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AN OVERVIEW OF ENGINEERING AND AGRICULTURAL DESIGN CONSIDERATIONS OF THE RAFT RIVER SOIL-WARMING AND HEAT-DISSIPATION EXPERIMENT

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Published April 1982

EG&G Idaho, Inc.
Idaho Falls, Idaho 83415

Prepared for the
U.S. Department of Energy
Idaho Operations Office
Under DOE Contract No. DE-AC07-76ID01570

DISCLAIMER

ABSTRACT

This report presents the engineering and agricultural considerations of the Raft River soil-warming and heat-dissipation experiment. The experiment is designed to investigate the thermal characteristics of a subsurface pipe network for cooling power-plant condenser effluent, and crop responses to soil warming in an open-field plot. The subsurface soil-warming system is designed to dissipate approximately 100 kW of heat from circulating, 38°C geothermal water. This report focuses on summer operating conditions in the Raft River area, located on the Intermountain Plateau. Design is based on the thermal characteristics of the local soil, the climate of the Raft River Valley, management practices for normal agriculture, and the need for an unheated control plot. The resultant design calls for 38-mm polyvinyl chloride (PVC) pipe in a grid composed of parallel loops, for dissipating heat into a 0.8-hectare experimental plot.

FOREWORD

The Geothermal Technical Assistance Program was developed under the premise that the majority of groups or individuals with available geothermal resources do not have the experience or manpower necessary to do a preliminary engineering and economic feasibility evaluation for geothermal energy projects. In order to disseminate technical information and to facilitate expanded use of geothermal energy resources, assistance was provided through FY-1981 in a consulting format on a first-come, staff-and-funds-available basis. Technical assistance can relate to conceptualization; engineering; economics; water chemistry implications for environmental, disposal, and material selection considerations; and planning and development strategies. This report is one of a series adapted from consultation provided to requesters either through in-house efforts or through limited efforts subcontracted to local engineering firms. The Geothermal Technical Assistance (GTA) reports in this series, which are listed below, will be available for purchase early in 1982 by those with interest in specific geothermal applications from the U.S. National Technical Information Service:

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13.	*EGG-2146	Geothermal Feasibility Analysis II for Polo School District No. 29-2, South Dakota (subcontractor report)
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15.	*EGG-2148	Inventory of Thermal Springs and Wells Within a One-Mile Radius of Yucca Lodge, Truth or Consequences, New Mexico (subcontractor report)

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16.	EGG-2149	Utilization of Geothermal Energy, Feasibility Study--Ojo Caliente Mineral Springs Company, Ojo Caliente, New Mexico (subcontractor report)
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20.	EGG-2153	Comparison of Two Options for Supplying Geothermal Energy to the Veterans Administration Medical Center, Marlin, Texas (subcontractor report)
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27.	EGG-GTH-5779	Pipe Selection Guide
28.	EGG-GTH-5804	An Overview of Engineering and Agricultural Design Considerations of the Raft River Soil-Warming and Heat-Dissipation Experiment
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*Published as of 4/1/82

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INTRODUCTION

The abundant moderate-temperature geothermal resources in the western United States could supply much of the energy needed in the vast region between the Rockies and the Cascades and Sierras. Scientists are investigating the economics of technologies for utilizing these resources. An important issue affecting widespread geothermal resource use in this area is net water consumption. Unfortunately, conventional power-generating techniques consume a great deal of water--a precious resource in the arid west.

Geothermal power plant conversion efficiencies range from 8 to 15%; for every 10 units of energy put into the system, only one to two units are converted to electrical energy. The unused heat is typically rejected from open cooling towers that cool by evaporating water. In arid western climates, these wet towers consume up to 190 million liters of water for every MW(e) produced. A 50-MW(e) geothermal power plant rejecting 300 MW of heat with wet cooling towers would consume 9.5 billion liters of water per year. An equivalent amount of water could be used to irrigate about 1700 hectares of agricultural land. Therefore, alternative cooling methods need to be developed.

A closed-cycle soil-heating system is a potential alternative. According to Wilkinson[1] and Shapiro,[2] a closed-cycle system would provide advantages over the use of conventional cooling towers by transforming rejected heat into a beneficial agricultural resource, reducing the need for antifouling chemicals, and reducing the consumptive use of water. A soil-heating system on 700 to 1000 hectares could dissipate the waste heat of a 40- to 45-MW(e) geothermal power plant. Both the initial condenser discharge temperature (∿38°C) and the desired temperature drop (8 to 12°C) are compatible with soil-warming requirements.

Boersma,[3] Mays,[4] Allred,[5] and others have demonstrated that selected field crops respond favorably to warmed soils in their root zones. If power-plant rejection of waste heat were accomplished with a soil-warming system, crop growth and development rates could be accelerated, and the water conserved would more than satisfy crop irrigation requirements. Typical Raft River Valley crops like hay or sugar beets, grown on a 700- to 1000-hectare warmed plot would consume about 5.7 billion liters of water and produce from 0.5 to 1.5 million dollars of gross revenue annually. The 3.8 billion-liter difference between cooling-tower consumption and irrigation requirements represents the gross reduction of water use possible when geothermal-power production and agricultural activities are combined.

