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GEOTHERMAL DEVELOPMENT ISSUES: Recommendations to Deschutes County

by

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I. INTRODUCTION

Geothermal exploration is a recent phenomenon in Deschutes County. As in other Oregon counties that harbor geothermal resources, the role of the County's planning process in geothermal issues is in need of refinement. The elusive nature of geothermal resources is partly to blame. Recent, successful drilling indicates nevertheless, a sharp and distinct need to think now about geothermal development standards and land-use planning.

This report is a discussion of processes and issues related to geothermal development. It is intended to inform planners and interested individuals in Deschutes County about geothermal energy, and advise County officials as to steps that can be taken in anticipation of resource development.

II. DEFINITION

The State of Oregon defines geothermal resources in ORS 522.005 (7) as:

> "the natural heat of the earth, the energy, in whatever form, below the surface of the earth present in, resulting from, or created by, or which may be extracted from, the natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases, and steam, in whatever form, found below the surface of the earth, exclusive of helium or of oil, hydrocarbon gas or other hydrocarbon substances, but including specifically:
>
> a) All products of geothermal processes, embracing indigenous hot water, and hot brines;
> b) Steam and other gases, hot water, and hot brines resulting from water, gas, or other fluids artificially introduced into geothermal formations;
> c) Heat of other associated energy found in goethermal formations; and
> d) Any byproduct derived from them."

III. GEOTHERMAL RESOURCE ASSESSMENT

The processes of estimating geothermal resources, depending on current technology and the state of the economy, is a combination of those used for estimating mineral and petroleum resources. Geothermal resources are measured in units of potential thermal, or electric energy, rather than millions of tons or barrels of oil. Furthermore, geothermal energy figures refer to a temperature, normally the mean temperature of the resource. Only a fraction of the total geothermal resource can be used effectively. Recovery rates range from less than one percent up to twenty-five percent in highly permeable rock.[1]

IV. GEOLOGIC ENVIRONMENTS OF GEOTHERMAL SYSTEMS

Volcanic regions, particularly volcanic belts younger than one million years, host much of the world's hydrothermal development. Volcanic rocks and associated intrusions in the western U.S. are found in the Aleutian Volcanic Chain, the Cascade Range, and throughout the Basin-Range Province. In these areas, as in other geothermal sites internationally, converging margins of major plates create stress regimes favorable to formation of volcanic rocks.

Where the earth's crust is under active stress, geothermal energy may be present. Such areas may be characterized geologically by active faulting and folding, mountain ranges, deep basins containing thick highly compressed sedimentary fill, and by local young volcanic activity. Examples include the Basin and Range Province of Nevada, Utah, and Oregon, and the Rio Grande Rift of central New Mexico and southern Colorado.[2]

Hot springs and fumaroles are often surface manifestations of underlying geothermal resources. A lack of surface indicators, however, does not in any way preclude a site's geothermal resource potential.

V. GEOTHERMAL UTILIZATION

A. General

Oregon currently utilizes geothermal energy directly in commercial greenhouses, pool heating, residential and industrial space heating, pavement de-icing, aquaculture facilities, accelerated curing of concrete, milk pasteurization, and hog raising. As an electric power source, geothermal resources are just beginning to be applied in Oregon using low temperature (250°F or less) binary well head generators in Lakeview and Vale. The most extensive direct (non-electrical) utilization in the United States exists in Klamath Falls, Oregon, where on-site geothermal heat supplies an estimated 60 thermal megawatts (MW_t) of energy during peak winter use.[3]

The following table is a summary of state geothermal resource potential recently updated by the Pacific Northwest Utilities Conference Committee (PNUCC).

Table 1

Estimate of Geothermal Generation Potential
(based on hydrothermal reservoirs with temperatures above 150° C)

AREA NAME	Theoretical Potential (MW of Capacity)	Engineering Potential [1] (MW of Capacity)	Practical Development Potential by 2000 [2] (MW of Capacity)
Oregon			
Newberry Caldera	1563	200 [3]	
Lakeview Area	267	50	
Crumbs Hot Springs	81	50	
Mickey Hot Springs	213		
Alvord Hot Springs	65	150	
Hot (Borax) Lake	121		
Trout Creek Area	32		
Neal Hot Springs	48		
Vale Hot Springs	1160	250	
Cascade Range [4]	2485	200	
Total	6035	900	100

[1] Engineering potential is the amount of energy which may be available from each source if environmentally and politically acceptable, and if cost effective. Development, if accomplished, would be beyond the identified planning horizon.

[2] Limited development of engineering potential because of economic and institutional barriers.

[3] Development most likely external to Newberry Caldera.

[4] Included because of new data developed by the Department of Oregon Geology and Mineral Industries that will be published in 1982.

Source: Internal memo from Geothermal Subcommittee to PNUCC Alternative Resources Committee. May 18, 1982.

The use of geothermal energy, whether direct or electric, and its related impacts depend ultimately upon the form of heat discovered. The following subsections will: a) describe various applications of geothermal energy based on temperature, and b) consider siting factors and development impacts based on type of application.

B. Electrical Generation

Temperatures feasible for traditional electrical power production methods begin at about 300° F., however recent research and development projects in Lakeview show commercial electrical production may be made at temperatures of as low as 175° F. Actual installation of a power plant is dependent upon a number of factors, both technical and social. The Governor's Geothermal Task Force Final Report estimates five years from initial discovery as a minimum time required to bring 50 to 100 megawatts on line.[4] Mike Lane, of Chevron Resource Company, approximated mere pre-development time and costs as follows:[5]

Activity	Cumulative time	Cumulative costs
Preliminary exploration	2 years	$100,000
Detailed exploration	4 years	$1 million
Pre-development deep wells	6 years	$10 million

Factors affecting the ultimate cost of geothermal power production include: a) resource parameters; b) power plant size, design, and efficiency; c) proximity to load center and/or existing transmission; d) field ownership; e) utility-specific methods and structure of financing, tax treatment, indirect costs; and f) terms and conditions of contracts with resource producers.[6]

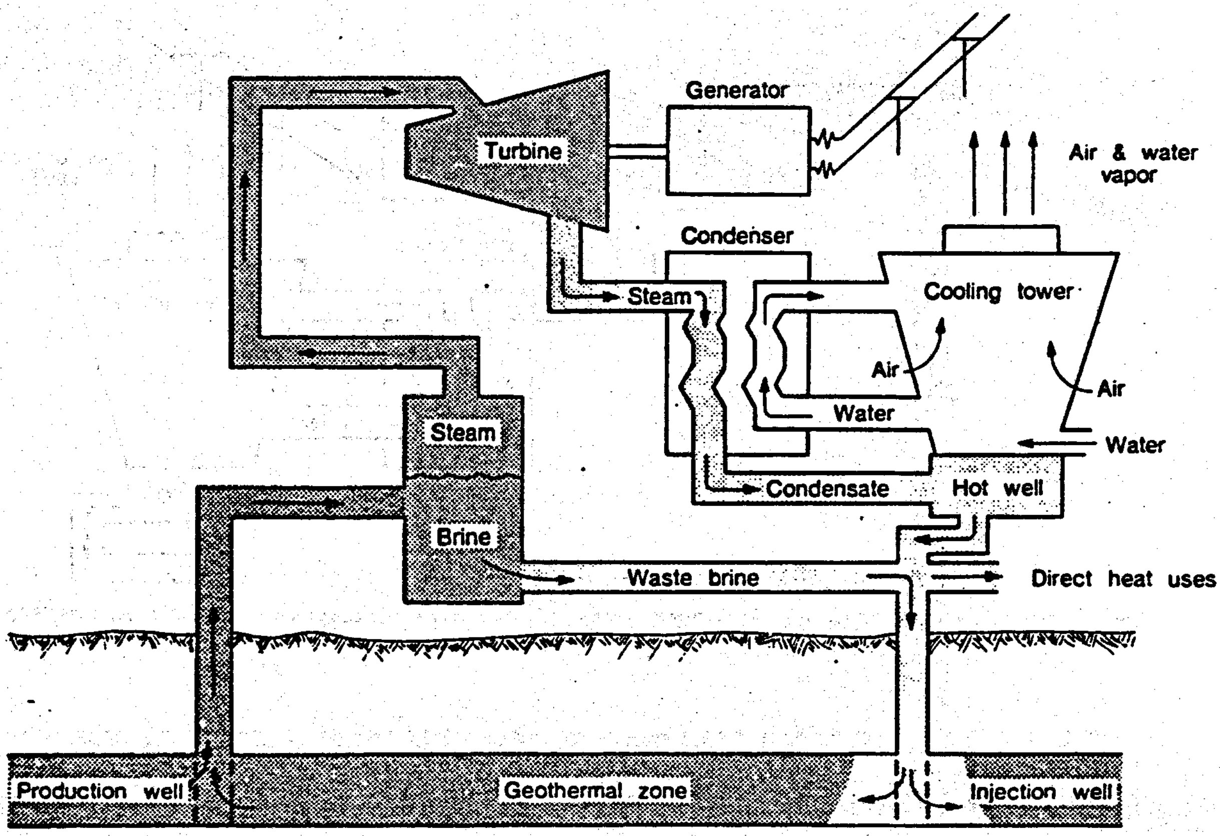
High Temperature Systems

The most common types of geothermal systems are vapor-dominated and fluid-dominated. The former, while most economic to develop, is rare. A vapor-dominated reservoir contains fluid (both liquid and steam) which changes phase to dry, superheated steam as pressure is decreased upon production. The steam is then piped directly through a turbine generator. In a fluid-dominated system, fluid at depth is mainly in the liquid phase only. The fluid is produced from a well into a separator where it is allowed to boil or "flash" partially to steam which is then fed to a turbine generator (figures 1&2). Quantities of waste fluid in a hot water system are large, since only a small percentage of the water flashes to steam, and are generally reinjected into the peripheries of the reservoir.

Two other types of geothermal utilization, still experimental and not yet economic, are: 1) hot-dry-rock and 2) geopressured. Los Alamos Scientific Laboratories estimates that hot dry rock at temperatures above 290° C (550° F) at depths of 5 kilometers (16,400 ft.) comprises about seven percent of the 13-state Western Heat Flow Province.[7] Heat could be extracted by artificially fracturing and circulating a fluid as a heat transfer medium, in a closed loop cycle, through the heated earth (figure 3). Geopressured geothermal reservoirs are saturated basins under pressure, prevented from upward movement by overlying impermeable rock. Water in geopressured sediments sometimes contains an anomolous amount of heat and dissolved methane gas. The technology for producing geothermal energy from geopressured zones is costly, yet may be found to be economic sometime in the future when combined with methane extraction.

Figure 1

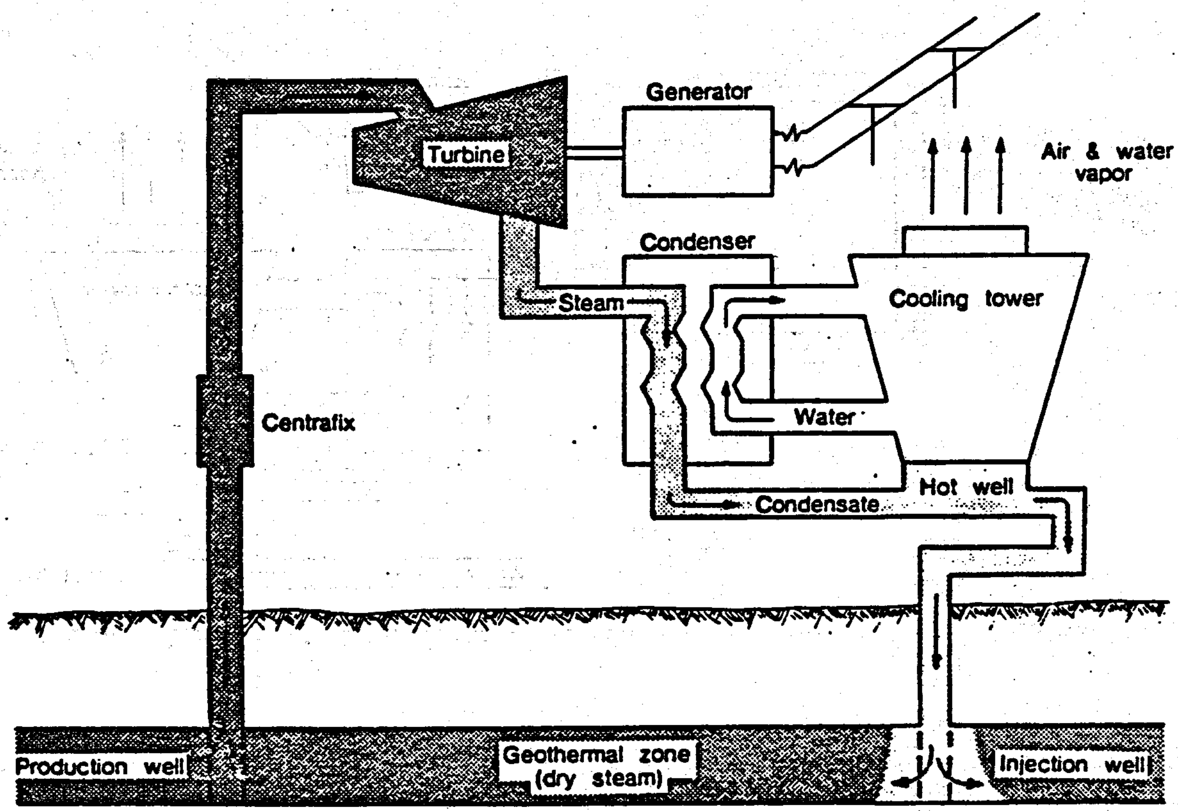
Flash Steam Power Plant



Courtesy of Earth Science Laboratory, University of Utah Research Institute

Figure 2

Dry Steam Power Plant



Courtesy of Earth Science Laboratory, University of Utah Research Institute

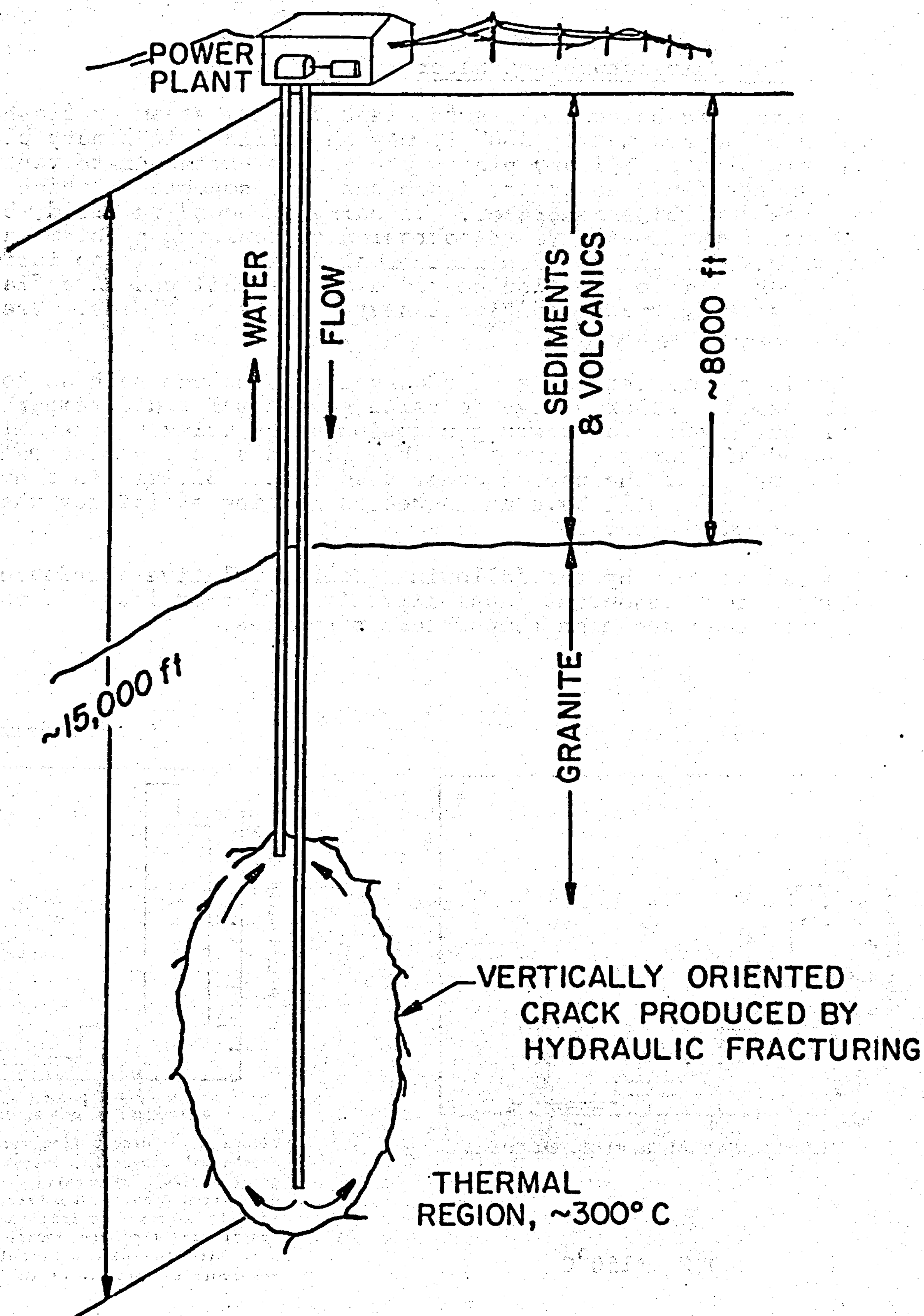


Fig. 3 Typical dry-rock geothermal-energy system produced by drilling and hydraulic fracturing.

Source: The Potential for Hot-Dry-Rock Geothermal Energy in the Western United States, Donald W. Brown.

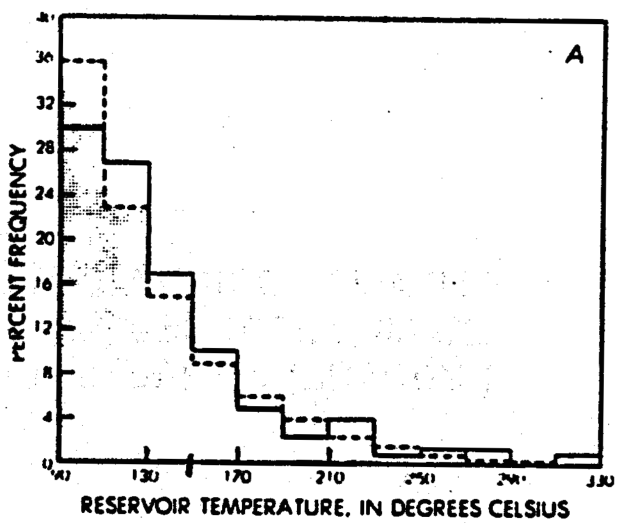
Low Temperature Hot Water Systems

Temperatures below those sufficient for dry steam or flashed steam plants (approximately 300° F) may be utilized in binary plants or hybrid plants. Binary plants use a heat exchanger to vaporize a secondary fluid as freon, isobutane, or isopentane, which in turn drives a turbine generator. In using a secondary fluid, binary plants serve to alleviate corrosion or scalding problems associated with certain brine-laden geothermal fluids and air pollution potential. A binary system can also be added at the tail end of a flashed steam process to extract additional heat from waste fluids. See figure 4 for schematic.

Hybrid plants require a secondary energy source such as fossil fuels, biomass, or solar energy to raise geothermal fluid temperatures up to that needed for power generation or by using geothermally preheated air for the burner intake. In this way, geothermal is used to complement the use of other resources. Biomass in a hybrid plant, for example, will have an increased burning efficiency when dried by geothermal resources.

As can be seen by the following graphs, relative abundance of low temperature resources (approximately 300° F or less) is considerably higher than the high temperature resources.

1978 data



1975 data

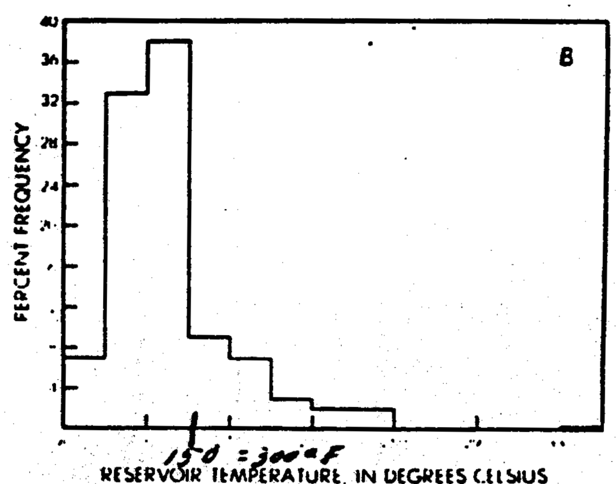


Figure 10.—Percent frequency of identified hydrothermal convection systems by reservoir temperature (20°C classes). A, 1978 data. B, 1975 data (from Renner and others, 1975). Also shown in A is a synthetic frequency histogram (shaded) constructed from the equation of the line that best fits the plot of cumulative frequency vs. reservoir temperature of the 1978 data (fig. 11).

300°F ⟶ 150°C

Source: USGS Circ. #790, p. 29.

C. Direct Utilization

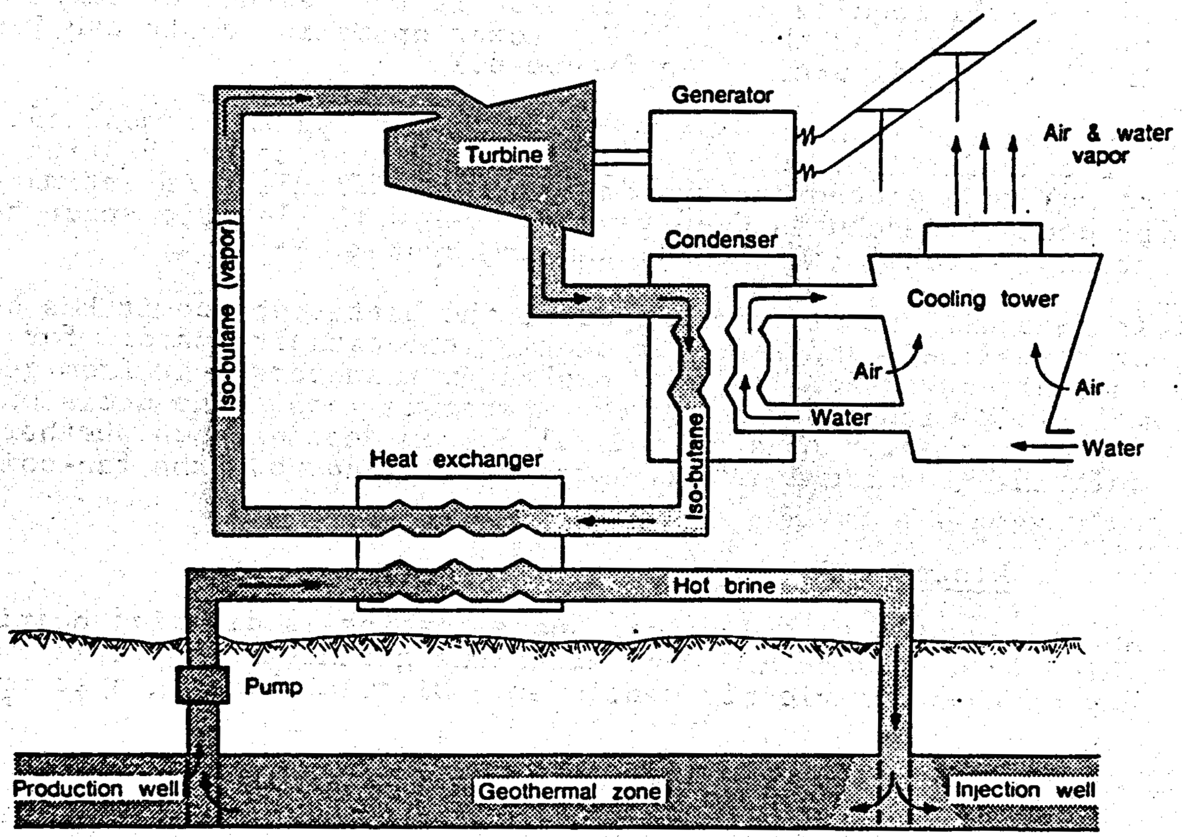
Geothermal fluids with temperatures in the 80° F to 300° F range are more common and heat can be extracted with much greater efficiency than geothermal electric power production. Direct-use conversion efficiencies are typically between 70-90 percent vs. 5-25 percent efficiencies for electrical production. Other advantages include the following:

1) Resources with direct-use potential outnumber electrical prospects by as much as five to one.
2) Capital costs of direct use are significantly lower--using conventional water well drilling equipment and eliminating transmission lines and power facilities.
3) Development time is apt to be shorter.
4) Hot water can be transported greater distances with temperature losses of as little as 0.1 C (0.2 F) per kilometer in comparison to steam transport which is limited to approximately 2 km. [8,9]
5) Limited environmental impact.

Multi-stage use of geothermal resources, or "cascading" as it is known, can further enhance efficiency. An optimal situation could use the resource for electrical production, the cooled effluent for an industrial process, on to an even lower temperature for space-heating application, and finally for an aquacultural or recreational activity. In this way, thermal "waste" from each step provides heat for successive processes that require less heat.

Figure 4

Binary Cycle Power Plant



Courtesy of Earth Science Laboratory, University of Utah Research Institute

Industrial Processing

An example of geothermal-fueled industrial processing is in the Tasman Pulp and Paper Company in New Zealand, which uses geothermal energy for timber drying, black liquor evaporation, and pulp and paper drying. Tasman's investment cost was approximately $70 per thermal KW, a 70 percent reduction compared to conventional fuels for an annual savings of $1.3 million. Annual maintenance costs are 2 percent of the capital cost.[10]

In the western United States, two plants show similar savings. Medo Bel Creamery in Klamath Falls, Oregon uses a low-temperature geothermal fluid to pasteurize milk. Geothermal Food Processors at Brady Hot Springs, Nevada uses a high temperature fluid to dehydrate onions and other vegetables. A third plant, Ore-Ida Foods, Inc. in Ontario, Oregon, is considering converting to geothermal. Some industrial and agricultural processes that could benefit from extracted geothermal heat are shown in figure 5 .

Space Conditioning

Three systems for heating residences with significant heat loads are commonly used: forced air, circulating water, and radiant heat from electrical resistance. In examining geothermal as a heating fuel, a homeowner has two possibilities: designing a new system or retrofitting the present system to geothermal. A conversion requires matching specifications, which may be expensive. For example, a system designed for a 10 gallon per minute (gpm) flow at 180° F will require additional flow if the geothermal temperature available is less than 180° F. Lower operating costs can justify initial expenditure. (See figure 6.)

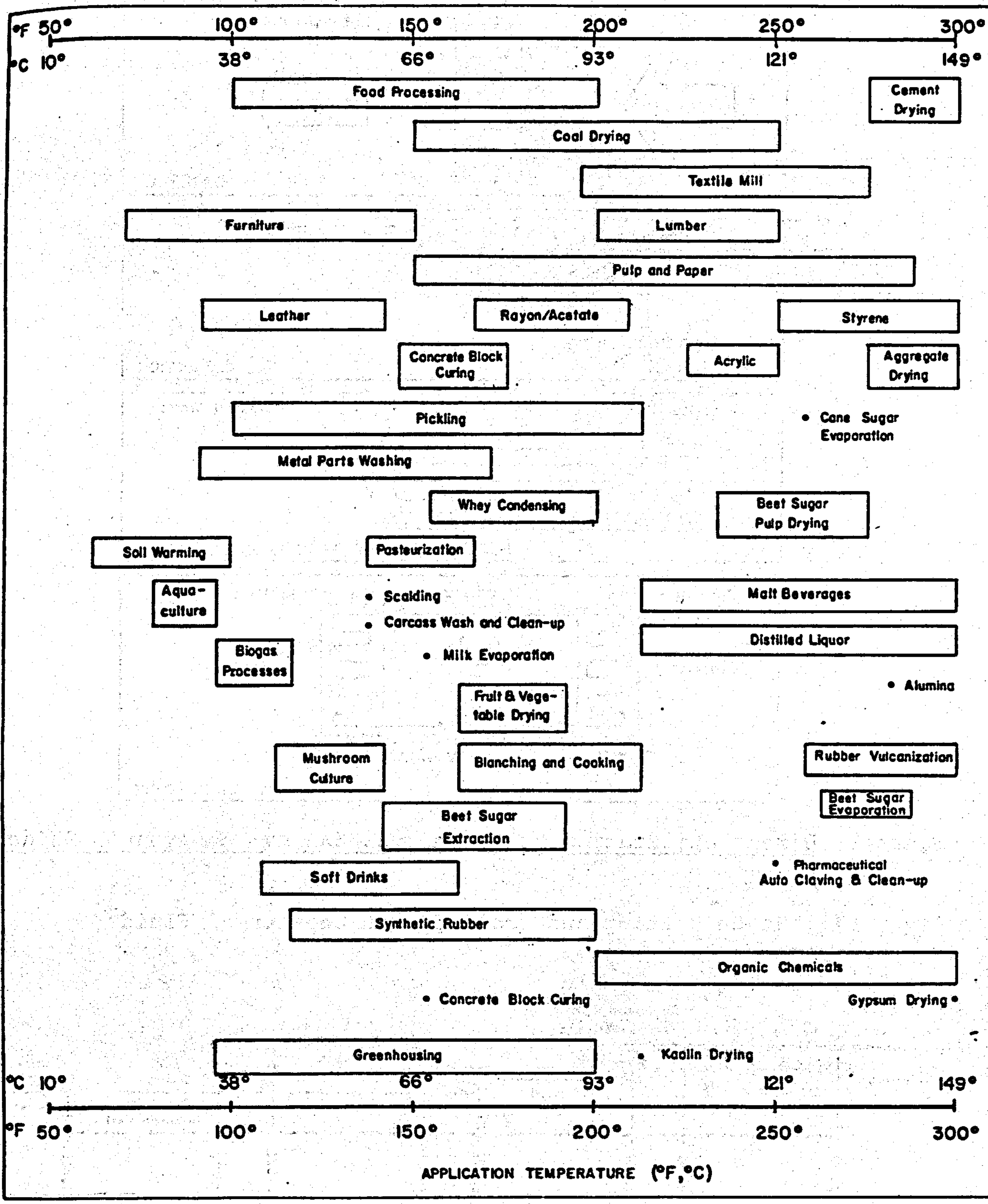
For electrical space heat, the forced-air system is most adaptable for retrofitting. Converting electrical resistance heating (baseboard) to a geothermal system is more difficult. An estimated 25 percent of Deschutes County residences with electric space heat utilize a zonal (baseboard) heating system.[11]

In general, the older the system, the better chance it has been over-designed, and hence of meeting the capacity needed for a geothermal conversion. A heat exchanger transfers heat from geothermal fluid with about a 10° F temperature loss. The decision to add a heat exchanger to a geothermal system depends upon whether circulating geothermal fluids directly will corrode the fan-coil unit.[12]

District Heating

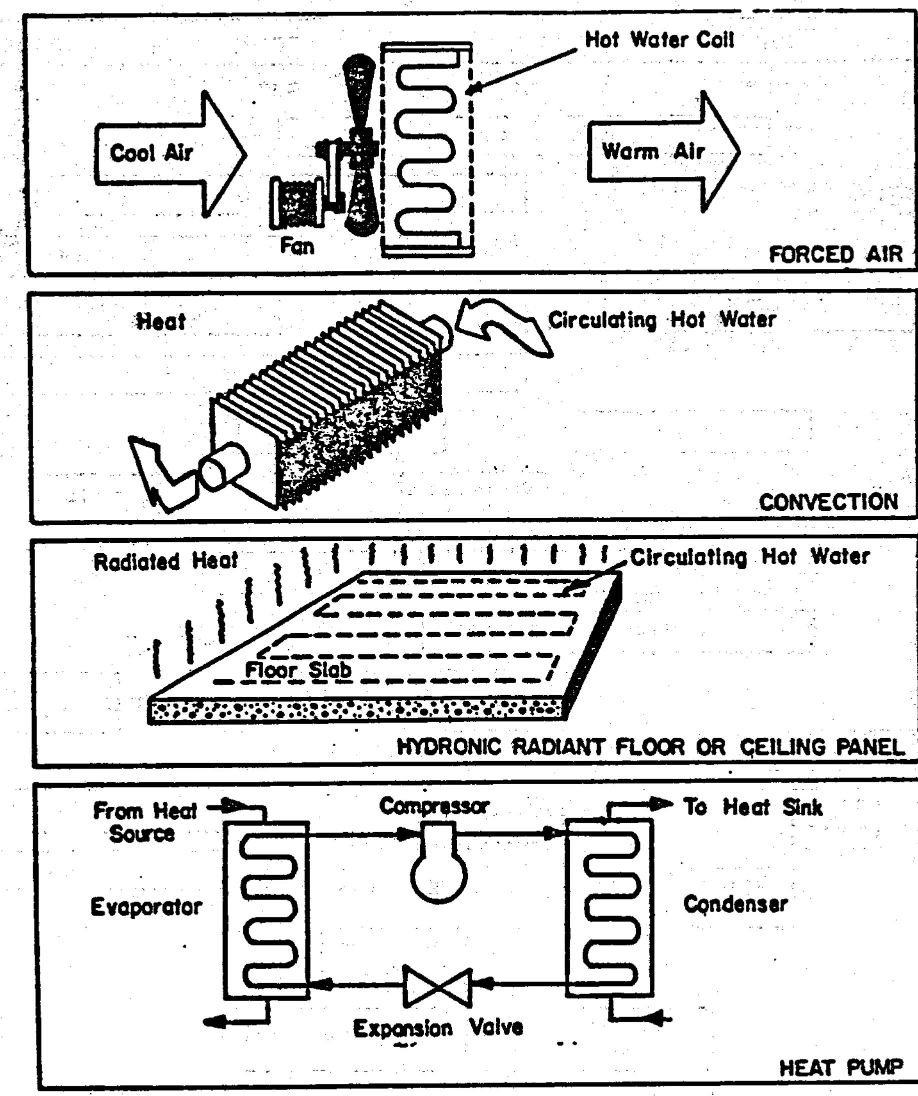
An alternative to individual space heating is district heating which is a broader and more efficient geothermal application than any of those previously mentioned. District heating systems, such

Figure 5. Application Temperature Range for Some Industrial Processes and Agricultural Operations.



