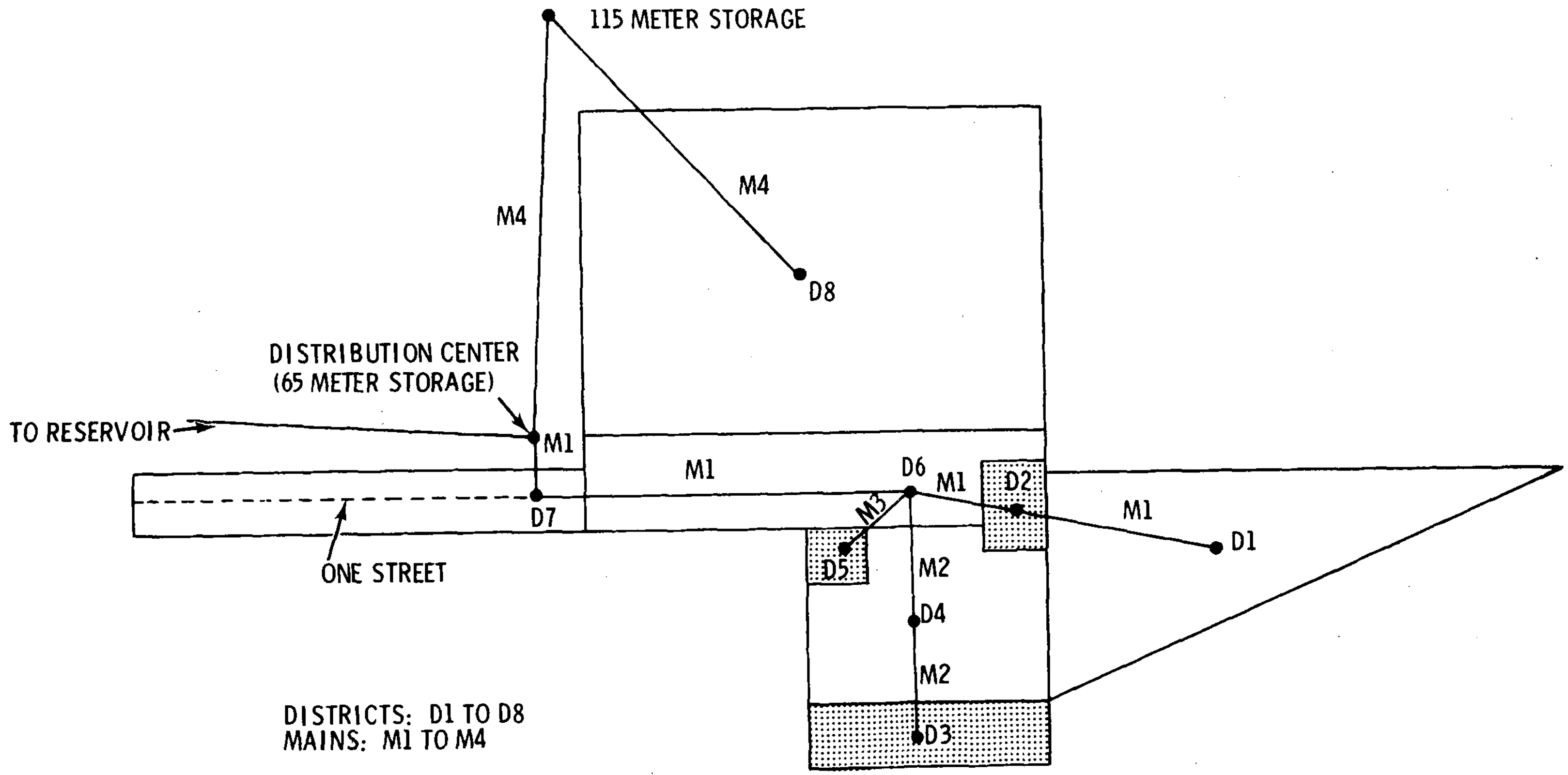


FIGURE 8. Layout of Districts and Mains for Simplified Version of Akureyri, Iceland, District Heating System with Branching Mains

TABLE 4. Summary of District Input Data for GEOCITY Simulation of Akureyri

District Definition Parameters

GEOCITY District Number	District Type	Area (sq.mi.)	Width (mi.)	Length (mi.)	Length of Main Serving the District (mi.)
1	1	0.193	0.932	0.466	0.404
2	2	0.023	0.124	0.180	0.217
3	2	0.062	0.124	0.497	0.28
4	1	0.185	0.373	0.497	0.249
5	2	0.015	0.124	0.124	0.186
6	1	0.232	0.248	0.932	0.777
7	1	0.156	0.932	0.167	0.124
8	1	0.399	0.932	0.932	1.740

District Type Parameters

District Type	Density (Bldg/ sq.mi.)	Peak Heat Demand/Bldg. (MBtu/hr)	Hot Water Demand (gal/day)	Diversity Factor	Reject Temperature (°F)
1 (Residential)	2731	0.0254	37.8	0.72	113.
2 (Industrial)	3000	0.1905	0.	0.72	113.

Branching Main Matrix

Matrix DNET (District No., Main No.) Defining the Districts Served by the Mains

Main Number

District Numbers Served by Main	1	2	3	4	5 . . . 20
1	2	0	0	0	
2	2	0	0	0	
3	1	2	0	0	All 0s
4	1	2	0	0	
5	1	0	2	0	
6	2	0	0	0	
7	2	0	0	0	
8	0	0	0	2	
9					
.	All 0s				
.					
20					

63

Definition of Matrix Entries

0 - main does not serve district

1 - main transports flow to district through branching main

2 - main transports flow directly to district

The distribution system is designed as a single pipe system (PO=6) in which the used water is disposed through the sewer system (INJP=0). The design features of the distribution piping system are:

- Single supply pipe, seamless schedule 40 carbon steel (PO = 6, PMO = 1)
- Polyurethane foam insulation (IO = 2)
- Polyvinyl chloride (PVC) casing with no annular air spacing (CO = 2, TA = 0.)
- Conduit buried 1/2 meter deep in a dirt and rock mixture (default trenching model in Section 3.4.4.4)
- Transmission line, mains, laterals and street pipes designed to meet current (1978) diversified peak heat demand (GROWTH (District no.) = 0, DIVF (district type) = .72).

SAMPLE CASE INPUT

```
Col. 2
 DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI, ICELAND
 $RESVOR FLORAT= 500000., PWTEMP=90., AVGWL=30., FRCEPW=0.1,
  FRCNPW=0.05, DCPW=200000., DCNPW=150000., DCINJW=175000.,INJP=0,
  IAVWEL=1, DINPUT(4)=1., DINPUT(6)=0, DINPUT(14)=1978, LL6=1$
 $DISTRB DRES=7.46, NDTR=8, ADGDAY=10800., DDGDAY=10440., TMIN=-2.2,
  TDES=10.4, DENSE=2731., 3000., 6*0., HQ=.0254, .1905, 6*0., HW=37.8,
  7*0., TREJ=2*113., 6*0, IDTR=1,2,2,1,2,3*1,12*0,
  AREA=.193,.023,.062,.185,.015,.232,.156,.399,12*0.,
  WIDTH=.932,.124,.124,.373,.124,.248,.932,.932,12*0.,
  XLNGTH=.466,.18,.497,.497,.124,.932,.167,.932,12*0.,
  DDTR=.404,.217,.28,.249,.186,.777,.124,1.74,12*0.,
  DNET=2,2,1,1,1,2,2,13*0,0,0,2,2,16*0,4*0,2,15*0,7*0,2,12*0,320*0,
  PO=6, IO=2,CO=2,TA=0., VMBTU=3, DINPUT(39)=1., DINPUT(41)=0.,
  DINPUT(49)=1978.$.
```

The key technical and economic input conditions selected for defining the reservoir, transmission, and distribution system characteristics are summarized below. The input variables not included above were left set to the default values defined in Sections 3.3 and 3.4.

Reservoir and Transmission System Input Conditions

Variable	Description	Value
FLORAT	Maximum Flow Rate per Well	500,000 lb/hr
PWTEMP	Wellhead Temperature	90°C
AVGWL	Average Well Life	30 yr
FRCEPW	Fraction of Excess Producing Wells	0.1
FRCNPW	Fraction of Dry Wells	0.05
DCPW	Drilling Cost of Producing Well	$200,000/well
DCNPW	Drilling Cost of Dry Well	$150,000/well
DCINJW	Drilling Cost of Exploratory Well	$175,000/well
INJP	Option to Reinject into Injection Well Field	No (Use Sewer System)
IAVWEL	Option to Reduce Recomputation in Fluid Transmission Submodel	Yes
DINPUT(4)	Fraction of Reservoir and Transmission System Investment in Bonds	1.
DINPUT(6)	Earning Rate on Reservoir and Transmission System Equity After Taxes	0.
DINPUT(14)	Start-up Year for Operation of the Distribution System	1978
LL6	Option to Print Distribution System Demand and Fluid Transmission Iteration History	1(Last Iteration Only)

Distribution System Input Conditions

Variable	Description	Value
DRES	Length of Transmission Line to City Distribution Center	7.46 miles
NDTR	Number of Districts in City	8
ADGDAY	Total Annual Degree Days	10,800 °F days
DDGDAY	Degree Days at System Design Temperature	10,440 °F days
TMIN	Minimum Outdoor Temperature	-2.2°F
TDES	Design Outdoor Temperature	10.4°F
DENSE(N)	Density of Buildings in District Type N	Table 4
HQ(N)	Peak Heat Demand per Building in District Type N	Table 4
HW(N)	Daily Hot Water Demand per Building in District Type N	Table 4
TREJ(N)	Temperature of Return Water in District Type N	Table 4
IDTR(M)	District Type N of District Number M	Table 4
AREA(M)	Area of District Number M	Table 4
WIDTH(M)	Width of District Number M	Table 4
XLNGTH(M)	Length of District Number M	Table 4
DDTR(M)	Length of Main Serving District Number M	Table 4
DNET(Dist. No., Main No.)	Matrix Defining the Districts Served by the Mains	Table 4
PO	Pipe Option	6(Supply Piping System Only)
IO	Insulation Option	2(Polyurethane Foam)
CO	Casing Option	2(Prefabricated Plastic (PVC) Casing)
TA	Casing Annular Air Space	0.

Distribution System Input Conditions

Variable	Description	Value
VMBTU	Value of One Million Btus of Heat, for Optimization of Insulation Thickness	$3/MBtu
DINPUT(39)	Fraction of Distribution System Investment in Bonds	1.
DINPUT(41)	Earning Rate on Distribution System Equity After Taxes	0.
DINPUT(49)	Start-up Year for Operation of the Distribution System	1978

The output corresponding to the sample case input is shown in Appendix E and discussed in Section 4. The option to print only the final iteration between the distribution system demand subroutine CALQNA and the fluid transmission submodel was selected (LL6 = 1). The default option to print the full distribution system output was used (DFLAG = .TRUE.). The default option to print the full economic output for the reservoir, transmission system, and distribution system was also used (LL11 = 1, LL12 = 1).

3.3 DEFINITION OF NAMELIST INPUT VARIABLES AND DEFAULT VALUES FOR THE RESERVOIR AND FLUID TRANSMISSION SYSTEM

This section defines all NAMELIST input variables and default values for the reservoir and fluid transmission system. The input variables are grouped into the following categories:

- Reservoir Characteristics and Well Properties
- Well Drilling Costs
- Fluid Transmission and Disposal
- Reservoir Financial and Tax Data
- Reservoir Exploration, Development, and Operation
- Output Options
- Miscellaneous Variables Used Only for Printout Information (Well Design and Stratigraphy)

The variables in the category, Well Design and Stratigraphy, are used only for informative purposes in the printout. Well drilling costs are input directly to GEOCITY rather than calculated internally as a function of well design and stratigraphy.

3.3.1 Reservoir Characteristics and Well Properties

AVGWL — Average production life (years) of reservoir wells. The default is 10 years.

FLORAT — Maximum flow rate (lb/hr) of the geothermal fluid from the reservoir wellhead. The default is 400,000 lb/hr/well.

FRCEPW — Fraction of excess producing wells to provide spare wells. The default is 0.2.

FRCNPW — Fraction of nonproducing (dry) wells. The default is 0.2.

PRDRAT — Ratio of injection well to producing well flow rate. The default is 2.

PWTEMP — Temperature of the geothermal fluid at the reservoir wellhead. Positive input values are treated as Centigrade and negative input values as Fahrenheit. The default is 100^{o}C.

PRFACT — Wellhead pressurization factor ($\geqq$ 1.) provided to set the wellhead pressure of the geothermal fluid at saturation (PRFACT=1.) or compressed liquid state (PRFACT > 1.). Subroutine DGHEAT sets the wellhead pressure as follows:

> Wellhead Pressure (psia) = PRFACT * (Pressure at saturation corresponding to the input wellhead temperature PWTEMP).

The default value of PRFACT is 2.

WELSPC — Reservoir well spacing in acres. The default is 20 acres.

3.3.2 Well Drilling Costs

DCPW — Total cost ($) of all tasks involved in drilling one producing well. The default is $400,000.

DCNPW — Total cost ($) of all tasks involved in drilling one nonproducing well. The default is $300,000.

DCINJW — Total cost ($) of all tasks involved in drilling either one exploratory well or one injection well. The default is $350,000.

PERCNT(N)
N = 1,2 — Fraction (not percentage) tangible and intangible parts respectively of the drilling costs for producing wells. The optional breakdown into tangible and intangible parts is provided because of possible differential tax treatment. The tangible part is capitalized and expensed through a depreciation account. The intangible part is expensed immediately. Nonproducing wells are expensed and injection wells are capitalized, with costs recovered through the depreciation account. The default values for the PERCNT array are as follows:

> PERCNT(1) = 1/3 fraction tangible,
> PERCNT(2) = 2/3 fraction intangible.

3.3.3. Fluid Transmission and Disposal

COPUMP — Electrical cost ($/kWh) of operating the transmission booster pumps to maintain geothermal fluid pressure at saturation or above saturation (compressed liquid state) in the fluid transmission lines. The default is 0.025$/kWh.

EVALUE(1) — Design parameter to change the internal diameters of all pipes in the fluid transmission system in order to alter the pressure degradataion. The equations optimizing the internal pipe diameters are programmed in subroutine PIPE. Since EVALUE(1) occurs with an exponent of 0.163 in these equations, an increase (decrease) in EVALUE(1) by a factor of 2, for example, will increase (decrease) the internal pipe diameter by about 12%. The default value of EVALUE(1) is 0.02.

IAVWEL — Option to speed up the execution time required to calculate the fluid degradation on a nodal basis in the transmission system. This option eliminates redundant calculations in a uniform matrix of well nodes. The execution time for the transmission system can be reduced almost in half for large well fields. This option activates subroutine STORE, which saves and retrieves variables previously calculated to describe the characteristics of the pipe and fluid exiting well (nonmanifold) nodes. Assuming that all reservoir wells have the same average conditions (temperature, pressure, etc.), the characteristics of the pipe and fluid exiting each node in a set of well (nonmanifold) nodes that have the same number of active wells upstream are identical. Therefore, these characteristics need only be computed once for this set of nodes. This property is illustrated in Section 4 describing the sample case output. This option should not be used when inactive well sites are present in the the well field matrix or when the wells have variable conditions.

IAVWEL (Contd)	0, calculate the fluid degradation individually for each well node.

1, calculate the fluid degradation individually only for those well nodes that have a different number of active wells upstream.

The default value for IAVWEL is 1.

INJP — Option to reinject the effluent water from the district heating system or heat exchanger.

0 = no reinjection
1 = reinjection

The default is reinjection into an injection well field. If no reinjection is specified, disposal of the effluent water is assumed to be into a sewage system or river. In this case, there is no cost for an injection well field. Both the supply and effluent (return) water are continuously maintained at saturation or above saturation (compressed liquid state) throughout the city district heating system by the use of booster pumps in the distribution system submodel (subroutine DIST). Both the capital cost and electrical cost of operating these pumps are factored into the accounting routines.

PLINJP — Distance (meters) from the city to the injection field. A pipe of this length is used to conduct the water effluent from the city or heat exchanger to the origin of the injection field if the reinjection option INJP is set to 1. The default distance is 1000 meters.

PLMANF — Distance (meters) from the first column of well nodes (J = 2 in Figure 11) to the manifold pipe nodes (J = 1). The default value of PLMANF is 0, in which case subroutine TRANS sets this distance identical to the distance between well nodes. To override the default value, set PLMANF to

PLMANF (Contd) the desired distance (meters) using the NAMELIST input data. The distance PLMANF applies to both the reservoir and injection fields.

PSALVG Fraction of transmission or disposal pipe that can be salvaged from a depleted or plugged well and used with a replacement well. This quantity is used in calculating the transmission and disposal interim capital replacement rates, as discussed later in the definition of DINPUT(18) and DINPUT(20). The default value for PSALVG is 0.1.

3.3.4 Reservoir Financial and Tax Data

DINPUT(N), N = 1,..., 35 is the array of financial and tax data for the reservoir defined below.

N	Description of Reservoir Parameters
1	Reservoir capital investment (millions of dollars), which is not input directly but calculated in subroutine RESVOR as the following sum: capitalized reservoir exploration costs + tangible part of drilling costs for producing wells + drilling cost of injection wells + capital cost of fluid transmission system + capital cost of fluid disposal system.
2	Project life (years) of reservoir and distribution system together, which is not input directly but calculated in subroutine RESVOR as the following sum: number of years from the beginning of reservoir exploration to the startup of distribution system operation + number of operating years of the distribution system, defined in DINPUT(26).
3	Not used; default is 0.
4	Fraction of initial investment in bonds; default is 0.42.
5	Bond interest rate; default is 0.08.
6	Earning rate on equity after taxes; default is 0.15.
7	Federal income tax rate; default is 0.48.

8 Reservoir thermal capacity (MWth); default is 400 MWth.

9 Depreciable life of reservoir wells (years); default is 10 yr. This is automatically set equal to the average reservoir well life (AVGWL) in subroutine LOAD.

10-13 Not used; default is 0.

14 Startup year for operation of the distribution system, default is 1985. The same year must also appear in DINPUT(49) in Section 3.4.5.

15 State income tax rate; default is 0.07.

16 State gross revenue tax rate; default is 0.

17 Property tax rate; default is 0.025.

18 Transmission system interim capital replacement rate, fraction of transmission capital cost. This rate is not input directly, but calculated in subroutine TRANS as (1. - PSALVG)/AVGWL, where PSALVG, input through NAMELIST, is the fraction of transmission pipe that can be salvaged, and AVGWL, input through NAMELIST, is the average reservoir well life (years).

19 Property insurance rate; default is 0.0012.

20 Disposal system interim capital replacement rate, fraction of disposal capital cost and cost of drilling injection wells. This rate is not input directly, but set equal to the transmission system interim capital replacement rate calculated in subroutine TRANS.

21-25 Not used; default values are 0.

26 Distribution system operating life (years); default is 30 years. The same time must also appear in DINPUT(61) is Section 3.4.5.

27 Royalty payments, percentage of reservoir annual power sales; default is 10%.

28 Transmission system maintenance rate, fraction of transmission capital cost; default is 0.05.

29 Disposal system maintenance rate, fraction of disposal capital cost; default is 0.05.

30-35 Not used; default values are 0.

DA Percentage depletion allowance. The default is cost depletion allowance (DA = 0.)

PIVTCR Percent investment tax credit for the reservoir, which applies only to the first year of energy production. The default is 0.

3.3.5 Reservoir Exploration, Development, and Operation

ACRES Size (acres) of each prospective geothermal site leased for reservoir exploration. This quantity is multiplied by the input unit costs per acre associated with lease procurement (UNITO(N), N = 6, 7, 8 in Tables 5A and 5B) to calculate the lease cost per site. Appendix A contains the cost equations for lease procurement. The default value is 15,000 acres.

LAGS (ITEX(N), K), ITEX(N) = 1, ..., 22; K = 1, 2 - Time array to schedule the tasks defining reservoir exploration, development, and operation in Tables 5A and 5B according to costs and the time the tasks are to take place. An internal array in subroutine RESVOR, ITEX(N), N = 1, ..., 39, currently subdivides the 39 tasks in Tables 5A and 5B into 22 subgroups of tasks as shown in Table 6. All tasks within a given subgroup are presumed to occur parallel in time. However, the user has the flexibility to schedule the different subgroups of tasks either sequentially or parallel in time.

The starting month and duration in months (≧1) for each set of tasks grouped together are defined by means of the input time array LAGS(ITEX(N), 1) and LAGS(ITEX(N), 2) respectively, indexed by the array ITEX. The starting month for

TABLE 5A. Tasks and Input Costs for Reservoir Exploration, Development, and Operation

Index for Itemizing Individual Tasks	Index for Grouping Tasks	Description of Grouped Tasks	Unit Costs (Dollars) for[a] Individual Tasks
N	IGP = GROUP(N)	RESERVOIR EXPLORATION TASKS	UNITO(N)
		Identification of Targets	
1	1	Literature Search	100./site
2	2	Preliminary Land Check	250./site
		Preliminary Reconnaissance	
3	3	Literature Search	700./site
4	4	Geological Reconnaissance	1000./site
5	5	Detailed Land Check	1200./site
		Detailed Reconnaissance	
6, 7, 8(b)	6	Lease Procurement	1./acre, 1./acre/year, 2./acre
9	7	Field Geology	5000./site
10	8	Geochemical Examination	6000./site
11, 12(b)	9	Geophysical Examination	10000., 15000./site
		Identification of Drillable Sites	
13	10	Heat Flow Wells (4 per site)	3000./well
14	11	Temperature Gradient Wells (10 per site)	1250./well
15	12	Electrical Resistivity	3500./well
16	13	Microseismic	5000./site
17	14	Detailed Geochemistry	7500./site
		Exploration Drilling	
18, 19, 20, 21(c)	15	Well Drilling	DCINJW/well
22	16	Well Testing	10000./site
		FIELD DEVELOPMENT TASKS	UNITO(N)
23, 24(c)	17	Production Well Drilling	DCPW/well
25(c)	18	Nonproduction Well Drilling	DCNPW/well
26, 27(c)	19	Injection Well Drilling	DCINJW/well
28	20	Transmission System	1.

TABLE 5A. (contd)

Index for Itemizing Individual Tasks	Index for Grouping Tasks	Description of Grouped Tasks	Unit Costs (Dollars) for[a] Individual Tasks
N	ICP = GROUP(N)		
29	21	Disposal System	1.
		FIELD OPERATION TASKS	
30	22	Replacement Well Drilling	1.
31	23	Nonproduction Well Drilling	0.2
32	24	Abandonment	10000./abandoned well
33	25	Well Maintenance	1000./production or injection well
34	26	Overhead and Management	Computed -- Ref. Appendix
35	27	Well Redrilling	5000./production well
36	28	Injection	0.
37	29	Injection Well Maintenance	0.
38	30	Transmission System Maintenance	Computed -- Ref. Appendix
39	31	Disposal System Maintenance	Computed -- Ref. Appendix

(a) NAMELIST input array -- default values.

(b) Tasks done at the same time that were consolidated into one aggregate task as follows:

Lease Procurement

6)Bonus payment to leaseholder
7)Annual payment to leaseholder
8)Administrative procurement cost

Geophysical Examination

11)Gravity survey
12)Seismic noise

(c) Drilling tasks were also consolidated into aggregate tasks, costed in this version of GEOCITY by means of the following input variables in NAMELIST defining drilling costs for each type of well:

Exploratory Well Drilling

18), 19), DCINJW with default value $350,000./well
20), 21)

Production Well Drilling

23), 24) DCPW with default value $400,000./well

Nonproduction Well Drilling

25) DCNPW with default value $300,000./well

Injection Well Drilling

26), 27) DCINJW with default value $350,000./well

TABLE 5B. Tasks, Input Times and Success Ratios for Reservoir Exploration, Development, and Operation

Index for Itemizing Individual Tasks	Index for Grouping Tasks	Index for Time Grouping	Start Month Relative to N=1[a]	Duration in Months[a]	Index for Decision Grouping	Success Ratio[a]	Number of Favorable Sites
N	IGP=GROUP(N)	ITEX(N)	LAGS[ITEX(N),1]	LAGS[ITEX(N),2]	NTARG(N)	FTF[NTARG(N)-1]	FAVSIT(IGP)
1	1	1	0	6	1		128
2	2	↓	↓	↓	↓		↓
3	3	2	1	7	2	0.5	64
4	4	↓	↓	↓	↓	↓	↓
5	5	↓	↓	↓	↓	↓	↓
6,7,8	6	3,3,3	2	11	3	0.5	32
9	7	4	4	10	4	0.67	21
10	8	↓	↓	↓	↓	↓	↓
11,12	9	↓	↓	↓	↓	↓	↓
13	10	5	11	24	5	0.75	16
14	11	↓	↓	↓	↓	↓	↓
15	12	↓	↓	↓	↓	↓	↓
16	13	↓	↓	↓	↓	↓	↓
17	14	↓	↓	↓	↓	↓	↓
18,19,20,21	15	6,6,6,6	23	24	6	0.25	4
22	16	7	47	1	↓	↓	↓
23,24	17	8,8	47	42	7	0.25	1
25	18	9	47	42	↓	↓	↓
26,27	19	10,10	89	27	↓	↓	↓
28	20	11	89	27	↓	↓	↓
29	21	12	89	27	↓	↓	↓
30	22	13	116	348	↓	↓	↓
31	23	14	116	348	↓	↓	↓
32	24	15	116	360	7	0.25	1
33	25	16	116	360	↓	↓	↓
34	26	17	116	360	↓	↓	↓
35	27	18	116	360	↓	↓	↓
36	28	19	116	360	↓	↓	↓
37	29	20	116	360	↓	↓	↓
38	30	21	116	360	↓	↓	↓
39	31	22	116	360	↓	↓	↓

(a) NAMELIST input arrays -- default values.

LAGS (Contd) each subgroup of tasks is defined relative to the first task, which is given the base value 0. The starting date for the first task, defining the beginning of reservoir exploration, is back calculated by subroutine RESVOR from the starting date input for the operation of the distribution system. GEOCITY schedules the starting date for the operation of the distribution system in January of the year defined in NAMELIST by DINPUT(14). The default value is January, 1985. The back calculation ensures the last task in the reservoir exploration and development ends in the month prior to the starting date input for the operation of the distribution system. With the default values, this date is December, 1984.

The default values shown for the starting months for all tasks included in reservoir operation are defined relative to the first task in reservoir exploration so as to coincide with the startup date input for the operation of the distribution system. However, regardless of the starting months specified for the tasks in the reservoir operation, subroutine RESVOR schedules the starting months to coincide with the startup date input for the operation of the distribution system. Similarly, regardless of the duration in months specified for the tasks in the reservoir operation, subroutine RESVOR schedules the duration based upon the operating life of the distribution system. Table 6 lists the subgrouping of the tasks presumed to occur parallel in time by the array ITEX and the default values of the array LAGS.