The poor thermal conductivity of soils requires an extensive subsurface pipe grid to transfer the heat from the water to the soil, making subsoil heat rejection of cooling condenser water costly. Still, the value of the conserved water and increased crop production, as well as the savings in cooling tower costs, would partially offset the cost of the soil-warming system. This cost trade-off makes the soil-warming system a viable alternative to using less expensive wet cooling towers, which would provide no secondary benefits.

Even when the temperature of available geothermal resources is not high enough for power-plant use--and much of the West's resource is in this low-temperature range (<200°C)--agricultural soil warming can make use of the warm water. Farming in the western U. S., particularly in the semiarid intermountain plateaus, is largely constrained by both short growing seasons and limited irrigation water. Surface or subsurface application of suitable warm geothermal water from the soil-warming system could provide the needed moisture, while a subsurface heat-dissipation system could warm the soil and extend the growing season.

Unfortunately, system designs to achieve desirable thermal characteristics for subsoil heat dissipation and for soil warming are opposite in nature. A uniformly high soil temperature is desirable for crop growth, while the efficiency of a heat-dissipation system depends on maintaining a relatively high temperature gradient between the distribution pipe and the surrounding soil. Also, heat-dissipation objectives are best met by using small-diameter, widely spaced, lengthy pipe runs at a shallow depth. Soil-warming objectives suggest shorter runs of closely spaced, large-diameter pipe, located near the plant root zone and below the reach of agricultural implements. A system design that satisfies both heat-dissipation and crop growth objectives requires compromises. Under particular circumstances, such a system may be economically feasible.

OBJECTIVES

The Raft River soil-warming experiment is designed to investigate (a) the capacity of the Raft River silt-loam soil to act as a heat sink, and (b) the feasibility of using geothermal water or condenser waste heat for the subsurface heating of farming land. The climate, altitude, and thermal characteristics of the soil at the experimental site are representative of several geothermal resource locations and prospective power-plant sites. Design of the Raft River experiment allows investigation of the design parameters, crop varieties, and agricultural management practices that affect the feasibility of soil-warming projects.

Specific objectives of this experiment are

- To examine the heat-sink capacity of Raft River silt-loam soil, and the seasonal variations in this capacity.
- To develop a computer model to predict the heat-dissipation capacity of the soil-warming system under varying climatic conditions. The model will be developed from operational field data and theoretical relationships and will identify the thermal-transfer characteristics of the soil-air interface.
- To evaluate the response of several crops to the soil-warming system and determine which ones are best suited to soil warming in the Raft River area.
- To develop agricultural management practices adapted to the saline soil and water, the selected crops, and the soil-warming system.
- To investigate the economic feasibility of soil warming to dissipate waste heat and increase crop production.

Heat-dissipation and crop-response experiments will be conducted over a three-year operational period. Field and vegetable crops adapted to the

Raft River climate and saline conditions of the soil and water will be grown on a portion of the heated plot, with the assistance of Utah State University consultants. On the remainder of the plot, pulpwood trees of established value will be grown under intensive management conditions to determine the effects of soil warming on tree biomass production. University of Idaho Forestry Department personnel will supervise this phase of the experiment.

Special objectives of the tree biomass investigation are:

- To determine the effects of soil warming on the biomass production of woody species
- To investigate the effects of tree cover and irrigation on the heat dissipation of a warm-water, subsurface-cooling system
- To evaluate genotypic variation in growth response and to select desirable clones.

EXPERIMENT DESCRIPTION

The experiment will be performed on a 1.2-hectare (0.8 ha heated and 0.4 ha control) plot on Bureau of Land Management (BLM) land in the Raft River Geothermal Development Area. The plot's dimensions were chosen so as to produce both measurable and statistically significant information. Before the plot was cleared and levelled, it supported a stand of greasewood (Sarcobatus vermiculatus) and other native vegetation. The experimental plot is divided into three areas: the heated field crop-response plot, the heated tree biomass-production plot, and the unheated control plot. Each area is large enough to accommodate investigation of a number of plant varieties and provide space for good agricultural management practices.

Soil Characteristics

The experimental plot exhibits several soil characteristics that are detrimental to agricultural productivity. Its selection for this experiment was based primarily on its availability, proximity to an existing geothermal water source, and the need for a demonstration using geothermal water for farming under adverse conditions representative of many geothermal resource areas in the West. The plot soil, classified as Bram Silt Loam, is strongly saline, finely textured, and exhibits moderate-to-slow permeability. Gypsum and barnyard manure were incorporated into the soil surface, and a leaching irrigation was employed in an effort to lower the pH, increase fertility, and remove salt from the topsoil.

Soil-Warming System

The subsurface soil-warming grid consists of a series of parallel, 38-mm-diameter, PVC pipes buried 0.61 m below the soil surface (Figure 1).