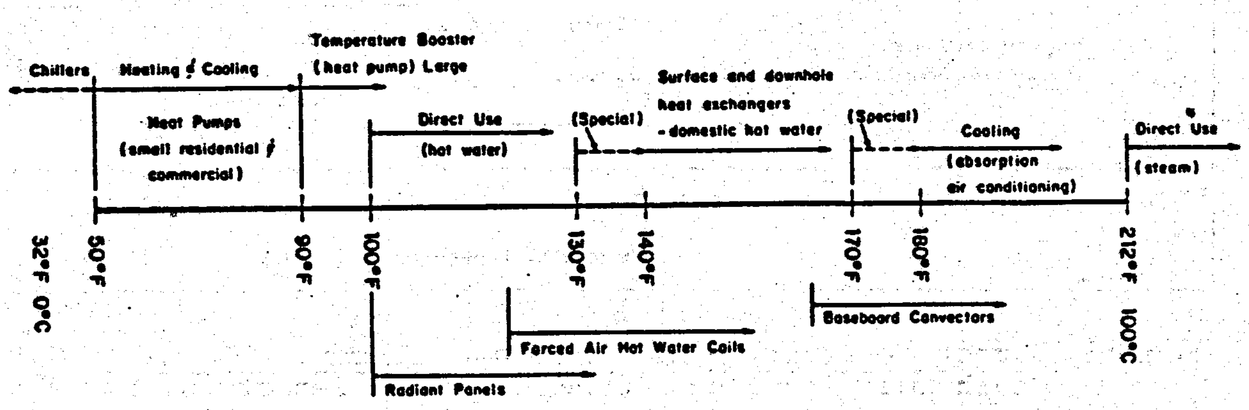
Source: Direct Utilization of Geothermal Energy: A Layman's Guide Geothermal Resources COuncil Special Report No. 8, 1979

Figure 6. Space-heating Systems Suitable for Geothermal Applications



Source: <u>Direct Utilization of Geothermal Energy: A Layman's Guide</u>

Figure 7. Space Heating and Cooling with Geothermal Fluids



Source: <u>Oregon: A Guide to Geothermal Energy Development</u>

as those of Klamath Falls, Oregon (see case study below) and Boise, Idaho, pump geothermal fluid to a central heat exchange facility after which it is reinjected. A closed loop secondary pipeline filled with treated city water then supplies heat to surrounding residences and buildings.

Geothermal district heating offers several practical advantages which could speed large scale implementation:

1) The technical feasibility is well established, having been demonstrated over an extended period in Europe, the U.S., and elsewhere.
2) Geothermal district heating should be well-accepted by a community as an alternative heating system. Heat quality is high and air quality extremely favorable compared to conventional fuel use.
3) Capital investment per dwelling is comparable to providing electrical service.
4) Organizations exist which could be franchised to install and operate heat systems; these are the investor-owned and municipal utility systems which now provide natural gas, electricity, and water.[13]

District Heating Economics--Case Study

The Klamath Falls district heating project has incurred the following costs:

Item	Amount	Status
Production wells	$ 63,965	Complete
Primary Pipeline	1,269,711	Complete
Secondary Pipeline	790,966	Complete
Engineering and Administration	205,468	
Total	$2,330,110 (Cost share DOE 65%)	

Natural gas, the least costly energy source available, was used to evaluate the economics of the geothermal system. The 14-building project, at $.31 per therm shows a pay off period of 6.2 years, based on present worth of eight percent and capital cost of eight percent. A 20-year equivalent annual cost summary, including operation and maintenance costs, indicates an annual equivalent cost for geothermal of $216,096 per year vs. $576,944 per year for natural gas. ($.82 per therm for natural gas used as a conservative estimate. Higher gas costs will place the geothermal project in yet a more favorable position.)[14]

The competitiveness of geothermal depends, to a large extent, on the proximity of the area to be heated. Obstacles include the cost of distribution, the loss of heat in distribution, the high cost of heating one-family residences, and the high initial capital investment. The main advantage of district heating is an 80 percent heating efficiency as opposed to 50-70 percent for an individual heating system. Iceland has been extremely successful in using geothermal for district heating. Approximately 65 percent of the country's buildings, and 97 percent of the buildings in Reykjavik, are heated geothermally. [15]

Agricultural Uses of Direct Geothermal

Low temperature geothermal resources (either virgin fluids or those cascaded from previous uses) are ideal for various agricultural processes.

Geothermal water circulated through floor pipes or contained in finned-coil heat exchangers, for example, can heat greenhouses using temperatures as low as 90° F. [16] Similar applications in animal husbandry (raising of animals), aquaculture (cultivation of fresh-water and/or marine organisms), soil warming, mushroom raising, and bio-gas generation, can replace conventional fuels and aid agricultural productivity.

The Soviet Union and Hungary use over 350 MW_t annually in geothermally supplemented agriculture. In the U.S., Geo-Products Corporation near Susanville, California, provides heat to thirty greenhouses, and is planning expansion for over 200 units, to grow cucumbers and tomatoes. [17] And Fish Breeders, near Buhl, Idaho, use 6,000 gpm of 90° F. water to raise approximately 500,000 pounds of fish annually.

D. Heat Pumps

Heat pumps are an application for temperatures even lower than 90° F, and are often used in individual wells and district heating to take advantage of the lowest temperature resources. A heat pump transfers heat from a low-temperature heat source to a higher temp medium, using fluid temperatures as low as 50° F and up to 120° F. The greatest efficiency occurs in the 60-90° F range.

The advantage of using geothermal fluids in a water-to-water or water-to-air heat pump is that the heat source is not contingent upon atmospheric conditions. Compared to air-to-air systems, water source heat pumps exhibit a higher, and more consistent, coefficient of performance (COP): 70° F water allows a COP of 3.0, whereas seasonal average COP's for air source heat pumps range from 1.7 to 2.5. [18] [19]

Several heat pump installations are currently operating. A heat pump in Criel, France extracts a 100 percent increase by using return water from the first stage of a large 4,000-home heating system. [20] A 28-story office building in Salt Lake City, Utah is entirely space-conditioned using a water to air heat pump operation, and locally, a Government Camp, Oregon condominium heat pump system produces .5 million Btu's per hour.[21] A lot of buildings in downtown Portland use groundwater heat pumps. Approximately 150-200 homes in Oregon are heated by ground water heat pumps.

An economic analysis for a home-heating system in an 1,800-square foot house in Klamath Falls, Oregon was conducted by the Oregon Institute of Technology. The study compares the cost of an oil furnace, electric furnace, heat pump using city domestic water, and heat pump requiring a separate 300 ft. well with a 100 ft. static water level. The assumed economic inflation was seven percent, the projected inflation rate for electricity was 8.9 percent through 1988 and 6.8 percent thereafter, and No. 2 diesel oil was projected to inflate as follows:

Year	Heating Oil
1979-1980	15.4%
1981-1984	7.8%
1985-1989	8.8%
1990-1994	11.3%
1995-2000	11.4%

The results were as follows;

Table 2

Residential Groundwater Heat Pump Cost Comparison [22]

A Type of System	B Capital Investment	C 20-Year Amortization	D First -Year Operating Costs	E Total 20-Year Annual Equivalent Costs
Oil Furnace	$2,775	$372	$866	$1,965
Electric Furnace	$1,950	$261	$782	$1,696
Heat Pump Using Domestic Water	$3,640	$487	$494	$1,396
Heat Pump With Well	$7,760	$1038	$261	$1,518

The annual equivalent cost savings of geothermal heat pump systems are due to its low-cost extraction of heat from ground water. After initial capital outlay, there remains a negligible cost of pumping 10 gpm.[23]

It is estimated that low-temperature shallow geothermal water heat pumps could be used for residential heating and cooling in over 75 percent of the continental United States.

Difficulties with heat pump utilization include: locating and extracting geothermal water (deep drilling may be required); and developing heat pump evaporators that can withstand the physical and chemical makeup of geothermal fluid.[24]

VI. GEOTHERMAL SITING CONSIDERATIONS AND ENVIRONMENTAL IMPACTS

A. General Considerations for Electrical Generation

Four general parameters of any hydrothermal convection system are 1) source of heat, 2) permeability, 3) water, and 4) cap rock.

A typical 110 MW unit at the Geysers dry steam power plants in California includes the following major components:

Leasehold size: 800-1000 acres

Power plant--total area: 4-6 acres
a) turbine generators and building
b) cooling towers
c) switchyard
d) abatement/treatment facilities

Steam supply--total area: 25-100 acres
a) well and well pad
b) steam pipeline
c) mufflers

Other facilities
a) offsite fill areas--site specific
b) transmission lines: 5 acres
c) roads: 20-40 acres

General siting criteria are 1) that an adequate resource is contained within the leasehold, 2) that transmission distance is minimized, and 3) that the site is environmentally, technically, and economically feasible for development.[25]

Sunoco Energy Development Company (Sunedco), in reference to a geothermal leasing on the federally-owned Belknap-Foley area, Lane County, Oregon, cites "basic and immutable" operational limitations to geothermal electrical development:

1) Heat loss in pipeline transport of geothermal steam dictates a limitation of no more than ½ to 1 mile as the distance between well head and generating facility.
2) Relatively flat transmission line elevation is required to avoid pumping and transmission difficulties.
3) Drilling experience in the Breitenbush area of Oregon, the first deep well in the Cascades, indicates that "directional drilling[26] will not be a viable technique in the Cascade region" due to enormity of costs and expected geologic complexity.[27]

Sunedco notes as well, four key geologic elements needed to support an electrical generating plant in the Cascades:

1) a reservoir rock of volcanic material
2) a complex faulting and fracturing system
3) association with a large rechargeable subsurface hydrologic flow, and
4) proximity to an adequate heat source.

More specifically, it says, a resource suitable for development must "generate flows in excess of 100,000 lbs/hr from a reservoir with temperatures higher than 400° F with adequate pressure to maintain a consistent level of flow for the expected plant life, i.e. 20 to 30 years."[28]

The Oregon Nuclear and Thermal Energy Council State-wide Task Force further states that "the location of geothermal fueled plants is restricted to the areas that have high heat potential with a suitable amount of water, either on the surface or stored within the geothermal field. There are conflicting land uses currently recognized that will impair plant siting. State recognized Natural Resource areas are in general unsuitable for any form of industrial development. Water restrictions proclude the industrial consumption of surface waters that have been set aside for recreational, municipal, and other water uses."[29]

Natural resource areas include: national parks, monuments and memorials; wilderness and roadless areas; botanical and geologically sensitive areas; fishery resource areas; and state parks. Of the above, wildlife management areas, refuges, and migratory feeding areas, and fishery resource areas may be compatible with thermal power development. These areas are classified as "less suitable" rather than unsuitable" by the Energy Facilities Siting Council.[30]

B. Environmental Impacts

Environmental impacts will differ widely depending on the type, location, stage of development, and ultimate end-use of the geothermal resource. Decisions on environmental issues must be site-specific. This section will identify general environmental considerations. Major environmental issues common to geothermal development include land use, air pollution, subsidence, water pollution, induced seismicity, well blowers, noise, archeological disturbance, fish and wildlife degradation, and socio-economic change. Important to note is that most experience with these issues are associated with electrical geothermal projects. See appendix A for a more thorough analysis of the environmental implications of geothermal development at Newberry Crater.

Geothermal development may be identified in six stages, each phase with its own environmental impact. These are: 1) exploration, 2) test drilling, 3) production testing, 4) field development, 5) power plant and powerline construction, and 6) full scale operations.[31] Representative activity occuring in each stage is outlined below. Impacts of development are essentially cumulative with successive phases.

Development Stages and Associated Impacts of Electrical Production

PHASE I Initial Exploration defines commercial geothermal reservoirs, and identifies possible impact upon surface and subsurface resources and conflicting land use. Principal exploration activities are surface oriented and include:

* geochemical surveys--to analyze water and vegetative samples.
* stratographic, lithographic, and structural mapping--to examine outcrops and topography.
* micro gas surveys--to analyze air and soil samples from various points within a given area.
* reconnaissance surveys--to note surface features and natural phenomena.
* shallow drilling--to obtain geophysical data.[32]

IMPACT: Generally, exploration activity is conducted through the use of existing roads and trails. Minimal adverse impacts to wildlife and vegetation may result from vehicular travel, low-flying aircraft, and shallow hole-drilling.

PHASE II <u>Test Drilling</u> provides subsurface geologic data, locates potential productive zones within the geothermal reservoir, helps delineate reservoir limits, and aids physical chemical analyses of reservoir fluids. Locations for test drilling are selected on the basis of Phase I activity and approved exploration plan.

Test wells vary; boreholes range in size from four to twenty-four inches in diameter and a few hundred to several thousand feet in depth (the deepest being in the 5,000 to 10,000 foot range). Larger well drilling impacts are comparable to those oil and gas operations. Drill sites (pads) are generally one acre or less, and are cleared of vegetation and graded to a flat surface. A drilling rig, usually truck-mounted, with a conventional superstructure, mud pumps, together with mud tanks, generators, drill pipe rack, tool house, etc. usually is located on the drilling pad.

Other facilities may be located off the drill pad. A reserve pit of approximately 1,000 ft^2, 6-8 ft deep, is sometimes dug to contain waste fluids during drilling operations. Road construction to accomodate transport of the heavy drilling rig and other equipment is typically needed. Larger and/or deeper holes require larger equipment and inevitably occupy a larger site.

IMPACT: Unavoidable impacts of road construction or enlargement will occur in this stage, and could include: vegetative cover removal, surface disturbance, soil erosion, and siltation. Approximately ½ to 1 acre at each drill site is taken out of vegetative resource production. Moderate levels of noise will accompany drilling and grading. Spillage of geothermal fluids, drilling mud, or other surface contaminants could occur. While the impacts of test drilling are generally temporary in nature, they may result in loss of wildlife habitat and wilderness value.

PHASE III <u>Production Testing</u> determines flow rate, composition, temperature, recharge characteristics, pressure, and compatibility of geothermal fluids.

IMPACT: Establishing the maximum production rate in this phase involves venting of the well to the atmosphere with accompanying vapor release and noise. Considerable monitoring and analyzing of fluids is necessary to determine their toxicity. In the event that preliminary stages 1-3 indicate a geothermal field has economic potential for power development, a commitment from a customer electric utility must be obtained to warrant further development.

PHASE IV Field Development means the drilling of additional wells to develop more of the same field. Field development can continue for many years as additional power-generating units are constructed. Uncertainties as to the depth of the producing zone and type of fluid to be encountered are less than in the initial prospecting stages. Contaminating substances contained in geothermal fluids, if present, must be removed or otherwise treated before surface disposal. If the fluid is sufficiently pure, potable water may be produced at a geothermal installation.

A desirable, although expensive, method of fluid disposal is deep-well injection. Injection (sometimes called re-injection) is the emplacement of wastes back into a reservoir, usually below the water table and beneath a confirmed stratum in order to protect water supplies. Injection can a) perpetuate long-term use of a reservoir by maintaining its pressures, and b) eliminate surface environmental contamination by circulating fluids in a closed-loop system. A technological problem sometimes encountered in injection, though largely mitigated, is a buildup of scale on pipes and wells, caused by silica or carbonate deposits from waste fluids. Corrosion from briny geothermal fluids may also plague well apparatus.

IMPACT: Generally similar to that occuring in the test-well stage but on a greater scale: there will be further, more permanent construction of service facilities and living quarters. Fluid disposal is potentially dangerous to vegetation, wildlife, and soil structure. Greater land clearance reduces habitat. Air and water quality may be a concern.

PHASE V Power Plant and Power Line Construction comprises phase 5. Above ground insulated pipes are used to transport the steam from well to power plant. An underground pipe system is not economically feasible due to service and equipment requirements. Power plant installation would probably not exceed 100 MW at an individual site, considering steam pressure and temperature loss factors in transport. A typical plant at the Geysers consists of two turbine generators housed in a single building with an adjoining structure housing cooling towers. Each plant is served by twenty or more wells at spacings of about 40 acres per well, although sometimes several wells are drilled off the same pad. High voltage transmission lines connect the power plants.

IMPACT: Noise up to 120 dBA at most (noise level at The Geysers is a maximum of 73, at a distance of 1 mile); construction related effects, including permanent landscape alteration from building industrial complex, visual quality reduction, wildlife/vegetation depletion.

PHASE VI <u>Full-Scale Operations</u> and residual management would involve a) operation and maintenance of power plants and related facilities, and drilling, re-drilling, and working over of geothermal wells to maintain production capacity. Overall activity would be considerably reduced over that required in phases 4 and 5.

IMPACT: * Aesthetic quality would be affected by the completed development of a well and steam transmission system, power generation facilities, transmission lines, and permanent roads.

* Operating noise levels as high a 120 dBA may affect human population and local fauna within a ½ mile radius.

* Possible nuisance and toxicity to wildlife, humans, and vegetation from uncontrolled noxious gas emissions close to the production area. A hydrogen sulfide (rotten egg) odor may be present.

* Increased air temperature in plant vicinity.

* Potential for land subsidence because reservoir material compacts as fluid is removed.

* Potential for seismic events resulting from withdrawl and/or injection of hydrothermal fluids along unstable formations.

* Potential destruction of cultural/archeological sites.

* Possible decrease of timber production area at power plant site.

* Potential water use conflicts. Cooling facilities can require 12-14 million gallons/month.

* Potential water pollution from geothermal fluids with a high dissolved solid content.

* Potential land-use conflicts--e.g. wilderness, agriculture, habitat preservation, recreation.

FAVORABLE IMPACTS:

* Development of geothermal in an environmentally acceptable manner provides a relatively clean power source compared to conventional fuels.

* Geothermal heat can be cascaded for a variety of uses, as is noted in previous sections. Fluids may also contain mineral or gas potential (such as methane) and valuable water resources for domestic, irrigative, or industrial use. Wells might be used even after power production has ended.

* Investment in geothermal development results in an increased tax base for the area of development. Employment of personnel would stimulate the demands for goods and services in Bend and adjacent areas.

* A geothermal installation could enhance the special interest quality of existing geologic and volcanic areas.

D. Direct Use Siting Considerations

Many potential environmental impacts from geothermal electrical development are avoided when geothermal fluids are used directly as a heat source. Construction disturbance and capital investment needed for common direct heating applications is much lower than that associated with electrical projects, since direct use requires no transmission lines, power-generating equipment, or cooling facilities. Direct use also requires considerably fewer wells per development, shallower depths, and lower temperatures.

Many direct use geothermal systems supply energy at a fraction of the cost of conventional fuels.[33] Significant variables in pricing a direct use geothermal system include: water quality, site location, pumping depth, system efficiency, daily hours of energy use, transportation distance, drilling costs, and cost of investment.[34]

Geothermal direct use evaluations must be site-specific. Nevertheless, some guidelines to insure a positive benefit to the geothermal user can be suggested:

1) Resources at shallow depths that have flow rates and temperatures compatible to the needs of the user should be developed. Water that has few corrosive elements is desirable for keeping costs down.
2) Pipeline distances between the production well and the user should be kept to an absolute minimum, due to costs and heat loss.
3) Users must operate at least 20-50 percent of the time if the cost is to be competitive with that of other energy forms.[35]
4) The developer must obtain low-interest loans and be willing to reduce the short-run rate of return on the investment in order to reap the long-term benefits.[36]

C.H. Bloomster, in Residential Heating Costs: A Comparison of Geothermal, Solar, and Conventional Resources says, likewise, that:

> "geothermal energy is most competitive when employed on a large scale to serve concentrated markets. The economics of geothermal district heating is very dependent on the size and density of heat demand, which are determined by population, population density, and climate. Because of sensitivity to the distance, locating geothermal resources near to the demand is important. A high degree of participation within the heating district is also necessary for commercial success."[37]

Bloomster concludes that the major impediments to widespread geothermal heating will be: a) the timely demonstration that reliable, commercially-productive geothermal resources exist near enough to market, and b) the organization of heating districts which are both large enough and concentrated enough to be economically competitive. He estimates, however, that "geothermal energy will be more economic than solar or conventional energy in most high-density urban areas provided that geothermal resources are nearby."

VII. PERMIT PROCESS

The first step for any potential developer of geothermal energy is to identify land-ownership status. At this point, the developer may have to deal with two people: the owner of the land, and the owner of the mineral rights. Frequently, access problems in geothermal are similar to those in the petroleum industry. Obtaining the rights to a geothermal resource is more complicated than obtaining the rights to a coal field, for example. Because geothermal resources are akin to water, to gases, and to minerals, the Oregon Geothermal Resources Act of 1975 grants ownership rights of geothermal resources to the surface owner. The Act states:

> "Ownership rights to geothermal resources shall be in the owner to the surface property underlain by the geothermal resources unless such rights have been otherwise reserved or conveyed. However, nothing in this section shall divest the people or the state of any rights, title, or interest they may have in geothermal resources." (ORS 522.085)

As there is some confusion about the nature of geothermal resources as defined by ORS 522.005(7) and the ownership of geothermal resources as defined above, the developer is advised to secure all resource rights, surface and subsurface, that may constitute a claim to geothermal resources. The following pages provide a detailed account of state, federal, and private leasing processes excerpted from Debra Justus (Oregon: A Guide to Geothermal Development.)

A. Access and Development Rights

1. Private Land

Access to private land can be obtained by purchase, lease, permit, option, or any other mutual agreement with the owner of the surface property and geothermal estate. If the land and resources are purchased outright, it is important that the developer secure clear title to the surface and subsurface rights.

In most instances, access to private land is obtained through a geothermal lease. Leasing terms generally include length of lease, royalty payments, lease fees, and stipulations governing exploration and development activities. This mechanism is often based on oil and gas leasing procedures.

Landowners may permit access prior to a lease or purchase option. This allows the developer to conduct agreed upon preliminary exploration activities. Such activities could include geological and geophysical investigations which do not disturb the surface and temperature gradient hole drilling. A state well drilling permit would be required for exploratory drilling on private land.

If the area of interest is already under lease for other purposes such as farming or grazing, the developer must secure permission from the lessee for surface access rights.

2. State Land

The State Land Board, through the Division of State Lands, is authorized to issue leases for geothermal resources underlying state-owned lands. A geothermal resources lease is required to explore, develop or dispose of any state-owned geothermal resources. However, the lease does not authorize construction of a power plant on state land.

Casual exploration activities can be carried out before lease acquisition under a geothermal exploration permit issued by the Division of State Lands. The procedure requires the applicant to submit a description of the exploration plan, evidence of compliance with insurance and bonding requirements and other information deemed necessary. The permit is used for a one year period and allows nonexclusive access to state land for geothermal exploration. An exploration permit does not give preferential right to lease.

To obtain a lease, application must be filed with the Division of State Lands for a minimum of 40 acres. A pre-lease environmental report is required to address the potential effects of proposed exploration, development and production activities for the lease in terms of environmental and socioeconomic acceptability.

The Division also requires: An archaeological survey before entry for exploration, proposed program for monitoring and surveillance of the geothermal resource and ground water quality and quantity during production, program for subsidence monitoring, re-vegetation for disturbed areas, and compliance with Department of Environmental Quality (DEQ) standards governing air and water quality, noise, and waste disposal.

Generally, applications are accepted on a first come, first served basis, although the Division may favor an applicant with adjacent lands under lease. When the assessment is complete, the Division circulates the application and environmental report to appropriate state and local agencies for comment. If no serious concerns arise, the application goes to the State Land Board for final approval.

To date, the Division of State Lands has received one application for lease in Deschutes County encompassing 480 acres in T20S. R12E. S16(NE 1/4 of S 1/2) submitted by Cal Energy of Santa Rosa, California.

3. Federal Land

Surface access and the right to explore, develop and use geothermal resources on federal lands are acquired with a geothermal lease issued by the U.S. Bureau of Land Management (BLM). Pursuant to the Geothermal Steam Act of 1970, the Secretary of the Interior can issue leases for the development and use of geothermal resources on certain federal lands. Exempted from leasing are lands within the National Park System, national recreation areas, fish hatcheries, identified wildlife areas (e.g. refuges, ranges, management areas, waterfowl production areas), Indian lands, Department of Defense lands, and other lands selected by the Secretary. Wilderness areas may be leased in accordance with the terms of the Wilderness Act of 1964.

Limited exploration involving canal-use activities and other preliminary evaluation operations may be conducted before securing a lease by obtaining a temporary use permit from the local BLM District Office or the Forest Supervisor's Office. Canal use refers to activities such as geologic mapping that are transitory and do not appreciably disturb the land.

Pre-lease exploration activities including test drilling up to 152 meters (500 feet) may begin upon approval of a "Notice of Intent and Permit to Conduct Exploration Operations" from the District Manager of the BLM, who coordinates with the USGS. The notice requires site specific information concerning exploration plans and a $5,000 bond or other bond assurance. The approved notice requires compliance with all applicable federal and state laws and local ordinances. When the exploration activities are complete, a "Notice of Completion of Exploratory Operations" must be filed with the BLM. Similar procedures are required by the U.S. Forest Service, which issues Prospecting Permits on National Forest Lands for exploratory operations.

Casual-use and exploration under a Notice of Intent gives the nonexclusive right to conduct operations on federal land, but no preference for a lease. A geothermal lease gives the exclusive right to drill for, develop, and use geothermal resources under the leased land and the nonexclusive right to perform exploration and casual-use operations. Persons other than the lessee, who wish to explore leased lands may gain access by obtaining an exploration permit from the appropriate surface management agency.

The Bureau of Land Management has primary responsibility for issuing geothermal leases on all available federal lands. The U.S. Geological Survey and U.S. Forest Service also have responsibilities governing the issuance and administration of federal geothermal leases. The major role of these agencies in the federal leasing program is outlined below:

Bureau of Land Management

- Receiving and processing lease applications for non-competitive areas.
- Publishing lease sale notices and receiving bids for competitive lands.
- Preparing environmental assessments on suitability of BLM lands for geothermal leasing purposes.
- Providing input to the USGS on surface consideration of post-lease environmental evaluations (USGS has primary responsibility for post-lease activities).
- Preparing lease stipulations governing special surface management programs for BLM lands.
- Supervising land uses on BLM leased land outside areas of operations.

- Awarding all leases.
- Administering lease (except those functions assigned to the USGS or Forest Service).

USGS
- Providing input on geologic setting and geothermal operations for pre-lease environmental evaluations.
- Supervising activity within the area of operation on leased lands for all phases of exploration, development and utilization.
- Preparing post-lease environmental assessments on site specific exploration and development plans. The surface management agency, BLM or Forest Service, provides input.
- Designating "Known Geothermal Resource Areas" (KGRA)
- Administering terms of lease.
- Issuing Geothermal Resource Operational Orders.
- Reviewing lease stipulations formulated by the BLM or Forest Service
- Parcelling of lease tracts.

Forest Service
- Preparing environmental assessments on suitability of national forest lands for geothermal leasing purposes.
- Providing input to the USGS on surface considerations of post-lease environmental evaluations.
- Preparing lease stipulations for governing surface management for Forest Service lands.
- Supervising land uses on leased land outside areas of operation.
- Issuing special use permits for surface occupancy.

The procedures for obtaining a federal geothermal lease depends upon the competitive interest classification of the land. Lands may be classified as "Known Geothermal Resource Areas" (KGRA) and leased on a competitive bid basis. Non-KGRA acreage is offered through a noncompetitive lease to the first qualified applicant.