The time sequences of the tasks corresponding to the default values of the LAGS array and default distribution system startup date of January, 1985, are delineated in the bar graph of Figure 9. A discussion of the use of these arrays in subroutine RESVOR is in Appendix A.

TABLE 6. Subgrouping of Reservoir Tasks Occurring Parallel in Time

Reservoir Exploration

Task N	1	2	3 4 5	6 7 8	9 10 11 12	13 14 15 16 17	18 19 20 21	22
ITEX(N)	1	1	2 →	3 →	4 →	5 →	6 →	7
LAGS[ITEX(N), 1]		0	1	2	4	11	23	47
LAGS[ITEX(N), 2]		6	7	11	10	24	24	1

Reservoir Development

Task N	23	24	25	26	27	28	29
ITEX(N)	8	8	9	10	10	11	12
LAGS[ITEX(N), 1]		47	47		89	89	89
LAGS[ITEX(N), 2]		42	42		27	27	27

Reservoir Operation

Task N	30	31	32	33	34	35	36	37	38	39
ITEX(N)	13	14	15	16	17	18	19	20	21	22
LAGS[ITEX(N), 1]	116	116	116	116	116	116	116	116	116	116
LAGS[ITEX(N), 2]	348	348	360	360	360	360	360	360	360	360

UNITO(N), N = 1, ..., 39 - Cost array defining costs (dollars) for the tasks in the exploration, development, and operation of the reservoir on a unit basis, primarily per target site, acre, or well, based upon industry estimates. The total cost associated with each task is calculated in subroutine RESVOR by multiplying the appropriate unit cost in the UNITO array by the number of favorable target sites, acres, or wells calculated by GEOCITY for that task. The cost equations based on the UNITO array are given in Appendix A. The default values for the UNITO array are shown for each of the reservoir tasks in Table 5A.

FTF [NTARG(N) - 1], NTARG(N) = 1, ..., 7 - Success ratios, indexed by the array NTARG(N), associated with the major decision points in the step-by-step process of reducing the number of prospective reservoir sites. The process converges on one site for development and operation. An internal variable NUMFTF in subroutine RESVOR currently sets the number of major decision points in the reservoir exploration

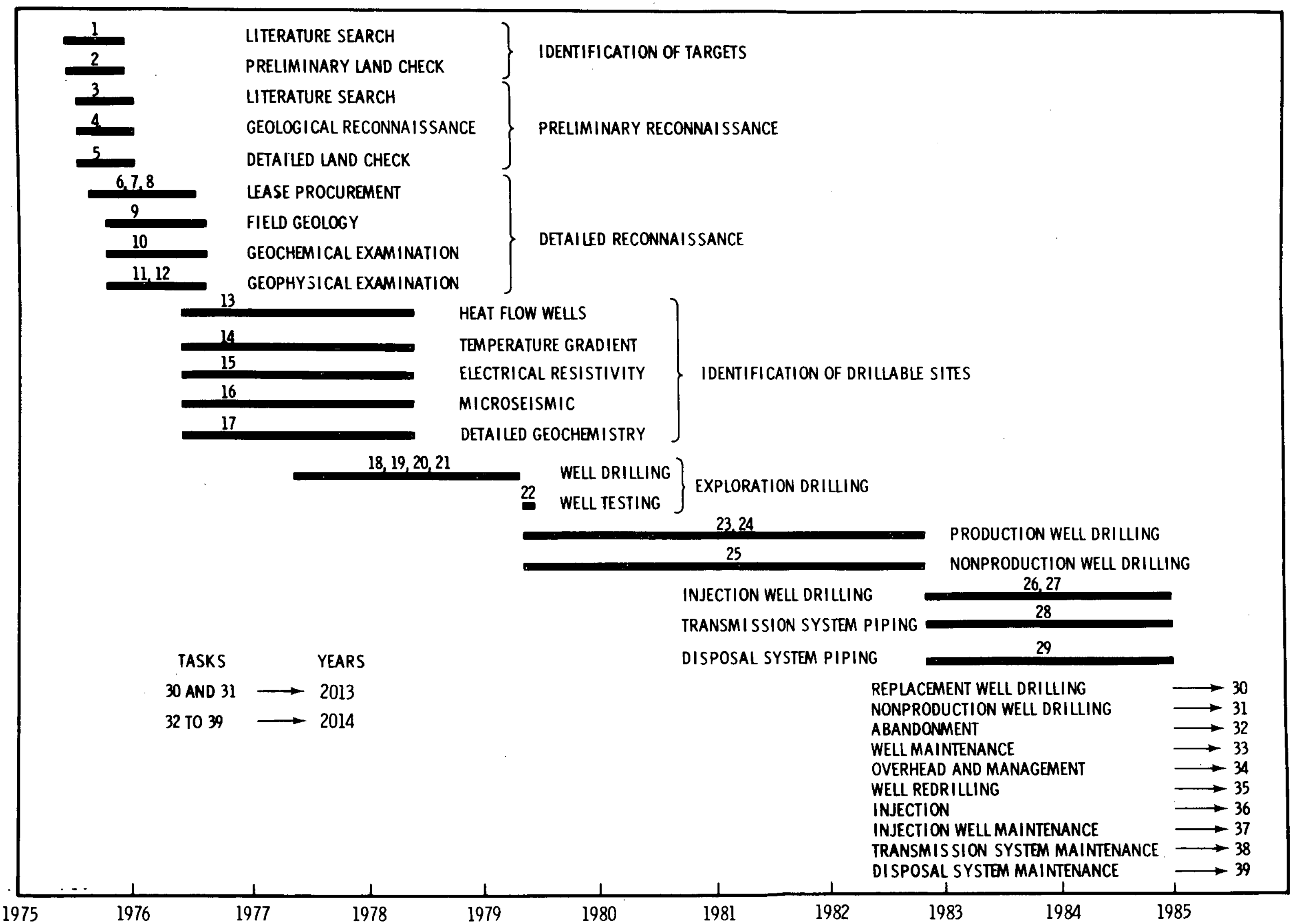


FIGURE 9. Default Time Sequence of Reservoir Exploration, Development, and Operation Tasks

process to six. An internal array, NTARG(N), N = 1,...,39, subdivides the 39 tasks in Table 5B into 7 series of tasks (one more than the number of decision points) according to the major decision points. Appendix A has a description of the calculation by GEOCITY of the initial number of target sites to identify for exploration and number of sites to retain at each decision point for further exploration based upon the success ratios FTF[NTARG(N) -1]. Table 7A shows the subgrouping of the tasks by the array NTARG, the corresponding decision points and the default values of the array FTF. Table 7B describes the decision points.

3.3.6 Output Options

LL6 — Print switch for selecting the distribution system demand and fluid transmission iteration history from GEOCITY.

0, suppresses printout of the iterations
1, prints only the last iteration upon convergence
2, prints all iterations

Default suppresses all iteration printout.

LL11, LL12 — Print switches for selecting the reservoir and distribution economic printout.

LL11 = 1, LL12 = 1, prints all economic output
LL11 = 1, LL12 = 0, prints an economic summary of the reservoir and distribution system, including the breakdown of energy costs from the reservoir and heating costs from the distribution system, but excluding the statements of annual cash flow, tax deductible expenses, income, and payout of investments.
LL11 = 0, LL12 = 0, suppresses all economic output.
Default is full economic printout.

TABLE 7A. Subgrouping of Reservoir Tasks by Decision Points

Task N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
NTARG(N)	1	1	2 →			3 →			4 →				5 →				
NTARG(N)-1= Decision Point					1			2				3					4
FTF[NTARG(N)-1]					0.5			0.5				0.67					0.75

Task N	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
NTARG(N)	6 →					7 →																
NTARG(N)-1= Decision Point					5																	6
FTF[NTARG(N)-1]					0.25																	0.25

TABLE 7B. Description of Decision Points

Decision Point	Description
1	Fraction of sites to retain for preliminary reconnaissance after identification of target sites
2	Fraction of sites to lease after preliminary reconnaissance
3	Fraction of leased sites to retain for detailed reconnaissance
4	Fraction of sites to evaluate for subsequent exploratory drilling
5	Fraction of sites to retain for exploratory drilling
6	Fraction of sites to develop and operate

3.3.7 Miscellaneous Variables Used Only for Printout Information (Well Design and Stratigraphy)

CASFRC — Fraction of each producing well cased. The default cases the entire well depth.

DIA — Average diameter (centimeters if positive, inches if negative) of the reservoir wells to be drilled. The default is 22.225 centimeters.

NUMTYP — Number of different generic types of rock hardness comprising the strata encountered in drilling the entire depth of each reservoir well. The variable NUMTYP should be left preset to its default value of 1, indicating one hardness for the entire depth of the well.

STRATA(M,N) M = 1,2; N = 1,... 10 - Stratigraphic data array defining the type of rock hardness to be drilled (M = 1) and the depth (M = 2, positive if meters, negative if feet) of each type of strata (N) encountered in drilling the reservoir wells.

The possible values of STRATA (1,N) are:

1 = soil, 2 = soft, 3 = medium, 4 = hard, and 5 = very hard.

The default values are as follows:

STRATA(1,1) = 4, indicating that the rock type to drill is hard for the entire depth of the well.

STRATA(2,1) = 2000., total well depth in meters.

3.4. DEFINITION OF NAMELIST INPUT VARIABLES AND DEFAULT VALUES FOR THE DISTRIBUTION SYSTEM

This section defines all NAMELIST input variables and default values for the distribution system. The input variables are grouped into the following categories:

- City Characteristics
- District Characteristics
  - District Type Parameters
  - District Definition Parameters
- Distribution Piping, Insulation, and Casing Design Parameters

- Parameters for Special Options and Adjustment Factors
  - Branching Mains
  - Point Demand
  - Heat Exchanger
  - Adjustment Factors
  - Output Option
- Distribution System Financial and Tax Data

3.4.1 City Characteristics

DRES	Length (miles) of the transmission line from the geothermal reservoir to the city distribution center. The default is 10 miles.
NDTR	Number of districts in the city. The default is 1.
ADGDAY	Total annual degree days (^{o}F days), used for calculating supplemental heat requirements. The default is 6500^{o}F days.
DDGDAY	Degree days (^{o}F days) at the system design temperature. Average annual heat demand and annual heat sales are derived from this quantity. The default is 6000^{o}F days.
TMIN	Minimum outdoor temperature (^{o}F). The default is -5^{o}F.
TDES	Design outdoor temperature (^{o}F). The default is 0^{o}F.
TWATC	Cold water temperature (^{o}F) prior to heating for sanitary hot water usage in the city. The default is 50^{o}F.
TWATH	Hot water temperature (^{o}F) after heating for sanitary hot water usage in the city. The default is 140^{o}F.

3.4.2 District Characteristics

There are two types of input parameters for districts, district definition and district type parameters. Districts comprise continguous areas of relatively homogenous building heat demand density. Several districts may include similar demand densities. Thus, the district type parameters are related to the demand density, while the district definition parameters define the size and location of the districts. Up to eight district types may be defined by the user. A description of the five default residential district types used by the distribution systems model is given in Table 8. District type parameters are vectors where the Nth element corresponds to the Nth district type. By specifying that the type of district [IDTR(M)] for district M is equal to N, the Nth element of each district type parameter below is associated with district M.

3.4.2.1 District Type Parameters

DENSE(N) N=1,8 — Density of buildings (buildings/square mile) for district type N. The default values for the five default residential district types in GEOCITY are given in Table 8.

HQ(N) N=1,8 — Peak heat demand per buildings (MBtu/hr) in district type N at the design temperature. The default values are given in Table 8.

HW(N) N=1,8 — Daily hot water demand per building (gal/day) in district type N. The default values are given in Table 8.

TREJ(N) N=1,8 — Temperature (^{o}F) of the return water at the outlet of the building heating system for district type N. The default values are given in Table 8.

DIVF(N) N=1,8 — Diversity factor (fraction) for district type N. The diversity factor is used to reduce the size of laterals and mains supplying a district by considering that the peak load for all buildings in a district will not occur simultaneously. See also the discussion of single point demand in section 3.4.4.2. The default values are 0.72.

POPHSE(N) N=1,8 — Number of residents per building in district type N. The default values are given in Table 8. This parameter is used only for printout.

TABLE 8. Description of the Five Default Residential District Types Used by the Distribution Systems Model

District Type	Density (Buildings/ sq. mile)	Building Peak Heat Demand (MBtu/hr)	Building Hot Water Demand (gallons/ day)	Diversity Factor	Reject Temperature (°F)	People Per Unit	Number of Residences Per Unit	Floor Area (sq ft/ Residence)
1 = Suburban	2560	.053	60.6	.72	100	3.2	1	1620
2 = High Density Single Family	4480	.034	55	.72	100	4	1	1000
3 = Garden Apartments	293	1.38	3030	.72	100	162	60	990
4 = Townhouses or Rowhouses	373	.9	1515	.72	100	81	30	1012
5 = High Rise Apartments	385	1.728	5400	.72	100	324	108	780

Heat demand is based on 65°F inside temperature, -5°F outside temperature and a 15 mph wind

CRTF(N) N=1,8 — Cost($/building) of retrofitting or redoing building heating systems to handle geothermal heating for district type N. The default values are 0.

3.4.2.2 District Definition Parameters

District definition parameters are arrays where the Mth element is part of the definition of the Mth district. Up to 20 districts may be defined for the city.

IDTR(M) M=1,20 — Type of district, an integer from 1 to 8. This parameter appends density, heat demand, hot water demand, reject temperature, diversity factor, number of residents, and retrofitting cost, i.e., the district type parameters to the description of district M. The default is 1.

AREA(M) M=1,20 — Area (sq.miles) of district M. The default is 1.

WIDTH(M) M=1,20	Width (miles) of district M. The default is 1.
XLNGTH(M) M=1,20	Length (miles) of district M. The width and length parameters are used to determine the approximate shape of the district. Thus, when the graph for the district is created in subroutine GRAPH, the ratio of rows to columns in the rectangular grid used to approximate the shape of the district is the same as the ratio of width to length. The user can approximate the width and length of a district from a map of the district or by judgment. The default length is 1.
DDTR(M) M=1,20	Length (miles) of the main serving district M. Lengths are measured from either the end of the transmission line or the last junction in the main to the center of district M. Illustrations are given in Section 3.4.4.1 and Figure 10. The default is 1.
ELDIFF(M) M=1,20	Elevation (feet) of district M above the end of the transmission line. This parameter alters the sizing of the pumps and the calculation of pumping requirements. The default is 0.
GROWTH(M) M=1,20	Total heat demand growth (fraction) in district M over the specified number of growth years (NYGRO) following the startup of the distribution system, expressed as a fraction of the initial heat demand. Mains and laterals are sized to carry the total future demand. Street and house pipes are sized to carry only current demand. Capital expenditures, increased operating costs, and increased heat sales are incurred during each year of growth. The default is 0.
NYGRO	Number of years of growth. The default is 0.

3.4.3 Distribution Piping, Insulation, and Casing Design Parameters

PO — Pipe option to design the configuration of the conduit bundle (pipe, insulation, and casing) for the distribution system. The pipe options are:

1. Two pipes, only supply insulated, with supply and return in common casing.
2. Two pipes, supply and return in common insulation and casing.
3. Two pipes, supply and return insulated separately in a common casing.
4. Two pipes, supply and return insulated separately in separate casings.
5. Two pipes, supply pipe insulated only and in separate casing from the return pipe.
6. Single pipe, supply insulated in casing.

The default is 1.

PMO — Pipe material options:

1. Carbon steel, schedule 40
2. Fiberglass reinforced plastic, schedule 40

The default is 1.

IO — Insulation options (IO is declared a floating-point variable in the GEOCITY code):

1. Calcium silicate
2. Polyurethane foam

The default is 1.

CO	Casing options: 1. Prefabricated steel, class A casing 2. Prefabricated plastic (PVC) casing 3. Field erected poured concrete casing The default is 1.
TA	Annular air space size (meters). The annular air space is between the insulation and the casing to allow air circulation to dry out the insulation. The default is .0254 meters (1 inch).
DPTH	Burial depth (meters) of casing, measured from the top of the casing to the surface. The default is 0.5 meter.
CP	Thermal conductivity of the pipe (joules/sec-m -^{o}C). The default is 3.56 joules/sec-m -^{o}C or 24.7 Btu/hr-ft^{2}-^{o}F/in.
CG	Thermal conductivity of the ground (joules/sec-m -^{o}C). The default is 0.36 joules/sec-m -^{o}C or 2.5 Btu/hr-ft^{2}-^{o}F/in.
KINS	Thermal conductivity of the insulation (joules/sec-m -^{o}C). The variable KINS is declared a floating-point variable in the GEOCITY code. The default values defined in subroutine DIST are: 1. Calcium silicate - .0418 joules/sec-m-^{o}C or .29 Btu/hr-ft^{2}-^{o}F/in. 2. Polyurethane foam- .0187 joules/sec-m-^{o}C or .13 Btu/hr-ft^{2}-^{o}F/in.
TG	Average year-round ground temperature (^{o}K). The default is 283^{o}K.

ETA — Combined motor and pump efficiency (fraction) of the distribution system pumps used to maintain geothermal fluid pressure at saturation or above saturation (compressed liquid state). The default is .65.

AC — Annualized cost factor (fraction), used in the pipe size and insulation thickness optimization in subroutine size. The default defined in subroutine DIST is 0.1.

VMBTU — Value of one million Btu of heat ($/MBtu), used for determining the value of lost heat for optimization of the insulation thickness. The default is $6/MBtu.

3.4.4 Parameters for Special Options and Adjustment Factors

3.4.4.1 Branching Mains

A variety of main configurations can be simulated to serve the districts in GEOCITY. The configuration of mains is defined by means of two matrices: DDTR (district no. M), M = 1 to number of districts (NDTR), and DNET (district no. M, main no. MM), M = 1 to number of districts, MM = 1 to number of mains. The matrices DDTR and DNET are dimensioned 20 and 20x20 respectively. The Mth element, DDTR (district no. M), defines the length (miles) of the main serving district M. Lengths are measured from either the end of the transmission line or the last junction in the main to the center of district M.

The matrix DNET defines the districts served by each main. The element DNET (district no. M, main no. MM) is set to one of the following values:

2, if main no. MM connects directly to district no. M

1, if main no. MM transports flow to district no. M but does not connect directly to district no. M

0, if main no. MM does not transport flow to district no. M in any way.

The procedure for setting up this matrix is defined later in this section. Two options are available for defining the configuration of mains.

Option 1. Each Main Serves One and Only One District. Option 1 is used to simulate a simple layout of mains in which each main from the distribution center serves one and only one district. The configuration of mains is illustrated by sample configuration no. 1 in Figure 10. The matrix DDTR (district no. M), M = 1 to number of districts, is used to define the length (miles) of the main serving district M. The matrix DNET (district no. M, main no. MM), M = 1 to number of districts, MM = 1 to number of mains, can be left set to its default value of all zeroes. As an alternative approach, option 1 can also be simulated using the procedure discussed in option 2 below. In this approach, the element DNET (district no. M, main no. MM) is set to 2 whenever main no. MM connects directly to district no. M and 0 otherwise.

Option 2. At Least One Main Serves More Than One District. Option 2 is used to simulate more complex configurations of mains in which at least one main serves more than one district. With this option, the following main configurations can be simulated.

- One or more mains serve several districts in series, i.e., one or more mains serving a district continue beyond that district to serve additional districts, as illustrated by sample configuration no. 2 in Figure 10.
- One or more mains branch (subdivide) into two or more mains to serve additional districts, as illustrated by sample configuration no. 3 in Figure 10.
- Combinations of the above two configurations, as illustrated by sample configuration no. 4 in Figure 10.

The following steps are suggested for defining option 2:

Step 1. Number all districts served by a main and each main intersection such that the number at the main intersection is greater than any district further down the main from the distribution center. A main intersection may occur at a district, as number 9 in configuration no. 4, or away from a district, as number 4 in configuration no. 4. A main intersection away from a district is considered as a district with zero area and zero heat demand.

Step 2. Number the mains such that each intersection has at least two main numbers. The sample configurations in Figure 10 illustrate the numbering of mains.

Step 3. Set up the matrix DDTR (district no. M), M = 1 to number of districts (NDTR), defining the distance (miles) from the higher number district on the same main or from the main intersection immediately preceding the district. The sample configurations in Figure 10 illustrate the definition of the lengths of the mains.

Step 4. Set up the matrix DNET (district no. M, main no. MM), M = 1 to number of districts (NDTR), MM = 1 to number of mains, defining the districts served by each main. Set the element DNET (district no. M, main no. MM) to one of the following values:

2, if main no. MM connects directly to district no. M

1, if main no. MM transports flow to district no. M but does not connect directly to district no. M

0, if main no. MM does not transport flow to district no. M in any way.

In defining the 20 x 20 two-dimensional matrix DNET through the NAMELIST input data, the user should be careful to input the array values by columns, i.e., define all rows (district nos.) for the first column (main no.), next all rows (district nos.) for the second column (main no.), and so on. The user should also define the entire 20 rows for each column, inputting 0s if necessary to complete the 20 entries for each column. Additionally, 0s should be input if necessary to complete the entries for all 20 columns. This will result in a matrix with values defined for all 400 (20 x 20) entries.

The matrices DNET (district no., main no.), DDTR (district no.), and AREA (district no.) are defined below for the sample configurations 2-4 in Figure 10 to illustrate the procedure for defining option 2. These matrices are defined for sample configurations 2-4 using NAMELIST input data as follows:

Sample Configuration 2

DNET = 2*2, 18*0, 380*0,

DDTR = l_1, l_2, 18*0,

AREA = a_1, a_2, 18*0,

Sample Configuration 3

DNET = 2, 1, 2, 17*0, 0, 2, 0, 17*0, 360*0,

DDTR = l_1, l_2, l_3, 17*0,

AREA = a_1, a_2, 0, 17*0,

Sample Configuration 4

DNET = 2, 2, 1, 2, 4*1, 2, 11*0, 2*0, 2, 17*0, 4*0, 1, 2, 1, 2, 12*0,
4*0, 2, 15*0, 6*0, 2, 13*0, 300*0,

DDTR = l_1, l_2, l_3, l_4, l_5, l_6, l_7, l_8, l_9, 11*0,

AREA = a_1, a_2, a_3, 0, a_5, a_6, a_7, 0, a_9, 11*0,

CONFIGURATION # 2

District Number	DNET: Main Number 1	DDTR	AREA
1	2	l_1	a_1
2	2	l_2	a_2

CONFIGURATION # 3

District Number	DNET: Main Number 1	2	DDTR	AREA
1	2	0	l_1	a_1
2	1	2	l_2	a_2
3	2	0	l_3	0

CONFIGURATION # 4

District Number	DNET: Main Number 1	2	3	4	5	DDTR	AREA
1	2	0	0	0	0	l_1	a_1
2	2	0	0	0	0	l_2	a_2
3	1	2	0	0	0	l_3	a_3
4	2	0	0	0	0	l_4	0
5	1	0	1	2	0	l_5	a_5
6	1	0	2	0	0	l_6	a_6
7	1	0	1	0	2	l_7	a_7
8	1	0	2	0	0	l_8	0
9	2	0	0	0	0	l_9	a_9

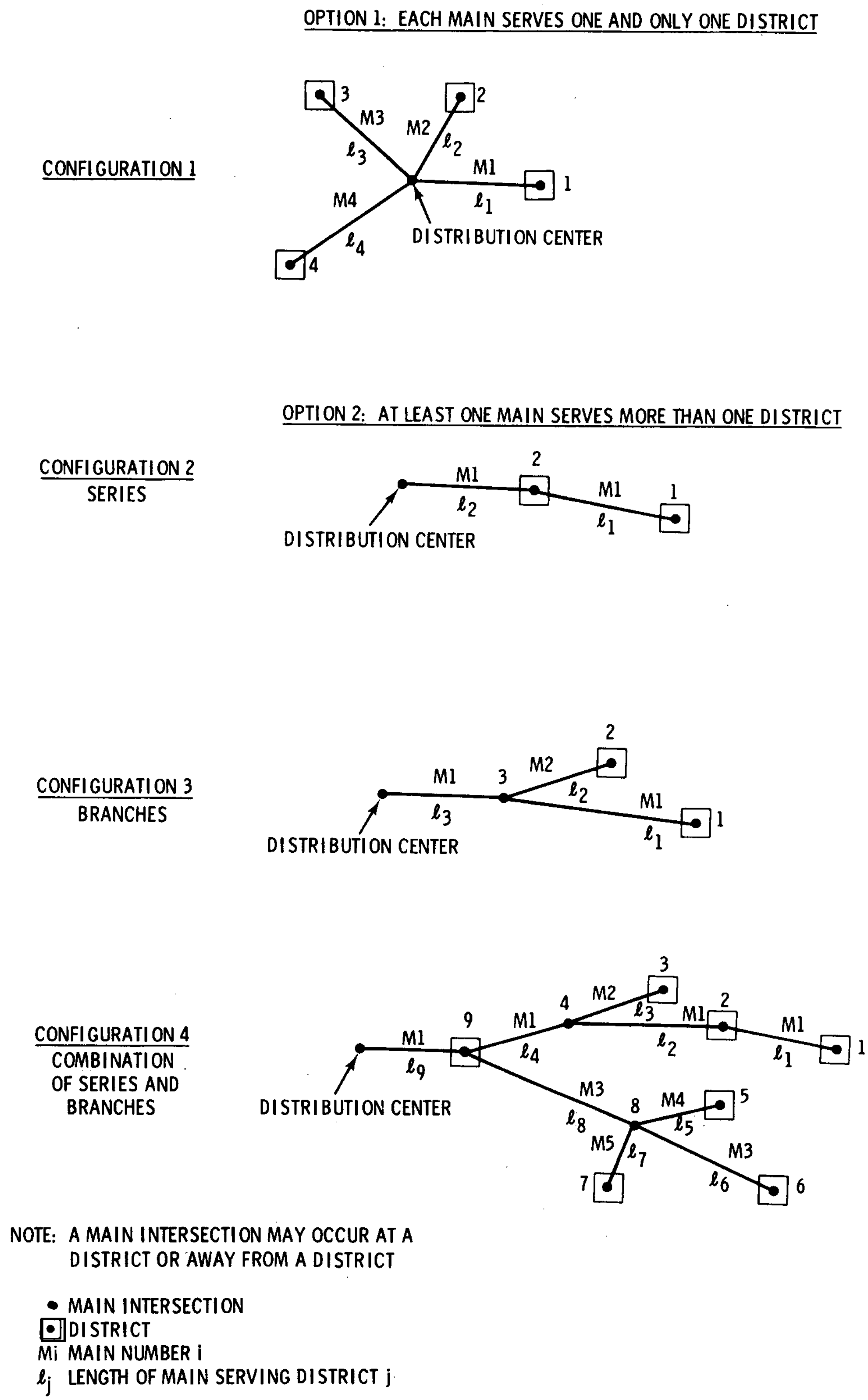


FIGURE 10. Examples of Main Configurations That Can Be Simulated in GEOCITY

3.4.4.2 Point Demand

An option is available in GEOCITY to define an entire district as one point of heat demand, for example, district number M as a single building or factory. This option is implemented by setting the area of district number M and the density of the district type N corresponding to district number M to the values defined below. It is also recommended that the user set the diversity factor of district type N consisting of a single point demand to 1.