The loop arrangement for the field-crop plot is a parallel-pipe system of 20 pipes, with a lateral spacing of 1.52 m. Supply and return legs for each flow loop are 152 m long. Valves allow either five or ten parallel pipes to flow in the same direction; that is, supply and return lines run

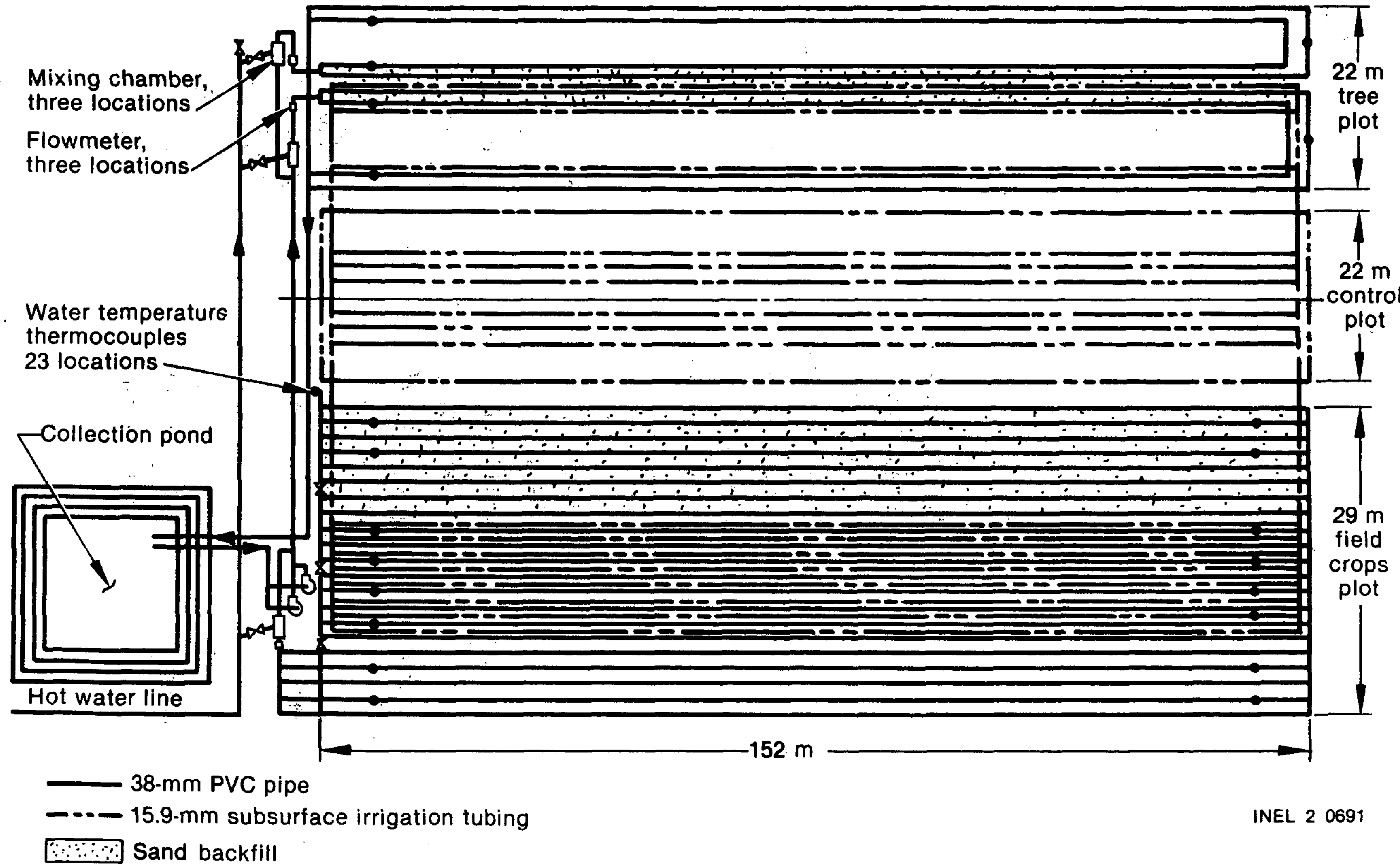

Figure 1. Soil-warming experiment piping system.

alternately in banks of five or ten pipes. The design was based on the selection of a rectangular 1.2-hectare plot, and produces a water-temperature drop of about 10°C at reasonable flow rates.

Supply and return headers are located in a single trench at the upper end of the field. Flow controls, mixing chambers, and instrumentation are also located in the trench, which prevents the pipe from freezing during periods of winter shutdown.

The tree-crop plot is heated by two twin-pipe, U-shaped loops (see Figure 1). The twin pipes in each loop are 1 m apart, and each loop's supply pipes are 8 m from the return pipes, so that each loop puts a 1-m frame around a plot 8 m wide. There are 2 m between the adjacent sides of the two loops, and the adjacent pipes provide the supply. The supply would thus flow through four lines down the center of the heated exerimental tree plot and branch in both directions at the end. Two pipes return down each side of the heated plot's periphery. The lateral pipe spacings of 1, 2, and 8 m allow investigation of lateral-spacing effects on heat dissipation, as well as an investigation of the effects of distance from the heat source on growth response.

Warm water would be distributed to the pipe grid through a 1-1/2-hp, 70-gpm pump. The pump would draw energy-expended water from the collection pond and distribute it to three mixing chambers, where the temperature would be adjusted before entering the supply manifolds. The desired temperatures would be obtained by mixing 120°C geothermal water from a 1500-m-deep well with energy-expended water from the collection pond. The proportions of hot and cool water would be regulated by means of automatic temperature-control valves installed in the hot-water supply lines.

The fluid temperature in the field-crop plot and in one tree biomass production loop would be adjusted to simulate power-plant condenser effluent (∿38°C). The fluid temperature in the second tree biomass production loop would be adjusted to 60°C, to obtain data on the effects of higher temperatures on a variety of tree species.