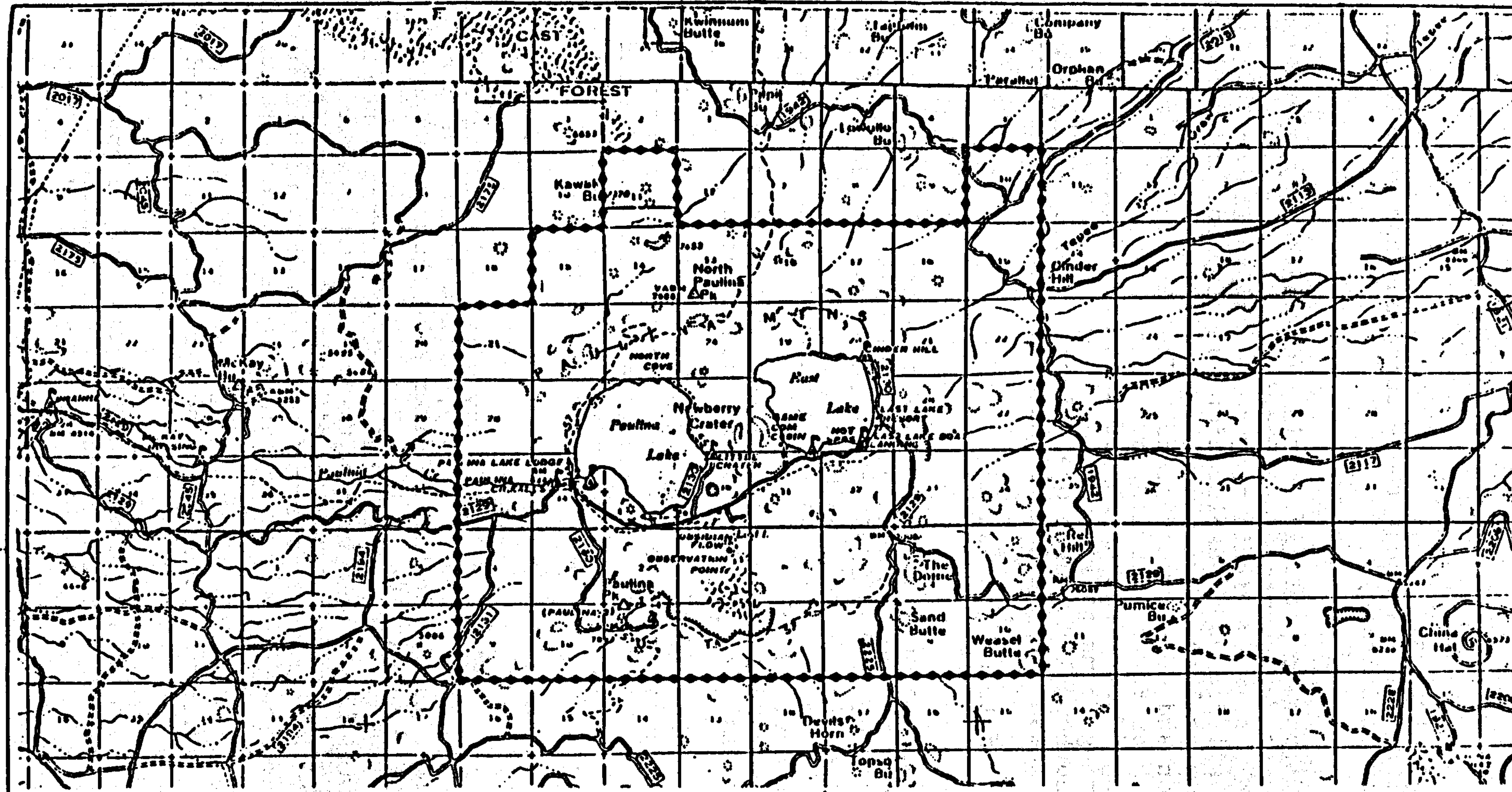
<u>Competitive Leasing</u>

Lands designated by the USGS as KGRA's may only be leased through competitive bidding. In Deschutes County, 31,284 acres have been so classified. This is the Newberry Crater KGRA shown in figure 8 . The Geothermal Steam Act defines a KGRA as:

> "...an area in which the geology, nearby discoveries, competitive interest or other indicia would, in the opinion of the Secretary (of Interior), engender a belief in men who are experienced in the subject matter that the prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for the purpose."

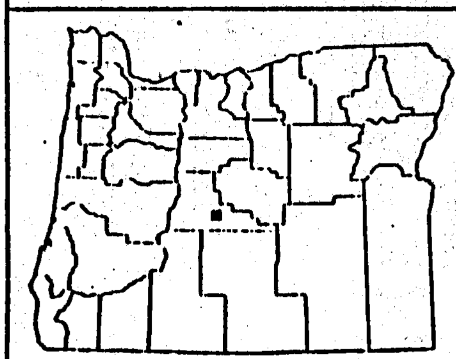
Competitive interest will also exist if at least one-half of the lands in an application are covered by another application filed during the same month.

The BLM State Office manages leasing on KGRA lands. The appropriate surface management agency, BLM or Forest Service, conducts the



NEWBERRY CRATER KNOWN GEOTHERMAL RESOURCE AREA

Finure 8



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SCALE IN MILES

NORTH

K G R A BOUNDARY

necessary pre-lease environmental review and determines which areas will be available for leasing. The BLM sets the lease sale date and publishes public notices. Prior to the day of the sale, each bidder must submit a statement of qualifications for leasing and a sealed bid which includes payment for at least one-fifth of the bid amount. Leases generally are awarded to the highest bidder. The federal government reserves the right to reject any and all bids.

For a detailed account of the Newberry Crater KGRA see Appendix C.

Noncompetitive Leasing

Federal lands which have not been classified as a KGRA or excluded from leasing are available to qualified applicants on a noncompetitive basis. The procedure begins with the filing of an "Application to Lease Geothermal Resources". The application requires a site description, map, proposed plan, methods for diligent operation, proof that an individual, corporation, or municipality is qualified to hold a lease, and other specified information. Each application must be filed with the BLM State Office. Applications will be considered, environmental assessments conducted, and leases awarded for lands found suitable for geothermal development on the basis of priority by date of filing.

	# of lease applications	# of applicants	# of acres	# of drill sites 500'	2000'	# of acres
Fort Rock	144	44	396,858	20	8	7
Bend District	20	4	162,389	3	0	1
Sisters Dist.	60	7	133,565	5	2	1 1/4

Geothermal Leasing and Drilling Activity in the Deschutes National Forest as of August, 1980

B. Exploration and Development Regulations

When clear title has been secured for a particular geothermal resource area, exploration and development should follow. Before initiating any activity the geothermal developer must obtain the necessary permits from the appropriate local, state, and federal regulators. The length of permit application review time and the number of permits required will vary depending upon the size of the project and the environmental sensitivity of the area. For example, a commercial geothermal greenhouse will require fewer permits and less processing time than a geothermal electric facility sited on federal land.

The following section describes the general types of permits that may be required. It is suggested that the developer contact the local, state, and federal agencies which may have regulatory authority for a specific project for additional details. The Oregon Department of Energy can also provide information regarding permitting requirements for a particular project.

1. Private Land

The following types of permits may apply to geothermal projects:

- Conditional land use permits may be required from cities or counties to comply with local zoning ordinances and Land Conservation and Development Commission goals and guidelines. Contact the local planning department for information regarding applicable laws and regulations.
- Construction permits and building inspections to insure compliance with state and local codes should be coordinated through the local building and safety division.
- Drilling permits will be required from the Department of Water Resources or the Department of Geology and Mineral Industries, depending on expected well depth and temperature.
- A permit is required from the DEQ for disposal of liquid wastes such as drilling muds, equipment oils, geothermal fluids, and solid wastes.
- A Water Pollution Control Facilities permit from the DEQ may be required for injection wells.
- Other permits may be required from the DEQ to set limits on air emissions and fluid discharges. Contact the local or state DEQ office for specific information.
- An energy facility site certificate is required for large facilities over 25 MW.

2. State Lands

When a lease has been issued, exploration and development activities are subject to state, federal, and local regulations governing land use, well drilling, facility siting, and waste disposal, as outlined in the preceding section.

In addition, to develop a geothermal resource on state land, the Division of State Lands requires: a proposed testing program, certified copies of all tests and measurements, legal confirmation of the well's primary purpose, design alternatives considered in development planning, and measurements of the quality and quantity of all production.

3. Federal Lands

When BLM has issued the lease, the U.S. Geological Survey assumes primary responsibility for exploration and development operations within the federal lease area. The surface managing agency is responsible for all other areas. The USGS Conservation Division Area Geothermal Supervisor maintains regulatory control pursuant to the Geothermal Resources Operational Orders. The BLM is responsible for licensing electrical power generating facilities of 20 MW or more.

Activities related to geothermal resource exploration, development, production and utilization are carried out under a Plan of Operation approved by the Area Geothermal Supervisor. Necessary permits and environmental reviews are coordinated by the Area Supervisor with the exception of permits required for emissions to the atmosphere and waste disposal which are issued by the Department of Environmental Quality. The developer must also obtain a well drilling permit from the Oregon Department of Geology and Mineral Industries. Plans of operation may be submitted sequentially by development phases or in combination, depending upon project scale and developer's data.

Environmental Review Procedures

Federal agencies, generally the surface management agency and the USGS, are responsible for the preparation of environmental documents necessary to satisfy requirements of the National Environmental Policy Act and state or local environmental laws for activities conducted on federal land. State and local regulations are applicable to federal lands, but these standards are generally enforced by federal agencies. It may be necessary for the developer to perform an archaeological and native American religious site survey and sometimes a biological survey for any threatened and endangered species.

Deep exploration drilling, development, production and utilization activities are considered major surface disturbing activities and require a site specific environmental assessment. The evaluation must discuss the affect the operation will have on the environment, recommend mitigating measures, and determine whether the operation will be a "major federal action", requiring a complete Environmental Impact assessment period. If not considered a major federal action, the Plan of Operation is jointly approved by the Area Supervisor and the appropriate surface manager. Mitigating measures are incorporated as special conditions of approval. The developer must then obtain the necessary drilling or construction permits from the Area Supervisor.

The environmental evaluations are prepared by the relevant federal agencies, usually at no cost to the developer. However, they may require information from the lessee, and adequate time for the preparation and review process needs to be allocated by the developer. Small scale projects may not require a full scale environmental impact statement if analyses show that net environmental impacts are adequately offset by proposed mitigating measures.

Production

Resource production is regulated by an approved Plan of Production from the Area Geothermal Supervisor. Before the plan is approved, the applicant must gather environmental baseline data describing the existing environmental setting for a one-year period. Requirements for baseline data may be waived by the Area Supervisor for projects that will have minimal impact. Waivers are determined on a case-by-case basis. It is important for the developer to have an early consultation with the Area Supervisor to determine which requirements will apply to a specific project to facilitate planning of sufficient time and labor allocations.

Facilities Construction

Small scale facilities on federal land are permitted by the Area Geothermal Supervisor, and environmental evaluations are undertaken if necessary. Larger facilities such as electric generating plants are licensed and reviewed for environmental impact by the BLM in consultation with the USGS. The basic permit for facility siting covers activities only on the lease area. Transmission or distribution lines or any other off-site facility involves separate permitting procedures.

Large facilities of 25 MW or more on federal land also require an Oregon energy facility site certificate.

C. Oregon Well Permitting Procedures

The State regulates well drilling regardless of land ownership. In Oregon, regulatory responsibilities for geothermal resources are divided between two state agencies; Department of Geology and Mineral Industries (DOGAMI) and Department of Water Resources (DWR). DOGAMI regulates geothermal prospect and geothermal wells. Shallow (less than 2,000 feet) low-temperature wells are regulated by DWR, essentially in the same manner as common water wells.

If the intent is to explore for and produce geothermal fluids with temperatures of 250° or greater, then the necessary permits are obtained from DOGAMI. The agency issues blanket prospecting permits which may cover numerous gradient wells 2,000 feet deep or less.

The following sections outline the general procedures for obtaining well drilling permits.

1. Well Drilling Permitting Procedure for Shallow Low-Temperature Resources (Wells less then 250° F BHT and/or 2,000 feet deep)

Responsible agency: Department of Water Resources
Relevant laws: Oregon Administrative Rules (OAR) Chaper 690, Division 60; ORS Chapter 537

- A permit is not needed before drilling.
- Contact a licensed well contractor.
- The contractor will file a start card with the local Watermaster describing location, proposed use and expected depth.

- A $2,000 bond is required.
- Drilling and completion procedures must conform to OAR Chapter 690 "Rules and Regulations Prescribing General Standards for the Construction and Maintenance of Water Wells in Oregon".

2. Well Drilling Permitting Procedures for Geothermal Resources (Prospect of geothermal wells drilled for fluids hotter than 250° F)

Responsible agency: Department of Geology and Mineral Industries
Relevant laws: ORS Chapter 522, OAR Chapter 632, Division 20

DOGAMI issues permits for prospect and geothermal wells as defined below. All drilling permits are conditional upon approval of local authorities.

a. Prospect wells include and wells drilled as a geophysical test well, seismic shot hole, mineral exploration drillings, core drilling or temperature gradient test well, less than 2,000 feet in depth, and drilled in prospecting for geothermal resources.
   - File a plan of operation and hole locations (letter form).
   - Filing fee - $100 per permit.
   - File a bond or security deposit in the sum of not less than $5,000 or a blanket bond of $25,000.
   - DOGAMI sends notice of permit application to relevant state and local agencies who have a 15 day period in which to comment.
   - A permit is granted within 30 days of receipt of application. Restrictions are added to the permit if agency comments require them. General stipulations are made a condition of every permit. (Table 3). Casing and abandonment requirements are also made conditions of each permit.
   - Permitting of shallow holes is done on a blanket basis, area-by-area under one permit. As many as 100 holes may be drilled under one permit.
   - Formation logs and notations of water zones encountered are required of every operator. Blowout Prevention rules require operators to monitor hole temperatures. If the temperature exceeds 125° F, drilling is to cease and the hole completed as an observation hole, abandoned or equipped with safety devices as prescribed by rule.
   - A final statement is required of the operator describing plugging procedure. Final locations are to be submitted.
   - Sites are inspected for cleanup and to check for ground water leakage. The drilling bond is released if all conditions are met. Inspections are coordinated with the U.S. Geological Survey to avoid duplication.

Table 3

<u>General Stipulations Which Apply to Geothermal Drilling Permits</u>

Oregon Department of Geology and Mineral Industries

1. A plan of operation is to be submitted with the application to drill showing a plat of the drilling pad and including location of the mud sump and any road which is to be constructed. Dimensions of these items should be indicated on the plat.
2. Details of the mud system are to be submitted at the time of application giving the mud pit capacity (dimensions) and type of mud to be used.
3. An emergency contingency plan is to be submitted before drilling describing:
   a. field supervisor's name and how to contact,
   b. blowout prevention equipment, and
   c. blowout prevention drills planned

   In the event of an emergency, a department representative should be contacted.
4. In the event of a blowout, a DOGAMI representative is to be notified as soon as possible.
5. Permission must be obtained from the State DEQ for any extraordinary off-site disposal of drilling mud or wastes or any other emergency that could affect adjoining properties.
6. Notice is to be given the State Geologist or his representative:
   a. when drilling is commenced,
   b. before BOP tests after running casing strings,
   c. before performing work to complete or abandon a well, and
   d. before running or pulling casing strings.
7. Upon completion of drilling operations, the site is to be restored to as near original condition as is practical.

b. Geothermal wells include any excavation made for producing geothermal resources and any geothermal injection well.

- File an application and a detailed plan of operation including: hole location, estimated drilling depth, blowout prevention equipment, waste mud and drill cuttings disposal, emergency plans, and site and road construction.
- Filing fee - $100 per well.
- File a bond or security deposit of $10,000 per well or a $25,000 statewide bond.
- DOGAMI send notice of permit application to relevant state agencies and the County Board of Commissioners.
- A permit is issued within 45 days after receipt of application providing no serious concerns arise. Stipulations are made condition of every permit. Casing and cementing programs are approved and all requirements satisfied before a permit is issued.
- An inspection is made early in the operation to test blowout prevention equipment, see that mud is properly being handled, and that records are being kept and drill samples collected.
- Inspections are made when fluid tests or subsequent casing strings are run.
- All subsequent cementing or casing operations are witnessed, including abandonment plugging or completion work.
- Sites are inspected for well completion and site restoration.
- All records related to the drilling must be filed with DOGAMI within 20 days after completion or abandonment. Records are held confidential for a four-year period.
- When all requirements are met, the drilling bond is released.

D. Geothermal Fluid Disposal

Oregon policy, as established by the 1979 Legislature, states that all geothermal fluids shall be injected into the same reservoir from which withdrawn unless it is determined by the agency responsible for well permitting that disposal by other means is in the public interest. Legislation outlining this policy specifically mentions that disposal by other means includes secondary uses of fluids produced from electrical generation and direct applications for such uses as plant cooling, and agricultural, commercial or industrial purposes.

Both the Department of Geology and Mineral Industries and the Department of Water Resources are developing regulations governing the disposal of geothermal fluids from wells under their jurisdiction. These rules will include: Standards to determine contamination, injection well construction standards, testing procedures for identifying aquifers, guidelines for conservation of the resource, criteria for evaluating reservoirs for geothermal fluid disposal, and requirements for prior approval of all geothermal fluid injection proposals. A potential geothermal developer is urged to contact the pertinent agency regarding disposal requirements.

If geothermal fluids are to be injected into an aquifer other than the one producing the fluid which is of better water quality than the geothermal fluid, a Water Pollution Control Facilities (WPCF) permit is required from DEQ. If pollutants are added to the fluid prior to injection, a WPCF permit will also be required. The DEQ may elect not to require a WPCF permit when injection is to the producing aquifer, or to an aquifer of like quality.

Disposal of geothermal fluid by means other than injection will always require a WPCF permit unless the fluid is discharged to the surface waters. In that case, DEQ must issue a National Pollutant Discharge Elimination System (NPDES) permit as required by the Federal Clean Water Act.

E. Water Rights

All water from all sources of water supply belongs, by law, to the public, and is subject to existing rights and legislative and administrative withdrawls. A right to appropriate water is obtained from the Department of Water Resources.

Water appropriations follow the doctorine of first-in-time, first-in-right, so the geothermal developer should be concerned about the availability of a water right of sufficient quantity to satisfy project needs. If waters in an area have been fully appropriated, the developer may be able to obtain water rights by providing replacement supplies or purchasing rights from existing users.

In areas where waters may be appropriated, the developer files an application for a water right with the Department of Water Resources. Water may be appropriated for beneficial use by complying with the requirements of the state water code. A prudent developer should file for a water right in the initial planning stages of development.

Water rights are not required for the following applications:

- Domestic purposes of less than 15,000 gallons per day
- Irrigation of less than one half acre
- Stock watering
- Single industrial or commercial purposes of less than 5,000 gallons per day

F. Facility Siting

The Oregon Energy Facility Siting Council (EFSC) maintains siting jurisdiction for certain energy facilities on all lands, private, state, or federally owned. Site certificates are required for a geothermal power plant with a nominal electric generating capacity of more than 25 megawatts (ORS 469.300(10)(a)) or a pipeline transporting geothermal fluids which is six inches or greater in diameter, and five miles or longer in length (ORS 469.300(e)(A)). The Attorney General has determined that construction of a geothermal pipeline six inches or greater in diameter which is intended or can reasonably be expected to have an ultimate length of five miles or longer cannot begin until a site certificate has been issued, even if the first stage of construction will be shorter than five miles. EFSC also maintains siting jurisdiction for high voltage transmission lines of more than ten miles in length with a capacity in excess of 230,000 volts.

The EFSC has the power to conduct investigations into all aspects of site selection, designate areas within the state as suitable or unsuitable for geothermal power plants, and to establish standards and promulgate rules which must be satisfied in order to obtain a site certificate. Suitable and unsuitable sites for geothermal development are listed in "Oregon Nuclear and Thermal Energy Council Statewide Task Force Report 1974".

Unlike most electrical plants, a notice of intent is not required for a geothermal electrical facility, nor is one required for a geothermal pipeline. The certification process begins by submitting a site application and the necessary fees to the EFSC (ORS 469.350 and 469.420). If the specific site is within an area designated as unsuitable, the application is not accepted. However, the unsuitability classification may be amended by the Council's own motion or petition.

Specific standards for geothermal site certificates have not been established. General standards, which apply to all energy facilities, require the following mandatory findings: need for the proposed facility based on energy demand and economic prudence, protection of public health and safety, environmental protection, beneficial use of wastes and by-products, conformance with statewide planning goals and comprehensive land-use plans, protection of historical and archaeological sites, no infringement on existing water rights, necessary expertise to operate, construct and retire the facility, reasonable assurance of obtaining the necessary funds, and identification of forseeable socioeconomic impacts in the vicinity of the proposed facility (OAR 345-74-025). Specific standards for the siting of geothermal power plants and pipelines are likely to be developed in the next few years.

When a site application has been filed, EFSC distributes copies to twelve state agencies and any local governments affected by the application. This coordination with other agencies makes siting a one-stop process for the applicant to satisfy Oregon requirements. The agencies must make provisions that they would normally make in their own permitting process in the site certification process. Any stipulations must be included as site certification conditions, and once a site certificate is granted, the agency permits or licenses must be granted as a matter of course. The applicant, however, does need to apply directly for the necessary permits and licenses. The permitting agency retains the authority to enforce the requirements of the license.

The EFSC investigates each site application to determine satisfaction of mandatory finding and may commission independent studies of any proposed aspect of the facility. Costs of studies are paid from the filing fee; however, if costs exceed the fee, all additional expenses are borne by the applicant. Any unused portion of the filing fee is returned to the applicant.

Public hearings in the affected area and elsewhere are required as deemed necessary by the EFSC. The EFSC then either approves or rejects the application. The EFSC is required to make a decision within nine months after filing of an application for a geothermal power plant and within twelve months for a pipeline. Rejection or approval of an application is subject to direct judicial review by the Supreme Court.

A site certificate authorizes the applicant to construct and operate a geothermal facility under conditions set forth in the certificate. The signed certificate binds the state and all affected political subdivisions to the approval of the site for construction and operation of the facility. All necessary permits and licenses must be issued, subject only to the conditions in a site certificate. The EFSC can only initiate changes in a site certificate based upon a clear indication of danger to the public health and safety.

The holder of a site certificate is required to pay a fee each year during construction and operation of the facility. EFSC maintains continuing authority over the site.

G. Distribution and Use

The final phase of geothermal development is to provide for use of the resource. The extent of regulations governing transport and use of geothermal energy are proportional to the scale of the end-use. An investor-owned utility selling electricity must comply with the most comprehensive set of regulations while a one-well/one-home heating system represents the low end of the regulatory continuum.

Homeowners, who propose to use a geothermal well situated on their own property for space heating, are subject to local regulations governing land use and code enforcement. In some areas, such as Klamath Falls local entities are developing geothermal management ordinances, whereby new wells will have to comply with city regulations. Developers should contact city or county governments to determine applicability of zoning ordinances and identify necessary permits such as construction and plumbing permits.

Most other types of development include a distribution system that will require obtaining the right to cross many parcels of property. Transportation corridor selection will depend on the user's ability to secure rights-of-way. Outright purchase of property is one option. Systems intended for public use, such as a municipal district heating system, may be able to exercise the power of eminent domain to purchase private land for public benefit. Both public and private users can gain the limited right to access by obtaining an easement from the property owner. Easements along existing rights-of-way, such as highways and railroads, are obtained from the appropriate government agency or private owner.

Geothermal developments on all lands involving large pipelines or high voltage transmission lines require site certificates from the Oregon Energy Facility Siting Council before construction. EFSC authority over the site continues during operation. Federal authorities are responsible for regulating electric transmission lines.

Geothermal resources developed on federal leases require permits or licenses to transmit power or transport fluids. Authorizations are issued by the BLM under provisions of the Federal Land Policy and Management Act. Land use policies of the surface management agency and environmental assessments are considered in the permitting process.

All types of land uses must conform to local regulations, including zoning ordinances, comprehensive land use plans and building, plumbing and electrical codes.

When a system is in operation, financial considerations also come into effect. If development has taken place on leased land, royalty payments will be initiated. Utility service provided for electric or direct heat use will be subject to regulations by the Public Utility Commission. The Department of Environmental Quality may also impose regulations to govern a facility's operation to protect the public interest.

VIII. GEOTHERMAL TAX CREDITS

A. Federal

Residential income tax credits are available for geothermal energy expenditures involving water temperatures over 122° F. The credit is 40 percent of the cost of geothermal equipment up to $10,000 for a miximum credit of $4,000.

Businesses may qualify for a 15 percent investment energy tax credit for geothermal equipment, in addition to the regular 10 percent investment credit.

Private geothermal developments may be able to deduct intangible drilling costs and make allowances for percentage depreciation. Contact the local Internal Revenue Service for additional information.

B. State

Residential income tax credits are available to homeowners, renters, landlords, contract purchasers and builders for the cost of geothermal systems certified prior to installation by ODOE provided temperatures are 59° F or more. The credit equals 25 percent of the actual system costs up to $1,000 per dwelling.

Property equipped with a geothermal system is exempt from ad valorem taxation.

Residential taxpayers can claim a 25 percent income tax credit, up to a maximum of $1,000, for the cost of connection to a geothermal district heating system.

Business and industry income tax credits for the installation of equipment to use geothermal energy resources are available to facilities certified by ODOE prior to construction or improvements. The credit is equal to 35 percent of the cost of the equipment and is claimed over a five-year period.

Information regarding these programs may be obtained from the Oregon Department of Energy and the State Department of Revenue.

In addition to these financial incentives, Oregon has provided the nation's first institutional impetus for municipal heating districts by enactment of model legislation allowing many communities to beneficially manage local geothermal resources.

IX. POTENTIAL GEOTHERMAL DEVELOPMENT SITES OF DESCHUTES COUNTY

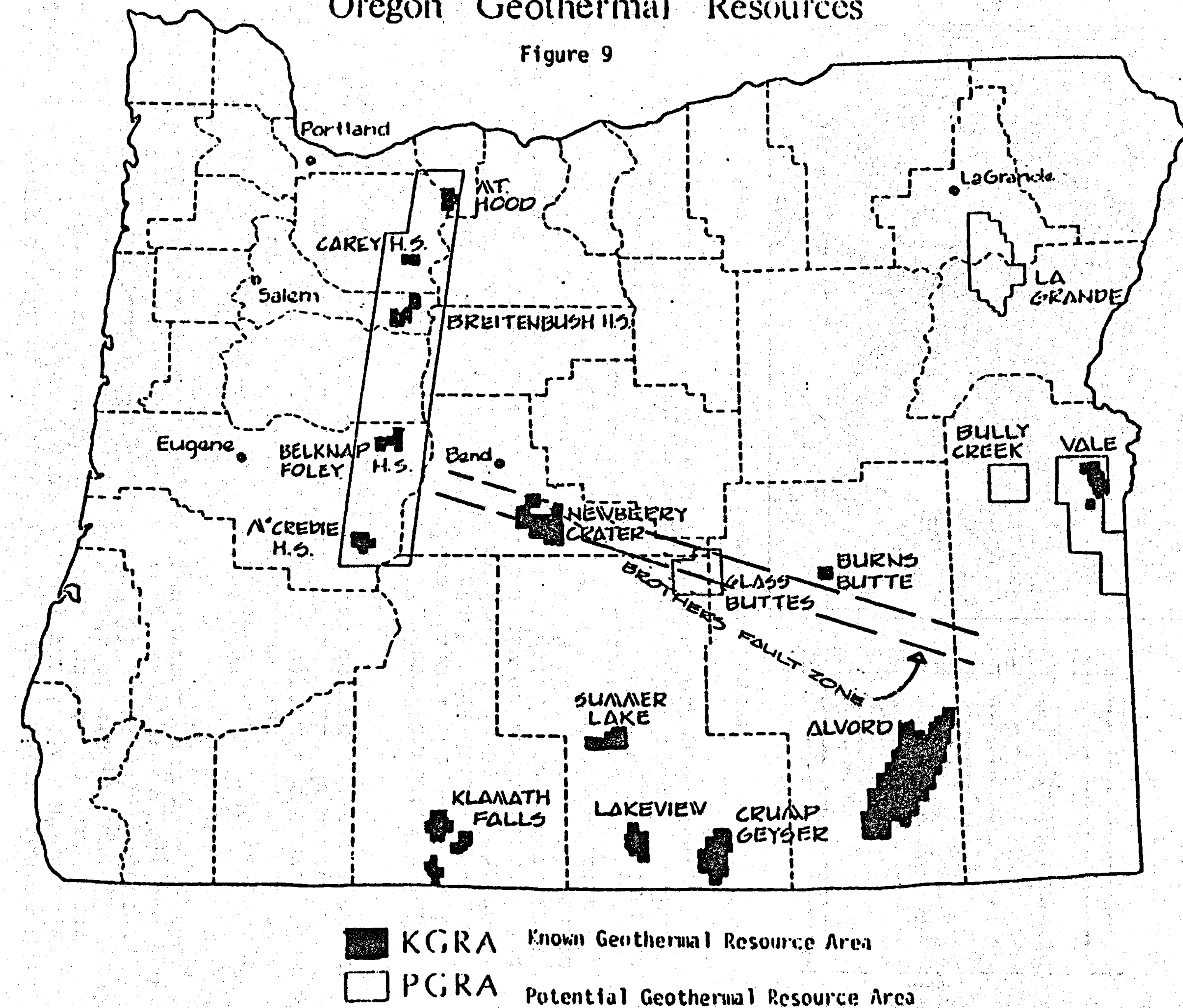
Thus far, likely geological characteristics of local geothermal sites (e.g. areas of young volcanism, hot springs, fumaroles, or warm water wells) have been described, and siting considerations for direct use and electrical generation development have been outlined. The following sections relate specifically to potential geothermal development sites in Deschutes County; results of past exploration, and plans for future development.

A. Newberry Crater and the Cascade Range

Several areas, as shown in Figure 9 , show potential in Deschutes County. Most reknown is Newberry Crater, located on Forest Service land, adjacent to the Cascade Range and the Brothers Fault Zone. Newberry is the only classified Known Geothermal Resource Area (KGRA) in Deschutes County, covering 31,284 acres. 39 A portion of the area, the caldera, is a reserved recreational area within

Oregon Geothermal Resources

Figure 9



b

the Deschutes National Forest, and has been declared "unsuitable" for geothermal development by the EFSC.

Newberry Crater has interested geothermal investigators for at least a decade. The caldera harbors young rhyolitic deposits (a fine-grained igneous rock, rich in silica) and active fumaroles. Upon the flanks of the mountain are hundreds of cinder cones, fissure vents, and pumice rings. Geological studies by Peterson and Groh (1969); MacLeod, Walker, and McKee (1975); and MacLeod and others (1981), in particular, suggest geothermal potential in the area.[40]

The most recent volcanism at Newberry occured about 1400 years ago. Thermal springs on the margins of Paulina and East Lakes, and near the large obsidian flow, are the limits of current activity. (See Figure 10.) Considering the time period over which Newberry has errupted, "the volcano should be considered dormant, but capable of future eruptions."[41]

Two test holes, the first drilled in 1977, were initiated by the U.S. Geological Survey. Caving problems plagued the Newberry 1 drilling, and when the pipe ultimately stuck, the drill pipe and the test hole were abandoned. Newberry 2 drilling began the following year, the site selection based largely on environmental and access criteria. A composite temperature profile and generalized lithologic log were kept. (See Figures 11 & 12.) As funds became available during the summers of 1979 and 1981, the second test hole was deepened. Its final depth of 932 m. (@ 3,000 ft.), reached in September 1981, showed the existence of high temperature (265° C or 510° F) geothermal fluids in permeable rock.[42] This is the highest temperature discovered in the United States.