AREA(M)	Set AREA(M) to 1.
DENSE(N)	If N is the district type of district number M, i.e., N= IDTR(M), set DENSE(N) to 1.
DIVF(N)	Recommend that DIVF(N) be set to 1.

3.4.4.3 Heat Exchanger

HTEXOP — Option for heat exchanger at the end of the transmission line from the geothermal reservoir (inlet to the distribution center).

0. No heat exchanger
1. Heat exchanger

The default is 0.

HXDELT — Geothermal fluid temperature drop (^{o}F) in the heat exchanger. The default is 100^{o}F.

TWATOT — Clean water temperature (^{o}F) out of the heat exchanger. The default is 195^{o}F. The temperature of the return water at the outlet of the building heating system, defined as TREJ(N) in Section 3.4.2.1, is used as the clean water temperature into the heat exchanger.

DIAL, DIAOL — Inner and outer tube diameters (ft) of the heat exchanger. The default values are:

DIAL = 0.1 ft
DIAOL = 0.1104 ft

WVELL	Velocity of the goethermal fluid (ft/hr) in the heat exchanger tubes. The default is 28,800 ft/hr.
FOULFI, FOULFO	Inside and outside fouling factors for the heat exchanger. These factors reduce the overall heat transfer coefficient in subroutine OHTCOE to allow for the accumulation of corrosion deposits on the inside or tube-side and outside or shell-side heat transfer surfaces. The default values are: FOULFI = 0.001 $hr\text{-}ft^2\text{-}^oF/Btu$; FOULFO = 0.001 $hr\text{-}ft^2\text{-}^oF/Btu$

3.4.4.4 Adjustment Factors

CSBTU	Cost of supplemental heat ($/MBtu). The difference in demand between design conditions and the coldest weather is met by using an auxiliary heat source to raise the temperature of the circulating water. The default is $6/MBtu.
CSF(M), M=1,20	Crooked street factor to increase (multiply) the lengths of lateral, street, and house pipes (but not mains) in simulating crooked streets. The default is 1.
AGFACT(I) I=1,3	Age factor to increase (multiply) friction losses in pipes due to the increase in relative roughness and the deterioration of pipes with age. Three multipliers are used, depending upon the nominal outer pipe diameter. The default values of the age factor were selected to correspond approximately to a pipe age of 10 years.[a]

(a) Hydraulic Handbook, Colt Industries, Fairbanks Morse Pump Division, 4th edition, 1965.

The default values are as follows:

Range I of Nominal Outer Pipe Diameter

	1 (< 4 in.)	2 (4 to 9 in.)	3 (>9 in.)
Age Factor AGFACT(I)	5.	3.6	1.8

The estimated pressure drop in a pipe equals the pressure drop calculated for new pipe times the age factor. This factor applies to all distribution system piping: mains, laterals, street, and house pipes.

TRDF — Trenching difficulty factor, used to increase (multiply) the cost of trenching depending on local conditions. The trenching model assumes vertical slopes with excavation through a dirt and rock mixture. Four inches of bedding fill is placed under the pipes. Sifted backfill material is hauled to the site and hand filled and tamped in 8 inch lifts until the distribution pipe casing is covered by 4 inches of fill. The rest of the trench is filled and packed by a bulldozer. The default value for TRDF is 1. The component costs of trenching, i.e., excavation, backfill, and resurfacing, can be individually adjusted through the input variables described below.

EXCC — Excavation cost of trenching, $\$/m^3$. The default value of $\$26.16/m^3$ is based on excavation through a dirt and rock mixture. These costs assume union labor and that the trenches are being dug in residential areas, requiring some hand excavation and relocation of existing utilities.

BEDC — Bedding fill cost, $\$/m^3$. The default value of $\$13.10/m^3$ is based on the use of sifted fill material hauled 10 miles to the site. Four inches of backfill is placed in the trench underneath the pipes.

BACKC — Backfill cost, $\$/m^3$. The default value of $\$13.10/m^3$ is based on the use of sifted fill material hauled 10 miles to the site and hand tamped in 8 inch lifts until the top of the pipe is covered by 4 inches.

FINC — Finish fill cost, $\$/m^3$. The default value of $\$1.30/m^3$ is based on using excavated material filled and packed to grade with a bulldozer.

RESRFC — Resurfacing cost, $\$/m^2$. The default value of $\$8.40/m^2$ is based on a 2 inch layer of pavement on top of 2 inches of gravel.

WLEAK — Fraction of fluid lost by leakage in the transmission and distribution system. The default is 0.

DFLAG — Print switch for selecting the distribution system printout. The variable DFLAG is declared logical in the program. The default is .TRUE.

DFLAG= .TRUE., prints the full distribution system output (pages E-7 to E-27).

DFLAG= .FALSE., prints only the first two pages of the distribution system output (pages E-7 and E-8) entitled "Definition of Districts" and "District Populations" and the last page (page E-27) entitled "Distribution System Description."

3.4.5 Distribution System Financial and Tax Data

DINPUT(N), N= 36, ..., 70 is the array of financial and tax data for the distribution system defined below.

N	Description of Distribution System Parameters
36	Distribution system capital investment (millions of dollars), which is not input directly, but calculated in subroutine DIST.

37 Project life (years) of distribution system, which is not input directly but calculated in subroutine DISTRB as follows: number of years of distribution system construction, input through NAMELIST as NYC, + number of operating years of distribution system, defined in DINPUT(61).

38 Not used; default is 0.

39 Fraction of initial investment in bonds; default is 0.59.

40 Bond interest rate; default is 0.08.

41 Earning rate on equity after taxes; default is 0.12.

42 Federal income tax rate; default is 0.48.

43 Not used; default is 0.

44 Depreciable life of distribution system (years); default is 30 yr.

45-48 Not used; default is 0.

49 Startup year for operation of the distribution system; default is 1985. The same year must also appear in DINPUT(14) in Section 3.3.4.

50 State income tax rate; default is 0.07.

51 State gross revenue tax rate; default is 0.04.

52 Property tax rate, fraction of distribution system capital investment; default is 0.025.

53 Interim capital replacement rate, fraction of distribution system capital investment; default is 0.0035.

54 Property insurance rate, fraction of distribution system capital investment; default is 0.0012.

55-60 Not used; default is 0.

61 Distribution system operating life (years); default is 30 yr. The same time must also appear in DINPUT(26) in Section 3.3.4.

62-70 Not used. Default is 0.

NYC Number of years to construct the distribution system. The default is 3 yr.

LL2 Depreciation option for recovering the reservoir and distribution system capital costs, including interim capital replacements.

1= straight line
2= sum-of-years-digits
The default is sum-of-years-digits.

PIVTCP Percent investment tax credit for the distribution system. In the first year of operation, the investment tax credit is computed as a fraction (PIVTCP*.01) of the total construction period capital cost and interim capital replacements. In any subsequent year of operation, the investment tax credit is computed as a fraction of the interim capital replacements for the year of interest. The default is 0.

4. DESCRIPTION OF OUTPUT

Appendix E lists the computer output generated by the sample case described previously to illustrate the input data using NAMELIST. The 41 pages of printout show the output for the final iteration between the distribution system demand subroutine CALQNA and fluid transmission submodel (LL6 = 1), the full output from the distribution system submodel (DFLAG = .TRUE.), and the full output from the reservoir and distribution economic submodels (LL11 = 1, LL12 = 1). The output results are printed in an easy-to-read format with an accompanying description. Table 9 presents an overview of the output, identifying the pages of output generated by the major submodels in GEOCITY. For the sake of brevity, a more detailed description is provided below only for output results that require further elucidation.

The input conditions to the fluid transmission submodel are on page E-1. The output from the final iteration of the fluid transmission submodel is on pages E-2 to E-6. Since the used water from the district heating distribution system is disposed through the sewer system in this sample case, there is no output from the fluid disposal submodel. This accounts for the printout of the asterisks for the return temperature.

The distribution demand subroutine CALQNA initially calculates the total geothermal fluid flow requirements for the distribution system based on wellhead conditions. After the initial iteration between the distribution demand subroutine and fluid transmission submodel, the total geothermal fluid flow requirement for the distribution system is calculated based on the degraded fluid conditions transported by the fluid transmission system. The inlet fluid conditions to the distribution center are shown on page E-4 for the final iteration of the fluid transmission submodel.

The degradation of the fluid during conduction is shown on a nodal basis on pages E-2 to E-4. Figure 11 shows the fluid temperature degradation on a nodal basis, corresponding to the output on pages E-2 to E-4. The fluid pressure is maintained at the initial wellhead pressure in the transmission system through the use of booster pumps simulated in the fluid transmission submodel (subroutine TRANS).

TABLE 9. Summary of Computer Output from GEOCITY

Description of Output		Appendix E Pages
Distribution System Demand and Fluid Transmission Iteration History (Final Iteration)		
• Fluid Transmission Submodel Input		E-1
• Fluid Transmission Submodel Output		E-2 to E-5
• Convergence Test for Distribution System Demand and Fluid Transmission Iteration		E-6
Distribution System Input and Output		
• Definition of Districts		E-7
• District Populations		E-8
• Piping Network and Fluid Conditions for District M	Repeats for M=1 to NDTR (no. of Districts)	E-9 to E-24
• Capital Costs and Material Requirements of Piping Network for District M		
• Main Network and Fluid Conditions for each District		E-25
• Total Capital Costs, Material Requirements, and Total Operating Expenses of the Distribution System Summed Over All Districts		E-26
• Summary of District Heating Requirements and Capital Costs and City Climatic Characteristics		E-27
Reservoir Technical and Economic Input and Output		
• Reservoir Characteristics and Well Properties		E-28
• Reservoir Exploration, Development, and Operation Costs		E-29
• Financial and Tax Data Input		E-30
• Annual Cash Flow Statement		E-31
• Annual Tax Deductible Expense Statement		E-32
• Annual Income Statement		E-33
• Annual Payout of Investments (Capitalization)		E-34
• Cost Distribution of Energy from the Reservoir		E-35
Distribution Economic Input and Output		
• Financial and Tax Data Input		E-36
• Annual Cash Flow Statement		E-37
• Annual Tax Deductible Expense Statement		E-38
• Annual Income Statement		E-39
• Annual Payout of Investments (Capitalization)		E-40
• Cost Distribution of Heat from the District Heating Distribution System		E-41

The layout of the nodes in the reservoir well field is shown on page E-3 and illustrated in Figure 11. The well field is based on a triangular grid shown in the 4th quadrant of a Cartesian coordinate system with distribution center at the origin. The previous representation in Figure 5 showed the well field in the 1st quadrant. However, the concepts and results are independent of the quadrant used in representing the well field layout.

The routing of the fluid transmission lines is shown in Figure 11. The pipe runs are parallel to the horizontal X-axis, joining with one manifold line leading to the distribution center. The fluid degradation is calculated in the order shown on page E-2 beginning with the perimeter well node (I = 3, J = 2) and proceeding downstream to the distribution center.

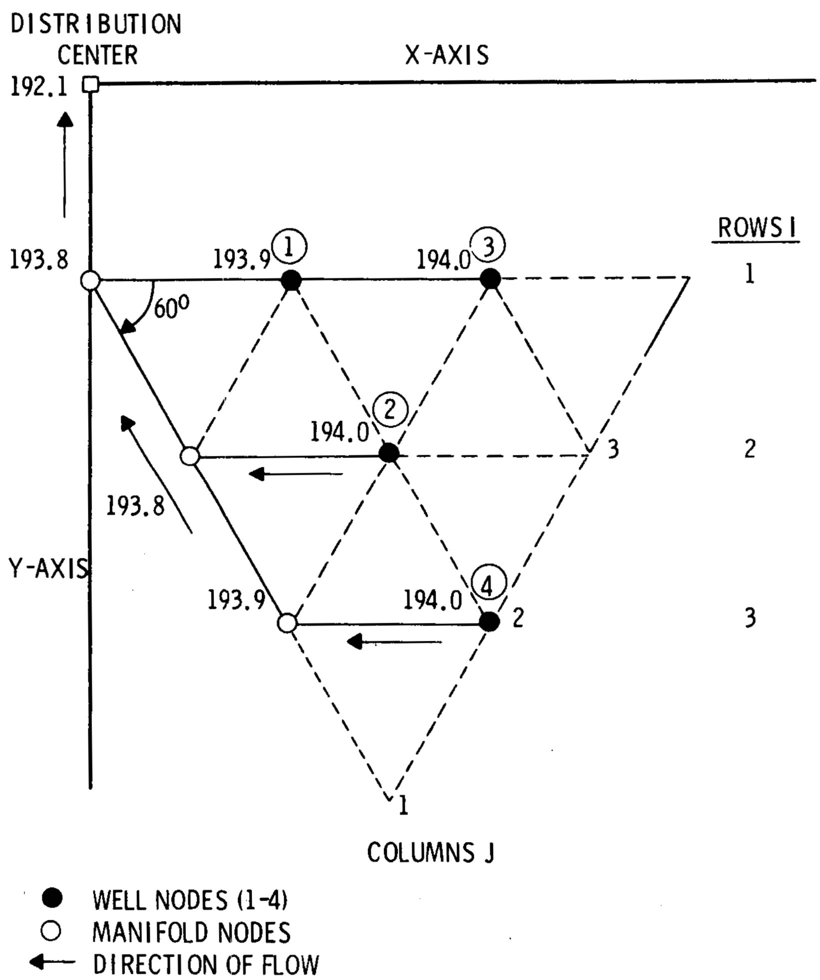


FIGURE 11. Well Field Nodes and Temperature Degradation on a Nodal Basis

The output from the first iteration at a node (iteration 1 on page E-2) shows the condition of the fluid exiting the node. The letter M is used to indicate the mixture of two inlet flows of fluid at a node:

- Fluid exiting a well node (J > 1 in Figure 11) is a mixture of fluid from the wellhead and degraded fluid transmitted from upstream well nodes.
- Fluid exiting a manifold node (J = 1 in Figure 11) is a mixture of degraded fluid from the upstream manifold line and degraded fluid from the row of wells leading into the manifold node.

The exit enthalpy is a mass-weighted average of the inlet enthalpies. The exit temperature is calculated using the steam library function TPHL for compressed liquid or TSLH for saturated liquid based upon the exit enthalpy and pressure.

The output from the last iteration at a node on page E-2 shows the degraded condition of the fluid immediately prior to its entry into the next downstream node. Fluid degradation between neighboring nodes is a function of the internal pipe diameter. Inversely, the optimization algorithm used in the fluid transmission submodel to calculate the internal pipe diameter is a function of the mass flow rate and fluid conditions. The initial estimate of the internal pipe diameter is calculated assuming no fluid degradation between neighboring nodes. The fluid degradation is then calculated as a function of the internal pipe diameter. Using the degraded fluid conditions, the internal pipe diameter is recalculated. The process iterates until the degraded fluid temperature at the entry into the downstream node changes by less than 0.10°F from the temperature calculated in the previous iteration. The internal diameters of the pipes are shown on a nodal basis on pages E-2 and E-4.

The condensed output on page E-2 for nodes with 0 iterations lists only the degraded fluid conditions immediately prior to entry into the next downstream node. Well nodes with 0 iterations reflect the savings in nodal computations obtained by setting the input option IAVWEL=1. This option takes advantage of the property that well nodes with the same number of upstream wells have identical inlet and outlet fluid conditions, provided that all wells in the well field have identical flow rates and fluid conditions. The well nodes can be grouped according to the number of upstream wells (including the current well) shown for each node on page E-3 as follows:

Number of Upstream Wells	Well Node Identification Number
1	2,3,4
2	1

The number of well nodes that require recomputation can thus be reduced from 4 to 2 nodes. This reduction in recomputation cannot be extended to manifold nodes which are all individually computed. In addition, the reduction in computation cannot be used if the user revises the fluid transmission submodel to simulate a reservoir in which all wells do not have identical flow rates and fluid conditions.

The input characteristics to the distribution system submodel defining the districts are given on page E-7 in both English and metric units. The district populations are on page E-8; however, the information on population per se is not used in the distribution system submodel.

The design, fluid conditions, capital costs, and material requirements of the piping network are summarized for each district on pages E-9 to E-24. The length of pipe, number of fittings, valves, and expansion loops, and the capital costs of pipes, fittings, valves, insulation, casings, expansion loops, and trenches are summarized by up to 17 categories of nominal outer pipe diameters that can be used throughout the piping network. These costs are summed over all pipe sizes and combined with the cost of meters and pumps to give the total capital cost for each district piping system.

The output describing the layout and fluid conditions of the piping network for each district is given in a condensed format. Since the piping network is designed symmetrically about the main and lateral, output for one house (building), one half-street (above or below the lateral), one half-lateral (to the left or right of the main), and the main is sufficient to summarize the layout and fluid conditions of the entire piping network for the district.

The layout of the piping network for district 2 with 68 buildings (corresponding to 68 meters on page E-12) in the sample output on page E-11 is shown in Figure 12. The layout was constructed from the output on page E-11 together with the number of buildings (68) to illustrate the interpretation of the condensed output for the district piping networks. The output on page E-11 summarizes the layout of the piping network and fluid conditions for the following sections of pipe:

- street-to-house pipe for each house (building)
- pipe sections down each half-street connecting house pairs 1-4
- pipe sections across the half-lateral connecting full streets 1-3
- main pipe connecting the midpoint of the full lateral in district 2 with the junction at D6 in Figure 8.

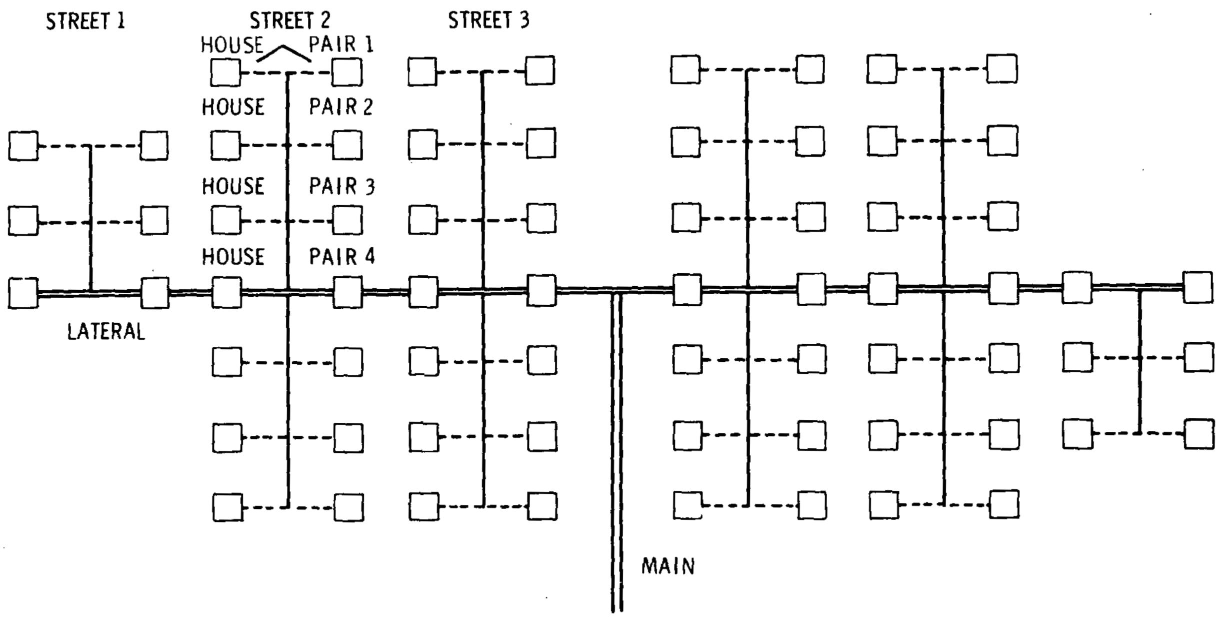


FIGURE 12. Layout for District 2 with 68 Buildings in Sample Case; the Piping Network is Symmetrical about the Main and the Lateral

Two additional comments are in order. First, the value of 0 for heat loss and head loss for house pair 4 on page E-11 indicates that the lateral in district 2 is directly below the 4th house pair as shown in Figure 12. If the heat loss and head loss are nonzero for the last house pair, as in district 3, the location of the lateral is half way between house pairs, as illustrated in Figure 6. The location of the lateral is selected in subroutine GRAPH to preserve the symmetry of the piping network about the lateral and main. Secondly, two short half-streets are used in Figure 12, one on each end of the lateral, to obtain 68 buildings while preserving the symmetry of the piping network about the main and lateral. The 4 full streets account for 56 buildings (4x14), leaving a remainder of 12 buildings, which is not enough to fill out a full street.

The output summarizing the design and fluid conditions of the mains and the districts served by each main is on page E-25. The total capital costs and material requirements of the piping networks summed over all districts are summarized by up to 17 categories of nominal outer pipe diameters that can be used throughout the piping network on page E-26. The total capital costs summed over all pipe sizes, the cost of meters and pumps, and the total operating expenses of the distribution system are also given on page E-26. The heating requirements and capital costs of the piping network for each district together with the city climatic characteristics are summarized in English and metric units on page E-27.

The output from the reservoir economic submodel is on pages E-28 to E-35. Page E-28 lists the characteristics of the reservoir and properties of the wells. The output listed under well properties includes the following information; descriptions of the calculation of these quantities are in succeeding paragraphs.

1) Number of producing wells
2) Number of nonproducing (dry) wells
3) Number of injection wells
4) Thermal energy per well
5) Actual flow rate per well

1) Number of producing wells =

{[total flow rate (lb/hr) demanded by the distribution system]/maximum flow rate (lb/hr) per well} * (1. + fraction of excess producing wells)

where:

Fractional results are rounded up to the next largest integer.

The maximum flow rate per well is input as the variable FLORAT.

The fraction of excess producing wells is input as the variable FRCEPW.

2) Number of nonproducing (dry) wells =

(number of producing wells) * (fraction of nonproducing wells)

where:

Fractional results are rounded to the nearest integer.

The fraction of nonproducing wells is input as the variable FRCNPW.

3) Number of injection wells =

[flow rate (lb/hr) from the distribution system]/[maximum injection well flow rate (lb/hr)]

where:

Fractional results are rounded to the next largest integer.

The maximum injection well flow rate =

[ratio of injection well to producing well flow rate, input as PRDRAT] * [maximum producing well flow rate, input as FLORAT].

4) Thermal energy (MWth) per well =

[maximum flow rate (lb/hr) per well] * [enthalpy at the wellhead-enthalpy at the exit from the distribution system]/ $(3.41443*10^6)$

5) Actual flow rate (lb/hr) per well =

[total flow rate (lb/hr) required by the distribution system]/ [number of producing wells].

The direct expenses associated with reservoir exploration, development, and operation are on page E-29. Page E.30 contains the financial and tax input data for the reservoir. Annual cash flow data for the major reservoir expenses are on page E-31; summary accounts of deductible expenses are on page E-32. A simplified income statement is on page E-33 and the net cash flow and investment position are on page E-34.

The cost of energy for the reservoir is summarized on page E-35. The unit cost of energy for this sample case is $1.55/MBtu. The equivalent annual cost during the operating life of the distribution system is $1,059,670. In the right-hand column labeled "Distribution of Energy Costs," the taxes, royalty payments, and bond interest are reallocated to the direct cost components for the reservoir. The rate of return on investment is included in the distributed energy cost for each component. The deductible nature of bond interest causes this expense to be partially included in the rate of return (the part which is included in the present worth factor) and the remainder is accounted for separately under the caption "Bond Interest."

The output from the distribution economic submodel is on pages E-36 to E-41. Pages E-37 to E-40 contain the same economic and accounting information for the distribution system as pages E-31 to E-34 for the reservoir. The cost of heat for the distribution system is summarized on page E-41. The unit cost of heat for this sample case is $3.46/MBtu. The equivalent annual cost during the operating life of the distribution system is $2,320,390. All costs from the reservoir are included in the energy supply cost item. The energy supply costs are derived from the energy cost account on page E-37. The energy cost account is identical to the total energy sales from the reservoir on page E-33. The difference between the unit cost for energy supply at the distribution system and the unit cost of energy from the reservoir is caused by heat losses in the distribution system piping. As with the reservoir cost distribution, the taxes and bond interest are reallocated to the direct cost components in the right-hand columns of the cost distribution.

5. CONTROL CARDS AND EXECUTION TIME

The GEOCITY program can be converted to the user's computing facilities with a minimal set of basic control cards necessary to compile, load and execute a FORTRAN source program available on tape. In order to execute GEOCITY, it is necessary to compile and load all GEOCITY subroutines and the following steam table subroutines:

STEAM TABLE SUBROUTINES REQUIRED BY GEOCITY

CCSR1	COMT3	P23T	STER	VISL
CCSR2	GRS	PSL	SVT3	VPH
CCSR3	HCL	PVT3	TPS	VPT1
CCBLL	HPT1	SPH	TPSL	VPT2
COMALL	HPT2	SPT1	TSL	VPT3
COMT1	HPTL	SPT2	TSLH	VPTD
COMT2	HVT3	SPTL	VFT	VPTL

The object code generated by compiling GEOCITY and these steam table subroutines can be stored on disk as a sequential file or as a random library file. The file containing the object code can then be subsequently attached and loaded for executing input data sets. It is recommended that the user initialize computer memory to 0 with an appropriate control card before executing the GEOCITY code.

The GEOCITY code required one minute to compile with the CDC FTN version 4.6 compiler at optimization level 1 on the Cyber 73 computer with Scope 3.4.4 operating system. The sample case described in Section 3.2 required 16 seconds of CPU time for execution.

ACKNOWLEDGMENTS

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REFERENCES

1. R. B. McClintock and G. T. Silvestri, Formulation and Iterative Procedures for the Calculation of Properties of Steam, The American Society of Mechanical Engineers, New York,NY,1968.

2. C. A. Meyer, R. B. McClintock, G. T. Silvestri, and R. C. Spencer,Jr., 1967 ASME Steam Table--Thermodynamic and Transport Properties of Steam Comprising Tables and Charts for Steam and Water, The American Society of Mechanical Engineers, United Engineering Center, New York, NY, December 1967.