Heat-transfer properties of the subsurface pipe-soil interface would be investigated by using a sand backfill for some pipe runs in each plot and by employing a porous subsurface irrigation pipe directly above several of the pipe runs in the grid. A separation of about 5 to 10 cm would allow maintenance of high soil moisture content at the heat-transfer interface and provide subsurface irrigation for increased plant growth. Comparison of the effects and water-volume requirements of the two irrigation methods would also be made. The following four combinations of components would be evaluated:

1. Soil with heating pipe

2. Soil with heating pipe and subsurface irrigation

3. Soil with heating pipe in sand envelope

4. Soil with heating pipe in sand envelope and subsurface irrigation.

Selection of Pipe Material

PVC pipe was selected for use in this soil-warming experiment, primarily because of its simple installation, low capital cost, and corrosion resistance.

The thermal conductivity of PVC pipe is approximately 0.14 W/m K; aluminum is 204 W/m K and iron is 52 W/m K. Although aluminum or galvanized pipe would provide better heat transfer, the decrease in total heat dissipation with the PVC pipe is considered insignificant due to the low thermal conductivity of the soil. In addition, Miller[6] found the Raft River geothermal fluids and topsoils extremely corrosive to aluminum and steel. This corrosion would cause rapid deterioration of those metals, rendering them unacceptable for a long service life.

PVC pipe loses fiber strength and working pressure at higher temperatures. Manufacturers of PVC pipe do not recommend its use at temperatures above 60°C (Figure 2). The calculated condenser fluid

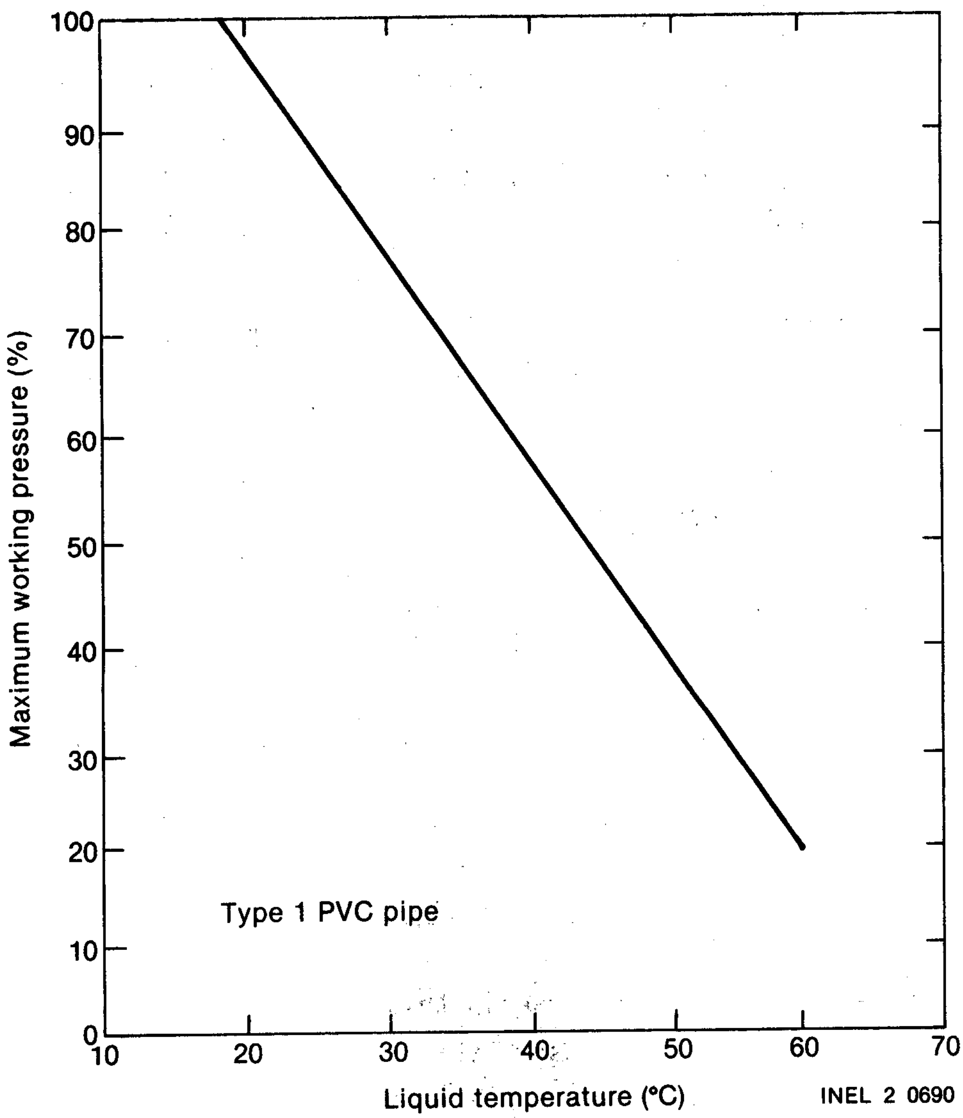

Figure 2. Temperature of Type I PVC pipe as related to working pressure.

discharge temperature for a typical moderate-temperature geothermal power plant is approximately 38°C, well below the maximum for PVC.