Figure 10. Geologic Sketch Map of Newberry Crater

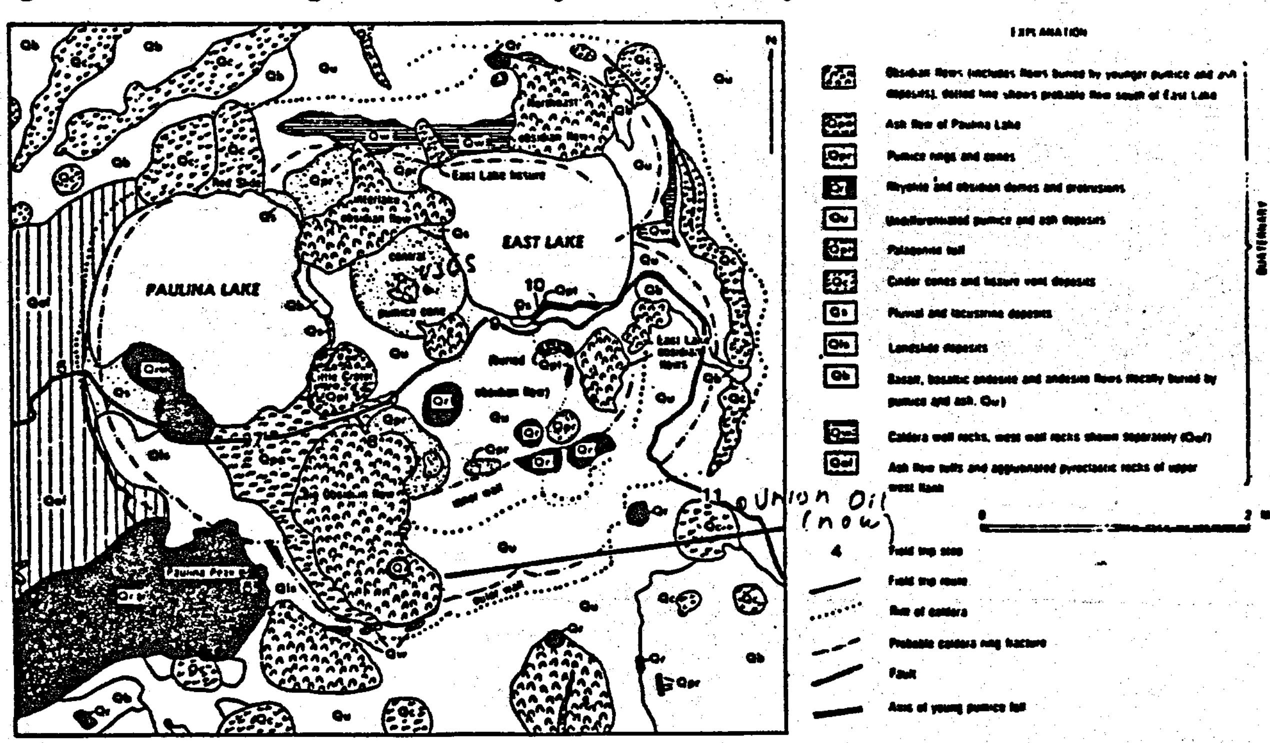
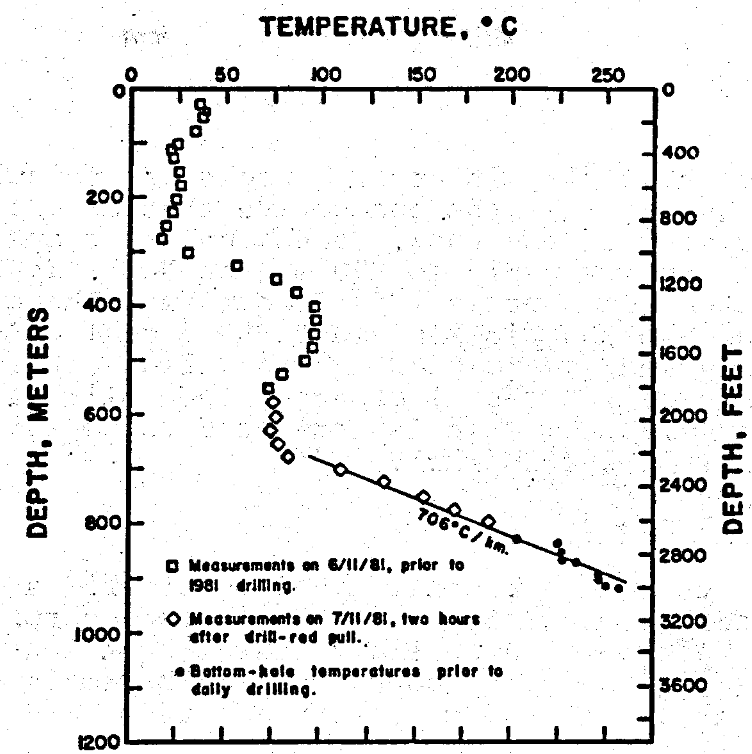
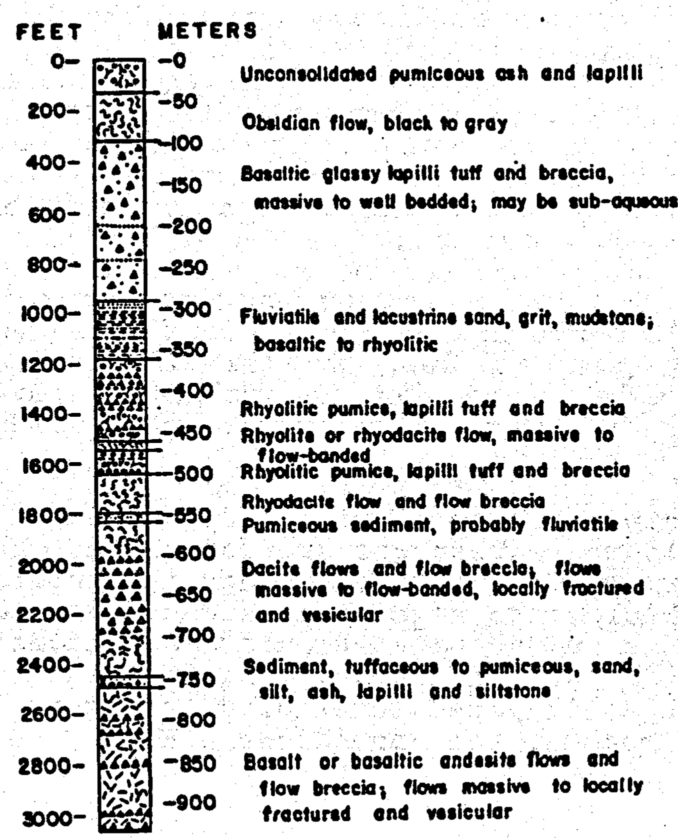


Figure 11.



Composite temperature profile of Newberry 2.

Figure 12.



Preliminary generalized lithologic log of Newberry 2. Descriptions of the upper 305 m of core were made from core in the adjacent hole, Newberry 3. rock names are based solely on visual examinations and have not been confirmed by chemical analyses.

Source: "Results of Test Drilling at Newberry Volcano, Oregon", Edward Sammel, Geothermal Resources Bulletin, December 1981.

Estimates of heat flow in crustal rocks are calculated from two measurable quantities: the conductive thermal gradient, and the thermal conductivity of the rock. Based on the temperature profiles in the depth interval 675 to 930 m. for Newberry 2 (see Figure 11), the calculated gradient is 706° C. per km. The average thermal conductivity of the zone is figured to be 5 mcal $cm^{-1}s^{-1}°K^{-1}$. Using these two figures, the conductive heat flow estimation is .35 Heat Flow Units (cal $cm^{-2}s^{-1}$) or about 1500 milliwatts per square meter ($mW\ m^{-2}$). Flow rate is estimated to be 1.5 kilograms per second (kg/s; 12,000 lbs/hr).

Conclusion: Newberry

Newberry's setting: a recently active caldera, a high-temperature thermal gradient, and high bottom-hole temperature, "strongly implies the presence of a shallow crustal heat source." [43] The nature and origin of the geothermal fluid remain matters for speculation: forms of dry steam, saturated steam, and hot water are possible.

The Newberry findings are illustrative of the geothermal prospect of the Cascade region. Edward Sammel of the U.S. Geological Survey, notes three important conclusions:

1. "The underlying high-temperature anomaly and the associated conductive thermal gradient at Newberry are masked by the flow of cooler water. Such masking is probably common in the Cascades."
2. "Preliminary analysis of drilling data indicates that permeable sections of volcanic rocks are capable of intercepting large heat flows and redistributing the heat over larger areas by lateral convection. Little of the precipitation at Newberry percolates deep beneath the crater, suggesting a lack of connected vertical permeability which prevents the surface discharge of most geothermal fluids."
3. "At Newberry a mass of hot and perhaps partly molten rock either underlies the caldera at shallow depths or heats geothermal fluids at greater depths in the crust. These findings support previous hypotheses (Smith and Shaw; 1975) that areas of young silicic volcanism are the best targets for exploration for igneous-related geothermal systems. Other hidden geothermal systems may be present in the Cascade Range." [44]

Sammel's findings and conclusions are pertinent to Deschutes County in that development prospects are favorable. He states, "the results of the Newberry drilling, even though incomplete, and, at present, ambiguous, should encourage those engaged in geothermal exploration in the Cascades and perhaps stimulate additional efforts." [45] For more information on the history of geothermal exploration of Newberry and the anticipated level of development associated with environmental impacts, see Appendices B-E.

B. Powell Butte

Located within economic piping distance of the industrial districts of three major communities in Central Oregon (Bend, 10 miles; Prineville, 5 miles; and Redmond, 5 miles) is Powell Butte. A preliminary evaluation of this area, based on geology, geophysics, geochemistry, probing of existing water wells, and drilling of eight 152 m. (500 ft.) and one 460 m. (1570 ft.) gradient holes indicate potential for 100° C (212° F) temperatures at depths of 1000 m. (3,300 ft.). The existance of elevated temperatures and useable fluids, has not, however, been proven.[46] Geothermal development in the Powell Butte area, if feasible, would likely be for direct-use application.

C. Brothers Fault Zone

The Brothers Fault Zone is a major structural lineament crossing Central Oregon from the Folly Farm area at the north end of the Steens Mountains, through Brothers, and possibly extending to the Cascades (see Figure 9). Walker (1969) suggests that "normal faults of the zone and the many volcanic vents along the zone represent only the surface manifestation of deformation on a large, deeply buried structure, the exact nature of which is not known."

Walker (1974), and MacLeod and others (1973) have noted a general progressive decrease in silicic volcanic vents from east to west along the zone. In reporting on the geothermal potential in southeastern Oregon, MacLeod and others (1975) state, "Most electric power-producing geothermal fields in the world occur in or proximal to areas of young silicic volcanic rocks. On the basis of the well-defined age progression of rhyolitic domes in southeastern Oregon, silicic bodies sufficiently young to be heat sources for geothermal systems are likely only in the vicinity of Newberry Volcano at the west end of the northern belt of domes."[47] This area is largely in Deschutes County.

In a study of the Brothers Fault Zone by DOGAMI, measured Heat Flow values and geothermal gradients showed development potential in the Harney Basin, Newberry, and Glass Butte areas. Non-competitive geothermal leases have been issued to private companies on all of these areas. (At Newberry, non-competitive leases border that area designated as a KGRA.)

D. Devils Hill Domes and Rock Mesa

No drilling has been done to verify high temperatures in the Devils Hill Domes area (near Devils Lake) and Rock Mesa (Three Sisters Wilderness Area). The geologic characteristics of these spots; young silicic volcanism like that found at Newberry, are highly indicative of geothermal resource potential.

E. Alfalfa Valley

Domestic water wells in the Alfalfa Valley, south of Powell Butte and near Millican, have demonstrated temperatures of $\pm 70^{\circ}$ F. Such temperatures supplemented by a heat pump, could be used in space heating and other low-temperature direct-use applications.

F. Other Sites

An updated geothermal resource map of Oregon compiled by DOGAMI and ODOE is due to be completed by late summer of 1982.

X. GEOTHERMAL DEVELOPMENT CONCLUSIONS AND RECOMMENDATIONS

1. Local geothermal development is likely, given a) favorable geologic environment, b) rising energy costs of conventional fuels, and c) stimulated exploration due to Newberry findings. There is potential in Deschutes County for both electric and direct-use geothermal projects. Be prepared.
2. Geothermal energy is indigenous to Oregon and cleaner than fossil fuels. The general political climate, government incentive structure, and public knowledge ought to be favorable toward environmentally sound exploration of the resource.
3. Research on state-wide geothermal resources is picking up, but solid hydrological and structural geologic data is lacking. Dave Brown of ODOE speculates that low temperature fluids may exist under Bend. The City and County should consider supporting non-electric geothermal research that, in particular, provides the area with a comparative advantage for new industrial and agricultural processes.
4. There are environmental, and social consequences of constructing power generating facilities. Often, the areas with the highest development potential are those most valued for aesthetic beauty, wildlife habitat, and as productive ecosystems. Evaluate energy need. Utilize conservation and simple solar orientation measures before developing a resource. Cooperation with involved state and federal agencies is essential.
5. Other than the urban areas, most of the areas in the County which exhibit geothermal potential are within forest management zones. The County should coordinate with the U.S. Forest Service and Bureau of Land Management in designating areas unsuitable for development, and provide a conditional use process for geothermal activities beyond the exploration phase coordinated with federal agency procedure.
6. For electrical generation projects, the County should require baseline data regarding soil, hydrology, vegetation, wildlife, air quality, and ambient noise levels. Specify that measures be taken to ensure appropriate re-vegetation, erosion control, safe disposal methods, and noise and air quality control during the length of development and operation.

7. Geothermal exploration including soil and geological mapping and low-gradient wells that have minimum impact should be outright uses in all zones of the cities and County.

8. Direct geothermal utilization should be particularly encouraged, where appropriate, given its displacement effects of fossil fuels and its low environmental impact.

9. The technology of power generation is changing very rapidly. Low-temperature (less than 200° F) power generation, already in use in Lake County may be quite pertinent to Deschutes resources. Low-temperature, small scale power generation should be encouraged in Deschutes County.

10. Acreage limits should correspond to the needs of geothermal development. Minimum acreages that are too high may inhibit small-scale projects, while maximum acreages that are too low may impede and prevent developers from securing their investments in a reservoir.

11. Given the possibility of geothermal applications in an urban setting in Deschutes County, urban planners should be prepared to work with geological researchers and consider:
    a) commercial and industrial land use designations congruous with geothermal reservoir characteristics and cascading potential; or in the case of district heating potential
    b) population density controls consistent with the cost-effectiveness of district heating services.

12. Geothermal exploration activity on Newberry Volcano has taken a dramatic leap forward as the number of well drilling applications by private firms has increased to 4 and DOGAMI and U.S.G.S. continue a geothermal mapping and resource exploration effort in the summer of 1982. These facts show that the potential and interest in geothermal development on Newberry is high. Deschutes County should work with the Geothermal Section of ODOE, the geologists and staff at DOGAMI, the U.S.F.S., and all other concerned agencies and groups to determine where geothermal development would be most favorable and how to mitigate the environmental, social, and land use impacts likely to result from such a development. Newberry Caldera is currently considered "unsuitable for development" by the EFSC. Deschutes County should coordinate with the U.S.F.S., ODOE, and other concerned agencies to determine whether or not to retain that status and reserve areas outside the caldera for geothermal development.

13. The extent of geothermal development at Newberry is bound by a number of constraints, including the underground water supply, the extent of the resource, and conflicting uses. Ralph Patt, a hydrologist with Century West Engineering speculates from his study of the LaPine Basin (see Appendix F) that there is plentiful water at depth under Newberry.[49] Being reasonably assured that there is a geothermal resource at Newberry, data and knowledge need to be attained regarding the nature and extent of the underground water system in the area.

14. As Newberry Crater supports two lakeside resorts, six campgrounds, and is a popular full-season recreational area, possible environmental impacts from electrical generation in the caldera include, smell, noise, cooling tower drift, fogging, and facility visibility. The amount of use of the area for recreation needs to be examined and meteorological monitoring needs to occur to determine wind direction and speed, relative humidity and temperature, and estimated cloud cover and fogging occuring in the course of one year. See Appendix A, Recommendations.

ENDNOTES

[1] David N. Anderson and John W. Lund, eds., Direct Utilization of Geothermal Energy: A Layman's Guide (Geothermal Resources Council Special Report No. 8, 1979), p. 12.

[2] Ibid., p.10.

[3] Debra Justus, Geothermal Resources in Oregon: Site Data Base and Development Status (Geo-Heat Utilization Center, April 1979), p. 402.

[4] Geothermal Task Force, p. 7.

[5] Mike Lane, Geothermal Resources Seminar (February 26, 1982).

[6] Geothermal Task Force, pp. 20-21.

[7] Donald W. Brown, The Potential for Hot-Dry-Rock Geothermal Energy in the Western United States (Los Alamos Scientific Laboratory, no date given), pp. 1-2.

[8] Debra Justus and others, Oregon: A Guide to Geothermal Energy Development (OIT Geo-Heat Utilization Center, June 1980), p. 41.

[9] Anderson and Lund, p. 50.

[10] Paul Lienau, "Geothermal Direct Use" (Geothermal Resources Seminar, February 26, 1982), p.2.

[11] Harold Baughman, Pacific Power and Light District Manager, Bend, Phone Conversation, March, 1982.

[12] Anderson and Lund, pp. 43-49.

[13] C.H. Bloomster, Residential Heating Costs: A Comparison of Geothermal, Solar and Conventional Resources (Battelle Northwest Laboratories, August, 1980), p. xi.

[14] John W. Lund, "Klamath Falls, Oregon, District Heating Project", Geo-Heat Bulletin (Fall 1981), p. 9.

[15] The Reykjavik geothermal system is an excellent economic model for district heating. Its cost-effectiveness is difficult to compare, however, with that of a typical U.S. site, due to different political, climatic, and social conditions. For a discussion of these issues, see Charles V. Higbee's "The Economics of Direct-Use Geothermal Energy for Process and Space Heating", Geo-Heat Center, OIT. COPE has a copy.

[16]Anderson and Lund, p. 30.

[17]Lienau, p. 3.

[18]Geothermal Task Force, p. 17.

[19]COP is calculated by dividing the Btu output of the system by the Btu input. A COP of 3.0 means that the heat output will be about three times greater than the electricity needed to operate it. Energy savings will rise with the temperature of the geothermal resource.

[20]Justus and others, p. 49.

[21]Ibid.

[22]Lienau, p. 2.

[23]Geothermal Task Force, p. 18.

[24]Paul Lienau, "Heat Pumps and Geothermal", Geo-Heat Bulletin March, 1980), p. 4.

[25]Lavonne Blucher-Nameny, "Geothermal Power Plant Siting" Geothermal Resources Seminar, February 26, 1982), p. 2.

[26]Df. Directional drilling means that a hole is drilled at an angle or series of angles to reach a bottom hole location other than directly beneath the rig. It is used when unstable surface conditions, access problems, or an immovable object prevents vertical drilling. The directional hole may be used to drill more than one subsurface location from a single surface location (especially common in offshore oil rigging), thus economizing on surface pipework and land acquisition costs. Ideal conditions for directional drilling are poorly compacted sediments with little or no faulting and simple geologic structures. Geothermal resources often occur in hard metamorphic or igneous rock in typically faulted, complex structures, making control of directional drilling difficult.

[27]Gordon P. Selfridge, "Appeal of the Decision on Geothermal Leasing in the Belknap-Foley Geothermal Area Contained in the Final Environmental Statement Prepared by R.E. Worthington of USDA--Forest Service--Willamette and Deschutes National Forests Dated September 18, 1982" (Geothermal Resources Seminar, February 26, 1982) pp. 2-3.

[28]Selfridge, pp. 3-4.

[29]The Oregon Nuclear and Thermal Energy Council State-Wide Siting Task Force Report (July, 1974), p. 6-12.

[30]Ibid, p. 1-1.

[31]Environmental Analysis Report Covering Geothermal Leasing, Fort Rock Ranger District Deschutes National Forest (October, 1975), p. 7.

[32]Ibid, p. 8.

[33]Anderson and Lund, p. 77

[34]Ibid.

[35]Two observations of the Task Force in its discussion of geothermal energy transportaion economics: 1) there is an "obvious need for a high load factor or year-around base load--either industrial, commercial, or agricultural to keep the cost of a district heating system at a minimum." 2) "The transmission cost of large volumes with high load factors would result in a small portion of the total cost." Final Report, Appendix D, p. 12.

[36]Anderson and Lund, p. 77.

[37]Bloomster, p. xviii.

[38]Bloomster, p. xvii.

[39]Justus, p. 149.

[40]Edward A. Sammel, "Results of Test Drilling at Newberry Volcano, Oregon and Some Implications for Geothermal Prospects in the Cascades" Geothermal Resources Council Bulletin (Vol. 10 #11, December 1981) p. 3.

[41]Ibid., p. 4.

[42]Ibid., p. 3.

[43]Ibid., p. 7.

[44]Ibid., pp. 7-8.

[45]Ibid., p. 8

[46]Preliminary Geology and Geothermal Resource Potential of the Powell Buttes Area, Oregon. (DOGAMI, 1980), p. 35.

[47]Justus, p. 183.

[48]Ralph Patt, Senior Hydrologist, Century West Engineering, Phone Conversation, July, 1982

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26. United States Geological Survey Circulars #647 and # 710.

APPENDIX A

ENVIRONMENTAL ASPECTS OF GEOTHERMAL POWER DEVELOPMENT AT NEWBERRY CRATER

I. Introduction

The Newberry Crater area is currently listed as unsuitable in EFSC's 1974 site suitability report. Recent exploratory drilling in the area has indicated that the site holds the potential to generate more than 25 megawatts of electricity. These findings have sparked interest in reviewing EFSC's policy on geothermal development at Newberry.

ODOE Siting staff has made a preliminarily assessment of the environmental implications of locating a generating facility in the crater. This assessment is limited because the type of facility proposed for the Newberry Crater resource is not known and insufficient environmental data is currently available for the area and the resource. The appropriate steps to develop a more definitive assessment is included in the following discussion.

Preliminary Draft

Terry Vernig, Siting Section, Oregon Department of Energy
Prepared March, 1982

III. Environmental Impacts

Most of the world's operating facilities are flash-steam systems. This is mainly because high quality (hot temperatures) resources necessary to support dry steam plants have not been found in large numbers and because the binary cycle systems are only recently being seriously developed.

The types of environmental impacts which result from a geothermal development are related to the chemical and physical make-up of the resources and to the components of the geothermal plant as well as the constraints inherent in the particular environmental setting. For instance, air emissions from a particular facility depend on the contaminants found in the geothermal fluid, emissions control devices, the cooling tower design, non-condensible gas scrubbing system, shutdown procedures, well blowout preventions, and site physical parameters such as meteorology, topography, proximity to ecologically sensitive areas, etc.

1. Air Quality

Although the composition of geothermal fluid will be different from one location to another, the following pollutants might be expected from geothermal fluids: hydrogen sulfide (H_2S), Boron (B), Ammonia (NH_3), Carbon dioxide (CO_2), Mercury (Hg), Arsenic (As), Radon (Rn^{222}), Hydrocarbon (CH_4), Methane (CH_3), Benzene, and particulates. It is noteworthy that the geology of a particular resource may not produce some of these pollutants and alternatively the resource may contain additional pollutants. Possible pollutants are listed in Appendix A.

Other air quality problems associated with geothermal plants are visibility degradation, fogging, and cooling tower drift.

H_2S

Hydrogen Sulfide (H_2S) is a traditional concern at geothermal developments. H_2S in geothermal water ranges from .18 ppm to 1600 ppm in geothermal fluids. At the Geysers, California, it averages about 222 ppm.

In the air near the Geysers, H_2S has been measured as high as 200 ppb, but is generally below 30 ppb. At Lake County Ridge/Sonoma, it reaches 100 ppb but seldom is above 30 ppb and in Cobb Valley it rarely exeeds 30 ppb.

H_2S irritates the eyes at levels of 50 ppm. H_2S is the "rotten egg" odor associated with some hot springs and some paper plants. The odor is detectable by some individuals down to 30 ppb. The odor overpowers the senses and becomes undetectable at 150-200 ppm, and it is lethal at 1,000 ppm. H_2S affects plant growth at 300 ppb, and is injurious to plants at 1-2 ppm.

H_2S has also been implicated as a source of sulfate (SO_4) particulates. This may create a regional problem, although it is difficult to predict because the rate reactions in the atmosphere are unknown. The implications for a large facility with high H_2S emissions would be to reduce the local visibility and add to acid rain regionally.

Systems are available which can easily remove 80-90% and claim to remove as much as 95 percent of H_2S at the condenser. Placement of these systems on wells should reduce H_2S to levels which ~~reduce~~ prevent problems. Development and placement of H_2S control system at the well head should prevent emissions to non-problem levels for wells requiring venting directly to atmosphere during a shutdown.

Ammonia

NH_3 must be about 1000 ppm in air to be harmful to humans. At the Geysers, it ranges between 5-1,600 ppm in the steam from the wells and averages 194. Emissions from the cooling tower are about 12 ppm, which is below the 50 ppm odor threshold. However at Salton Sea, it averages only 35 ppm by weight in the geothermal brine. Ammonia is generally thought not to be a problem at geothermal plants.

Boron

Boron can be found in high levels in geothermal fluids such as at the Geysers, where it exists in quantities up to 100 ppm in steam. However, 99 percent remains with the liquid so the greatest problem is cooling tower drift from systems cooling the geothermal fluids using direct contact condensing systems. This type of drift has produced leaf burn at the Geysers area.

Mercury

Mercury is a heavy metal often found in geothermal fluids. It is of concern because it is volatile and thus emitted to the air. About 1 g Hg/MW_t-day has been calculated as the emissions from the Geysers. This is similar to emissions from coal-fired power plants and is considered to be acceptable. No build-up of mercury has been shown near coal plants where monitoring has occurred.

Arsenic

Arsenic is also associated with geothermal fluids, but it is generally discounted as an air pollution problem because it remains in the liquid fraction. However, high level of drift prevention from cooling towers is warranted where high levels of arsenic have been found in a geothermal fluid.

No data is available at Newberry, but the Geysers have about 90-360 mg/l in the cooling tower liquid. No problems have been demonstrated from those levels.

Radon

Radon is a radioactive noble gas and has been associated with cancer in humans. It ranges from .1 to 1 pCi/l in ambient air. Geothermal wells allow better access for radon gas to be released from the earth's crust and are thus a cause of concern.

It is released at the Geysers at about 1.4 Ci/day which is about three times natural emissions in the area. This translates to .00145 WL (working level) arithmetic average and .00112 $\pm$ 2.07 WL geometric average.

Natural background is about .0013 to .0026 WL and thus radon emissions are not significant there.

Particulates

Particulates are more of a concern from the physical operations at a geothermal site, such as equipment movement and the drilling activity itself. These emissions are easily controlled by watering, grading, etc.

CO_2

CO_2 emissions are a concern because some geothermal plants may give off as much or more CO_2 as equivalent fossil-fuel plants. High values of CO_2 are often associated with volcanic activity and geothermal resources associated with them tend to be high in CO_2. Values in mg/kg (ppm) of fluid at various locations are as follows: Geysers - 290 - 30600, ave. 3260; Salton Sea - 1100 - 3800, ave. 1900; Heber - Ave. 34.6; Brawley - ave. 23500. One facility in Italy gives off 10 times as much CO_2 on a per MW basis as an equivalent fossil plant. However, most geothermal facilities give off considerably less. For instance the Geysers emit a CO_2 factor of about 10 less than an equivalent coal plant. Large amounts of CO_2 could contribute to the green house effect if very large geothermal developments come into existence and thus should be evaluated as an aspect of the trade-offs between geothermal and competing technologies.

2. Drift

Drift is the carryover of small moisture droplets in the warm air passing out of the cooling towers. The affects tend to be very localized typically only within several hundred meters of the source. The best cooling tower drift eliminators have a drift rate of about .001 percent while uncontrolled drift is about 1-2 percent of volume. For plants which use a secondary source water in the cooling loop, no problem should arise from drift unless the source water is contaminated with substances which tend to stay in solution, the carry-over can produce problems for the nearby vegetation. This occurs when the contaminates are toxic, like Boron.

3. Water Quality

Geothermal facilities from exploration through production can degrade surface and ground water supplies. During exploration contaminated fluids and residue from the drilling is brought to the surface and must be disposed of. Without proper caution, contaminants may seep into water supplies.

Drilling also has the potential to contaminate ground water supplies as different geological strata are penetrated by the drilling process. This is of particular concern in the hot rock process, where zones of rock in the geothermal resource are fractured and thus potentially produce access routes into clean aquifers for the water forced into the zone under pressure. When a groundwater aquifer is contaminated it may not be possible to reverse the problem.

During the operational phase of geothermal plants, there is potential to chemically contaminate water supplies with process geothermal fluids or blowdown from cooling towers. Often geothermal fluids have relatively high concentration of toxic substances such as heavy metals. Contamination of surface water by geothermal fluids is prevented in many conventional designs by reinjecting the fluid. Cooling tower blowdown can be treated so that the water quality is acceptable. However, sludge generated in the treatment process will require disposal.

Also since geothermal plants are relatively inefficient in their use of heat to produce electricity, there is a large amount of heat rejection required. They may need an evaporative equivalent of 50 acre-feet/MW thermal of water for cooling purposes, many times more than comparison sized fossil or nuclear fuel plants. If all this heat is disposed of in local water bodies, the potential for thermal degradation of those bodies exists.

In addition to contamination of groundwater aquifers there is also the potential to use up groundwater supplies, this can cause localized subsidence of land and dry up hot springs areas which are popular with the public. Consumption of the water also makes it unavailable for other uses.

4. Noise Pollution

At a geothermal site, one can expect noise from machinery, drill rigs, traffic, well venting and other day-to-day operations. Pressure wells can produce particularly objectionable noise, when they are tested or vented for other reasons (125 dBA at 50-100 ft.). Wilderness areas are typically around 20-30 dBA, so such noise levels can be a real intrusion. The USGS requires the max noise level at the boundary of the lease or 1/2 mile from the source, whichever is greater to be no more than 65 dBA.

Noise can be controlled by a variety of attenuating devises. Mufflers for escaping air and steam, the most intensive noise sources, range from rock-filled barrels to large expansion towers. Noise can also be attenuated by distance, barrier walls, topography, and vegetation.

5. Solid Waste

Depending on the nature of the geothermal resource, a significant solid waste disposal problem can occur. The principal effects of pollution from land-disposed geothermal fluid-derived solid or brine wastes would result from leachate run-off and/or percolation to groundwater. Solid wastes can be generated from air pollution control equipment, treatment of geothermal brine (to prepare it for further use such as for cooling water or for reinjection), drilling needs, etc.

Control methods include site selection and landfill methods and use of impervious lines. In some cases off-site disposal may be necessary.

In the case of the Raft River about 2,500 gallons of sludge per day is disposed of in a landfill. The sludge is a by-product of treatment of cooling tower makeup and blowdown water.

IV. Newberry Crater Data

Little can be definitively said about impacts at Newberry Crater given the scarcity of information available about it. However, using the data from drilling and operating experience at other facilities scenarios can be posed. The data is contained in Table C.

TABLE C

Newberry Analysis

% concentration of gases in non-condensable gases

94.0%	CO_2
1.8	H_2S
3.9	H_2
0.3	N
0.8	Methane

PPM in fluid/vapor

	i		f	
H_2S	14	(Water)	25	(water)
H_2S	16	(Vapor)	22	(vapor)
NH_3	42	(Water)	61	(water)
NH_3	100	(Vapor)	78	(Vapor)
PH	6.14	(Water)		
	5.73	(Vapor)		

Testing on water from the bore holes at Newberry indicates that H_2S is about 22 ppm in the vapor and 25 ppm in the water. This is quite low compared to the Geysers. However, H_2S is generally associated with volcanism and geology of the Newberry area is a product of that action. Also, there have been occasional reports of high H_2S in the area of the drilling. For example, puffs of H_2S have been high enought to set off alarm signals which warn employees of dangerous levels. This indicates that H_2S has the potential to be a problem despite these early data.

