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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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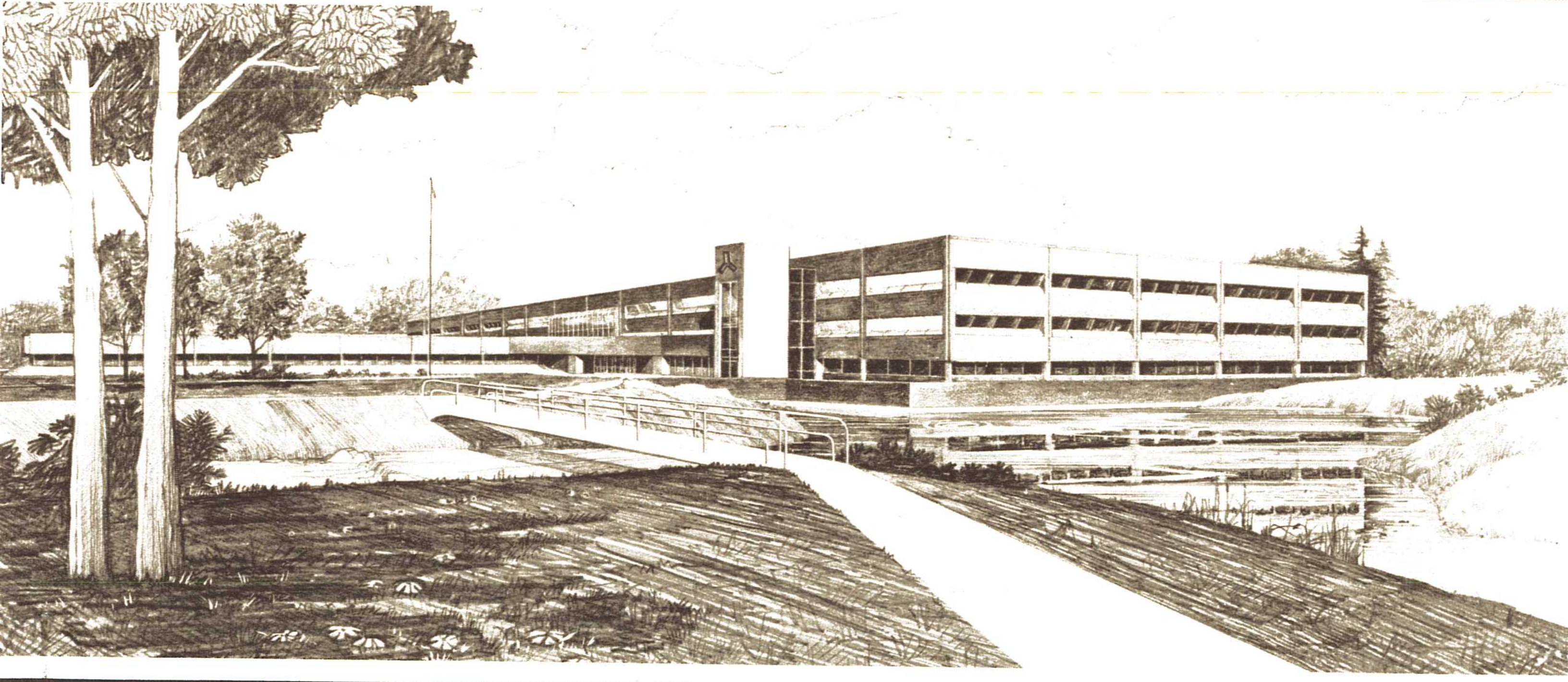

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EG&G Idaho

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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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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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3.	*EGG-GTH-5573	Geothermal Conversion at Veterans Hospital, Boise, Idaho