3. C. L. McDonald, C. H. Bloomster, and S. C. Schulte, GEOCITY: A Computer Code for Calculating the Costs of District Heating Using Geothermal Resources, BNWL-2208, Pacific Northwest Laboratory, Richland, WA, February 1977.

4. C. L. McDonald and C. H. Bloomster, The GEOCITY Model: Description and Application, BNWL-SA-6343, Pacific Northwest Laboratory, Richland, WA, June 1977.

5. CRC Handbook of Tables for Applied Engineering Science, Edited by R. E. Boltz and G. L. Tuve, The Chemical Rubber Co., Cleveland, OH, 1970.

6. CRC Handbook of Chemistry and Physics, 50th Edition, R. C. Weast, Editor, The Chemical Rubber Co., 1969.

7. ASHRAE Handbook of Fundamentals, American Society of Heating, Refrigerating, and Air Conditioning Engineers, 1967.

APPENDIX A

RESERVOIR EXPLORATION, DEVELOPMENT, AND OPERATION COST EQUATIONS

APPENDIX A

RESERVOIR EXPLORATION, DEVELOPMENT, AND OPERATION COST EQUATIONS

The basic equations used in subroutine RESVOR to calculate the costs associated with the exploration, development, and operation of the reservoir are given in this section to aid program users who may wish to change the default input values in Table 5A. The original list of 39 tasks indexed by N in Table 5B are grouped in three different ways during the calculations in subroutine RESVOR by means of the internal arrays: GROUP(N), ITEX(N), and NTARG(N), N = 1, ..., 39. The array GROUP is used to consolidate the 39 tasks into 31 tasks according to the description of the task. The array ITEX is used to group the tasks according to the time the tasks are scheduled to take place. The array NTARG is used to group the tasks by the major decision points in the reservoir exploration process. Any changes contemplated for these arrays, such as adding tasks or decision points, will require some slight reprogramming in subroutine RESVOR. For this reason, these three arrays are not listed as input arrays.

The cost equations given in this section calculate the total, capitalized, and expensed costs for the tasks in Tables 5A and B without breaking the costs down according to the time in which the tasks occurred. Since the reservoir exploration and development tasks may start in any month during one year and end in any month during another year, subroutine RESVOR uses the input time arrays LAGS(ITEX(N), 1) and LAGS(ITEX(N), 2), ITEX(N) = 1, ..., 22, to calculate total, capitalized, and expensed costs for the tasks according to the months in which the tasks are scheduled to occur. This enables the total, capitalized, and expensed costs of the tasks to be accurately totaled on an annual basis in order to calculate annual statements of cash flow, deductible expenses, income, and payout of investments for the reservoir from the beginning of exploration through the economic life of the distribution system.

The input array FTF(NTARG(N)-1), NTARG(N) = 2, ..., 7, is used by subroutine RESVOR to calculate the total number of target sites to be initially identified in order to converge on one site for development and operation after the final decision point.

(Expected number of target sites to identify) * (Fraction of sites retained after decision point I, I = 1, ..., number of decision points) = 1. Substituting FORTRAN variables from subroutine RESVOR and solving this equation,

Expected number of target sites to identify,

FAVSIT(1) = 1/[FTF(1) * FTF(2) ... * FTF(NUMFTF)].

For the default values,

FAVSIT(1) = 1/[1/2 * 1/2 * 2/3 * 3/4 * 1/4 * 1/4] = 128.

The number of sites to retain after each decision point is calculated as follows:

Number of sites to retain after decision point J = (Expected number of target sites to identify) * (Fraction of sites retained after decision point I, I = 1, ..., J).

Substituting FORTRAN variables from subroutine RESVOR,
Number of sites to retain after decision point J =

FAVSIT(1) * FTF(1) * FTF(2) * ...   FTF(J).

The array UNIT representing unit costs used in the calculations below is defined at the beginning of subroutine RESVOR as the following function of the input array UNITO (defined in Table 5):

UNIT(N) = RATPR * UNITO(N), N = 1, . . ., 22
UNITO(N)   , N = 23, . .., 39

where:

RATPR is defined in subroutine LOAD as the ratio of the calculated distribution system heat demand (MWth) stored in DINPUT (43) to the input reservoir thermal capacity (MWth) stored in DINPUT (8):

RATPR = DINPUT(43) / DINPUT(8), DINPUT(8) $\geqq$ DINPUT(43).

The ratio RATPR is used to scale the input array UNITO in order to prorate only the fraction of the costs for the reservoir exploration tasks (N = 1, ..., 22) required to provide enough energy supply for the calculated distribution system heat demand.

The FORTRAN variables appearing in the following equations taken from subroutine RESVOR are defined as follows:

CSTNEW(IGP) = total dollars required by task IGP

FAVSIT(IGP) = number of favorable sites for task IGP

CAP(IGP) = capitalized dollars for task IGP

EXPENZ(IGP) = expensed dollars for task IGP

where:

IGP = GROUP(N) as defined in Table 5.

Reservoir Exploration Tasks Indexed by N = 1 to 5, N= 9 to 12, N = 15 to 17, and N = 22

$$CSTNEW(IGP) = \sum_{N \text{ in Group } IGP} UNIT(N) * FAVSIT(N)$$

$$CAP(IGP) = \sum_{N \text{ in Group } IGP} UNIT(N)$$

EXPENZ(IGP) = CSTNEW(IGP) - CAP(IGP)

where:

IGP is defined as GROUP(N) in Table 5.

Lease Procurement, N = 6,7,8; IGP = 6

$$CSTNEW(6) = \sum_{N \text{ in Group } IGP} UNIT(N) * ACRES * FAVSIT(N)$$

$$CAP(6) = \sum_{N \text{ in Group } IGP} UNIT(N) * ACRES$$

EXPENZ(6) = CSTNEW(6) - CAP(6)

where:

ACRES, input through NAMELIST, is the size of each geothermal site leased.

Heat Flow Wells, N = 13, IGP = 10

CSTNEW(10) = UNIT(13) * 4. * FAVSIT(10)

CAP(10) = UNIT(13) * 4.

EXPENZ(10) = CSTNEW(10) - CAP(10)

based upon the assumption that 4 wells are drilled per site to measure heat flow.

Temperature Gradient Wells, N = 14, IGP = 11

CSTNEW(11) = UNIT(14) * 10. * FAVSIT(11)

CAP(11) = UNIT(14) * 10.

EXPENZ(11) = CSTNEW(11) - CAP(11)

based upon the assumption that 10 wells are drilled per site to measure temperature gradient.

Exploratory Well Drilling, N = 18, 19, 20, 21; IGP = 15

RATPR = DINPUT(43)/ DINPUT(8)

CSTNEW(15) = RATPR * DCINJW * FAVSIT(15)

CAP(15) = PERCNT(1) * CSTNEW(15) / FAVSIT(15)

EXPENZ(15) = CSTNEW(15) - CAP(15)

where:

RATPR is the ratio of the calculated distribution system heat demand (MWth) to the input reservoir thermal capacity (MWth). DCINJW, input through NAMELIST, is the cost (dollars) of drilling one exploratory or injection well.

PERCNT(1), input through NAMELIST, is the tangible fraction of the drilling cost.

Production Well Drilling, N = 23, 24; IGP = 17

CSTNEW(17) = DCPW * WELLS * FAVSIT(17)

CAP(17) = PERCNT(1) * CSTNEW(17)

EXPENZ(17) = CSTNEW(17) - CAP(17)

where:

DCPW, input through NAMELIST, is the cost (dollars) of drilling one production well.

WELLS, calculated in subroutine TRANS, is the number of required production wells.

PERCNT(1), input through NAMELIST, is the tangible fraction of the drilling cost.

Nonproduction Well Drilling, N = 25, IGP = 18

CSTNEW(18) = DCNPW * BADWEL * FAVSIT(18)

CAP(18) = 0.

EXPENZ(18) = CSTNEW(18)

where:

DCNPW, input through NAMELIST, is the cost (dollars) of drilling one nonproduction well.

BADWEL, calculated in subroutine TRANS, is the number of nonproduction wells.

Injection Well Drilling, N = 26,27; IGP = 19

CSTNEW(19) = DCINJW * WELINJ * FAVSIT(19)

CAP(19) = CSTNEW(19)

EXPENZ(19) = 0.

where:

DCINJW, input through NAMELIST, is the cost of drilling one injection well.

WELINJ, calculated in subroutine INJECT, is the total number of injection wells.

Transmission System, N = 28, IGP = 20

CSTNEW(20) = UNIT(28) * TCCOST * FAVSIT(20)

CAP(20) = CSTNEW(20)

EXPENZ(20) = 0.

where:

TCCOST, calculated in subroutine TRANS, is the capital cost of the fluid transmission system.

Disposal System, N = 29, IGP = 21

CSTNEW(21) = UNIT(29) * DCCOST * FAVSIT(21)

CAP(21) = CSTNEW(21)

EXPENZ(21) = 0.

where:

DCCOST, calculated in subroutine INJECT, is the capital cost of the fluid disposal system

Replacement Wells Based on Production Well Life, N = 30, IGP = 22

CSTNEW(22) = CSTNEW(17) * UNIT(30) / AVGWL

CAP(22) = PERCNT(1) * CSTNEW(22)

EXPENZ(22) = CSTNEW(22) - CAP(22)

where:

CSTNEW(17) is the production well drilling cost.

AVGWL, input through NAMELIST, is the production well life (years).

PERCNT(1), input through NAMELIST, is the tangible fraction of the drilling cost.

Nonproduction Well Drilling Associated with Replacement Wells, N = 31, IGP = 23

CSTNEW(23) = FRCNPW * CSTNEW(22)

CAP(23) = 0.

EXPENZ(23) = 0.

where:

FRCNPW, input through NAMELIST, is the ratio of nonproduction to production wells drilled.

CSTNEW(22) is the cost of replacement wells drilled.

Well Abandonment, N = 32, IGP = 24

CSTNEW(24) = UNIT(32) * (WELLS/AVGWL) * FAVSIT(24)

CAP(24) = 0.

EXPENZ(24) = 0.

where:

WELLS, calculated in subroutine TRANS, is the number of required production wells.

AVGWL, input through NAMELIST, is the production well life (years).

Well Maintenance, N = 33, IGP = 25

CSTNEW(25) = UNIT(33) * (WELLS + WELINJ) * FAVSIT(25)

CAP(25) = 0.

EXPENZ(25) = 0.

where:

WELLS, calculated in subroutine TRANS, is the number of required production wells.

WELINJ, calculated in subroutine INJECT, is the number of injection wells.

Overhead and Management, N = 34, IGP = 26

CSTNEW(26) = 0.01 * (Total reservoir development cost) + 0.10 * (Total reservoir operation cost excluding overhead and management)

CAP(26) = 0.

EXPENZ(26) = 0.

Well Redrilling Due to Scale Build-Up in the Production Wells, N = 35, IGP = 27

CSTNEW(27) = UNIT(35) * WELLS * FAVSIT(27)

CAP(27) = 0.

EXPENZ(27) = 0.

where:

WELLS is the number of required production wells.

Annual Injection Well Costs, N = 36, IGP = 28

CSTNEW(28) = UNIT(36) * WELINJ * FAVSIT(28)

CAP(28) = 0.

EXPENZ(28) = 0.

where:

WELINJ, calculated in subroutine INJECT, is the number of injection wells.

Injection Well Maintenance, N = 37, IGP = 29

CSTNEW(29) = UNIT(37) * FAVSIT(29)

CAP(29) = 0.

EXPENZ(29) = 0.

Transmission System Maintenance, N = 38, IGP = 30

CSTNEW(30) = UNIT(38) * TMCOST * FAVSIT(30)

CAP(30) = 0.

EXPENZ(30) = 0.

where:

TMCOST is calculated in subroutine TRANS as TMAINT * TCCOST,

TMAINT, input through NAMELIST, is the transmission maintenance factor (fractional).

TCCOST, calculated in subroutine TRANS, is the capital cost of the fluid transmission system.

Disposal System Maintenance, N = 39, IGP = 31

CSTNEW(31) = UNIT(39) * DMCOST * FAVSIT(31)

CAP(31) = 0.

EXPENZ(31) = 0.

where:

DMCOST is calculated in subroutine INJECT as DMAINT * DCCOST,

DMAINT, input through NAMELIST, is the disposal maintenance factor (fractional).

DCCOST, calculated in subroutine INJECT, is the capital cost of the fluid disposal system.

APPENDIX B

CAPITAL AND OPERATING COST MODELS FOR DISTRICT HEATING DISTRIBUTION SYSTEM

APPENDIX B

CAPITAL AND OPERATING COST MODELS FOR DISTRICT HEATING DISTRIBUTION SYSTEM

As pipes are sized for each segment of the distribution network, capital cost models are used to price the piping string and associated components. The capital cost models are primarily functions of pipe size and design options, although other parameters are used in many of the models. Other capital cost models and operating cost models are used for pumps, instrumentation, operating expenses, and taxes.

This appendix describes the cost models in three sections: capital cost models, operating cost models, and cost model equations. The first two sections describe the bases and assumptions used in the models. The third section lists the equations or cost tables used. Each cost model is associated with an account in which the costs are accumulated.

CAPITAL COST MODELS

Costs are calculated for the entire piping system up to the outer wall of housing units. The basic design is a two-pipe network (Figure B-1). A two-pipe network includes both a supply and a return pipe for each building. The cost models also apply to one-pipe networks which have only a supply pipe for each building.

The total piping bundle is called a conduit. The conduit consists of one or more pipes, which may be insulated, enclosed by the casing.

Depending upon the pipe option, insulation option, conduit option, and material option chosen, applicable component cost models are selected, and costs generated. Component costs are then added to give total piping system capital costs. Fittings and valves are costed at each pipe intersection.

Pipe

Optimal pipe diameter is selected for each segment of the piping network by minimizing the sum of the annualized capital cost of pipe,

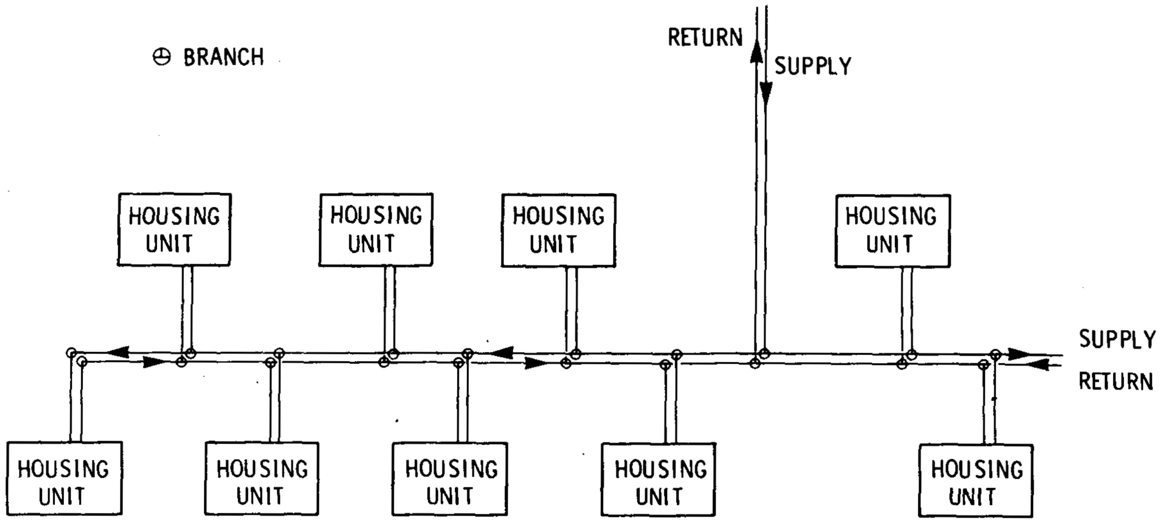

FIGURE B-1. District Heating System Two Pipe Network (shown without expansion loops)

fittings, insulation, casing valves, pump capacity and the annual costs of heat loss and pumping. Head losses are based on correlations for aged pipe. The default value assumes a pipe age of 10 years, but the value can be changed through the input data. Pipe may be either carbon steel, schedule 40, or fiberglass reinforced plastic (FRP) depending on the pipe material options.

The pipe account includes only the material cost for straight lengths of pipe.

Insulation

Optimal insulation thickness is that which produces minimum annual costs of insulation and casing and heat loss values. Either polyurethane foam or calcium silicate insulation can be specified. Insulation is assumed to be factory installed unless foam insulation and field erected concrete casing is specified. For that situation, it is assumed that the insulation is foamed in place.

The insulation account includes material and labor cost for insulating straight pipe lengths and pipe fittings.

Casing

The smallest standard casing size that will contain the pipe(s), insulation, and annular air space is selected for each segment of the piping network. Casing may be either felt- and tar-wrapped steel, polyvinyl chloride (PVC) or concrete. Concrete casing is assumed to be a field constructed rectangular box.

The casing account includes costs of material, labor for placing the pipe(s) in the casing, warehousing, transportation, field placement, and alignment of the casing sections.

Fittings

Two pipe fittings and one casing fitting, sized according to the pipe and casing, are accumulated at each pipe intersection. Two additional fittings are accumulated for each pipe into a building.

The fitting account includes both material cost for the fittings and labor for field connection of the pipes and casing sections.

Expansion Loops

One expansion loop is located in each 300 ft segment of the piping network. The size of the loop is calculated as a function of pipe diameter. Expansion loop cost is the sum of the pipe, fitting, insulation casing, trench and installation costs. Each of these component costs for the expansion loops are calculated separately as described previously and then summed.

The expansion loop account includes all labor and material costs associated with the expansion loop.

Trench

The trench model assumes vertical slopes in a rock and dirt mixture. Sifted fill material is hauled to the site. The casing is laid on 4 in. of sifted fill and is covered to a depth of 4 in. with hand sifted fill material which is hand tamped in 8 in. lifts. The rest of the trench is then filled and packed by dozer. Resurfacing consists of 2 in. of pavement on top of 2 in. of gravel. The top of the casing will be at the specified burial depth below the surface. Costs for trenching, representing differences from the default values in this model, can be easily adjusted by use of the NAMELIST input variables EXCC (excavation cost), BEDC (bedding fill cost), BACKC (back fill cost), FINC (finish fill cost), and RESRFC (resurfacing cost). A trenching difficulty factor (TRDF) may be specified through input to reflect unusual circumstances.

The trench account includes excavation, purchase and delivery of sifted fill, hand filling and tamping, and dozer filling and packing costs.

Valves

One valve, sized according to the larger pipe size, is located at each pipe intersection. Screwed valves are used when the nominal pipe size is less than 2.5 in. Larger sized valves are flanged. The valve is assumed to be a forged steel ball type.

The valve account includes valve, mating flange, bolt-up, handling, insulation, casing and field connection costs.

Meters

One meter is located at each building. Meters are sized according to the expected range of flowrates.

The meter account includes meter, connections, and installation labor costs.

Pumps

One pump and a standby pump are located in each district. The pump is sized to overcome the total head loss and pump the district fluid requirements. Pump motor size is determined from the hydraulic horsepower and the input pump and motor efficiency factors.

The pump account includes the main pump, standby pump, motors, vault, setting and installation, fittings, and labor costs.

Metering and Control

This account covers the cost of instrumentation, additional flow controllers, and sensors required to operate the distribution system. The metering and control account covers capital and installation costs, and is calculated to one percent of the piping system capital cost.

Building and Land Use

This account covers the expense of purchase or lease of land and the construction or modification of a building to house the system's instrumentation and control equipment. The costs are calculated to one percent of the piping system capital cost.

Building Retrofit

The user can specify retrofit costs for buildings in each district type in order to study total costs of district heating in old built-up areas. The user specifies the retrofit cost per building in input data. The retrofit account will consist of retrofit costs for all of the buildings in the distribution system.

Heat Exchanger

If the heat exchanger option is specified, a tube and shell heat exchanger is designed to satisfy the input requirements and is located at the end of the transmission line (inlet to the distribution center), even though the costs appear in the distribution system account.

The heat exchanger account includes material, installation, and indirect costs.

Engineering and Administration

This account is 12% of the piping system total cost to cover the engineering and administration costs of building the distribution system.

OPERATING COST MODELS

The operating cost accounts consist of annual expenses and taxes. Meter reader and operating costs are related to the number of meters connected in the system. Maintenance cost is proportional to the capital investment and is based on estimates from water distribution systems. The pump operating, heat pump, supplemental heat, and heat exchanger costs are derived from models which are controlled by the system design. The other accounts(interest, taxes, capital replacement and insurance) are percentages of capital investment or portions of annual revenue. The percentages are specified through the input data.

Operating

This account includes the personnel cost for operating the distribution system and administrative functions. The charges to this account depend on the number of meters connected to the system.

Maintenance

The maintenance account includes routine repair and maintenance of the distribution system. The charges depend on the pump size, the number of buildings connected, and the flow to each building.

Pump Operation

This account includes charges for the annual pumping costs, calculated from the input values for the cost of electricity, and pump and motor efficiencies.

Meter Readers

This account includes wages, benefits, and overhead for meter readers with an assumed productivity of 50 meters/day.

Supplemental Heat

The difference in heat demand at design temperature and the minimum temperature is met by purchasing heat and elevating the temperature of the circulating water. The charges to this account depend on the climatic data, the design temperature, and input value for the cost of supplemental heat.

Heat Exchanger

The annual operating cost of the heat exchanger is assumed to be 2% of the total capital cost of the heat exchanger.

Other Operating Cost Accounts

The following accounts are calculated as percentages of other accounts. The percentages are specified in the input data.

- Interim Capital Replacement - percent of total system capital cost
- Bond Interest - percent rate, charges assume compound interest on unpaid portion of debt and are calculated for each year
- Gross Revenue Tax - percent of annual revenue

- State Income Tax - percentage of taxable income (revenue less operating expenses including capital costs, energy costs, operating costs, interim capital replacement, property tax and insurance, interest and depreciation)
- Federal Income Tax - percentage of taxable income less state income tax
- Property Tax and Insurance - percentage of distribution system capital cost

COST MODEL EQUATIONS

Capital cost models are summarized in Table B-1, and operating cost models are summarized in Table B-2. The cost models use the equational form:

$$\text{Cost} = a + b(x)^{(s)(t)}$$

Equation coefficients reflect fixed costs (a), variable costs (b), and scale size (s) and (t). Costs are in July 1976 dollars. Where cost equations are not appropriate, cost tables (Tables B-3 through B-6) are used. Cost data were gathered from three sources: industry vendors, mechanical contractors, and architect-engineers.

Costs are factored to reflect lower unit costs for larger piping systems; such systems have reduced material unit costs because of quantity purchase discounts. Also the installation labor learning curve lowers unit labor costs for large systems. Costs are "factored" after they are generated from component cost models. Pipe, insulation, casing, expansion loop, and trenching labor costs are multiplied by FACTOR 1. Fitting, valve, and meter costs are multiplied by FACTOR 2. Table B-7 lists values for these factors.

TABLE B-1. District Heating System Capital Cost Coefficients (July 1976 Dollars) (NOTE: All measurements are in meter units) Cost = $a + b(x)^{st}$

Account No.	Component	Unit	a	b	x	s	t
1.0	Pipe						
	· Carbon Steel Pipe	Meter	0	368.71	P	1.27	1
	FRP Pipe (Fiberglass reinforced plastic)	Meter	0	2.89	2.72 (=e)	11.62	P
2.0	Insulation						
	Calcium Silicate	Meter	0	3.12	2.72 (=e)	4.25	P
						+22.33	R
	Fiberglass	Meter	-1.30	51.90	P		
				+221.77	R		
	Rigid Polyurethane (See Note 1)	Meter	0	1	2.72 (=e)	3.56	
						+4.83	P
						+1.00	ln(R)
	Foam-in-Place Polyurethane	Meter	0	141.00	$(Q)(P)+(Q)(R)(2)-(Y)(P)^2(0.79)$		
	Fitting Insulation	Each	0	0.91	F		
	Valve Insulation						
	- Nom. pipe size ≤ 0.0635 Meters	Each	0	0.61	F		
	- Nom. pipe size > 0.0635 Meters	Each	0	9	F		

NOTE: (1) If nominal pipe diameter = 0.0254 meters and pipe material = carbon steel - Add $3.50/meter to pipe cost.
If nominal pipe diameter = 0.0381 meters and pipe material = carbon steel - Add $1.70/meter to pipe cost.

F = Insulated Cost/Meter P = Pipe Diameter Q = Outside Diameter of Pipe & Insulation R = Insulation Thickness
Y = Number of Pipes in Conduit

TABLE B-1. District Heating System Capital Cost Coefficients (July 1976 Dollars) (NOTE: All measurements are in meter units) Cost = $a + b(x)^{st}$ (contd)

Account No.	Component	Unit	a	b	x	s	t
3.0	Casing						
	Steel (One Pipe Conduit)	Meter	0	40.54	2.72 (=e)	2.06	U
						-0.07	V
	Steel (Two Pipe Conduit)	Meter	0	38.99	2.72 (=e)	2.16	U
						-0.06	V
	PVC (See Note 1)	Meter	0	5.54	2.72 (=e)	5.09	U
	Concrete Box	Meter	18.87	49.73	Q		
				+142.27	P		
				+284.54	R		
	Placement Labor	Meter	0	110	U		
4.0	Fittings						
	Steel Pipe Fitting	Each			See Table B-3		
	FRP Pipe Fitting	Each	0	5.47	2.72 (=e)	14.30	P
	Fitting Steel Casing	Each			See Table B-4		
	Fitting PVC Casing	Each			See Table B-5		
	Valve Casing						
	- Nom. pipe size ≤ 0.0635 meters	Each	0	0.61	H		
	- Nom. pipe size > 0.0635 meters	Each	0	9	H		

NOTE: (1) If U = 0.0266 meters and pipe is carbon steel then add $3.50/meter to pipe cost.
If U = 0.0408 meters and pipe is carbon steel then add $1.70/meter to pipe cost.

H = Casing Cost/Meter

N = Casing Diameter

U = Nominal Casing Size

V = Pipe Diameter

Q = Outside Diameter of Pipe and Insulation

TABLE B-1. District Heating System Capital Cost Coefficients (July 1976 Dollars) (NOTE: All measurements are in meter units) Cost = a + b(x)st (contd)

Account No.	Component	Unit	a	b	x	s	t
5.0	Expansion Loop						
	Expansion loop (See Note 2)	Each			(C)(D) +(4)(E) +(F)(C+3.66) +(4)(G) +(C)(H) +(4)(J) +(C)(K)		
6.0	Trenching Costs (See Note 3)						
	Excavation	Cu. Meter		TRD*TRW	EXCC		
	Bedding Fill	Cu. Meter		.0508*TRW	BEDC		
	Back Fill	Cu. Meter		(N+.05)*TRW	BACKC		
	Finish Fill	Cu. Meter		(DPTH-.05)*TRW	FINC		
	Resurfacing	Sq. Meter		TRW	RESRFC		

NOTE: (2) Expansion loop length = (19.27)(nom. pipe dia.)$^{0.46}$ - (9)(nom. pipe dia.)