Ammonia has been measured at about 100 ppm in the vapor and 42 ppm in water from the test drilling holes at Newberry.

East Lake Hot Springs (near East Lake in Newberry Crater) had less than 0.9 mg/l (ppm) of Boron in its water.

No data on Hg is available from the Newberry area except for a measurement from East Lake Hot Springs which measured 0.3 mg/l.

At Newberry, tests of gases from the drill holes showed 94 percent CO_2. East Lake Hot Springs also has high CO_2 levels. No data on arsenic and radon were available in the Newberry area.

V. Discussion - Newberry Crater Area

Some data has been collected on water brought up by the drilling rig at Newberry Crater. This data indicates that the water tested may have been introduced by the drilling operation, since some of the chemical parameters resemble that of introduced drilling water. For this reason, existing data may not be very useful data to predict pollutants. The water brought up by the drilling rig, after being exposed to the Newberry geothermal reservoir, was low in pollutants as compared to the Geysers Geothermal fluid.

Limited data has been collected on the chemistry of several local hot springs near Newberry Crater. However, geologists do not believe this data is comparable to the chemistry of the Newberry geothermal source because the fluids of the system of springs are believed to be mixed with the local lake waters. Nonetheless, for discussion purposes, absent better data, data from the springs is discussed below.

1. Air Quality

The most pollutants would be expected from a system with a direct contact condenser. We have used H_2S data from the Geysers to predict a worse case scenario at Newberry since so much data is available there and H_2S has been identified as a problem. The analysis is contained in Appendix B.

In the first step, we consider Newberry as an independent meteorological unit. This may not be realistic because air movements in the crater sufficient to mix the atmosphere contents would probably dilute the parcel of air within. However if we reduce the calculated concentration by a factor of 10 in recognition of this movement out of the crater, the results still produce 100 ppb in the crater which would cause a strong nuisance odor.

If a the Gaussion Dispersion equation is used with some worse case modeling conditions and data from Geysers, we calculate that an instantaneous value of 32 ppm could be produced at East Lake Campground. This value is far above the level which could produce plant damage and 60% of the level which irritates the eyes. Even if H_2S was reduced 90% by controls, the result would be 3.2 ppm at East Lake which would produce an unpleasant odor and affect plants if it were to last for any length of time. Note also that the "uncontrolled" well (venting directly to atmosphere) would produce .8 ppm of H_2S at East Lake which would be quite unpleasant for campers.

A facility located outside the Crater area but tapped into the geothermal resource under Newberry Crater would be difficult to make any useful predictions about. Such a facility would likely be subject to very site-specific meteorological conditions producing site-specific impacts. Such complications as high terrain and downslope or upslope winds, etc. would make predictions difficult. Thus, it is important that a useful environmental data base be available to deal with these issues before any large scale development at Newberry be allowed. This base could provide the background necessary to predict the affects of any pollutants of concern which may result from Newberry.

2. Drift, Fogging and Visibility

Since campgrounds are within 1-2 km of the Newberry USGS drill site, drift from a plant there could pose a problem. This is of real concern if Boron is found in high concentrations in the geothermal fluid. Although drift would not likely directly affect these campsites, the effect of Boron on vegetation within several hundred meters of the plant would pose an aesthetic problem for campers using the campgrounds.

There could be problems in the immediate vicinity of the campgrounds at Newberry from excessive fogging and consequent reduced visibility. These problems probably would not be serious for a facility located outside the crater.

3. Water Quality

During drilling, potential contamination of local water bodies like East and Pauline Lakes should be prevented. Fluids and solids from the drilling must be properly contained and disposed of. However, the means to do so should be a straightforward process involving landfills. Depending on the nature of the material a design level of lea chate protection can be achieved.

Shallow groundwater supplies in the area are expected to be of high quality and should be protected. There are drinking water wells in the area of East Lake campground. Reinjection of the geothermal fluids and/or cooling tower blowdown will need to be into another isolated aquifer, if one exists, to avoid contamination.

It is doubtful that use of Paulina or East Lake as heat sinks would be acceptable. This leaves two options: 1) a closed-cycle system which reinjects the geothermal fluid using a cooling tower system supplied by local wells or 2) a direct contact condenser.

Either approach has disadvantages. If the direct-contact condenser is used and the geothermal fluid contains contaminates like H_2S, Boron or other air pollutants the contaminates will be released to the air as discussed earlier. If a closed system using water from an outside source is used, then large amounts of makeup water and blowdown of the cooling tower will be required. A supply of fresh makeup water will be needed but it is if it is available. For a large facility, the blowdown volume may be too much water to add to the reinjection and thus would require a discharge. Whether this discharge could be accommodated will require better site-specific information on the type of facility which would be developed and water quality data of the geothermal fluid.

4. Water Sources

The source of available water for a geothermal facility would likely be wells drilled into shallow aquifers near the drill site but isolated from the geothermal resource. It is believed that these wells can supply enough water to provide the make-up for a system with a closed loop cooling tower. If a direct contact condenser is used, the geothermal resource can be used as make-up directly. Alternately the geothermal resource may be treated and used for make-up. The latter would produce sludges which would need to be disposed of. At Raft River, Idaho, the small geothermal binary cycle plant there generates 2,500 gallons per day of sludge in this manner.

5. Noise Pollution

It is expected that noise pollution also would be of major concern. Newberry is a recreational and sensitive area. It is expected that any intrusion producing excessive noise levels will be looked upon with disfavor. It can be expected that extraordinary precautions to prevent noise pollution would be necessary at Newberry.

However, noise control technology to do so is available.

6. Aesthetic Concerns

Finally, there is the aesthetic pollution of visually seeing the plant, steam plumes, etc. Industry's presence in an area where many people go to get away from those things could produce major public objections to the plant. These "aesthetic" values have always been difficult to measure.

The amount of use of the area for recreation needs to be examined. This includes study to evaluate if a geothermal facility would seriously impair that recreation in ways other than pollutants.

VI. Recommendations

1. A chemical sampling program which will do a complete chemical analysis on fliuds from the Newberry bore holes. Test for H_2S, Hg, NH_3, Boron, Arsenic, CO_2, radon gas and other heavy metals (See Appendix A). This sampling should be conducted on five different days, two samples each day.

2. Atmospheric soundings, measuring wind speed and direction, temperature and relative humidity. At a minimum, twice daily for several weeks.

3. Meteorological monitors at the surface. Stations at the crater rim and at the crater floor which measure i) relative humidity or dew point, ii) temperature, iii) wind speed, and iv) precipitation. The station at the point of emission should be collecting data 50-200 feet above the ground. Data collected for one year.

4. An attempt should be made to estimate cloud cover and fogging over the course of one year.

5. A tally of recreational use of the Newberry area should be conducted to determine who may be impacted.

APPENDIX B

Geothermal Potential of Newberry Crater and Conflicts of Development with Current State Policy

Location and Geology

Newberry Crater is one of the largest volcanoes in the North American continent (covering 500 square miles) and is located in west-central Oregon. Though the summit crater of the mountain itself is located 20 air miles southeast of Bend, Oregon, cinder cones formed on the flanks of the volcano can be found within the city limits. Faults, folds, lava flows, cinder cones, and other goelogic features subordinate to the mountain extend from Bend to state highway 31, some 309 miles to the south.

Newberry Crater is unique geologically and geographically. It is of a type of volcano classified as "silicic", which means the primary lavas under the mountain are very viscous in nature. However, surrounding the central "silicic" vent are numerous cinder cones which are small volcanic forms classified as "mafic", which means the lavas extruded from these vents are very fluid in nature. This mix of lava types makes Newberry Crater geologically unique. In addition, the summit crater is occupied by three clear water lakes which have been classified as alpine in nature because they are at an elevation of 6,300 feet. What makes them unique is that even though they alpine, the area surrounding the mountain is a high desert environment.

Even though the volcano erupted only 1,200 years ago, there is no seismicity associated with the mountain. No eruptions are imminent, and geothermal development would not trigger such an event.

History of Geothermal Activity

The first federal lease applications in the United States were filed in the early 1960's on Newberry Crater. As of now, no lease applications have been processed. The Portland office of the U.S. Bureau of Land Management hopes to have leased on the flanks of the volcano issued by November, 1982 and the leases on the summit crater, which will be competitive in nature and will require active bidding, issued by March, 1983. Both of these lease sales are expected to gross several millions of dollars.

Exploration offorts on Newberry Crater have been carried out mainly by the United States Geological Survey (USGS) under their geothermal research program. They have performed; detailed geological mapping and research, sampling of the local lakes, hot springs and fumaroles;

Source: Memo to Mock Legislative Interim Committee. Dave Brown, ODOE, March 15, 1982.

several geophysical studies, including studying the earth's magnetic and gravitational field on the mountain; and the drilling of shallow temperature gradient holes.

The deepest hole, of three the USGS drilled, was completed during the summer of 1981 to a total depth of 3,057 feet. At that depth the temperature in a test hole was 510° F which makes it the highest temperature recorded in a test hole in the continental United States. This temperature can be gauged against producing steam wells at the Geysers Geothermal Field near San Francisco where temperatures of 480° F have been recorded at 8,000 to 10,000 foot depths. Thus, Newberry Crater has temperatures higher than the largest geothermal field in the world at less than one-half the drilling depth. And indications are, the temperatures will undoubtedly be higher at depth.

The USGS hole at Newberry Crater produced considerable steam and gases over a one day flow test. However, after several discussions with the USGS it is unclear, from inspection of chemical analyses of the produced fluids, whether the fluid is formational fluid, or merely a return of fluid used to drill the hole.

Conflicts with Development

Oregon Department of Geology and Mineral Industries (DOGAMI) has made preliminary calculations of the theoretical potential for electrical generation at Newberry. These calculations, which are based on the above drill hole data and available USGS geological data, can be assumed to be a minimum value and are presented below as Table 1. The values for electrical energy are given in electrical megawatts based on a 30-year life span.

Two things are immediately obvious from the information contained in Table 1. First, the new data from the Newberry 2 test well more than double the theoretical electrical generation potential of the caldera portion of the Newberry Volcano; and second, there may be enormous potential outside the caldera proper. The 15,837 MWe estimate for the entire gravity anomaly associated with the volcano is, of course, an absolute maximum. It is based on the assumptions that (1) the intrusive causing the gravity anomaly is everywhere providing heat at the rate found in the Newberry 2 test hole, and (2) the reservoir is everywhere 2.07 km thick (i.e., the top of the reservoir lies everywhere at a depth of approximately 1 km). While these assumptions are certainly not completely valid, they provide a useful upper limit on the potential of the volcano. The extent to which they are in error and the true geothermal potential of the volcano can be determined only by exploratory drilling.

These figures indicate even at the lowest value (case 2) there is potential for electrical power generation exceeding Trojan Nuclear Power Plant, or Bonneville Dam including its second power house. Clearly, when the flanks of the volcano are considered (case 4), the potential for power generation is enormous.

Table 1. Estimates of Volume, Temperature, and Energies of Newberry Crater

Source of Calculation	Reservoir Volume (km^3)	Reservoir Temperature (° C)	Reservoir Thermal Energy (10^{18} J)	Electrical Ene Electrical Energy (MWe for 30 years)
1. USGS Circ. 790[1]	47 $\pm$ 16	230 $\pm$ 20	27 $\pm$ 10	740
2. DOGAMI[2]	47	312.5	38	1,316
3. DOGAMI[3]	66	312.5	53	1,843
4. DOGAMI[4]	569	312.5	457	15,837

[1]Brook and others, 1979, p. 54

[2]Oregon Department of Geology and Mineral Industries (DOGAMI) calculation, using reservoir volume estimate of Brook and other (1979) and new temperature data from Newberry 2 Hole.

[3]DOGAMI calculation using increases in both reservoir temperature and volume from Newberry 2 hole (Sammel, 1981).

[4]DOGAMI calculation using volume estimate based on gravity work of Williams and Finn (1981).

Even though the above figures are obviously impressive and construction costs for geothermal steam plants are very low (approximately $850/kw installed versus $1500/kw for nuclear), at present no development of geothermal resources is allowed in the crater or on the surrounding flanks. This is because in 1974 the Oregon House of Representatives passed a joint resolution (HJR 31) which directed the Nuclear Thermal Energy Council, which was the forerunner of the Energy Facility Siting Council (EFSC), to declare Newberry Crater as "unsuitable" for geothermal development. The reasons behind the resolution were the unique geologic character of the volcano, the visual beauty, the heavy recreational use of the entire area, and the alleged negative impact a geothermal power plant would have on the area.

The Administrative Rules under which the EFSC functions and which defines areas which are "unsuitable" for geothermal development allow for re-examination of the designation when "...investigations are concerned with specific sites, detailed information may result in reclassification of areas. Such reclassification would make allowance for change resulting from advanced technology."

Clearly, there has been a "change resulting from advanced technology" due to the recent discovery of elevated temperatures at shallow depths beneath Newberry Crater. And it is timely that this committee is re-evaluating those changes versus the present state policy and what it may mean for the development of renewable energy resources in the State of Oregon.

APPENDIX C

SITE: NEWBERRY CRATER KGRA, OREGON

Source: Geothermal Resources in Oregon: Site Data Base and Development Status. Debra Justus. OIT Geo-Heat Utilization Center, April, 1979.

NEWBERRY CRATER

The Newberry Crater KGRA covers 31,284 acres in Deschutes County in central Oregon, T.21S., R.13E., W.M. The KGRA is centered on Newberry Volcano, a broad Quaternary shield volcano rising 1,200 m. above the lava plains. Two large lakes, East and Paulina, occupy the summit caldera. The floor of the crater is marked by young volcanic features such as cinder cones, tuff rings and obsidian flows. Elevations range from 1,315 m. at Paulina Creek to 2,434 m. at Paulina Peak and vegetation ranges from sagebrush and juniper to lodgepole and ponderosa pine forest according to elevation.

Newberry Crater has been classified as a KGRA based primarily on the geology of the area. It is an area of young silicic volcanism, and lies between two major regional fault systems: High Cascades and Brothers fault zone. The youngest dated silicic rock is 1,300 years and recent activity along the faults is evident (Peterson and Groh, 1969). Much of the shield volcano was developed during Pleistocene times and although the date of caldera formation is uncertain, flows and pyroclastics are not covered by Mazama ash and therefore are less than 6,600 years old (Higgins and Waters, 1967).

Underground heat sources are indicated by the hot springs situated along the northeast shore of Paulina Lake and the south shore of East Lake. Temperatures of the springs are fairly low, 57.3°C and 62°C respectively, but these readings are influenced by cooler water in the lakes.

A heat flow and temperature gradient study also suggests the existence of a potentially valuable geothermal resource. Although measurements were inconclusive due to shallow well depths and the effects of migrating groundwater, still Newberry Volcano was one of three areas near the Brothers fault zone that was identified as being especially promising for geothermal development.

A U.S. Geological Survey report (MacLeod and others, 1975) suggests that Newberry Volcano has significant potential based on the probability of a shallow heat source situated directly under the caldera. The U.S.G.S. is conducting an on-going temperature gradient drilling program including holes within the caldera and on the flanks of the volcano.

Energy needs in the immediate area which could be satisfied with non-electric applications of geothermal resources are limited. Except for the families operating the two resorts the area is essentially uninhabited. Extensive recreation use is made, primarily day-use and outdoor activities which do not require structured facilities.

However, the Bend area is one of the fastest growing in the state. Bend, about 40 km north of Newberry Volcano, is the largest urban center east of the Cascade Mountains. The estimated 1978 population is 17,100. Timber production and recreation are two of the most important aspects of the area's economy.

A large part of the growth in Deschutes County is occurring in the area between Bend and LaPine which is about 20 km southeast of Newberry Crater. Much of the development is in the form of subdivisions to provide housing for year-round residents and recreationists. Reportedly, 15,000 undeveloped lots have been sold in the Bend area.

Recreation is a year-round business. In the winter large numbers of people are attracted to the area for skiing at Mt. Bachelor and snow-mobiling and cross-country skiing in the Deschutes National Forest. In the summer the high lakes country and forest areas are heavily used for fishing, hiking, camping and other outdoor activities.

Clearly there could be a large demand for geothermal energy to be utilized in the wood products industry and for district space heating if a resource were readily available. The problems are: distance from the site and insufficient data on the true nature of the resource. If a resource suitable for non-electric applications was discovered within the crater, pumping hot water up and out of the volcano could prove too costly to justify a project in the Bend area. The flanks of the volcano appear to offer some potential for geothermal development but less than within the volcano itself.

The potential for electric generation from geothermal reservoirs at Newberry Volcano is not well known since the resource has yet to be defined. But several major oil companies, who are assumed to be interested in power production, have filed non-competitive lease applications on a considerable portion of land in and around Newberry Volcano. Lease applications in total, including private companies and individuals, cover about 264,000 acres in a 9-11 km. radius of the volcano.

Processing of lease applications awaits completion of an Environmental Analysis Report addressing non-competitive leasing in the Newberry area. The Deschutes National Forest is currently preparing the document which has a target date of early 1979 for publication in draft form. A complete Environmental Impact Statement (EIS) will be compiled for considering competitive leasing within Newberry Crater. The EIS is planned for release in fiscal year 1980. As well, the U.S. Geological Survey has tentatively scheduled a December 1980 lease sale for tracts in the KGRA.

The leasing situation is not the only barrier to geothermal exploration and development at Newberry Crater. Environmental considerations are also a controlling factor. Of primary concern are the area's geologic uniqueness, roadless qualities, recreational opportunities and scenic values.

In 1975 the Oregon Legislature passed House Joint Resoluation 31 which directed the Nuclear and Thermal Energy Council (now the Energy Facility Siting Council) to designate 39,000 acres, including Newberry Crater and the Lava Cast Forest geologic interest area, as unsuitable for thermal power plants. Environmental groups have also expressed concern about potential adverse impacts from geothermal development at Newberry Crater.

It seems evident that any geothermal development at Newbery Crater will have to be compatible with environmental factors and conform to existing land uses. Otherwise state regulatory bodies and public pressure will not likely preclude such activities.

SITE DATA SUMMARY

SITE: NEWBERRY CRATER KGRA

..Physical Reservoir Date

..Temperature °C
Surface: 62°C

..Site Land Status

Total Acres - 31,284 (Federal)
Total Acres Lease - 0 (Federal)

..Geothermal Development Status:

A temperature gradient drilling program was begun in 1977 by the U.S. Geological Survey and is expected to continue into 1979.

..Local and State Attitude Toward Geothermal Development:

Highly sensitive.
House Joint Resolution 31 (1975) directed the Nuclear and Thermal Energy Council to designate 39,000 acres including Newberry Crater and Lava Cast Forest as unsuitable for thermal power plants.

..Land Use and Population:

The crater is essentially uninhabited, but is heavily used for recreation and timber production.
Deschutes County area is one of the most rapidly expanding regions in Oregon. Timber production, recreation, agriculture and livestock raising are the primary economic activities.

SITE LOCATION AND PHYSICAL DESCRIPTION

SITE: NEWBERRY CRATER KGRA

..Latitude: 43° 44' N

..Longitude: 121° 14' W

..Rectilinear: Secs. 11, 13, 14, 15, 21-28, 33-36, T.21S., R.12E; W.M.
Secs. 1-4, 9-12, T.22S., R.12E.;
Secs. 10, 15-22, 27-34, T.21S., R.13E.;
Secs. 3-10, T.22S., R.13E.

..County: Deschutes

..Adjacent Counties: Lane, Jefferson, Crook, Lake, Klamath

..Map Reference: U.S.G.S. topographic - Paulina Peak
AMS - Crescent 1:250,000

..Topography

Newberry Volcano is a broad shield volcano, elevation 2,440 meters, rising 1,219 meters above the basalt plateus of central Oregon. The volcano is marked by a large caldera which contains East and Paulina Lakes. The lakes are separated by cinder cones and a large obsidian flow. Elevations at the lakes are: 1,930 m. (6,331 ft.) Paulina Lake and 1,942 m. (6,371 ft.) at East Lake. The overall terrain is varied ranging from rolling topography with many cinder cones and lava fields to steep bluffs. Elevations range from 1,315 m. (4,314 ft.) on Paulina Creek to 2,434 m. (7,985 ft.) at Paulina Peak, Paulina Creek drains the caldera to the west.

..Present Land Use: Heavily used recreation and timber production area.

..Future Land Use Plans:

Future land use is expected to continue recreation and forest products focus.

..Aesthetics:

Unique attractions within the area give a high aesthetic value. Paulina Peak is a significant viewpoint. Hiking trails and fishing in the lakes within the crater are popular recreational activities. Young volcanism has resulted in a variety of interesting geologic features such as: lava tubes, obsidian flows, pumice deposits, cinder cones and ash flow sheets. (1)

..Historical/Archaeological Significance:

Three known sites have been nominated to the National Register of Historic Places. Others may be present.
Charcoal Cave
Pipeline Archaeological Site (1)
Paulina Lake Archaeological Site

GEOLOGICAL/GEOPHYSICAL DESCRIPTION

SITE: NEWBERRY CRATER KGRA

..Geologic Description:

Newberry Volcano is a broad shield volcano rising about 1,200 meters above the basalt plateus of central Oregon. The basal diameter is approximately 32 km.

The volcano has a summit caldera which contains two large lakes, Paulina and East Lakes. The lakes are separated by obsidian flows, pumice cones and basaltic tuff rings. Paulina Creek, flowing west to the Deschutes River, is the only surface drainage for the crater.

The caldera is an oval depression in the summit of Newberry Volcano about 8 km long and 6.4 km wide. It was formed as lavas beneath the volcano were erupted withdrawing support which caused subsidence along concentric faults. These ring fractures are marked by cinder and spatter cones.

Cinder cones and small vents numbering more than 150 are also located on the flanks of the volcano, primarily on the southeast and northwest sides. They generally trend N.25^{o} W.

Numerous northwest-trending faults are apparent on Newberry Volcano itself and within the crater. The most recent and obvious of these is a zone of en echelon faults trending N.30^{o} W. beginning in the caldera at the fissure at East Lake and extending about 24 km to slightly north of Lava Butte. At least eight separate basaltic lava flaws have occurred along this "northwest rift zone" (Peterson and Groh).

Much of the shield volcano was developed during Pleistocene times with eruptions continuing until a few centuries ago. The early flows were basalt which were followed by thick sheets of rhyolite and later with basaltic ash. After the flanks of the volcano had reached their maximum height, basaltic eruptions removed support beneath the summit causing its collapse, thereby forming Newberry Crater.

A variety of features including pumice cones, rhyolite domes, basaltic tuff rings and obsidian flows were formed in the crater after its creation. Most of these landforms are less than 12,000 years old. The Big Obsidian Flow southeast of Paulina Lake is the youngest feature with an age of approximately 1,200 years.

Newberry Volcano is located between two regional fault systems; the north-sourth trending High Cascades and the Brothers fault zone. The Brothers fault zone extends from the Steens Mountains in southeast Oregon to near Bend generally trending N.60° W. Near Newberry Volcano the zone appears to take a turn and head in a N.35° W trending direction towards Sisters. The implications of these tectonic features in regards to their association with Newberry Volcano is not well understood. (4)(7)(8)(9)(10)

RESERVOIR CHARACTERISTICS

SITE: NEWBERRY CRATER KGRA

..Reservoir Temperature

..Surface: 62°C (2)

..Subsurface: No estimates available

..Geochemical - Chemical concentrations in the hot springs water is very similar to those of normal groundwater, thereby preventing the application of geothermometry techniques.

Waring lists the following spring temperature:
East Lake - 61°C (141°F)
Paulina Lake - 21°C (70°F) (3)

..Fluid Chemsitry:

	East Lake Hot Springs	
Specific conductance (micromhos)	396	
Silicia	36	
Calcium	38	
Magnesium	16	
Sodium	32	
Potassium	3.8	(Units mg/l)
Lithium	.01	
Sulfate	58	
Chloride	0.4	
Flouride	0.2	
Boron	.93	

Composition of Escaping Gases (in volume percent)

Carbon Dioxide	56
Nitrogen	30
Methane	9
Oxygen and Argon	6

East Lake Hot Springs - T.21S., R.13E., Section 29

LAND OWNERSHIP AND LEASING

SITE: NEWBERRY CRATER KGRA

..Land Ownership - Federal ownership managed by the Deschutes National Forest.

TOTAL AREA (KGRA)	-	31,284 acres
FEDERAL	-	31,284 acres

..Land Leased - FEDERAL (Acres) - 0

..Highest Prices Leases (Dollars/Acre) - N/A

..Lessee - N/A

..Tentative Lease Sale Dates: 12/80

..Number of Sales Offered But No Bids: N/A

..Number of Bids Rejected (Resulting in No Lease): N/A

..Summary of Leasing Status and Needs:

An environmental impact statement covering Newberry Crater must be completed before competitive leasing can take place. Approximately 117 non-competitive lease applications have been filed on 264,000 acres in a 9-11 km radius of the rim of Newberry Crater. Processing of these applications should begin in 1979 following approval of the EAR for non-competitive leasing. Lease applicants include Phillips Petroleum, Union Oil, Chevron, California Geothermal, Sunoco and others.

GEOTHERMAL DEVELOPMENT STATUS

SITE: NEWBERRY CRATER KGRA

..Present Development Status: There are no current developments.

Industry interest in exploring for geothermal resources, as evidenced by filing of lease applications, is extremely high.

..Exploration Activities:

The U.S. Geological Survey has selected three sites; one in the crater, one on the southwest side of the crater and another on the northeast flank of the crater, for drilling temperature gradient holes. The northeast location was drilled in 1977 to a depth of 384 meters. A stuck drill pipe prevented further drilling. In September 1978 the hole inside the crater was drilled to 304 meters. Reported bottom hole temperature shortly after drilling ceased was about 90°C. (6) It is expected that the well will be drilled to a depth of 609 meters in 1979. Dr. Ed Sammel is directing the project for the U.S.G.S.

The Oregon Department of Geology and Mineral Industries measured temperature gradients in five drilled holes and four water wells near Newberry Volcano and Bend. None of the sites were on the volcano. Data from these wells are available in the cited references.X

One well located in T.21S., R.11E., Section 25 west of Paulina Lake had an average gradient from 12.5-35 meters of 39.6°C/km. The gradient increased with depth and was found to be 65° C/km from 27.5-35 meters. The estimated heat flow is 2.4 HFU (Heat Flow Units). This value is of low reliability because of the shallow depth of the hole and possible effects of groundwater migration.

The Brothers Fault Zone heat flow study suggests that Newberry Volcano is one of three areas along the lineament which appear particularly promising for geothermal development. Heat flow measurements in the area are not reliable in holes less than 152 meters due to groundwater effects. The study states that holes in basalt will need to be at least 300 meters in order to obtain reliable data. The need for further testing seems apparent. (5) (11)

..Projected or Planned Exploration:

Further temperature gradient drilling by the U.S.G.S. in 1979.

INSTITUTIONAL CONSIDERATIONS

SITE: NEWBERRY CRATER KGRA

..Institutional Requirements:

Oregon House Joint Resoluation 31 (1975) directed the Nuclear and Thermal Energy Council (now the Energy Facility Siting Council) to designate Newberry Crater, Lava Cast Forest and contiguous roadless areas as unsuitable for thermal power plants. This area covers 39,000 acres.
Exploration can apparently take place outside the 11,000 acres of the caldera.

..Agency and Public Attitudes:

Attitudes, as expressed by Oregon Legislature, are negative towards geothermal development in Newberry Crater.

..Status of Requirements (i.e., EIA/EIS Requirements):

An Environmental Analysis Report covering geothermal leasing for the Ft. Rock Ranger District was issued in October 1975. This EAR did not address geothermal leasing in Newberry Crater.
The Deschutes National Forest is planning to do an Environmental Impact Statement for geothermal leasing in Newberry Crater. Release date is targeted for fiscal year 1980.
An Environmental Analysis Report addressing non-competitive leasing in the Newberry area is being compiled by the Forest Service. A draft copy should be available in early 1979.

Two areas totally surrounding East and Paulina Lakes on Newberry Volcano are being examined by the U.S. Forest Service as part of the RARE II process for possible inclusion in the National Wilderness Preservation System. As classified in the Oregon Supplement to the Draft Environmental Statement - Roadless Area Review and Evaluation, neither area has producing, proven or possible geothermal resources.

The areas are as follows:

Area	Area Code	Administrative District	Total Acreage
North Paulina	6196	Deschutes National Forest Ft. Rock Ranger District	22,200
South Paulina	6197	Ft. Rock Ranger District	10,200

(12)

ENVIRONMENTAL FACTORS

SITE: NEWBERRY CRATER KGRA

..CLIMATE

..Precipitation (Annual): 64-76 cm

Average mid winter snow depth is about 2-3 meters. Snow depth in Newberry Crater has been measured as high as 5 meters.

..Average Temperature: 8.6°C (47.5°F)

Minimum: -59° C (-25° F)
Maximum: 40.5° C (105° F)

..AIR QUALITY: Generally high due to remoteness from industrial and population centers.

..WATER QUALITY:

Quality is high but there is hardly any surface water due to the permeability of volcanic materials at the surface and subsurface. Paulina Creek flowing west to the Deschutes River from Paulina Lake is the only stream in the crater.

..NOISE: Low levels.

..BIOLOGICAL

..Dominant Flora:

Mixed lodgepole pine, ponderosa pine and white fir forest assocation.
Non-forested areas - Juniper, sagebrush and rabbit brush.

..Dominant Fauna: Mule deer, Black bear, cougar, coyote, squirrel,
procupine, pocket gophers and others.
Numerous bird species.
Big game such as deer, antelope, elk and bear may water within the crater, but must go outside to feed. (1)

..Endangered Species

Flora: Unknown
Fauna: Northern bald eagle (Haliaeetus Levcocephalus alascanus)

TRANSPORTATION AND UTILITIES

SITE: NEWBERRY CRATER KGRA

..Utility or Energy Transmission Corridors and Facilities

Two Bonneville Power Administration transmission lines are in the vicinity, one to the east and one on the west side of Newberry Crater. A private utility transmission line parallels the BPA line east of the caldera.

Natural gas pipeline parallels Highway 97. (Cascade Natural Gas Co.)

..Transportation Corridors or Facilities

U.S. Highway 97 connects the Columbia River area to the north with Klamath Falls and California to the south.

U.S. Highway 20 runs east-west between the Bend-Sisters area to the eastern border of the state at Ontario.

Others: State Route 31, Century Drive Scenic Loop (Cascade Lakes Highway), numerous Forest Service and logging roads.

Burlington Northern rail line runs north-south near Highway 97.

POPULATION

SITE: NEWBERRY CRATER KGRA

..General Description of Population

Newberry Crater is essentially uninhabited except for families operating the two resort facilities. However, the Deschutes County area is one of the fastest growing regions in the state. Between 1960 and 1970 the Deschutes County rural population increased 66%. Much of this growth has taken place in the Bend area between Sisters and LaPine. Developments range from small wooded lots to large planned communities such as Sunriver and Black Butte Ranch. Subdivisions are becoming more common and growth is expected to continue as 15,000 undeveloped lots have been sold. Recreationist and retirees are particularly attracted to the Bend area. (1) (4)

Population Centers:

Bend	-	17,100 approximately 40 km north of Newberry Crater.
La Pine	-	20 km SE
Sunriver	-	30 km NW
Redmond	-	6,450 about 66 km north of Newberry Crater.