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4.	*EGG-GTH-5574	Geothermal Applications for Highway Rest Areas
5.	*EGG-GTH-5575	Geothermal Applications for a Tannery
6.	*EGG-GTH-5599	Preliminary Conceptual Design for Geothermal Space Heating Conversion of School District 50 Joint Facilities at Pagosa Springs, Colorado
7.	EGG-GTH-5617	Selected Geothermal Technical Assistance Efforts (comprising short descriptions of ten space heating projects, five district heating projects, and three heat exchanger projects)
8.	*EGG-2137	Geothermal Source Potential and Utilization for Methane Generation and Alcohol Production (subcontractor report)
9.	*EGG-2138	Geothermal Source Potential and Utilization for Alcohol Production (subcontractor report)
10.	*EGG-2139	Potential Geothermal Energy Applications for Idaho Elks Rehabilitation Hospital (subcontractor report)
11.	*EGG-2144	Technical Assistance Report on a Geothermal Heating Utility for Lemmon, South Dakota (subcontractor report)
12.	*EGG-2145	Economic Analysis for Utilization of Geothermal Energy by North Dakota Concrete Products Company (subcontractor report)
13.	*EGG-2146	Geothermal Feasibility Analysis II for Polo School District No. 29-2, South Dakota (subcontractor report)
14.	*EGG-2147	Preliminary Feasibility Study of Heating and Cooling Alternatives for Nebraska Western College, Scottsbluff, Nebraska (Subcontractor report)
15.	*EGG-2148	Inventory of Thermal Springs and Wells Within a One-Mile Radius of Yucca Lodge, Truth or Consequences, New Mexico (subcontractor report)

GTA Report Number	EG&G Report Number	Title
16.	EGG-2149	Utilization of Geothermal Energy, Feasibility Study--Ojo Caliente Mineral Springs Company, Ojo Caliente, New Mexico (subcontractor report)
17.	*EGG-2150	Geothermal Heated Office Building at Glenwood Springs, Colorado (subcontractor report)
18.	EGG-2151	Final Report--Dickinson Geothermal Study, Dickinson, North Dakota (subcontractor report)
19.	EGG-2152	CANCELLED
20.	EGG-2153	Comparison of Two Options for Supplying Geothermal Energy to the Veterans Administration Medical Center, Marlin, Texas (subcontractor report)
21.	EGG-2154	Geothermal Utilization at Castle Oaks Subdivision Castle Rock, Colorado (subcontractor report)
22.	EGG-2155	Space Heating for Twin Lakes School Near Gallup, New Mexico (subcontractor report)
23.	*EGG-2156	Pumping Tests of Well Campbell et al. No. 2, Gila Hot Springs, Grant County, New Mexico (subcontractor report)
24.	*EGG-GTH-5739	Geothermal Deicing of Highways and Bridge Structures
25.	*EGG-GTH-5740	Assessment of a Geothermal Application at Tucson, Arizona
26.	*EGG-GTH-5741	Heat Pump Systems for Spring Creek, Montana
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
29.	EGG-GTH-5812	Design of the Glenwood Springs Downhole Heat Exchanger