Either PVC or ABS plastic pipe would be appropriate for this application. ABS heat-transfer characteristics are slightly better; however, the PVC was available with pressure-ring bell and spigot connections, allowing quick assembly and lower labor cost. An inquiry of vendors also revealed that PVC pipe was less costly. Based on these considerations, PVC pipe was selected.

Instrumentation and Data Collection

Industrial Type-J thermocouples with watertight, stainless steel sheaths 1 m long were installed in each end of 12 selected water lines for measuring water-temperature decreases for 152 m of pipe flow. Soil temperatures would be monitored with permanently installed thermocouples and portable probes. The permanently installed thermocouples are located in single vertical stacks at depths of 152, 122, 91, 61, 40, 20, and 5 cm. Thermocouples are now installed at the center of the control plot, and in the middle of both the surface and the subsurface-irrigated field-crop plots.

The "porta-probes" consist of a 1.28-cm-diameter stainless steel tube 1 m long, with themocouples attached at depths of 76, 61, 46, 30, and 15 cm. At various locations, these probes would be used to determine the effects of different combinations of subsurface irrigation, sand backfilling, and cover type upon soil-heat transmissibility, soil temperatures, and crop responses. Figure 3 is schematic diagram of the soil thermocouple locations.

Operational and climatological data would be used to verify the validity of the assumed design conditions and of the procedures for estimating heat-dissipation and warm-water flow rates. These data would also be used to evaluate the effects of sand backfill and subsurface irrigation on the rate of heat dissipation, and to calculate the land area necessary for dissipating heat from a 50-MW(e) geothermal power plant. Possible optimization of system design and the seasonal variation in the heat-dissipation capacity of soil-warming systems would be other factors included in calculating land area.

The variation of heat-dissipation capacity as a function of climatic conditions would be investigated, and a computer model would be developed to predict this variation. A description of heat transfer at the soil-air interface, a controlling factor in the heat-dissipation capacity of a soil-warming system, would receive particular attention.

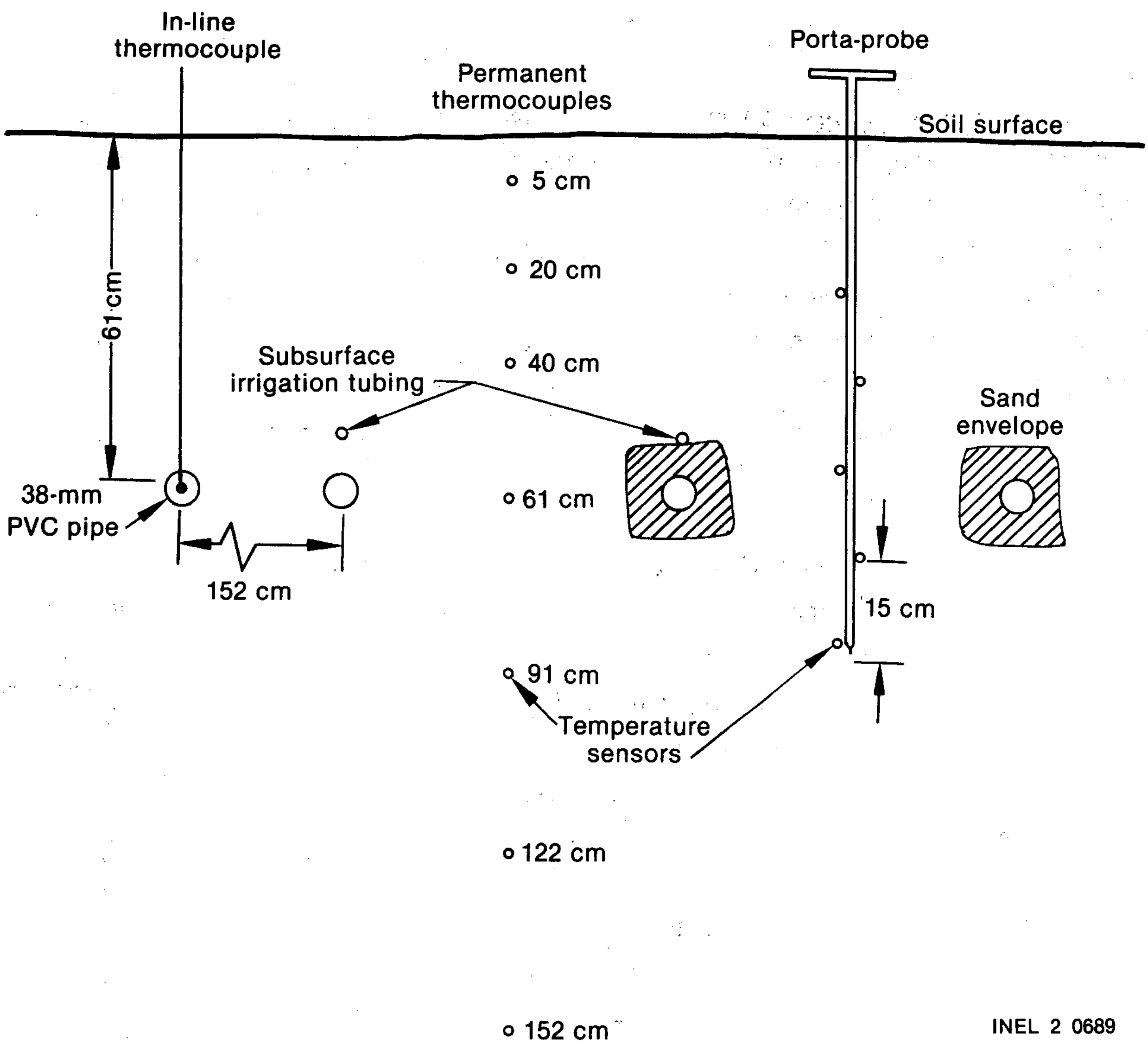

Figure 3. Cross section of soil-warming plot.