NOTE: (3)

	TRD	TRW
Pipe options 1, 2, 3	N+DPTH+.1016	N+.2036
Pipe option 4	N+DPTH+.1016	2*N+.3048
Pipe option 5	N+DPTH+.1016	2*N+P+.31
Conduit option 3	2*R+P+DPTH+.26	2*R+P+.3048

C = Expansion loop length D = Pipe cost/meter E = Pipe fitting cost F = Insulated Cost/Meter G = Insulation fitting cost
H = Casing Cost/Meter J = Casing fitting cost K = Trenching cost/meter N = Casing Diameter P = Pipe Diameter
R = Insulation Thickness Q = Outside Diameter of Pipe and Insulation DPTH = Depth from surface to top of conduit (meters)
EXCC = Excavation cost ($/m^3) BEDC = Bedding fill cost ($/M^3) BACKC = Backfill cost ($/m^3) FINC = Finish fill cost ($/m^3)
RESRFC = Resurfacing cost ($/m^2)

TABLE B-1. District Heating System Capital Cost Coefficients (July 1976 Dollars) (NOTE: All measurements are in meter units) Cost = a + $b(x)^{st}$ (contd)

Account No.	Component	Unit	a	b	x	s	t
7.0	Valves						
	Valve	Each			See Table B-3		
8.0	Meters						
	Water meter (1 per housing unit)	Each			See Table B-6		
9.0	Pumps						
	Basic Pump (2 per district)						
	- horsepower ≤ 26	Each	1269	80	M		
	- horsepower > 26	Each	4929	64	M		
	Accessor Pump (2 per district)	Each	0	81.53	2.72 (=e)	6.08	P
10.0	Metering and Control		0	.01	CT		
11.0	Building and Land Use		0	.01	CT		
12.0	Building Retrofit		0	Input	NB		
13.0	Not Used						
14.0	Not Used						
15.0	Heat Exchanger			93.3	HTA	.78	
16.0	Engineering and Administration		0	.12	CT		

M = Horsepower CT = Piping System Capital Cost HTA = Heat Transfer Areas
NB = Number of Buildings Connected to the System P = Pipe Diameter

TABLE B-2. Operating Cost Models

$$Cost = a + b(x)^{st}$$

Account	Component	a	b	x	s	t
1	Operating	25,000	5	NB		
2	Maintenance	500	.1	CP		
			+.05	CM		
3	Pump Operation		6532	HP*CKW*PF / ETA		
4	Meter Readers	25,000	2.1	NB		
5	Not used					
6	Supplemental Heat		CSHEAT	SDD		
7	Heat Exchanger		.02	HEC		
8	Interim Capital Replacement		Input	CT		
9	Bond Interest		Input	UB		
10	Gross Revenue Tax		Input	REVENUE		
11	State Income Tax		Input	Revenue-(items 1-9 above, and energy costs)		
12	Federal Income Tax		Input	Revenue-(items 1-11 above, and energy costs)		
13	Property Tax and Insurance		Input	CT		

NB = Number of Connected Buildings

CP = Total Cost of Pumps

CM = Total Cost of Meters

HP = Total Hydrualic Horsepower

CKW = Cost of Electricity ($/KwH)

AD = Average Annual Heat Demand (MBTU/yr)

COP = Coefficient of Performance

CSHEAT = Cost of Supplemental Heat ($/MBTU)

SDD = Supplemental Heat Requirements (MBtu/yr)

HEC = Heat Exchanger Capital Cost

CT = Total Distribution System Capital Cost

UB = Amount of Unpaid Bonds

TABLE B-3. Valves and Carbon Steel Fitting

Nominal Pipe Diameter (meters)	Cost/Fitting ($)	Cost/Valve ($)
0.0254	3	58
0.0381	3	70
0.0508	3	85
0.0635	4	118
0.0762	5	274
0.1016	9	375
0.1524	24	528
0.2032	41	776
0.2540	84	1276
0.3048	109	1687
0.3556	162	2535
0.4064	227	3802
0.4572	322	5052
0.5080	433	6740
0.6096	638	9678

TABLE B-4. Steel Casing Fitting

Nominal Inside Casing Diameter (meters)	Cost/Fitting ($)
0.1614	145
0.2122	158
0.2662	189
0.3170	222
0.3488	238
0.3996	259
0.4504	295
0.5012	315
0.5489	340
0.5997	373
0.6505	406
0.6998	432
0.7506	436
0.8014	505
0.8522	550
0.9144	558

TABLE B-5. PVC Casing Fitting

Nominal Inside Casing Diameter (meters)	Cost/Fitting ($)
0.0762	27
0.1016	27
0.1143	35
0.1270	40
0.1524	40
0.1778	57
0.2032	76
0.2540	108
0.3048	143
0.3556	190
0.4064	247
0.4572	437
0.5080	591
0.6096	828

TABLE B-6. Meter

Minimum Flow (GPM)	Maximum Flow (GPM)	Cost/Meter ($)
0	7	144
7	30	209
30	50	313
50	100	608
100	160	921
160	360	2990
360	500	4589
500	1000	9400

TABLE B-7. Cost Factors

Housing Units in District >	800	FACTOR 2 = 0.6
Housing Units in District >	600 and ≤ 800	FACTOR 2 = 0.75
Housing Units in District >	400 and ≤ 600	FACTOR 2 = 0.85
Housing Units in District >	200 and ≤ 400	FACTOR 2 = 0.95
Housing Units in District ≤	200	FACTOR 2 = 1.00

Length of Same Diameter Pipe in District ≥	4000 m	FACTOR 1 = 0.85
Length of Same Diameter Pipe in District ≥	2500 m and < 4000 m	FACTOR 1 = 0.90
Length of Same Diameter Pipe in District ≥	1000 m and < 2500 m	FACTOR 1 = 0.95
Length of Same Diameter Pipe in District <	1000 m	FACTOR 1 = 1.00

APPENDIX C

DESCRIPTION OF PREDEFINED RESIDENTIAL DISTRICT TYPES FOR DEFAULT USE IN GEOCITY

APPENDIX C

DESCRIPTION OF PREDEFINED RESIDENTIAL DISTRICT TYPES FOR DEFAULT USE IN GEOCITY

Many residential areas in the United States can be described by one of five residential district types defined in the GEOCITY model data base. These district types are:

- Suburban
- High density single family
- Garden apartments
- Townhouses
- Highrise apartments.

The district type parameters of peak heat demand, hot water demand, density, reject temperature and diversity factor have been calculated for each of these district types. The user may use these district types as defined or may modify one or more parameters as required through the NAMELIST input data.

Peak heat demand was calculated by designing typical residential units for each district type and calculating the heat loss according to ASHRAE procedures assuming -5^{o}F outside temperature, 67^{o}F inside temperature and a 15 mph wind. Floor plans, dimensions and construction parameters for each of these district types are summarized in Figures C-1 through C-5. Hot water demand is based on the number of residents in a typical building and ASHRAE design recommendations. Density data are averages of the values recommended in various planning books and zoning guides. The district type parameters used by GEOCITY are also summarized in Tables C-1 through C-5.

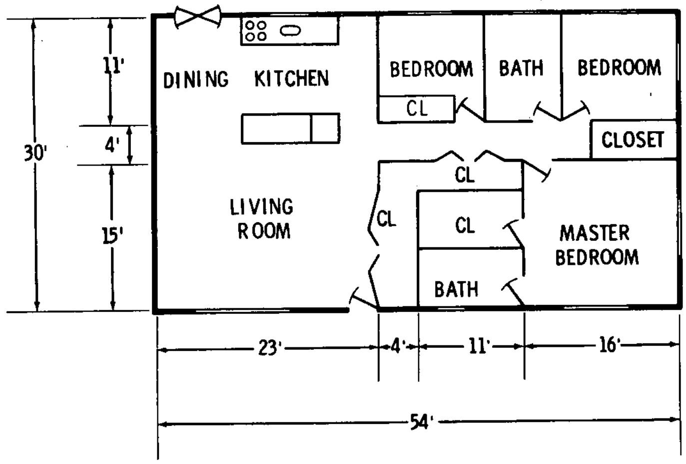

FIGURE C-1. Plan of Suburban Residential House 54 x 30 ft. Attached garage not shown.

TABLE C-1. Design Basis for Suburban Residential House 54 x 30 ft

SUBURBAN RESIDENTIAL	
NUMBER OF STORIES - 1	
DIMENSIONS	
FLOOR ft^2	1620
EXTERIOR WALL AREA ft^2	918 (NET OF GLASS)
GARAGE WALL AREA ft^2	240
WINDOW GLASS ft^2	186
DOOR AREA ft^2	21
CEILING ft^2	1620
STORY HEIGHT ft^2	8
CONSTRUCTION PARAMETERS	
FLOOR	MAPLE FINISH FLOORING ON YELLOW PINE SUBFLOORING.
EXTERIOR WALLS	BRICK VENEER, BUILDING PAPER, WOOD SHEATHING, STUDDING, METAL LATH, 2 in. INSULATION
CEILING	METAL LATH AND PLASTER, 6 in. INSULATION
WINDOWS	DOUBLE-HUNG WOOD WINDOWS
DISTRICT TYPE PARAMETERS	
PEAK HEAT DEMAND	53,000 BTU/hr
HOT WATER DEMAND	60 gallons/day
DENSITY	2560 HOUSES/SQ. MILES
REJECT TEMPERATURE	100 °F
DIVERSITY FACTOR	0.72

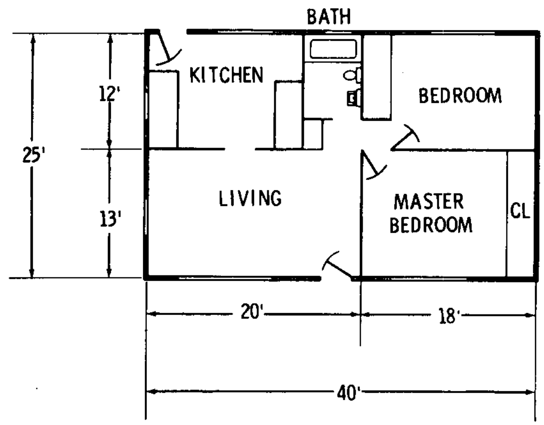

FIGURE C-2. Plan for High Density Single Family Home

TABLE C-2. Design Basis for High Density Single Family Home

HIGH DENSITY	
NUMBER OF STORIES 1	
DIMENSIONS	
FLOOR ft^2	1000
EXTERIOR WALLS ft^2	865
WINDOW ft^2	133
DOOR ft^2	42
CEILING ft^2	1000
STORY HEIGHT ft	8
CONSTRUCTION PARAMETERS	
FLOOR	MAPLE FINISH FLOORING ON YELLOW PINE SUBFLOORING
EXTERIOR WALLS	BRICK VENEER, BUILDING PAPER, WOOD SHEATHING, STUDDING, METAL LATH, 2 in. INSULATION
CEILING	METAL LATH AND PLASTER, 6 in. INSULATION
WINDOWS	DOUBLE-HUNG WOOD WINDOWS
DISTRICT TYPE PARAMETERS	
PEAK HEAT DEMAND	34,000 BTU/hr
HOT WATER DEMAND	55 gallons/day
DENSITY	4,480 HOUSES/SQ. MILE
REJECT TEMPERATURE	100°F
DIVERSITY FACTOR	0.72

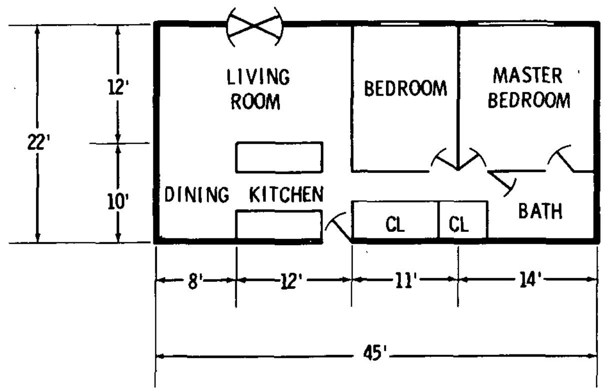

FIGURE C-3. Plan for Garden Apartment Unit

TABLE C-3. Design Basis for Garden Apartment Unit

GARDEN APARTMENT	
NUMBER OF STORIES - EACH APARTMENT IS ONE STORY AND IS CONTAINED IN A 2 STORY BUILDING	
DIMENSIONS	
FLOOR ft^2	990
EXTERIOR WALLS ft^2	617
WINDOWS ft^2	82
DOOR ft^2	21
CEILING	1/2 (990) FOR HEAT LOSS
STORY HEIGHT ft	8
CONSTRUCTION PARAMETERS	
FLOOR	MAPLE FINISH FLOORING ON YELLOW PINE SUBFLOORING
EXTERIOR WALLS	BRICK VENEER, BUILDING PAPER, WOOD SHEATHING, STUDDING, METAL LATH, 2 in. INSULATION
CEILING	METAL LATH AND PLASTER 6 in. INSULATION
WINDOWS	DOUBLE-HUNG WOOD WINDOWS
DISTRICT TYPE PARAMETERS	
PEAK HEAT DEMAND	1.38 MBTU/hr
HOT WATER DEMAND	3030 gallons/day
DENSITY	293 BUILDINGS/SQ. MILE
REJECT TEMPERATURE	100 °F
DIVERSITY FACTOR	0.72

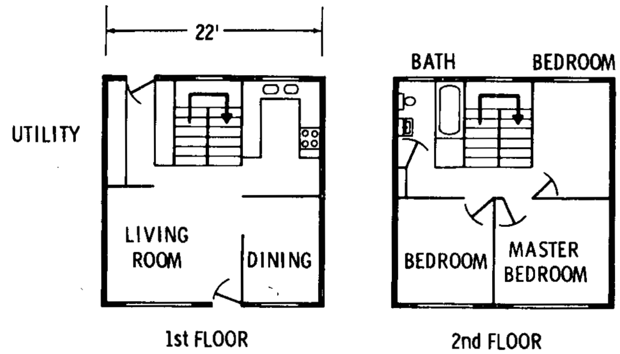

FIGURE C-4. Plan for Townhouse Unit

TABLE C-4. Design Basis for Townhouse Unit

ROW HOUSE	
NUMBER OF STORIES - 2	
DIMENSIONS	
FLOOR ft^2	506 (1st STORY)
FLOOR ft^2	506 (2nd STORY)
EXTERIOR WALL ft^2	582
WINDOW ft^2	124
DOOR ft^2	21
CEILING ft^2	506
STORY HEIGHT ft	8
CONSTRUCTION PARAMETERS	
FLOOR	MAPLE FINISH FLOORING ON YELLOW PINE SUBFLOORING
EXTERIOR WALLS	BRICK VENEER, BUILDING PAPER, WOOD SHEATHING, STUDDING, METAL LATH, 2 in. INSULATION
CEILING	METAL LATH AND PLASTER, 6 in. INSULATION
WINDOWS	DOUBLE-HUNG WOOD WINDOWS
DISTRICT TYPE PARAMETERS	
PEAK HEAT DEMAND	0.9 MBTU/hr
HOT WATER DEMAND	1515 gallons/day
DENSITY	373 BUILDINGS / SQ. MILE
REJECT TEMPERATURE	100 °F
DIVERSITY FACTOR	0.72

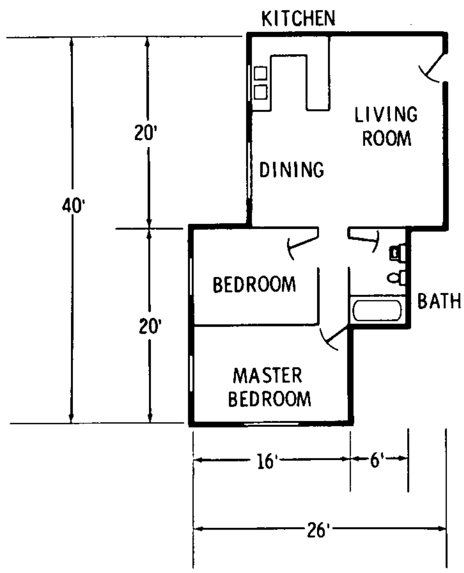

FIGURE C-5. Plan for High Rise Apartment Unit Eight Apartments per Floor

TABLE C-5. Design Basis for High Rise Apartment Unit

HIGH RISE APARTMENT	
NUMBER OF STORIES -	EACH APARTMENT IS ONE STORY AND IS CONTAINED IN A 9 STORY BUILDING.
DIMENSIONS	
FLOOR ft^2	780
EXTERIOR WALL ft^2	370
WINDOWS ft^2	78
DOOR ft^2	21
ROOF ft^2	1/9 (780) FOR HEAT LOSS
STORY HEIGHT ft	8
CONSTRUCTION PARAMETERS	
EXTERIOR WALLS	BRICK VENEER, BUILDING PAPER, WOOD SHEATHING, STUDDING, METAL LATH, 2 in. INSULATION
CEILING	METAL LATH AND PLASTER, 6 in. INSULATION
WINDOWS	DOUBLE-HUNG WOOD WINDOWS
DISTRICT TYPE PARAMETERS	
PEAK HEAT DEMAND	1.73 MBTU/hr
HOT WATER DEMAND	5400 gallons/day
DENSITY	385 BUILDINGS/SQ. MILES
REJECT TEMPERATURE	100°F
DIVERSITY FACTOR	0.72

APPENDIX D

DIMENSIONAL RESTRICTIONS ON INPUT DATA

APPENDIX D

DIMENSIONAL RESTRICTIONS ON INPUT DATA

The economic arrays beginning with CAP and ending with TAXCR in the blank common array CCC (COM11 in the code) are dimensioned by 50 to allow the reservoir and distribution system lifetime to be simulated up to 50 years.

The district type arrays defined in Section 3.4.2.1 are dimensioned by 8 in labeled common DHEAT (COM13 in the code) to accommodate up to 8 district types in the distribution system. The district definition arrays defined in Section 3.4.2.2 are dimensioned by 20 in labeled common DHEAT (COM13 in the code) to allow up to 20 districts in the distribution system.

The transmission nodal arrays beginning with NODE and ending with EWH in subroutine TRANS, which are used in modeling the fluid conduction and degradation in the fluid transmission submodel, are dimensioned 25x25 to accommodate a maximum well field size of 625 wells. Since no dynamic storage is used and no economically viable district heating system is likely to require 625 wells, these dimensions could be reduced to 20x20 or 15x15 if memory size is a problem at the user's computing facilities.

The transmission nodal arrays are currently equivalenced to 9475 decimal locations in the blank common array CCC (COM10 in subroutine TRANS). A set of economic arrays beginning with CAP and ending with TAXCR, which are used in the reservoir and distribution economic submodels, are equivalenced to the first 7050 decimal locations in the blank common array CCC (COM11 in subroutine LOAD). The transmission nodal and economic arrays are permitted to share the same locations in blank common to conserve memory, since they are required at different times during the program execution and need not be saved. A reduction in the dimension of the well field to 15x15 (225 wells) would permit equivalencing the transmission nodal arrays to the first 3390 decimal locations in the array CCC. The dimension of the CCC array could then be reduced to 7050 decimal, the maximum size based upon the economic arrays. The result would be a reduction in memory arrays to the first 3390 decimal locations in the array CCC. The dimension of the CCC array could then be reduced to 7050 decimal, the maximum size based upon the economic arrays. The result would be a reduction in memory requirements of 2425 decimal (4571 octal) words. The following changes would also be necessary in the code:

1) Reset MD and KD to 15 in subroutine DGHEAT
2) Reset NDUP used in subroutine TRANS to 15 in BLOCK DATA
3) Change the FORTRAN statement, CALL CLEAR [CCC(1276),MK], to read CALL CLEAR [CCC(466),MK] in subroutine TSTART.

APPENDIX E

LISTING OF SAMPLE CASE OUTPUT

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

GEOTHERMAL WELL AND FLUID TRANSMISSION INPUT DATA

WELLHEAD TEMPERATURE (F)	1.940000E+02
WELLHEAD PRESSURE (PSIA)	2.033686E+01
WELLHEAD PRESSURE AT SATURATION (PSIA)	1.016843E+01
WELLHEAD STEAM FRACTION	0.
WELLHEAD FLUID STATE	COMPRESSED
WELLHEAD PRESSURIZATION FACTOR (PRFACT)	2.000000E+00
MAXIMUM FLOW RATE/WELL (LB/SEC)	1.388889E+02
WELL SPACING (ACRES)	2.000000E+01
FRACTION EXCESS PRODUCING WELLS	1.000000E-01
FRACTION NONPRODUCING WELLS	5.000000E-02
WELL LIFE (YRS)	3.000000E+01
MAXIMUM ROWS IN WELL DESIGN MATRIX	25
MAXIMUM COLUMNS IN WELL DESIGN MATRIX	25
TRANSMISSION MAINTENANCE FACTOR	5.000000E-02
DISPOSAL MAINTENANCE FACTOR	5.000000E-02
FRACTION OF PIPE THAT CAN BE SALVAGED	1.000000E-01
TOTAL FLOW RATE REQUIRED BY PLANT (LB/HR)	1.439999E+06
OPTIONAL INJECTION WELLS USING DISTRB EFFLUENT	0
DISTANCE FROM DISTRB TO INJECTION WELLS (M)	1.000000E+03
RATIO OF INJECTION/PRODUCTION WELL FLOW RATE	2.000000E+00
LABOR COST FOR PIPE INSULATION ($/FT)	4.500000E+00
OPTION TO REDUCE NODAL RECOMPUTATION	1
SCALING FACTOR TO ADJUST PIPE SIZES (EVALUE)	2.000000E-02
ANNUALIZED COST FACTOR	1.600000E-01

NODAL FLUID TRANSMISSION THERMODYNAMIC DEGRADATION FOR LINE 1

NODE I	J	ITR	MIX	FLUID STATE	STEAM FRACT	FLOW RATE (LB/SEC)	HEAT LOSS (BTU/SEC-FT)	TEMP (F	PRES(PSIA)	SATURATION PRES(PSIA)	ENTHALPY (BTU/LB)	PIPE SCHD	INTER DIAM(IN)	EXTER DIAM(IN)	INSUL THK(IN)
3	2	1		COMPRESSED	0.0000	100.	0.000	194.000	20.337	10.168	162.078	10.	6.846	8	3.000
3	2	2		COMPRESSED	0.0000	100.	.012	193.882	20.337	10.143	161.960	10.	6.846	8	3.000
3	2	3		COMPRESSED	0.0000	100.	.012	193.882	20.337	10.143	161.960	10.	6.846	8	3.000
3	1	1		COMPRESSED	0.0000	100.	0.000	193.882	20.337	10.143	161.960	10.	6.846	8	3.000
3	1	2		COMPRESSED	0.0000	100.	.012	193.764	20.337	10.118	161.841	10.	6.846	8	3.000
3	1	3		COMPRESSED	0.0000	100.	.012	193.764	20.337	10.118	161.841	10.	6.846	8	3.000
2	2	0		COMPRESSED	0.0000	100.	.012	193.882	20.337	10.143	161.960	10.	6.846	8	3.000
2	1	1	M	COMPRESSED	0.0000	200.	0.000	193.823	20.337	10.130	161.900	10.	9.387	10	3.000
2	1	2		COMPRESSED	0.0000	200.	.014	193.752	20.337	10.115	161.829	10.	9.387	10	3.000
1	3	0		COMPRESSED	0.0000	100.	.012	193.882	20.337	10.143	161.960	10.	6.846	8	3.000
1	2	1	M	COMPRESSED	0.0000	200.	0.000	193.941	20.337	10.156	162.019	10.	9.387	10	3.000
1	2	2		COMPRESSED	0.0000	200.	.014	193.870	20.337	10.141	161.948	10.	9.387	10	3.000
1	1	1	M	COMPRESSED	0.0000	400.	0.000	193.811	20.337	10.128	161.889	10.	12.874	14	3.000
1	1	2		COMPRESSED	0.0000	400.	.018	192.045	20.337	9.756	160.116	10.	12.874	14	3.000
1	1	3		COMPRESSED	0.0000	400.	.018	192.045	20.337	9.756	160.116	10.	12.874	14	3.000

TRANSMISSION DESIGN, THERMODYNAMICS, AND COST

LINE NUMBER 1 (WATER)

INLET TEMPERATURE INTO LINE	1.940000E+02	(F)
INLET PRESSURE INTO LINE	2.033686E+01	(PSIA)
INLET ENTHALPY INTO LINE	1.620784E+02	(BTU/LB)
NUMBER OF TRANSMISSION LINES INTO CENTER	1	(LINE)
NUMBER OF PRODUCING WELLS	4	(WELLS)
NUMBER OF DRY WELLS	0	(WELLS)
ACTUAL WELL FLOW RATE	9.999995E+01	(LBM/SEC
EFFECTIVE WELL SPACING	2.100000E+01	(ACRES)
PIPE LENGTH BETWEEN WELL NODES	3.132585E+02	(METERS)

WELLFIELD DESIGN LATTICE WITH ACTIVE WELLS NUMBERED

CENTER COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

0	1	3
0	2	0
0	4	0

NUMBER OF UPSTREAM WELLS FLOWING INTO EACH NODE

CENTER COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

4	2	1
2	1	0
1	1	0

INITIAL WELLHEAD CONDITIONS

TEMPERATURE (F) COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

	COL 1	COL 2	COL 3
ROW 1	0.	1.940000E+02	1.940000E+02
ROW 2	0.	1.940000E+02	0.
ROW 3	0.	1.940000E+02	0.

PRESSURE (PSIA)

	COL 1	COL 2	COL 3
ROW 1	0.	2.033686E+01	2.033686E+01
ROW 2	0.	2.033686E+01	0.
ROW 3	0.	2.033686E+01	0.

VISCOSITY (LB/FT-SEC)

	COL 1	COL 2	COL 3
ROW 1	0.	2.092038E-04	2.092038E-04
ROW 2	0.	2.092038E-04	0.
ROW 3	0.	2.092038E-04	0.

DENSITY (LB/CU FT)

	COL 1	COL 2	COL 3
ROW 1	0.	6.025200E+01	6.025200E+01
ROW 2	0.	6.025200E+01	0.
ROW 3	0.	6.025200E+01	0.

NODAL EXIT CONDITIONS AFTER DEGRADATION AND MIXING

TEMPERATURE (F) . COL 1 = MANIFOLD NODES, OTHER COLS = WELL NODES

	COL 1	COL 2	COL 3
ROW 1	1.938112E+02	1.939409E+02	1.940000E+02
ROW 2	1.938227E+02	1.940000E+02	0.
ROW 3	1.938817E+02	1.940000E+02	0.