..Economics

..Present Land Use:

Deschutes County has a diversified economy based primarily on timber production, agriculture, livestock raising and recreation. Forest products manufacturing is increasing. Land use at Newberry Crater is focused on extensive recreational use and timber management by the Deschutes National Forest.

..Future Land Use:

No major land use changes in the caldera are anticipated.
Continued growth of residential developments in surrounding areas is apparent.

APPENDIX D

An estimate of the geothermal potential of Newberry Volcano, Oregon

by Gerald L. Black, Oregon Department of Geology and Mineral Industries

INTRODUCTION

Newberry Volcano is a large Quaternary volcano located in central Oregon about 32 km (20 mi) southeast of Bend (Figure 1). It covers an area of nearly 1,300 km² (500 mi²) and, according to MacLeod and others (1981), consists of "basalt and basaltic andesite flows, andesitic to rhyolitic ash-flow and air-fall tuffs and other types of pyroclastic deposits, dacite to rhyolite domes and flows, and alluvial sediments produced during periods of erosion." More than 400 cinder cones dot the flanks of the volcano. The most recent activity occurred approximately 1,400 years ago in the summit caldera and resulted in the formation of the Big Obsidian Flow. The volcano is considered dormant but capable of future eruptions (MacLeod and others, 1981).

During the summer of 1981, the Geothermal Research Program of the U.S. Geological Survey (USGS) completed drilling a 930-m (3,051-ft) test hole (Newberry 2) in the summit caldera of Newberry Volcano. Fluids at a temperature of 265° C (509° F) were encountered in permeable rocks in the bottom 1.8 m (6 ft) of the hole (Sammel, 1981).

The intent of this paper is to provide a general update of the estimated geothermal electrical generation potential of the volcano, based on refinements in the estimates of reservoir temperature and volume. The temperature refinements are based on considerations of the relative validity of various methods of geothermometry and on data obtained from the USGS drill hole. The volume refinements are based on USGS drill-hole data and on gravity modeling recently completed in the area by the USGS (Williams and Finn, 1981).

PREVIOUS RESERVOIR ESTIMATES

In USGS Circular 790, Brook and others (1979) estimate the mean reservoir thermal energy of Newberry to be $27 \pm 10 \times 10^{18}$ J (joules), resulting in a theoretical electrical generation potential of 740 MWe (megawatts electric). These estimates are based upon a mean reservoir temperature of 230° ± 20° C and a mean reservoir volume of 47 ± 16 km³.

GEOTHERMOMETRY

Normally, chemical geothermometers are used to estimate the reservoir temperatures of geothermal systems. These temperature-dependent water-rock reactions, however, are valid only for hot-water systems, as the chemical constituents used in the calculations (Na, K, Ca, Mg, SiO_2, Cl) are not soluble in steam (White, 1973). Although there are two hot springs in the summit caldera of Newberry Volcano (East Lake and Paulina Hot Springs), their chemistry is not considered a reliable indicator of reservoir temperature. Both springs issue from lapilli tuffs along the shores of lakes occupying the caldera floor and are characterized by low flow rates and high silica concentrations. Mariner and others (1980) believe that (1) the springs are probably drowned volcanic gas vents, and (2) the solution of glass from the lapilli tuffs could account for observed high silica and magnesium concentrations which, in turn, would be a function of the length of time that heated lake waters were in contact with the tuffs. A warm well located in Little Crater Campground (between East and Paulina Lakes) probably suffers from the same limitations.

Because of the uncertainty surrounding the geothermometers derived from the chemistry of East Lake and Paulina Hot Springs, Brook and others (1979) infer a reservoir temperature of 230° ± 20° C, based on temperatures estimated for other Quaternary volcanoes. Since results of the Newberry 2 test hole (Figure 2) indicate a minimum temperature of 265° C at the top of the reservoir, the problem becomes one of estimating maximum and mean reservoir temperatures. One possible solution is to use the chemical geothermometers while keeping in mind their limitations. Unfortunately, the Na-K, Na-K-Ca, and SiO_2 geothermometers all indicate minimum reservoir

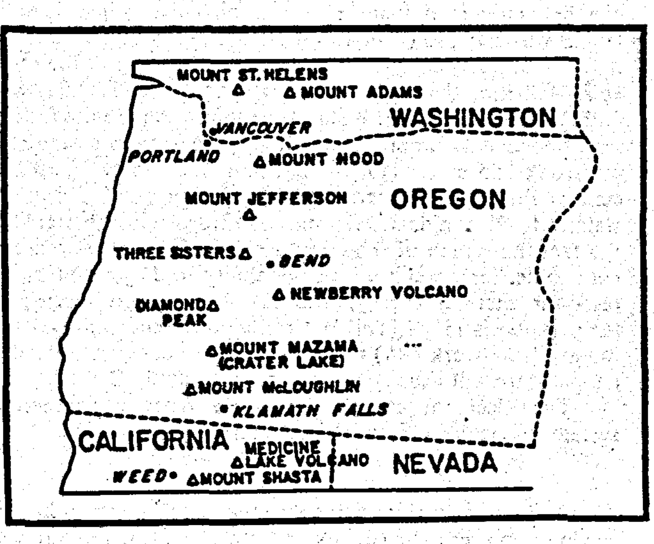

Figure 1. Map showing locations of some major volcanoes in the High Cascades Range of Washington, Oregon, and California. Taken from Sammel (1981).

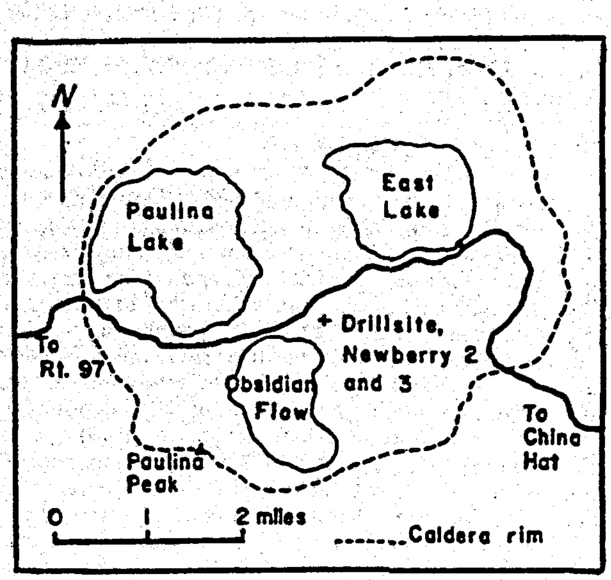

Figure 2. Map of Newberry Caldera, showing the Newberry 2 test site. Taken from Sammel (1981).

DOGAMI

temperatures of less than 200° C (Mariner and others, 1980). A new method based on the Na/Li ratio (Fouillac and Michard, 1981) gives reservoir temperatures of 335° C, 375° C, and 370° C for East Lake Hot Springs, Paulina Hot Springs, and the Little Crater Campground warm well, respectively (based on analyses from Mariner and others, 1980).

The reliability of the Na/Li geothermometer is difficult to assess. In general, higher temperatures correspond to lower Na/Li ratios. If, however, the concentration of sodium in the thermal water is a function not only of temperature but also of the length of time that the water has been in contact with lapilli tuffs (Mariner and others, 1980), then the result is a higher Na/Li ratio and a lower estimated reservoir temperature. This implies that the calculated temperatures are minimums, assuming, of course, that the concentration of lithium in the thermal water is a function of subsurface temperature and is not affected by the length of time the water is in contact with the tuffs. This may indeed be the case. According to Fouillac and Michard (1981), the concentration of lithium in thermal waters increases with increasing temperature, varying over about four orders of magnitude between 0° and 300° C. They feel that it is unlikely that the concentration of lithium in thermal waters is due to chemical equilibrium between water and a lithium mineral, and they believe that water-rock ratios and rock type do not affect lithium concentrations. Given these findings, it is possible that the temperatures resulting from Na/Li ratios give useful indications of minimum reservoir temperatures beneath the caldera at Newberry Volcano. Even if Paulina and East Lake Hot Springs are drowned fumaroles, the Na/Li ratios should be characteristic of the temperature of the thermal fluid at the point of mixing. Since the temperature of the mixture is presumably less than the temperature at depth, the resulting Na/Li geothermometer should give useful minimum reservoir temperatures.

Based on the above considerations, a maximum reservoir temperature of 360° C and a mean reservoir temperature of 312.5° C have been selected for use in the calculations of geothermal potential. The maximum is simply the mean of the three Na/Li geothermometers (335° C, 375° C, and 370° C) discussed above, while the mean reservoir temperature is the arithmetic average of the maximum (360° C) and the temperature encountered at the bottom of the Newberry 2 test hole (265° C). These temperatures are higher than those encountered in many producing geothermal fields around the world, but they are not unheard of. The Cerro Prieto field in the Mexicali district of Mexico, for example, produces fluids at temperatures of 310° to 350° C from depths of 1,700-2,000 m (Espinosa, 1982).

RESERVOIR VOLUME

Brook and others (1979) assume a reservoir volume of 47 ± 16 km³ in their estimation of the geothermal potential of Newberry Volcano. This estimate is based upon a caldera area of 32 km² and a minimum, maximum, and most likely depth to the top of the reservoir of 0.5, 2.0, and 1.5 km, respectively. They chose these numbers because the depths to the tops of the reservoirs in most drilled geothermal systems fall within that range and because at the time of their study there were no drill hole data available from Newberry indicating the true top of the reservoir. Assuming a maximum drillable depth of 3 km for the reservoir bottom, Brook and others (1979) calculate a maximum reservoir thickness of 2.5 km, a minimum of 1.0 km, and a most likely thickness of 1.5 km. The results from Newberry 2 indicate a depth to the top of the reservoir of 0.93 km (Sammel, 1981) and thus a calculated reservoir thickness of 2.07 km, the value that is used in this paper in calculating reservoir thermal energy. An important assumption used in the calculation of reservoir volumes is that all portions of the reservoir are considered to be equally porous and permeable; no attempt is made to separate those portions of the reservoir which are porous and permeable from those which are not (Brook and others, 1979).

Williams and Finn (1981), in a reexamination of gravity data from Newberry, delineate a large positive residual gravity anomaly associated with the volcano. The anomaly extends well outside the margins of the volcano, covers an area of approximately 275 km² (D.L. Williams, 1982, personal communication), and is interpreted by Williams and Finn (1981) to be a subvolcanic intrusive. The top of the intrusive lies at a depth of less than 2 km (D.L. Williams, 1982, personal communication) and is probably composed of a complex of many separate intrusions in different states of cooling (Williams and Finn, 1981). While it is highly unlikely that temperatures similar to those encountered in the Newberry 2 test hole underlie the entire area of the positive gravity anomaly, calculations will be made using that assumption in order to arrive at an upper limit for the electrical generation potential of the volcano.

ELECTRICAL POWER CALCULATIONS

The techniques developed by Brook and others (1979) for estimating the electrical generation potential of a geothermal area are relatively straightforward, once reasonable estimates of reservoir temperatures and volumes have been made. As a first step, the accessible resource base (the stored heat of the system above 15° C and shallower than 3 km) is calculated, using the formula:

$$q_R = pc \cdot a \cdot d \cdot (t - t_{ref}),$$

where q_R is the reservoir thermal energy in joules (J), pc is the volumetric specific heat of rock plus water (2.7 J/cm³/° C), a is the reservoir area in km², d is the reservoir thickness in km, t is the reservoir temperature, and t_{ref} is the reference temperature (15° C). The value for pc assumes a reservoir porosity of 15 percent and t_{ref} is the mean annual surface temperature, which for simplicity is assumed to be constant throughout the United States.

Once the reservoir thermal energy (q_R) has been calculated, the problem becomes one of determining how much of that energy can be turned into electricity. To generate electricity, the thermal energy of the reservoir is converted into mechanical energy (work), which in turn is converted to electrical energy. The mechanical work available (W_A') at the wellhead can be determined from a graph conveniently provided in USGS Circular 790 (Brook and others, 1979). For a reservoir temperature of 312.5° C and a depth to the center of the reservoir of 2 km, the ratio W_A'/q_R is equal to 0.082 (W_A'/q_R = 0.082). Hidden within this simple computation are the following important assumptions which are discussed in more detail by Brook and others (1979): (1) In an ideal reservoir, 50 percent of the reservoir thermal energy can be recovered at the wellhead; (2) nonideal reservoir conditions, mostly related to the fact that much of the reservoir volume is not porous and permeable, limit wellhead recoverability to 25 percent of the reservoir thermal energy; and (3) the condenser rejection temperature is 15° C. This last assumption tends to maximize the available work (W_A') term, as the true condenser rejection temperature will usually be higher, around 40° C.

The electrical energy obtainable from a geothermal system is calculated from the equation:

$$E = W_A' \cdot \eta_u,$$

where η_u is a utilization factor that accounts for losses that occur in the power cycle (Brook and others, 1979). The value of η_u is simply the ratio of actual work to available work (W_A') for a given system. A value of 0.4 was chosen by Brook and others (1979) as typical of hot water systems and is used in this paper. It should be noted that the calculation of actual work (used in determining η_u) assumes a condenser rejection temperature of 40° C.

Table 1 lists the results of the various calculations made for Newberry Volcano. The values for electrical energy are given in electrical megawatts based on a 30-year life span.

Table 1. *Estimates of volume, temperature, and energies of Newberry Volcano*

Source of calculation	Reservoir volume (km³)	Reservoir temperature (° C)	Reservoir thermal energy (10^{18} J)	Electrical (MWe for 30 years)
USGS Circ. 790[1]	47 ± 16	230 ± 20	27 ± 10	740
DOGAMI[2]	47	312.5	38	1,316
DOGAMI[3]	66	312.5	53	1,843
DOGAMI[4]	569	312.5	457	15,837

[1] Brook and others, 1979, p. 54.
[2] Oregon Department of Geology and Mineral Industries (DOGAMI) calculation, using reservoir volume estimate of Brook and others (1979) and new temperature data from Newberry 2 test well.
[3] DOGAMI calculation using increases in both reservoir temperature and volume from Newberry 2 hole (Sammel, 1981).
[4] DOGAMI calculation using volume estimate based on gravity work of Williams and Finn (1981).

Two things are immediately obvious from the information contained in Table 1. First, the new data from the Newberry 2 test well more than double the theoretical electrical generation potential of the caldera portion of the Newberry Volcano; and second, there may be enormous potential outside the caldera proper. The 15,837-MWe estimate for the entire gravity anomaly associated with the volcano is, of course, an absolute maximum. It is based on the assumptions that (1) the intrusive causing the gravity anomaly is everywhere providing heat at the rate found in the Newberry 2 test hole, and (2) the reservoir is everywhere 2.07 km thick (i.e., the top of the reservoir lies everywhere at a depth of approximately 1 km). While these assumptions are certainly not completely valid, they provide a useful upper limit on the potential of the volcano. The extent to which they are in error and the true geothermal potential of the volcano can be determined only by exploratory drilling.

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MEETING ANNOUNCEMENTS

GSOC luncheon meetings

The Geological Society of the Oregon Country (GSOC) holds noon meetings in the Standard Plaza Building, 1100 SW Sixth Avenue, Portland, in Room A adjacent to the third floor cafeteria. Topics of upcoming meetings and speakers include:

April 16—*Bella Coola by Freighter and Beyond*: by Phyllis and John Bonebrake, members and president of GSOC, 1975.

May 7—*The Columbia River Gorge: Who Is Watching?* by Nancy Russell, lecturer on Oregon native plants and chairwoman of Friends of the Columbia Gorge.

May 21—*Forty Floods*: by John Eliot Allen, Emeritus Professor of Geology, Portland State University.

For additional information, contact Viola L. Oberson, Luncheon Chairwoman, phone (503) 282-3685.

AIME dinner meeting

The monthly dinner meeting of the Oregon section of the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) will be held Friday evening, April 16, at the Flamingo Best Western Motel and Restaurant, 9727 NE Sandy Boulevard in Portland. The speaker will be Herbert H. Kellogg, 1982 Henry Krumb Lecturer and Professor of Metallurgy at the Henry Krumb School of Mines at Columbia University, who will speak on *Energy Use in Metal Production*.

Cocktail hour is at 6 p.m., dinner at 7 p.m., and program at 8 p.m. Reservations should be made by Wednesday, April 14, with either Mike York in Corvallis (phone 757-0349) or the Oregon Department of Geology and Mineral Industries receptionist in Portland (phone 229-5580). ▢

DOGAMI publishes new geologic map of Bourne quadrangle, eastern Oregon

A new geologic map for a part of eastern Oregon, published by the Oregon Department of Geology and Mineral Industries (DOGAMI), shows gold and silver mines and prospects as well as the geology of a historic mining area.

The multicolored map, *Geology and Gold Deposits Map of the Bourne Quadrangle, Baker and Grant Counties, Oregon*, was prepared by H.C. Brooks, M.L. Ferns, R.I. Coward, E.K. Paul, and M. Nunlist and appears in DOGAMI's Geological Map Series as Map GMS-19. At a scale of 1:24,000, it delineates 11 different bedrock and surficial geologic units, identifies 61 gold and silver lode and placer mines and prospects, and indicates known quartz veins. In three cross sections, it interprets basic geologic structure. Also printed on the map, partly in tabular form, is a summary of geologic and historical data for the deposits.

The Bourne 7½-minute quadrangle covers a part of the northwest corner of Baker County and about one square mile of Grant County. The region's mining areas, especially the North Pole-Columbia lode and the Cracker Creek, Cable Cove, and Rock Creek mining districts, are well known from their active periods between 1895 and 1940, when their total production value was an estimated $11 million.

DOGAMI Map GMS-19 is available now at the Department of Geology and Mineral Industries, 1005 State Office Building, Portland, OR 97201. The purchase price is $5.00. Orders under $20.00 require prepayment. ▢

APPENDIX E
USGS Circular 838

NEWBERRY VOLCANO, OREGON

Norman S. MacLeod, David R. Sherrod, U.S. Geological Survey, Menlo Park, California 94025

Lawrence A. Chitwood, U.S. Forest Service, Bend, Oregon 97701

and

Edwin H. McKee, U.S. Geological Survey, Menlo Park, California 94025

GEOLOGIC SUMMARY

Newberry Volcano, centered about 20 miles southeast of Bend, Oregon, is among the largest Quaternary volcanoes in the conterminous United States. It covers an area in excess of 500 mi^2, and lavas from it extend northward many tens of miles beyond the volcano. The highest point on the volcano, Paulina Peak with an elevation of 7,984 ft, is about 4,000 ft higher than the terrain surrounding the volcano. The gently sloping flanks, embellished by more than 400 cinder cones, consist of basalt and basaltic andesite flows, andesitic to rhyolitic ash-flow and air-fall tuffs and other types of pyroclastic deposits, dacite to rhyolite domes and flows, and alluvial sediments produced during periods of erosion of the volcano. At Newberry's summit is a 4- to 5-mile-wide caldera that contains scenic Paulina and East Lakes. The caldera has been the site of numerous Holocene eruptions, mostly of rhyolitic composition, that occurred as recently as 1,400 years ago.

Many geologists have studied various aspects of Newberry Volcano starting with I. C. Russell (1905) who visited it during a horseback reconnaissance of central and eastern Oregon in 1903. Howell Williams (1935, 1957) mapped the flanks of the volcano in reconnaissance and studied the caldera in more detail. His outstanding work forms the basis for subsequent investigations, most of which have focused on caldera rocks or young flank basalt flows. No comprehensive study has been made of the geology of Newberry's forest-covered and Mazama ash-covered flanks even though they form more than 95 percent of the area of the volcano. As part of a geothermal resource investigation of central and eastern Oregon, the first three authors have mapped the sixteen 7-1/2' quadrangles that cover the flanks of Newberry at a scale of 1:62,500, and reinterpreted and partly remapped the caldera. Highly generalized geologic sketch maps are shown in figures 1 and 2. The new mapping and K-Ar dating by the last author require substantial reinterpretation of the history of the volcano and of formation of the caldera and subsequent volcanic activity within it.

Newberry lies 40 miles east of the crest of the Cascade Range in a setting similar to Medicine Lake Volcano in California (Donnelly and others, this vol.). Both volcanoes have the same shape, are marked by summit calderas, contain abundant rhyolitic domes and flows, have widespread ash flows in addition to the more areally extensive basalt and basaltic-andesite flows and their related cinder cones, have similar petrochemistry, and have been the sites of eruptions of pumiceous tephra and obsidian flows during the last few thousand years.

Newberry lies at the west end of the High Lava Plains, a terrain formed of Miocene to Quaternary basalt flows and vents punctuated by rhyolitic domes and vent complexes (Walker and others, 1967; Greene and others, 1972; Walker and Nolf, this vol.). The rhyolitic rocks show a well-defined monotonic age progression starting at about 10 m.y. east of Harney basin and decreasing to less than 1 m.y. at Newberry's eastern border (Walker, 1974; MacLeod and others, 1975; McKee and others, 1976). Newberry rhyolites appear to be a continuation of these age-progressive rhyolitic rocks.

A complexly faulted terrain surrounds Newberry. The northeast-trending Walker Rim fault zone impinges on Newberry's southern flank but offsets only its older flows. A zone of faults that offsets older flows on the lower northern flank extends northwestward into the Cascade Range at Green Ridge. Although Newberry lavas obscure the relations of the Walker Rim and Green Ridge fault zones, they likely join beneath Newberry and represent but one curving fault system. The Brothers fault zone, a major west-northwest-trending zone of faults, extends across the extreme northeastern flank but does not apparently offset surficial Newberry flows. It probably extends at depth to join or abut against the Green Ridge-Walker Rim fault zones.

The north and south flanks of Newberry Volcano, which extend the greatest distances from the summit caldera, are almost exclusively veneered by basalt and basaltic andesite flows and associated vents. The basalt flows form much of the surface in a broad region extending far north of the volcano (Peterson and Groh, 1976) as well as southward to the Fort Rock basin. Individual flows are a few feet to more than 100 ft thick and cover areas of less than 1 square mile to many tens of square miles. Flow margins are commonly well preserved even on older flows, but the flows are complexly interwoven and it is difficult and time consuming to trace individual flow boundaries. Most flows are of block or aa type; pahoehoe surfaces occur locally on a few lower flank flows. Lava tubes are common, and some extend uncollapsed for distances of 1 mile (Greeley, 1971); some lower flank flows may have been fed by tube systems. Casts of trees occur in many flows, particularly the younger ones.

The basalt and basaltic andesite flows can be readily divided into two groups on the basis of their age relative to Mazama ash (^{14}C age 6,600-6,700 years) derived from the volcano at Crater Lake 70 miles distant. The youngest lava flows overlie Mazama ash, and their ^{14}C ages range from 5,800 to 6,380 years (^{14}C ages of this magnitude are generally about 800 years younger than actual

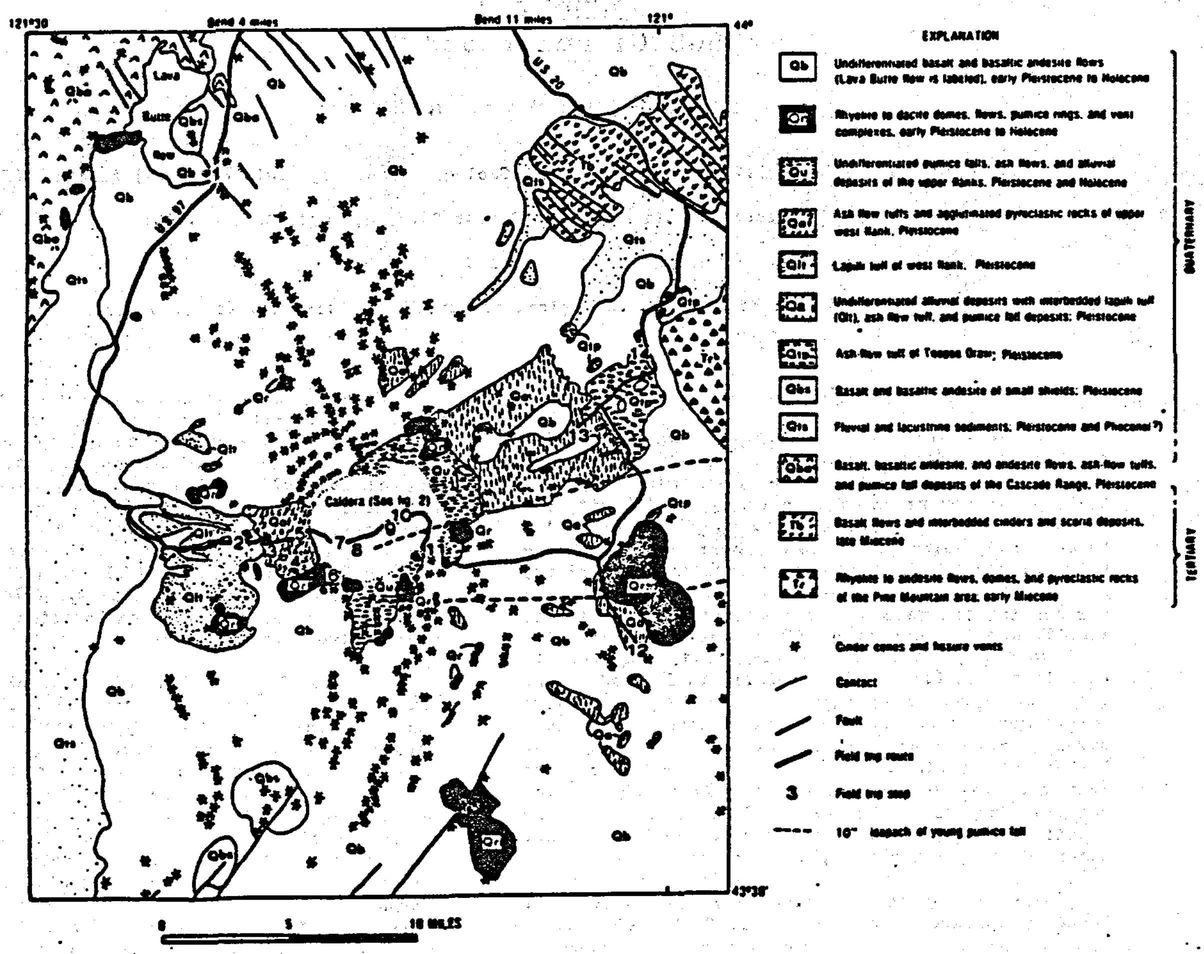

Figure 1. Geologic sketch map of Newberry Volcano. Geology of the caldera is shown in figure 2.

ages). Carbon for isotopic dating was obtained from carbonized root systems at the bases of lava tree casts (Peterson and Groh, 1969) and from beneath cinder deposits that extend as plumes leeward of cinder vents related to the flows (Chitwood and others, 1977). The young flows may have erupted during a much shorter period of time than the age spread indicates, perhaps as little as a few weeks or several years. All other flows are covered by Mazama ash and are older than 6,700 ^{14}C years; surface features on some flows suggest a relatively young age, perhaps 7,000 to 10,000 years, others are likely several tens or hundred of thousands of years old.

Seventy-three basaltic to andesitic flow rocks or bombs from associated vents analyzed by Higgins (1973) and Beyer (1973) contain 48 to 60 percent SiO_2. The mean silica content of these rocks is about 54 percent, similar to that of analyzed rocks from the adjacent Cascade Range. Of these analyzed Newberry rocks, only about 20 percent contain less than 52 percent SiO_2, about 60 percent lie between 52 and 56 percent, and the remaining 20 percent have 56 to 60 percent. Thus the dominant analyzed rock type is basaltic andesite similar to many rocks in the Cascade Range. The analyzed rocks are generally biased toward younger rocks, however, and many of the older voluminous flows on the lower flanks are basalt, mostly of high-alumina type (table 1, col. 1). The 6,000-year-old flows contain 52 to 57 percent SiO_2 and are basaltic andesites (table 1, col. 2).

More than 400 cinder cones and fissure vents have been identified on the flanks of Newberry—few other volcanoes in the world contain so many. They are concentrated in three broad zones that join on the upper part of the volcano. The eastern zone is a continuation of the High Lava Plains zone of basaltic vents and parallels the Brothers fault zone; except for cones high on the east flank, most cones in this zone appear relatively old. The northwestern zone of vents is colinear with the zone of faults on the lowermost flank that extends to Green Ridge in the Cascade Range, and the southwestern zone is collinear with the Walker Rim fault zone. Fissures and alined cinder cones generally parallel the belts in which they occur. The distribution of the vents, and particularly of alined vents and fissures, suggests that the northwest and southwest zones, and perhaps the faults that they parallel, are part of one broad arcuate zone that curves in the vicinity of Newberry's summit. Some alined cinder cones and fissure vents near the summit occur in arcuate zones parallel to the caldera rim and likely lie along ring fractures; some occur along faults whose caldera side is downdropped.

Most of the cinder cones are well preserved owing to their high porosity and consequent absorption rather than runoff of water. Larger cones are as much as 500 ft high, typical cones are 200 to 300 ft. Most are marked by summit craters and flows emerge from their bases. Cinders dispersed by prevailing winds during eruptions form aprons extending leeward from some cones such as Lava Butte (Chitwood and others, 1977) (stop 1, road log). Fissure vents consist of long ridges or trenchlike depressions formed by cinders, spatter and agglutinate flows. Small pit craters are developed along some fissure vents. Cinder cones and fissure vents on the lower flanks are generally devoid of fragments of rhyolitic rock, whereas many of those higher on the volcano contain rhyolitic inclusions (stop 3, road log).

Shieldlike vents occur at Spring and Green Butte on the southwest flank and Green Mountain to the northwest of Newberry. They are 1 to 3 miles across, have gentle slopes, and are more faulted and older than most surficial Newberry flows.

Many of the hills on Newberry's flanks are rhyolitic domes. In addition, pumice rings, obsidian flows, and small rhyolite or obsidian protrusions occur in many places. Most of the domes form rounded hills, such as McKay Butte on the west flank, that are 100 to 500 ft high and up to 4,000 ft across. The largest dome, which forms Paulina Peak (stop 6, road log), extends southwestward from the caldera wall for 3 miles. Its very elongate outcrop suggests that it was emplaced along a northeast-trending fissure or fault; an obsidian flow crops out farther down the slope on a direct extension of the axis of the Paulina Peak dome and may have been erupted from the same buried fissure or fault.

Several small rhyolitic outcrops may be the tops of rhyolite domes that are more extensive at depth. An example is along Paulina Creek on the west flank of Newberry where obsidian irregularly invades basaltic andesite flows over a small area. In addition, the common occurrence of rhyolite as fragments in cinder cones on the upper flanks attests to the relative abundance of rhyolite at depth on the upper part of the volcano.

K-Ar ages were determined on six rhyolite domes and flows. The ages range from 400,000 to 700,000 years, although many undated rhyolites are probably younger. Some small spinal protrusions, domes, and pumice rings on the upper southeast flank may be less than 10,000 years old. In contrast to the relative antiquity of many rhyolites on the flanks, those in the caldera are commonly younger than Mazama ash and as young as 1,400 years.