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CONTENTS

FIGURES

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

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

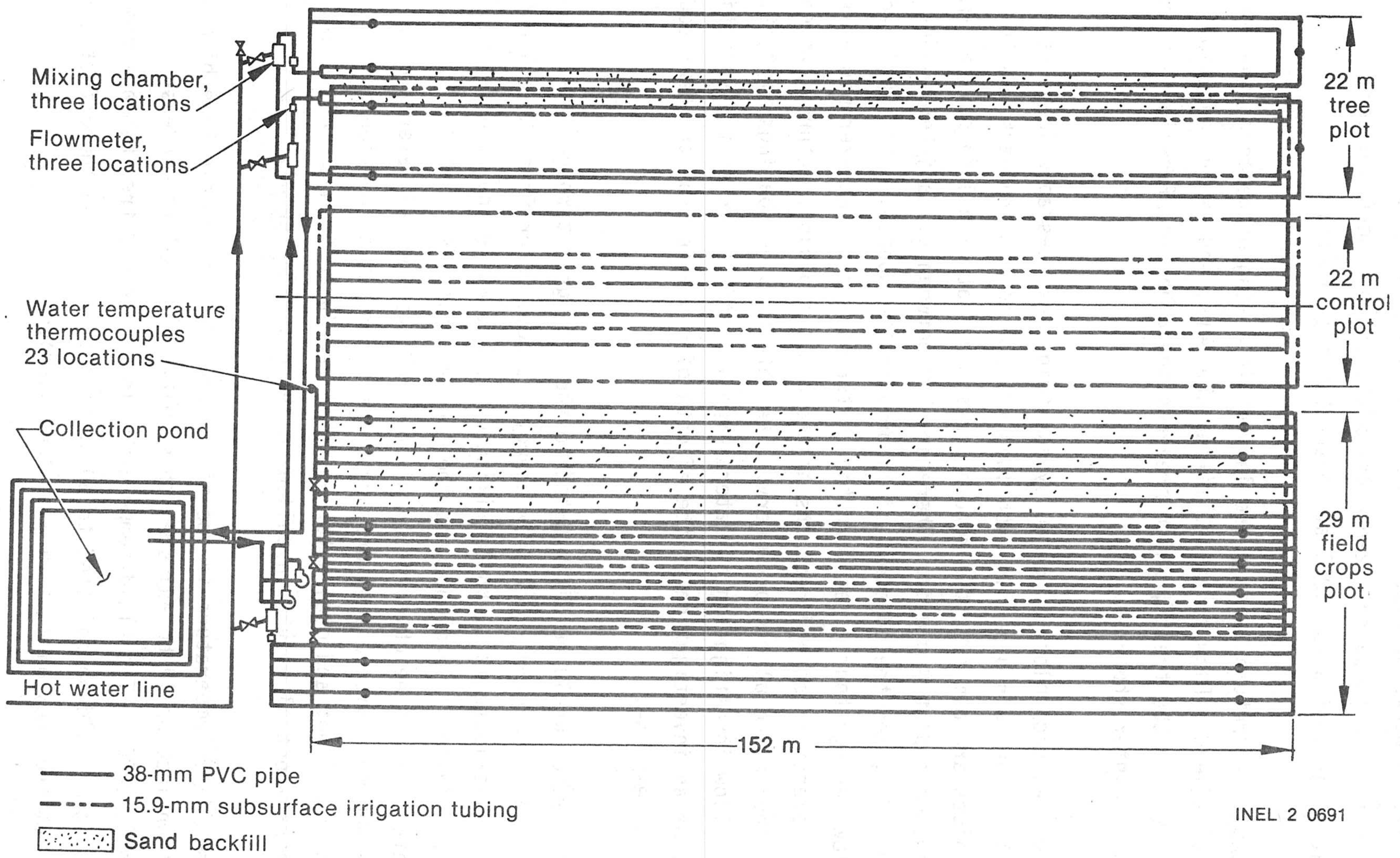

Figure 1. Soil-warming experiment piping system.