PRESSURE (PSIA)

	COL 1	COL 2	COL 3
ROW 1	2.033686E+01	2.033686E+01	2.033686E+01
ROW 2	2.033686E+01	2.033686E+01	0.
ROW 3	2.033686E+01	2.033686E+01	0.

VISCOSITY (LB/FT-SEC)

	COL 1	COL 2	COL 3
ROW 1	2.094555E-04	2.092825E-04	2.092038E-04
ROW 2	2.094402E-04	2.092038E-04	0.
ROW 3	2.093614E-04	2.092038E-04	0.

DENSITY (LB/CU FT)

	COL 1	COL 2	COL 3
ROW 1	6.025643E+01	6.025339E+01	6.025200E+01
ROW 2	6.025617E+01	6.025200E+01	0.
ROW 3	6.025478E+01	6.025200E+01	0.

INTERNAL PIPE DIAMETER (IN)

	COL 1	COL 2	COL 3
ROW 1	1.287437E+01	9.387059E+00	6.846087E+00
ROW 2	9.387102E+00	6.846087E+00	0.
ROW 3	6.846118E+00	6.846087E+00	0.

PIPE INSULATION THICKNESS (IN)

	COL 1	COL 2	COL 3
ROW 1	3.000000E+00	3.000000E+00	3.000000E+00
ROW 2	3.000000E+00	3.000000E+00	0.
ROW 3	3.000000E+00	3.000000E+00	0.

C E N T E R   I N L E T   C O N D I T I O N S
(INCLUDES DEGRADATION FROM LAST NODE TO CENTER)

FLOW RATE	1.439999E+06	(LBM/HR)
TEMPERATURE	1.920454E+02	(F)
PRESSURE	2.033686E+01	(PSIA)
ENTHALPY	1.601156E+02	(BTU/LB)

T R A N S M I S S I O N   S Y S T E M   C O S T S ($)

TOTAL TRANSMISSION COST	3.655318E+06
PIPE COST	2.590123E+06
INSULATION COST	4.004864E+05
WELLHEAD VALVES	2.000000E+04
INSTRUMENTATION	4.000000E+03
SOLIDS SEPARATORS	2.000000E+04
TRANSMISSION BOOSTER PUMPS	2.290670E+05
ENGINEERING AND DESIGN (12%)	3.916412E+05
TRANSMISSION MAINTENANCE COST	1.827659E+05
TRANSMISSION CAPITAL REPLACEMENT	3.000000E-02 (RATE)

D I S T R I B U T I O N - F L U I D   T R A N S M I S S I O N   C O N V E R G E N C E   T E S T

PREVIOUS GEOTHERMAL FLOW RATE DEMANDED BY DISTRIBUTION SYSTEM	1.439977E+06
CURRENT GEOTHERMAL FLOW RATE DEMANDED BY DISTRIBUTION SYSTEM	1.439999E+06
DIFFERENCE (LBM/HR)	2.246899E+01
DIFFERENCE (PER CENT)	1.560347E-03
CONVERGENCE CRITERION (PER CENT)	2.000000E+00

DISTRIBUTION SYSTEM DEMAND SUBROUTINE CALQNA AND FLUID TRANSMISSION SUBMODEL SATISFY CONVERGENCE CRITERION

NUMBER OF DISTRICT HEATING - TRANSMISSION ITERATIONS 4

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

D E F I N I T I O N   O F   D I S T R I C T S

DIST NO	DIST TYPE	DIS TO DISTRB (MI)	DENSITY (UN/SMI)	AREA (SMI)	LENGTH (MI)	WIDTH (MI)	DIVERS FACTOR	PEAK HEAT DEMAND/UN (MBTU/HR)	HOT WATER DEMAND (GAL./DAY)	HOUSE SPACING (MI)	STREET SPACING (MI)	GROWTH FACTOR (%)	REJECT TEMP (DEG F)	PEOPLE PER UNIT
01	01	.404	2731.00	.193	.466	.932	.72	.025400	37.8	.0191	.038	0	113.0	3.2
02	02	.217	3000.00	.023	.180	.124	.72	.190500	0.0	.0183	.037	0	113.0	4.0
03	02	.280	3000.00	.062	.497	.124	.72	.190500	0.0	.0183	.037	0	113.0	4.0
04	01	.249	2731.00	.185	.497	.373	.72	.025400	37.8	.0191	.038	0	113.0	3.2
05	02	.186	3000.00	.015	.124	.124	.72	.190500	0.0	.0183	.037	0	113.0	4.0
06	01	.777	2731.00	.232	.932	.248	.72	.025400	37.8	.0191	.038	0	113.0	3.2
07	01	.124	2731.00	.156	.167	.932	.72	.025400	37.8	.0191	.038	0	113.0	3.2
08	01	1.740	2731.00	.399	.932	.932	.72	.025400	37.8	.0191	.038	0	113.0	3.2

METRIC EQUIVALENTS

DIST NO	DIST TYPE	DIS TO DISTRB (KM)	DENSITY (UN/SKM)	AREA (SKM)	LENGTH (KM)	WIDTH (KM)	DIVERS	PEAK HEAT DEMAND/UN (MCAL/HR)	HOT WATER DEMAND (LITERS/DAY)	HOUSE SPACING (KM)	STREET SPACING (KM)	GROWTH FACTOR (%)	REJECT TEMP (DEG C)	PEOPLE PER UNIT
01	01	.650	1054.44	.50	.75	1.50	.72	6.40	143.1	.0308	.0616	0	45.0	3.2
02	02	.349	1158.30	.06	.29	.20	.72	48.00	0.0	.0294	.0588	0	45.0	4.0
03	02	.451	1158.30	.16	.80	.20	.72	48.00	0.0	.0294	.0588	0	45.0	4.0
04	01	.401	1054.44	.48	.80	.60	.72	6.40	143.1	.0308	.0616	0	45.0	3.2
05	02	.299	1158.30	.04	.20	.20	.72	48.00	0.0	.0294	.0588	0	45.0	4.0
06	01	1.250	1054.44	.60	1.50	.40	.72	6.40	143.1	.0308	.0616	0	45.0	3.2
07	01	.200	1054.44	.40	.27	1.50	.72	6.40	143.1	.0308	.0616	0	45.0	3.2
08	01	2.800	1054.44	1.03	1.50	1.50	.72	6.40	143.1	.0308	.0616	0	45.0	3.2

DISTRICT POPULATIONS

DISTRICT TYPE	DISTRICT NUM	NUM OF HOUSES	PEOPLE/HOUSE	NUM OF PEOPLE
1	1	527.1	3.2	1687.
	4	505.2	3.2	1617.
	6	633.6	3.2	2027.
	7	426.0	3.2	1363.
	8	1089.7	3.2	3487.
	TOTAL	3181.6		10181.
2	2	69.0	4.0	276.
	3	186.0	4.0	744.
	5	45.0	4.0	180.
	TOTAL	300.0		1200.

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRIBUTION SYSTEM OF DISTRICT 1 SINGLE PIPE SYSTEM

		FLOWRATE (LB/SEC)	HEAT LOSS (BTU/SEC)	TEMPERATURE (F) SUPPLY	RETURN	HEAD LOSS FEET	NOMINAL DIAM(IN)	INSUL (IN)
HOUSE DESCRIPTION								
HOUSE		.1	-.1	188.	113.	2.98	1.00	2.5
STREET DESCRIPTION								
STREET	HOUSE							
1	1	.2	-1.6	189.	****	.30	1.00	2.5
	2	.4	-1.6	190.	****	1.08	1.00	2.5
	3	.6	-1.6	190.	****	2.28	1.00	2.5
	4	.9	-1.6	191.	****	3.88	1.00	2.5
	5	1.1	-1.6	191.	****	5.85	1.00	2.5
	6	1.2	0.0	191.	****	0.00	1.00	0.0
LATERAL DESCRIPTION								
LATERAL	STREET							
1	1	.9	-2.8	191.	****	7.42	1.00	3.5
	2	2.6	-2.8	191.	****	55.99	1.00	3.5
	3	4.3	-3.3	191.	****	18.33	1.50	3.5
	4	6.0	-3.3	191.	****	34.05	1.50	3.5
	5	7.7	-3.7	191.	****	16.14	2.00	3.5
	6	9.4	-3.8	191.	****	9.99	2.50	3.5
	7	11.1	-3.8	191.	****	13.58	2.50	3.5
	8	12.9	-3.8	192.	****	17.67	2.50	3.5
	9	14.6	-3.8	192.	****	22.25	2.50	3.5
	10	16.3	-3.8	192.	****	27.30	2.50	3.5
	11	18.0	-4.2	192.	****	8.33	3.00	3.5
	12	19.7	-4.2	192.	****	9.85	3.00	3.5
	13	20.6	0.0	192.	****	0.00	3.00	0.0
MAIN DESCRIPTION								
MAIN		41.2	-44.1	192.	****	375.71	3.00	3.5

Since the used water from the distribution system is disposed through the sewer system (no reinjection) in this sample case, there is no output from the fluid disposal (reinjection) submodel. This accounts for the the printout of the asterisks for the return temperature.

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRICT 1 CAPITAL COSTS AND MATERIAL REQUIREMENTS

PIPE SIZE (IN)	PIPE (LIN.FT)	PIPE COST $X1000	NUMBER OF FTNGS	FTNGS COST $X1000	NUMBER OF VALVES	VALVE COST $X1000	INSUL COST $X1000	CASING COST $X1000	NUMBER OF EXP LOOPS	EXP LOOP COST $X1000	TRENCH COST $X1000	LIN.FT. COST ($/FT)
1.0	59338	51.9	1638	.1	819.	.1	98.7	513.6	194	23.6	175.5	14.80
1.5	808	1.4	8	.1	4.	.1	1.5	12.9	2	1.4	4.1	26.59
2.0	404	1.0	4	.1	2.	.2	.6	6.3	1	.7	2.0	26.82
2.5	2020	6.8	20	.1	10.	.2	3.0	31.3	6	3.9	10.1	27.43
3.0	2941	12.5	14	.0	7.	.7	4.7	56.2	9	7.2	17.1	33.45
TOTALS	64513	73.6		.3		1.4	108.5	620.2		36.7	208.8	16.27

COST OF 527. METERS OF FLOW RATING 7. GPM IS $ 65. (THOUSAND)
COST OF PUMPS WITH 67. HORSEPOWER CAPACITY IS $ 9. (THOUSAND)

PIPING SYSTEM($X1000.)

PIPE	73.64
INSULATION	108.51
CASING	620.21
FITTINGS	.31
EXPANSION LOOP	36.75
TRENCH	208.75
VALVES	1.38
METERS	64.50
HEAT PUMP	0.00
PUMP	9.38

TOTAL SYSTEM CAPITAL COST 1123.43

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRIBUTION SYSTEM OF DISTRICT 2 SINGLE PIPE SYSTEM

		FLOWRATE (LB/SEC)	HEAT LOSS (BTU/SEC)	TEMPERATURE (F) SUPPLY	RETURN	HEAD LOSS FEET	NOMINAL DIAM(IN)	INSUL (IN)
HOUSE DESCRIPTION								
HOUSE		.7	-.1	191.	113.	4.55	1.00	2.5
STREET DESCRIPTION								
STREET	HOUSE							
1	1	1.4	-1.5	191.	****	9.02	1.00	2.5
	2	2.8	-1.7	191.	****	4.19	1.50	3.0
	3	4.2	-1.7	192.	****	8.83	1.50	3.0
	4	4.9	0.0	192.	****	0.00	1.50	2.5
LATERAL DESCRIPTION								
LATERAL	STREET							
1	1	3.0	-3.1	192.	****	9.26	1.50	3.5
	2	10.1	-3.6	192.	****	10.85	2.50	3.5
	3	17.2	-2.4	192.	****	3.94	3.00	2.5
MAIN DESCRIPTION								
MAIN		34.4	-27.9	192.	****	170.10	4.00	3.5

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRICT 2 CAPITAL COSTS AND MATERIAL REQUIREMENTS

PIPE SIZE (IN)	PIPE (LIN.FT)	PIPE COST $X1000	NUMBER OF FTNGS	FTNGS COST $X1000	NUMBER OF VALVES	VALVE COST $X1000	INSUL COST $X1000	CASING COST $X1000	NUMBER OF EXP LOOPS	EXP LOOP COST $X1000	TRENCH COST $X1000	LIN.FT. COST ($/FT)
1.0	4868	4.8	152	.3	76.	.5	9.3	47.7	16	.8	16.3	16.37
1.5	1928	3.4	52	.1	26.	.2	3.3	25.6	6	2.7	8.5	22.67
2.5	385	1.3	4	.1	2.	.3	.6	6.0	1	.7	1.9	28.20
3.0	192	.8	4	.1	2.	.9	.2	2.3	0	.3	.8	28.40
4.0	1145	7.0	2	.1	1.	.9	2.0	21.9	3	3.2	6.7	36.50
TOTALS	8520	17.3		.6		2.8	15.3	103.5		7.9	34.2	21.31

COST OF 68. METERS OF FLOW RATING 7. GPM IS $ 10. (THOUSAND)
COST OF PUMPS WITH 15. HORSEPOWER CAPACITY IS $ 3. (THOUSAND)

PIPING SYSTEM($X1000.)

PIPE	17.35
INSULATION	15.34
CASING	103.51
FITTINGS	.56
EXPANSION LOOP	7.87
TRENCH	34.17
VALVES	2.78
METERS	9.79
HEAT PUMP	0.00
PUMP	2.59

TOTAL SYSTEM CAPITAL COST 193.97

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRIBUTION SYSTEM OF DISTRICT 3 SINGLE PIPE SYSTEM

		FLOWRATE (LB/SEC)	HEAT LOSS (BTU/SEC)	TEMPERATURE (F) SUPPLY	RETURN	HEAD LOSS FEET	NOMINAL DIAM(IN)	INSUL (IN)
HOUSE DESCRIPTION								
HOUSE		.7	-.1	191.	113.	4.55	1.00	2.5
STREET DESCRIPTION								
STREET	HOUSE							
1	1	1.4	-1.5	191.	****	9.02	1.00	2.5
	2	2.8	-1.7	191.	****	4.19	1.50	3.0
	3	4.2	-1.0	191.	****	4.77	1.50	2.0
LATERAL DESCRIPTION								
LATERAL	STREET							
1	1	1.5	-3.1	191.	****	2.59	1.50	3.5
	2	7.6	-3.5	192.	****	14.94	2.00	3.5
	3	13.6	-3.6	192.	****	18.84	2.50	3.5
	4	19.7	-4.0	192.	****	9.42	3.00	3.5
	5	25.8	-4.0	192.	****	15.43	3.00	3.5
	6	31.8	-4.7	192.	****	6.36	4.00	3.5
	7	37.9	-4.7	192.	****	8.77	4.00	3.5
	8	44.0	-4.7	192.	****	11.52	4.00	3.5
	9	47.0	0.0	192.	****	0.00	4.00	3.5
MAIN DESCRIPTION								
MAIN		94.0	-36.0	192.	****	326.93	4.00	3.5

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRICT 3 CAPITAL COSTS AND MATERIAL REQUIREMENTS

PIPE SIZE (IN)	PIPE (LIN.FT)	PIPE COST $X1000	NUMBER OF FTNGS	FTNGS COST $X1000	NUMBER OF VALVES	VALVE COST $X1000	INSUL COST $X1000	CASING COST $X1000	NUMBER OF EXP LOOPS	EXP LOOP COST $X1000	TRENCH COST $X1000	LIN.FT. COST ($/FT)
1.0	14231	12.7	434	1.1	217.	1.9	24.2	124.8	47	2.9	42.7	14.77
1.5	5013	8.4	132	.1	66.	.2	7.3	57.1	16	6.3	19.4	19.70
2.0	385	1.0	4	.1	2.	.2	.6	6.0	1	.7	1.9	26.96
2.5	385	1.3	4	.1	2.	.3	.6	6.0	1	.7	1.9	28.20
3.0	771	3.3	8	.1	4.	1.1	1.2	14.7	2	1.9	4.5	34.79
4.0	2635	16.1	18	.1	9.	.9	4.7	50.3	8	7.5	15.3	36.04
TOTALS	23422	42.7		1.5		4.6	38.6	258.9		20.0	85.7	19.30

COST OF 185. METERS OF FLOW RATING 7. GPM IS $ 27. (THOUSAND)
COST OF PUMPS WITH 74. HORSEPOWER CAPACITY IS $ 10. (THOUSAND)

PIPING SYSTEM($X1000.)

PIPE	42.68
INSULATION	38.61
CASING	258.94
FITTINGS	1.46
EXPANSION LOOP	19.99
TRENCH	85.72
VALVES	4.58
METERS	26.64
HEAT PUMP	0.00
PUMP	9.79

TOTAL SYSTEM CAPITAL COST 488.41

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRIBUTION SYSTEM OF DISTRICT 4 SINGLE PIPE SYSTEM

HOUSE DESCRIPTION		FLOWRATE (LB/SEC)	HEAT LOSS (BTU/SEC)	TEMPERATURE (F) SUPPLY	RETURN	HEAD LOSS FEET	NOMINAL DIAM(IN)	INSUL (IN)
HOUSE		.1	-.1	188.	113.	2.98	1.00	2.5
STREET DESCRIPTION								
STREET	HOUSE							
1	1	.2	-1.6	189.	****	.30	1.00	2.5
	2	.4	-1.6	190.	****	1.08	1.00	2.5
	3	.6	-1.6	190.	****	2.28	1.00	2.5
	4	.9	-1.6	190.	****	3.88	1.00	2.5
	5	1.1	-1.6	191.	****	5.85	1.00	2.5
	6	1.3	-1.6	191.	****	8.18	1.00	2.5
	7	1.5	-1.6	191.	****	10.86	1.00	2.5
	8	1.7	-1.6	191.	****	13.88	1.00	2.5
	9	1.9	-1.6	191.	****	17.24	1.00	2.5
	10	2.2	-.8	191.	****	11.01	1.00	2.5
LATERAL DESCRIPTION								
LATERAL	STREET							
1	1	1.0	-2.8	191.	****	10.09	1.00	3.5
	2	4.1	-3.3	191.	****	17.13	1.50	3.5
	3	7.3	-3.7	192.	****	14.39	2.00	3.5
	4	10.4	-3.8	192.	****	11.88	2.50	3.5
	5	13.5	-3.8	192.	****	19.28	2.50	3.5
	6	16.6	-4.2	192.	****	7.18	3.00	3.5
	7	19.7	-2.5	192.	****	5.29	3.00	2.5
MAIN DESCRIPTION								
MAIN		39.5	-41.1	192.	****	76.17	6.00	3.5

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRICT 4 CAPITAL COSTS AND MATERIAL REQUIREMENTS

PIPE SIZE (IN)	PIPE (LIN.FT)	PIPE COST $X1000	NUMBER OF FTNGS	FTNGS COST $X1000	NUMBER OF VALVES	VALVE COST $X1000	INSUL COST $X1000	CASING COST $X1000	NUMBER OF EXP LOOPS	EXP LOOP COST $X1000	TRENCH COST $X1000	LIN.FT. COST ($/FT)
1.0	55332	49.3	1494	.1	747.	.1	93.2	486.2	184	22.0	166.2	14.77
1.5	404	.7	4	.1	2.	.1	.8	6.5	1	.7	2.0	26.86
2.0	404	1.0	4	.1	2.	.2	.6	6.3	1	.7	2.0	26.82
2.5	808	2.7	8	.1	4.	.2	1.2	12.5	2	1.6	4.1	27.65
3.0	606	2.6	8	.1	4.	.8	.9	10.2	2	1.3	3.2	31.29
6.0	1314	13.5	2	.1	1.	1.1	3.0	34.6	4	6.0	9.4	51.53
	------	------		-----		-----	-----	------		------	------	-----
TOTALS	58870	69.7		.4		2.6	99.6	556.2		32.3	187.0	16.10

COST OF 505. METERS OF FLOW RATING 7. GPM IS $ 62. (THOUSAND)
COST OF PUMPS WITH 43. HORSEPOWER CAPACITY IS $ 8. (THOUSAND)

PIPING SYSTEM($X1000.)

PIPE	69.74
INSULATION	99.64
CASING	556.20
FITTINGS	.42
EXPANSION LOOP	32.35
TRENCH	186.97
VALVES	2.55
METERS	61.81
HEAT PUMP	0.00
PUMP	7.89

TOTAL SYSTEM CAPITAL COST 1017.57

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRIBUTION SYSTEM OF DISTRICT 5 SINGLE PIPE SYSTEM

HOUSE DESCRIPTION		FLOWRATE (LB/SEC)	HEAT LOSS (BTU/SEC)	TEMPERATURE (F) SUPPLY	RETURN	HEAD LOSS FEET	NOMINAL DIAM(IN)	INSUL (IN)
HOUSE		.7	-.1	191.	113.	4.55	1.00	2.5
STREET DESCRIPTION								
STREET	HOUSE							
1	1	1.4	-1.5	191.	****	9.02	1.00	2.5
	2	2.8	-1.7	191.	****	4.19	1.50	3.0
	3	4.2	-1.7	191.	****	8.83	1.50	3.0
	4	4.9	0.0	191.	****	0.00	1.50	2.5
LATERAL DESCRIPTION								
LATERAL	STREET							
1	1	.5	-3.1	191.	****	.34	1.50	3.5
	2	7.6	-3.5	192.	****	14.94	2.00	3.5
	3	11.1	0.0	192.	****	0.00	2.00	3.5
MAIN DESCRIPTION								
MAIN		22.2	-18.4	192.	****	223.83	2.50	3.5

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRICT 5 CAPITAL COSTS AND MATERIAL REQUIREMENTS

PIPE SIZE (IN)	PIPE (LIN.FT)	PIPE COST $X1000	NUMBER OF FTNGS	FTNGS COST $X1000	NUMBER OF VALVES	VALVE COST $X1000	INSUL COST $X1000	CASING COST $X1000	NUMBER OF EXP LOOPS	EXP LOOP COST $X1000	TRENCH COST $X1000	LIN.FT. COST ($/FT)
1.0	3422	3.4	104	.3	52.	.5	6.5	33.5	11	.8	11.5	16.50
1.5	1928	3.4	52	.1	26.	.2	3.3	25.6	6	2.7	8.5	22.67
2.0	385	1.0	8	.1	4.	.2	.6	6.0	1	.7	1.9	27.00
2.5	982	3.3	2	.0	1.	.1	1.4	15.2	3	1.9	4.9	27.44
TOTALS	6718	11.1		.5		1.0	11.8	80.3		6.1	26.8	20.47

COST OF 44. METERS OF FLOW RATING 7. GPM IS $ 6. (THOUSAND)
COST OF PUMPS WITH 8. HORSEPOWER CAPACITY IS $ 2. (THOUSAND)

PIPING SYSTEM($X1000.)

PIPE	11.07
INSULATION	11.77
CASING	80.31
FITTINGS	.47
EXPANSION LOOP	6.13
TRENCH	26.78
VALVES	1.01
METERS	6.34
HEAT PUMP	0.00
PUMP	2.06

TOTAL SYSTEM CAPITAL COST 145.93

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRIBUTION SYSTEM OF DISTRICT 6 SINGLE PIPE SYSTEM

HOUSE DESCRIPTION		FLOWRATE (LB/SEC)	HEAT LOSS (BTU/SEC)	TEMPERATURE (F) SUPPLY	RETURN	HEAD LOSS FEET	NOMINAL DIAM(IN)	INSUL (IN)
HOUSE		.1	-.1	188.	113.	2.98	1.00	2.5
STREET DESCRIPTION								
STREET	HOUSE							
1	1	.2	-1.6	189.	****	.30	1.00	2.5
	2	.4	-1.6	189.	****	1.08	1.00	2.5
	3	.6	-1.6	190.	****	2.28	1.00	2.5
	4	.9	-1.6	190.	****	3.88	1.00	2.5
	5	1.1	-1.6	190.	****	5.85	1.00	2.5
	6	1.3	-1.6	190.	****	8.18	1.00	2.5
	7	1.4	0.0	191.	****	0.00	1.00	2.5
LATERAL DESCRIPTION								
LATERAL	STREET							
1	1	.4	-2.8	191.	****	1.74	1.00	3.5
	2	2.4	-2.8	191.	****	49.91	1.00	3.5
	3	4.4	-3.3	191.	****	19.58	1.50	3.5
	4	6.5	-3.7	191.	****	11.67	2.00	3.5
	5	8.5	-3.8	191.	****	8.24	2.50	3.5
	6	10.5	-3.8	192.	****	12.21	2.50	3.5
	7	12.6	-3.8	192.	****	16.89	2.50	3.5
	8	14.6	-3.8	192.	****	22.25	2.50	3.5
	9	16.6	-4.2	192.	****	7.18	3.00	3.5
	10	18.6	-4.2	192.	****	8.87	3.00	3.5
	11	20.7	-4.2	192.	****	10.73	3.00	3.5
	12	22.7	-4.2	192.	****	12.74	3.00	3.5
	13	24.7	-2.7	192.	****	2.28	4.00	3.0
MAIN DESCRIPTION								
MAIN		49.4	-128.2	192.	****	918.34	6.00	3.5

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRICT 6 CAPITAL COSTS AND MATERIAL REQUIREMENTS

	PIPE SIZE (IN)	PIPE (LIN.FT)	PIPE COST $X1000	NUMBER OF FTNGS	FTNGS COST $X1000	NUMBER OF VALVES	VALVE COST $X1000	INSUL COST $X1000	CASING COST $X1000	NUMBER OF EXP LOOPS	EXP LOOP COST $X1000	TRENCH COST $X1000	LIN.FT. COST ($/FT)
	1.0	69882	62.2	1946	.0	973.	.1	118.1	614.8	232	28.1	210.1	14.79
	1.5	404	.7	4	.1	2.	.1	.8	6.5	1	.7	2.0	26.80
	2.0	404	1.0	4	.1	2.	.2	.6	6.3	1	.7	2.0	26.75
	2.5	1616	5.4	16	.1	8.	.2	2.4	25.0	5	3.1	8.1	27.44
	3.0	1616	6.9	16	.1	8.	.8	2.6	30.9	5	4.0	9.4	33.78
	4.0	202	1.2	4	.1	2.	.9	.3	3.1	0	.5	1.0	35.32
	6.0	4102	39.9	2	.1	1.	1.0	8.9	102.5	13	17.9	28.0	48.34
		------	------		-----		-----	-----	------		------	------	-----
TOTALS		78228	117.4		.5		3.3	133.6	789.1		55.0	260.7	17.38

COST OF 633. METERS OF FLOW RATING 7. GPM IS $ 68. (THOUSAND)
COST OF PUMPS WITH 65. HORSEPOWER CAPACITY IS $ 9. (THOUSAND)

PIPING SYSTEM($X1000.)