Ash flows, pumice falls, mudflows, and other pyroclastic deposits are common on the west and east flanks of Newberry and are likely present at depth on the north and south flanks below the veneer of basalt and basaltic andesite flows. The oldest known unit occurs on the lower northeast and east flank and consists of a widespread rhyolitic ash flow identified by G. W. Walker (pers. commun., 1973) during reconnaissance mapping of adjacent areas to the east. It has been referred to informally as the Teepee Draw ash flow for outcrops along Teepee Draw (stop 14, road log). The Teepee Draw ash flow crops out along ravine walls for at least 6 miles toward the caldera before being buried by younger rocks. Along some ravines it exceeds 70 ft in thickness, but it may be considerably thicker because its base is exposed only where kipukas of older basalt project through it; also the upper part is eroded. The ash flow crops out roughly over a 50° quadrant of the volcano, and, as it is apparently older than the surficial rocks on the other flanks, may be present at depth completely around the volcano. Original volume of the unit is difficult to estimate without information on distribution at depth on the other flanks, but it likely is much more than 10 cubic miles. The Teepee Draw ash flow probably relates to an early, perhaps the earliest, period of caldera collapse.

Farther up the northeast flank the Teepee Draw ash flow is buried to progressively greater depth by alluvial sediments derived by erosion of rocks higher on the slopes. Interbedded in or underlying this alluvium are basalt and andesite flows, and several other ash-flow tuff units (stops 12 and 13, road log). Some of these ash flows are widespread, others occur in only a few scattered localities (commonly plastered on the caldera side of cinder cones). Most of these post-Teepee Draw ash flows are characterized by dark-colored, probably dacitic, pumice.

The west flank of the volcano contains two major tephra units. The older unit forms most of the lower two-thirds of the slope and overlies basalt flows and vent deposits that in many places are deeply eroded. This unit also occurs on the northeast flank where it occurs higher in the section than most of the ash flows. Although locally over 200 ft thick, it is rarely exposed. Most of the scree-covered roadcuts along the paved road on the west flank that leads to the caldera are in this unit (stop 2, road log). The unit consists of gray to black ash, lapilli, and small bombs and abundant accidental lithic fragments. The lapilli and bombs have characteristic cauliflowerlike surfaces and virtually all contain angular to rounded inclusions of rhyolite, dacite, and andesite; some inclusions are fused and frothed. Trenches dug in the deposit show that it is massive. In no place have we seen any indication of collapse of pumiceous lapilli or welding. All of the lapilli and bombs, as well as the ashy matrix, have the same normal natural remnant magnetization, as measured by a field fluxgate magnetometer, which suggests emplacement temperatures above the Curie point for the entire unit. Most of the unit was likely deposited as pyroclastic flows. In one area the unit is palagonitized and much more indurated and has characteristics more like that of a lahar. Lapilli and bombs identical to those in this unit are an ubiquitous and voluminous component of most alluvial deposits on the volcano. Furthermore, numerous gravel pits beyond the flanks of the volcano contain similar lapilli as a major component of the gravel. The original volume of the unit was probably several cubic miles. Its eruption could have been accompanied by caldera collapse.

The second major tephra unit on the west flank forms the smooth and gently dipping upper part of the flank extending for about 2 miles from the caldera rim. At localities farthest from the rim (stop 4, road log) the unit consists of many thin ash-flow units, commonly 3 to 20 ft thick. They are reddish to brownish in color and consist of andesitic scoria and pumice and accidental lithic fragments in a poorly sorted lithic- and crystal-rich ashy matrix. Bases of individual units are commonly welded. Toward the caldera rim, the ash flows progressively change character and in many places near the rim, as at Paulina Falls (stop 5, road log), thick units have the appearance of agglutinate flows. These deposits probably represent hot co-ignimbrite lag deposits.

Alluvial deposits occur over broad areas of the northeast, lower southeast, and upper south flanks where they form rounded slopes with virtually nonexistent exposure. Most of the deposits are gravel and sand, but the occurrence of boulders as float at some horizons along sides of ravines indicates that boulder beds are present also; pumice falls and ash flows are interbedded in the alluvial deposits in some areas. Because most of the uppermost slopes of the volcano in areas where the alluvium is present are veneered by young pumice falls, we were not able to determine the origin of the deposits near the caldera. They may be fluvial but equally well may be of glacio-fluvial or glacial origin. Farther down the slope they are probably entirely fluvial, representing broad alluvial fans.

Much of the uppermost northeast, east, and southern flanks extending for about 1 to 2 miles outward from the caldera rim are formed of pumice and ash deposits derived from vents within the caldera. Most of the deposits are younger than Mazama ash, but scattered holes dug through them show that similar deposits underlie Mazama ash in a few places. Much of the east flank of the volcano is covered by an extensive pumice fall (stop 11, road log) derived from the vent for the Big Obsidian flow in the caldera (Sherrod and MacLeod, 1979). It extends as a plume oriented N. 80° E., is well over 10 ft thick near the caldera rim, and thins to about 10 in. at a distance of about 40 miles from the caldera.

Williams (1935, 1957) first recognized that the 4- to 5-mile-wide depression at the summit of the volcano is a caldera; Russell (1905) had originally suggested that it was a large glacial cirque. Owing to the absence of known ash flows on the flanks, Williams (1957) interpreted the caldera as resulting from "* * * drainage of the underlying reservoir either by subterranean migration of magma, or, more likely, by copious eruptions of basalt from flank fissures * * *," with summit collapse occurring along ring fractures. Higgins (1973), on the other hand, interpreted caldera formation as due to tectonic-volcanic collapse along fault zones that supposedly intersected at the summit. As noted by Peterson and Groh (1976), the main axis of the Brothers fault zone lies far north of the caldera, rather than crossing the summit, and faults within the zone do not appear to offset Newberry lavas. Also, most of the faults shown by Higgins on the upper part of Newberry that he uses as part of his structural interpretation could not be corroborated.

Ash flows and other tephra units are now known to be common and voluminous on the flanks. Thus the caldera seems much more likely to be the result of voluminous tephra eruptions from magma chambers below the former summit with concomitant collapse of the summit in a manner similar to that of most other calderas the size of Newberry's or larger. As there were several major tephra eruptions, it seems likely that collapse occurred several times, each collapse involving areas smaller than that of the present caldera. Accordingly, the present caldera is interpreted as several nested calderas of different age.

The ages of the calderas and of the ash flows that we consider to be related to their formation are poorly known. Higgins (1973) interprets the caldera age as Holocene on the basis of the absence of obvious widespread glacial deposits. However, many rocks on the volcano, particularly on its upper flanks, are now known to be several hundred thousand years old, so absence of glacial features probably is not meaningful. Also, several of the larger volcanoes on the east side of of the Cascade crest, which are about the same height as Newberry, show no obvious glacial features, yet some of them are nearly a million or more years old.

The ring fractures along which collapse occurred are not exposed, yet their general location is indicated by arcuate zones (fig. 2), visible on aerial photographs. It is not possible to relate individual ash-flow units to collapse along specific ring fractures. Also it is possible that collapse occurred along parallel ring fractures at the same time. Two parallel walls on the southeast side of the caldera present an interesting problem in interpreting the origin of the caldera wall sequences (described later). If the inner wall is the younger, then the area between the inner and outer wall may be formed of old caldera-fill deposits. The inner wall is thickly mantled by young tephra deposits, and the only exposures are a relatively small area of rhyolite in the lower part of the slope. The remainder of the slope on this wall dips 30° to 40°, near the angle of repose, and has a very uniform smooth shape. If the young tephra deposits were locally underlain by indurated rocks, as are present in the other walls, it seems likely that the slope would be more irregular. Thus this caldera wall likely is dominantly or entirely formed of relatively unconsolidated fragmental rocks, probably caldera-fill deposits. The rhyolite exposed locally at the base of the wall may be a faulted dome that was originally within the caldera. The upper part of the northeast wall, above exposures of caldera wallrocks, may also be formed of caldera-fill deposits, the older caldera wall being farther north.

The walls of the caldera are mostly covered by younger deposits (talus, pumice falls, etc.) and the wallrocks are only locally exposed. They are described by Williams (1935) and in more detail by Higgins (Higgins and Waters, 1968; Higgins, 1973). The most continuous exposures are along the north wall extending from the Red Slide, north of Paulina Lake, to the northeast obsidian flow, which drapes the wall northeast of East Lake. The base of the wall sequence is formed of platy rhyolite. Higher in the section are basaltic andesite flows, palagonite tuff, cinder and agglutinated spatter deposits, and at the top of the exposures are palagonite tuffs.

Exposures in the east wall are found only from about midway on East Lake northward to the Sheeps Rump, a cinder cone along the wall at the northeast corner of the caldera. The intermittent exposures consist of basaltic andesite or andesite flows, palagonite tuff, and pumice deposits. The last range from unwelded and uncollapsed pumice to densely welded deposits.

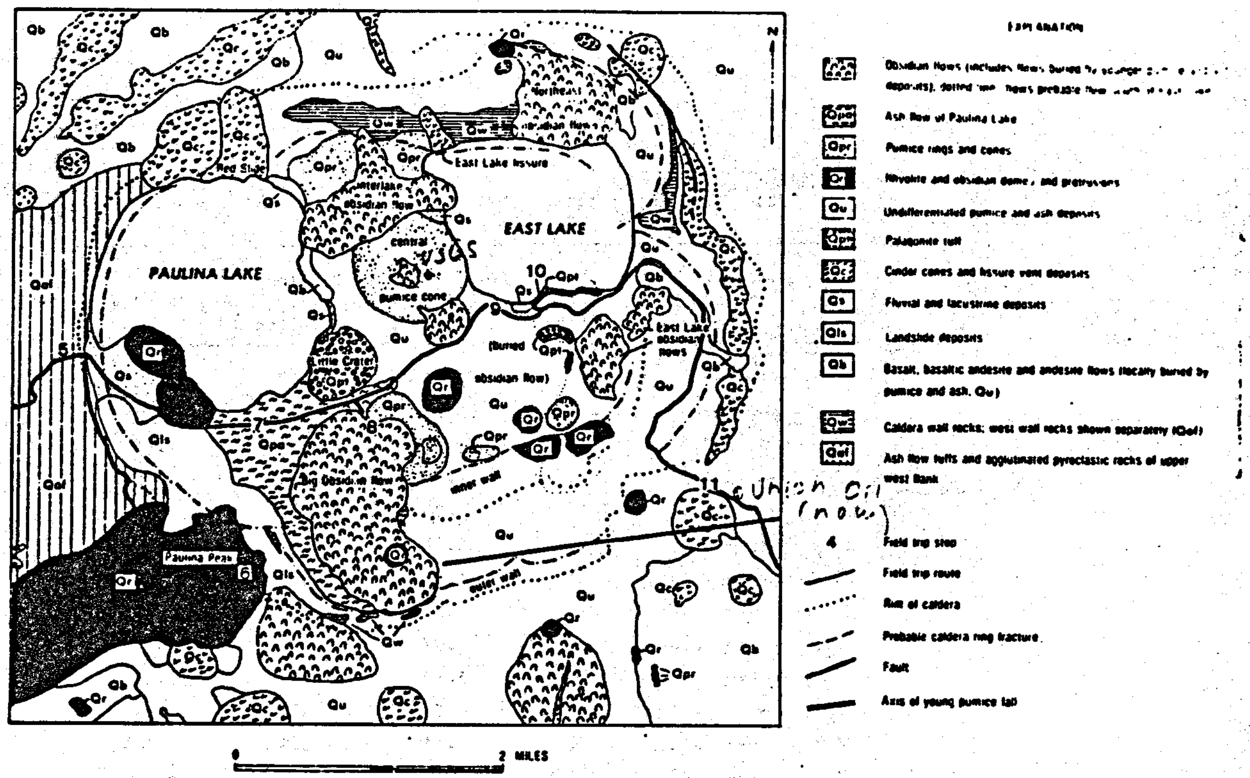

Figure 2. Geologic sketch map of Newberry caldera.

Other than exposures of rhyolite south of East Lake, the inner south caldera wall is unexposed and is covered by thick pumice fall deposits. The outer south wall has exposures only near the Big Obsidian flow and farther west below Paulina Peak. The best exposures, midway between Paulina Peak and the Big Obsidian flow, consist of a lower platy rhyolite, overlain by basaltic andesite flows, dikes, and cinder deposits with local interbedded pumice fall deposits, and with a cliff-forming obsidian flow at the top. At the west end of this exposure are outcrops of bedded pumiceous tuffs that have been fused near their contact with the overlying obsidian flow; part of the apparent base of the obsidian flow is fused tuff even on the east end of the outcrop. South of the Big Obsidian flow vent are exposures of andesitic or dacitic ash flows and basaltic andesite flows, and below Paulina Peak a ledge of basalt crops out in one small area.

Most of the caldera floor is formed of rhyolitic rocks including domes, flows, and pumiceous tephra deposits (ash flows, pumice falls, explosion breccias), but basaltic andesite and andesite flows and palagonite tuff rings occur in several places. Williams (1935) and Higgins (1973) have provided much useful data on the floor rocks, although we interpret the relative ages of many of the units differently. The floor rocks represent but the tip on the iceburg with respect to the total fill present in the caldera. A core hole, currently being drilled for the U.S. Geological Survey has so far penetrated 1,700 ft of caldera-fill deposits, mostly pumiceous tephra, with a few rhyolitic and dacitic flows, and lake sediments 1,000 ft below the surface.

Mazama ash is a useful datum with which to roughly subdivide the caldera rocks as older or younger than about 6,700 ^{14}C years. All the mafic rocks are older than Mazama except for those along the East Lake fissure. The East Lake fissure has not yielded carbon for dating, but the summit basaltic andesite flows along the same fissure less than a mile north are about 6,090 ^{14}C years old (S. W. Robinson, written commun., 1978). Included in the pre-Mazama basaltic rocks are the interlake basaltic andesite flow (east shore of Paulina Lake), Red Slide cinder vent and flows (north side of Paulina Lake), Sheeps Rump cinder cone and flow (northeast side of East Lake), and east-rim fissure and the associated flow from it that extends to East Lake. The palagonite tuff rings that occur southeast of Paulina Lake (Little Crater) and near the south shore of East Lake (stop 10, road log) are also pre-Mazama in age. Rhyolitic rocks of pre-Mazama age include two domes along the south shore of Paulina Lake, a large obsidian flow in the northeast corner of the caldera, an obsidian dome that crops out near the caldera wall south of East Lake with an obsidian flow that extends northward from the dome to East Lake, and a poorly exposed dome(?) south of the Central Pumice cone. In addition, rhyolitic pumice falls, lacustrine deposits (i.e., east shore of Paulina Lake), and landslide deposits (north of Paulina Peak) are known to locally underlie Mazama ash.

The post-Mazama rhyolitic deposits occur in the eastern half of the caldera (fig. 2). They include obsidian flows, pumice rings and cones, ash flows, pumice falls, and other pumiceous tephra deposits. Hydration-rind dating by Friedman (1977) indicates that the Central Pumice cone, between East and

Table 1. Representative chemical analyses of Newberry rocks.
[n.r. = not reported]

	Flank basalt	Lava Butte basaltic-andesite	Paulina Falls andesitic-agglutinate	Paulina Peak rhyolite	Big Obsidian flow
SiO_2	49.1	56.0	60.43	71.07	72.02
Al_2O_3	17.6	16.1	16.06	14.92	14.61
$FeO+Fe_2O_3$	9.0	7.7	6.51	2.81	2.43
MgO	8.9	4.49	1.71	.22	.164
CaO	10.0	8.2	4.58	1.08	.85
Na_2O	2.6	3.72	5.71	6.04	5.16
K_2O	.43	1.25	1.54	3.03	3.89
H_2O+	.71	n.r.	.53	.17	n.r.
H_2O-	.10	n.r.	.07	.01	n.r.
TiO_2	1.0	1.13	1.30	.29	.24
P_2O_5	.31	n.r.	.39	.05	n.r.
MnO	.16	.14	.15	.09	.064
CO_2	<.05	n.r.	.61	<.05	n.r.

Column 1. Higgins (1973, table 6, col. 62).
Column 2. Beyer (1973, table 1c, LB-4).
Column 3. Higgins (1973, table 4, col. 19).
Column 4. Higgins (1973, table 4, col. 27).
Column 5. Laidley and McKay (1971), average of 66 analyses.

Paulina Lakes, and the Interlake and Game Hut obsidian flows that crop out north and south of it, are only slightly younger than Mazama ash (^{14}C age, 6,600-6,700 years). The East Lake obsidian flows are apparently about 3,500 years old, and the Big Obsidian flow is about 1,400 years old.

Widespread pumiceous tephra deposits cover much of the eastern part of the caldera. They underlie the East Lake obsidian flows and probably are slightly older than the Central Pumice cone and the obsidian flows on its north and south sides. These tephra deposits may have been derived from several different vents, but holes dug through them indicate that they consist dominantly of 5 to 10 ft of massive to poorly bedded pumice with accidental fragments (palagonite tuff, basalt, rhyolite, etc.) overlain by several feet of well-bedded mud-armored pumice, accretionary lapilli, ash, and pumice (stop 9, road log).

The youngest period of volcanism within the caldera was associated with the vent for the Big Obsidian flow. It began with eruptions that produced a widespread pumice fall that covers the southern part of the caldera and the eastern flank of the volcano (Sherrod and MacLeod, 1979). ^{14}C ages of 1,720±200 (Higgins, 1969) and 1,550±120 (S. W. Robinson, written commun., 1978) years were obtained on carbon directly beneath the fall. On the basis of thickness measurements from 150 holes dug through the pumice fall, the axis of the fall extends N. 80° E., away from the vent for the Big Obsidian flow. At about 5-1/2 miles from the vent the fall is about 12 ft thick, and at 40 miles it decreases to about 10 in.

The pumice fall was followed by eruptions that produced an ash flow that extends over a broad area between the Big Obsidian flow and Paulina Lake. It is well exposed in roadcuts near the Big Obsidian flow (stop 7, road log). ^{14}C ages of the ash flow are 1,270±60 and 1,390±200 years (Pierson and others, 1966; Meyer Reubin, in Friedman, 1977), with an older age (2,054±230 years) obtained many years ago by Libby (1952). The final event was the eruption of the Big Obsidian flow and the domal protrusion that marks its vent. Slight collapse occurred over a one-half-mile-wide area around the vent before the flow was erupted. The flow extends northward from near the outer caldera wall to near the paved road in the caldera and, in its northern part, partly filled an older pumice ring (stop 8, road log).

Considering the long time over which eruptions took place on Newberry, the volcano should be considered dormant but capable of future eruptions even though about 1,300-1,400 years have transpired since the last eruptions. Newberry is ideally suited for those who wish to see diverse volcanic features. Its rocks range widely in composition, and examples from it could be used to illustrate a nearly complete atlas of the types of products of volcanism.

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APPENDIX F

HYDROLOGY OF THE LAPINE BASIN

Modern studies have shown at least 95% of geothermal fluids must be derived from surface precipitation and volcanic steam contributes no more than 5%. In order to evaluate geothermal resources it is necessary to understand the hydrology and hydrogeology of the geothermal fluids. The source of ground water feeding the geothermal reservoir beneath Newberry Crater is probably from precipitation recharged in the High Cascades to the west and southwest.

The U.S. Geological Survey test hole was drilled about 3,000 feet from an elevation of about 6,300 feet. This would place the bottom hole elevation at about 3,300 feet and possibly into the regional ground water flow system.

The following hydrology information is condensed from the LaPine Aquifer Management Plan for Deschutes County by Century West Engineering, June, 1982.

Additional studies are needed to better understand the flow systems and their relationship to the geothermal fluids.

PHYSIOGRAPHY

The LaPine basin is located in the High Lava Plains geographic province, and the north central part of the Upper Deschutes drainage basin. It is flanked by the High Cascades on the west and Newberry Volcano (the Paulina Mountains) to the east. The area of the basin is about 600 square miles.

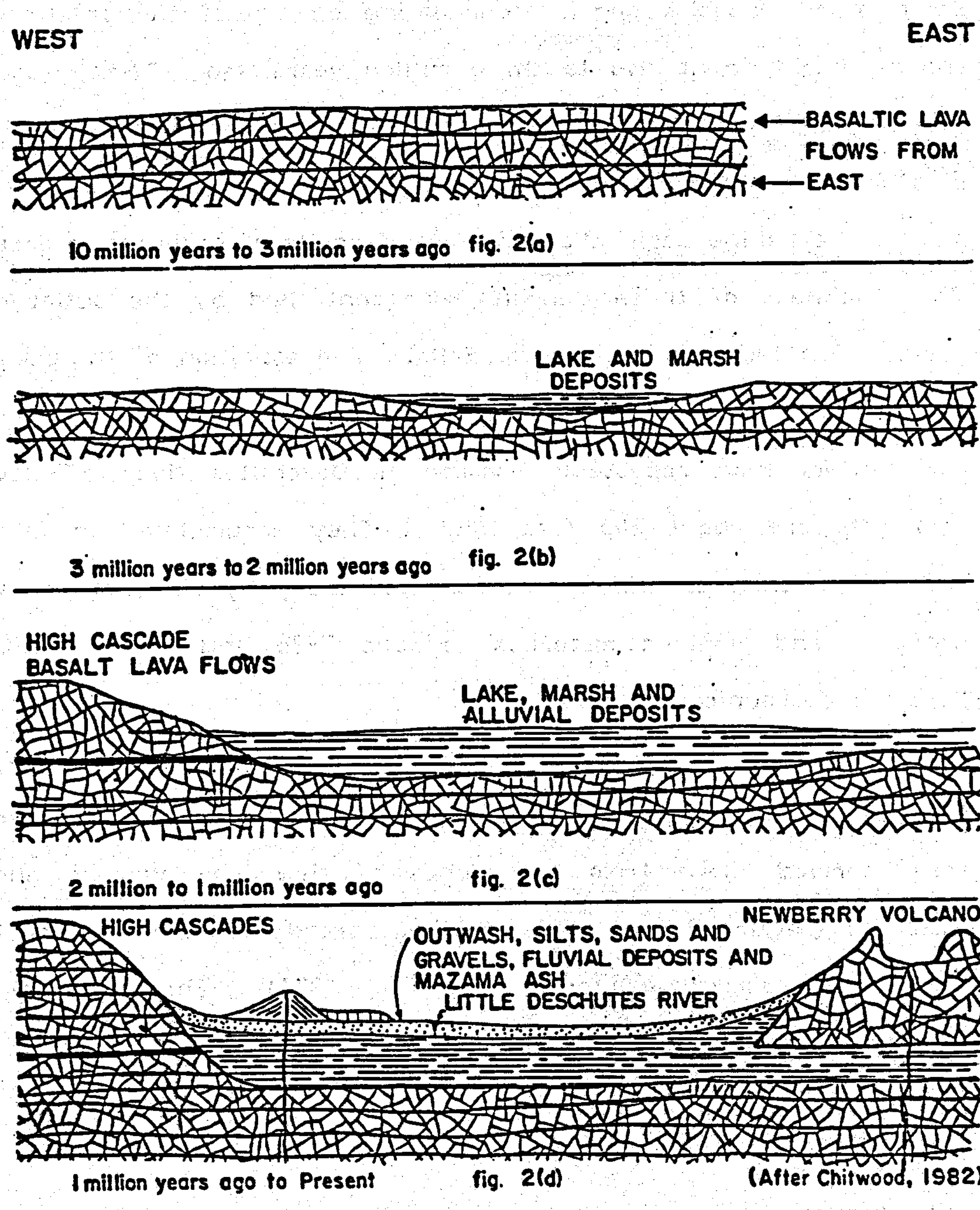
The basin narrows to the north as a result of converging hill terrain and broadens to the south. Newberry Volcano to the east covers an area in excess of 500 square miles. The highest point on the volcano, Paulina Peak with an elevation of 7,984 feet, is about 4,000 feet higher than the terrain surrounding the volcano. Cinder cones and buttes west of the basin vary from 6,200 to 4,500 feet in elevation. The basin floor, made up of sediments, is relatively flat and slopes gently to the north at about six feet per mile with elevations varying from 4,300 feet to 4,100 feet. The floor also slopes toward rivers in the central part of the basin, with gradients of five feet to about 25 feet per mile. Within the study area, local topographic relief is about two to 20 feet due to a system of shallow drainages.

GEOLOGY

HISTORY

The LaPine basin is a low, sediment-filled area between the Cascade Range to the west and Newberry Volcano to the east. Before the basin existed, numerous basaltic lava flows spread over central and eastern Oregon from about ten million years to three million years ago. These lavas form the floor of the basin (Figure 7-2a). At the end of this period, numerous overlapping shield volcanoes, made up of basaltic lava flows, began to form the High Cascades. Lavas from these volcanoes overlapped the older lavas from the east. Volcanism in the High Cascades has continued nearly to the present time and formed the

LAPINE BASIN
GENERALIZED GEOLOGIC HISTORY



western side of the LaPine basin. Low lava uplands to the east provided the beginnings of an eastern side to the basin.

Sedimentary deposits began accumulating on top of the basalts in the shallow basin about two to three million years ago. Then, about one million years ago, Newberry Volcano began building on top of the low lava uplands to the east. This enormous volcano formed a major eastern side to the LaPine basin allowing thick deposits of sediment to accumulate. The thickness of these deposits was controlled by the outlet of the basin which today is at Benham Falls. The elevation of the outlet has varied considerably over time depending on eruptions of lava flows and domes which have repeatedly dammed the Deschutes River. Today, the sediments are about 500 feet thick. They accumulated in lake and marsh environments and are represented today by silts, clays, sands, gravels, and organic materials (Figure 7-2b and 7-2c) (Chitwood, Personal Communication, 1982).

During periods of glaciation, large amounts of silt, sand, and gravel were carried down from the slopes of Newberry Volcano and the Cascades (Figure 7-2d). This alluvium spread over the basin on top of the older sediments (Peterson, et. al., 1976). Thickness has been controlled by climate and by volcanic events around Benham Falls.

STRATIGRAPHY

Introduction

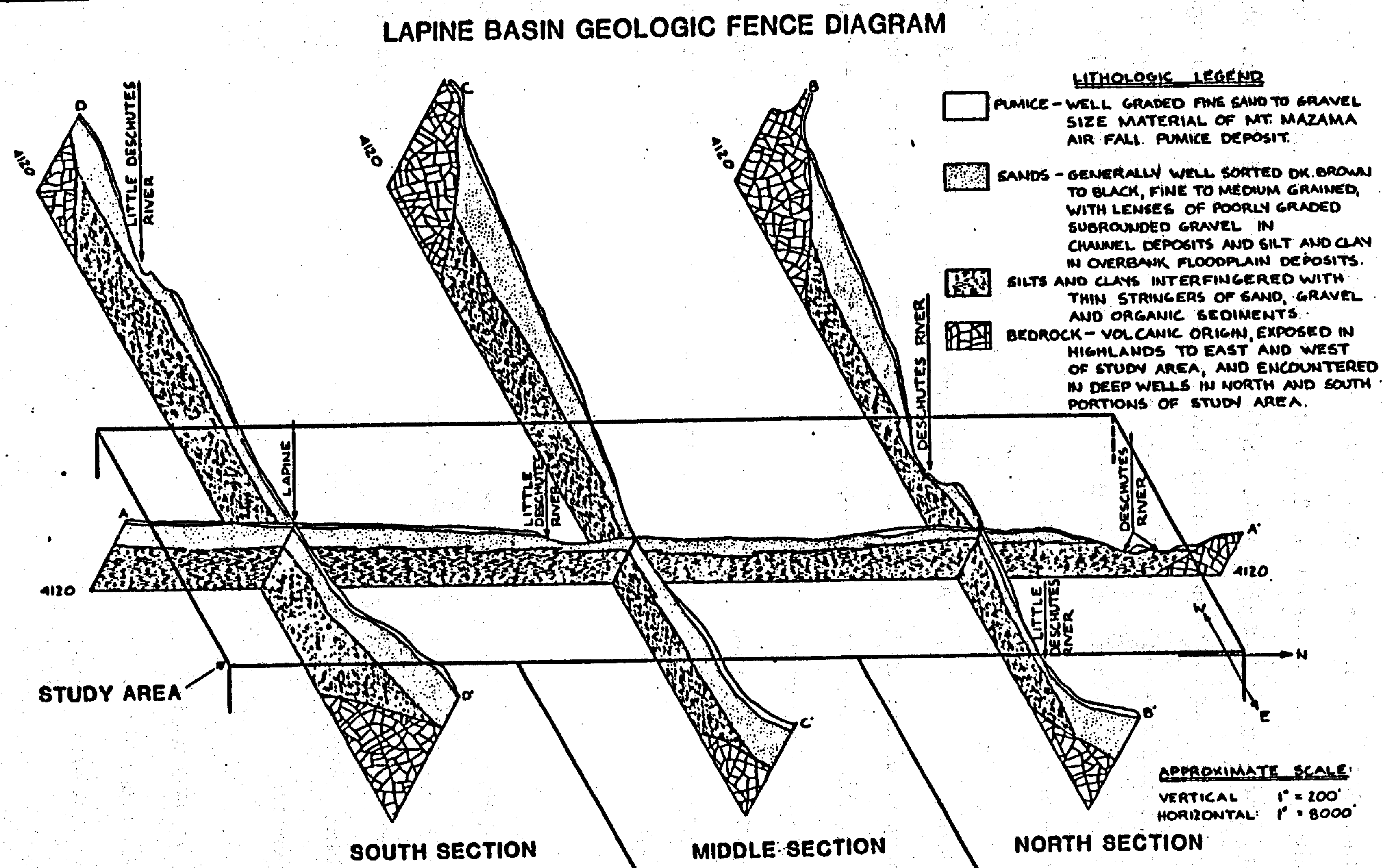
The stratigraphy of the LaPine Basin can be generalized by dividing it into three main units: (1) older basaltic lava flows at depths of more than 500 feet in the center of the basin, (2) an intermediate layer of silts and clays as much as 800 feet thick interbedded with thin layers of sand, gravel, and organic sediments from lake, marsh, and stream deposition, and (3) an alluvial layer of up to 50 feet of interfingered sands and gravels, glacial outwash and floodplain deposits, topped with recent pumice and ash from the eruption of Mount Mazama. This layer generally thins to the north.

Figure 7-4 is a geologic fence diagram showing the generalized stratigraphy of the LaPine Basin based on more than 1,000 drillers' logs filed with the Oregon Water Resources Department (WRD), and electrical resistivity soundings. The resistivity soundings and monitoring well logs confirm the information in drillers' logs showing the presence and variability of interbedded clays, silts, sands, and gravels in the LaPine basin.

The general stratigraphic section as shown in Figure 7-4 shows a basin formed by old basalt flows as a base, and younger basalt flows to the east, west, and north. A thick sedimentary layer overlying the basalt flows is capped by alluvium that thickens toward the mountains and thins toward the north. Overlying the alluvium is a blanket of recent pumice.

GROUND WATER

Ground water in the LaPine basin occurs in regional, intermediate, and local flow systems.



LAPINE AQUIFER MANAGEMENT PLAN

FIGURE 7-4

CENTURY WEST ENGINEERING

Regional ground water flow systems are defined as being deepest and at the opposite end of the spectrum from local flow systems. The water of intermediate flow systems lies beneath local systems and above regional systems. Local flow systems may cover only a few acres and be less than 100 feet thick.

REGIONAL FLOW SYSTEM

A regional flow system in the LaPine basin probably occurs in the basalt lava flows underlying the basin. The Ponderosa Pines No. 2 Well penetrates basalt and produced 550 gallons per minute (gpm) with a drawdown of only 1.3 feet after 8 hours.

A WRD inventory well near the town of Crescent, 17 miles south of LaPine, is 267 feet deep, and water was found in lava rock at a depth of 245 feet. A pump test yielded 117 gpm with a drawdown of 8 feet after 8 hours of pumping (State Water Resources Board, 1961, page 59).