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

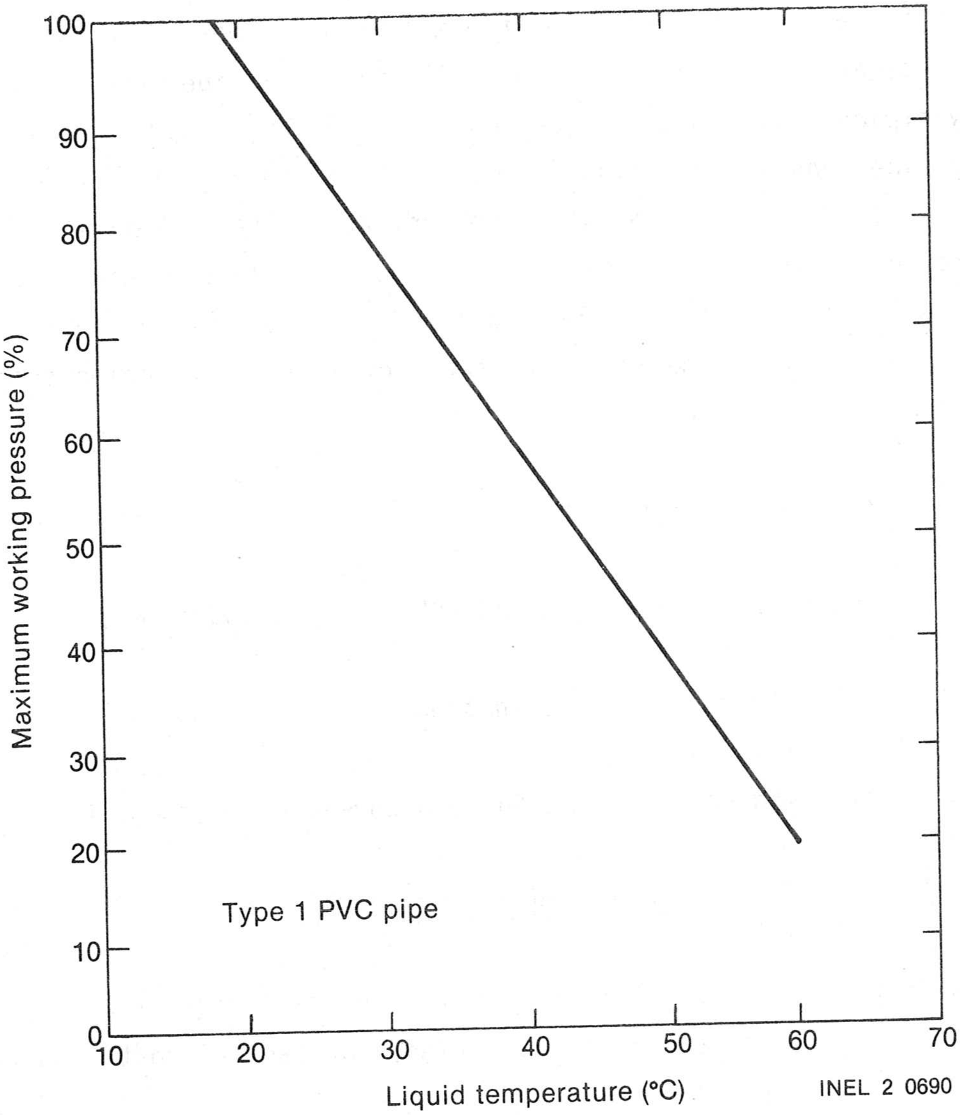

Figure 2. Temperature of Type I PVC pipe as related to working pressure.

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.

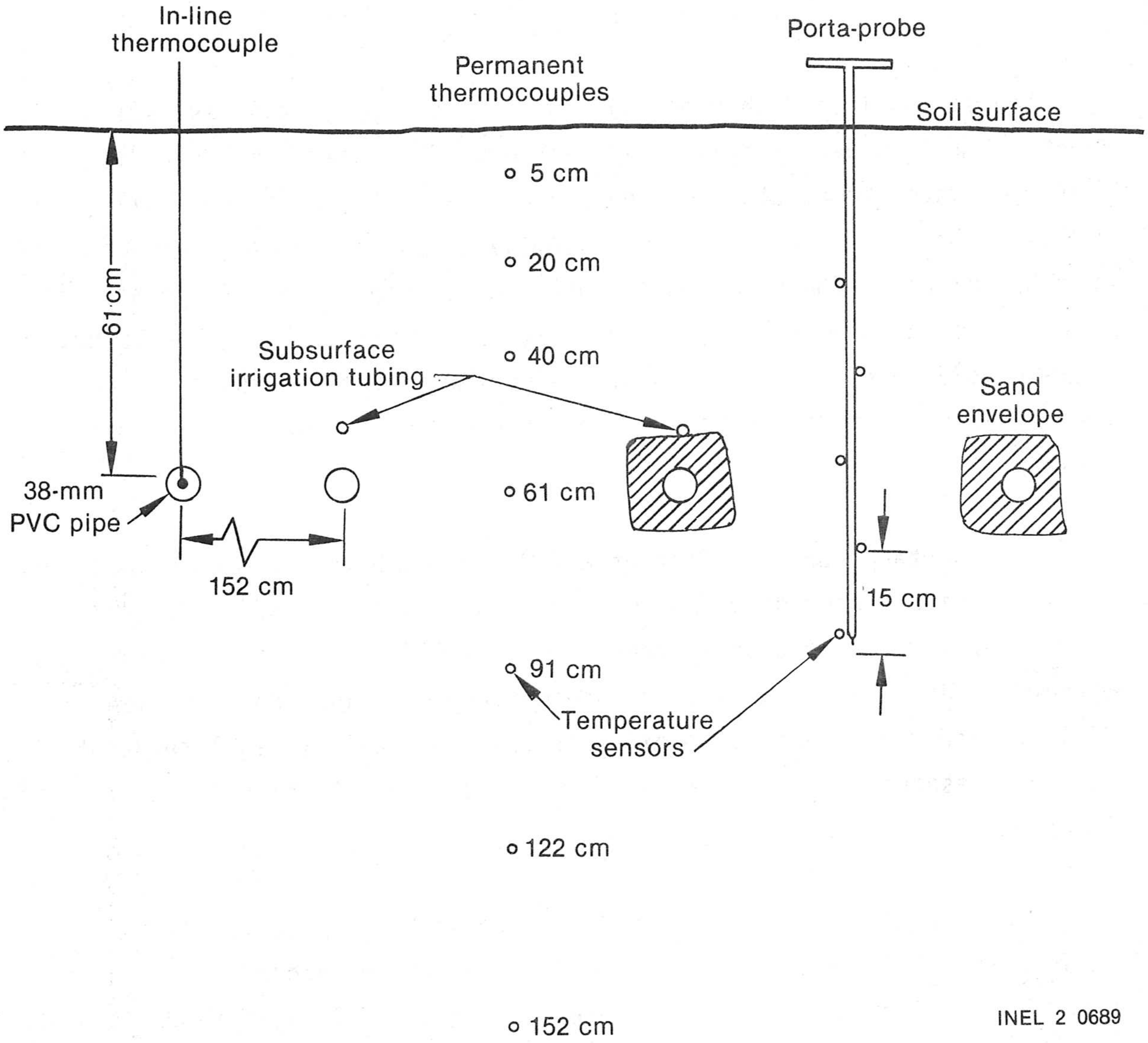

Figure 3. Cross section of soil-warming plot.