Selection of Crops

A total 0.13 hectare, including both warmed and control plots, has been allocated for each field crop variety, and 0.55 hectare for investigating tree responses. Figure 4 shows the arrangement of crops. An attempt would be made to optimize controllable management conditions, based upon available information for the various crops being grown, so that the effects of soil warming upon crop growth could be isolated and evaluated.

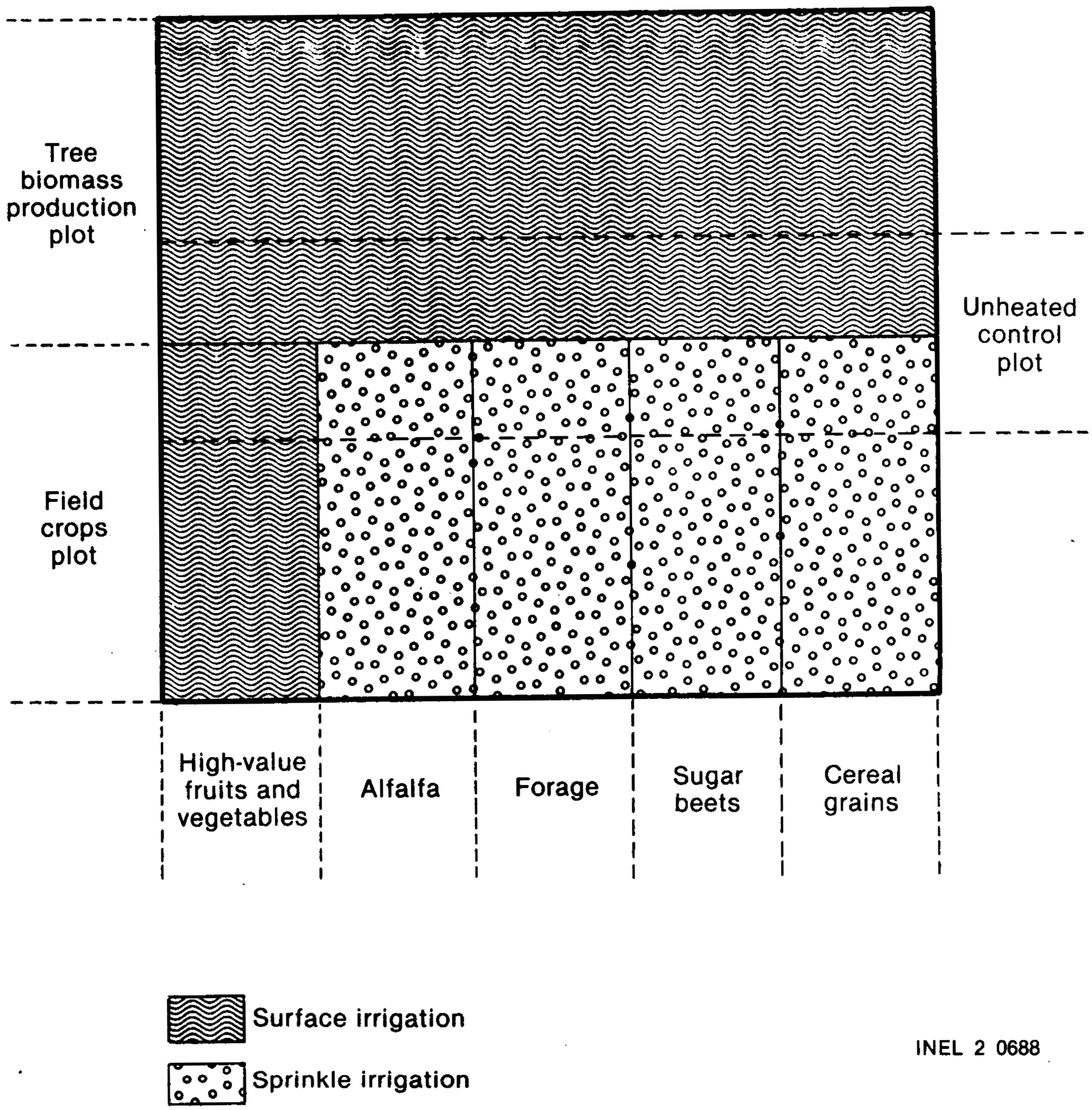

Figure 4. Crop and water distribution.

The Raft River growing season is short, with an average frost-free period of only 120 days. Also, as stated previously, the experimental plot soils and geothermal irrigation waters are saline. This combination of adverse factors requires that experimental crops be tolerant of salt and adapted to cool climates. The plant types in Table 1 have been selected for initial experimentation because of their tolerance of saline soils, their adaptability to the Raft River area climate (1480-m elevation), and their economic value.

