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Increasingly, the availability of water through either new appropriations or purchase is being recognized as a constraint in Western energy development. Several oil shale and coal gasification projects have already confronted the questions of where and how to get the necessary water supplies to support commercial-sized plants. Since most of the known geothermal resources are located in Western areas which experience chronic water deficiencies, widespread implementation of geothermal technology in electric and direct-use applications must ultimately address the water supply question. In direct-use applications, every attempt must be made to use the geothermal fluid wisely following a primary heat extraction process. In electric applications, the issue of major importance concerns the rejection of from 85 to 90% of the total heat from power plants. Moderate-temperature geothermal electric power production is particularly handicapped compared to fossil-fueled or nuclear power plants, as indicated by this comparison:

<table>
<thead>
<tr>
<th>Power Plant Type</th>
<th>Discharge Heat Annual* Water Use (Cubic Meters/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>1.5</td>
</tr>
<tr>
<td>Nuclear (LWR)</td>
<td>2.0</td>
</tr>
<tr>
<td>Geothermal (Geysers type)</td>
<td>4.0</td>
</tr>
<tr>
<td>Geothermal (Raft River 143°C binary cycle)</td>
<td>7.0</td>
</tr>
</tbody>
</table>

* 1000 MW plant, 80% load factor

Costs and power requirements of both conventional and fluidized-bed dry cooling towers suggest that neither will be cost effective or competitive in the foreseeable future.

A recent research effort to gauge the regional water use requirements of geothermal development presents a pessimistic conclusion. The Department of Energy's "Forecast 2" energy-demand and fuel-supply scenario postulates the somewhat implausible possibility of about 30 GWe geothermal electric capacity in the Western states by 2000. More conservatively, Bloomster and Engle used a linear programming-optimization technique under different competitive scenarios, estimating the installed geothermal electric capacity might be between 9 and 17 GWe by 1990 and between 28 and 65 GWe by 2015. Using these estimates, it is plausible to expect a 15 to 20 GWe geothermal electric production capacity sometime near the turn of the century, of which 20% might be of the Geysers and Roosevelt Springs quality, and the remainder from the moderate-temperature reservoirs identified throughout the West by USGS Circular 726. Assuming that evaporative cooling towers will be used, this suggests a regional annual water requirement of perhaps 2220.3 to 2960.4 million cubic meters. Without other intervening factors, this requirement by itself would seem to present an imposing constraint on geothermal electric development. Obviously, there is a necessity for new water-conservation measures and technological innovations.

Soil-cooling systems may be a viable alternative to evaporative cooling towers. While impractical for large fossil-fueled plants, buried pipe grids may be feasible for 50 to 100 MW geothermal power plants. In many locations, this alternative may be economically more attractive, use less water, yield a secondary income from surface crops, and offer environmental advantages.

EG&G Idaho, Inc. as part of its activities performed for the Department of Energy's Division of Geothermal Energy located at DOE's Idaho Operations Office, is conducting a three-year experiment to study the technical and economic feasibility of using heat dissipation-soil warming systems to reject heat from modular-sized geothermal power plants in cool desert regions. The project focuses on two areas of study. First, a computer program is being developed to model the performance of soil cooling systems. Second, field studies are being conducted to evaluate the performance of an underground pipe system installed at the Raft River Geothermal Test Site in south-central Idaho.

Direct extrapolation of the experimental field data to large-scale heat dissipation-soil warming systems would be difficult, at best. At Raft River, the approach taken is to use the experimental data to assess the accuracy of a computer program which models heat and mass transfer in soils. Given sufficient accuracy (or agreement between predictions and field data), the computer program would then be used to model proposed large-scale systems in order to assess their feasibility and potential benefits.
The computer program being developed for the Raft River experiment is similar to an existing program which was developed to model transient two-dimensional heat and mass transfer in soils and has been used to model continuous operation of soil warming systems using waste heat from nuclear power plants. The program uses available information on soil type, depth and spacing of heat sources, heat source temperature, and climatological data to solve equations modeling heat and moisture transfer in soils. Results obtained to date have been predicted soil temperature and moisture-content distributions, estimates of increases in the length of the growing season for crops, design guidelines for soil warming systems, and estimates of the total land surface required to dissipate a given amount of energy. Figure 1 presents a typical soil-temperature distribution.

Figure 2 presents a typical seasonal variation in predicted soil temperature, using the computer program. Once its accuracy is verified, the computer program will be used to predict soil temperatures and heat dissipation rates, thereby providing estimates of the size and potential benefits of heat dissipation-soil warming systems using rows of buried pipes to dissipate the heat from geothermal electric power plants. Results from the computer-program development, winter-spring system operation, and crop responses will be available for reporting at Hilo.

Fig. 1 Isotherms (°C) for August conditions, pipe spacing of 280 cm and pipe depth of 100 cm. The left pipe temperature was 41 °C, while the right was 31 °C.

Fig. 2 Simulated annual temperature variation at 20 cm depth. Pipe depth is 50 cm.

The field layout involves three experimental plots, 24 meters wide by 152 meters long, two of which are heated by dissimilar configurations of PVC pipe, buried 0.6 meters beneath the soil surface. The remaining plot is unheated and serves as a control plot. Warm geothermal water, simulating power plant condenser discharge, circulates through the grid while heat dissipation rates and soil temperatures are monitored. In the near future, the heat-dissipation system will be linked to an operational 60-kW binary fluid geothermal power plant currently under construction.

Apparent soil thermal conductivity is influenced by properties of the solid materials, texture, temperature, and water content. In general, thermal conductivity increases with soil moisture content and particle size. In order to evaluate the heat transfer properties of different pipe-soil interfaces and to inhibit the formation of a "baked," insulating jacket of soil around the pipes, the soil heat-dissipation system incorporates the use of sand envelopes around some pipes and employs sub-surface irrigation tubes above several pipes in each configuration (Figure 3). The heat dissipation and soil temperature data will be used to validate the computer model and to correlate crop responses to warmed soils.

It has been demonstrated by Boersma, Mays, Allred, and others that selected field crops respond favorably to warmed soils in their root zones. In many locations, if geothermal power-plant waste-heat rejection were accomplished with soil warming systems, crop growth and development rates could be accelerated, and the water conserved would more than satisfy crop irrigation requirements.
Fig. 3 Cross section of heat-dissipation soil warming plot showing the combinations of pipe-soil interfaces.

A variety of field, vegetable, and tree crops is being cultured on the experimental open-field plots. The crops are adapted to the Raft River climate and are tolerant of saline soils and water. Accepted intensive-management techniques are being used to culture barley, sugar beets, alfalfa, forage grasses, garden vegetables, and trees. Researchers are examining plant germination, emergence, growth rates, maturation, water requirements, plant-soil relationships, and yield data to assess the agricultural economics of the soil heat-dissipation concept and to develop appropriate management practices to maximize productivity.

The experiment will provide information useful to a variety of locations, especially those where the development of both agriculture and power plants are limited by the amount of available water.

REFERENCES