PIPE	117.40
INSULATION	133.62
CASING	789.07
FITTINGS	.47
EXPANSION LOOP	55.01
TRENCH	260.66
VALVES	3.32
METERS	68.36
HEAT PUMP	0.00
PUMP	9.32

TOTAL SYSTEM CAPITAL COST 1437.22

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRIBUTION SYSTEM OF DISTRICT 7 SINGLE PIPE SYSTEM

		FLOWRATE (LB/SEC)	HEAT LOSS (BTU/SEC)	TEMPERATURE (F) SUPPLY	RETURN	HEAD LOSS FEET	NOMINAL DIAM(IN)	INSUL (IN)
HOUSE DESCRIPTION								
HOUSE		.1	-.1	188.	113.	2.98	1.00	2.5
STREET DESCRIPTION								
STREET	HOUSE							
1	1	.2	-1.6	189.	****	.30	1.00	2.5
	2	.4	-1.6	190.	****	1.08	1.00	2.5
	3	.6	-1.6	190.	****	2.28	1.00	2.5
	4	.9	-.8	190.	****	2.04	1.00	2.5
LATERAL DESCRIPTION								
LATERAL	STREET							
1	1	.4	-2.8	190.	****	1.74	1.00	3.5
	2	1.6	-2.8	191.	****	24.37	1.00	3.5
	3	2.9	-2.8	191.	****	69.11	1.00	3.5
	4	4.1	-3.3	191.	****	17.13	1.50	3.5
	5	5.4	-3.3	191.	****	27.83	1.50	3.5
	6	6.6	-3.7	191.	****	12.19	2.00	3.5
	7	7.9	-3.7	191.	****	16.75	2.00	3.5
	8	9.1	-3.8	192.	****	9.39	2.50	3.5
	9	10.4	-3.8	192.	****	11.88	2.50	3.5
	10	11.6	-3.8	192.	****	14.65	2.50	3.5
	11	12.9	-3.8	192.	****	17.67	2.50	3.5
	12	14.1	-3.8	192.	****	20.95	2.50	3.5
	13	15.4	-3.8	192.	****	24.48	2.50	3.5
	14	16.6	-2.5	192.	****	3.85	3.00	2.5
MAIN DESCRIPTION								
MAIN		33.2	-28.9	192.	****	8.48	10.00	3.5

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRICT 7 CAPITAL COSTS AND MATERIAL REQUIREMENTS

	PIPE SIZE (IN)	PIPE (LIN.FT)	PIPE COST $X1000	NUMBER OF FTNGS	FTNGS COST $X1000	NUMBER OF VALVES	VALVE COST $X1000	INSUL COST $X1000	CASING COST $X1000	NUMBER OF EXP LOOPS	EXP LOOP COST $X1000	TRENCH COST $X1000	LIN.FT. COST ($/FT)
	1.0	46503	41.4	1280	.1	640.	.1	78.7	410.8	155	18.5	140.2	14.83
	1.5	808	1.4	8	.1	4.	.1	1.5	12.9	2	1.4	4.1	26.59
	2.0	808	2.0	8	.1	4.	.2	1.2	12.5	2	1.4	4.1	26.52
	2.5	2424	8.2	24	.1	12.	.2	3.6	37.5	8	4.7	12.2	27.40
	3.0	202	.9	4	.1	2.	.8	.2	2.4	0	.3	.9	27.44
	10.0	654	12.9	2	.2	1.	2.1	2.4	25.2	2	5.8	5.9	83.29
		------	------		-----		-----	-----	------		------	------	-----
TOTALS		51402	66.7		.6		3.5	87.7	501.3		32.2	167.3	16.72

COST OF 426. METERS OF FLOW RATING 7. GPM IS $ 52. (THOUSAND)
COST OF PUMPS WITH 58. HORSEPOWER CAPACITY IS $ 9. (THOUSAND)

PIPING SYSTEM($X1000.)

PIPE	66.72
INSULATION	87.67
CASING	501.32
FITTINGS	.57
EXPANSION LOOP	32.18
TRENCH	167.25
VALVES	3.50
METERS	52.14
HEAT PUMP	0.00
PUMP	9.04

TOTAL SYSTEM CAPITAL COST 920.40

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRIBUTION SYSTEM OF DISTRICT 8 SINGLE PIPE SYSTEM

HOUSE DESCRIPTION		FLOWRATE (LB/SEC)	HEAT LOSS (BTU/SEC)	TEMPERATURE (F) SUPPLY	RETURN	HEAD LOSS FEET	NOMINAL DIAM(IN)	INSUL (IN)
HOUSE		.1	-.1	188.	113.	2.98	1.00	2.5
STREET DESCRIPTION								
STREET	HOUSE							
1	1	.2	-1.6	189.	****	.30	1.00	2.5
	2	.4	-1.6	190.	****	1.08	1.00	2.5
	3	.6	-1.6	190.	****	2.28	1.00	2.5
	4	.9	-1.6	190.	****	3.88	1.00	2.5
	5	1.1	-1.6	190.	****	5.85	1.00	2.5
	6	1.3	-1.6	190.	****	8.18	1.00	2.5
	7	1.5	-1.6	191.	****	10.86	1.00	2.5
	8	1.7	-1.6	191.	****	13.88	1.00	2.5
	9	1.9	-1.6	191.	****	17.24	1.00	2.5
	10	2.2	-1.6	191.	****	20.93	1.00	2.5
	11	2.4	-1.6	191.	****	24.94	1.00	2.5
	12	2.5	0.0	191.	****	0.00	1.00	0.0
LATERAL DESCRIPTION								
LATERAL	STREET							
1	1	1.2	-2.8	191.	****	14.78	1.00	3.5
	2	4.8	-3.3	191.	****	22.86	1.50	3.5
	3	8.4	-3.8	191.	****	8.10	2.50	3.5
	4	12.0	-3.8	191.	****	15.56	2.50	3.5
	5	15.6	-3.8	191.	****	25.17	2.50	3.5
	6	19.2	-4.2	191.	****	9.36	3.00	3.5
	7	22.8	-4.2	191.	****	12.83	3.00	3.5
	8	26.4	-4.2	191.	****	16.79	3.00	3.5
	9	29.9	-4.9	191.	****	5.93	4.00	3.5
	10	33.5	-4.9	191.	****	7.30	4.00	3.5
	11	37.1	-4.9	191.	****	8.80	4.00	3.5
	12	40.7	-4.9	191.	****	10.43	4.00	3.5
	13	42.5	0.0	191.	****	0.00	4.00	3.5
MAIN DESCRIPTION								
MAIN		85.0	-223.4	191.	****	1667.53	4.00	3.5

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRICT 8 CAPITAL COSTS AND MATERIAL REQUIREMENTS

	PIPE SIZE (IN)	PIPE (LIN.FT)	PIPE COST $X1000	NUMBER OF FTNGS	FTNGS COST $X1000	NUMBER OF VALVES	VALVE COST $X1000	INSUL COST $X1000	CASING COST $X1000	NUMBER OF EXP LOOPS	EXP LOOP COST $X1000	TRENCH COST $X1000	LIN.FT. COST ($/FT)
	1.0	122524	109.1	3334	.0	1667.	.1	206.4	1075.5	408	50.4	367.8	14.77
	1.5	404	.7	4	.0	2.	.1	.8	6.5	1	.7	2.0	26.70
	2.5	1212	4.1	12	.1	6.	.2	1.8	18.8	4	2.3	6.1	27.45
	3.0	1212	5.1	12	.1	6.	.7	2.0	23.2	4	3.0	7.0	33.82
	4.0	10804	59.5	22	.0	11.	.6	17.3	185.8	36	27.5	56.4	32.12
		------	------		-----		-----	-----	------		------	------	-----
TOTALS		136157	178.5		.2		1.6	228.2	1309.7		83.9	439.3	16.46

COST OF 1089. METERS OF FLOW RATING 7. GPM IS $ 94. (THOUSAND)
COST OF PUMPS WITH 150. HORSEPOWER CAPACITY IS $ 15. (THOUSAND)

PIPING SYSTEM($X1000.)

PIPE	178.45
INSULATION	228.23
CASING	1309.66
FITTINGS	.24
EXPANSION LOOP	83.91
TRENCH	439.34
VALVES	1.59
METERS	94.09
HEAT PUMP	0.00
PUMP	14.67

TOTAL SYSTEM CAPITAL COST 2350.18

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DESCRIPTION OF MAINS SERVING THE DISTRICTS

MAIN NUMBER	DISTRICT NUMBER	FLOWRATE (LB/SEC)	HEAT LOSS (BTU/SEC)	TEMPERATURE (F) SUPPLY	TEMPERATURE (F) RETURN	HEAD LOSS FEET	NOMINAL DIAM(IN)	INSUL (IN)	CUMULATIVE FLOWRATE (LB/SEC)
1	1	41.2	-44.1	192.	****	375.71	3.00	3.5	41.2
	2	34.4	-27.9	192.	****	170.10	4.00	3.5	75.5
	6	49.4	-128.2	192.	****	918.34	6.00	3.5	280.7
	7	33.2	-28.9	192.	****	8.48	10.00	3.5	313.9
2	3	94.0	-36.0	192.	****	326.93	4.00	3.5	94.0
	4	39.5	-41.1	192.	****	76.17	6.00	3.5	133.5
3	5	22.2	-18.4	192.	****	223.83	2.50	3.5	22.2
4	8	85.0	-223.4	191.	****	1667.53	4.00	3.5	85.0

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

TOTAL CAPITAL COSTS AND MATERIAL REQUIREMENTS

PIPE SIZE (IN)	PIPE (LIN.FT)	PIPE COST $X1000	NUMBER OF FTNGS	FTNGS COST $X1000	NUMBER OF VALVES	VALVE COST $X1000	INSUL COST $X1000	CASING COST $X1000	NUMBER OF EXP LOOPS	EXP LOOP COST $X1000	TRENCH COST $X1000	LIN.FT. COST ($/FT)
1.0	375103	334.7	10382	1.8	5191.	3.4	635.1	3306.9	1250	147.1	1130.2	14.82
1.5	11698	20.1	264	.6	132.	1.2	19.2	153.6	38	16.6	50.5	22.36
2.0	2792	7.1	32	.4	16.	1.1	4.0	43.2	9	5.0	14.0	26.77
2.5	9836	33.1	90	.6	45.	1.7	14.8	152.2	32	19.0	49.3	27.51
3.0	7543	32.0	66	.5	33.	5.8	11.8	139.9	25	18.0	42.8	33.25
4.0	14787	83.8	46	.2	23.	3.4	24.3	261.1	49	38.7	79.4	33.21
6.0	5417	53.4	4	.2	2.	2.1	11.9	137.1	18	24.0	37.5	49.12
10.0	654	12.9	2	.2	1.	2.1	2.4	25.2	2	5.8	5.9	83.38
	------	------		-----		-----	-----	------		------	------	-----
TOTALS	427833	577.1		4.5		20.7	723.4	4219.2		274.2	1409.6	16.90

COST OF 3477. METERS IS $ 384. (THOUSAND)
COST OF PUMPS WITH 491. HORSEPOWER CAPACITY IS $ 65. (THOUSAND)

CAPITAL COST ACCOUNTS ($X1000.)

PIPING SYSTEM	
PIPE	577.05
INSULATION	723.40
CASING	4219.22
FITTINGS	4.50
EXPANSION LOOP	274.19
TRENCH	1409.64
VALVES	20.70
METERS	383.68
PUMPS	64.73
TOTAL PIPING SYSTEM	7677.12
METERING CONTROL	76.77
BUILDING AND LAND USE	76.77
BUILDING RETROFIT	0.00
STORAGE	0.00
HEAT PUMP	0.00
HEAT EXCHANGER	0.00
ENGINEERING AND ADMINISTRATION	921.25
TOTAL CAPITAL COSTS	8751.91

OPERATING EXPENSE ACCOUNTS ($X1000.)

OPERATING EXPENSES	42.39
MAINTENANCE	21.15
PUMP OPERATION	68.25
METER READERS	32.24
HEAT PUMP OPERATION	0.00
SUPPLEMENTAL HEAT	138.91
HEAT EXCHANGER OPERATION	0.00
TOTAL OPERATING EXPENSES	302.94

DISTRIBUTION SYSTEM DESCRIPTION

DIST NO	TOTAL PEAK HEAT DEMAND (MBTU/HR)	UNIT TEMP DROP (F)	UNIT FLOW RATE (LB/HR)	TOTAL PEAK FLUID DEMAND (KLB/HR)	ANNUAL HEAT DEMAND (TBTU)	DISTR SYSTEM COSTS ($M)
01	11.153	75.2	390.	148.	.07	1.123
02	9.464	75.2	2527.	124.	.06	.194
03	25.512	75.2	2527.	338.	.16	.488
04	10.690	75.2	390.	142.	.06	1.018
05	6.172	75.2	2527.	80.	.04	.146
06	13.406	75.2	390.	178.	.08	1.437
07	9.015	75.2	390.	120.	.05	.920
08	23.056	75.2	390.	306.	.14	2.350
TOTALS	108.468	0.0	0.	1436.	.67	7.677

DISTANCE FROM SOURCE TO DISTR. CENTER (MI)	7.5
SOURCE FLUID TEMPERATURE (F)	194.0
RETURN FLUID TEMPERATURE (F)	*****
DISTRIBUTION SYSTEM HEAT LOSS (MBTU/HR)	-1.212
SUPPLEMENTAL HEAT REQUIREMENTS	
DEGREE DAYS	360.
PERCENT OF TOTAL DESIGN DEMAND	3.4
PEAK SUPPLEMENTAL HEAT REQUIREMENTS (MBTU/HR)	31.838
TOTAL SUPPLEMENTAL HEAT REQUIREMENTS (MBTU/YR)	23151.6

LOAD FACTOR	.71
TOTAL DISTRICT AREA (SMI)	1.3
COLDEST DAY TEMPERATURE (F)	-2.2
DESIGN TEMPERATURE (F)	10.4
ANNUAL DEGREE DAYS	10800.
DEGREE DAYS AT DESIGN TEMPERATURE	10440.

METRIC EQUIVALENTS

DIST NO	TOTAL PEAK HEAT DEMAND (MCAL/HR)	UNIT TEMP DROP (C)	UNIT FLOW RATE (KG/HR)	TOTAL PEAK FLUID DEMAND (KG/HR*1000)	ANNUAL HEAT DEMAND (GCAL)	DISTR SYSTEM COSTS ($M)
01	2810.348	41.8	177.	67.	17.08	1.123
02	2384.841	41.8	1146.	56.	15.20	.194
03	6428.702	41.8	1146.	154.	40.97	.488
04	2693.857	41.8	177.	64.	16.37	1.018
05	1555.331	41.8	1146.	36.	9.91	.146
06	3378.243	41.8	177.	81.	20.53	1.437
07	2271.577	41.8	177.	54.	13.81	.920
08	5809.995	41.8	177.	139.	35.31	2.350
TOTALS	27332.894	0.0	0.	651.	169.19	7.677

DISTANCE FROM SOURCE TO DISTR. CENTER (KM)	12.0
SOURCE FLUID TEMPERATURE (C)	90.0
RETURN FLUID TEMPERATURE (C)	*****
DISTRIBUTION SYSTEM HEAT LOSS (MCAL/HR)	-305.370
SUPPLEMENTAL HEAT REQUIREMENTS	
DEGREE DAYS (C)	200.
PERCENT OF TOTAL DESIGN DEMAND	3.4
PEAK SUPPLEMENTAL HEAT REQUIREMENTS (GCAL/HR)	.008
TOTAL SUPPLEMENTAL HEAT REQUIREMENTS (GCAL/HR)	5.8

LOAD FACTOR	.71
TOTAL DISTRICT AREA (SKM)	3.3
COLDEST DAY TEMPERATURE (C)	-19.0
DESIGN TEMPERATURE (C)	-12.0
ANNUAL DEGREE DAYS (C)	6000.
DEGREE DAYS AT DESIGN TEMPERATURE	5800.

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI, ICELAND

ECONOMIC ANALYSIS FOR GEOTHERMAL DISTRICT HEATING

RESERVOIR CHARACTERISTICS

AVERAGE DEPTH	2000.0	M
AVERAGE TEMPERATURE	90.0	C
THERMAL CAPACITY	400.0	MW(TH)

WELL DESIGN (AVERAGE)

DEPTH	2000.0	M
BOTTOM DIAMETER	22.225	CM
FRACTION CASED	1.00	

WELL PROPERTIES (AVERAGE)

MW(TH)/WELL	81.0	
MAXIMUM FLOW RATE/WELL	500000.0	LB/HR
WELL LIFE	30.0	YEARS
PRODUCING WELLS ON LINE	4.0	
DRY WELLS	0.0	
INJECTION WELLS	0.0	
INPUT WELL SPACING	20.0	ACRES
ACTUAL FLOW RATE/WELL	359999.8	#/HR
TOTAL FLOW RATE	1439999.3	#/HR
WELLHEAD TEMPERATURE	194.0	F
WELLHEAD PRESSURE	20.3	PSIA
SATURATION PRESSURE	10.2	PSIA
WELLHEAD PRESSURIZATION	2.000	
WELLHEAD STEAM FRACTION	0.00	

STRATIGRAPHY

ROCK TYPE	DEPTH(M)
HARD	2000.0

FLUID COMPOSITION

CACO3	0.00	%	
NACL	0.00	%	
SIO2	0.00	%	0. PPM
OTHER	0.00	%	
TOTAL DISSOLVED SOLIDS	0.00	%	

PH= 7.00

NONCONDENSIBLE GASES

H2S	0.000	%	0. PPM
CO2	0.000	%	
CH4	0.000	%	
OTHER	0.000	%	
TOTAL NONCONDENSIBLE GASES	0.000	%	

RESERVOIR ECONOMIC DEVELOPMENT FACTORS

FAVORABLE TARGET FRACTION	.500
FAVORABLE SITE FRACTION	.500
FRACTION OF SITES TO EVALUATE	.667
FRACTION OF SITES TODRILL	.750
FRACTION OF WELLS TO CASE	.250
FRACTION OF SITES TO DEVELOP	.250
PERCENT NONPRODUCING WELLS	5.0
INJECTION/PRODUCTION WELL FLOW RATE	2.000
FRACTION EXCESS PRODUCING WELLS	.10

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

RESERVOIR EXPLORATION COSTS

	TOTAL (DOLLARS)	CAPITALIZED (DOLLARS)	EXPENSED (DOLLARS)	FAVORABLE SITES	BEGINNING MONTH/YEAR	ENDING MONTH/YEAR
IDENTIFICATION OF TARGETS						
LITERATURE SEARCH	729.	5.7	723.7	128.	MAY/1968	OCT/1968
PRELIMINARY LAND CHECK	1823.	14.2	1809.2	128.	MAY/1968	OCT/1968
PRELIMINARY RECONNAISSANCE						
LITERATURE SEARCH	2553.	39.9	2512.9	64.	JUN/1968	DEC/1968
GEOLOGICAL RECONNAISSANCE	3647.	57.0	3589.9	64.	JUN/1968	DEC/1968
DETAILED LAND CHECK	4376.	68.4	4307.9	64.	JUN/1968	DEC/1968
DETAILED RECONNAISSANCE						
LEASE COST	109407.	3419.0	105988.0	32.	JUL/1968	MAY/1969
FIELD GEOLOGY	5983.	284.9	5698.3	21.	SEP/1968	JUN/1969
GEOCHEMICAL EXAMINATION	7180.	341.9	6837.9	21.	SEP/1968	JUN/1969
GEOPHYSICAL EXAMINATION	29916.	1424.6	28491.4	21.	SEP/1968	JUN/1969
IDENTIFICATION OF DRILLABLE SITES						
HEAT FLOW	10941.	683.8	10256.9	16.	APR/1969	MAR/1971
TEMPERATURE GRADIENT	11397.	712.3	10684.3	16.	APR/1969	MAR/1971
ELECTRICAL RESISTIVITY	3191.	199.4	2991.6	16.	APR/1969	MAR/1971
MICROSEISMIC	4559.	284.9	4273.7	16.	APR/1969	MAR/1971
DETAILED GEOCHEMISTRY	6838.	427.4	6410.6	16.	APR/1969	MAR/1971
EXPLORATION DRILLING						
COST OF DRILLING	39888.	3324.0	36564.0	4.	APR/1970	MAR/1972
WELL TESTING	2279.	569.8	1709.5	4.	APR/1972	APR/1972
TOTAL EXPLORATION COST *	244707.	11857.2	232849.8	1.00		
FIELD DEVELOPMENT						
PRODUCING WELLS	800000.	266666.7	533333.3		APR/1972	SEP/1975
NONPRODUCING WELLS	0.	0.0	0.0		APR/1972	SEP/1975
INJECTION WELLS	0.	0.0	0.0		OCT/1975	DEC/1977
TRANSMISSION SYSTEM	3655318.	3655317.6	0.0		OCT/1975	DEC/1977
DISPOSAL SYSTEM	0.	0.0	0.0		OCT/1975	DEC/1977
TOTAL FIELD DEVELOPMENT COST	4455318.					
FIELD OPERATION						
REPLACEMENT WELL COST	24242.	8080.8	16161.6		JAN/1978	DEC/2006
NONPRODUCING WELL DRILLING COST	1212.	0.0	0.0		JAN/1978	DEC/2006
ABANDONMENT	1333.	0.0	0.0		JAN/1978	DEC/2007
WELL MAINTENANCE	4000.	0.0	0.0		JAN/1978	DEC/2007
OVERHEAD AND MANAGEMENT	73586.	0.0	0.0		JAN/1978	DEC/2007
WELL REDRILLING COST	20000.	0.0	0.0		JAN/1978	DEC/2007
INJECTION COST	0.	0.0	0.0		JAN/1978	DEC/2007
PUMP OPERATIONAL COST	56775.	0.0	0.0		JAN/1978	DEC/2007
TRANSMISSION SYSTEM MTE.	182766.	0.0	0.0		JAN/1978	DEC/2007
DISPOSAL SYSTEM MTE.	0.	0.0	0.0		JAN/1978	DEC/2007
TOTAL FIELD OPERATION COST	363915.					

* TOTAL EXPLORATION COST ALLOCATED TO THIS 22.8 MW(TH) DISTRICT HEATING SYSTEM IS .0570 OF TOTAL EXPLORATION COST FOR THIS 400.0 MW(TH) RESERVOIR THERMAL CAPACITY

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

R E S E R V O I R   I N P U T   D A T A

BOND REPAYMENT PROPORTIONAL
SUM OF YEARS DIGITS DEPRECIATION

CAPITAL INVESTMENT, $M	3.9338	(INITIAL FINANCING)
PROJECT LIFE, YEARS	40.0000	
FRACTION OF INITIAL INVESTMENT IN BONDS	1.0000	(MUNICIPAL UTILITY FINANCING)
BOND INTEREST RATE	.0800	
EQUITY EARNING RATE (AFTER TAXES)	0.0000	
FEDERAL INCOME TAX RATE	0.0000	
DEPRECIABLE LIFE OF WELLS, YRS.	30.0000	
FIRST YEAR OF OPERATION	1978.	
STATE INCOME TAX RATE	0.0000	
STATE INCOME TAX RATE	0.0000	
STATE GROSS REVENUE TAX RATE	0.0000	
PROPERTY TAX RATE	0.0000	
DISPOSAL SYSTEM REPLACEMENT RATE	.0300	
TRANSMISSION SYSTEM REPLACEMENT RATE	.0300	
PROPERTY INSURANCE RATE	.0012	
ROYALTY PAYMENT,%	10.00	
DISTRB SYSTEM OPERATING LIFE	30.0000	
TRANSMISSION SYSTEM MTE. RATE	.0500	
DISPOSAL SYSTEM MTE. RATE	.0500	
EVALUE	.020000	
DISTRIBUTION REINJECTION OPTION	0	
DISTANCE(M) DISTRB TO INJECTION FIEL	1000.0000	
DRILLING COST PER PRODUCING WELL($)	200000.	
DRILLING COST PER NONPRODUCING WELL($)	150000.	
DRILLING COST PER INJECTION WELL($)	175000.	
PERCENTAGE INVESTMENT TAX CREDIT	0.0000	
RESERVOIR TO DISTRIBUTION CENTER(MI)	7.5	

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

ANNUAL CASH FLOW DATA, EXPENSES IN $M/YR

	YEAR	LOAD FACTOR	FIELD IDENT.	FIELD EXPLOR.	FIELD DEVELOPMENT	RESERVOIR OPERATION	PROPERTY TAXES AND INSURANCE	INTERIM CAPITAL REPLACEMENT	TOTAL	TAX CREDIT
1	1968	0.00000	.00255	.08748	0.00000	0.00000	.00000	0.00000	.09004	0.00000
2	1969	0.00000	0.00000	.08942	0.00000	0.00000	.00001	0.00000	.08943	0.00000
3	1970	0.00000	0.00000	.03342	0.00000	0.00000	.00001	0.00000	.03343	0.00000
4	1971	0.00000	0.00000	.02456	0.00000	0.00000	.00001	0.00000	.02457	0.00000
5	1972	0.00000	0.00000	.00727	.17143	0.00000	.00008	0.00000	.17878	0.00000
6	1973	0.00000	0.00000	0.00000	.22857	0.00000	.00017	0.00000	.22875	0.00000
7	1974	0.00000	0.00000	0.00000	.22857	0.00000	.00027	0.00000	.22884	0.00000
8	1975	0.00000	0.00000	0.00000	.57757	0.00000	.00082	0.00000	.57840	0.00000
9	1976	0.00000	0.00000	0.00000	1.62459	0.00000	.00277	0.00000	1.62736	0.00000
10	1977	0.00000	0.00000	0.00000	1.62459	0.00000	.00472	0.00000	1.62931	0.00000
11	1978	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
12	1979	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
13	1980	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
14	1981	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
15	1982	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
16	1983	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
17	1984	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
18	1985	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
19	1986	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
20	1987	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
21	1988	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
22	1989	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
23	1990	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
24	1991	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
25	1992	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
26	1993	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
27	1994	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
28	1995	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
29	1996	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
30	1997	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
31	1998	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
32	1999	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
33	2000	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
34	2001	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
35	2002	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
36	2003	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
37	2004	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
38	2005	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
39	2006	.70656	0.00000	0.00000	0.00000	.36392	.00472	.10966	.47830	0.00000
40	2007	.70656	0.00000	0.00000	0.00000	.33846	.00472	0.00000	.34318	0.00000