TABLE 1. CROPS SELECTED FOR SOIL-WARMING EXPERIMENT

Field and Forage	Vegetables	Trees
Barley	Beets	Hybrid poplars
Sugar beets	Asparagus	Elm
Alfalfa	Spinach	Willow
Mixed grasses	Broccoli	Ash
	Tomatoes	Spruce
	Potatoes	Fir
		Pine
		Juniper
		Russian olive

For each crop cultured on the warmed and control plots, the following data would be recorded:

- Dates of planting, emergence, phenological activity, and crop maturity
- Annual yield per hectare
- Crop quality
- Water requirements--for both subsurface and surface irrigation
- Disease, insect, and weed problems and controls
- Tolerance to geothermal salts
- Winter hardiness (biennials and perennials) and frost susceptibility
- Unusual morphological activity
- Cost per hectare for soil warming and crop production.

Irrigation Methods

Selected portions of the experimental plot are irrigated by sprinkling and by subsurface trickle methods (Figure 4). Each method offers some advantage when applying saline water to specific crops. A sprinkle irrigation system, consisting of a 10.16-cm mainline with 7.62-cm laterals 45.72 m long and spaced 15.24 m apart, would be installed as solid sets on the field-crop plots. This system minimizes manpower requirements and provides uniform application across the plots. Barley and sugar beets are tolerant of foliar exposure to saline water and should respond favorably to sprinkling. Alfalfa and other experimental forage crops are moderately tolerant. Flood irrigation would be applied to the tree and vegetable crops to minimize foliar exposure to saline waters.

Cooled geothermal water from the RRGE-1 reserve pit would be delivered to the sprinkling system through a 10-hp centrifugal pump producing 296 kPa of head at the sprinkler nozzles. The geothermal water used to maintain the soil-warming fluid temperatures would accumulate in the plot collection pond and be distributed to the surface irrigation plots through gated irrigation pipe.

Eleven 1.59-cm-diameter, porous plastic subsurface irrigation tubes were installed directly over heat sources at a depth of 45 to 50 cm (Figure 1). All lines extend the full length of the grid and are supplied with water through distribution manifolds located at each end of the plot. The tubing is designed to deliver approximately 0.22 liter/s per 1000 m of line at an operating pressure of 281 g/cm^2.

ENERGY DISSIPATION FROM UNDERGROUND HEAT SOURCES

The rate of energy dissipation from an underground heat source to the surrounding soil is dependent on the thermal conductivity of the soil and the temperature gradient in the area of the source.

Thermal Conductivity of Raft River Soil

Apparent thermal conductivity is influenced by properties of solid materials, texture, temperature, and water content of the soil. In general, thermal conductivity increases with soil moisture content and particle size. Soil temperature may also have a slight influence; higher temperatures tend to increase the apparent conductivity through increased vapor-energy migration rates and surface evaporative energy losses. The effect of soil temperature on thermal conductivity is expected to be minimal, however, because of the restricted temperature range (<30°C) expected under steady-state operation of the soil-warming system.

The experiment plan calls for a significant soil moisture level, to promote plant growth and to enhance heat transfer at soil-pipe and soil-air interfaces. For design purposes, the average soil moisture content is taken to be 0.42 cm^3/cm^3. The design thermal conductivity of the Raft River silt-loam soil is then calculated to be 2.5 mcal/cm s °C, based on information published by Oregon State University.[3] Measurements of the thermal conductance of the local soil, with moisture contents of 0.25 and 0.32 cm^3/cm^3, gave results of about 1.4 and 2.0 mcal/cm s °C. These results agree well with the calculation cited above.[a]

Soil Temperature Gradient

The soil temperature gradient is the difference between the water temperature in the pipe grid and the temperature at the soil surface. The

a. Measurements were taken with the C-Matic Thermal Conductance Tester, manufactured by DYNATECH, Cambridge, Massachusetts.

gradient magnitude is influenced by the temperature reduction along the length of the pipe network and by the surface air temperature. The temperature drop across the pipe grid is a function of the heat given up to the soil and the flow rate of water in the pipes. An inlet temperature of about 38°C and a temperature drop of 8 to 12°C is proposed to simulate condenser-water temperature and to produce a somewhat uniform soil temperature across the experimental plot. The average temperature of the circulating water would be 28°C.

The average temperatures of Malta air and Kimberly soil are given in Table 2. Maximum summer temperatures in that area approach 38°C. Higher summer temperatures would limit heat transfer; the spring and fall temperatures, at either end of the normal growing season, would be more important to crop growth enhancement. For design purposes, a summertime temperature gradient of 13°C is assumed.