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.

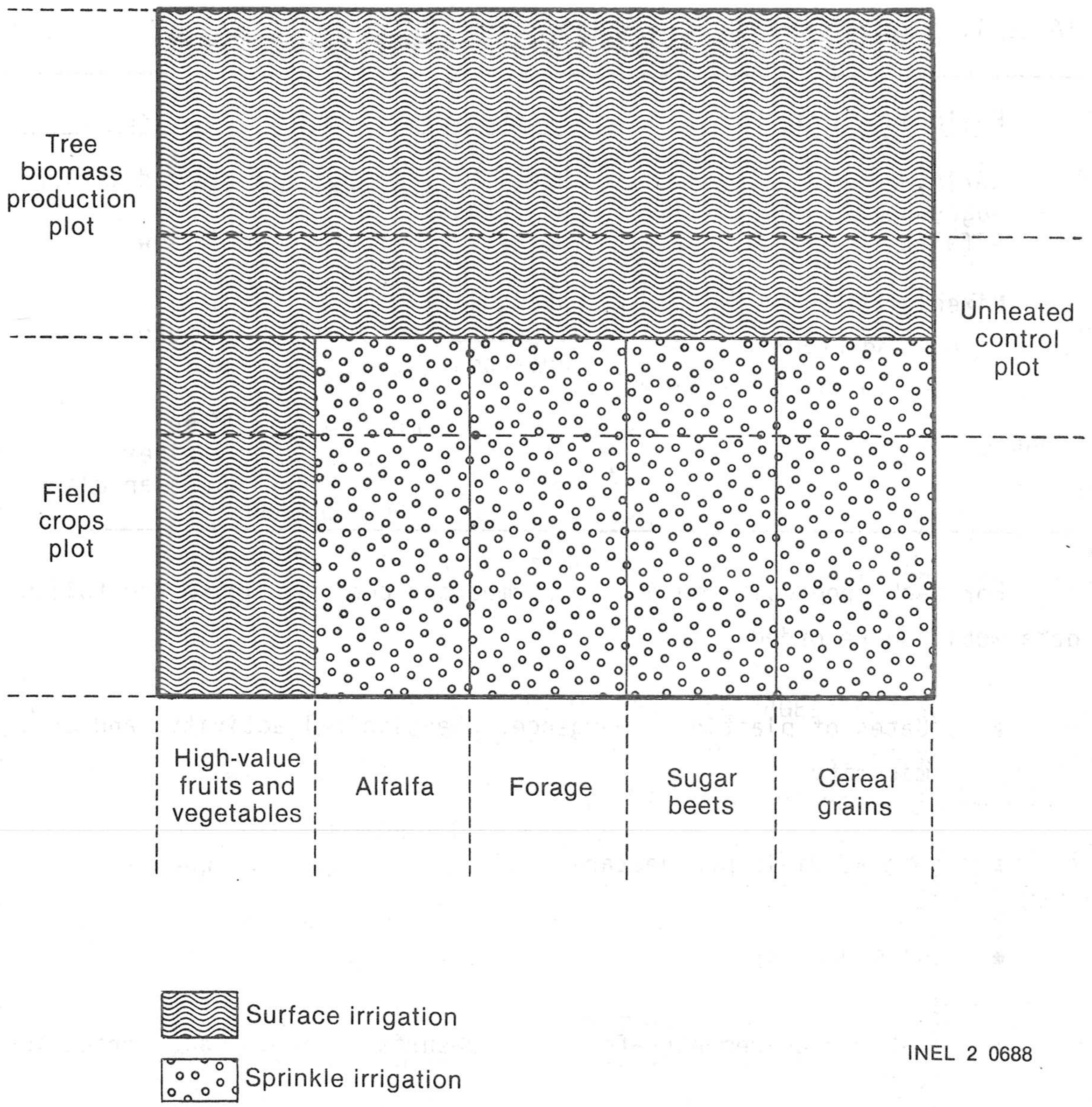

Figure 4. Crop and water distribution.

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.