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI, ICELAND

ANNUAL DEDUCTIBLE EXPENSES, $M

	YEAR	8.000 PCT PRESENT WORTH FACTOR	FIELD OPERATING EXPENSES	BOND INTEREST	WELL DEPRECIATION	RESERVOIR DEPLETION AND DEPRECIATION	TOTAL DEDUCTIBLE OPER. EXP.	STATE INCOME TAXES
1	1968	.96225	.00128	0.00000	0.00000	0.00000	.00128	0.00000
2	1969	.89097	.04558	.00720	0.00000	0.00000	.05278	0.00000
3	1970	.82497	.01372	.01493	0.00000	0.00000	.02866	0.00000
4	1971	.76387	.04657	.01880	0.00000	0.00000	.06538	0.00000
5	1972	.70728	.24010	.02227	0.00000	0.00000	.26237	0.00000
6	1973	.65489	.15256	.03836	0.00000	0.00000	.19091	0.00000
7	1974	.60638	.15265	.05973	0.00000	0.00000	.21237	0.00000
8	1975	.56146	.11511	.08281	0.00000	0.00000	.19792	0.00000
9	1976	.51987	.00277	.13571	0.00000	0.00000	.13848	0.00000
10	1977	.48136	.00472	.27675	0.00000	0.00000	.28147	0.00000
11	1978	.44571	.36055	.42924	.01720	.23622	1.04322	0.00000
12	1979	.41269	.36055	.42554	.02421	.33118	1.14149	0.00000
13	1980	.38212	.36055	.42155	.02316	.31695	1.12223	0.00000
14	1981	.35382	.36055	.41725	.02216	.30320	1.10315	0.00000
15	1982	.32761	.36055	.41259	.02118	.28991	1.08424	0.00000
16	1983	.30334	.36055	.40757	.02025	.27710	1.06547	0.00000
17	1984	.28087	.36055	.40214	.01934	.26476	1.04679	0.00000
18	1985	.26007	.36055	.39628	.01847	.25289	1.02819	0.00000
19	1986	.24080	.36055	.38995	.01764	.24149	1.00963	0.00000
20	1987	.22297	.36055	.38311	.01684	.23056	.99107	0.00000
21	1988	.20645	.36055	.37573	.01607	.22011	.97247	0.00000
22	1989	.19116	.36055	.36775	.01534	.21012	.95378	0.00000
23	1990	.17700	.36055	.35914	.01465	.20061	.93496	0.00000
24	1991	.16389	.36055	.34984	.01399	.19157	.91596	0.00000
25	1992	.15175	.36055	.33980	.01336	.18300	.89672	0.00000
26	1993	.14051	.36055	.32895	.01277	.17491	.87718	0.00000
27	1994	.13010	.36055	.31723	.01222	.16728	.85728	0.00000
28	1995	.12046	.36055	.30458	.01170	.16013	.83695	0.00000
29	1996	.11154	.36055	.29091	.01121	.15345	.81612	0.00000
30	1997	.10328	.36055	.27615	.01076	.14724	.79470	0.00000
31	1998	.09563	.36055	.26021	.01034	.14150	.77260	0.00000
32	1999	.08854	.36055	.24299	.00996	.13623	.74974	0.00000
33	2000	.08198	.36055	.22440	.00961	.13144	.72600	0.00000
34	2001	.07591	.36055	.20432	.00930	.12711	.70128	0.00000
35	2002	.07029	.36055	.18263	.00902	.12326	.67547	0.00000
36	2003	.06508	.36055	.15921	.00878	.11988	.64842	0.00000
37	2004	.06026	.36055	.13391	.00857	.11697	.62001	0.00000
38	2005	.05580	.36055	.10659	.00839	.11454	.59008	0.00000
39	2006	.05166	.36055	.07709	.00825	.11257	.55847	0.00000
40	2007	.04784	.34318	.04522	.08626	1.17112	1.64579	0.00000
TOTALS=					.50101	6.84730		

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

ANNUAL INCOME STATEMENT, $M

	YEAR	ENERGY UNITS (T BTU)	TOTAL ENERGY SALES	BY PRODUCT SALES	PERCENTAGE DEPLETION ALLOWANCE	ROYALTY PAYMENTS EXPENSES	TOTAL TAX DEDUCTIBLE EXPENSES	TAXABLE INCOME (FEDERAL)	FEDERAL INCOME TAX
1	1968	0.00000	0.00000	0.00000	0.00000	0.00000	.00128	-.00128	0.00000
2	1969	0.00000	0.00000	0.00000	0.00000	0.00000	.05278	-.05278	0.00000
3	1970	0.00000	0.00000	0.00000	0.00000	0.00000	.02866	-.02866	0.00000
4	1971	0.00000	0.00000	0.00000	0.00000	0.00000	.06538	-.06538	0.00000
5	1972	0.00000	0.00000	0.00000	0.00000	0.00000	.26237	-.26237	0.00000
6	1973	0.00000	0.00000	0.00000	0.00000	0.00000	.19091	-.19091	0.00000
7	1974	0.00000	0.00000	0.00000	0.00000	0.00000	.21237	-.21237	0.00000
8	1975	0.00000	0.00000	0.00000	0.00000	0.00000	.19792	-.19792	0.00000
9	1976	0.00000	0.00000	0.00000	0.00000	0.00000	.13848	-.13848	0.00000
10	1977	0.00000	0.00000	0.00000	0.00000	0.00000	.28147	-.28147	0.00000
11	1978	.68202	1.05967	0.00000	0.00000	.10597	1.04322	-.08952	0.00000
12	1979	.68202	1.05967	0.00000	0.00000	.10597	1.14149	-.18778	0.00000
13	1980	.68202	1.05967	0.00000	0.00000	.10597	1.12223	-.16852	0.00000
14	1981	.68202	1.05967	0.00000	0.00000	.10597	1.10315	-.14945	0.00000
15	1982	.68202	1.05967	0.00000	0.00000	.10597	1.08424	-.13054	0.00000
16	1983	.68202	1.05967	0.00000	0.00000	.10597	1.06547	-.11176	0.00000
17	1984	.68202	1.05967	0.00000	0.00000	.10597	1.04679	-.09309	0.00000
18	1985	.68202	1.05967	0.00000	0.00000	.10597	1.02819	-.07449	0.00000
19	1986	.68202	1.05967	0.00000	0.00000	.10597	1.00963	-.05593	0.00000
20	1987	.68202	1.05967	0.00000	0.00000	.10597	.99107	-.03737	0.00000
21	1988	.68202	1.05967	0.00000	0.00000	.10597	.97247	-.01876	0.00000
22	1989	.68202	1.05967	0.00000	0.00000	.10597	.95378	-.00008	0.00000
23	1990	.68202	1.05967	0.00000	0.00000	.10597	.93496	.01874	0.00000
24	1991	.68202	1.05967	0.00000	0.00000	.10597	.91596	.03775	0.00000
25	1992	.68202	1.05967	0.00000	0.00000	.10597	.89672	.05698	0.00000
26	1993	.68202	1.05967	0.00000	0.00000	.10597	.87718	.07652	0.00000
27	1994	.68202	1.05967	0.00000	0.00000	.10597	.85728	.09642	0.00000
28	1995	.68202	1.05967	0.00000	0.00000	.10597	.83695	.11675	0.00000
29	1996	.68202	1.05967	0.00000	0.00000	.10597	.81612	.13758	0.00000
30	1997	.68202	1.05967	0.00000	0.00000	.10597	.79470	.15900	0.00000
31	1998	.68202	1.05967	0.00000	0.00000	.10597	.77260	.18110	0.00000
32	1999	.68202	1.05967	0.00000	0.00000	.10597	.74974	.20397	0.00000
33	2000	.68202	1.05967	0.00000	0.00000	.10597	.72600	.22770	0.00000
34	2001	.68202	1.05967	0.00000	0.00000	.10597	.70128	.25242	0.00000
35	2002	.68202	1.05967	0.00000	0.00000	.10597	.67547	.27824	0.00000
36	2003	.68202	1.05967	0.00000	0.00000	.10597	.64842	.30528	0.00000
37	2004	.68202	1.05967	0.00000	0.00000	.10597	.62001	.33369	0.00000
38	2005	.68202	1.05967	0.00000	0.00000	.10597	.59008	.36362	0.00000
39	2006	.68202	1.05967	0.00000	0.00000	.10597	.55847	.39523	0.00000
40	2007	.68202	1.05967	0.00000	0.00000	.10597	1.64579	-.69209	0.00000

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI, ICELAND

PAYOUT OF INVESTMENTS, $M

	YEAR	NET CASH FLOW	OUTSTANDING BONDS	EQUITY CAPITAL NOT RECOVERED	BOND INTEREST	EARNINGS ON UNRECOVERED EQUITY	BONDS REPAID	RECOVERY OF EQUITY
1	1968	-.09004	0.00000	0.00000	0.00000	0.00000	-.09004	0.00000
2	1969	-.09664	.09004	0.00000	.00720	0.00000	-.09664	0.00000
3	1970	-.04837	.18668	0.00000	.01493	0.00000	-.04837	0.00000
4	1971	-.04338	.23504	0.00000	.01880	0.00000	-.04338	0.00000
5	1972	-.20105	.27842	0.00000	.02227	0.00000	-.20105	0.00000
6	1973	-.26710	.47947	0.00000	.03836	0.00000	-.26710	0.00000
7	1974	-.28856	.74657	0.00000	.05973	0.00000	-.28856	0.00000
8	1975	-.66121	1.03513	0.00000	.08281	0.00000	-.66121	0.00000
9	1976	-1.76306	1.69634	0.00000	.13571	0.00000	-1.76306	0.00000
10	1977	-1.90606	3.45940	0.00000	.27675	0.00000	-1.90606	0.00000
11	1978	.04617	5.36546	0.00000	.42924	0.00000	.04617	0.00000
12	1979	.04986	5.31929	0.00000	.42554	0.00000	.04986	0.00000
13	1980	.05385	5.26943	0.00000	.42155	0.00000	.05385	0.00000
14	1981	.05816	5.21557	0.00000	.41725	0.00000	.05816	0.00000
15	1982	.06281	5.15741	0.00000	.41259	0.00000	.06281	0.00000
16	1983	.06784	5.09460	0.00000	.40757	0.00000	.06784	0.00000
17	1984	.07327	5.02676	0.00000	.40214	0.00000	.07327	0.00000
18	1985	.07913	4.95349	0.00000	.39628	0.00000	.07913	0.00000
19	1986	.08546	4.87436	0.00000	.38995	0.00000	.08546	0.00000
20	1987	.09230	4.78891	0.00000	.38311	0.00000	.09230	0.00000
21	1988	.09968	4.69661	0.00000	.37573	0.00000	.09968	0.00000
22	1989	.10765	4.59693	0.00000	.36775	0.00000	.10765	0.00000
23	1990	.11627	4.48928	0.00000	.35914	0.00000	.11627	0.00000
24	1991	.12557	4.37301	0.00000	.34984	0.00000	.12557	0.00000
25	1992	.13561	4.24745	0.00000	.33980	0.00000	.13561	0.00000
26	1993	.14646	4.11183	0.00000	.32895	0.00000	.14646	0.00000
27	1994	.15818	3.96537	0.00000	.31723	0.00000	.15818	0.00000
28	1995	.17083	3.80720	0.00000	.30458	0.00000	.17083	0.00000
29	1996	.18450	3.63636	0.00000	.29091	0.00000	.18450	0.00000
30	1997	.19926	3.45187	0.00000	.27615	0.00000	.19926	0.00000
31	1998	.21520	3.25261	0.00000	.26021	0.00000	.21520	0.00000
32	1999	.23241	3.03741	0.00000	.24299	0.00000	.23241	0.00000
33	2000	.25101	2.80499	0.00000	.22440	0.00000	.25101	0.00000
34	2001	.27109	2.55399	0.00000	.20432	0.00000	.27109	0.00000
35	2002	.29278	2.28290	0.00000	.18263	0.00000	.29278	0.00000
36	2003	.31620	1.99012	0.00000	.15921	0.00000	.31620	0.00000
37	2004	.34149	1.67392	0.00000	.13391	0.00000	.34149	0.00000
38	2005	.36881	1.33243	0.00000	.10659	0.00000	.36881	0.00000
39	2006	.39832	.96362	0.00000	.07709	0.00000	.39832	0.00000
40	2007	.56530	.56530	0.00000	.04522	0.00000	.56530	0.00000

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI, ICELAND

	DETAILED CASH FLOW		DISTRIBUTION OF ENERGY COSTS	
	CENTS PER MBTU	ANNUAL ($ MILLIONS)	CENTS PER MBTU	ANNUAL ($ MILLIONS)
COST OF ENERGY	155.37222	1.05967		
FIELD IDENTIFICATION AND EXPLORATION	5.89250	.04019	6.54722	.04465
FIELD DEVELOPMENT (TOTAL)	63.86542	.43558	70.96158	.48397
PRODUCING WELLS	13.68504	.09333	15.20560	.10371
TRANSMISSION SYSTEM	50.18038	.34224	55.75598	.38027
DISPOSAL SYSTEM	0.00000	0.00000	0.00000	0.00000
NONPRODUCING WELLS	0.00000	0.00000	0.00000	0.00000
FIELD OPERATING COSTS (TOTAL)	70.07708	.47794	77.86342	.53104
DISPOSAL COSTS	0.00000	0.00000	0.00000	0.00000
PRODUCING WELLS	7.23758	.04936	8.04176	.05485
TRANSMISSION COSTS	51.05900	.34823	56.73222	.38693
OTHER OPERATING COSTS	11.78050	.08035	13.08944	.08927
REVENUE TAXES	0.00000	0.00000		
STATE INCOME TAXES	0.00000	0.00000		
ROYALTY PAYMENTS	15.53722	.10597		
FEDERAL INCOME TAXES	0.00000	0.00000		
BOND INTEREST	0.00000	0.00000		
BY PRODUCT REVENUE	0.00000	0.00000	0.00000	0.00000
TOTALS	155.37222	1.05967	155.37222	1.05967

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

DISTRICT HEATING DISTRIBUTION SYSTEM INPUT DATA

BOND REPAYMENT PROPORTIONAL		
SUM OF YEARS DIGITS DEPRECIATION		
DISTRB SYSTEM INVESTMENT, $M	8.7519	(INITIAL FINANCING)
PROJECT LIFE, YEARS	33.0000	
FRACTION OF INITIAL INVESTMENT IN BONDS	1.0000	(MUNICIPAL UTILITY FINANCING)
BOND INTEREST RATE	.0800	
EQUITY EARNING RATE (AFTER TAXES)	0.0000	
FEDERAL INCOME TAX RATE	0.0000	
DEPRECIABLE LIFE OF DISTRB,YRS.	30.0000	
DISTRB CONSTRUCTION AND LICENSING,YRS.	3.0000	
FIRST YEAR OF OPERATION	1978	
STATE INCOME TAX RATE	0.0000	
STATE GROSS REVENUE TAX RATE	.0400	
PROPERTY TAX RATE	0.0000	
INTERIM CAPITAL REPLACEMENTS, RATE/YR	.0035	
PROPERTY INSURANCE RATE	.0012	
ROYALTY PAYMENT, %	0.0000	
DISTRB SYSTEM OPERATING LIFE	30.0000	
PERCENTAGE INVESTMENT TAX CREDIT	0.0000	
OPTION DEFINITIONS IN USER MANUAL		
PIPE OPTION (PO)	6.	
PIPE MATERIAL OPTION (PMO)	1.	
INSULATION OPTION (IO)	2.	
CASING OPTION (CO)	2.	

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

CASH FLOW TABLE DISTRIBUTION SYSTEM, $ MILLIONS

	YEAR	LOAD FACTOR	CAPITAL COSTS	ENERGY COSTS	DISTRB OPERATING COSTS	INTERIM CAPITAL REPLACEMENT	PROPERTY TAXES INSURANCE	TOTAL COSTS	TAX CREDIT
1	1975	0.00000	.82797	0.00000	0.00000	0.00000	0.00000	.82797	0.00000
2	1976	0.00000	4.75165	0.00000	0.00000	0.00000	.00099	4.75264	0.00000
3	1977	0.00000	3.17229	0.00000	0.00000	0.00000	.00670	3.17899	0.00000
4	1978	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
5	1979	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
6	1980	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
7	1981	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
8	1982	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
9	1983	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
10	1984	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
11	1985	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
12	1986	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
13	1987	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
14	1988	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
15	1989	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
16	1990	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
17	1991	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
18	1992	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
19	1993	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
20	1994	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
21	1995	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
22	1996	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
23	1997	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
24	1998	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
25	1999	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
26	2000	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
27	2001	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
28	2002	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
29	2003	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
30	2004	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
31	2005	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
32	2006	.70656	0.00000	1.05967	.30294	.03063	.01050	1.40374	0.00000
33	2007	.70656	0.00000	1.05967	.30294	0.00000	.01050	1.37311	0.00000

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

ANNUAL TAX DEDUCTIBLE EXPENSES, $ MILLIONS

	YEAR	8.000 PCT PRESENT WORTH FACTOR	OPERATING EXPENSES	BOND INTEREST	DEPRECIATION	TOTAL DEDUCTIBLE OPERATING EXPENSES	STATE INCOME TAX
1	1975	.96225	0.00000	0.00000	0.00000	0.00000	0.00000
2	1976	.89097	.00099	.06624	0.00000	.06723	0.00000
3	1977	.82497	.00670	.45175	0.00000	.45844	0.00000
4	1978	.76387	1.37311	.74221	.56464	2.67996	0.00000
5	1979	.70728	1.37311	.73568	.57454	2.68333	0.00000
6	1980	.65489	1.37311	.72862	.55394	2.65568	0.00000
7	1981	.60638	1.37311	.72101	.53347	2.62759	0.00000
8	1982	.56146	1.37311	.71278	.51314	2.59903	0.00000
9	1983	.51987	1.37311	.70390	.49293	2.56994	0.00000
10	1984	.48136	1.37311	.69430	.47286	2.54027	0.00000
11	1985	.44571	1.37311	.68394	.45292	2.50997	0.00000
12	1986	.41269	1.37311	.67275	.43311	2.47897	0.00000
13	1987	.38212	1.37311	.66066	.41343	2.44720	0.00000
14	1988	.35382	1.37311	.64761	.39388	2.41460	0.00000
15	1989	.32761	1.37311	.63351	.37447	2.38109	0.00000
16	1990	.30334	1.37311	.61828	.35519	2.34658	0.00000
17	1991	.28087	1.37311	.60184	.33604	2.31099	0.00000
18	1992	.26007	1.37311	.58408	.31702	2.27421	0.00000
19	1993	.24080	1.37311	.56490	.29813	2.23614	0.00000
20	1994	.22297	1.37311	.54418	.27937	2.19667	0.00000
21	1995	.20645	1.37311	.52181	.26075	2.15568	0.00000
22	1996	.19116	1.37311	.49765	.24226	2.11302	0.00000
23	1997	.17700	1.37311	.47156	.22390	2.06857	0.00000
24	1998	.16389	1.37311	.44337	.20567	2.02216	0.00000
25	1999	.15175	1.37311	.41294	.18757	1.97362	0.00000
26	2000	.14051	1.37311	.38007	.16961	1.92279	0.00000
27	2001	.13010	1.37311	.34456	.15178	1.86945	0.00000
28	2002	.12046	1.37311	.30622	.13407	1.81341	0.00000
29	2003	.11154	1.37311	.26481	.11650	1.75443	0.00000
30	2004	.10328	1.37311	.22009	.09907	1.69227	0.00000
31	2005	.09563	1.37311	.17179	.08176	1.62667	0.00000
32	2006	.08854	1.37311	.11963	.06459	1.55733	0.00000
33	2007	.08198	1.37311	.06329	.34365	1.78005	0.00000

DEPRECIATION SUM = 9.6402

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI, ICELAND

ANNUAL INCOME STATEMENT, $ MILLIONS

	YEAR	HEAT UNITS (T BTU)	TOTAL HEAT SALES	REVENUE TAXES	TOTAL TAX DEDUCTIBLE EXPENSES	TAXABLE INCOME (FEDERAL)	FEDERAL INCOME TAX
1	1975	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
2	1976	0.00000	0.00000	0.00000	.06723	-.06723	0.00000
3	1977	0.00000	0.00000	0.00000	.45844	-.45844	0.00000
4	1978	.67140	2.32039	.09282	2.67996	-.45238	0.00000
5	1979	.67140	2.32039	.09282	2.68333	-.45575	0.00000
6	1980	.67140	2.32039	.09282	2.65568	-.42810	0.00000
7	1981	.67140	2.32039	.09282	2.62759	-.40001	0.00000
8	1982	.67140	2.32039	.09282	2.59903	-.37145	0.00000
9	1983	.67140	2.32039	.09282	2.56994	-.34236	0.00000
10	1984	.67140	2.32039	.09282	2.54027	-.31269	0.00000
11	1985	.67140	2.32039	.09282	2.50997	-.28239	0.00000
12	1986	.67140	2.32039	.09282	2.47897	-.25139	0.00000
13	1987	.67140	2.32039	.09282	2.44720	-.21962	0.00000
14	1988	.67140	2.32039	.09282	2.41460	-.18703	0.00000
15	1989	.67140	2.32039	.09282	2.38109	-.15351	0.00000
16	1990	.67140	2.32039	.09282	2.34658	-.11900	0.00000
17	1991	.67140	2.32039	.09282	2.31099	-.08341	0.00000
18	1992	.67140	2.32039	.09282	2.27421	-.04663	0.00000
19	1993	.67140	2.32039	.09282	2.23614	-.00856	0.00000
20	1994	.67140	2.32039	.09282	2.19667	.03091	0.00000
21	1995	.67140	2.32039	.09282	2.15568	.07190	0.00000
22	1996	.67140	2.32039	.09282	2.11302	.11456	0.00000
23	1997	.67140	2.32039	.09282	2.06857	.15901	0.00000
24	1998	.67140	2.32039	.09282	2.02216	.20542	0.00000
25	1999	.67140	2.32039	.09282	1.97362	.25395	0.00000
26	2000	.67140	2.32039	.09282	1.92279	.30479	0.00000
27	2001	.67140	2.32039	.09282	1.86945	.35813	0.00000
28	2002	.67140	2.32039	.09282	1.81341	.41417	0.00000
29	2003	.67140	2.32039	.09282	1.75443	.47315	0.00000
30	2004	.67140	2.32039	.09282	1.69227	.53531	0.00000
31	2005	.67140	2.32039	.09282	1.62667	.60091	0.00000
32	2006	.67140	2.32039	.09282	1.55733	.67025	0.00000
33	2007	.67140	2.32039	.09282	1.78005	.44752	0.00000

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI, ICELAND

PAYOUT OF INVESTMENTS, $ MILLIONS

	YEAR	NET CASH FLOW	OUTSTANDING BONDS	EQUITY CAPITAL NOT RECOVERED	BOND INTEREST	EARNINGS ON UNRECOVERED EQUITY	BONDS REPAID	RECOVERY OF EQUITY
1	1975	-.82797	0.00000	0.00000	0.00000	0.00000	-.82797	0.00000
2	1976	-4.81888	.82797	0.00000	.06624	0.00000	-4.81888	0.00000
3	1977	-3.63074	5.64685	0.00000	.45175	0.00000	-3.63074	0.00000
4	1978	.08163	9.27759	0.00000	.74221	0.00000	.08163	0.00000
5	1979	.08816	9.19596	0.00000	.73568	0.00000	.08816	0.00000
6	1980	.09521	9.10780	0.00000	.72862	0.00000	.09521	0.00000
7	1981	.10283	9.01259	0.00000	.72101	0.00000	.10283	0.00000
8	1982	.11105	8.90977	0.00000	.71278	0.00000	.11105	0.00000
9	1983	.11994	8.79872	0.00000	.70390	0.00000	.11994	0.00000
10	1984	.12953	8.67878	0.00000	.69430	0.00000	.12953	0.00000
11	1985	.13989	8.54925	0.00000	.68394	0.00000	.13989	0.00000
12	1986	.15109	8.40935	0.00000	.67275	0.00000	.15109	0.00000
13	1987	.16317	8.25827	0.00000	.66066	0.00000	.16317	0.00000
14	1988	.17623	8.09510	0.00000	.64761	0.00000	.17623	0.00000
15	1989	.19032	7.91887	0.00000	.63351	0.00000	.19032	0.00000
16	1990	.20555	7.72854	0.00000	.61828	0.00000	.20555	0.00000
17	1991	.22199	7.52299	0.00000	.60184	0.00000	.22199	0.00000
18	1992	.23975	7.30100	0.00000	.58408	0.00000	.23975	0.00000
19	1993	.25893	7.06125	0.00000	.56490	0.00000	.25893	0.00000
20	1994	.27965	6.80231	0.00000	.54418	0.00000	.27965	0.00000
21	1995	.30202	6.52266	0.00000	.52181	0.00000	.30202	0.00000
22	1996	.32618	6.22064	0.00000	.49765	0.00000	.32618	0.00000
23	1997	.35228	5.89446	0.00000	.47156	0.00000	.35228	0.00000
24	1998	.38046	5.54218	0.00000	.44337	0.00000	.38046	0.00000
25	1999	.41090	5.16172	0.00000	.41294	0.00000	.41090	0.00000
26	2000	.44377	4.75083	0.00000	.38007	0.00000	.44377	0.00000
27	2001	.47927	4.30706	0.00000	.34456	0.00000	.47927	0.00000
28	2002	.51761	3.82779	0.00000	.30622	0.00000	.51761	0.00000
29	2003	.55902	3.31018	0.00000	.26481	0.00000	.55902	0.00000
30	2004	.60374	2.75116	0.00000	.22009	0.00000	.60374	0.00000
31	2005	.65204	2.14742	0.00000	.17179	0.00000	.65204	0.00000
32	2006	.70420	1.49538	0.00000	.11963	0.00000	.70420	0.00000
33	2007	.79117	.79117	0.00000	.06329	0.00000	.79117	0.00000

DISTRICT HEATING SYSTEM WITH BRANCHING MAINS FOR AKUREYRI,ICELAND

	DETAILED CASH FLOW CENTS PER MBTU	DETAILED CASH FLOW ANNUAL ($ MILLIONS)	EQUIVALENT CASH FLOW CENTS PER MBTU	EQUIVALENT CASH FLOW ANNUAL ($ MILLIONS)
C O S T O F H E A T	345.60742	2.32039	345.60742	2.32039
C O S T D I S T R I B U T I O N				
INITIAL DISTRB SYSTEM	122.64217	.82341	127.75226	.85772
INTERIM CAPITAL REPLACEMENTS	4.52212	.03036	4.71054	.03163
ENERGY SUPPLY	157.83088	1.05967	164.40717	1.10382
OPERATING EXPENSES	45.12092	.30294	47.00096	.31556
PROPERTY TAXES AND INSURANCE	1.66703	.01119	1.73649	.01166
STATE REVENUE TAX	13.82430	.09282		
STATE INCOME TAX	0.00000	0.00000		
FEDERAL INCOME TAX	0.00000	0.00000		
BOND INTEREST	0.00000	0.00000		
TOTAL	345.60742	2.32039	345.60742	2.32039

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