Heat-Dissipation Rates

The effects of temperature gradient and pipe spacing on heat dissipation were investigated with the aid of the Kendrick and Havens[7] formulation for energy dissipation by a parallel, subsurface, heating grid operating under steady-state conditions:

$$Q = \frac{2\pi k \Delta T}{\ln\left(\frac{2d - r}{r}\right) + \sum_{n=1}^{N} \ln \frac{(nl)^2 + (2d - r)^2}{(nl)^2 + r^2}} \qquad (1)$$

where

Q = rate of heat loss/unit length of pipe (cal/cm s)

r = pipe diameter (cm)

l = spacing of parallel pipes (cm)

TABLE 2. AVERAGE AIR AND SOIL TEMPERATURES
(Degrees Celsius)

Station	January	February	March	April	May	June	July	August	September	October	November	December
Malta (air)	-3.9	3.6	6.7	7.2	13.3	17.7	21.1	20.6	12.8	8.9	1.7	-6.1
Kimberly (soil--10.16 cm deep)	-0.9	0.7	3.9	8.0	15.5	18.3	23.2	22.3	17.1	10.8	4.3	0.1

d = depth of grid (cm)

k = soil thermal conductivity (cal/cm s °C)

ΔT = temperature difference between the pipe surface and soil surface (°C)

n = number of parallel pipes on each side of a center pipe.

Wilkinson[1] has tabulated the following simplifying assumptions employed in the Kendrick and Havens formulation:

1. Constant uniform soil conductivity

2. Pipe wall temperature equal to water temperature

3. Both pipe and water without temperature gradients

4. Constant, uniform soil temperature

5. Steady-state operation with constant surface temperature

6. Heat transfer in soil only by conduction

7. Heat transferred only in radial direction.

These assumptions do not seriously affect the use of the equation for initial design calculations, because a parametric study can be employed to investigate the major effects of deviation from steady-state conditions.

Calculations for a nine-pipe grid give heat-dissipation rates of 0.39 and 0.44 cal/m °C for lateral spacings of 1.22 and 1.83 m, respectively. Reducing the number of pipes in the parallel grid to five increases the unit heat-dissipation rates by about 3% in each case. These results indicate that designs based only on obtaining maximum heat dissipation per unit length of pipe would require extraordinarily large areas of land. It appears more economical to sacrifice some heat-dissipation efficiency in favor of a more compact grid, and thereby reduce the land area required to provide a specific amount of heat dissipation. Also, soil temperature in a more compact grid would be more uniform, which is desirable for enhancing crop production.

Additional calculations indicate that the heat dissipation per unit length of pipe increases about 20% in going from a 1-m spacing to a 2.4-m spacing (with a three-pipe parallel grid). However, there is also a 140% increase in surface area with that increase in spacing. Surface heat dissipation is estimated by dividing the heat dissipation per unit pipe length by the lateral spacing. Representative linear and surface unit heat dissipation rates are shown in Table 3.

TABLE 3. REPRESENTATIVE UNIT HEAT-DISSIPATION RATES[a]

Lateral spacing (m)	1[b]	1.219	1.524	1.829	2.44[b]
Linear heat-dissipation rate (cal/m s °C)	0.40	0.39	0.42	0.44	0.48
Surface heat-dissipation rate (cal/m^2 s °C)	0.40	0.32	0.29	0.24	0.26

a. For 38-mm plastic pipes, buried 61 cm below the soil surface to allow clearance for farming implements. Assumes a thermal conductivity, k, of 0.256 cal/m s °C for 0.42 cm^3/cm^3 soil moisture.

b. Three-pipe grid; all others nine-pipe grid.

The 38-mm pipe provides sufficient capacity without undue frictional heat loss--less than 430 Pa per 100 m of pipe at a flow rate of 0.13 liter/s. Heat transfer is enhanced if the flow is turbulent--mixing the flowing water and providing a near-uniform temperature radially across the pipe. The flow is expected to be turbulent at flow rates above 0.3 liter/s (Reynolds number $\geq$ 3000) and laminar below 0.2 liter/s (Reynolds number $\leq$ 2000). For intermediate flow rates, the flow is expected to be turbulent only if the pipe or flow encounters a disturbance, such as vibration, flow constrictions, or directional changes.

The summertime heat-dissipation rate for the two-pipe systems can be estimated by multiplying the unit heat-dissipation rates by the respective pipe lengths and the average temperature difference between the soil surface and the circulating warm water (neglecting the pipe material). Assuming an inlet water temperature of 38°C, a temperature drop of 10°C, and a moist-soil surface temperature of 20°C, the average temperature difference would be 13°C. Lengths of the two systems are approximately 3040 and 1216 m, with unit heat dissipation averaging 0.42 and 0.43 cal/s m °C, respectively. Under these conditions, the design heat-dissipation rate, R, is:

$$R = (3040 \times 0.42 + 0.43 \times 1216)13$$
$$= 2.340 \times 10^4 \text{ cal/s, or about 98 kW.}$$

Soil-warming systems would be operated throughout a two- to three-year experimental period. During this period, data would be collected to verify the calculated seasonal fluctuations in heat-dissipation capacity. Responses of perennial crops to year-round soil warming would also be studied.

SUMMARY

The Raft River soil-warming experiment would generate data of importance to farmers, environmental scientists, water managers, and power industry personnel. In addition, it would provide an opportunity for the power industry, engineers, federal and state agencies, educational institutions, and local farmers to participate in an agricultural experiment that might benefit all these groups.

The experiment would provide baseline data useful for developing and verifying design techniques in a large area where little experimental data are available. An observation of crop emergence, maturation, and yield would aid in the economic assessment of soil-warming systems, in the development of appropriate agricultural management practices, and in the selection of suitable crops to maximize production. This information would be useful in a wide variety of locations, especially those where the growth of farming and the development of power-production facilities are limited by the amount of available water.

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