Three wells near Gilchrist were reported drilled to about 300 feet and penetrated clays, then hard basalt and red cinders with large amounts of good quality water.

The regional flow system is recharged in the High Cascades to the west, highlands to the south and the Paulina Mountains to the east. The direction of flow is probably to the east-northeast.

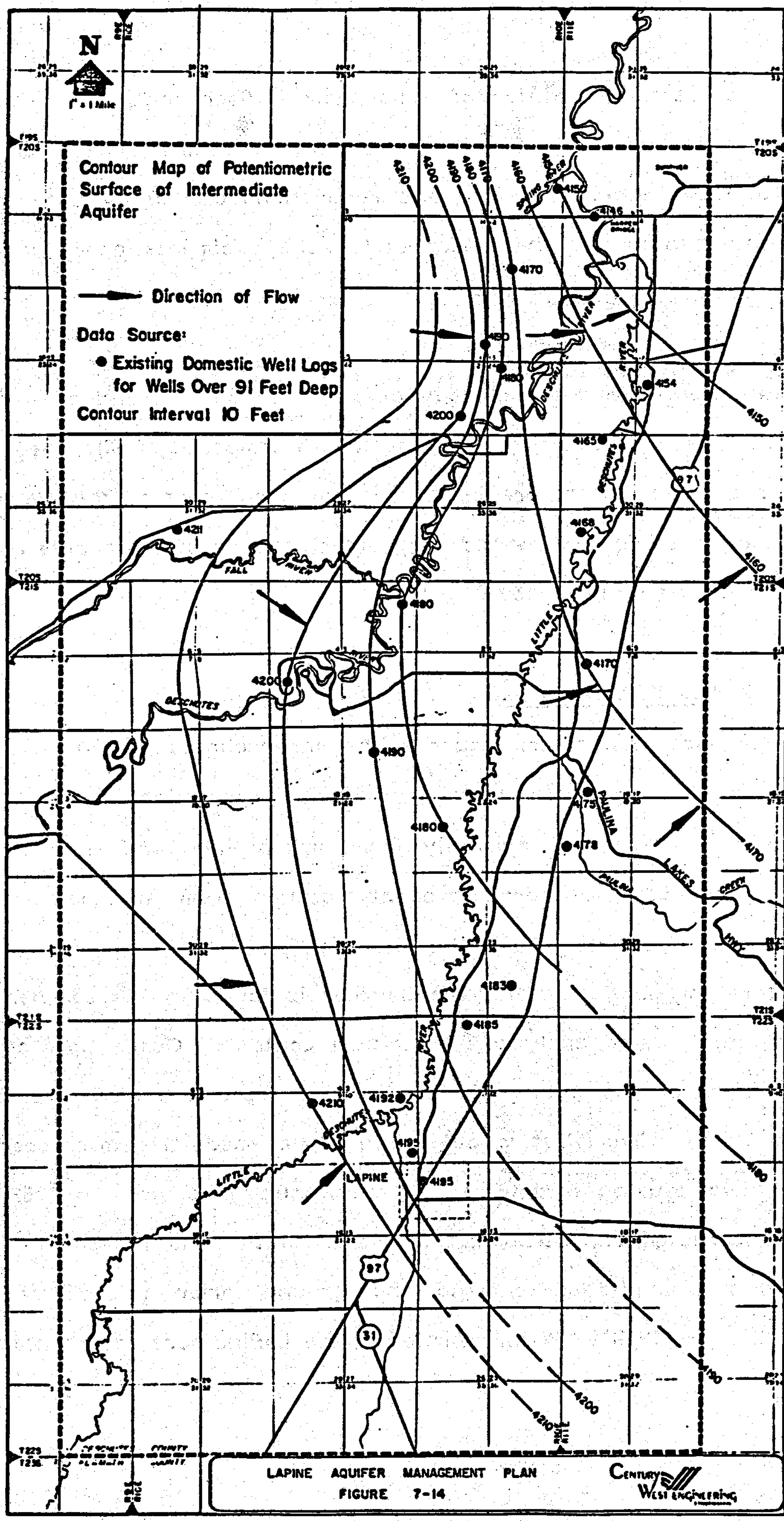
INTERMEDIATE FLOW SYSTEM

The intermediate flow system occurs in the saturated sedimentary deposits of the basin (Figure 7-2c). The clays and silts have low permeability and well yields are low (less than 5 gallons per minute). The sands and gravels show well yields of up to 50 gallons per minute. Bail test information from driller's logs show transmissivity values ranging from 670 to 145,000 gallons per day per foot estimated by the method of Theis and others (1954).

Figure 7-14 is a contour map of the potentiometric surface of the intermediate aquifer based on water levels in wells greater than 91 feet deep. This map shows the direction of flow to the east and northeast.

Static water levels reported on driller's logs were used in preparation of the potentiometric surface contour map. Because these wells were drilled and completed in some cases to different water bearing sedimentary strata, the contour map shows the generalized flow direction and is subject to substantial local variability. It is believed, however, to be a reasonable representation of the intermediate flow system.

The intermediate aquifer was slowly recharged from precipitation in the basin, along the edges of the basin and possibly from recharge moving up from the regional flow system. Because the silts and clays of the intermediate aquifer have low permeability, recharge takes place slowly. The intermediate aquifer is reported by well drillers to be saturated. Because the intermediate aquifer is saturated, little or no water moves downward from the alluvial or upper aquifer.



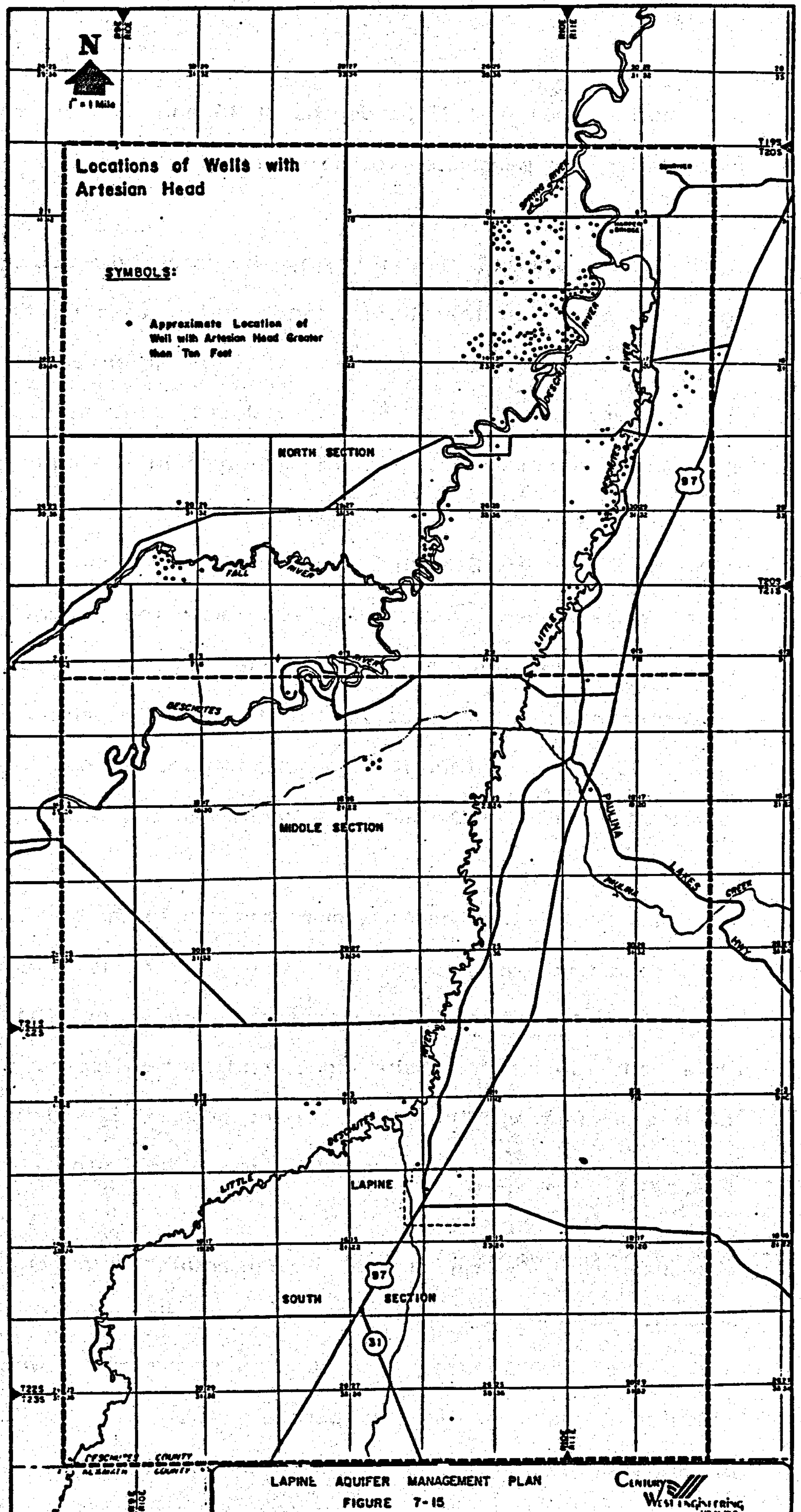
LAPINE AQUIFER MANAGEMENT PLAN
FIGURE 7-14

The artesian condition of wells show a discharge potential of the intermediate aquifer in the north part of the basin. The discharge is due to topographic narrowing and restrictions caused by basaltic lava flows and thinning of the intermediate zone sediments near the depositional edge of the basin.

Artesian wells are generally deeper than 50 feet and commonly indicate the presence of major confining layers composed of silt, clay and basaltic lava flows. Most are located in the north part of the study area, although there are isolated deep artesian wells in the middle and southern sections (Figure 7-15).

LOCAL FLOW SYSTEM

The local flow sytem occurs in the unconsolidated alluvium of the LaPine basin under water table (unconfined) conditions. Recharge to the shallow aquifer is primarily from precipitation and surface runoff, although some recharge probably occurs from snowmelt moving down through basalts along the basin edges into alluvium. Evidence for this recharge from surface sources is found in the samples of shallow ground water analyzed for tritium content. Occurrence of tritium in waters of the hydrologic cycle arises from both natural and man-made sources. The first major source of man-made tritium entered the atmosphere during initial tests of thermonuclear devices in 1952. If water samples contain less than 5 tritium units it is reasonable to conclude that precipitation entered the ground prior to 1952 (Freeze and Cherry, 1979). Water samples in the LaPine core area contained tritium



N
1" = 1 Mile
Locations of Wells with
Artesian Head
SYMBOLS:
Approximate Location of Well with Artesian Head Greater than Ten Feet
NORTH SECTION
MIDDLE SECTION
SOUTH SECTION
LAPINE
FALL RIVER
DESCHUTES
LITTLE
PAULINA
LAKES
HWY
97
31
T19S
T20S
T20S
T21S
T21S
T22S
T22S
T23S
DESCHUTES COUNTY
KLAMATH COUNTY
LAPINE AQUIFER MANAGEMENT PLAN
FIGURE 7-15

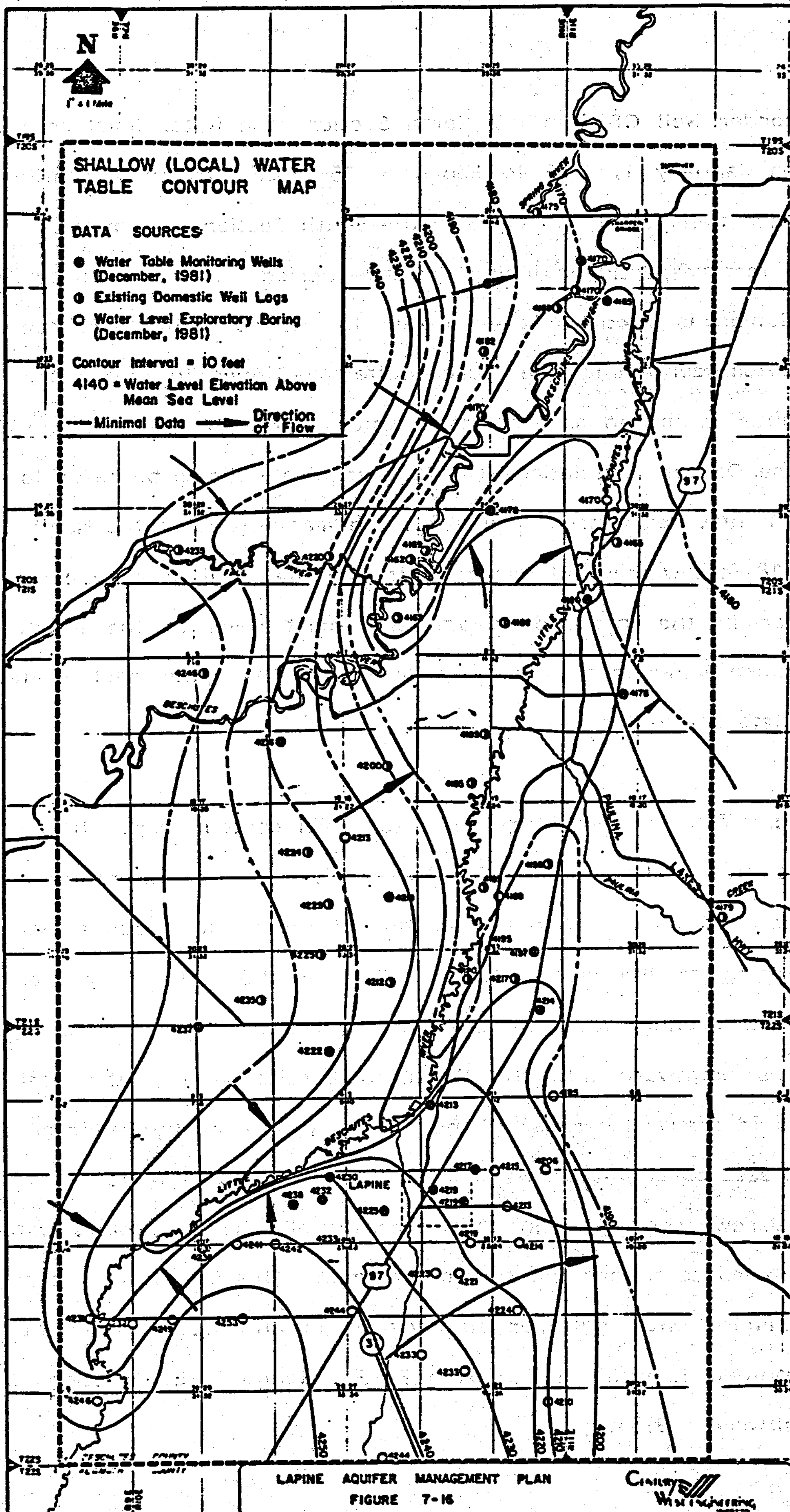
unit counts of 31 and 37 at depths of 15 and 33 feet, confirming that precipitation has percolated to the water table since 1952.

In the South Section of the basin, the local flow system is well defined. It exists in the alluvial sands and gravels up to 50 feet thick that lie above the thick clay layers of the intermediate aquifer. Although there are stringers of clay and silt found in some wells in the area, there is no consistent confining layer in the aquifer. Nearly all domestic wells in the South Section are drilled into this aquifer. Water wells in the South Section are generally less than 50 feet deep and water levels average about 15 feet below the ground surface. No shallow wells in this area are reported to show artesian conditions. Piezometer nests installed at various depths in the alluvium show similar water levels. From this it is assumed there is no significant vertical movement of water in the local flow system in the South Section.

The local flow system becomes more complex in the Middle Section. Alluvial sands and gravels thin and stringers of silts and clays thicken. Wells within two miles of the rivers are usually less than 50 feet deep while wells toward the basin edges tend to be deeper. The contact of the intermediate and the local aquifers becomes less defined toward the basin edges because of more complex depositional processes.

The local flow system in the alluvial aquifer thins out in the North Section. Ground water can be found above clay and silt layers within a few feet of the surface. The clay layers restrict downward movement of surface recharge and this perched water shows faster response to precipitation recharge than wells in the South Section. In continuous recorder well CR-2 in the North Section, the water level rose .99 feet from January 1, 1982 to February 15, 1982. Water in continuous recorder wells CR-1 and CR-3 in the South Section rose only .26 feet and .15 feet respectively during the same period. Response to precipitation recharge is probably even faster to the north of CR-2 because the alluvium containing the local aquifer continues to thin. The alluvial aquifer is limited as a domestic water source in the North Section because Oregon Regulations (61-126) require wells to be cased to a depth of 18 feet below ground surface. In many parts of the North Section, an 18 foot well would penetrate the alluvial aquifer and develop deeper water in the intermediate aquifer. Most wells in the North Section produce water from sands and gravels in the upper part of the intermediate aquifer.

Figure 7-16 is a local aquifer water level contour map. It is based on data from wells installed for this project and representative domestic wells. It shows the upper portion of the shallow aquifer system discharging to the river system. East of the Little Deschutes River, shallow ground water flows to the east and northeast and apparently moves downward into the fractured basalts forming the basin edge. This is assumed because of the rapidly steepening hydraulic gradient to the east as shown by water level measurements in wells. This system is somewhat unusual in that normally all shallow ground water in a basin moves toward the stream drainage. This east to northeast flow is consistent with previous findings of ground water movement in the Southwest Landfill in Township 21 S., Range 11 E., Sections 5 and 6 (Chitwood, 1975).



N
SHALLOW (LOCAL) WATER TABLE CONTOUR MAP
DATA SOURCES
Water Table Monitoring Wells (December, 1981)
Existing Domestic Well Logs
Water Level Exploratory Boring (December, 1981)
Contour Interval = 10 feet
4140 = Water Level Elevation Above Mean Sea Level
Minimal Data
Direction of Flow
LAPINE
97
31
LAPINE AQUIFER MANAGEMENT PLAN
FIGURE 7-16
Century West Engineering

TABLE 7-2

REPRESENTATIVE TRANSMISSIVITY VALUES
IN GALLONS PER DAY PER FOOT OF AQUIFER
USING THEIS SPECIFIC CAPACITY METHOD

South Section

Location	Upper (Local) Aquifer	Intermediate Aquifer	Regional Aquifer
22/10/2	10,000		
22/10/3	10,000	10,000	
22/10/4	21,000		
22/10/5	17,000	10,000	
22/10/7		50,000	850,000
22/10/8	12,000		
22/10/9	24,000	45,000	
22/10/10	6,000	2,200	
22/10/11	10,000		
22/10/12	500	6,000	
22/10/14	12,200	50,000	
22/10/15	10,000		
22/10/16	12,000		
22/10/17	12,000		
22/10/19	12,000		
22/10/21	10,000		
22/10/27	12,000		
22/10/30	12,000	14,000	

Middle Section

Location	Upper (Local) Aquifer	Intermediate Aquifer	Regional Aquifer
21/10/8	3,000	60,000	
21/10/9	3,200	20,000	
21/10/13	3,000		
21/10/14	13,000	1,500	
21/10/16	11,000		
21/10/21	7,000		
21/10/22	14,000		
21/10/23	5,000	2,300	
21/10/24	9,000		
21/10/26	6,300	5,300	
21/10/27	21,000		
21/10/28	13,000		
21/10/29	10,000		
21/10/31	10,000	4,000	
21/10/32	15,000		

TABLE 7-2 (Continued)

REPRESENTATIVE T VALUES

North Section

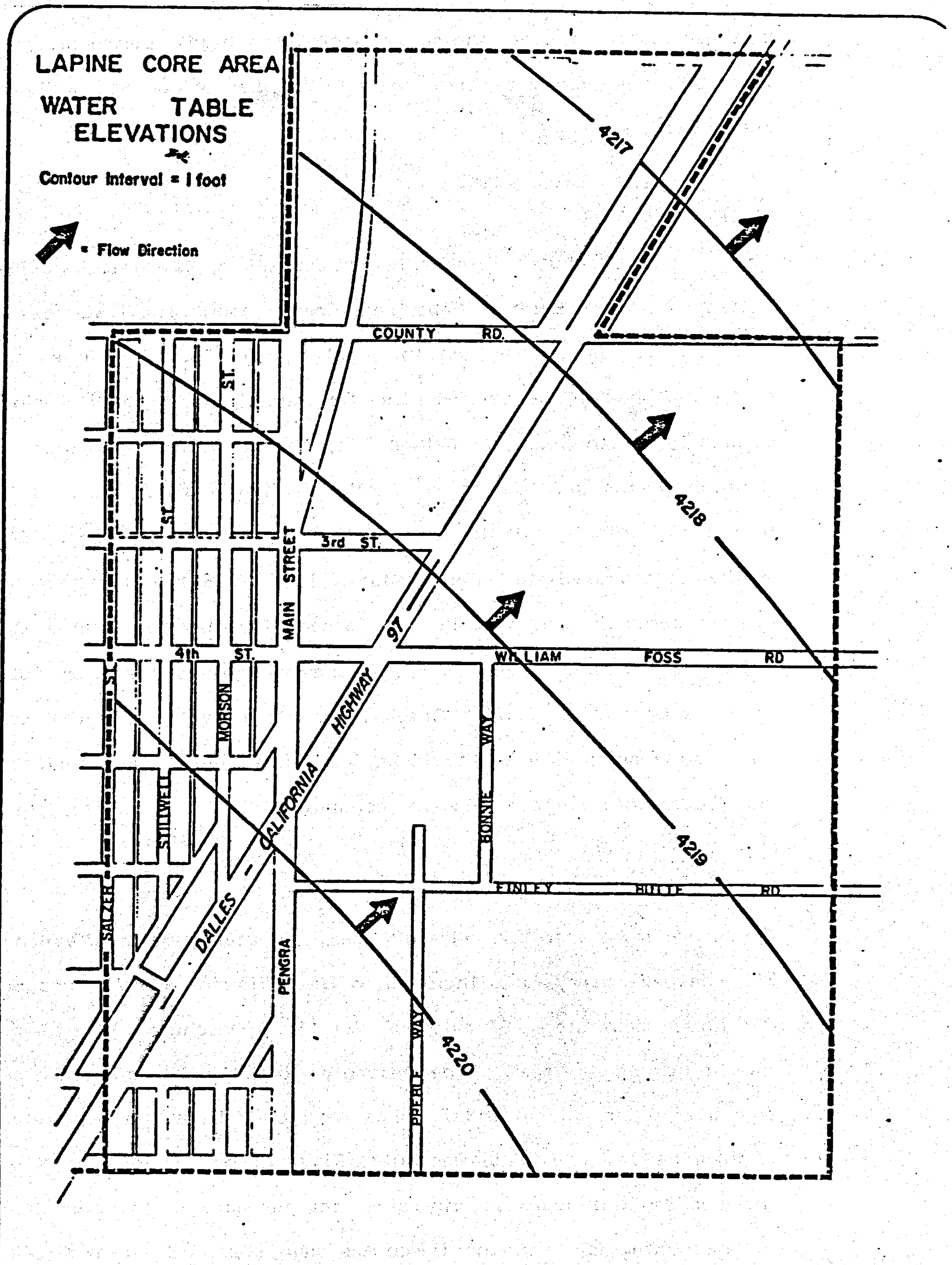
Location	Upper (Local) Aquifer	Intermediate Aquifer	Regional Aquifer
21/10/1		9,400	
21/10/3		14,000	
20/11/7		40,000	
20/11/16		24,000	
20/11/30		8,800	
20/10/1		145,000	
20/10/13		30,000	
20/10/32		15,200	
20/10/31		14,000	
20/10/34		40,000	
20/10/35		50,000	

Aquifer Pump Tests

Figure 7-17 shows the direction of the local flow system in the LaPine core area moving to the northeast with a shallow gradient of about 4 feet per mile.

The average transmissivity for three tests was 33,000 gallons per day per foot and the average specific yield, a percentage of the water that can be removed by pumping from total volume of the aquifer (effective porosity), was .11.

Based on aquifer test data, the average velocity of the ground water flow in this area was calculated to be from 0.39 to 0.95 feet per day or 142 to 347 feet per year using the method of Loman (1972). The results



LAPINE AQUIFER MANAGEMENT PLAN

FIGURE 7-17

Century West Engineering

of these tests show that the shallow aquifer is highly permeable, unconfined and will yield more than adequate supplies to domestic wells in the South section.

SURFACE WATER

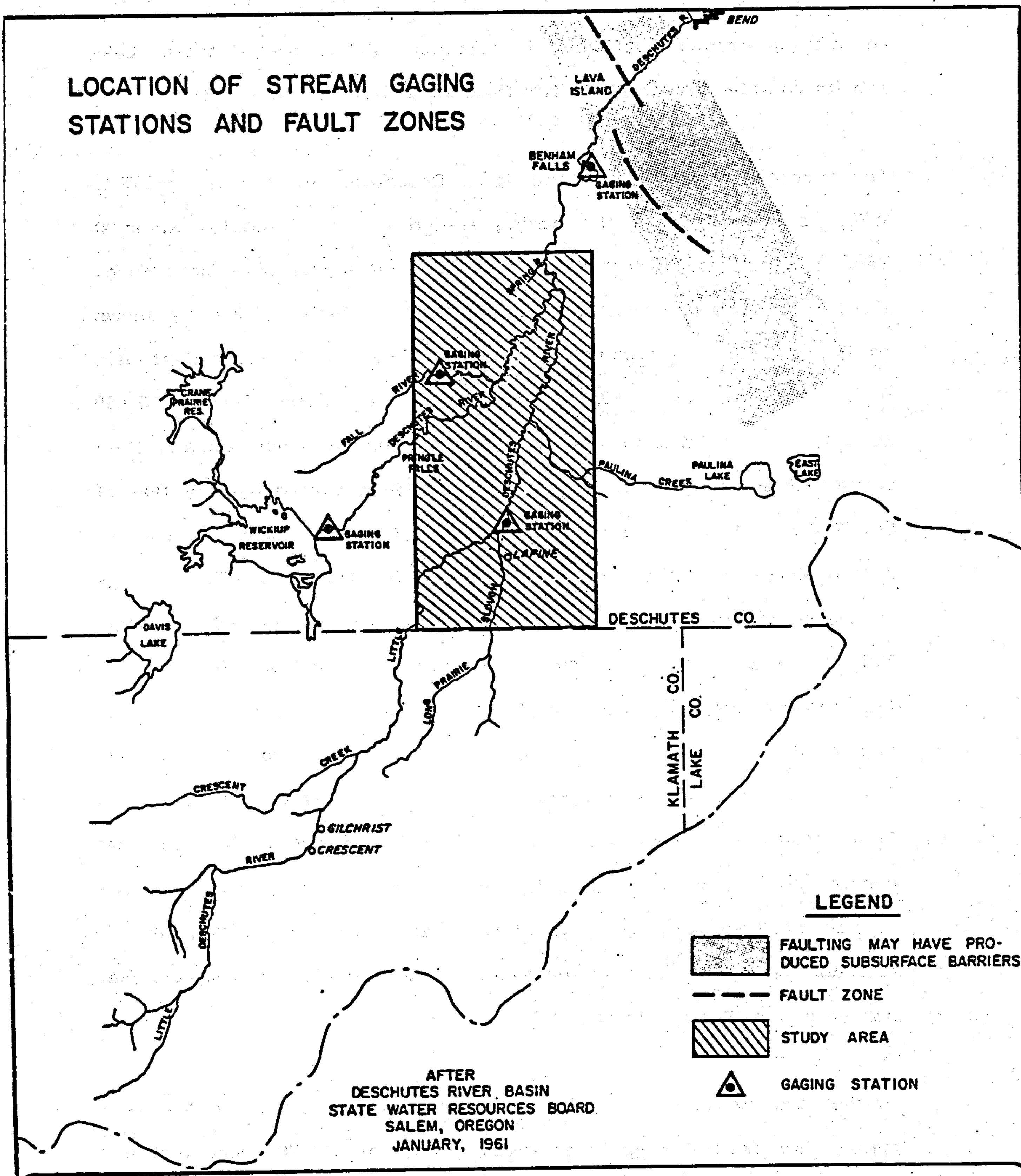
The Upper Deschutes subbasin includes all of the Deschutes River watershed above Benham Falls and drains about 1,710 square miles. The subbasin is bounded on the west by the Cascade Range, on the south by the divide between the Deschutes and Klamath Basins (at Chemult), on the east by Walker Rim, Carter Buttes, and the Paulina Mountains, and on the north by the arbitrary divide which extends from the Paulina Mountains through Benham Falls to the Three Sisters in the Cascades (State Water Resource Board, 1961). All major streams in this subbasin originate in the Cascade Mountains. Paulina Creek, which originates at Paulina Lake, is the only stream that does not flow from the Cascades. Paulina Creek is an intermittent stream that contributes only minor flow to the Little Deschutes River. Most surface flow disappears into surface deposits consisting mainly of pumice, cinders, alluvium and lava.

There are more than 750 miles of streams in the subbasin of which only 310 miles are perennial. Included in these figures are 71 miles of the Deschutes main stem, 97 miles of the Little Deschutes River, and 30 miles of Crescent Creek. The Deschutes River has an average gradient of 8.5 feet per mile in the 71 miles from Lava Lake, its headwater, to Benham Falls. The Little Deschutes River drops 350 feet in its upper three miles, but averages only nine feet per mile in its lower 94 miles to the confluence with the Deschutes main stem. Crescent Creek has an average gradient of about 15 feet per mile between Crescent Lake and its confluence with the Little Deschutes River (Figure 7-21).

The average annual yield of the Upper Deschutes subbasin from 1907 to 1978, as determined at the gaging station on the Deschutes River at Benham Falls was 1,029,000 acre feet (Water Resource Data for Oregon, 1978). Three long-term gaging stations above Benham Falls are shown on Figure 7-21. The gaging station at LaPine on the Little Deschutes River with 54 years of record shows an average yearly flow of 150,000 acre feet. The gaging station below Wickiup Reservoir on the Deschutes River with 40 years of record shows an average yearly flow of 541,900 acre feet. The gaging station at Fall River with 40 years of record shows an average yearly flow of 110,800 acre feet. The average annual combined discharge of these three stations is 802,700 acre feet. This shows that the river system acquires an additional 200,000 acre feet between the three upstream gaging stations and Benham Falls. A gaging station located at the mouth of Spring River from 1907 to 1924 showed an annual average flow of about 139,000 acre feet per year. Flow measurements taken March 12, 1982 showed a flow of 155 cubic feet per second in a low flow period of Spring River (Main, 1982). Extrapolated over one year, this would represent a low flow of 112,000 acre feet per year and supports the average flow figure of 139,000 acre feet per year from Spring River.

Adding the average flow from the three gaging stations and the estimated flow from Spring River gives a total of 941,700 acre feet per

LOCATION OF STREAM GAGING STATIONS AND FAULT ZONES



AFTER
DESCHUTES RIVER BASIN
STATE WATER RESOURCES BOARD
SALEM, OREGON
JANUARY, 1961

LAPINE AQUIFER MANAGEMENT PLAN

FIGURE 7-21

CENTURY WEST ENGINEERING CORPORATION

year, and indicates that approximately 87,300 acre feet of ground water is discharged to the river system above Benham Falls.

One plausible explanation for such a large ground water discharge between the LaPine study area and Benham Falls is the existence of a fault producing subsurface barriers that cause ground water to discharge before reaching Benham Falls (Figure 7-21), (State Water Resource Board, 1961).

This accretion of water in the river system comes from gravity ground water discharge from the local aquifer and artesian discharge from the intermediate aquifer. The regional aquifer may be discharging some water to the Deschutes River due to fault barriers.

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